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A Data Link Layer Protocol for Hybrid Vehicular Sensor Networks Using Practical Mobility Models with Real Maps

Sarah Madi

This thesis is submitted in partial fulfillment of the requirements
for the Master of Science in Electrical Engineering degree

Under the direction of Dr. Hend Al-Qamzi

June 2013

I, Sarah Madi, the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of the thesis titled “A Data Link Layer Protocol for Hybrid Vehicular Sensor Networks Using Practical Mobility Models with Real Maps”, hereby solemnly declare that this thesis is an original work done and prepared my me under the guidance of Dr. Hend Al-Qamzi, in the College of Engineering at UAEU. This work has not been previously formed as the basis for the award of any degree, diploma or similar title at this or any other university. The materials borrowed from other sources and included in my thesis have been properly acknowledged.

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ABSTRACT

Safety applications in Hybrid Vehicular Sensor Networks (HVSN) require robust transmission of messages in order to deliver safety to roads and drivers as intended. Since moving vehicles are equipped with wireless sensors that utilize and share the unreliable wireless channel for communication, the transmission of safety messages must be coordinated to minimize or completely eliminate collision of exchanged packets. The first step on the way of achieving that is through the Media Access Control (MAC) layer which is responsible for managing the access to the shared media safely and without collisions.

This thesis aims at designing and implementing a HVSN MAC protocol to help exchange safety and control messages between the network elements, i.e. vehicles' on board sensors and road side sensor units. The Time Division Multiple Access (TDMA) is one of the media access techniques used for eliminating collisions. However, it imposes few challenges in implementation, namely, rescheduling and time synchronization among communicating nodes.

In this proposed protocol, we provide a complete solution for such problems. Instead of dividing the time frame between just the available nodes, the protocol provides fixed schedules or time frames with enough time slots that are able to accommodate the maximum number of vehicles that may fit in one segment at a time. Such arrangement eliminates the need for re-scheduling and unnecessary processing. The synchronization problem is solved as well, with coordination from the network controller which is the road side unit.

Since we are dealing with HVSN, the protocol has not only considered the network or the communication part, but also included the vehicles' behavior in the design process, through realistic mobility modeling. The mobility model and the protocol operations are employed on a small real map where vehicles interact and communicate.

Moreover, a new Packet Delivery Ratio calculation method that considers the vehicles' mobility in the analysis is applied to practically evaluate the protocol performance.

The devised MAC protocol is characterized by several features; first, it is a collision free MAC protocol that does not require the re-configuration of time slots division as well as it accounts for the time synchronization problem. Second, the protocol is one of the initial works that employs the IEEE 802.11p in HVSN and utilizes its features and specifications. Third, the design is comprehensive and it is built and based on a realistic mobility model that helped in assessing the protocol performance through a unique TDMA mobility based-PDR calculation method.

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All praise and thanks are due to Allah. It is with his will and blessings with health, power and patience that I was able to reach this point. I would like to express my sincere regards to my thesis advisor, Dr. Hend Al-Qamzi, for her valuable inputs, able guidance, encouragement, thoughts, patience and whole-hearted support throughout the duration of this thesis. Her positivity, focused point of views and comments were of great help every time we meet.

Big thanks are also to the Research and Graduate studies Department of the College of Engineering represented by administration staff and to my examination committee. The gratitude is extended to all the instructors throughout my academic life, who influenced me, taught me and helped me reach where I am now. Last but not least, I would like to pay my special respect and love to my parents, family members, and friends for their love, encouragement, and support during my studies.

Dedication

This thesis is dedicated to my parents, whom I learned from that ambition has no limits, knowledge has no boundaries, and that work is supposed to be done with dedication and loyalty. I thank them for their endless love, support and encouragement.

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List of Abbreviations

ITS: Intelligent Transportation System

VANETs: V [illegible] NETworks

WSN: Wireless Sensor Networks

MANETs: Mobile Ad-hoc NETworks

InVANETs: Intelligent VANETs

iMANET: Internet Based MANETs

TCP/IP: Transmission Control Protocol/Internet Protocol suite

LLC: Logical Link Layer

MAC: Medium Access Control

IEEE: Institute of Electrical and Electronics Engineers

RSU: Road Side Unit

OBU: On Board Unit

V2V: Vehicle to Vehicle communication

V2I: Vehicle to Infrastructure communication

RWP: Random Way Point model

RD: Random Direction model

META: Metropolitan Taxis mobility model

TIGER: Topologically Integrated

SSM: Stop Signal Model

PTSM: Probabilistic Traffic Sign Model

TLM: Traffic Light Model

NS-2: Network Simulator 2

GIS: Geographic Information System

IMM: Integrated Mobility Model

RUM: Rice University Model

PHY: Physical layer

DSRC: Dedicated Short Range Communication

WAVE: Wireless Access in Vehicular Environment

OFDM: Orthogonal Frequency Division Multiplexing

HVSN: Hybrid Vehicular Sensor Network

RSS: Road Side Sensor

AODV: Ad hoc On-Demand Distance Vector

DSR: Dynamic Source Routing

BS: Base Station

GPS: Global Positioning System

Geographic Encoding and Referencing

CSMA/CD: Carries Sense Multiple Access /Collision Detection

CSMA/CA: Carries Sense Multiple Access /Collision Avoidance

IFS: Inter Frame Space

FDD: Frequency Division Duplex

TDD: Time Division Duplex

FDMA: Frequency Division Multiple Access

TDMA: Time Division Multiple Access

CDMA: Code Division Multiple Access

FS: Free Space model

LOS: Line Of Sight

SUMO: Simulation of Urban MObility

LAN: Local Area Network

MAN: Metropolitan Area Network

WAN: Wide Area Network

GUI: Graphical User Interface

XML: Extensible Markup Language

CSMA: Carries Sense Multiple Access

CHAPTER 1

Introduction

A report by the Abu Dhabi statistics center shows that the total road and traffic causalities in Abu Dhabi during the period from 2009 to 2011 are 13395 (1113 dead and 12282 injured). Similar reports by the Dubai statistics center also show that the total causalities in Dubai are estimated to be 7043 casualties (511 dead and 6532 injured) [1]. These numbers are the driving motives for both academicians and industrial researchers to find solutions and ideas to improve road safety, especially in the area of Intelligent Transportation System (ITS).

In this chapter, a general introduction to the topics related to this thesis is presented. We start with ITS and introduce its technologies and applications which include MANETs and VANETs along with their application and research interests.

1.1 Intelligent Transportation Systems (ITS)

ITS is an integration of various innovative services related to transportation and traffic management to achieve better communications with the users and make safer, more coordinated, and smarter use of transportation networks. It has been under development for the past 20 years to achieve high levels of security and efficiency during the interaction among vehicles. The integrated services can be related to telecommunications, electronics and information technologies [2]. These technologies can be applied to manage systems such as traffic signal control systems, variable message signs, and speed cameras. They can be used also in monitoring applications with or without live feedback such as parking guidance and weather information. In order to develop the required application, other systems may be integrated for better performance and feasibility such as wireless communications, computational technologies, sensing technologies, cellular data, etc.

The main applications of ITS in real life are emergency vehicle notification systems, variable speed limit signs based on road congestion status, collision avoidance systems, etc. The majority of these applications require coordination between vehicles, information gathering, and dissemination; hence, a network of vehicles and control centers should be established. The Vehicular Ad-Hoc Networks (VANET) is an example of such applications.

1.2 Wireless Ad-hoc Networks

A wireless ad hoc network is similar to ordinary wireless networks but differs in the fact that it is a decentralized version of it, i.e. there is no infrastructure such as routers or access points. They can be static such as Wireless Sensor Networks, or mobile, such as Mobile Ad-hoc Networks. Static or mobile nodes can form temporary networks without the help of a centralized administration. The organization of networks is achieved by the nodes themselves where they may arrange themselves arbitrarily. In case of mobile networks, the mobility of nodes leads to fast changes in the topology and connections [3]. Two main types of wireless ad hoc networks are presented in this section namely, Wireless Sensor Networks and Mobile Ad hoc Networks.

1.2.1 Wireless Sensor Networks (WSN)

WSNs consist of wireless sensor nodes that have the ability of sensing, processing, and distributing information attained from the environment or the surrounding nodes through a mutual effort from all the nodes [4]. The significant advances in hardware manufacturing technologies have played a big role in building sophisticated sensors at low cost and high performance. Since the nodes are wirelessly connected thus little wiring or road work may be required. That is the reason why the installation and maintenance expenses of WSN are reduced. The role of WSN will be magnified if integrated with other technologies as their drawbacks will be alleviated or solved. One of these disadvantages is their limited life time due to power limitations. WSN can be used in conjunction with other technologies leading to more complex applications such as: traffic safety, traffic law enforcement, traffic control, and smart parking applications.

1.2.2 Mobile Ad hoc Networks (MANETs)

MANETs are a collection of dynamic and self-configuring networks of mobile nodes connected wirelessly. The mobile nodes communicate directly with each other and without the aid of access points, so no fixed infrastructure is available. Each node acts as a host or a router that offers connectivity to the neighboring node in the network. A packet can travel from the source to the destination either directly or through intermediate packet-forwarding nodes. Because of the mobility feature of these networks, the communication should be able to adapt to changes in the location of the nodes or any changes that are due to the surrounding environment. Note that nodes' mobility can be in any direction at any speed. It is important to find the multi-hop route between the source and the destination. Once the route is found, then each node in the path forwards the traffic (or packets) till the target node is reached. The final node then checks the packet integrity and concludes that the information contained in the traffic has arrived at its destination. MANETs could be used to connect people, computers, vehicles, etc. There are many types of MANETs: Vehicular Ad hoc Networks (VANETs), Intelligent Vehicular Ad hoc NETworks (InVANETs) and the Internet Based Mobile Ad hoc NETwork (iMANET) [5].

1.3 Vehicular Ad-hoc NETworks (VANETs)

VANETs are a subset of MANETs, where vehicles are connected with each other as mobile nodes. The same features that are found in MANETs exist in VANETs. VANETs have vehicles as mobile nodes, and this will result in quick changes in the topology of the network. When dealing with VANETs, it is important to consider two important parts of the system: the traffic part and the communication part. Research has been carried out for the traffic part in fields such as mobility modeling, traffic management, and modeling with the consideration of road elements could be intersections, traffic lights, bridges, etc. On the other hand, the communication part deals with the connection establishment among vehicles and protocols that can be implemented to set effective communication links. These links should enable the successful delivery of messages since these packets may contain critical information such as emergencies or update information about the status of the network. The main challenges that researchers face are the following:

- The high speed of mobile nodes that lead to quick topology changes
- Communication between vehicles is prone to frequent fragmentations
- Rapid changes in connectivity will cause many paths to be disconnected before they are utilized
- There is no constant density in VANETs

- Messages may be the cause of the topology changes. For example, in emergency cases vehicles will change their speeds and directions when they receive alert messages.

Figure 1.1 illustrates general communication architecture for VANETs.

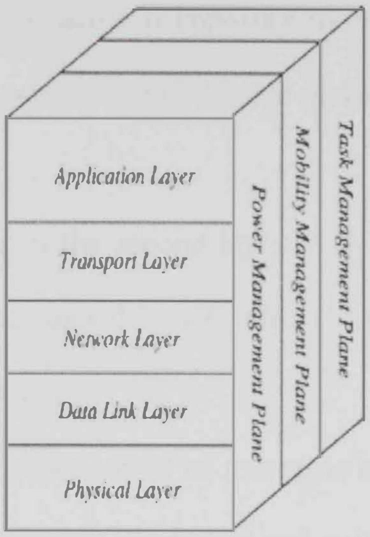

Figure 1.1: Communication architecture for VANETs [6]

It can be noticed that the physical, data link, network, transport and application layer are common with the Transmission Control Protocol/Internet Protocol suite (TCP/IP) model, but they are extended to have 3 planes that will assist in the performance and applications. The first plane is the power management plane that has tasks such as defining the sleep and wake status for the operation. The second plane is the mobility management plane that monitors the movement of the vehicles or sensors. Finally there is the task management plane that balances and coordinates the sensing tasks [6].

Existing research in the VANETs field is extensive and covers different aspects. For example, for the transport layer that is responsible for the end to end reliable delivery, congestion control, and Quality of Service, research has been conducted towards improving and developing congestion control algorithms to preserve network resources and reliably deliver sensor data to the base station to obtain the detection and tracking of an event signal. Additionally, it is important to find a balance or a tradeoff between reliability and energy efficiency. Another example is the data link layer where it is important to improve sending and receiving data frames between the communicating nodes and make it reliable and collision free.

1.4 Data Link Layer

The Data Link Layer is the second layer in the TCP/IP protocol stack and consists of two sub layers; the Logical Link Control (LLC) sub-layer and the Medium Access Control (MAC) sub-layer.

In order to assure accurate arrival of messages at each receiving vehicle, the links should be secure with minimal congestion and collision. Packet collision is one of the main issues in communication protocols designs as it leads to packet loss and wasting of bandwidth and resources. Minimizing and avoiding data packet collisions is the responsibility of the data link layer and especially the MAC sub-layer. The later provides access control mechanisms to the physical medium (radio) shared by nodes. Moreover, The MAC protocol helps to efficiently and practically share the network resources among nodes [7]. Moreover, data stream multiplexing, data frame detection and error control are some additional tasks of the data link layer.

1.5 Thesis Overview

The aim of the thesis research is to design a data link layer protocol that is suitable for Hybrid Vehicular Sensor Networks (HVSNs) with the consideration of different aspects of modeling a HVSN such as mobility and traffic features.

Additionally, realism in design using real maps, real world parameters and practical scenarios in the analysis is a major design factor during the protocol building process. This report begins with a discussion about the topics that have driven and inspired the thesis research in Chapter 2. Chapter 3 illustrates the aspects of the protocol designed in details, including the problem statement, design challenges, the network setup and the protocol methodology and operation. Chapter 4 discusses the implementation of the protocol, the parameters used, simulation model and presents an illustration and a discussion of the results. Finally, chapter 5 concludes the thesis.

CHAPTER 2

Literature Review

In this chapter, the main topics required to build the necessary background to achieve the aims of the project are presented and explained in details. After this brief introduction we start with a discussion about VANETs, followed by introducing the HVSN and what comes with that type of networks whether it is a system or a concept. The following topic is related to channel access methods and how to fairly share the available resources. Moreover, propagation models are discussed as their concepts will be dealt with during the design and analysis. Finally, the main topics related to simulations are presented starting from the main types of simulations and ending with the different simulators available in the research field.

2.1 VANETs

Vehicular Ad-Hoc NETworks or VANETs, represent a network of vehicles that has an ad-hoc nature, i.e. not having a fixed infrastructure such as access points. Instead, every node will participate in the process of relaying the information. Each node will act as a host and a router that will offer connectivity to the sub-sequent node in the network. Because of the mobility feature of these networks, the communication should be able to deal with any changes in the location of the nodes or any changes that are due to the surrounding environment [1]. VANETs are a specific version of MANETs, as they connect a group of vehicles together and help organize the communication among them with the help of hardware. Moreover, since they communicate wirelessly, then their mode of operation usually follows the IEEE

802.11 designed for wireless networks unless the application intended requires otherwise.

There are two main components in VANETs: the On-Board Units (OBU) located in each vehicle and the Road Side Units (RSU) or the infrastructure located along the road. These units consist of short and medium range communication equipment, processing, sensing, and storage units, etc.

VANETs offer several types of communication between its components. The first type is the vehicle to vehicle communication (V2V) where vehicles exchange information that are of interest among them. The second type is the vehicle to infrastructure communication (V2I) where in this case a connection is established between the vehicles and the infrastructure. Additionally, depending on the application, it may be necessary to have a connection between the RSUs available in the network to exchange information about the status of the areas surrounding them. Finally, a connection may be required as well between the RSUs and the main control centers in the city, to serve applications related to emergencies for example [7].

VANETs have advantages and disadvantages. The advantages include the large memory size, high processing capabilities, long life power sources, and the variety of applications that can be achieved. On the other hand, there are some drawbacks to the system. First, their proper behavior is conditioned by the number of vehicles travelling and whether these vehicles are equipped with the appropriate units. Second, the mobility feature leads to a dynamic topology and short link lifetimes.

In spite of these drawbacks, VANETs are applied in a lot of useful applications such as traffic signal violation warning, pre-crash sensing, cooperative forward collision warning, lane change warning, traffic jam warning, facility information retrieving, etc.

The main purpose behind VANETs is delivering more safety to the drivers on the roads. Since mobility is the main feature of VANETs, then any corresponding simulation model should consider the effects of mobility and different mobility patterns, and apply an appropriate mobility model that presents different aspects of the movement experienced.

2.1.1 Mobility Modeling

As mentioned earlier, mobility is the main feature of VANETs and it has to be included in the design and modeled properly.

Vehicular mobility is actually related to cars, railways, bicycles, motor bikes, etc., which is anything that moves on wheels [8]. As for cars in VANETs, there are many factors that affect their mobility, such as street construction, traffic control mechanisms, interdependent vehicular motion, and average speed [9][10][11]. So in order to propose a new mobility model for VANETs, these factors or at least some of them should be considered.

There are mainly two types of mobility models based on the movement of nodes: Random Node movement and Real World Mobility Models. The first type presents mainly the early approaches to modeling mobility. They were based on randomly moving nodes in any direction at any speed. These models clearly do not describe real car movement on roads. On the other hand, The real world mobility models are based on the data recorded from simulation traces (Artificial Traces) or real world observations by using means such as Global Positioning System (GPS), street map databases such as GIS (Geographic Information System) and the TIGER database (Topologically Integrated Geographic Encoding and Referencing) [12].

2.1.1.1 Random Node Movement

In this section, the main idea behind two random node movement models is presented. The first model is the Random Way Point model (RWP) and the second one is the Random Direction model (RD).

The RWP model is one of the main mobility models from the proposed Random Node Movement category [13]. Destination, velocity, and direction of each node are all chosen arbitrarily and independently. The velocity is determined from a given range [v_{min}, v_{max}]. The step sequence of this model is as follows: the node will move in its chosen direction with a velocity v. After reaching the destination, there will be a pre-determined pause time before resuming the movement with new destination, velocity, and direction [10]. A Couple of other models were based on this model such as the city section mobility model, the random direction mobility model [8], and the Gauss-Markov model [10]. Notice that the RWP model is not applicable in VANETs because it does not represent the actual behavior of vehicles. However, it is still the most commonly used model in the simulation of other wireless ad hoc networks such as WSNs [14].

On the other hand, the RD model deals specifically with pedestrians who move on straight walk segments (the move phase) at constant velocity with the possibility of pausing for a while between each walking segment (the pause phase). Each node will independently select a direction and speed of movement at the beginning of the move phase [10].

2.1.1.2 Real World Mobility Models

Most of the present mobility models were surveyed and classified based on their approach to constructing the model. For each category in this section, some examples are studied. The first category is related to models based on simulation traces. Simulation traces are divided into two classes: real world traces extracted from realistic traces such as GPS traces, and artificial traces in which roads are proposed and modeled by software to generate the corresponding trace file that contains the traffic or movement information. The second category is related to models based on real world maps obtained from databases. As for the third category, one promising approach was adopted which is the integration of existing models to create new models. The surveyed mobility models are presented in terms of mobility simulation followed by a comparison between them from different aspects.

