Implementation of Dynamic Vehicular Rerouting, Vehicular Safety and Pollution Reduction Techniques Using VANET

A Thesis submitted to the
Dept. of Electrical & Electronic Engineering, BRAC University
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DECLARATION

We do hereby declare that the thesis titled “Implementation of Dynamic Vehicular Rerouting, Vehicular Safety and Pollution Reduction Techniques Using VANET” is submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Bachelor of Science in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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ABSTRACT

Vehicular Ad hoc NETwork (VANET) is based on V2V communications between vehicles and V2I communications between vehicles and V2I communications between vehicles and access points located at the road-side infrastructures. This network would enable accessing real-time traffic conditions, emergencies, routing information and facilitate traffic safety, driver assistance, traffic police assistance and infotainment for passengers. Our research challenge is to ensure communication between incoming vehicles in a certain routes with emergency situations and compare different scenarios in order to give the best alternate route to the user. The choice of routing software along with the mapping and traffic enabling tools were crucial for carrying out the research. This thesis aims at implementation of dynamic re-routing techniques in VANET networks, addresses the challenges and improves by enhancing network capacity and then analyses on challenges and future trends of VANETs. The primary goal is to establish mathematical models to enhance the underlying traffic conditions, driver and vehicle safety applications and the current state of pollution gradient. The secondary goal is to base on the models to devise networking functions and protocols to exploit mobility and radio conditions to optimize VANETs. This re-routing can also be used to investigate and optimize the internetworking between vehicles and vehicles to infrastructure for different types of roads including urban, rural and highways as well as different traffic conditions.

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CHAPTER 1:

INTRODUCTION

"**W**e are continually faced by great opportunities brilliantly disguised as insoluble problems."- said Lee Iacocca, an American engineer and an automobile executive. In modern times when both science and business worlds are booming, we can certainly do without cynical waste of precious time and meaningless casualties. According to a report by The Daily Star back in 2017 [1], congestion in Dhaka eats up 3.2 million working hours per day. On the face of such blatant misuse of time, money and energy on our daily commutes, vehicular networking can offer some much needed solutions and enhance our travel experiences. Vehicular Ad-hoc Network (VANET) is an exclusive network designed to establish communication-based cooperative systems. VANET is adjudged to be one of the most potentially defining enabling technologies required to implement a myriad of applications related to vehicles, driver and passenger safety, congestion control and many more. These applications are far more than hollow ideas or musings of a group of researchers and companies. Vehicles of the modern day have in-built intra vehicular networks in the form of smart phones, Global Positioning System (GPS), Rear-view cameras etc. and wirelessly connected electronic control center's to govern all these devices and applications. But a shared network between vehicles is still unavailable. VANETs are designed to do just that.

Intelligent Transportation Systems (ITS) were introduced to contemporize and simplify the operation of vehicles, manage vehicle traffic, assist drivers with safety and other information's along with provisioning of infotainment applications for passengers. To support these services, different standardization bodies have defined the networking architecture of ITS stations, including vehicles' On-Board Units (OBU) and infrastructure's Road-Side Units (RSU). Multiple network interface cards of different communication technologies coexist within a same OBU or RSU to support different use cases. Thus, cellular or broadband wireless interfaces provide the vehicle with connectivity to the infrastructure network (V2I), while dedicated short-range communications (DSRC) in the 5.9 GHz frequency band allow for vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2R) data transfers. In these cases, vehicles form a vehicular ad hoc network (VANET) in which collaborative services can be deployed. [2]

Advances in ubiquitous computing [3] and wireless technologies [4] have offered new trends in intelligent transportation systems, which help the systems to be more adaptable to different scenarios due to their flexibility. Mobile Ad Hoc Networks (MANET) is a term coined for the continuously varying network topology for handheld mobiles devices. VANET is one of its subsets. It deploys the concept of continuously varying vehicular motion. VANET uses vehicles as nodes to form a mobile ad hoc network for the dissemination of safety and entertainment messages. The nodes in VANET can move around with no boundaries on their direction and speed. VANET supports a large spectrum of decentralized vehicular applications ranging from traffic light optimization solutions to dynamic vehicle rerouting applications. Usually, solutions which uses VANET target to build a distributed Inter Vehicular Communication (IVC) [5] network which is autonomous, cost efficient and based on flexible architectural design principles.

The vehicular safety application should be thoroughly tested before it is deployed in a real world to use. Simulator tool has been preferred over outdoor experiments because it simple, easy and cheap as it does not require extensive changes in infrastructure and substantial support staff engagement. With respect to the simulation methodology, a set of standardized benchmarks and test scenarios will be useful to make protocols and model proposals comparable to each other [6]. Vehicular traffic simulations and network layer simulations should be juxtaposed in order to evaluate the effectiveness of Inter Vehicular Communications (IVC) on vehicle routing strategies, congestion resolution, safety measures etc. and to optimize the solutions. Vehicular traffic simulators generate dynamic vehicular mobility, taking into account that these simulator allow us to autocratically control an array of key variables such as vehicle density, speed, direction, network topology etc. Network simulators map vehicles as nodes in a wireless network like structure and simulate data dissemination topologies between nodes by emulating data transfer.

IEEE has developed a system architecture called WAVE (Wireless Access in Vehicular Environments), which is a unification of the standards IEEE 802.11p and IEEE 1609.x to address characteristics unique to VANETs and provide wireless access in vehicular environments. It is engineered to connect wireless devices attempting to communicate in a rapidly changing networking environment and in situations where data transactions should be done in shorter amounts of time. Significant research has taken place and a lot of investment has been made around the world on this, especially in Japan, USA and Europe.

1.1 MOTIVATION

The extensive fervor surrounding VANET is not just because of the applications or their vividly apparent potential benefits, but also due to the challenges and scale of the solutions. Among numerous technical challenges to be overcome, high mobility of vehicles, huge array of relative speeds between vehicles, real-time nature of applications, and a multitude of system and application related requirements can be listed. Moreover, considering ITS applications that require information to be relayed multiple hops between vehicles, VANET is poised to become the most widely distributed and largest scale ad hoc network. Such fascinating challenges and promising opportunities serve as the background of the widespread interest in VANET by governmental, industrial and academic circles alike.

The motivation for this thesis came from one of the many futuristic aspects of VANET that piqued interest of engineers from all around the globe is the opportunity to implement a plethora of IOT based smart city applications that will truly revolutionize urban lives. Installing embedded systems in vehicles containing sensors, microchips and enabling the vehicles to store and communicate the data make the vehicles more intelligent, such that the vehicles can be thought of as a network of sensors/actuators on wheels.

The development of an efficient system in VANETs has the potential to be highly beneficial to both the traffic control authority and the drivers. Proper traffic alerts and real-time information about traffic incidents will make safe driving, increase road safety and reduce the traffic jams in the city. It also helps to identify where the traffic rules violations takes place. It has an important economic aspect within it as well; real-time traffic alerting will reduce trip time and fuel consumption and therefore decrease pollution [8]. Furthermore, Air pollution measurement and reduction, traveler information support applications, accident prediction and alert systems etc. are some of the applications of paramount importance that can be implemented through VANET.

Fig 1 [9] shows an Intelligent Transportation system made up of a meshed network topology.

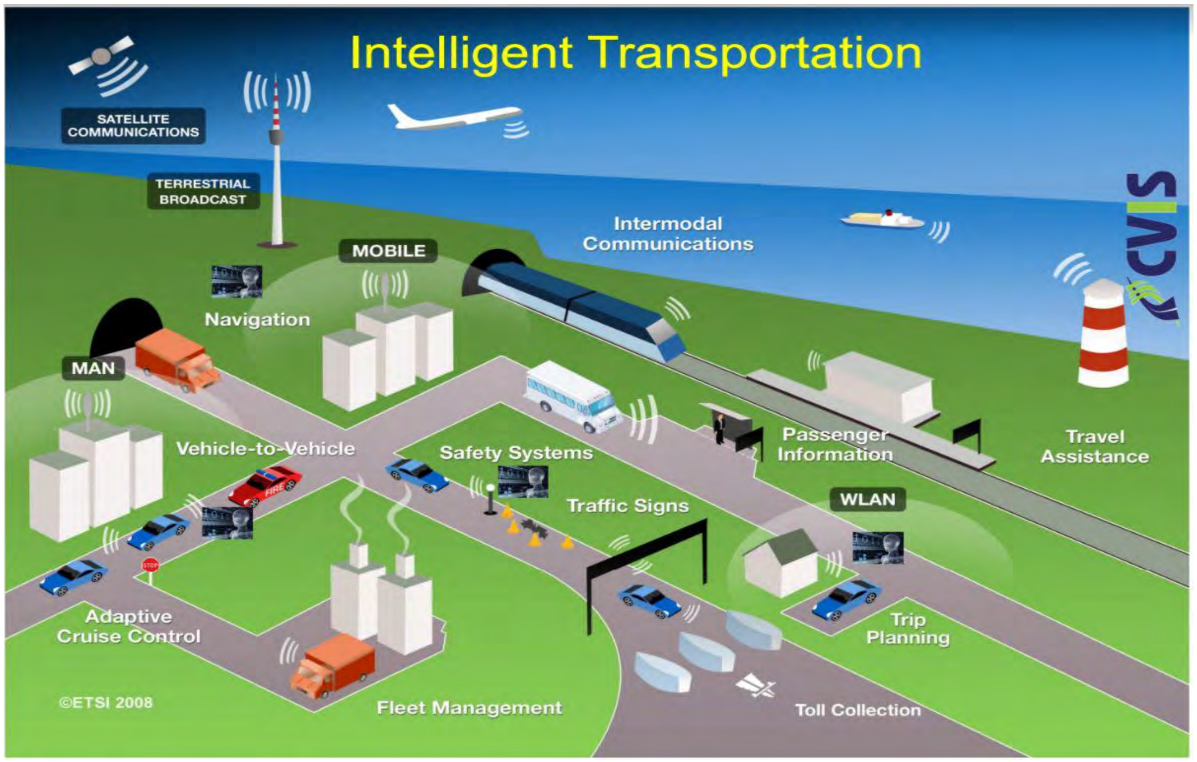

Fig. 1. Intelligent Transportation [9]

1.2 THESIS STATEMENT

The purpose of this thesis in three fold. *Firstly*, we propose an ***Intelligent Rerouting Solution*** for vehicles in case of accidents, road blocks, poor road conditions etc. *Secondly,* we propose a ***Dynamic Rerouting Solution*** for vehicles to reduce Carbon-di-Oxide emission in hospital areas. *Thirdly,* we propose a ***Speed Control Mechanism*** in case of emergency weather conditions (i.e. heavy rainfall, storm etc.). Lack of visibility, slippery conditions and frequently faltering road surfaces during heavy rainfalls cause a lot of accidents in Dhaka. Road blockage and abrupt weather conditions are two reasons on top of the pecking order which cause traffic gridlocks in Dhaka city. Here, we attempt to simulate the potential solutions that can ameliorate such situations and compare their outcomes. For our study we have selected SUMO

(Simulation of Urban Mobility) as the traffic simulator and OMNeT++ as the network simulator. Since traffic simulators and network simulators differ significantly in structure, usually there is a concrete requirement for a mediation framework operating between them. Here, we are using VEINS (Vehicles in Network Simulation) toolkit as the mediation framework between SUMO and OMNeT++. Fig 1 describes few popular traffic simulators, network simulators and mediation frameworks and the toolset we selected for our study, whereas fig 2 illustrates more detailed overview of the selected toolset for our experiment.

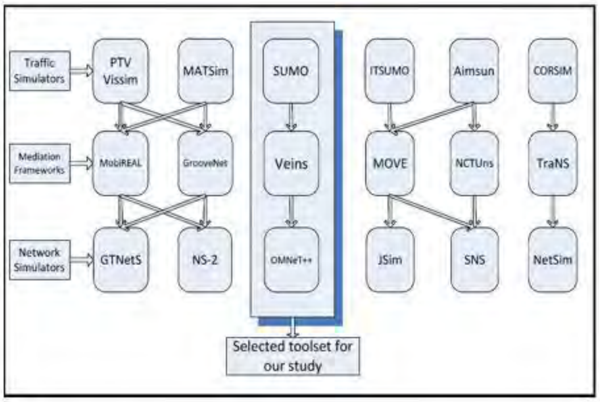

Fig. 2 Overview of various simulators and some sample interaction flows [6]

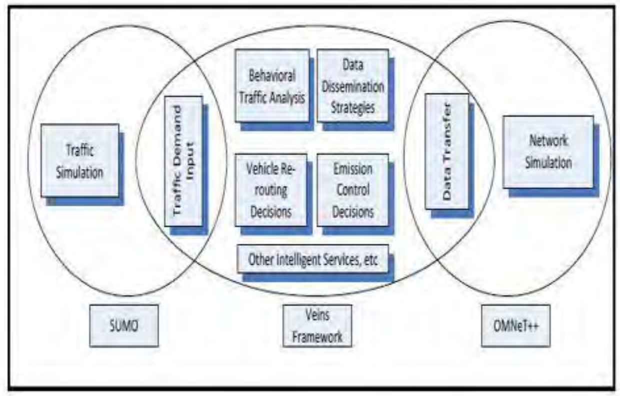

Fig. 3: More detailed overview of selected toolset for the study [6]

CHAPTER 2:

BACKGROUND STUDY

2.1 VANET: EVOLUTION, FEATURES AND RELATED WORK

'Ad hoc' in "Vehicular Ad Hoc Network" (VANET) stands for 'created for a particular reason'. VANET was fashioned by pertaining the primary principles of Mobile Ad Hoc Networks (MANET) – a continuously self-configuring network of mobile devices connected wirelessly – to the domain of vehicles[3]. Although the majority of the principles of MANET was retained while designing VANET, a number of subtle changes were introduced for it to better suit vehicular networking. A significant expansion in range of communication, higher mobility and periodic motion of nodes, an increased bandwidth, introduction of location based addressing, dense and frequently variable node density etc. are key features that were brought into the fold while designing VANET, with necessary trade-offs such as increased system production cost and weakening of multi hop routing support [13].

2.1.1 EVOLUTION OF VANET AND ITS

In early 2000s, VANET was considered as an exclusive derivative on MANET. The term was first coined in 2001 under "car-to-car ad hoc mobile communication and networking" applications, where networks can be formed and information can be relayed among cars. It was shown that vehicle-to-vehicle (V2V) and vehicle-to-roadside (V2I) communication architectures will co-exist in VANET to offer a plethora of applications. VANET is a salient part of the Intelligent Transportation Systems (ITS) framework. Sometimes, VANETs are referred as Intelligent Transportation Networks.[14]

ITS Standardization:

- *USA*: United States Congress via ISTEA (Intermodal Surface Transportation Efficiency Act) demanded the creation of the IHVS (Intelligent Vehicle Highway Systems) in 1991 to ameliorate the prevailing state of traffic systems by increasing safety and efficiency, to reduce pollution and downturn consumption of fossil fuel. The U.S. Department of Transportation (DOT), who were entrusted with the creation of IHVS program, sought cooperation of the ITSA (Intelligent Transportation Society of America). By 1996, a framework denoted as 'National ITS Architecture' had been established for planning and integration of the IHVS services. The aforementioned services are presently known as Intelligent Transportation Systems (ITS). Wireless communication was the chosen method of National ITS Architecture for the implementation of ITS services. The pioneering ITS services used the frequency spectrum between 902 MHz and 928 MHz, which consequentially proved far too small. Therefore, in 1997 the National ITS Architecture pleaded the FCC (Federal Communications Commission) for allocating a frequency bandwidth of 75 MHz in the 5.9 GHz frequency range with the support of DSRC (Dedicated Short Range Communications) in sight. This petition was granted in 1999 which lead to the conception of the DSRC-based ITS radio spectrum. From 2002 thereon, ITSA started urging FCC for DSRC licensing, service rules and most importantly the adoption of one single standard for physical and MAC layers, specified by the ASTM (American Society for Testing Materials) based on IEEE 802.11. This proposal was approved during 2003-2004. Development of an amendment to the 802.11 standard to include vehicular environments picked up pace in 2004, which is currently known as standard IEEE

802.11p. The IEEE working group 1609 started laying down the additional layers of the protocol suite which are: IEEE 1609.1-resource manager, IEEE 1609.2-security, IEEE 1609.3-networking, IEEE 1609.4 multichannel operation. The combination of IEEE 802.11p and the IEEE 1609 protocol suite is denoted as WAVE (Wireless Access in Vehicular Environments).[15]

- *EUROPE:* Three bodies who have been working for planning, development and implementation of European standards are, the European Committee for Standardization (CEN), the European Committee for electro-technical standardization (CENELEC) and European Telecommunication Standards Institute (ETSI). CEN are responsible for instilling European ITS DSRC 5.9 GHz radio communication technology. ETSI technical committee has numerous working bodies for several operations such as, describing basic set of requirements, providing architecture specification, development of network and transport protocols, European profile investigation and improvement of security infrastructure. These European standardization bodies have been working hand in hand with international standardizations such as the ISO (International Organization for Standardization), the IEC (International Electro-technical Commission) and ITU (International Telecommunication Union). In 1993, ISO created ISO/TC 204 that overlays all ITS based activities and also ISO/TC 22 that covers in-vehicle transport information and control Systems. Furthermore, ERTICO ITS was founded in Europe comprising of leading members of European commission, Ministries of Transport and European Industries to fast-track the development and deployment of ITS in Europe.

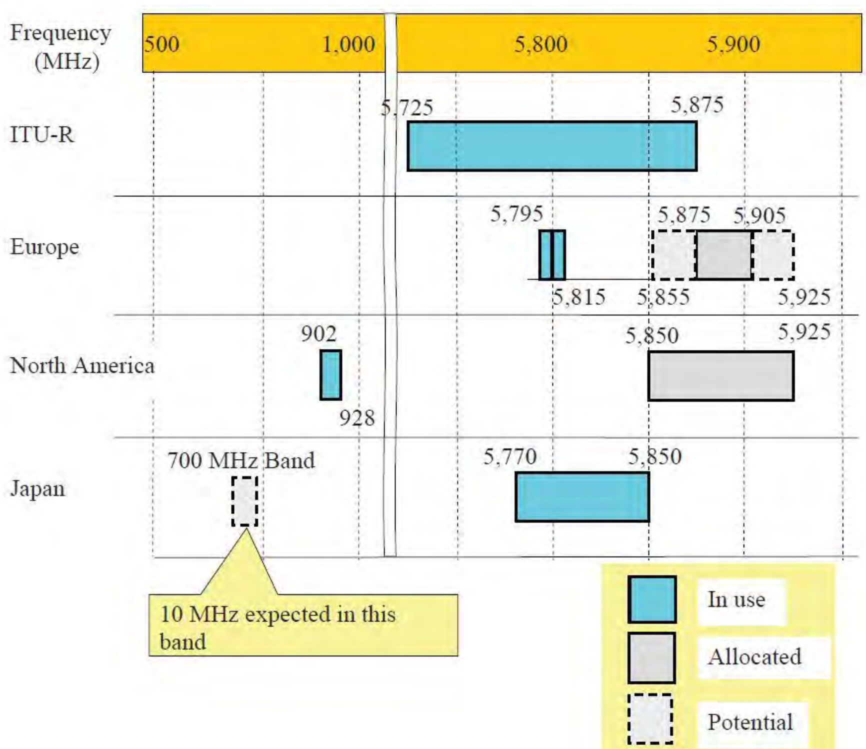

Fig. 4. DSRC frequency band specifications in Europe, North America and Japan [6]

- *JAPAN:* In 1996, five associated government bodies- National Police Agency (NPA), Ministry of International Trade and Industry (MITI), Ministry of Transport, Ministry of Posts and Telecommunications (MPT), and Ministry of Construction jointly put forth a "Comprehensive Plan for ITS in Japan"[15]. In 1999, these five bodies jointly released a proposal named "System Architecture for ITS". ARIB (Association for Radio Industry and Businesses) is responsible for standardization and allocation of DSRC frequency band for ITS applications in Japan. ARIB STD-T109 builds on a variant of the same radio technology operating on a single frequency in the 700 MHz band. The protocol stack enables TDMA operation to multiplex road side services and pure V2V communication. [15]

2.1.2 FEATURES OF VANET

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VANET can be thought of as a highly mobile ad-hoc network between vehicles, road side units, and infrastructure related to traffic control, where mobility is accounted for by the nodes, which in case of VANET are vehicles. The following are a few key features that characterize VANET:

- *Highly dynamic network topology:* Nodes in VANET move and change positions continuously according to the underlining variables such as direction, routes, velocity, acceleration etc.
- *Varying node density:* Node density can be varied in VANET depending on peak or off peak hours, rural or urban scenarios and so on.
- *Varying node velocities:* The relative velocity between vehicles moving in opposite directions are considered high as opposed to vehicles moving in the same direction, where relative velocity is considered significantly lower.
- *Varying environments for communications:* Buildings and other manmade objects in urban areas present themselves as obstacles for communication. Whereas in rural areas, topographical changes are perceived as obstacles for communication in VANET.
- *High, dynamic and frequent connection and disconnection:* Pondering the high velocity of the nodes and communication range of nodes and RSU's in VANET, which is between 240 meters to 500 meters, the connection and disconnection between networks occur rapidly.
- *Regular trace:* Unlike MANETs, the traces of the nodes in VANETs are regular due to the confined roads, buildings and other manmade infrastructures.
- *Power consumption through On board Source:* In stark contrast to MANETs, power consumption in VANET's are barely an issue. The power needed for sensors and other necessary devices is supplied by On-Board Units (OBU). [19, 16]