- **Model (1)**

The model proposed by [15] used GPS data reported by 4000 taxis running in an urban area for three months (real world traces). It is called the META model (Metropolitan Taxis mobility model). GPS reports are not sent continuously, but there is a time interval between consecutive messages. The GPS data collected has to be analyzed in order to extract the information and parameters needed in the simulation to prepare the traces. The main model parameters are:

  - Turn probability: Although the travelling path is determined in advance, but due to traffic rules or the driver's common sense, this path may change. Additionally, since there is a period of time between two messages, then this

  parameter is used to predict the path to be taken between two sequential GPS reports.
  - Road section speed: This parameter represents the average speed of a road section in a given period of time (assumed 5 minutes). It is calculated after receiving a GPS report using the length of the path crossed and the interval of time. The answer is then assigned to that particular path as a road section speed.
  - Travel pattern: This is defined as the probability that a vehicle travels from one area to another. The whole simulation area is divided into grids of 1km x 1km each, and then series of GPS reports with same status are searched to identify the origination (first data) and the destination (last data) of the travel path. Probabilities are then arranged in a probability matrix and used to plan travels.

- **Model (2)**

Gaikwad & Zaferi [10] proposed a model by considering several parameters of real traffic situations on the roads such as attraction points, speed variations, traffic lights, node movement, and the topology of the simulation area. The simulation area was proposed and designed in the simulation program by the authors. The main parameters included in this model are:

  - Attraction points: Attraction points are set to narrow down the destinations of the nodes. Attraction points may be schools or universities in the morning or rush hours, shopping malls and restaurants during weekends and so on.

    - In this model, they represented the attraction point as a function of the probability value at the signaling point. Each vehicle is assigned a probability value for its destination.
- Speed variation: The speed of any vehicle in the simulation area does not remain constant throughout the simulation time and area. It changes according to the neighboring vehicles, traffic lights, street layout, etc.
    - In this model, the authors have changed the vehicle's speed after some specific distance in accordance to the neighboring vehicles. For example, if vehicle A is overtaking vehicle B, then B will slow down for some time, A will increase its speed and overtake.
- Traffic light: Traffic lights are important elements in the roads as they help managing intersections. In this model, they assumed a single horizontal lane in each intersection branch. Once the traffic light is green, vehicles will cross the intersection and the ones that will turn to the left will turn directly. Once the light turns to red, vehicles on that lane will stop, giving the chance to other lanes to cross the intersection.
- Simulation area: The vehicle's behavior in this model is as follows: the vehicle will enter the simulation area on the left side of the road, then moves to the right direction with a speed ranging from 5-25m/s. There are traffic lights at intersection points to handle traffic in both directions.
- Node movement: at the beginning of the simulation, all the nodes are distributed along the starting points of the horizontal and vertical lanes. They move on the pre-determined path mentioned in the previous point. Each node

is assigned a probability value according to its point of interest. After reaching the destination, it checks the next direction according to a new probability value and attraction point and so on.

To implement this model, Matlab software was used and the simulation area was 800m x800m.

- **Models (3), (4) and (5)**

In [9], the authors introduced three new mobility models; each model included more realistic vehicular movement details than the previous one. They based their models on real maps obtained from the TIGER database, which provided them with additional information on speed limit and number of lanes. Below is a brief description of the proposed models.

- Stop Sign model (SSM): In this model, it was assumed that every street at an intersection has a stop sign so that each approaching vehicle will stop for 3 seconds. On the roads, each vehicle will move according to the vehicle ahead of it. In other words, no vehicle can move further than the vehicle in front of it unless it is a multilane street where overtaking is allowed. When a vehicle reaches a stop sign, then it will stop and so will the following vehicles. Each vehicle will wait for 3 seconds then move, till all vehicles' queue at the intersection leave. According to the authors, the main problem in this model was that it is unrealistic to have stop signs only at all intersections in any region.

- Probabilistic Traffic Sign Model (PTSM): To improve the previous model, stop signs were replaced by traffic signals at intersections. Vehicles will stop at red light and depart when it turns to green. In this model, the operation of the traffic signal was approximated, that is; when a vehicle reaches an intersection with an empty queue, it will either stop with probability p (red right) or crosses the signal with probability 1-p (green light). If it is going to wait, then there will be a pause time between 0 and **n** seconds, where **n** is a random number. Also, if other vehicles arrive at a non-empty signal, then they have to wait for the remaining time till the light turns to green plus 1 second as a startup delay. All the vehicles in the queue will continue to move after 1 second till the queue is empty.

- Traffic Light Model (TLM): PTSM was improved by permitting greater levels of mobility details such as:
  - ✓ Coordinated traffic lights: Traffic lights in this model are coordinated by allowing traffic to cross the intersection from a single pair of opposing sides. This is applied for an intersection with an even number of roads, single lane each. After some time, green lights are rotated to another pair of roads.
  - ✓ Acceleration and deceleration: This feature implies that vehicles will decelerate before stopping, from the maximum speed till they stop gradually and vice versa regarding vehicles at rest.
  - ✓ Multiple lanes: This model introduced multiple lanes which can be determined from the real maps obtained from TIGER database. Vehicles entering a new road with multiple lanes, they will select the lane with the least number of vehicles.

These models were implemented independently using C++ to generate the mobility files that are used as an input to the NS2 (network simulator). Initial positions for vehicles and destinations were chosen randomly. It was assumed that vehicles will take the shortest path to the destination. After arriving, a new destination will be assigned.

- **Model (6)**

The following model [16] is a result of integrating Manhattan, Freeway, stop sign and traffic sign mobility models in addition to some characteristics. That is why it is called the Integrated Mobility Model (IMM). Manhattan model is a model where nodes have vertical and horizontal streets with intersections to represent urban areas. Each street has two lanes and as the node approaches an intersection it will choose a turning direction based on a turning probability. Additionally, each lane has a velocity while keeping in mind that there is velocity dependency between two nodes in series in the same lane. Freeway model differs from Manhattan model in terms of streets' representation. In this case there are freeways, each with a number of lanes in both directions. Vehicles are restricted to move in their lane. Safety distance is maintained between nodes and the velocity of the following node cannot exceed that for the preceding one.

The IMM is a model proposed to have more parameters for simulation and testing purposes. The streets representation is the same as the freeway case, while the nodes' distribution once entering the simulation area is similar to Manhattan's. Additionally, acceleration/deceleration, stop signs, traffic lights, stop time, wait time, and safe inter-vehicle distance are features integrated in this model to increase the level of realism. Table (1) compares between the presented models [17].

	Model 1 (META)	Model 2	Models 3, 4, and 5 (SSM, PTSM, TLM)	Model 6 (IMM)
Traces	GPS traces	Artificial (simulation)	Artificial	Artificial
Topology	20 km^2 real map	16m^2 road topology	1200x1200m real map	1200x1200m
Simulator	-	Matlab	C++, NS-2	NS-2
Performance metrics	PDR, delay	Link availability	PDR, end to end delay	PDR, end to end delay
Comparison	RWP	RD Model	RWP, RUM	Manhattan, Freeway
Category	Cat 1-1, Cat 2	Cat 1-2	Cat 1-2, Cat 2	Cat 1-2, Cat 3

Table (1): A comparison between the presented mobility models

2.1.2 Communication protocols

It is well known that VANETs are a part of wireless networks, but they have different requirements and operate under specific conditions and that make them differ from other systems such as WLAN, cellular, etc. For that, IEEE 802.11 protocol was modified to suit the operation of VANETs as will be illustrated. Let us start with the Dedicated Short Range Communication (DSRC) which is a licensed frequency spectrum between 5.850-5.925 GHz dedicated to vehicular communication. Work was directed toward developing a single standard for the physical (PHY) and the Medium Access Control (MAC) layer and including it in the IEEE 802.11 standard in what is known as the IEEE 802.11p. The rest of the layers were kept in mind as well and were covered by the IEEE 1609 standard set that includes four parts; the IEEE 1609.1, IEEE 1609.2, IEEE 1609.3 and IEEE 1609.4. The IEEE 802.11p combined with the IEEE 1609.x are called the Wireless Access in Vehicular Environment (WAVE) standard. The WAVE PHY and MAC in particular, follows the IEEE 802.11p standard which specifies the PHY (physical layer) and

MAC functions required for an IEEE 802.11 device to work in the vehicular environment. A WAVE system consists of units called the RSUs that are usually located on light poles, traffic lights, road signs, etc. The second type of elements is the OBUs that are mounted on vehicles so they are mobile. They are the same components found in VANETs as WAVE is the standard applied. The spectrum allocated for WAVE (DSRC spectrum) is divided into 7 channels, 10 MHz each where 6 of those channels are called service channels and the remaining one is a control channel. The service channels are designed to handle different types of messages that can be used in applications for traffic management and efficiency, critical safety, or non-safety applications [18]. The service channels could be combined based on the customized application intended. It supports the Orthogonal Frequency Division Multiplexing (OFDM) to provide transmission rates of:

- 9, 12, 18, 27, and 27 Mbps for 0-60 km/hr vehicle speed
- 3, 4.5, 6, 9, and 12 Mbps for 60-120 km/hr

Additionally, WAVE can use two types of radio devices; single channel devices which exchanges data and listens to only one RF channel at a time, and multi-channel devices that exchanges data on one channel and listen to another channel [19][20].

2.2 Hybrid Vehicular Sensor Networks (HVSN)

HVSNs are a result of integrating VANETs and Wireless Sensor Networks (WSN) in an innovative combination that may solve a lot of issues related to the disadvantages of both systems.

WSNs are a subset of wireless ad-hoc networks where a large number of sensor nodes are deployed and capable of sensing, computing and communicating.

Nodes in these networks are densely deployed, mainly use broadcast communication and the cost of installation and maintenance is reduced. Their disadvantages are their limitation in power and computational resources. WSNs can have a great advantage if applied in ITS.

Recently, research has been directed into integrating both VANETs and WSNs together for a better performance in addition to compensating for their disadvantages in what is known as HVSN. For example, VANETs are known for the existence of reusable power facilities such as car batteries, power lines for traffic lights along the roads, solar panels, etc. and that can help with power limitations in WSNs. Additionally, all the heavy processing that a sensor should perform, could be relayed on the roadside units and that may be considered as a solution to the processing limitation in WSNs. The output of such integration is as follows:

- VANETs will use data gathered from onboard sensors to obtain their state.
- WSNs will monitor the roads to get valuable information prior to the vehicles' arrival
    - There will be a small overlap between data and that will help increasing system robustness
- Information will be propagated through both; WSN which will keep the information static for vehicles to receive when they arrive, and VANETs which will assist in moving information from one WSN to another.

There are three possible design scenarios for simulation area to target through HVSN; urban, highway and rural areas. These scenarios will help determining the circumstances under which the system operates. Additionally, for a successful design, the following requirements should be satisfied: low cost, lifetime, Flexibility, scalability, reliability, robustness and fault tolerance [4].

The first example about HVSN is found in [21] where they aim to design a feasible, efficient and robust vehicular sensor network that will monitor road traffic and provide reliable information for users. The following assumptions were made: first, all vehicles are equipped with GPS devices, second, all sensor nodes are loaded with identical digital maps, also, sensors will have plentiful of storage and finally, vehicles can detect and recognize road information correctly. They focused mainly on vehicle's mobility, the collaboration between mobile and static node, and the information exchanged among mobile cars.

The system consisted of Road Side Sensors (RSS) (static nodes) and mobile sensors (mobile nodes). The roads were separated into segments, each with a certain amount of RSS that are usually positioned near intersections, to collect information from vehicles passing by. The road segments have varying speeds according to road conditions. Their main task was to manage connections between static and mobile sensors and mobile and mobile sensors (same or opposite direction).

The implementation of the system was through simulation where they used java as a simulator and simulated a map consisting of 40 road segments and 25 intersections, each segment is 300 m.

Another example was presented in [22], where they described and evaluated a communication protocol between VANETs and WSN using NCTUns. Instead of information flooding, they chose to use a Multi-hop network in which information is spread from a vehicle to another till it reaches the destination. Their main task was to build a communication protocol that can fulfill all types of communication produced between VANETs and WSNs; static sensors to vehicle, and vehicle to vehicle whether in same or in the opposite direction. The simulator used was NCTUns (freeware) and they evaluated their communication protocol under two well know routing protocols; Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR).

The next example was proposed by [6]. This HVSN in this case was an attempt to solve the problem of the low vehicles' density at night in highways and how will that affect the transmission of important packets in case of an emergency such as accidents or fire. They suggested utilizing WSN nodes on both sides of the highway. In this protocol, there are three components; the vehicle nodes, the RSS and the Base Station (BS). Vehicle nodes have to:

- Collect real data, and send it to the BS via the RSS
- Receive information from the BS via the RSS

So in this case, the RSS is just a hop to facilitate the transmission of information.

The last few examples presented are the most related ones to this research as they present either HVSN systems that covered the main research fields related to that topic or they are concerned with the same media access technique modified. Let us start with the system presented in [23]. They proposed a distributed and scalable mechanism for WSN-based road traffic monitoring that is low in cost and provide secure transmission. It consists of distributed cluster heads that are deployed along the road sides. A full duplex communication will be established among the vehicles in a time multiplexed manner. Each node is provided with a dynamic and a unique time slot, and sometimes more than one slot may be allocated for each node, depending on the traffic load. The distance between cluster heads depends on the physical and data link layer and since they proposed to have the IEEE 802.15.4 (ZigBee) as their communication protocol, then that distance was set to 100 m. Each head comprises a WSN where the power will not be an issue, but they were concerned with reliability and security.

The first contribution to their protocol is applying a security algorithm to assure the safe arrival of messages with no interference or intruding from other nodes or from attackers. Their second contribution was the designing of a collision free data link layer protocol. Each cluster head is provided with a unique and confidential physical address Ai and private key Pki that is refreshed multiple times to assure the reinforcement of network security. The communication between the vehicles and the head is performed using a private key encryption algorithm Data encryption standard algorithm.

As mentioned earlier, the communication will be established among the vehicles in a time multiplexed manner, so they divided the frame into three parts; the vehicle messages, the service messages and the emergency messages. All the available vehicles have a slot in each part to communicate.

The proposed scheme was implemented in TinyOS and evaluated using the build-in simulator in TinyOS, TOSSIM. The cluster heads were separated by 100m to cover the maximal number of vehicles while reducing overlaps between the clusters. Each cluster was assigned a group of vehicles running at different speeds.

The system proposed in [7] integrates roadside sensors and vehicles to achieve driving safety in highways during night hours where vehicles' density is low. The sensor nodes will sense road conditions, collect and process sensing data and deliver the information to vehicles that need it. This integration of VANETs and WSNs helps in connecting partitioned segments, provide timely detection of road conditions and lower the cost. Each vehicle node in this system has two communication interfaces: Wi-Fi; used in the communication among vehicle nodes and ZigBee interface for the communication within roadside sensor nodes. Sensor nodes are deployed along one side of the highway and they are found in two forms; regular nodes and access point nodes. The system's objectives of energy efficiency and quality of service were achieved through an event-driven duty cycle scheduling. They proposed a TDMA-based protocol where each sensor has a limited number of pre-determined neighboring nodes, to facilitate the assignment of time slots. Sensor nodes are divided into groups and within each group, duty cycles of nodes and bi-directional propagation are scheduled. Inter-group communication is handled by access points shared by different groups while sensors in the same group are time synchronized and communicate during time slots of fixed lengths.

The last related example is presented in [24] which is the VeMAC protocol. It is a multichannel TDMA protocol based on Ad hoc MAC and mainly designed for VANETs. On the control channel, the protocol provides a reliable one-hop broadcasting service in addition to a multi-hop broadcast service to disseminate information all over the network. This protocol assigns disjoint sets of time slots to vehicles moving in opposite direction and to RSUs to decrease the collisions in the control channel caused by the nodes' mobility. Moreover, new techniques for the nodes to access the available time slots and to detect collisions were employed. The VANET consists of a set of RSUs and a set of vehicles moving in opposite directions. It has one control channel responsible for the transmission of high priority information and media access information. Similarly, it has another M service channels used for the transmission of safety or non-safety related applications. Each node is ensured to access the control channel once per frame. Additionally, time slots are accessed by nodes in a distributed way designed to avoid the hidden terminal problems, whether it is in the control or service channels.

2.3 Medium Access Control Protocol

Media Access Control (MAC) is one of two important sub-layers that belong or construct the Data Link Layer. It is layer 2 from the TCP/IP model and deals encapsulation of data bits into frames, synchronization, error control, and flow control in addition to accessing the shared/reserved medium, for multiple nodes that share one medium or even one node alone. The access part is specifically the task of the MAC sub-layer.

It is important to treat all nodes fairly by sharing the medium and dividing the available resources. Mediums can be a copper wire, a fiber optic or even air. With shared mediums, another problem is added which is collision and frame loss. In this thesis, the shared medium will be air since we have a wireless communication protocol designed and according to that, MAC protocol should be surveyed and studied. The main approaches that are used to address the sharing of the medium are categorized as follows: Static Channelization and Dynamic Medium Access Control.

The Dynamic MAC is further categorized into Random Access technique, and Scheduling techniques (see figure 2.1) [25].

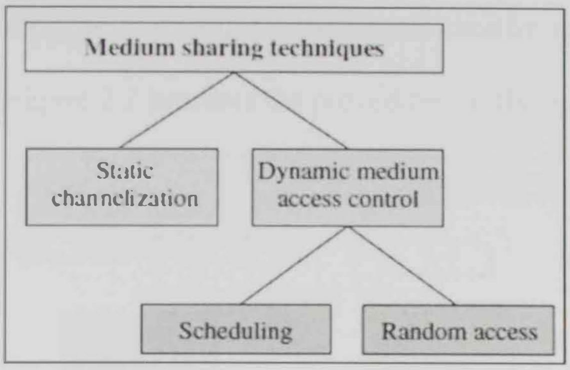

Figure 2.1: Medium sharing techniques [25]

2.3.1 Dynamic Medium Access Control

2.3.1.1 Random Access methods:

Random Access methods are characterized by the fact that no station or node is controlling other nodes and there is no superior in the protocol that allow or prohibit sending. The sending process is initiated whenever a node has data to send according to a procedure or an approach defined by one of the protocol discussed later. In this section some of the techniques that belong to this category will be presented. The approaches listed in the section are: ALOHA, Carrier Sense Multiple Access (CSMA), Carrier Sense Multiple Access/Collision Detection (CSMA/CD), and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA).

ALOHA or Pure ALOHA is a protocol that was developed in 1971 in the University of Hawaii. In this protocol the station that has a frame to send will do so and wait for a time period $(2 \times propagation\ time)$; if it receives and acknowledgement, then the frame is successfully received, otherwise, the station will wait for a random multiple of the propagation time, and then repeat the sending process. The problem is when multiple stations try to send at the same time or during common parts of the time, collisions will occur. The time where collisions are expected to happen is called the vulnerable time and is usually equal to twice the frame transmission time. Figure 2.2 presents the procedure for the pure ALOHA.