2.1.3 RELATED WORK

- *GrooveSim:* GrooveSim [28] was the first created tool for assessment of VANET concepts and performance analysis. Its primary objective was to evaluate traffic flow and forecast. GrooveSim could operate in five different modes and kept log of certain data parameters such as message penetration, delay, vehicle grouping, packets dropped etc. GrooveSim did not contain any network simulator.
- *NHTSA (National Highway Traffic Safety Application):* NHTSA [31] was built on top of NS-2 simulator to provide network estimation with networking research in mind. The prime motive of this project was to DSRC standardization.
- *FleetNet:* The aim of FleetNet was to provide a platform based on simulation tools and a software prototype titled FleetNet Demonstrator FND [30]. This software was designed to state the problems found in inter-vehicular communication and also for more realistic evaluation of VANET.
- *CARLINK:* This project was developed for wireless communications between cars and road side units to form a wireless traffic service platform. This enabled the researchers to apply their tests in a simulated environment before being installed into a real network.
- *Car2Car:* The Car2Car [29] communication is an organization prompted by European vehicle manufacturers which open to providers, researchers and other partners. Here IEEE 802.11 standard is used for wireless communication. Car2Car communication is based on a few points such as Advanced Driver Assistance, Decentralized Floating Car Data and User Communication and Information services.
- *Clarion:* This communication method for Intelligent Multimode Transit System (IMTS) utilizes a particular spectrum to autocratically control multiple nodes and record information such as speed and position from vehicles through the installed transmitter/receiver modules.
- *IP PReVENT:* PReVENT is a EU backed project intended to validate safety applications such as safe speed and safe following, collision migration, intersection safety, lateral support, development and improvement of ADAS (Advanced Driver Assistance System) etc. using sensors, maps and communication systems.
- *CVIS:* The purpose of Cooperative Vehicles and Infrastructure Systems (CVIS) was to increase road safety and efficiency and reduce the environmental effect due to these road safety applications.
- *Demo 2000:* A joint venture by Tsukuba and Japan to evaluate feasibility of inter-vehicular communication technologies.
- *Car Talk 2000:* European based project directed to provide reliable components for Advanced Driver Assistance System (ADAS) such as Advanced Cruise Control (ACC), information and warning function, communication-based longitudinal control system and Co-operative assistance system. [17]
- *IntelliDrive:* Introduced to verify and enhance WAVE/ IEEE 1609 features and to enable secure wireless V2V and V2I connections.
- *Vehicle Safety Communications (VSC):* Goals of this projects were the development of traffic safety applications such as forward collision warning, curve speed warning, pre-crash sensing traffic signal violation warning, lane change warning etc.

- *Cooperative Intersection Collision Avoidance System (CICAS):* Aim of this project was to develop a cooperative network to address problems such as intersection collision, stop-sign movements and unprotected signalized left turn maneuvers.
- *SafeTrip21:* This project was designed for running operation tests on near-market-ready ITS technologies and also to provide travelers information needed to arrive at their destination safely and with minimal delay.
- *ETC:* Japan based project for electronic toll collection.
- *VICS (Vehicle Information and Communication System)*: Japan based project focusing on driver safety and navigation systems.
- *AHSRA (Advanced Cruise Assist Highway Systems Research Association):* Initiated in Japan for development of V2I communications and information collection by infrastructure sensors.
- *ITS Safety 2010:* This project focused on ITS safety and security and used millimeter wave technology to determine distance between vehicles.
- *Communications for eSafety (COM-eSafety):* Goals of this European based project was to allocate frequency spectrum for ITS applications and dissemination of the system properties towards all stakeholders.
- *Adaptive Integrated Driver-vehicle interface (AIDE):* FP6 project for development of an adaptive driver-vehicle interface to enable a large number of functions.
- *Network on Wheels (NoW):* German project for development of communication protocols, safety and infotainment applications, enhancement of IEEE 802.11 technology and standardization on European level with the Car2Car Communication Consortium.
- *Connect and Drive (C & D):* Dutch HTAS (High Tech Automotive Systems) project that worked on design and implementation of Cooperative Adaptive Cruise Control (C-ACC).
- *Cooperative Systems for Intelligent Road Safety (COOPERS):* Objective of this project was enhancement of road safety by cooperative traffic management and real time data communication between vehicles and infrastructure.
- *GeoNET:* FP7 IP project aimed to develop geographic addressing and routing with feasible communication technologies to enable wireless communication in a particular geographic area. [15]

2.2 DSRC/WAVE

WAVE (Wireless Access in Vehicular Environments) standards were proposed on DSRC (Dedicated Short Range Communication) frequency band in a view to meet the extremely short latency requirements in ITS applications. The two classes of components in a WAVE system, OBU's (On-board Unit) and RSU's (Road ride unit) are analogous to Mobile Stations (MS) and Base Stations (BS) in the cellular systems. V2V and V2I are the two classes of communications enabled by OBU's and RSU's. While in cellular systems an MS can communicate with another MS via the BS, OBU's can communicate with each other without assistance of RSU's. WAVE networks can carry out an array of safety, infotainment and traffic management applications. WAVE networks have a unique set of technical challenges compared to other wireless networks such as faster signal fading and higher Doppler frequency spread because of very high relative speed between nodes or vehicles moving in opposite directions. WAVE networks may operate in a wide range of hash environments and thus certain messages taking even a slightly longer time than required may bring forth fatal consequences. To meet such challenges, WAVE networks need to be scalable and robust; have low latency and high throughput and be cognitive. [9] WAVE standard was obtained by merging the entire DSRC protocol stack that includes both IEEE 802.11p and IEEE 1609 standards and further combined with 1609.x to form a universally accepted standard. [13]

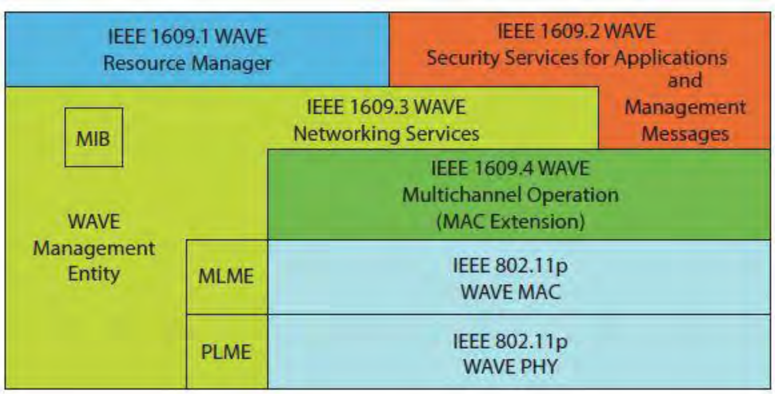

Fig 5: The IEEE 1609 (WAVE) reference architecture and relationship to the IEEE 802.11p MAC and physical layers [2]

2.2.1 IEEE 802.11p

IEEE 802.11 is a set of specifications for Media Access Control (MAC) layer and Physical (PHY) layer for wireless communication. Many amendments have been made enhance MAC and PHY layers for different operations. Longer range of operation, high relative speeds of vehicles, transmitting high priority messages with low latency, high influence of multi-path fading due to environmental and geographical challenges are some of the key factors that led to the modifications in the 802.11 baseline for ITS services. In USA, the 75 MHz of spectrum in the 5.9 GHz frequency allocated for DSRC applications, has been split into seven 10 MHz channels; One Control Channel (CCH) and six Service Channels (SCH). 5 MHz is reserved as the guard band. The control channels are responsible for carrying high priority short messages or management of data, while other data are transmitted on the service channels. As per IEEE 1609.4 standard, each second is segmented into ten sync intervals and each sync interval has CCH and SCH intervals. During CCH intervals, al WAVE stations monitor the CCH. A station switches to a SCH during SCH intervals if it needs to transmit or receive through that channel. [18]

The standards need to accommodate the aforementioned band and channel bandwidths. Hence, IEEE 802.11a physical layer was taken as reference which employs Orthogonal Frequency Division Multiplexing (OFDM) in a view to prevent inter-symbol interference and inter-carrier interference in multi-path environments.

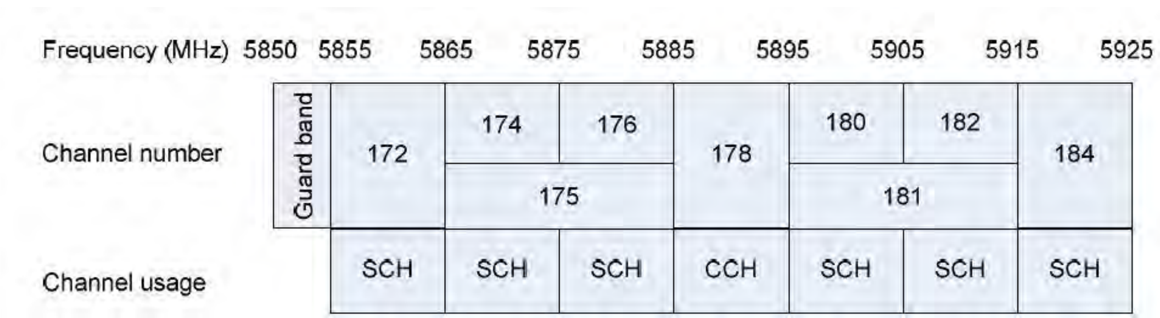

Fig 6: DSRC frequency allocation is USA [1]

These DSRC standards differ in other parts on the world. For instance, half duplex communication is being used for both OBU's and RSU's in USA and Europe, while Japan uses half-duplex communication for OBU's and full-duplex for RSU's. Furthermore, while USA is using 75 MHz bandwidth in 5.9 GHz frequency, Europe uses 20 MHz band in 5.8 GHz frequency and Japan uses 80 MHz in 700 MHz frequency. The major improvements made over the baseline IEEE 802.11 to create the IEEE 802.11 are:

Fast Connection Setup: As VANETs have highly dynamic network topology and a vital need for low latency, a faster connection setup is needed to ample time to communicate the available data while the connection lasts.

10 MHz Channels: 75 MHz spectrum allocated for DSRC/WAVE in USA are split into 10 MHz service and control channels.

Random MAC Address: To ensure the anonymity of the vehicles and to make them untraceable, random MAC addresses are assigned to the vehicles.

Priority Control: This feature facilitates the goal to achieve Quality of Service (QoS) in ITS services. Data generated from different applications are prioritized and critical data gets access to the channel first.