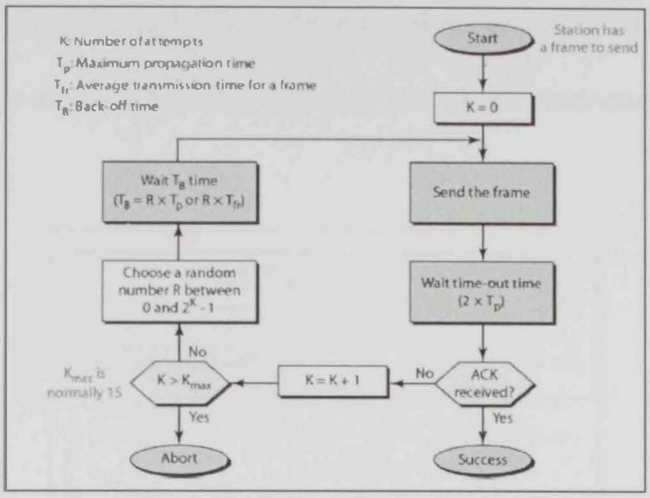

Figure 2.2: Pure ALOHA algorithm [26] [27]

Slotted ALOHA is an improved version of the pure ALOHA, invented to improve the efficiency of the pure ALOHA. The improvement is a result of adding a new feature, which is dividing the time into slots, each equal to the frame transmission time. Stations are forced to send only at the beginning of the slot. As a result, the venerable time is reduced to half of that for the ALOHA and so will the amount of collisions. If a collision occurs, that will be because two stations decided to transmit at the same time, while in ALOHA, collisions could occur because the end of one frame collided with the beginning of another frame, so resources are wasted, and more frames could be affected.

The next protocol is the CSMA protocol. It was developed to increase the performance by minimizing the collisions. This is achieved by making the stations listen to the media before transmitting their frame. Collisions may still occur because a station may transmit when the media was clear, but in actual it was not, and that is because of the propagation time. Another channel sensed the media and sent before the first channel, and that frame took time to propagate and arrive to a point where it can be sensed by the first channel. The vulnerable time in this case is equal to the propagation time. If the media is found to be busy, one of the procedures in figure 2.3 will be followed.

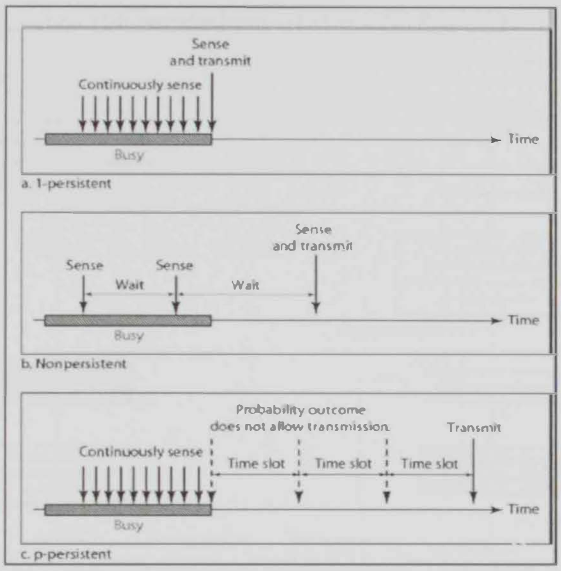

Figure 2.3: Behavior of the three persistent methods [26] [27]

The 1-persistent method is used by Ethernet where the station will continuously sense the media and send once the media is free. In the non-persistent method the station will sense media, if it is busy; it will wait for a random wait time that will increase exponentially every time the media is found busy. Once the media is free after that wait time, the station will send immediately. The last method is the P-persistent method in which the station will continuously sense the media, once the media is free, it will generate the probability of sending; if that probability is acceptable, it will send, otherwise it will wait for a certain time slot before checking that probability again.

The CSMA was modified to be able to detect collisions (CSMA/CD). The stations will monitor the media even after sending the frame. If collision is detected, the transmission will be aborted and the frame will be re-transmitted. Note that the collision should be detected before the last bit of that frame is transmitted, otherwise. The frame will be lost, as the station does not keep a copy of the frame once transmitted. Figure 2.4 presents the procedure of the CSMA/CD.

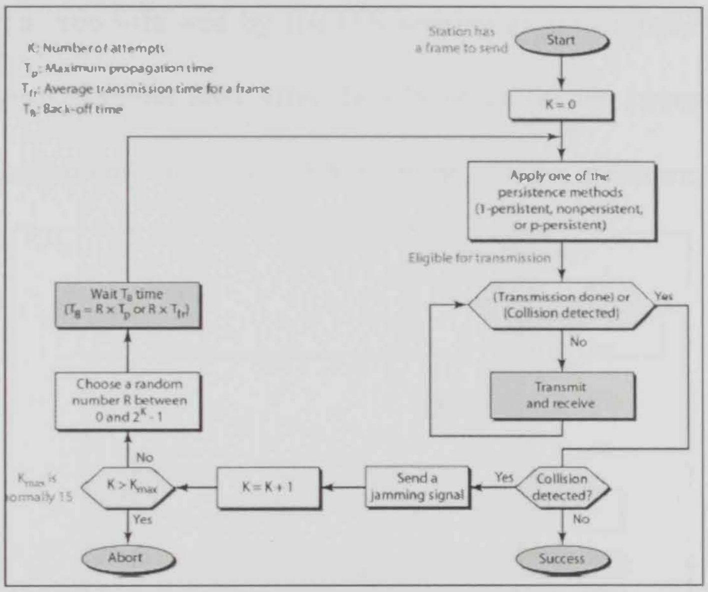

Figure 2.4: Flow diagram of the CSMA/CD [26][27]

CSMA was also modified to have another feature which is avoiding the collisions (CSMA/Collision Avoidance). It is mainly aimed for wireless networks as collisions are hard to be detected, the reason behind that is when a collision is detected; the station receives its signal plus the other station's signal. Since signals in wireless channels fade, it is hard to detect collisions, and for that, it is important to avoid collisions instead of just detecting them.

In this method, collisions are avoided through three strategies: the inter-frame space, the contention window, and acknowledgement. The station will again sense the media continuously until it is found idle. Then the station will wait for a period of time that is called the inter-frame space (IFS) which will help detecting any signal in the media by waiting for its propagation. After the IFS, the channel is again sensed, if still idle, it will additionally wait for a period of time called the contention time. Once that period is over, and the media is still idle, then the station will send the frame and wait for an acknowledgement. If the latter is not received, the process will be repeated right from the sensing step followed by the IFS waiting as illustrated in figure 2.5. Note that if the channel is found busy after the IFS period or the contention period, the process will be paused until it is idle again, then the process is resumed [27].

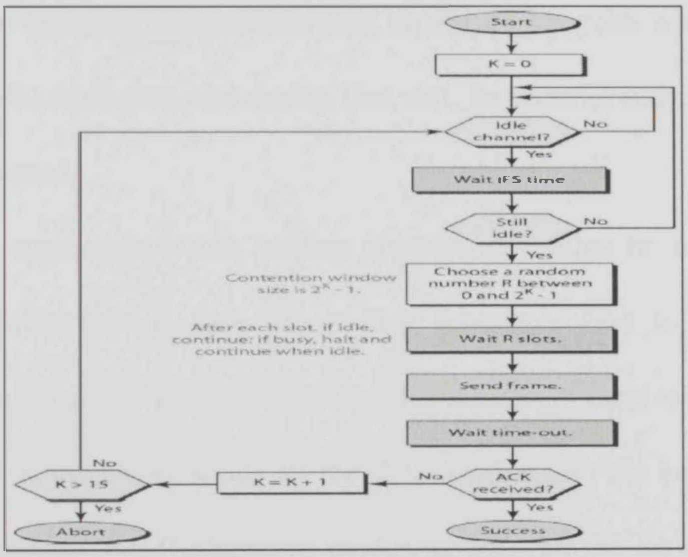

Figure 2.5: Flow diagram of the CSMA/CA [26] [27]

2.3.1.2 Scheduling (Controlled access) methods:

In the scheduling methods, stations coordinate with each other to choose and find which station to send so collisions can be avoided. A station can send only if authorized by other stations. This helps in achieving efficiency, fairness and constant delays. Three methods are discussed in this section; Reservation, Polling, and Token Passing.

Reservation systems can be either centralized or distributed systems based on the way the system is managed. Centralized systems consist of a central controller that accepts the requests from the station available and issues permits to send. There can be multiple permits as the media is divided based on frequency (Frequency Division Duplex (FDD) or time (Time Division Duplex (TDD)) and more than one user can share the media to send at the same time but at different frequency bands or time slots. On the other hand, distributed systems have to implement a de-centralized algorithm to decide whether a station can send or in other words; the transmission order.

In Reservation systems, transmissions are organized in cycles where there are reservation intervals for each slot, and during that slot, its corresponding station will ask for permission to send.

Similar to reservation systems, polling systems can either be centralized or distributed. The permits in this case are polling messages sent to the stations according to their transmission orders. Once a poll message is received, the station starts transmitting. A station may sends all the data available in the buffer plus the new arrivals while transmitting (Exhaustive mode), or only all the data available in the buffer when the poll message arrive (Gated mode). Additionally, the station may be limited to sending only one frame per poll (frame limited mode) or they can send for a specified period of time (Time limited mode).

The last type of systems is the Token-Passing Ring system where instead of poll messages, there are tokens that consist of a series of bits to represent either a free token as an indication of clear to send or a busy token as an indication of a busy media. Stations that are ready to send will wait for the free token, change it to the busy state, release it in the media, send the frames then re-insert the free token again to be claimed by another station.

The re-insertion of the free token can differ based on what method is applied. The first method is the Multi Token operation where the free token is inserted immediately after the last bit of the frame transmitted. The second method is the Single token operation, in which the free token is inserted only after the last bit of the busy token the station sent is received back. Finally there is the single frame operation where the station has to receive back the frame it sent before inserting the free token. Figure 2.6 illustrates these methods to clarify the idea further [27].

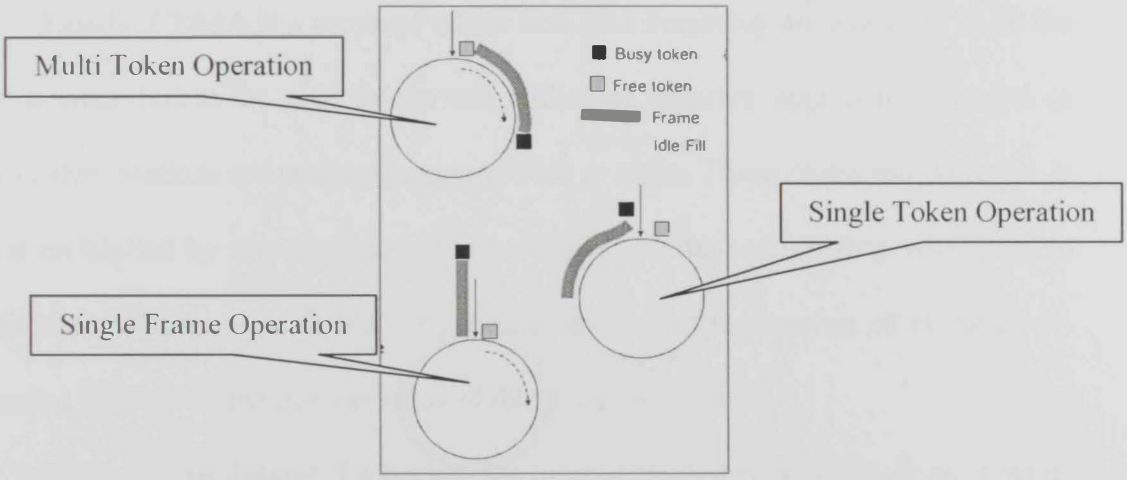

Figure 2.6: Token Re-insertion methods [26] [27]

2.3.2 Static Channelization

This represents another type of multiple access channels. The available bandwidth is shared in time, frequency or through a special method that uses codes.

The three main types of channelization protocols are the Frequency Division Multiple Access (FDMA), the Time Division Multiple Access (TDMA) and the Code Division Multiple Access (CDMA).

In FDMA, the bandwidth is divided into frequency ranges or bands and each station is allocated a band to send its data. These bands are available for the stations all the time but they need to use band-pass filters to tune into that band or to precisely reserve it for transmission. Since interference may occur between these bands, a small guard band is allocated along with the transmission range as well.

The second type is the TDMA, where instead of frequency, the bandwidth is divided into time slots and these time slots have the whole frequency range available for their use. Once the time slot arrives, its corresponding station will send its data. However, stations have to pay attention to the synchronization issue by applying guard bands or using synchronization bits at the beginning of each slot.

Finally, CDMA is a protocol where time and frequency are available to all the users at once but to be able to prevent collisions, another approach was used to achieve that. Stations are assigned unique codes or chips. These codes should result in zero if multiplied by one another and if multiplied by themselves they will result in the number of stations available. These chips consist of a sequence of elements (N elements) where N is the number of available stations.

During transmission; if a station has to send bit 0, it will encode it as -1 while it uses +1 if the bit to be sent is 1 and of course a zero signal corresponds to no signal. The bit intended to be transmitted is multiplied by the code of the transmitting station then released to the common channel. If a receiving station wants to know what a certain channel sent, it has to apply the inner product between the transmitting station's code and whatever data is on the channel. The product results will be summed to get the transmitted bit. Figures 2.7 and 2.8 represent a simple CDMA process.

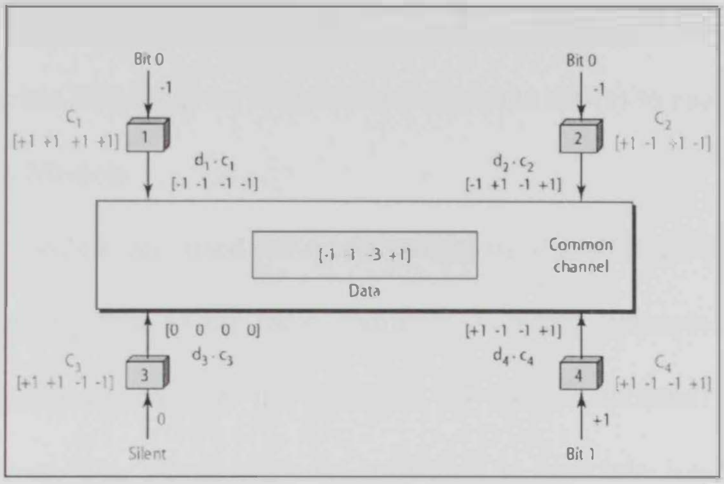

Figure 2.7: An example of a CDMA process (1) [26] [27]

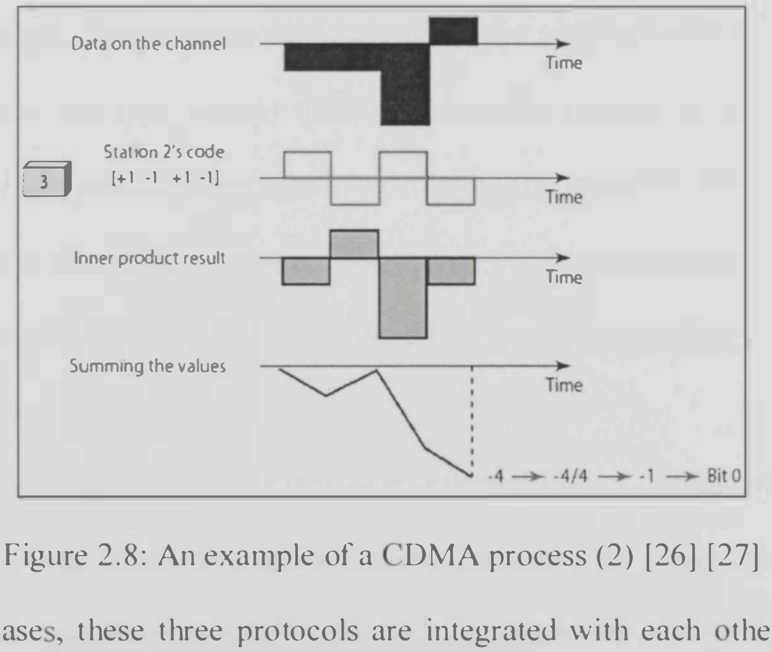

Figure 2.8: An example of a CDMA process (2) [26] [27]

In some cases, these three protocols are integrated with each other to form new hybrid protocols as in [28] where TDMA was integrated with FDMA in what is called the Hybrid TDMA/FDMA MAC layer protocol for WSNs. This protocol was designed to provide high throughput, bounded end-end delay and a collision free operation. The communication in this protocol will happen in fixed-length TDMA cycles composed of a number of frames. Each of those frames is divided into several fixed time slots equal to the time required to transmit a maximum sized packet. The scheduled slots are consecutive and located at the beginning of the cycle, while the remaining slots are called the contention slots. The Base station is responsible for assigning an appropriate frequency as well as a specific time slot(s) to each node [27].

2.4 Propagation Models

Propagation models are used to model some of the characteristics of the physical layer; especially that of the radio channels (wireless channels), where the packets/frames/signals propagate in the medium till they successfully reach the destination or receiver. The signal may be subjected to multiple interruptions or obstructions that will affect the signal's strength and as a result; affect the receiving and decoding process. The path between the transmitter and the receiver may be a simple line of sight, or may contain different obstacles such as buildings, trees, mountains, etc. Propagation models help in calculating the expected power received at a certain distance, after transmitting at a certain power level and where the signal was subjected to the different obstacles mentioned earlier that caused the signal to be reflected, diffracted, or scattered.

For example, if we have waves that were reflected from a certain object, those waves will travel along different paths of varying lengths. 'The interaction between those waves causes multipath fading at a specific location and the strength of the waves decreases as the distance between the transmitter and the receiver increases'

[29]. The signal may interfere with itself as well or with signals sent at different frequencies.

In this section, some of the main propagation models mostly used in VANETs' research are presented such as: the Free Space Propagation model, Two Ray Ground model, Log-Normal Shadowing model, Rayleigh model, Rice model, and Nakagami model. VANETs are applied in environments where vehicle only move in clear roads, but these roads are surrounded by farmlands, forests, urban layouts, bridges, etc. Also the vehicles themselves may be considered as dynamic obstacles.

2.4.1 Deterministic Models

Deterministic models allow the computation of the received signal strength based on actual parameters related to the environment such as the distance between the transmitter and the receiver. These models range from simple models that account for the distance only to very complex models that account for multipath propagation in an environment modeled exactly as the area of operation.

The first model in this category is the Free Space (FS) model where the communication path is modeled as an unobstructed communication path. The received power is related to the transmitted power, the antenna gain and the distance between the sender and the receiver, as illustrated in the following equation:

$$\Pr(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

where P_t is the transmitted power, G is the antenna gain whether it is for the transmitter or the receiver (constant), λ is the wavelength (constant), d is the distance between the transmitter and the receiver, and finally L is the system loss factor (a constant where $L \geq 1$) [29].

The Two Way Ground model assumes that there is a reflection via the ground so we result with a line of sight (LOS) component plus the reflected component that depends on the dielectric properties of the earth. This model is a more accurate version of the FS model that can give predication for longer ranges. The model is represented by the following equation:

$$\Pr(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L}$$

where h is the height of the transmitter or the receiver antennas. On the other hand, it can be noticed that the power loss in this model is faster than that for the FS model [29] [30].

2.4.2 Probabilistic Models

Probabilistic models allow more realistic modeling of radio wave propagation. A probabilistic model takes a deterministic model as one of its input parameters in order to get a mean transmission range. After that, and for each individual transmission, the received power is then drawn from a distribution. The result is a more diverse distribution of successful receptions.

The first model in this category is the Log-Normal Shadowing model that uses a normal distribution with variance σ to distribute the reception power.

$$P_r(d, \sigma^2) \sim LN(P_{r\,det}(d), \sigma^2)$$

Where $P_{r\,det}$ is the received power determined from one of the deterministic models. The received power is given by the following formula:

$$P_r(d) = P_t - \overline{PL}(d_o) + 10 \propto \log\left(\frac{d}{d_o}\right) + X_\sigma$$

In this case $\propto$ is the path loss component, $\overline{PL}(d_o)$ is a reference path-loss measured close to the transmitter.

The second model in this section is the Rayleigh propagation model. It models the case where there is no LOS and only multipath components exist. It takes into consideration the variations in the received signal power due to the differences in the combination of the multi-paths whether it is done constructively or destructively. The environment can affect the amplitude, the delay and phase shift of these components. Note that in order to find the Rayleigh model; it is required to depend on one of the deterministic models. Rayleigh model is given by:

$$P_r(d) = P_{r\,det}(d) \times 10^{PL(d)} \times \log\left(1 - unif(0{,}1)\right)$$

And the power loss factor is calculated by:

$$PL(d) = -\propto log10\left(\frac{d}{d_0}\right)$$

The Rice model is similar to the Rayleigh model but additionally considers the effect of the LOS path with a certain scale factor k:

$$P_r\,(d) = P_{r\,det}(d_0) \times 10^{PL(d)}$$

$$P_{r\,rice}\,(d) = P_r\,(d) \times F(d)$$

where F(d) is the Ricean PDF with a normal distribution.

The last model in this section is the Nakagami Model. The power received is determined by following a gamma distribution:

$$P_r(d; m) \sim Gamma\,\left(m, \frac{P_{r\,det}(d)}{m}\right)$$

The parameter m is used to specify the intensity of the fading effects. Nakagami includes other models, such as:

$$\sim Rayleigh\ for\ m = 1$$

$$\sim Free\ Space\ for\ \lim_{m \to \infty}$$

More models are available in both categories and can be used in different applications such as indoor and outdoor application, but these are the common ones for VANETs

2.5 Simulation

In order to have a close idea of how a VANET or a HVSN protocol will behave in real life, simulation is the best solution. Testbeds are available in the US, Europe, etc, but they are time consuming and expensive. It is important to have a simple, wide, informative introduction to VANETs' simulation in order to understand the topic and advance the research in that area. In this section, VANETs' and HVSNs' simulation is discussed from different aspects and in a step by step manner. Simulation areas, data inputs and simulators are illustrated in details along with examples from literature on each type and method [31]. The different aspects that could be modeled are mobility, roads, vehicles, traffic, network performance, etc. The term 'Vehicular Networks' is used to refer to VANETs and HVSN for the rest of this chapter.

Mobility modeling is important; to mimic the real life movement of vehicles in roads, at intersections, traffic lights, etc. Cars tend to move at different speeds, aiming at different destinations, and their movement could be affected by other vehicles, people, traffic lights and signs, etc. Also, the time of the day does affect destinations and densities; for example, during rush hours, cars' densities tend to be higher near schools and companies while at midnight for example, few cars may hit the roads. Traffic behavior may differ from one city to another. For example, capitals and main cities in the world may have high densities even during late times while small cities and towns tend to have different traffic situations at different times of the day.

Roads are needed to restrict the vehicles' direction of movement. Roads' modeling is important to achieve realistic modeling of vehicular networks whether we are modeling real life roads from maps or arbitrary roads just to define vehicles' paths. Roads may differ in their number of lanes, speeds, priorities, types, etc. They can be unidirectional or bidirectional and have restrictions on vehicles that are allowed on them.

As for modeling vehicles and traffic, usually one simulator is used for that. Modeling vehicles can be related to determining their type, maximum and minimum speeds, acceleration, human error, etc. Traffic modeling is about setting the traffic flow, routes that may be taken, departure times, source and destinations, etc.

The next thing to be modeled is the network, to simulate the performance of new protocols. Different parameters can be set, like the type of communication algorithm, connections, number of nodes, propagation effect if any, number of packets sent, etc.

2.5.1 Modeling Steps

- Aim of simulation

The first step in the modeling journey is setting the aim of modeling. Sometimes it is for traffic purposes such as modeling new road types or elements i.e.

roundabouts, bridges, intersections, etc. Examples on that are thesis works conducted by [32] and [33], where they tried to model a roundabout using different simulators and approaches. Another reason is for network simulations to test vehicular networks, evaluate and test communication protocols whether they are exiting or newly proposed, so modeling roads, vehicles, mobility, traffic, etc. is an important path to pass. Examples on that are very wide and available and in many areas such as: [34], [23], [35], and [36]. This step will determine the type of simulators required and their power or variety of options they offer.

- Simulation area

Areas of simulations are also different and there are many choices available to model and use. Urban areas are characterized by their high population and vehicles' density that differs during the days, in addition to trees, buildings, sign, etc. that may affect the signals. Urban areas may include cities, towns or part of them. On the other hand, rural areas are geographic areas located outside cities and towns. They are known for their low vehicles, obstacles and human densities. In addition to these two major areas, researchers sometimes tend to focus on parts of the roads like highways [7], intersections (with stop signs or traffic lights)[37][38][39][40], roundabouts, etc. in order to focus on studying or improving the network performance in that particular area.

The level of realism intended in the simulation will help identifying how to represent the simulation area. Sometimes all is needed is a small random area with some roads and intersections. In some other cases, a detailed map with road names, widths, lengths, speed limits, etc. is required. With mobility simulators, the choice is available to whether build your map from scratch; junction by junction and road by road, or just to import a map from different sources such as Google maps and other databases as will be discussed later.

- Input data

The type of input data available to use whether it is for demand modeling or for general information about roads, etc., will also help in determining the simulator and the expected level of details in the simulation. In some cases, GPS traces will be used as a movement reference while modeling different options in the demand such as sources, destinations, directions of movement, speed, etc. This was seen in [15] where parameters were extracted from the GPS traces of Taxis in an urban area.

Sometimes data could be collected manually, by spreading people or counting devices (detectors) in the simulation area to monitor the vehicles' movements, arrival rate, waiting time, etc. during several periods in the day as in [32]. The authors in [41] also proposed a mobility model based on traffic data collected from counting devices located on the roads, and also based on geographic information about the simulation area whether it is residential, industrial, commercial, etc. Moreover, the Geographic Information System (GIS) may be used to extract some useful information such as speed limit data as the authors of [42] proposed, where their intention was to investigate the impact of mobility model choice on the routing protocols performance.

Input data could also be artificial and set manually or automatically in simulators, by defining the flow of vehicles in the simulation area, in the required density, with departure and arrival times, source, destination, etc. so it can be used to represent different situations as the user prefers.

- Simulators

The next important element in modeling is of course choosing the right simulator. Note that there are mainly three types of simulators related to vehicular networks; mobility simulators, network simulator and integrated simulators.

Mobility simulators are related to simulating the network or in accurate terms, the simulation area (network of roads), then modeling the vehicles and the traffic demand, and extract the needed output after simulating.

Network simulators are software programs that help predicting the behavior of a network or a certain protocol in the network and provide researchers with enough and detailed information to perform their analysis.

On the other hand, Integrated Simulators consist of both; mobility and network simulators and communicate with each other through a middleware [43].

In the following sections, some of the main examples on each type are presented. Research is very extensive in this area to make the modeling process simpler, easier, and less time consuming.

2.5.2 Mobility Simulators

In this section, two of the main mobility simulators are discussed.

2.5.2.1 Simulation of Urban Mobility (SUMO)

This is an open source, powerful mobility simulator that is used in traffic planning, management and road design optimization, and can handle large road networks. It can be used also to build up vehicular mobility models that help reflecting the real situation of the vehicles' flow. In order to achieve the network design, a user can construct the network from junctions and roads, or just randomly choose an arbitrary area shape, or import the network since the simulator can accept input in different forms from different programs and databases, then convert it to be suitable for its use. Same applies to the demand modeling input, where the input can be artificially generated or imported and converted to be used. As for the output, SUMO allows to generate a large number of different measures. Some of the outputs' types are the vehicles' positions, trip information, routes' information, simulation state statistics, etc. The simulation can be visualized by the SUMO-GUI included, where roads, vehicles, junctions, etc. can be viewed and monitored while in action. The generated output can be used as an input to network simulators such as ns-2 and QualNet (presented later) to be able to study the network performance of the mobility model [44][45].

2.5.2.2 VanetMobiSim

This simulator is another generator for realistic mobility traces that can be used by network simulators. It enhances the methods of importing networks by allowing the extraction of maps from the TIGER database and allowing the graphs to be randomly generated as well [46].

2.5.3 Network Simulators

In the following section, four main network simulators are presented along with their features. The main performance metrics used by researchers to test their proposed protocols and models are the throughput, end to end delay and packet delivery ratio as seen in [37], [40], [47], [48], and[49].

2.5.3.1 Network Simulator (ns-2)

It is an open source discrete event simulator that provides significant support for TCP, routing and multicast protocols' simulation over both; wired and wireless networks. It is the widely used network simulator in the research and educational community [50]. NS-2 is used in evaluating and validating many MANETs' and IEEE 802.11 MAC layer protocols [43]. No Graphical User Interface is available, so all the connections and parameter specifications have to be set manually in code files. Thus, it requires the knowledge of Tcl scripting before starting to use it. As for the visualization, ns-2 uses a 2D animator (NAM) for that purpose [51].

2.5.3.2 Qualnet

It is a simulation platform that is used to predict the performance of wired, wireless and mixed networks. It is also used in analyzing the early stages of designs and applications. It allows users to set up, develop and simulate custom network models in a fast and scalable way. It includes a GUI for creating the model and its specifications without writing a code [52]. Although it is integrated in MOVE simulator (presented later), but this software is commercial.

2.5.3.3 OMNET++

It is an open source, object oriented, network simulator that is used for wired, wireless communication networks, on-chip networks, queuing networks and so on [43]. Additionally, it is a component based design, so new features and protocols can be supported through additional modules. OMNET++ is also equipped with a rich set of networking protocols and great support for physical and MAC layer simulations. It is claimed that OMNET++ is more suitable for VANETs' simulations than ns-2. One of the reasons behind that is the fact that we are dealing with wireless network simulations and they are affected by the lack of channel modeling. OMNET++ is extended to support different probabilistic propagation models i.e. Log-Normal shadowing, Nakagami, Rayleigh and Rice wave propagation models. So, it provides the ability to investigate multichannel modeling and to implement any abstract channel model specific to V2V communication [53].

2.5.3.4 Optimized Network Engineering Tool (OPNET)

It is another network simulator used for simulating both wired and wireless networks. It also helps in visualizing TCP/IP mechanisms and variations. Users can use it to design reliable and efficient wireless networks and implement them. It is used by students to understand the difference between LAN (Local Area Network), MAN (Metropolitan Area Network), and WAN (Wide Area Network) network architectures. Actually, it is commercial software, but there are offers for researchers and teachers to get the full version for free [54].

2.5.4 Integrated Simulators

Integrated simulators –as discussed earlier- integrate mobility and network simulators, sometimes with interaction and feedback between them. Modeling and simulation of VANETs was discussed in a book section in [55], where they distinguished the key buildings of VANET simulators as mobility models, networking models, and signal propagation models.

2.5.4.1 Mobility model generator for Vehicular Networks (MOVE)

This simulator is built on top of the mobility simulator SUMO. It provides a GUI that facilitates the generation of simulation scripts unlike SUMO, where the connections, definitions, routes, etc. has to be written to Extensible Markup Language (XML) files. The output of MOVE is a mobility trace file that can be immediately used by ns-2 or Qualnet network simulators. These simulators are also included in MOVE, where the simple GUI provided can be used to generate the required scripts and visualizes the simulators. The disadvantage of MOVE is that it is compatible with old versions of SUMO, and not improved to suit newer versions [56].

2.5.4.2 Traffic and Network Simulation Environment (TraNS)

This is another GUI simulator that integrates traffic and network simulators which are SUMO and ns-2. It helps generating realistic simulations of VANETs. A nice feature about this simulator is that it has it allows the exchange of information between VANETs and the mobility model. In other words, broadcasting information may affect the behavior of vehicles, like they may accelerate or decelerate depending on the type of information. However, TraNS is not compatible with the latest version of SUMO, so not all the features may be available [57]. Vehicles in Network Simulation (Veins)

This simulator integrates both SUMO and OMNeT++ by extending SUMO to be able to communicate with OMNeT++ through a TCP connection. It allows dynamic interaction between both simulators. This interaction or simulators' coupling provides benefits to the simulation as it increases the realism of the results and gives a better insight of the impact of network protocols on road traffic [58].

Note that there are some other simulators that are also used to model mobility or network that require the user to start the simulation and build the scenarios and protocols as wished. Example on that are MATLAB and C++ as seen in [38].

CHAPTER 3

Protocol Design

This chapter discusses the details of the proposed protocol in this thesis. It is aimed to clarify the idea behind the protocol to help understand the later stages of simulation and results.

3.1 Problem Statement

ITS has been applied to serve different types of applications and purposes related to driving safety, facility acquiring[1], emergency reporting, etc. In this project, the main target is to assure the transmission of safety messages that include information about vehicles' speed, locations, directions, destinations, road congestion, etc., since they are critical information and can help prevent accidents and late arrival to destinations. Such messages increases the level of safety in the roads, and for that, the issues that may affect their transmission efficiency should be addressed and solved. Since vehicles are communicating in a wireless environment, messages face losses at a higher rate due to different reasons related to propagation, resource limitations, collision of transmitted packets, etc.

The aim of this project is to design a communication protocol that assures the successful transmission of safety messages in the system through a collision free scheme that is applied in HVSN. Moreover, topics needed to achieve this design should be considered as well such as mobility modeling, traffic design and simulation. Note that since the main target is to have a collision free communication

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[1] A facility acquiring application is used by drivers to inquire about nearby facilities such as restaurants, petrol stations, hotels....etc.

protocol, then our concern is the MAC layer, since it is the layer responsible for the media access and that is coordinating the nodes' access to the communication links.

This protocol targets urban areas where a specific real map area is obtained and modeled. Since vehicles are an important element in this protocol, traffic is modeled to represent vehicles mobility in the simulation.

In the following sections, more details about the communication protocol are illustrated.

3.2 Design Challenges

To successfully achieve the design required for this project, it is important to state the main design challenges to expect and solve them. The main challenges were to reach a unique idea and then a design, since research in this area (VANETs, HVSN, communication protocols, etc.) is very wide and extensive.

Starting from the aim of the project, it is noticed that we need a collision free scheme using the MAC layer, so it is essential to survey the available media access techniques and choose the appropriate technique that can be modified to suit our application, to have a unique approach. To reach that point, the overall system should be set. It is mentioned that HVSN is used, that will include a WSN mounted on mobile vehicles and on road sides. This system was chosen for its simplicity, performance, and the fact that this topic is still fresh and needs more research. It has one more advantage related to its reduced cost compared with VANETs, but the cost is not an issue at this point since no implementation is intended.

Moving to more specific details in the HVSN; it is noticed that vehicles are the main elements and they have to be modeled as communicating nodes. They should be assigned a location, a speed, a destination, a road, a lane, movement; that is; all the aspects of mobility. The challenge in this point is to realistically model the mobility, in the amount required by the protocol for testing purposes. For example, if the simulation area chosen has no traffic lights or roundabouts but has intersections and stop signs, then there is no need to model what is not there and the simulation will be simpler if only what is modeled is actually what is needed. Moreover, since we do not only have one vehicle in the protocol, then vehicles' interaction with each other should be considered as well, in addition to traffic modeling.

The next thing to consider is how this modeling is going to be tested or applied, and for that a simulator is required. A choice has to be made on what simulator is better to be used after surveying the main available simulators. Some simulators may be more advance and have more features, but due to modeling purposes, they may not be the best choice. The same decision has to be taken regarding the simulation of the communication protocol designed. The integration between the two simulations is an important issue as well, because vehicles movement will affect the communication status and vise versa, and there should be a continuous feedback and interaction between both simulations. The last thing to consider is how to efficiently manage the network resources and utilize them wisely, whether it is time, frequency, bandwidth, power or memory. It is important that these resources are fairly shared among the nodes.

3.3 Network Setup

3.3.1 Network Overview

The main elements of this protocol are vehicles and WSN units. The vehicles' role is to transport people and information. Wireless sensors are used to collect information from the surrounding environment and vehicles then disseminate them back after analysis to the concerned parties, whether it is a vehicle sending important information to the network controller (RSU) or vice versa.

WSN units can be in two forms; the first form is dedicated to vehicles to send and receive information of interest, while the other form is located on the road sides to collect information, assign roles to vehicles, keep records, etc. The WSN units mounted on vehicles are mobile and known as the mobile nodes (Vehicles Nodes), while the ones located on the road sides are static, and known as the static nodes (Road Side Units). This setup represents; the Hybrid Vehicle Sensor Networks (HVSN).

HVSN recently became a hot research topic as a new promising system that will help reducing the costs, by eliminating the installation costs, using less expensive wireless sensors instead of the sophisticated onboard units installed in vehicles. More advantages are related to increasing the performance and smoothing the transition from the old vehicle traffic control systems to a new generation of safe and sophisticated traffic. These points and more were discussed earlier in chapter 2 (Literature review). The communicating nodes will be located in segments that are part of the roads and streets in the simulation area. The chosen simulation area will be divided into segments based on the wireless network range. Each segment will be assigned one network controller which is a fixed and always available Road Side Unit (RSU); that will provide the communication to all the vehicles in the range among other tasks that will be discussed later. So the segment will contain one cluster, with the RSU being the cluster head, and no cluster head will be chosen from vehicles. The reason is to reduce the complexity of electing a head among vehicles, then periodically re-electing another one to preserve resources, in addition to the fact that vehicles do not have fixed locations, but they are dynamic with high speeds. The methodology of the communication between the RSUs will be discussed in later sections.