Power Control: This feature permits the applications to specify transmission (TX) power to transfer packets over the channels depending on topographical characteristics, thus enabling intelligent transmission power management. [10]

Halved Data Transmission Rates: 802.11p supports data transmission rate half of what 802.11a supports, which results in drastically reduced errors in a highly altering environment

Table 2.1 shows comparison between IEEE 802.11a and IEEE 802.11p PHY values:

Parameter	**802.11p**	**802.11a**
Channel bandwidth	3 to 27 Mbps	6 to 54 Mbps
Data rates	10 MHz	20 MHz
Slot time	$16\mu s$	$9\ \mu s$
SIFS time	$32\ \mu s$	$16\ \mu s$
Preamble length	$32\ \mu s$	$20\ \mu s$
PLCP header length	$8\ \mu s$	$4\ \mu s$
Air Propagation time	$<4\ \mu s$	$<<1\ \mu s$
CWmin	15	15
CWmax	1023	1023

2.2.2 DSRC Standards

The IEEE 1609 family and IEEE 802.11p along with SAE (Society of Automotive Engineers) J2735 Message Set Dictionary standard jointly form the fundamentals of WAVE protocol stack. The major components of WAVE architecture are as follows:

- *IEEE P1609.0:* "The wireless access in vehicular environments (WAVE) architecture and services necessary for WAVE devices to communicate in a mobile vehicular environment are described in this guide" [19]
- *IEEE 1609.1:* "This standard specifies a wireless access in vehicular environments (WAVE) dedicated short-range communications (DSRC) application, known as the WAVE resource manager (RM), designed to allow applications at remote sites to communicate with devices known

as onboard units (OBUs), which are mounted in vehicles, through devices known as roadside units (RSUs), which are mounted on the roadside." [23]

- *IEEE 1609.2:* "This standard defines secure message formats and processing for use by Wireless Access in Vehicular Environments (WAVE) devices, including methods to secure WAVE management messages and methods to secure application messages." [24]
- *IEEE 1609.3:* "Services to WAVE devices and systems are provided in IEEE Std 1609.3(TM), IEEE Standard for Wireless Access in Vehicular Environments (WAVE)--Networking Services. Layer 3 and layer 4 of the open system interconnect (OSI) model and the Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) elements of the Internet model are represented. Management and data services within WAVE devices are provided." [20]

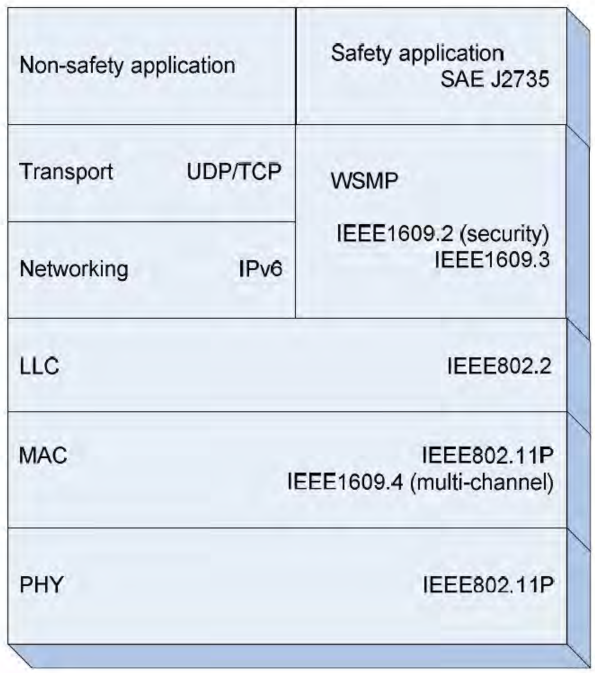

Fig 7: TCP/IP Model of DSRC/WAVE [1]

- *IEEE 1609.4:* "Multi-channel wireless radio operations, Wireless Access in Vehicular Environments (WAVE) mode, medium access control (MAC), and physical layers (PHYs), including parameters for priority access, channel switching and routing, management services, and primitives designed for multi-channel operations are described in this standard."[21]
- *IEEE P1609.11:* "Over-the-Air Data Exchange Protocol for Intelligent Transportation Systems (ITS)"
- *IEEE 802.11p:* "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications -Amendment: Wireless Access in Vehicular Environments"
- *SAE J2735:* Specifies a set of message formats that support a variety of vehicle-based applications such as Basic Safety Message (BSM).
- *SAE J2945.1:* Communication minimum performance requirements standard. [18, 22]

2.2.3 *WSMP*

The revamped standards and architecture of WAVE for inter-vehicular communication provides us with a new protocol that absorbs both Transport (OSI Layer 4) and Network (OSI Layer 3) layers which is denoted as WAVE Short Message Protocol (WSMP). WSM's have the exclusive privilege of propagating through CCH channels due to WSMP. WSMP is defined in IEEE 1609.3. Its main task is to amass data from higher layers for transmission over WSMP and to deliver received WSM's to higher layers. WSMP enables high-rate, low latency communication between fast moving vehicles in a dynamic and rapidly varying environment.

A WSMP packet consists of six segments:

Version: States the version of the WSM protocol.

PSID: Defines the higher layer destination of the WSM.

WSMP Header Extension Fields: Carries header information like channel number, data rate, transmission power and two dimensional location.

WAVE Element ID: Defines the type of WSM that follows the WSMP header.

Length: Defines the length of data.

WSM Data: Contains the data to be delivered to the upper layers. [19]

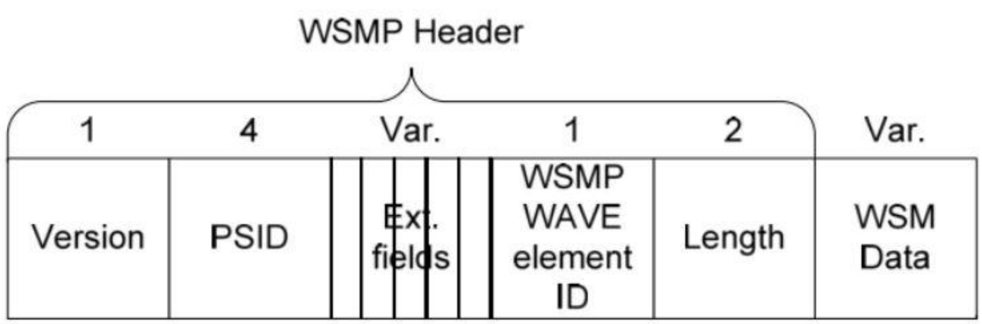

Fig 8: WSMP Packet [11]

2.2.4 DSRC/WAVE PHY

Physical layer, the bottommost layer of DSRC/WAVE protocol stack, was primarily defined in IEEE 802.11 and then amended by IEEE 802.11p. The physical layer is divided into two sub layers: the Physical Medium Dependent (PMD) sublayer and Physical Layer Convergence Procedure (PLCP) sublayer.

PMD interfaces directly with wireless medium. Upon PLCP request, PMD transmitter sends the coded bits that make up each OFDM frame. It also delivers information such as data rate and transmit power along with performing OFDM modulation which includes Fast Fourier transform (FFT), Guard Interval insertion, wave-shape filtering, RF modulation and power amplification. Conversely, the PMD receiver performs demodulation which includes Automatic Gain Control (AGC), Clock Recovery, RF demodulation, Guard interval removal and FFT while it also offers Received Signal Strength Indication (RSSI). The role of PLCP is to perform mapping between the MAC frame and the basic PHY layer data unit. PLCP function is to processes the bytes in a MAC frame to be transformed into OFDM symbols for transmission over the air by the PMD.[22]

2.2.5 DSRC/WAVE MAC

The role of MAC layer is to establish rules for accessing the common medium of communication for it to be efficiently shared among the stations. IEEE 802.11 defines two categories: the session-based rules to decide if a station is ready to communicate data on behalf of layer 3 and frame-by-frame rules governing an individual transmission. The IEEE 802.11p amendment introduces almost newly molded session-based rules while frame-by-frame rules remains entirely unchanged. IEEE 802.11 introduces Basic Set Service (BSS) which is basically a set of stations that agree to exchange data plane information. The role of BSS in WAVE will be discussed later. The basic medium access paradigm discussed in the 802.11 standard is CSMA/CA (Carrier Avoidance Sense Multiple Access/Collision). A simple communication scenario under CSMA/CA comprises of the following steps:

I. A station that has a frame to send needs to sense a wireless medium first.
II. The medium needs to be idle for transmission to begin. If the medium is busy the station performs a random “backoff” which calls an interrupt function when the medium becomes idle again and ready for transmission.
III. The sender station waits for an acknowledgement (ACK) from the recipient. If it doesn’t get the ACK bit within the timeout interval, it resends the frame.

2.2.6 BSS AND BSSID IN WAVE

Two categories of Basic Service Set's (BSS) are defined in IEEE 802.11; Infrastructured Basic Service Set (BSS) and Independent Service set (IBSS). A hub called Access Point (AP) is set for a group of stations in BSS, through which the stations communicate with one another and the source. In IBSS, the stations in the group communicate with each other in ad-hoc method. BSS's are joint together to form Extended Service Set (ESS). According to IEEE 802.11 standard, the logical network (ESS or independent-*BSS*) service set identifier is perceived as SSID, irrespective of whether an *SSID* identifies an infrastructure-*BSS's* ESS, or the peer-to-peer network of an independent-*BSS*. A unique BSSID is assigned to the group of stations that a BSS shares, which is basically the MAC address of the AP.

The need for a reformed BSS's for vehicular environment by the underlying WAVE standards lead to the creation of WBSS (WAVE BSS). The on-demand beacon is broadcast to create a WBSS and based on the beacon received, the stations can decide if they want to join the WBSS or not. The stations, whether or not they are a part of the WBSS, can broadcast emergency messages; which enables efficient propagation of emergency messages.[16]

CHAPTER 3:
SIMULATION TOOLSET AND METHODOLOGY

In this chapter the simulation toolset will be discussed that have been used for the implementation of different rerouting algorithms for three different scenarios.

3.1 OMNET++

Analyzing the effectiveness and reliability of a set of routing algorithms for DSRC/WAVE require testing in a simulated environment. This is a tangible and cost effective way of evaluating the efficiency of said algorithms and analysis of the resulting data sets help in implementing a more well-rounded system. Network simulation is commonly used for these evaluation purposes as it sidesteps the complexity immersed in actual deployment.

OMNET++ is a public-source C++ based event simulator for modeling communication network that can be meshed with other distributed or parallel systems. These distributed or parallel systems are allowed to run independently of OMNET++ and follow their own release cycles with a view to make it as general as possible. OMNET++ represents a framework approach which provides basic machinery and tools to write simulations rather than bluntly providing simulation components for computer networks, queuing networks, ad-hoc networks and other domains.