3.3.2 Network Elements Description

As mentioned in the previous section, there are two types of nodes in this protocol; mobile and static nodes. Although same units are used in both, but they are utilized differently and modified in some cases based on their use and application. They consist of a communication unit, a memory, a processing unit and a sensing unit based on the application or the requirements. Note that RSUs require more memory and processing capabilities since they will be keeping records of all the available vehicles, and controlling the communication process during the operation. Table 2 illustrates the main roles of the VNs and the RSUs.

Element	Role
Vehicle Node (VN)	• Sends its own speed and location • Receive speeds and locations of neighboring vehicles (heading in the same direction) • Process the received information and display it to the driver • Receive periodic updates on the road status from the RSU
Road Side Unit (RSU)	• Keep a record of the vehicles in the wireless range • Communicate with the new vehicles and assign them time slots to be able to send their information • Manage all the connections and resource allocations • Time synchronization • Periodically update vehicles in the segment about the road condition

Table 2: Network elements and their roles

Note that power is not an issue in our design, since VNs are continuously recharging their power sources from the car's battery. Same applies to RSUs which will use the power lines available to feed lights and traffic signs or use solar cells.

As mentioned earlier, there will be periodic messages from the RSU to all the vehicles in range, and this is the first type of messages. Also, there will be messages from each vehicle to all vehicles and the RSU during its allocated time slot, and that is the second type of messages. The last type of messages is the connection establishment message related to new vehicles arriving to the segment, where the RSU has to acquire their information, make them familiar with the segment and then finally assign them a time slot to be able to communicate with them. The main messages types in this protocol are:

a. Connection establishment messages:

This type of messages is required between vehicles and the RSU once a vehicle enters the range of the RSU. The latter needs information about the vehicles in the range such as: vehicles' id (given by the traffic authority), speed, destination address (as general information for the RSU), previous segment id, and previous segment speed. Additionally, vehicles also need information about the current segment such as, segment id, segment status and average speed. The connection establishment steps are as follows:

- A vehicle will detect a new segment, since the segment's range is fixed, where the vehicle will automatically know when a new segment starts according to the distance passed
- If the vehicle is starting its movement, there will be no way to know whether it is at the beginning of the segment or in the middle. For that, the points where vehicles emerge and enter the main roads will be known to RSUs and vehicles will send their slot request message. The RSU in that segment will expect that because it has another entry to the segment other than normal road movement. In this protocol we consider a main road, where vehicles know their location and they move continuously between

segments, so the case of vehicles just starting their movements is not applicable in our case.

- The vehicles will send a slot request message with their ids, destinations, speeds, locations (x and y GPS coordinates), etc.
- The RSU will reply with its id, the current average speed, the road status (good, weather, congestion, emergency), the suggested available time slot and that is just to the requesting vehicle (not a broadcast message). The RSU will assign the first free time slot to the vehicle.
- The vehicle will send an acknowledgement to confirm the reservation of the time slot, and start communicating with the other vehicles and with the RSU to update its information
- RSU will make an entry in the list of vehicle's table with the vehicle id, destination, and slot reserved to keep track of vehicles in the network.

Vehicles will remain in the table until no periodic messages are received for certain duration, determined by the timer.

b. Periodic messages from RSU to all vehicles in the segment.

These messages will contain the average speed in that segment, segment status indication (congestion, emergency, or normal), in addition to the clock to maintain the synchronization. According to the received clock, all the vehicles in the segment will adjust the drift in their clock to know when to start their transmission based on their specified time slot. Note that periodic messages took time to propagate and reach the vehicles. As a result, vehicles should add the amount of propagation time to the clock received. The location of the RSU is known to the vehicles as it is located in the middle of the segment and using GPS devices, each vehicle can know its location and accordingly calculate the propagation time.

c. Periodic messages from vehicles to RSU.

Since RSUs will know the number of vehicles from its table of entries, it has to know whether vehicles are still in the range or not. This will be achieved by periodic messages. Vehicles will send messages that contain their average speed, to serve two purposes; first: the RSU needs to collect average speeds from vehicles and calculate the average speed of vehicles in the roads and disseminate that information to all cars in the segment. Second, from the average vehicles' speed in that segment, the RSU can determine the road status, especially the congestion status. Congestion can be detected based on two cases; if the average speed of vehicles in the segment is lower than the segment's assigned speed limit or a certain threshold, then there is congestion, otherwise, no congestion. Another way is based on the number of vehicles in the segment, if the number of vehicles is more than a certain threshold with respect to the capacity of the segment, and then congestion is detected.

d. Communication between RSUs

This type of communication will be achieved physically using the vehicles themselves not through direct messages. Each vehicle will carry information about the segment such as segment's id and segment's condition from its current segment to the following segment. This information will be known to the vehicle through the periodic messages received from the RSU. Additionally, most roads disseminate that information to the vehicle's in the range. After that, the vehicles leaving the segment will deliver that information to the following segment as well so that the vehicles that are expected to arrive at the current segment will be informed.

3.3.3 Protocol Methodology

Moving to another aspect in the network setup which is the protocol methodology, and specifically the approach of reaching the aim of the project and that is minimizing the packet collisions. The media access method intended, is through channelization and specifically the Time Division Multiple Access method. As mentioned in chapter 2, the basic idea of the TDMA method is dividing the available time between all the available nodes so that they can communicate using the available frequency range.

What is new in this project is to know in advance; the maximum number of vehicles that may be available in a segment, i.e. the segment's capacity, and make sure that there are available slots for every vehicle at any time without the need for re-configuration or re-arranging of time slots and dividing the network resources over and over again. This will reduce the amount of processing required by the RSU, and save this processing power for other tasks. The frequency range available for communication will be divided as well, since the communication standard applied and followed is the IEEE 802.11 p WAVE protocol, and this standard; as discussed earlier, has two types of channels, service and control channels, each with its own frequency band.

WAVE protocol provides communication range up to 1000 m with minimum data rate of 3 Mbps [20]. Due to the high communication range and data rate, the idea is very feasible.

The capacity of the segment will be calculated based on the map area used, the range of a RSU, the average length of a vehicle and the safe distance between vehicles. So, if we place vehicle back to back with each other, and fill the segment; the maximum vehicle capacity will be found and so will be the number of time slots required.

As a simple example, we take one segment to explain the analysis; for example, the segment shown in figure 3.1. Note that we only care about the area where vehicles can move (not sidewalks), so mainly, only roads will be considered. It is assumed that each RSU has coverage of radius 50 m. However, when the unused edges and areas are cutoff, the segment size will be approximately a 100 m x 50 m area. It is possible to increase the range using higher transmission power; hence, for now we assume that the RSU coverage area is limited to this range. The RSU will be placed in the center of the segment, as we have an area separating the two directions of movement. In each lane there is a queue of cars depending on the length of the segment (100 m). The average car length is about 4.2 m and the safe distance is assumed to be 0.5 m, so one car will occupy approximately 4.7 m. The total number of cars in one lane in a segment is:

$$\frac{100}{4.7} = \text{ 22 Cars/lane/segment}$$

If the road has two lanes then the total number of cars in one segment is 44, likewise if there are three lanes, then the total number of cars is 66. In this segment, there are six lanes, three in the forward direction and three in the reverse direction, which will give a total of 132 cars and accordingly 132 time slots.

As a part of the realistic representation of the simulation area, it is important to benefit from all the information available about the extracted area such as speed limit and the GPS coordinates for the boundaries. The speed limit in that location is set to be 80 km/hr, which means that vehicles' speed can vary from 70 to a maximum of 100 km/hr. Some vehicles may accelerate to a higher speed, but 100 km/hr is the maximum speed a vehicle can go up to without getting a ticket. On the other hand, since the GPS coordinates for the segment are known, then any vehicle with a GPS coordinates within that area will be considered in the range of the RSU.

Figure 3.1: An example of one segment (100 m x50 m) (© Google Maps, 2013)

The simulation nodes in this case are the moving vehicles. To calculate the exact amount of time required for each time frame, it is important to know the size of the packets to be exchanged based on the enclosed information in each packet. Table 3 illustrates the types of messages in details with the length of each field but before that, let us explain more about these sizes that were allocated to each piece of information or frame field.

- ID: 2 bytes of data will give 65536 combinations for different IDs for vehicles and RSU, and this will be sufficient for now.
- GPS coordinates: to determine how many bytes to assign for the location information, the storage requirements for navigation devices were used. Internally, Garmin uses 32-bit binary values to represent latitude/longitude values and that allows for resolution down to 1cm. for that, 4 bytes were assigned to represent the location of each vehicle. The same is applied for the vehicles' destinations as we are using GPS coordinates as well.
- Speed: the speed will vary from 0 up to 100 km/hr or even more. 1 byte will allow a speed up to 256 km/hr, and that is more than enough.
- Slot number: according to the capacity of each segment, the average number of vehicles can be around 130 vehicles per segment and that is equal to the number of slots. For that, 1 byte is assigned for the slot number. The current time slot is given 1 byte as well, as it is important for the vehicle to know which time slot is operating, to be able to know when its turn will arrive.
- Road status: Roads may be clear, congested, having weather issues, or emergency. That is 4 statuses that need only two bits.

- Time: time uses the format of 00:00:00 where hours vary from 0 to 23 while minutes and seconds vary from 0 to 59. They require about 5 and 6 bits respectively. So, to represent an accurate time we need around 20 bits.
- In all message types, an additional part is added; which is the header, and is used to carry control and connection related information. The main fields in the header depend on the message type:
    - Slot request message: a time stamp field (20 bits) → total header size: 3 bytes
    - Slot assignment: Destination ID (2 bytes) → total header size: 2 bytes
    - Acknowledgment: time stamp (20 bits) → total header size: 3 bytes
    - Periodic from vehicles: time stamp (20 bits), direction 1bit → total header size: 3 bytes
    - Periodic from RSU: no overhead, because if a time stamp is going to be added, it will be considered as repeated information as the current time is already contained in the message
- Note that the overhead percentage was considered to be minimal. The maximum overhead percentage was found to be 30 %, which indicates that the resources are well utilized to send important safety messages.

Message type	**Message details**	**Size**	**Total size**
Connection establishment	1. Slot request message		14 bytes data + 3 bytes header = 17 bytes Overhead % = $\frac{3}{17} = 17\%$
	a. ID	2 bytes	
	b. GPS coordinates	4 bytes	
	c. Destinations	4 bytes	
	d. Speed	1 byte	
	e. Pervious segment ID	2 bytes	
	f. Previous segment condition	2 bits	
	2. Slot assignment		7 bytes data + 2 bytes header = 9 bytes Overhead % = 22%
	a. ID	2 bytes	
	b. Slot number	1 byte	
	c. Current time slot	1 byte	
	d. Current time	20 bits	
	3. Acknowledgment		8 bytes data + 3 bytes header = 11 bytes Overhead % = 27% Total: 37 bytes
	a. ID	2 bytes	
	b. GPS coordinates	4 bytes	
	c. Speed	1 byte	
	d. ACK	1 byte	
Periodic from vehicles	a. ID	2 bytes	7 bytes of data + 3 bytes header = 10 bytes Overhead % = 30%
	b. Speed	1 byte	
	c. GPS coordinates	4 bytes	
Periodic from RSU	a. Average speed	1 byte	5 bytes of data
	b. Road status	2 bits	
	c. Current Time	20 bits	
	d. Next segment status	2 bits	
	e. Next segment speed	1 byte	

Table 3: types of messages in addition to their sizes

After discussing the different types of data to be exchanged, it is time to go back and calculate the time required for each time slot and for the time frame in general. The total time required for a packet to be transmitted is equal to:

$$Total\ time = Transmission\ time + Propagation\ time$$

The transmission time is defined as the time required to push all the packet's bits into the transmission link. It is given by the following equation

$$Transmission\ time(s) = \frac{packet\ size(bits)}{data\ rate(bits\ per\ sec)}$$

On the other hand, the propagation time is defined as the time required for a packet to propagate through the media, and it depends on the distance between the transmitter and the receiver in addition to the propagation speed given by the speed of light. The propagation time is calculated using the following equation:

$$Propagation\ time\ (s) = \frac{Distance\ between\ Tx\ and\ Rx\ (m)}{speed\ of\ light\ (m/s)}$$

As seen in figure 3.2, **a** represents the farthest distance between the RSU and a vehicle and it is equal to $\sqrt{50^2 + 25^2} = 56\ m$. On the other hand, **b** represents the farthest distance between two vehicles and it is equal to$\sqrt{100^2 + 50^2} = 103\ m$. Note that the RSU is located 10 m above the ground, so the actual farthest distance between the RSU and the furthest vehicle as seen in figure 3.3 (line **c**) is: $\sqrt{56^2 + 10^2} = 57\ m$

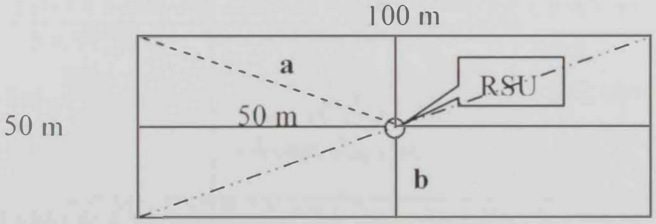


Figure 3.2: Calculating the farthest distances in the simulation area

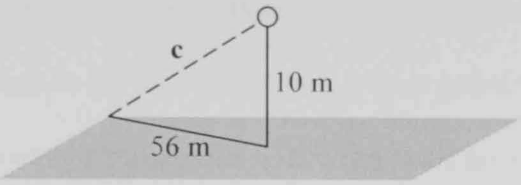


Figure 3.3: Representation of the RSU

Table (4) illustrates the calculation of the slot time, frame time, how frequent a vehicle will update its information through periodic messages, and the time available for each vehicle in the segment at different distances.

Also note that by periodic messages we mean the periodic message from vehicles followed by the periodic message from the RSU. So the time calculated includes the time required for both.

Parameters	Light speed = $3\ x\ 10^8$ m/s Packet sizes: given in table 3 Data rate = 3 Mbps Vehicle speed = 100 km/hr = 27.8 m/s Maximum distance between a RSU and vehicle (connection establishment) = 57m Maximum distance between two vehicles (Periodic messages) = 103m				
Communication type	Connection establishment	Periodic messages			
		Slot time	Frame time	Time available for a vehicle in the segment	Updating frequency
Calculation of slot times and updating frequency	$\frac{37\ bytes \times 8\ bits/byt}{3 \times 10^6 bits/s} + 3 \times \frac{57m}{3 \times 10^8} = 0.1ms$	$\frac{(10+5)\ bytes \times 8\ bits/by}{3 \times 10^6 bits/s} + (\frac{103m}{3 \times 10^8} + \frac{57m}{3 \times 10^8}) = 0.0405\ ms/slot$	$0.0405\ ms\ /slot \times 132\ slots = 5.35\ ms$	$\frac{100\ m}{27.8\ m/s} = 3.6\ sec$	$\frac{3.6\ sec}{5.35\ msec} \cong 670\ times$

Table 4: Calculation of the time required for each slot

As noticed from this table, time for updating and sending periodic messages several times will not be an issue at all, in fact, adding a time guard between time slots and even increasing the coverage range will still work with no problems. Additionally, having empty slots and delaying the transmission of periodic messages for vehicles that are waiting for their time slots to arrive although the transmission media is free is fine in this case, because vehicles will still have plenty of time to send and receive when their time slots arrive.

As a result of this analysis, the expected time frame is 5.35 milliseconds, and if a time guard was added (0.5 micro seconds), the time frame will be (5.35 msec + 131*0.5 μsec = 5.415 msec) , divided between the maximum number of vehicles that may be available in the segment at one time. Each vehicle is given a time slot of 0.041 milliseconds to send and receive periodic messages. Note that these calculations were made using the maximum speed a vehicle is allowed to reach, and the minimum data rate allowed by the WAVE communication protocol, so it is the worst case scenario.

On the other hand, the Connection establishment phase has no time slots to send and receive. It handles new vehicles one at a time based on the slot request message's arrival time. To assure that there will be minimal or no collision in the control information due to multiple vehicles arriving to the segment at the same time, another idea was implemented. Since all the new vehicles available in the control channel are under the same RSU coverage range, then they will be aware of what is happening in the network whether it is a vehicle sending a slot request message or the RSU replying with the slot assignment message. Vehicles that sense that the media is busy will not send their messages for certain amount of time equal to the connection establishment phase duration ($0.1ms$). Once the time is over, the vehicle will sense the media again and then send. This is the case when the vehicle finds the media busy before sending, but if the media is idle and two or more vehicles sense the channel and transmit at the same time. Well, in that case, if two or more messages are sent at the same time from the same location, then the collision will happen at the RSU and the vehicles will not be informed about that incident and will not receive any reply from the RSU. Accordingly, and after the waiting time is over with no response, the vehicles will know that something went wrong with the message they sent and will adopt the exponential back off algorithm before resending their slot request message. Depending on the number of attempts, the vehicle will back off for a random number of waiting times between 0 and 2^k -1 where k is number of attempts and then resend the message. The more the number of attempts, the less likely the vehicles trying to resend will choose the same random number as the range becomes wider [27]. Of course vehicles usually arrive to the segment at different instants of time even if it is in milliseconds and that is enough for them to go through the connection establishment phase with low probability of collision.

The next set of calculation to be performed is done to ensure that the transmission power is sufficient to transmit a packet to the receiving node. The free space propagation model was chosen since there is a clear Line of Sight between the transmitter and the receivers. Vehicles will only be sending periodic messages to the vehicles in the same direction and that emphasizes the clear line of sight idea since any trees or lights in the area between the two directions will not be an issue. The received power at the destination is calculated by:

$$P_r(d) = \frac{P_t\, G_t G_r \lambda}{4\pi d^2}$$

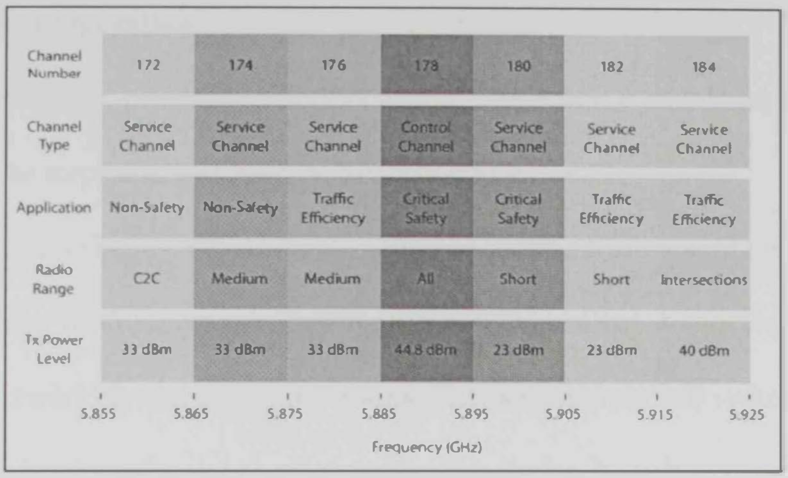
This equation was presented in chapter 2, where P_t is the power transmitted; G is the transmitter and receiver antenna gains, λ and d are the wave length and the transmitter-receiver separation respectively. It can be noticed that G and λ are constants related to the specification of the sensors hardware. For analysis purposes, a simplified version of the free space model is used where a constant (K) is assumed to represent all the unknowns in the equation as explained in [59]. K is expressed by equation below and assumed to be equal to 1:

$$K = \frac{G_t G_r \lambda}{4\pi}$$

The propagation model becomes:

$$P_r(d) = \frac{P_t\, K}{d^2}$$

According to figure 3.4 which presents the set of channels defined in the WAVE standard for multichannel operation in vehicular networks; the control channel has a transmission power level of 44.8 dBm (30.2 watt) while the power level for service channels vary between 23 dBm to 44 dBm depending on the application. To complete this analysis, a transmission power level of 33 dBm (1.99 watt) is chosen. This power level is usually applied in traffic efficiency related application [18].