While NS-2 is currently the most widely used network in academic and research circles, OMNET++ is largely used for VANET simulations due to a few key differences which are listed below:

I. NS-2 does not follow the same clear separation of simulation kernel and models as OMNET++.
II. NS-2 distribution contains the models together with their supporting infrastructure as one inseparable unit as opposed to the independently operating parallel systems in OMNET++.
III. The goal of NS-2 is to build a *network simulator,* while OMNET++ intends to provide a *simulation platform.*
IV. NS-2 does not support hierarchical models, a graphical editor, GUI-based execution environment, graphical analysis tools and simulation library features. [25]

3.2 SUMO

Simulation of Urban Mobility (SUMO) is an open source traffic simulator that is designed to function as a highly portable and microscopic road traffic simulation tool. SUMO is used efficiently emulate a wide range of traffic scenarios. A ***network file*** is required from where SUMO can obtain information such as nodes, edges and connections between them. This network file is generated by importing a ".osm" file from OpenStreetMap, which is a digital mapping application aimed to create a free editable map of the world. The ***routes file*** contains data about all of the streets and lanes along with the definite routes that each individual vehicle follows in the simulation. Further additional information such as traffic lights cycles, bus stops are stored in ***additional files.*** The extended API interface TRACI (Traffic Control Interface) carries out the job of manipulating vehicular mobility parameters during runtime. A unique ID, velocity, depart/arrival position, arrival time, departure time and a type which describes the physical property is assigned to each vehicle. This API remotely controls automatic driving and traffic management strategies. The road network importer ***netconvert*** enables SUMO to read networks from other traffic simulator and other common formats as well. Implemented rerouting techniques are investigated by the application ***duarouter***. [26]

3.3 VEINS

Modeling and implementation of a VANET simulation requires a mediator to couple the network simulation component and traffic simulation component. VEINS (Vehicles in Network Simulators) is an open source vehicular simulation framework designed to serve as a bridging interface to couple SUMO and OMNET++. VEINS also helps to take care of setting up, running and monitoring the simulation. Primary objective of VEINS is to write application specific simulation code and controlling necessary parameters of each simulation. This framework supervises the modeling of lower protocol layers and node mobility, proper execution of transferred and received BSM's and WSM's by adhering to the IEEE 802.11p and IEEE 1609.4 DSRC/WAVE standards and collecting results during and after the simulation. Veins contains a number of simulation models that serve as a toolbox for implementation of comprehensive and highly detailed simulations.

VEINS lets both OMNET++ and SUMO run in parallel by connecting them via a TCP socket. The protocol for this communication has been standardized by TRACI that allows bi-directionally coupled simulation of road traffic and network traffic. The mobility of nodes in SUMO is emulated in OMNET++ via TRACI. [27]

3.4 METHODOLOGY

In this chapter, the simulation methodology will be explained by fig 9. Here we can see OMNET++ and SUMO are coupled together by VEINS. The desired map is imported from OpenStreetMap. TRACI guidelines dictate the flow of Basic Safety Messages and WAVE Short Messages via Airframe 11p, the default message protocol in OMNET++. Three unique routing techniques will be implemented through three simulation scenarios, which will be discussed later. The results will be analyzes in the "Result and Analysis" Chapter.

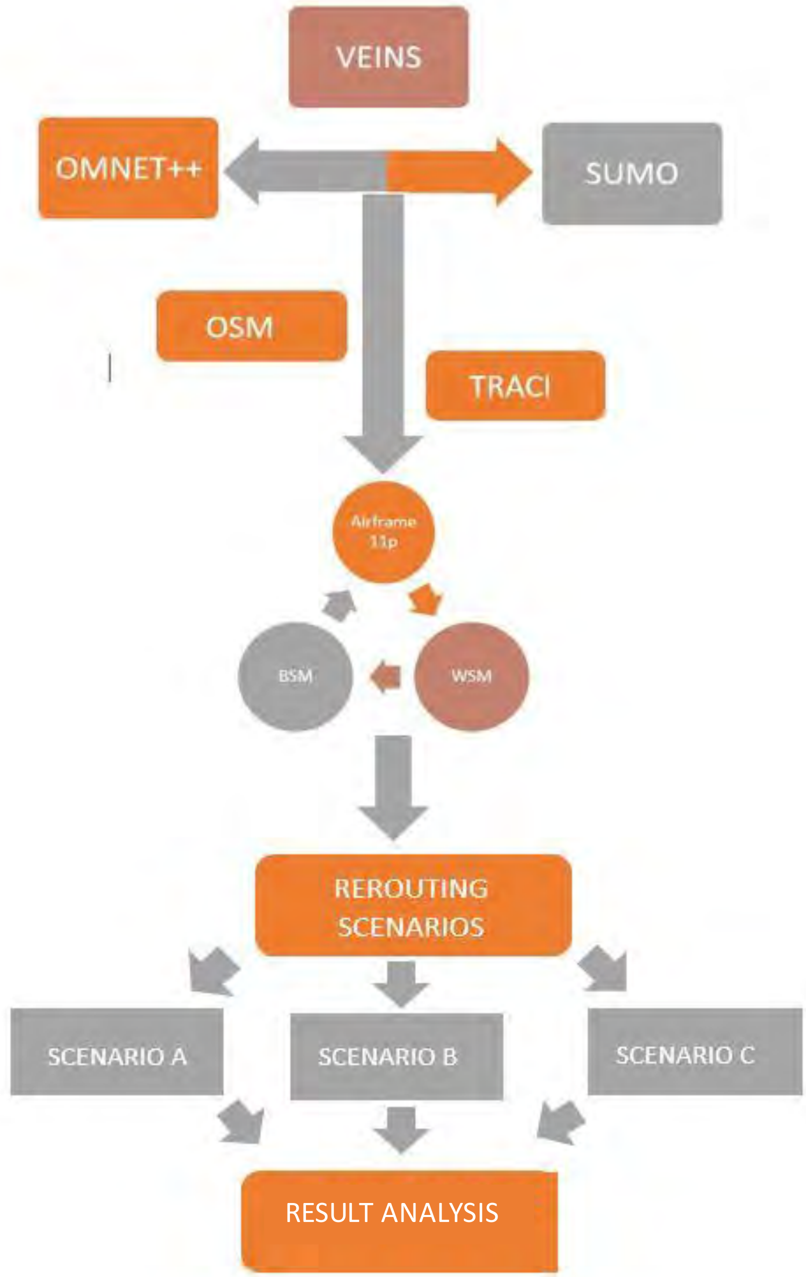

Fig 9: Simulation Methodology Flowchart

CHAPTER 4:

SIMULATION SETUP

In this chapter the simulation setup will be described consisting of map extraction, controlling the mobility of vehicles according to user's interest using SUMO and finally configuring as well as running the simulation in OMNET++.

4.1 SUMO SIMULATION SETUP

SUMO traffic simulation steps will be covered in this section.

4.1.1 EXPORTING THE DESIRED MAP FROM OPENSTREETMAP

Initially, we require the map that we want to run the simulation on and for that purpose we need to export the map from openstreetmap.org by manually selecting the area. If we click on "Export" option a ".osm" file will be downloaded which contains street map information in the form of nodes, ways and relations between street and object properties.

4.1.2 CREATING TYPEMAP.XML

At first, we need to write the following codes in a notepad and save it as "typemap.xml"

```
<polygonTypes>
   <polygonType id="waterway"            name="water"     color=".71,.82,.82" layer="-4"/>
   <polygonType id="natural"             name="natural"   color=".55,.77,.42" layer="-4"/>
   <polygonType id="natural.water"       name="water"     color=".71,.82,.82" layer="-4"/>
   <polygonType id="natural.wetland"     name="water"     color=".71,.82,.82" layer="-4"/>
   <polygonType id="natural.wood"        name="forest"    color=".55,.77,.42" layer="-4"/>
   <polygonType id="natural.land"        name="land"      color=".98,.87,.46" layer="-4"/>

   <polygonType id="landuse"             name="landuse"   color=".76,.76,.51" layer="-3"/>
   <polygonType id="landuse.forest"      name="forest"    color=".55,.77,.42" layer="-3"/>
   <polygonType id="landuse.park"        name="park"      color=".81,.96,.79" layer="-3"/>
   <polygonType id="landuse.residential"   name="residential" color=".92,.92,.89"  layer="-3"/>
   <polygonType id="landuse.commercial"    name="commercial"  color=".82,.82,.80"  layer="-3"/>
```

```
<polygonType id="landuse.industrial"      name="industrial"   color=".82,.82,.80"  layer="-3"/>
<polygonType id="landuse.military"        name="military"     color=".60,.60,.36"  layer="-3"/>
<polygonType id="landuse.farm"            name="farm"         color=".95,.95,.80" layer="-3"/>
<polygonType id="landuse.greenfield"      name="farm"         color=".95,.95,.80"  layer="-3"/>
<polygonType id="landuse.village_green"   name="farm"         color=".95,.95,.80"  layer="-3"/>

<polygonType id="tourism"                 name="tourism"     color=".81,.96,.79"  layer="-2"/>
<polygonType id="military"                name="military"    color=".60,.60,.36"  layer="-2"/>
<polygonType id="sport"                   name="sport"       color=".31,.90,.49" layer="-2"/>
<polygonType id="leisure"                 name="leisure"     color=".81,.96,.79"  layer="-2"/>
<polygonType id="leisure.park"            name="tourism"     color=".81,.96,.79"  layer="-2"/>
<polygonType id="aeroway"                 name="aeroway"     color=".50,.50,.50" layer="-2"/>
<polygonType id="aerialway"               name="aerialway"   color=".20,.20,.20"  layer="-2"/>

<polygonType id="shop"                    name="shop"        color=".93,.78,1.0" layer="-1"/>
<polygonType id="historic"                name="historic"    color=".50,1.0,.50"  layer="-1"/>
<polygonType id="man_made"                name="building"    color="1.0,.90,.90"  layer="-1"/>
<polygonType id="building"                name="building"    color="1.0,.90,.90"  layer="-1"/>
<polygonType id="amenity"                 name="amenity"     color=".93,.78,.78"  layer="-1"/>
<polygonType id="amenity.parking"         name="parking"     color=".72,.72,.70"  layer="-1"/>
<polygonType id="highway"                 name="highway"     color=".10,.10,.10"  layer="-1"
discard="true"/>

<polygonType id="boundary"  name="boundary"        color="1.0,.33,.33"  layer="0"  fill="false"
discard="true"/>
<polygonType id="admin_level"  name="admin_level"  color="1.0,.33,.33"  layer="0"  fill="false"
discard="true"/>
</polygonTypes>
```

4.1.3 GENERATING A SUMO NETWORK USING NETCONVERT

At first, we need to open command prompt from our desktop and run start-command-line.bat selecting the directory that contains this application. Then by using Netconvert application provided by SUMO we should get an output as .net.xml which contains road networks, geographic co-ordinates (Latitude and Longitude). The following command lines are executed in command prompt to get the desired network.

./ netconvert --osm-files map.osm -o map.net.xml --junctions.join --remove-edges.isolated --remove-edges.by-vclass "rail_slow , rail_fast , bicycle , pedestrian" -v

Table 4.1 describes the commands used in detail.

Commands	Description
--osm-files	.osm File Name
-o	Output .net.xml File Name
--junctions-join	Joins junctions that are close to each other
--remove-edges.isolated	Removes isolated edges
--remove-edges.by-vclass	Removes the edges related to the mentioned vehicle class
-v	Verbose output of the application

Table 4.1: Description of commands used in NETCONVERT [10]

4.1.4 OBSTACLE ADDITION

SUMO provides another application called polyconvert which is used to extract the polygons/buildings from the .osm file implementing the following command in command prompt.

./ polyconvert --net-file map.net.xml --osm-files map.osm --type-file typemap.xml -o map.poly.xml

Table 4.2 describes the commands used in detail.

Comamnds	Description
--net-file	.net.xml File Name
--osm-files	.osm File Name
--type-file	Typemap.xml File Name
-o	Output .poly.xml File Name

Table 4.2: Description of commands used in POLYCONVERT [10]

4.1.5 *VEHICLE ROUTES GENERATION USING DUAROUTER*

A 'Trips' file needs to be extracted using the RandomTrips python script provided as part of the SUMO package. Later on the resulting files are used to create vehicle routes. The command line is as follows.

python C:/Users/user/Downloads/sumo-0.30.0/tools/randomTrips.py -n map.net.xml -o map.trips.xml -b 0 -e 500 -v

Table 4.3 describes the commands used in detail.

Option	Description
"-n"	.net.xml file to be used
"-o"	Output .trips.xml File Name
"-b"	Start time in seconds, 0 in this case
"-e"	End time in seconds, 500 seconds in this case
"-v'	Verbose description of the application

Table 4.3: Description of commands used in RandomTrips [10]

Now, the generated map.trips.xml and map.net.xml are used to generate vehicle routes using the "Duarouter" application provided by SUMO package. The following command is as follows.

./ duarouter -n map.net.xml -t map.trips.xml -o map.rou.xml --remove-loops -b 0 -e 500\\ -v –ignore-errors

Table 4.4 describes the commands used in detail.

Commands	Description
"-n"	.net.xml file to be used
"-t"	.trips.xml file to be used
"-o"	Output routes file name
"--remove-loops"	Removes routes that have loops within them
"-b 0"	Start time in seconds, 0 in this case
"-e 500"	End time in seconds, 500 seconds in this case
"-v"	Verbose description of the application
"--ignore-errors"	Discards instances where a valid route cannot be generated.

Table 4.4: Description of commands used in DUAROUTER [10]

4.1.6 SUMO CONFIGURATION FILE

In every scenario there should be a ".sumo.cfg" file associated with it which points to the corresponding .net.xml and .rou.xml files to be used and also the start and end time of the simulation. The xml schema used is as described below:

```
<configuration xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="http://sumo.sf.net/xsd/sumoConfiguration.xsd">

    <input>
        <net-file value="map.net.xml"/>
        <route-files value="map.rou.xml"/>
        <additional-files value="map.poly.xml"/>
    </input>

    <time>
        <begin value="0"/>
        <end value="1000"/>
        <step-length value="0.1"/>
    </time>

<!--
    <report>
        <no-duration-log value="true"/>
        <no-step-log value="true"/>
    </report>
-->
</configuration>
```

4.2 OMNET++ SIMULATION SETUP

The simulation in OMNET++ is controlled by a ".ini" file corresponding to that simulation. The parameters used, and their specific values are discussed below with commands from the ".ini" file.

```
*.playgroundSizeX = 5000m
*.playgroundSizeY = 5000m
*.playgroundSizeZ = 50m

##########################################################
# Annotation parameters                                  #
##########################################################
```

```
*.annotations.draw = true

##############################################################
# Obstacle parameters                                        #
##############################################################
*.obstacles.debug = false
*.obstacles.obstacles = xmldoc("config.xml",
"//AnalogueModel[@type='SimpleObstacleShadowing']/obstacles")

##############################################################
#            TraCIScenarioManager parameters                 #
##############################################################
*.manager.updateInterval = 1s
*.manager.host = "localhost"
*.manager.port = 9999
*.manager.autoShutdown = true
*.manager.launchConfig = xmldoc("map.launchd.xml")

##############################################################
#                       RSU SETTINGS                         #
#                                                            #
#                                                            #
##############################################################
*.rsu[0].mobility.x  = 1000
*.rsu[0].mobility.y  = 100
*.rsu[0].mobility.z  = 50

*.rsu1[0].mobility.x  = 1000
*.rsu1[0].mobility.y  = 750
*.rsu1[0].mobility.z  = 3

*.rsu[*].applType = "TraCIDemoRSU11p"
*.rsu[*].appl.headerLength = 80 bit
*.rsu[*].appl.sendBeacons = true
*.rsu[*].appl.dataOnSch = false
*.rsu[*].appl.beaconInterval = 1s
*.rsu[*].appl.beaconUserPriority = 7
*.rsu[*].appl.dataUserPriority = 5

*.rsu1[*].applType = "TraCIDemoRSU11p"
*.rsu1[*].appl.headerLength = 80 bit
*.rsu1[*].appl.sendBeacons = true
*.rsu1[*].appl.dataOnSch = false
*.rsu1[*].appl.beaconInterval = 1s
*.rsu1[*].appl.beaconUserPriority = 7
*.rsu1[*].appl.dataUserPriority = 5
##############################################################
#            11p specific parameters                         #
#                                                            #
#                    NIC-Settings                            #
##############################################################
```

```
*.connectionManager.sendDirect = true
*.connectionManager.maxInterfDist = 2600m
*.connectionManager.drawMaxIntfDist = false

*.**.nic.mac1609_4.useServiceChannel = false

*.**.nic.mac1609_4.txPower = 20mW
*.**.nic.mac1609_4.bitrate = 6Mbps
*.**.nic.phy80211p.sensitivity = -89dBm

*.**.nic.phy80211p.useThermalNoise = true
*.**.nic.phy80211p.thermalNoise = -110dBm

*.**.nic.phy80211p.decider = xmldoc("config.xml")
*.**.nic.phy80211p.analogueModels = xmldoc("config.xml")
*.**.nic.phy80211p.usePropagationDelay = true

*.**.nic.phy80211p.antenna = xmldoc("antenna.xml", "/root/Antenna[@id='monopole']")

##########################################################
#                    WaveAppLayer                        #
##########################################################
*.node[*].applType = "TraCIDemo11p"
*.node[*].appl.headerLength = 80 bit
*.node[*].appl.sendBeacons = true
*.node[*].appl.dataOnSch = false
*.node[*].appl.beaconInterval = 1s

##########################################################
#                    Mobility                            #
##########################################################
*.node[*].veinsmobilityType.debug = true
*.node[*].veinsmobility.x = 200
*.node[*].veinsmobility.y = 200
*.node[*].veinsmobility.z = 1.895
*.node[*0].veinsmobility.accidentCount = 1
*.node[*0].veinsmobility.accidentStart = 75s
*.node[*0].veinsmobility.accidentDuration = 50s

[Config WithoutChannelSwitching]

[Config WithChannelSwitching]
*.**.nic.mac1609_4.useServiceChannel = true
*.node[*].appl.dataOnSch = true
*.rsu[*].appl.dataOnSch = true
```

CHAPTER 5:
SIMULATION RESULTS AND ANALYSIS

SCENARIO A: Rerouting on-rushing vehicles to bypass a roadblock

For this scenario, we have chosen the map of the route connecting Gulshan 1 and Mohakhali in the vicinity of BRAC University Mohakhali Campus in the northern part of Dhaka as shown in figure 10. This is one of the moderately busy routes in Dhaka where there are two uni-directional streets both having a solitary lane. There are multiple alternative routes which are not usually used by vehicles using this route.

Fig 10: Map of Gulshan 1- Mohakhali Route

In this scenario, we can see that that a road-block has appeared due to an accident which has taken place in the spot marked 'X' in figure 11. The RSU placed in the road intersection broadcasts a BSM to all the vehicles approaching the road-block to use the alternate route 'A' as shown in figure 12. The vehicles approaching the road block reach the road intersection and take the alternate route 'A'.

Fig 11: Appearance of a roadblock at 'X' marked

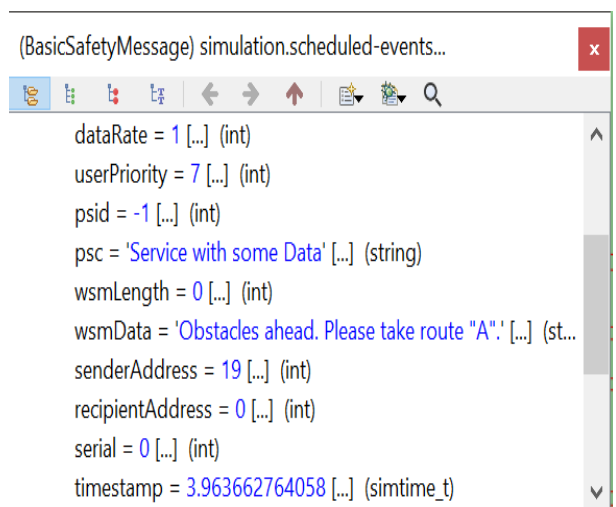

Fig 12: BSM broadcast by RSU

We can see the mobility of the vehicles from the distance versus time graph in figure 13. The vehicles approach towards the road blocks. After obtaining the BSM form the RSU, the vehicles take the alternate route, go around the road block and then go back to the main street. From then on, the distance from the road-block continues to increase as the vehicles continue move away from the roadblock.