Channel Number	172	174	176	178	180	182	184
Channel Type	Service Channel	Service Channel	Service Channel	Control Channel	Service Channel	Service Channel	Service Channel
Application	Non-Safety	Non-Safety	Traffic Efficiency	Critical Safety	Critical Safety	Traffic Efficiency	Traffic Efficiency
Radio Range	C2C	Medium	Medium	All	Short	Short	Intersections
Tx Power Level	33 dBm	33 dBm	33 dBm	44.8 dBm	23 dBm	23 dBm	40 dBm

Figure 3.4: Set of channels defined in the WAVE standard [18]

The last parameter to set is the distance between the transmitter and the receiver. We need to find the worst case for calculation, which is the farthest point between the communication nodes. These distances were found earlier to be 57 m between the RSU and the farthest vehicle, and 103 m between vehicles.

The received power in the control channel (RSU and vehicle or line **c** in figure 3.3) is:

$$\frac{(30.2)(1)}{57^2} = 9.3\ m\,Watt$$

On the other hand, the received power in service channels at the farthest point is (line **b** in figure 3.2):

$$\frac{(1.99)(1)}{103^2} = 0.2\ m\,Watt$$

According to the specification of the IEEE 802.11 [60] related to receiver sensitivities, they might range between -68 dBm (1.58×10^{-10}) till -85 dBm (3.16×10^{-12}) depending on the modulation type, which is a lot lower than the results we got. This proves that the range is acceptable and communication can be easily established.

3.4 Protocol Operation

To explain the protocol operation, a simple situation is presented to show clearly what the steps are, and how the process will go on.

Assume a vehicle entering a new segment coming from an old one. According to the WAVE communication protocol, the control channel is used to manage the networking and communications. The new vehicle will switch to the control channel and send a slot request message declaring its arrival to the segment along with the other information stated in table 3 earlier (connection establishment stage). The RSU will be listening all the time to that control channel, and will respond back to the message once received. Before that, the RSU will pick the first free time slot, sends its number to the new vehicle and waits for an acknowledgement (Slot assignment stage). The vehicle will send its slot occupying confirmation along with other information (Acknowledgment stage). After that, the vehicle will switch to the service channel and start its interaction with the existing vehicles in the segment. These vehicles will send their information to everyone during their time slot that is divided into two parts; the first part is dedicated to the vehicle to send its periodic message while during the other part all the vehicles will receive the periodic message from the RSU for the sake of information and synchronization. Figure 3.5 illustrates a detailed slot division with time details. Moreover, Note that even if a slot is free, the RSU will still update vehicles periodically, as seen in figure 3.6 which illustrates a timing diagram example for the protocol.

Periodic message from vehicle	**Periodic message from RSU**	**Time guard**
0.027 $msec$	0.0135 $msec$	0.5 μsec

Figure 3.5: time slot division and duration

Slot Occupied			Slot Free			Slot Occupied		
Vehicle x	RSU	Time guard	▨	RSU	Time guard	Vehicle y	RSU	Time guard
Slot 1			Slot 2			Slot 3		

Figure 3.6: Timing diagram example for 3 time slots

Once the vehicle is out of the coverage range, i.e. moved to the next segment, its entry in the RSU record will be removed once the timer expires, and whatever resources were allocated for it will be released to be used by new vehicles. Note that the vehicles will know when they arrive at a new segment from the distance they passed or in other words the mileage; every 100 m there is a new segment, and a slot request message is sent. Additionally, It is noticed that once a new vehicle arrives, it will be assigned the first free time slot even if that means it will be sending before other vehicles that are already waiting for their turn. This will not be considered as non fairness, because those vehicles will already wait for that time slot to be over even though it is free, so it is better to use that time slot and assign it to new vehicles.

It was mentioned earlier that the information enclosed in the periodic messages are used to display some information on the driver's screen in each car. This screen should be user friendly, as no distraction should be caused by this screen that may affect the user's safety. The information displayed on the screen includes the following:

- The vehicle's current location indicated by a green circle.
- The location of other nearby vehicles moving in the same direction as the user, indicated by a red cross.

As a result, the driver can spot all vehicles that are moving along with him in the same direction, including the ones that are not visible in side mirrors (e.g. those in blind spots) with the system's help. Other information may be displayed such as: the average speed and the road condition. Later in the following chapter, an example of the screen is presented among the simulation results.

To conclude this chapter, figure 3.7 represents the flow diagram of a scenario that illustrates the journey of a vehicle from the moment it arrives at a segment, till it leaves.

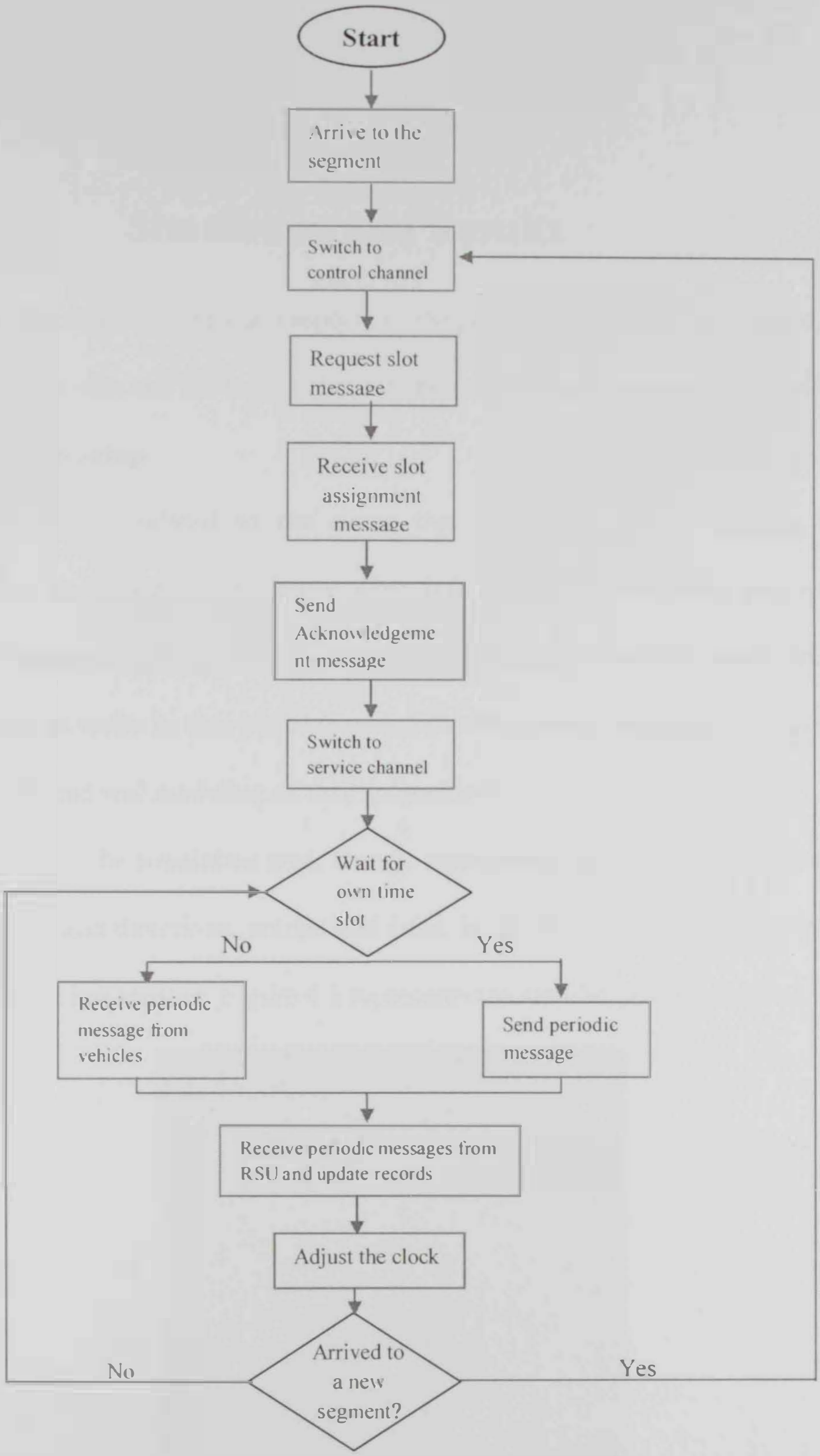


Figure 3.7: A simplified protocol flow chart

CHAPTER 4

Simulation and Results

In this chapter, the different steps and aspects of the protocol simulation is detailed, in order to explain the idea and the logic behind it and to be able to evaluate the results.

4.1 Simulation setup

This section is related to the setup that was done before starting the simulation. The main target is to know what information is available, and what parameters are needed to successfully construct the simulation. First, the main aim of the protocol is to be realistic; that includes real simulation areas, real representation of simulation nodes, and real modeling of their interaction.

Starting from the simulation area, Google maps was used to locate an area that has multiple lanes and directions, entries and exits, in addition to variations in speed limits from one road to another. Figure 4.1 represents the simulation area chosen.

Figure 4.1: Simulation area (© Google Maps, 2013)

In order to properly and realistically model the area, it is required to decide the type of information needed about each vehicle to successfully simulate the scenarios. All these parameters are presented in the following section.

4.1.1 Choosing the Simulator

Several simulators were surveyed earlier in chapter 2; either they are developed to simulate the mobility or the network. In this thesis, we have developed our own simulator due to the fact that this is a new protocol to build and evaluate, and there are some details in it that need to be modeled. That is why it was preferred to build a simulator that enables building the protocol from scratch until both mobility and network modeling are achieved.

Starting from modeling the simulation area, the knowledge learned about how mobility modeling is accomplished and the aspects to take into consideration were used to build our own mobility model. Based on the simulation area chosen, it was noticed that there are no traffic lights and no roundabouts in the simulation area, but there are some intersections, and roads with different number of lanes and speeds. As a result, there was no need to consider traffic lights and roundabout and instead focus on other road characteristics such as lanes, speed and of course vehicles' movement. Additionally, the records that contain the vehicles' parameters -as will be discussed later- should be created as well.

After that, the MAC protocol designed should be built to include all the unique features it contains such as segment capacity, time slots, messages types, and packets delivery, in addition to extracting all the related and needed results. Moreover, it will be more convenient to display some output such as the simulation area, some messages, vehicles' display screen, etc. For that, regular network and mobility simulators are not suitable, but the target was to choose a simulator where all the details required can be programmed as desired, and with all the files created from the very first word, development and expansion will be easy as well.

The first choice was to use C++, but due to the multiple libraries required and the need for additional software to display the results, MATLAB was the next and final choice.

In Matlab, no headers or libraries are required, so the simulation is a bit simpler, and the results can be displayed in any form that we need. One additional and important note is that Matlab is a computing tool, so all the processing and the heavy calculations that have to be done repeatedly over and over again can be easily achieved.

4.1.2 Representation of the Simulation Area

Since this is not a mobility simulator that has features of importing maps and creating the network of roads to generate the required traffic, the code has to be customized to meet the simulation requirements. Hence, we divided the simulation area into segments, each with its own RSU. So, after looking at the area chosen, it was noticed that all we care about are the actual roads, not the street trees or walking areas. Therefore, the segments created in this simulation area were all 100 meters areas with either 3 or 2 lanes in each direction. Once a segment is created, all the other segments are duplicates, so they could be repeated and linked together later on, during the results' phase. A sample of how a segment is represented is illustrated in later sections.

4.2 Protocol Parameters

In this section, all the parameters related to the protocol are introduced and explained. These parameters are part of memory records located in RSUs or vehicles. Some other parameters are required for the simulation to be used in calculations. Additionally, some parameters were introduced in the previous chapter as they were a part of the messages exchanged, but they are explained in details in this section.

4.2.1 Simulation Parameters

Data are required to start the simulation and for that, data records are generated. They contain information about the vehicles available in the simulation area once the simulation start.

First, it is important to differentiate between vehicles, and know which vehicle is where and so on. For that, a unique car ID is necessary, where it may be assigned to each vehicle by the traffic authorities or use the unique chassis number of vehicles. Additionally, the car ID could be the serial number of the onboard sensor, which should be unique as well.

Second, a car may already exist in the simulation area, or it newly arrives at the segment. For that, it is required to assign a vehicle status entry in the record. The processing required, packet types, etc. differs in each case for each vehicle.

The third important parameter is the speed value as we have moving nodes in the simulation. According to the chosen simulation area, the maximum speed in that area is 80 km/hr as discussed earlier. The speed of each vehicle is chosen randomly and it ranges from 70 to 100 km/hr.

Since the simulation area represents a two way road, we need to keep the vehicle's direction in mind. The fourth parameter in the record is the direction of the vehicle whether it is in the forward or the reverse direction.

Moreover, since vehicles are located in different lanes and locations in the simulation area, then each vehicle should be assigned a GPS location within the range of the simulation area. As discussed in the previous chapter, GPS coordinates are an important piece of information to be exchanged in multiple messages.

Since every vehicle starts its movement from a source location and is going to stop at a particular destination location, then the destination address has to be set as well. This information is important to be known by the RSU as the main network controller, but not to the other vehicles. So this destination is going to be exchanged between vehicles and RSU, but not between vehicles as mentioned in table 3.

The last two parameters are the data packet type or simply the message type and its corresponding size. This parameter depends on the vehicle's status. If the vehicle is new to the simulation area, then the message type to be exchanged is a connection establishment message. Likewise, if the vehicle is existing (has already been given a slot number by RSU), then the message should be periodic (either periodic from the RSU or periodic from the vehicles).

All these parameters construct the main data record of the simulation. This record is not related to any network element; it is just a simulation record. More on the generation and the role of this record is presented later in following sections.

One more record is kept during the simulation, which is the record of existing vehicles in the simulation that share the time slots and other resources. Once a vehicle is assigned a time slot it will be listed in this old vehicles array that will contain all vehicles that can communicate, or can be reached by the RSU for updates. This is pure simulation data, that has up to date information about everything, and once a vehicle is out of the segment, its record is removed as well.

4.2.2 RSU parameters

Since the RSU is the main controller of the network, then it should keep a record of all important information about all the vehicles. The records kept in the RSU's memory about each vehicle contain the vehicle's ID, its speed, final destination, its current location (GPS coordinates), its assigned time slot, and whether or not, an acknowledgement is received from it. The acknowledgement is part of the connection establishment message.

Another important record to be kept in the RSU's memory is the time slots record, as it is needed during the connection establishment phase where the RSU scans all the time slots to find the first free time slot and assign it to the new arriving vehicle. During simulation, RSUs carry out some processing tasks that will be discussed later in this chapter.

4.2.3 Vehicles Parameters

Since there is communication between vehicles, then each vehicle should keep a record of what is happening in the network. According to the periodic message that is sent and received from and to the vehicles, the main information exchanged are the vehicle's ID, the vehicle's speed, and the GPS coordinates for the location (periodic from vehicles).

Additionally, the information received from RSUs periodically is kept in the vehicle's memory storage units to be used in communications or for further analysis.

Moreover, the vehicles act as messengers between consecutive RSUs as they relay information about the segment from one RSU to the next one. The Vehicle's memory should keep details about the average speed and the status of the next segment.

4.3 Simulation Model

In this section, the simulation steps and methodology are explained in details. The simulation is divided into parts to simplify and facilitate the whole process. The code consists of several parts that are integrated all together in one file.

The first thing to do is to model our simulation area, in order to limit the movement and the placement of vehicles. We need to have two opposite roads, three lanes in each road, keeping in mind the size of the area separating the roads and setting a fixed location for the RSU in the center of the area. Figure 4.2 illustrates a simple representation of the simulation area. The RSU is represented by a yellow (*) sign and located at the middle of the simulation area. Additionally, and as seen in the figure, vehicles are represented as well and denoted by an (x) sign according to their location. Since we have new and existing vehicles, then it is logical that all the new vehicles are located at the beginning of the road whether it is in the forward or the reverse direction. For that, all new vehicles in the forward and the reverse roads are located in the first 20 m from both directions (the rectangle area). On the other hand, existing vehicles can be anywhere in the rest of the simulation area as long as it is not in the forbidden road separation area. The location of each vehicle in addition to other information is found in the main simulation record mentioned earlier. Now that the simulation area is created and vehicles are placed in a clear way, we discuss the main simulation record in details.

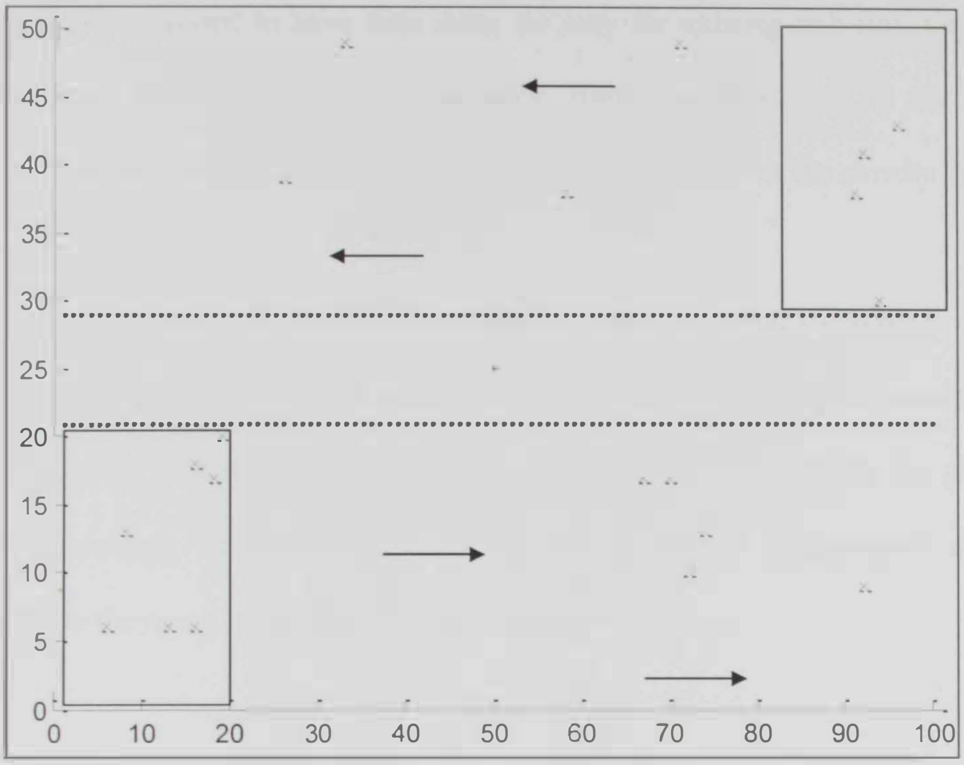


Figure 4.2: A simple representation of the simulation area

The chart in figure 4.3 illustrates the process of generating the record file. Each vehicle will be assigned an ID first, then a random speed from the range (road speed limit - 10 km/hr → road speed limit + 20 km/hr) range. After that, it is given a road direction (forward or reverse) and finally it is assigned a status which is either new or existing. Such initialization affects the types of messages exchanged and the location of the vehicles since new vehicles are placed in different areas than existing vehicles. Additionally, the processed entry in case of new vehicles is not set until all connection establishment messages are exchanged and ACK is received. Note that the vehicles are distributed uniformly in the simulation area and their speeds also follow a uniform distribution.