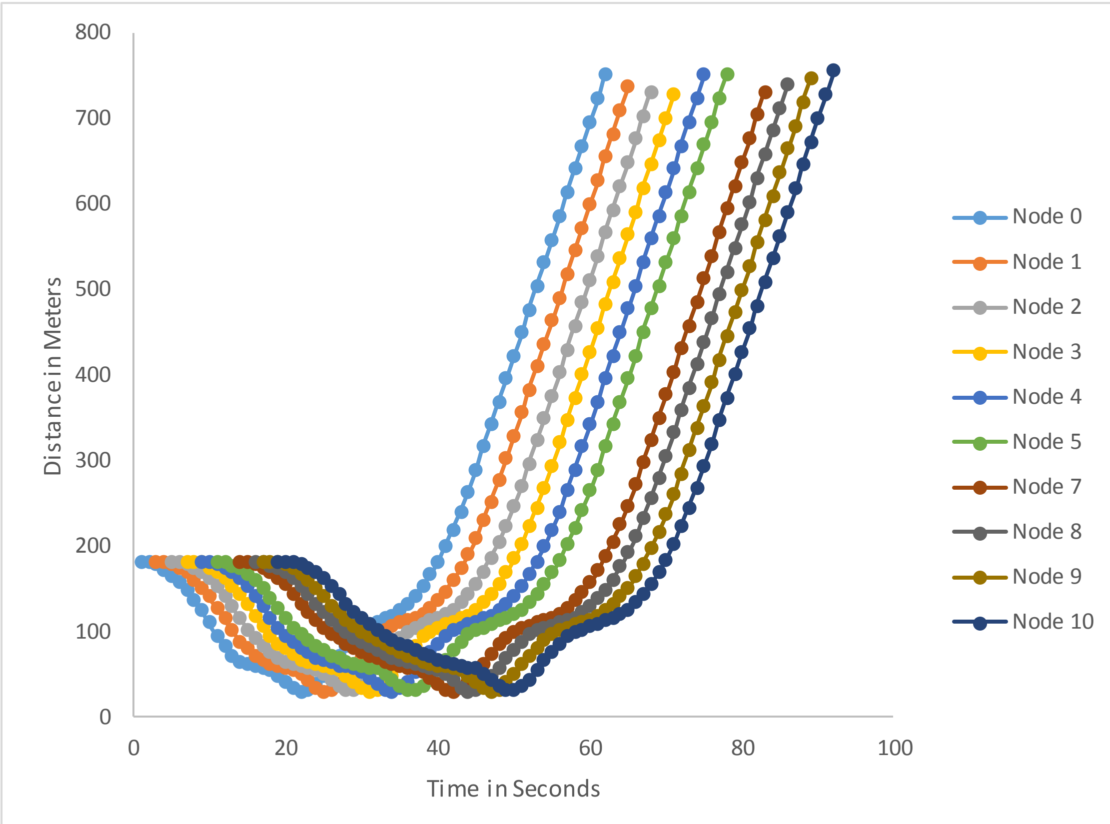

Fig 13: Distance from road-block

SCENARIO B: Vehicular Re-routing to reduce CO_2 emission in hospital areas

For this simulation, we have chosen the map of Dhaka Medical College Hospital in the southern part of Dhaka as shown in figure 14. This is one of the busiest routes of Dhaka. Due to the high density of vehicles, the rate of Carbon di-Oxide emission along this route is very high. Here, we are using a unique rerouting technique to reduce the CO2 emission in this area.

Fig 14: Map of Dhaka Medical College Hospital

For detailed analysis of the possible reduction of CO_2 emission in this area, we simulated two different vehicle traffic densities: high vehicle density during peak hours and low vehicle density during off peak hours.

For high vehicle density simulation, we have chosen vehicle density of 1600 vehicles per hour along the selected route. Here we are only considering the vehicles that are moving from the north to the south, southeast and southwest direction. For the vehicles moving to the southeast, every two out three vehicles will be rerouted to move along the alternate route because the alternate route is narrow and cannot efficiently contain more than 200 vehicles per hour.

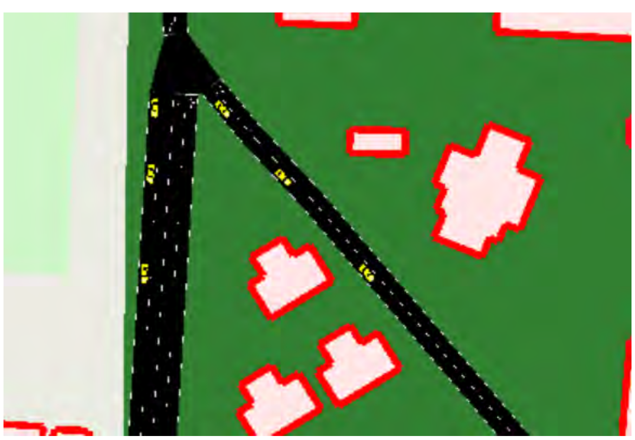

Fig 15: Selective southeast moving vehicles taking the alternate route

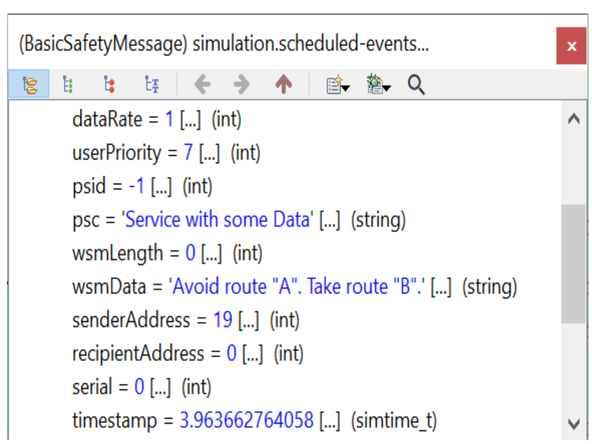

Fig 16: BSM sent to the rerouted vehicles

From figure 17 and 18 we can see that the highest instantaneous CO_2 emission has reduced from 138 liters to 84 liters which indicates a 39% reduction in highest instantaneous Carbon di-Oxide emission and 42% reduction in overall emission for high vehicle density in the hospital area.

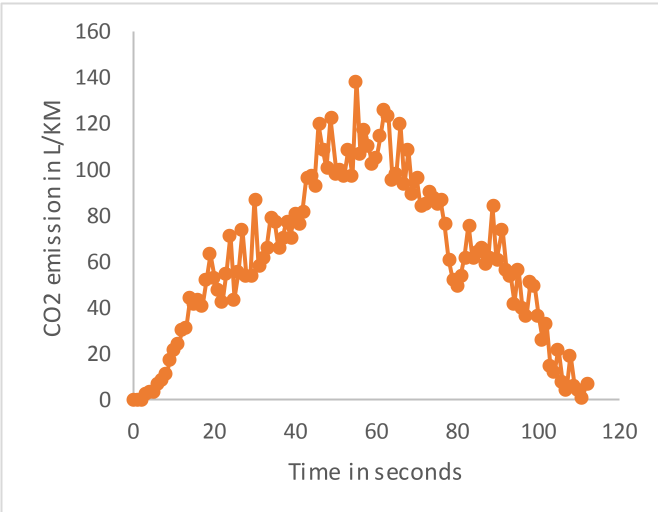

Fig 17: CO2 emission before rerouting for high vehicle density

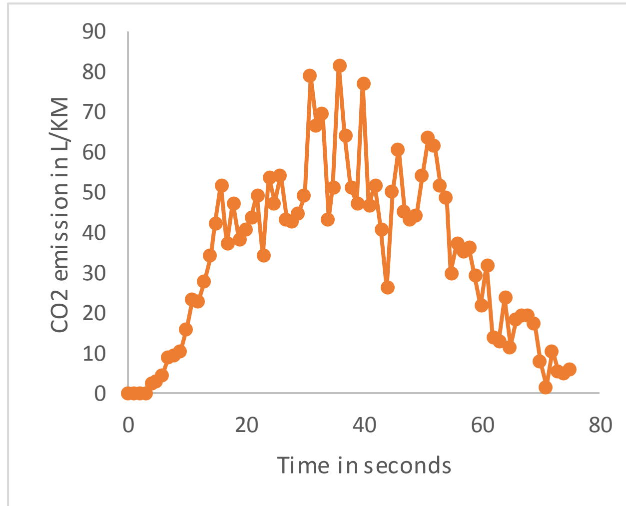

Fig 18: CO2 emission after rerouting for high vehicle density

For low vehicle density simulation, we have chosen vehicle density of 800 vehicles per hour. In this case, four out of five southeast moving vehicles will be rerouted along the alternate route complying with the route's capacity of 200 vehicles per hour.

The resultant graphs show that highest instantaneous Carbon di-Oxide emission has reduced from 104 liters to 55 liters, which indicates a 47% reduction in highest instantaneous Carbon di-Oxide emission and 48% reduction in overall emission for low vehicle density in the area.

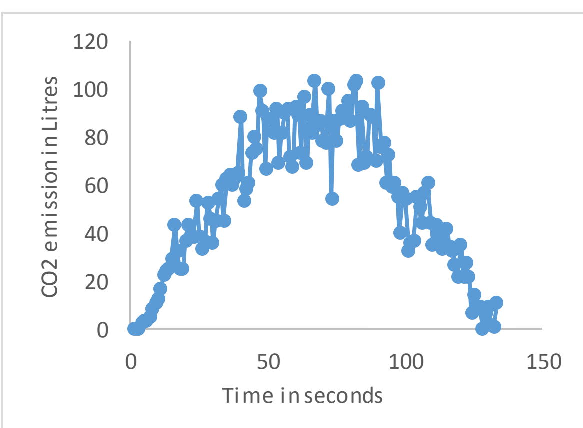

Fig 19: CO2 emission before rerouting for low vehicle density

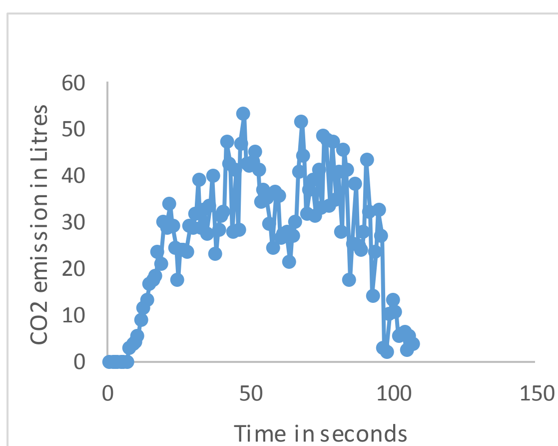

Fig 20: CO2 emission after rerouting for low vehicle density

SCENARIO C: Speed control technique in hazardous road conditions when alternate route is unavailable

For this simulation we have chosen the map of a hazardous street in Mohammadpur in the western part of Dhaka as shown in figure 21. Here we are assuming that the selected route is in hazardous condition due to torrential rain but it is the only feasible route to commute.

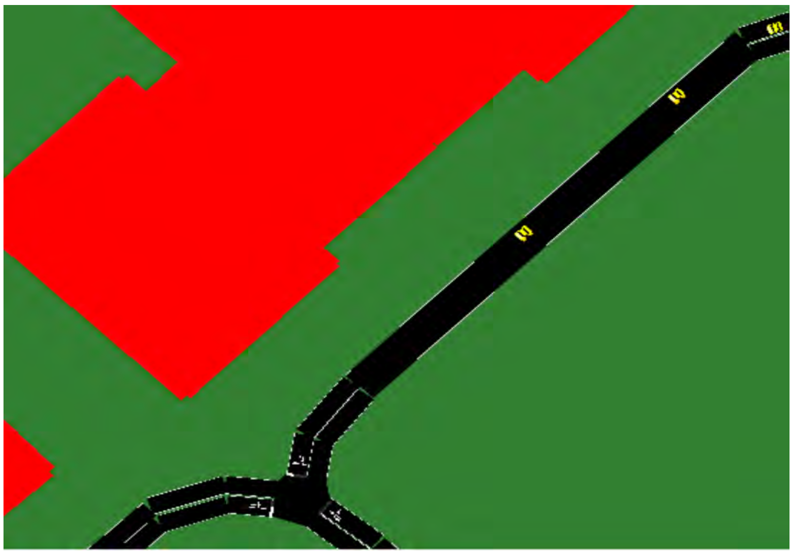

Fig 21: Map of Hazardous Route in Mohammadpur, Dhaka

In this case, the only possible way to ensure vehicle safety is by limiting the speed of the vehicles. A BSM is broadcast to all the vehicles taking this route that the recommended maximum speed is 20 Kilometers per hour. The BSM may also contain deceleration parameters.