Additionally, since existing vehicles are previously available in the simulation area, they are supposed to have time slots. So only for existing vehicles, time slots will be given and used once the simulation starts. Another note on the record generation is that the number of vehicles to simulate depends on the density targeted by the user.

Since we are in a dynamic environment where all vehicles move at certain speeds till they leave the simulation area, it is important to model the movement or in other words; the mobility. After a certain period of time, calculated by the program due to processing, the location of each existing vehicle is continuously updated according to the speed using the distance formula:

$$Distance\ (m) = Speed\ \left(\frac{m}{s}\right) \times Time(s)$$

So the new location is equal to the last location plus the distance passed between the time the location was updated last and the time at the moment of the new update as illustrated in the following formula.

$$New\ location = old\ location + (average\ vehicle's\ speed \\ \times duration\ between\ updates)$$

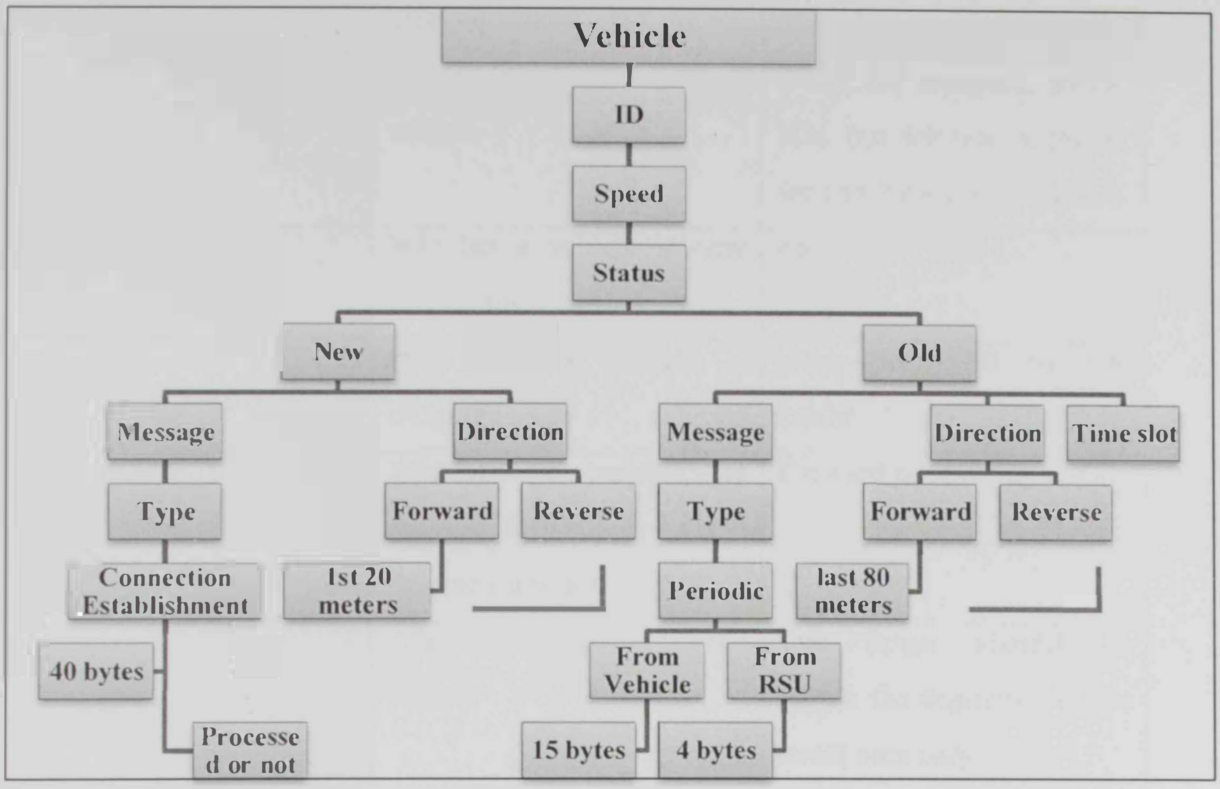


Figure 4.3: Record generation process

Speed variation is considered in the simulation since the speed given for each vehicle is an average speed, so during the simulation, the speed varies with a standard deviation of ±5% according to a uniform distribution.

Table (5) has all the parameters organized and listed with their specific details such as ranges and description.

Parameter	**Description**	**Details**
ID	An ID is assigned to each vehicle	8 bits are assigned, 65536 IDs, but for one segment, we can have up to 132 IDs
Status	Whether a vehicle is new or existing	Existing or new
Speed	How fast the vehicle is moving	range from 70 to 100 km/hr
Direction	Whether a vehicle is moving forward or in the reverse direction	Forward or reverse
Location	Where exactly is the vehicle	The range should be within the segment and on street area only
Destination	Where is the vehicle headed	Represented by GPS coordinates, but in simulation it is set as attraction points
Message type	Whether it is connection establishment or periodic message	Three type of message, chosen based on the current vehicle status
Message size	Three types of messages each with its own size	Total three sizes, refer to table 3

Table 5: parameters summary of the main data record in the simulation

As the vehicles move out of the segment, the simulation should keep on going. For that, new vehicles should arrive to the segment. In the simulation, new vehicles are added, according to a random number generated from the Poisson distribution with mean parameter lambda (lambda = 5). Note that only new vehicles are added since all the existing vehicles are already processed and since it is a running