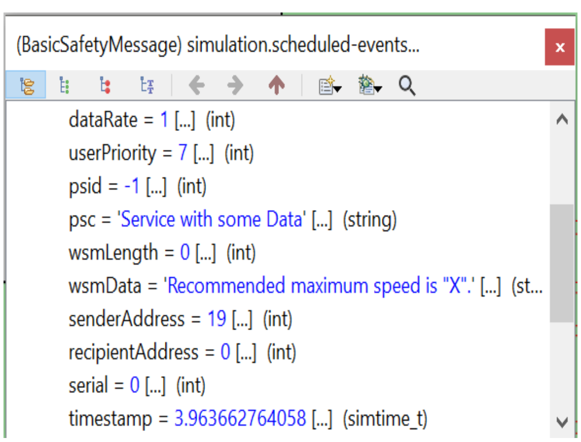

Fig 22: BSM sent to the vehicles approaching the hazardous route

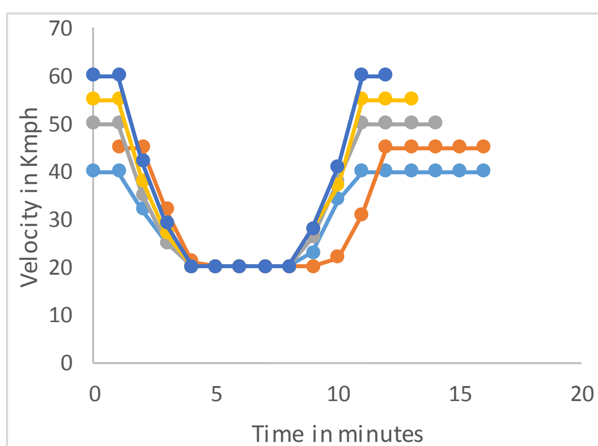

Fig 23: Speed Control Plot

Figure 23 shows that the vehicles approaching the road are slowing down until they reach the maximum permitted velocity which is 20 Kmph and then pace up when the hazardous route is safely crossed.

CHAPTER 6:
FUTURE RESEARCH AREAS

Vehicular rerouting can be perceived as a land of endless opportunities. A lot of work has already been done in this area to ameliorate the sudden upheaval of traffic congestion in recent years. A huge array of rerouting algorithms and techniques can be developed to address specific problems in specific geographical zones pertaining a specific set of variables.

In all of the three scenarios discussed in this thesis, we worked on one specific variable and kept all other possible variables unchanged. For **scenario A,** the key variable we worked on is the guided detection of an alternate path to bypass a roadblock. Here, we kept the physical properties of vehicles, velocity, acceleration/deceleration unchanged. Multiple alternate routes and existence of multiple lanes were not taken into consideration. For **scenario B**, we worked on CO_2 emission reduction where only one out of eight directional parameters was considered. The key variable we worked on here is vehicle density. Physical properties, velocity were kept unchanged. Traffic lights were also ignored while simulating this scenario. For **scenario C,** the variable that we worked on was the velocity limitation parameter. All other physical and mobility parameters were ignored for this simulation. All these variables need to be assessed and analyzed individually to compute their impact on the scenario. These individual computations can then lead to a more comprehensive cost minimizing rerouting algorithm to address the real-life scenario. And each zonal algorithm can be meshed to make a complex algorithm that contains zone-specific traffic rules.

One of the many other components to make the rerouting techniques more efficient is Vehicular Platooning. This technique allows the vehicles going in the same route to form a cluster of five to fifteen vehicles. There is a lead vehicle in a cluster and all other vehicles in the cluster follow the lead vehicle. The vehicles forming the cluster can be selected according to a selection algorithm performed by an RSU. One cluster can be thought of as a single node which significantly reduces node density in a vicinity. This can result in a simpler execution of rerouting algorithms.

Another future research area is the implementation of driver safety assistance systems. The evolution of cardiovascular sensors, blood pressure sensors and as such can be used to monitor the health condition of the drivers. If the sensors provide unusual readings, an emergency interrupt will be called and the vehicle will be remotely controlled to perform emergency auto parking. VANET simulations can provide us with the opportunity to test and analyze a wide range of traffic control hypotheses like these.

REFERENCES

[1] BSS, Dhaka. (09:28 PM, July 19, 2017 / LAST MODIFIED: 09:39 PM, July 19, 2017). Traffic jam in Dhaka eats up 3.2m working hrs everyday: WB. http://www.thedailystar.net/city/dhaka-traffic-jam-congestion-eats-32-million-working-hours-everyday-world-bank-1435630;

[2] Francisco J. Ros, Juan A. Martinez, Pedro M. Ruiz; A survey on modeling and simulation of vehicular networks: Communications, mobility, and tools.

[3] Martínez Torres et al., "The moderating role of prior experience in technological acceptance models for ubiquitous computing services in urban environments", Technological Forecasting and Social Change 91, 2015, pp. 146-160.

[4] Dar et al., "Wireless communication technologies for ITS applications [topics in automotive networking]", Communications Magazine, IEEE 48.5, 2010, pp. 156-162.

[5] Valente and Antonio Saverio, "Cooperative Driving in Inter-Vehicular Communication Network", 2015.

[6] H. Hartenstein and K. P. Laberteaux "A Tutorial Survey on Vehicular Ad Hoc Network" IEEE Communications Magazine, vol. 46, no. 6, pp 164-171, June 2008.

[7] S.T.Rakkesh, A.R.Weerasinghe, R.A.C.Ranasinghe; A Decentralized Vehicle Re-routing Approach using Vehicular Ad-hoc Networks

[8] Ferrari, G., Busanelli, S., Lotti, N., Kaplan, Y., "CrossNetwork Information Dissemination in VANETs," 11th International Conference on ITS Telecommunications, pp. 351-356, 2011.

[9] Flavio Bonomi et al., "The Smart and Connected Vehicle and the Internet of Things". Advanced Architecture and Research, Cisco

[10] H. Phule, Public safety application for approaching emergency vehicle alert and accident reporting in VANETs using WAVE: Rochester Institute of Technology, 2012.

[11] S. Gräfling, P. Mähönen, and J. Riihijärvi, "Performance evaluation of IEEE 1609 WAVE and IEEE 802.11 p for vehicular communications," in Ubiquitous and Future Networks (ICUFN), 2010 Second International Conference on, 2010, pp. 344-348.

[12] D. Satyajeet, A. Deshmukh, and S. Dorle, "Heterogeneous Approaches for Cluster based Routing Protocol in Vehicular Ad Hoc Network (VANET)," International Journal of Computer Applications, vol. 134, 2016.

[13] V. Jindal and P. Bedi, "Vehicular ad-hoc networks: introduction, standards, routing protocols and challenges," International Journal of Computer Science Issues (IJCSI), vol. 13, p. 44, 2016.

[14] J. Gandhi and R. Jhaveri, "Energy Efficient Routing Approaches in Ad hoc Networks: A Survey," in Information Systems Design and Intelligent Applications, ed: Springer, 2015, pp. 751-760.

[15] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, et al., "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," IEEE communications surveys & tutorials, vol. 13, pp. 584-616, 2011.

[16] Z. Zhang, "Fast propagation of messages in VANETs and the impact of vehicles as obstacles on signal propagation," 2015.

[17] A. Hassan, "VANET Simulation Master Thesis in Electrical Engineering, School of Information Science," Computer and Electrical Engineering, Halmstad University, 2009.

[18] Y. J. Li, "An overview of the DSRC/WAVE technology," in International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness, 2010, pp. 544-558.

[19] "IEEE Draft Guide for Wireless Access in Vehicular Environments (WAVE) - Architecture," IEEE P1609.0/D9, July 2017, pp. 1-104, 2017.

[20] "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Networking Services," IEEE Std 1609.3-2016 (Revision of IEEE Std 1609.3-2010), pp. 1-160, 2016.

[21] "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Multi-Channel Operation," IEEE Std 1609.4-2016 (Revision of IEEE Std 1609.4-2010), pp. 1-94, 2016.

[22] J. B. Kenney, "Dedicated short-range communications (DSRC) standards in the United States," Proceedings of the IEEE, vol. 99, pp. 1162-1182, 2011.

[23] "IEEE 1609.1-2006 - Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager", Standards.ieee.org, https://standards.ieee.org/findstds/standard/1609.1-2006.html ,Access Date: 25 March 2018

[24] "IEEE 1609.2-2016 - IEEE Standard for Wireless Access in Vehicular Environments--Security Services for Applications and Management Messages", Standards.ieee.org, https://standards.ieee.org/findstds/standard/1609.2-2016.html ,Access Date: 25 March 2018

[25] Varga, A & Hornig, R. (2008). An overview of the OMNET++ simulation environment. Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops, Simutools '08. 60:1-60:10.

[26] Behrisch, Michael and Bieker, Laura and Erdmann, Jakob and Krajzewicz, Daniel (2011) SUMO – Simulation of Urban MObility: An Overview. In: Proceedings of SIMUL 2011, The Third International Conference on Advances in System Simulation. ThinkMind. SIMUL 2011, 23.-28. Okt. 2011, Barcelona. ISBN 978-1-61208-169-4

[27] Car2ox.org. (09:28 PM, July 19, 2017 / LAST MODIFIED: 09:39 PM, July 19, 2017). VEINS Documentation; http://veins.car2x.org/documentation/

[28] H. Makino, "The Smartway project", July 2010, [online] Available: http://www.nilim.go.jp/japanese/its/3pepar/pdf/05120)we_ss26.pdf.

[29] Y. Toor, P. Mühlethaler, A. Laouiti, A. de la Fortelle, "Vehicle Ad Hoc Networks: Applications and Related Technical Issues", *IEEE Commun. Surveys Tutorials*, vol. 10, pp. 3, 2008.

[30] "Lessons Learned: Deployment of Public Sector Infrastructure for VII/IntelliDrive(sm)", May 2011, [online] Available: http://www.michigan.gov/documents/mdot/MDOT_IntelliDriveLessonsLearned_330618_7.pdf.

[31] "Official web site of the (National ITS Architecture)", May 2011, [online] Available: http://www.iteris.com/itsarch/index.htm.