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```
1. Start simulation.
2. Generate simulation records.
    a. Ask the user for the number of vehicles to generate.
    b. For monitoring purposes, ask for the targeted vehicle's ID.
    c. Create the arrays of information.
    d. Set the required parameters; speeds, sizes, message types, segment's area, average car length, etc.
    e. Follow the chart in figure 4.3 to generate the data record where all the dependencies and conditions are presented.
    f. Create the existing vehicles' record and fill it with the available vehicles that have been there since the beginning of the simulation.
    g. Assign time slots to the existing vehicles and reserve them as long as the vehicle is in the range of the RSU.
3. Create the RSU memory record for vehicles.
    a. Organize the available information related to the existing vehicles in it along with the assigned time slots.
4. Start the actual simulation and process the entries one by one.
    a. If the vehicles is new:
```

    i. Start the connection establishment phase by having the vehicle send a slot request message.
    ii. Inform the user (the program user) that a new vehicle has arrived.
    iii. Create an entry for that vehicle in the RSU memory records.
    iv. Save the information from the received slot request message.
    v. Search for the first available time slot.
    vi. Send the slot number along with other information (as discussed in table 3) to the vehicle during the second part of the connection establishment phase.
    vii. Wait for an acknowledgement from the vehicle, then move it to the existing vehicle's record and do the required adjustments in its status, message type and size.

b. If the vehicle is existing:
    i. Periodic messages are exchanged
    ii. The vehicle will send its information to all the nodes in the range including the RSU
    iii. Only vehicles in the same direction will receive the message, others will just drop it
    iv. Mean while, the RSU is processing the following:

    1. Calculating the average speed from the speed information available in the records
    2. Determining the road status
        a. If everything is normal then the status is good
        b. If the segment is more than 70% full, then there is congestion
        c. The weather part cannot be checked in simulation unless a probability is set for that
        d. The emergency option will be set in case an accident occurred. Accidents are not simulated.
    3. Fetching the system current clock in hours, minutes and seconds

v. The RSU periodic message is sent during its slot portion as shown in figure 3.5.

vi. A counter is set to count all the packets transmitted and received in the simulation to be able to evaluate the performance.

vii. The location is updated based on the speed, keeping in mind the direction of movement (reverse or forward).

viii. Once the vehicle is out of the segment range, its records in the RSU unit and the existing vehicles record are purged. The time slot will be free for new vehicles.

ix. Along with updating the location, the speed is varied with a standard deviation of ±5%.

x. Once all cars from the main entry are read and processed, we are left with only existing vehicles that have continue moving till they are out of the segment, while having new vehicles enter the segment as mentioned earlier.

xi. The existing vehicles' file will be processed the same way as existing vehicles were processed earlier.

xii. During this process, the vehicle defined by the user will be monitored by displaying its screen showing its location, the location of nearby vehicles, and the location of the RSU in that segment. Once the vehicle is out of the segment, the new segment will be displayed and that is the next 100 meters of the area.

xiii. Some extra features were added as well and they are discussed later

4.4 Results and Discussion

In this section the output of the simulation is displayed. The simulation area and the vehicles are shown in the figure below. Figure 4.4 illustrates one segment with 50 vehicles in it.

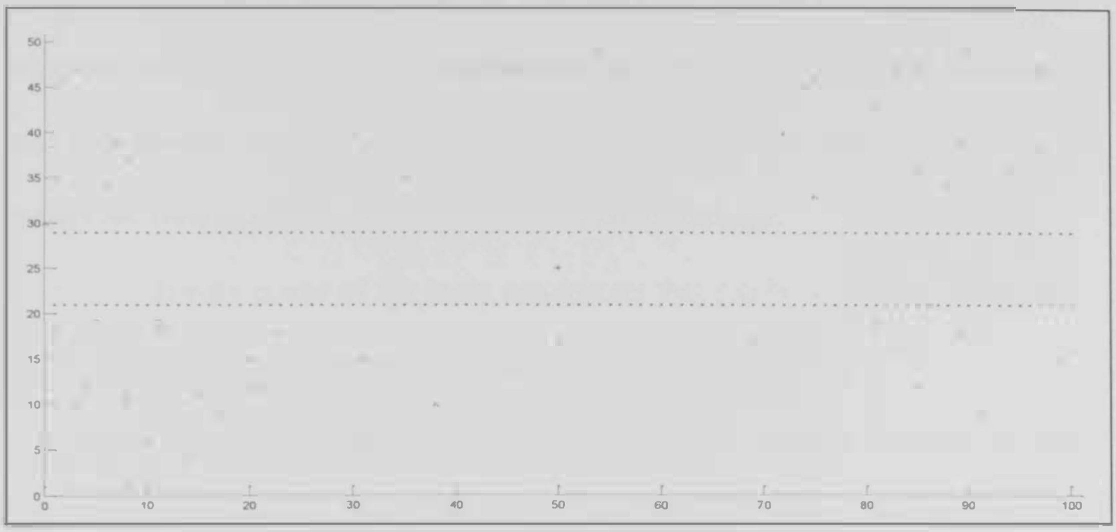

Figure 4.4: Representation of one segment

New vehicles are represented by green circles, and they are located in the first 20 meters from each side whether it is moving in the forward or the backward direction. Existing vehicles are represented by red crosses and they are available in the rest of the segment. Note that there is an area in the middle of the segment about 100x10 meters and according to the map extracted from Google maps, it is the area separating the two directions, and no vehicles are supposed to move there. That is why, that area is empty. The yellow dot represents the RSU and it is located in the middle of the segment.

Network performance can be measured by multiple metrics such as packet delivery ratio, end to end delay, utilization, etc. Packet delivery ratio (PDR) can be defined as the ratio of the number of successfully delivered data packet to the destination to the total packets sent by the transmitter, given by the following formula:

$$PDR = \frac{\sum packets\ successfully\ received}{\sum packets\ sent}$$

According to [61] many parameters can influence the probability of successfully receiving the packets. Some of these parameters include the traffic density, data rate, transmission power, channel condition, etc. For testing purposes some of these parameters are used to examine their effect on the performance.

Traffic density is one of the input parameters that can be varied by setting the number of vehicles in the segment at the beginning of the simulation.

Data rate in this simulation is set to the minimum allowed data rate in the WAVE protocol which is 3Mbps. This is considered as the worst case scenario in terms of data rate in this protocol.

Transmission power was discussed in the previous chapter along with the calculations performed to determine whether the signal received is well captured by the receiver's antenna under the worst case scenario, and as a result, there is no worry from the sufficiency of the transmission power.

Buffers are set to be sufficient for the maximum capacity of the network. Therefore, no buffers will be overflowed and packets will never be lost.

As for the channel condition, this protocol assures that no collision will occur because every transmission is scheduled and coordinated, and if any losses were to happen, that will be because of other factors that will be discussed later.

4.4.1 Packet Delivery Ratio (PDR)

To confirm the PDR results and assure that they are reliable, the simulation was run for four cases, with different number of vehicles. . For each run, the simulation was repeated 10 times and the average is illustrated in table (6). Some important quantities are shown such as the total number of packets sent, the total number of packets received, the number of packets lost, and the PDR.

Number of vehicles	**Segment capacity**	**Packets sent**	**Packets received**	**Packets lost**	**PDR**
30 vehicles	23%	2985	2295	689	0.7688
60 vehicles	46%	7764	6002	1762	0.7731
90 vehicles	69%	13913	10974	2939	0.7888
120 vehicles	92%	22305	17709	4596	0.7939

Table 6: Packet Delivery Ration (PDR)

It is a fact that these packets are broadcasted from the source to every node available in the segment, and no acknowledgments are expected in order to reduce the packets' traffic and preserve the resources. Moreover, there are no losses due to collisions because we are in a collision free environment, so to calculate the PDR and know the losses; another idea had to be adopted. Let us discuss table (6) first, then explain the methodology of calculating the PDR.

It can be noticed that the simulation generated an acceptable PDR. It may seem a bit low for a collision free protocol, since all the protocol operations lead to safe delivery of the transmitted packets. Additionally, the basic idea of the protocol is the TDMA channel access method, where there are available slots for every possible vehicle existing or not existing in the simulation, in addition to the high data rate, availability of resources such as buffers, processing capabilities and power capabilities. So, losses occur because the packets were sent, but the time required for that packet to be received was greater than the time remaining for the vehicle in the segment. So, when the packet was sent, the vehicle was still available in the segment, but maybe located at the end of the area, and by the time that packet arrives to where the vehicle is or propagate to the location, the vehicle has already left. Also, a vehicle may be out of the segment, but still available in the file for some time, till the timer expires when no update messages arrive. So even if the vehicle is not there, the packets lost are still counted till records are updated. The PDR is calculated as follows:

Once a packet is sent, the counter of the transmitted packets is incremented. In the RSU/vehicle, the time required to send that packet is calculated using the following equation:

$$\text{Total time} = \text{propagation time} + \text{transmission time}$$

Where the propagation time is:

$$propagation\ time\ (s) = {}^{Distance\ (m)}\!\big/_{propagation\ speed\ (m/s)}$$

And the transmission time is:

$$transmission\ time\ (s) = {}^{packet\ size(bits)}\!\big/_{data\ rate(bps)}$$

Then the remaining time for the vehicle in the segment is calculated from the basic time-distance relation; since the location of the vehicle or the receiver is known, the boundaries of the area are known (to calculate the distance), and the vehicle's speed is known as well, so it is easy to find the time remaining.

After finding these quantities, a comparison is held; if the time remaining for the vehicle is more than the time required for the packet to be transmitted, then the packet is successfully received, otherwise, it is lost and the lost packets' counter is incremented. The PDR calculation proposed in this research is concerned mainly with the service channel where most of the information exchanging happens. Figure (4.5) illustrates the flow chart of the PDR calculation method for the service channel.

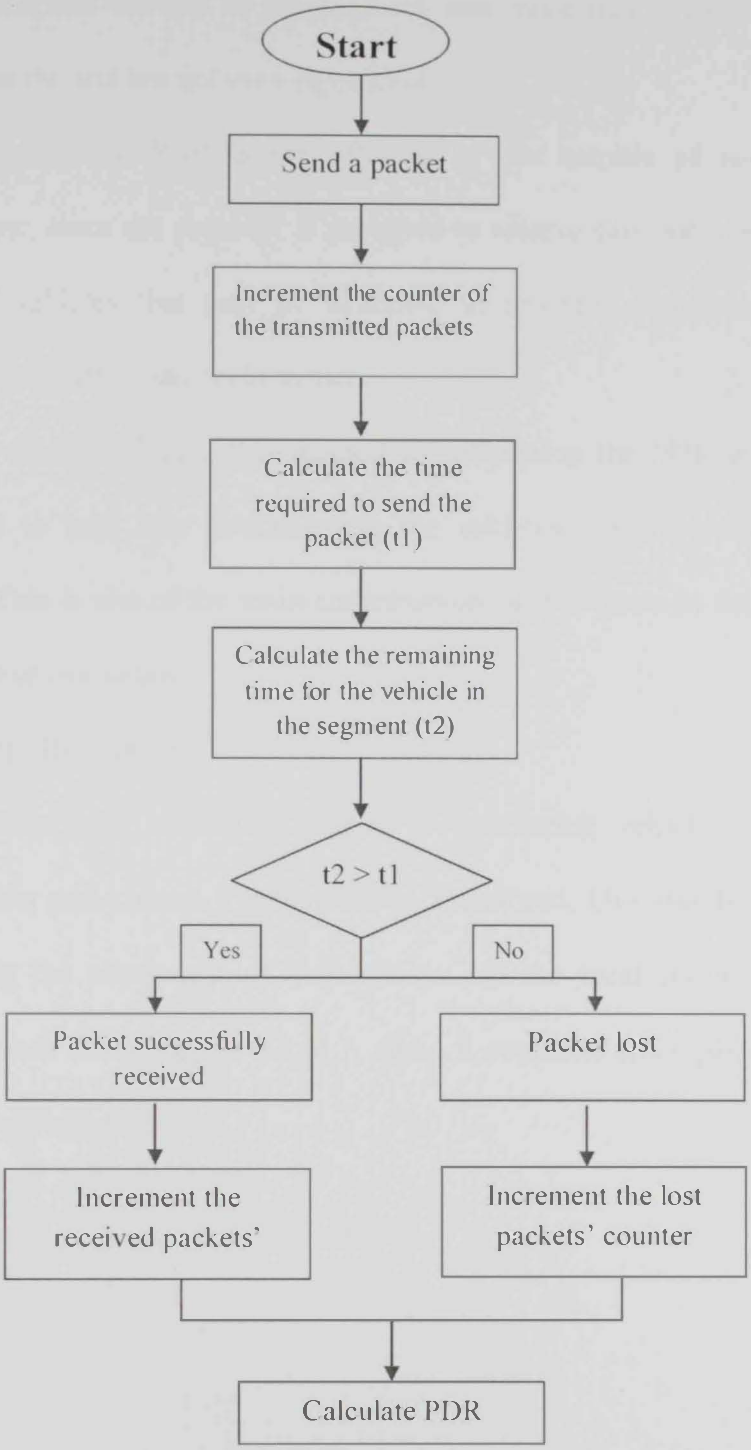

Figure 4.5: PDR calculation method

Additionally, these losses are not very important, or do not have a big impact in our case in particular, because the amount of update that occurred in the simulation before a vehicle has reached the end of the segment was more than enough, and couple of packets lost at the end are not very significant.

Moreover, note that the PDR is not affected by the number of vehicles available in the segment, since the protocol is designed to reserve time slots for the maximum number of vehicles that may be available at anytime, increasing the number of vehicles will not affect the performance.

To the best of our knowledge, this method of calculating the PDR is new, unique and developed to take into consideration the vehicles' mobility and the packets' propagation. This is one of the main contributions of this thesis in the field of VANETs' performance evaluation.

4.4.2 Traffic and Safety Results

Moving to another type of results related to monitoring vehicles in the simulation area. The user can choose a vehicle to be monitored. Our simulation is capable of representing the movement of that vehicle and the locations of other vehicles in the area at each time. Figures 4.6, 4.7, and 4.8, represent a sample of the vehicle's movement at different instants.

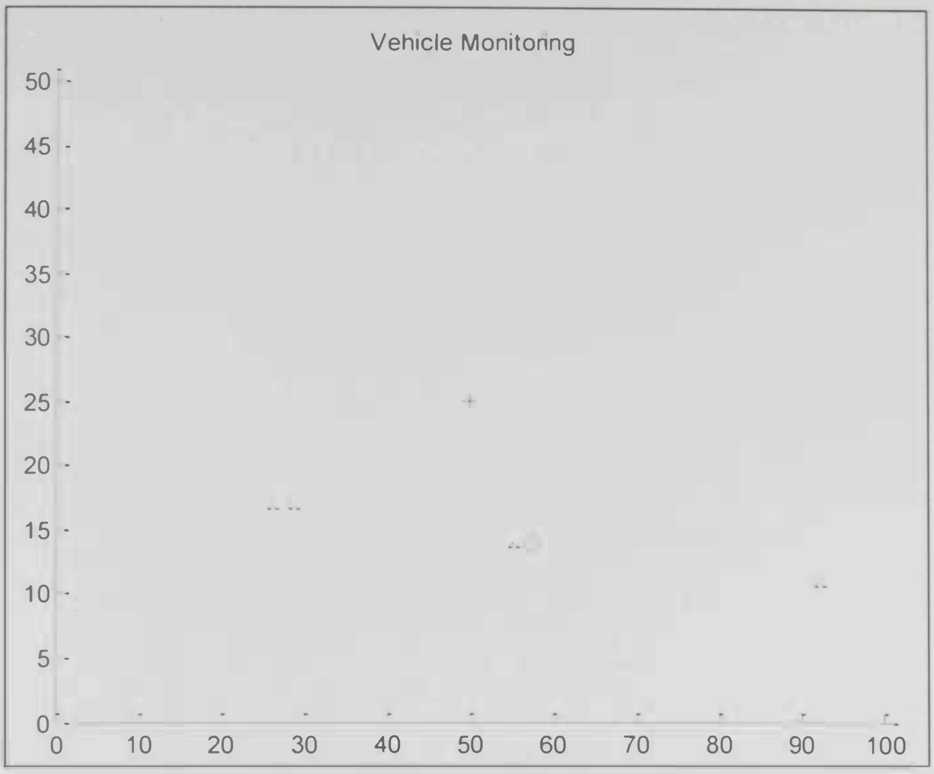

Figure 4.6: A sample of vehicle monitoring (1)

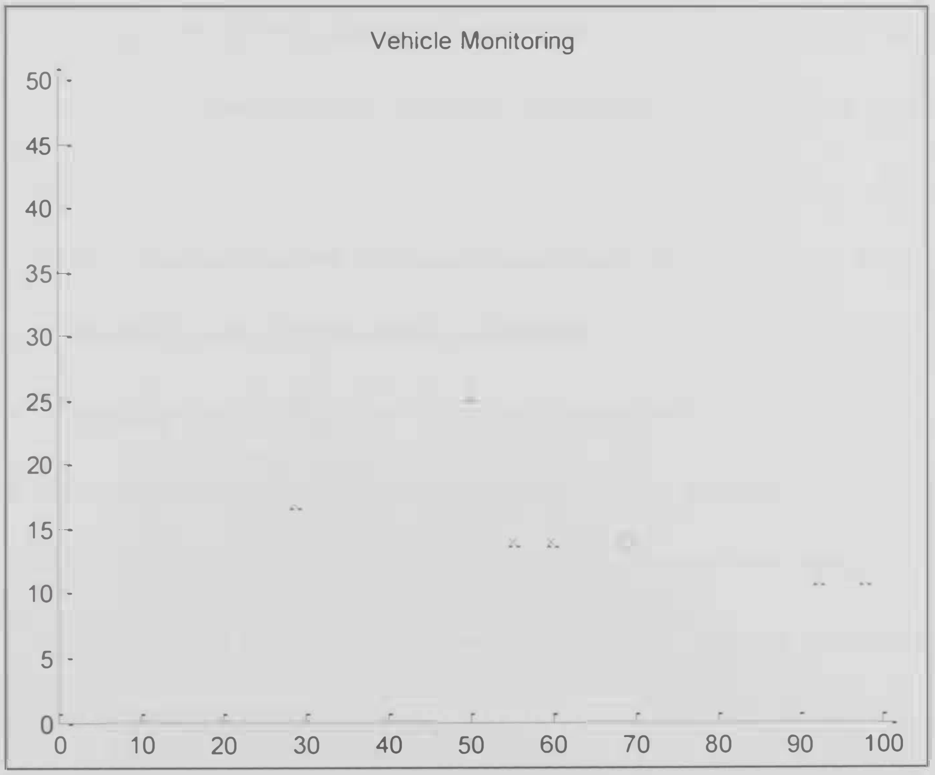

Figure 4.7: A sample of vehicle monitoring (2)

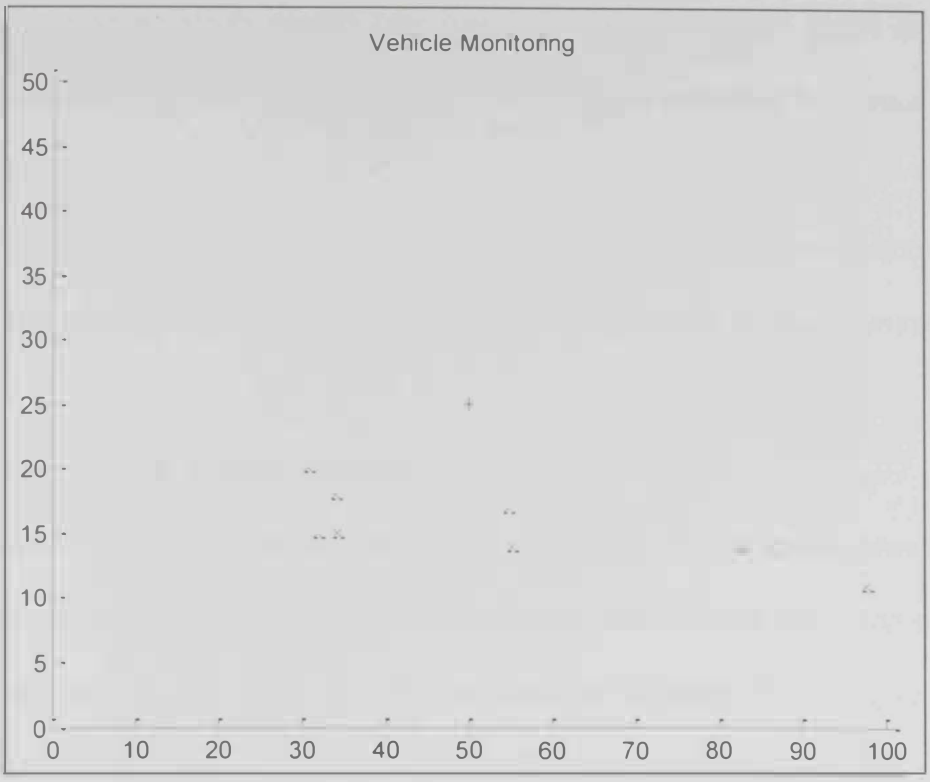

Figure 4.8: A sample of vehicle monitoring (3)

As an extra feature of the simulation, accidents were modeled to be able to have more details on the status of the segment. An accident is identified once the following is detected:

- Two vehicles sharing the same coordinates in simulation; either the latitudinal or the longitudinal coordinates.
- A sudden drop in the speed of one of the vehicles
- If a vehicle is captured in a restricted area in the simulation such as sidewalks (this is not an option here, because we have restriction on the update of locations for vehicles where they are not allowed to be on non-street areas)

Once an accident is detected, the road status will be adjusted to indicate that there is an accident in that area. This status will remain unchanged till the end of the simulation, because accidents usually take time to be resolved, since police has to come and make a report about the accident, and that requires more that the simulation time.

Overall, the protocol performed well, and the simulation results are reasonable and hence, the protocol is feasible and very promising if it is to be implemented in hardware.

4.4.3 Comparison with Related Protocols

Simulation results are not compared with previous works that were presented earlier in the chapter 2 due to the following reasons: It will not be a fair comparison as the performance metrics and parameters assumed are different depending on the preference and the application intended. Additionally, the overall idea and the way it is developed may affect the results and the performance evaluation.

The comparison criteria include the simulator used, the segment's length, the type of map used as an area, the main application for the protocol, the performance metrics used to evaluate the protocol, the packet size, and finally the communication protocol assumed or implemented.

Note that the fourth system that was presented in chapter 2 is not included in the comparison, because it was just a proposed system, but not implemented in simulation. As for table (7), it can be noticed that the systems vary in different aspects, in addition to their differences in the methodology of implementation and code writing.

Comparison aspect	Example (1) [21]	Example (2) [22]	Example (3) [23]	Example (4) [7]	Proposed protocol
Simulator	Java	NCTUns	The simulator in TinyOS, TOSSIM	NS-2	Matlab
Segment length	300 m	Depends on the road type	100 m	100 m	100 m
Map type	A built map of 40 roads and 25 intersections	No map, 1 road segment of 2 km	No map, A 2 km road	A highway of 18900m x 20 m	A 2.3km x 2.3km Real map
Main application	Traffic congestion control	Safety and road conditions	Car traffic management	Solve VANETs issues	Safety and road conditions
Performance metrics	Number of congested roads and time to arrive at destinations	Packet losses and delay with respect to speed	Packet losses and throughput with respect to number of nodes	Delay and energy consumption	PDR, including packet losses
Mobility modeling	Little or no details about the specifics of mobility				Yes
Propagation models	No				Yes
Packet size	-	500, 1000, 1500 bytes	17 bytes (vehicle messages), 13 bytes (service messages)	-	Variable based on message type
Communication standard	IEEE 802.11	IEEE 802.11 b	IEEE 802.15.4 (ZigBee)	Wi-Fi and ZigBee	IEEE 802.11 p

Table 7: Comparison between previous work and the proposed protocol

CHAPTER 5

Conclusion

This chapter illustrates an overall preview of the thesis. The problem statement along with the main features and contributions are highlighted to emphasis the importance of the work done.

Information loss in communication network has always been a major problem that affects the performance of protocols especially MAC protocols since it is the layer responsible for coordinating the media access. That is why minimizing collisions if not eliminating them is a big concern for researchers while developing new communication protocols. In vehicular networks, collision and loss of packets lead to loss of information related to drivers' safety, which is the main concern of vehicular networks.

Additionally, mobile or dynamic networks increase the load on protocols as the topology is continuously changing due to vehicles leaving or joining the network. However, connections must be maintained if time slots or frequencies are assigned to vehicles and scheduled based on the state of the network at a point of time, all the schedules and connections had to be updated accordingly once that state changes. The re-scheduling process and connection establishments increase the processing load on the network elements and introduce some delay in the communication.

This thesis aimed at designing and implementing a MAC protocol dedicated to HVSN to help exchange safety and control messages among the network elements. Collisions were eliminated by choosing a TDMA media access technique, where the time is usually divided among the available nodes in the network and each node transmits in its time slot; alone, so no collision will occur.

TDMA is known for two important drawbacks; re-configuration and rescheduling of time slots and time synchronization. This protocol is designed to solve the problem of re-scheduling whenever a new node joins the network, through fixed schedules with enough time slots that can accommodate the maximum number of vehicles available in the segment. This is feasible, since the segment length or the segment dimension is known, and its capacity can be calculated and used.

Furthermore, synchronization is implemented with the help of the network controller which is the RSU. It sends the system time periodically to all the vehicles in the segment to help them adjust the drift in their clocks. The vehicles consider the propagation time and include it in the time correction process. This helps vehicles to start transmitting correctly in their assigned time slots.

Each network is assigned one controller which is the RSU, that manages the scheduling and connections for the vehicles located within its range. The result is a collision free, mini centralized system where slots are fixed, and whenever the topology changes, the RSU removes vehicles from the entries and frees its time slot (in case a vehicle has left the range), or searches for the first free time slot and assigns it to the new vehicle (in case a new vehicle joins the network).

The protocol is designed to consider practical scenarios, where messages are created, and defined to efficiently utilize the bandwidth in conveying safety and traffic condition information, where all the fields are set to be used in the analysis and increasing the safety of drivers on the roads. Message formats are kept short, efficient with low overhead. Different communication scenarios are practically considered and a suitable communication protocol is chosen to fit the requirements of the HVSN. The IEEE 802.11p is chosen to be followed since it is designed for vehicle' communication. According to that choice, control and service channels are set with a predefined data rates.

Moreover, since the protocol is applied in a mobile environment, a special mobility model is designed to simulate the targeted area and the movement of vehicles in the selected segments. Knowledge of previous mobility models is employed in designing the mobility model for our system. Real maps are used for the simulated area.

The proposed protocol is evaluated using MATLAB, which is used to simulate the mobility and traffic in addition to simulating the devised MAC protocol. Packet losses and delivery are considered, and a new PDR calculation method is used to evaluate the performance. Results were analyzed, explained, and discussed.

The main contributions of this thesis are:

- The protocol is one of the first works to follow the IEEE 802.11p in HVSN
- A collision free MAC protocol that does not depend on re-configuration of time slots allocations, and considers synchronization using central controller which is the RSU. The proposed protocol provides a complete solution to the drawbacks of TDMA

- A modified TDMA access technique is used where segment capacity is included in the design to avoid the re-configuration and consequently, the time delay.
- The design is based on a realistic mobility model and studied from its point of view.
- A unique TDMA mobility based-PDR calculation method is used to practically assess the protocol performance for the service channel. As future work, this protocol may include designing and establishing algorithms that will enable RSU to RSU direct communication. The simulation area may be enlarged to include more road elements such as intersections and roundabouts that require other propagation model to be applied. Such changes will allow the proposed protocol to be applied for different types of road areas. Finally, the proposed protocol can also be implemented in hardware and examined on a real test bed.

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من الأعمال الأولية التي توظف معيار IEEE 802.11p في هذا النوع من الأنظمة الذكية ويستخدم معالمه والمواصفات المقدمة من قبله. أخيرا وليس آخرا، هو تصميم شامل يستند إلى تمثيل عملية التنقل للمركبات بطريقة واقعية ساعدت في تقييم أداء البروتوكول وذلك عن طريق حساب الرسائل الموصلة بنجاح بتوجه فريد من نوعه.

ملخص الرسالة

تطبيقات السلامة في أنظمة السيارات الذكية تتطلب انتقالا دقيقا للرسائل من أجل توفير السلامة في الطرق وللسائقين على النحو المنشود. عند تجهيز المركبات بأجهزة الاستشعار اللاسلكية التي تستخدم وتقاسم قناة لاسلكية يمكن الاعتماد عليها للاتصال، لابد أن يتم تنسيق نقل رسائل السلامة للحد من تصادم الرسائل أو القضاء على هذه الظاهرة تماما. الخطوة الأولى لتحقيق ذلك هو من خلال التحكم بطبقة الوصول إلى مجال الاتصال (MAC layer) المسؤولة عن تنظيم استخدام هذا المجال بسلام ودون اصطدام بين الرسائل المرسلة.

تهدف هذه الأطروحة إلى تصميم وتنفيذ بروتوكول للمساعدة على ايصال رسائل السلامة للتحكم و التنسيق بين عناصر الشبكة بنجاح، أي الآليات وأجهزة الاستشعار على متن المركبات و وحدات استشعار على جانب الطريق. تقنية تقسيم الوقت لتنظيم الاتصالات (TDMA) هي واحدة من التقنيات المستخدمة للقضاء على الاصطدامات بين الرسائل إلا أنها تعاني من بعض السلبيات كضرورة إعادة الجدولة كلما تغيرت الشبكة بزيادة عدد مستخدميها أو نقصانه وتزامن الوقت بين نقاط الاتصال.

هذا البروتوكول المقترح يقدم حلا كاملا لمثل هذه المشاكل. فبدلا من تقسيم الإطار الزمني بين مجرد نقاط الاتصال المتاحة، سنقوم باستخدام جداول ثابتة أو أطر زمنية محددة تكفي لاستيعاب أكبر عدد ممكن من المركبات التي قد تتسع لها مساحة محددة من الطريق. هذا الترتيب يلغي الحاجة لإعادة الجدولة ويقلل من المعالجة غير الضرورية للبيانات في الأليات المتحكمة في الشبكات. يتم حل مشكلة التزامن أيضا، بالتنسيق مع وحدة تحكم الشبكات المتواجدة في جوانب الطرق.

يشتمل هذا البروتوكول في عملية التصميم كذلك على تمثيل سلوك المركبات، من خلال النمذجة الواقعية للتنقل، حيث تم تمثيل خريطة حقيقة لمنطقة في مدينة العين بتفاصيها، شاملة تفاعل المركبات وتواصلها. علاوة على ذلك، ولتقييم أداء البروتوكول عمليا تم ابتكار طريقة حساب جديدة لنسبة إيصال الرسائل بنجاح مستوحاة من الحركة المستمرة للمركبات و وطريقة تنقلها.

يتميز البروتوكول المبتكر بالعديد من الميزات؛ أهمها، أنه بروتوكول خالي من التصادمات بين رسائل السلامة المرسلة بين المركبات المتواجدة في منطقة واحدة وهو كذلك لا يتطلب إعادة تقسيم الوقت المتوفر كلما تغيرت عناصر الشبكة عدا أنه قدم حلا لمشكلة تزامن الوقت بين النقاط المتواصلة. ثانيا؛ البروتوكول هو واحد

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كلية الهندسة

قسم الهندسة الكهربائية

تصميم و دراسة بروتوكول اتصالات يخدم نظام المواصلات الذكية

سارة ماضي

رسالة مقدمة لاستكمال متطلبات الحصول على درجة الماجستير في الهندسة الكهربانية
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