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Development of Infrastructure-to-Vehicle Module for Vehicular Communication Emulation through the MS-VAN3T Framework

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Abstract

Nowadays, the vehicle industries in toto are in the middle of a revolution. In a quite near future the vehicles will be connected with all the possible players of transportation, thanks to the new technologies such as Vehicle-to-Everything (V2X) connection, and fully automated further in the future.

V2X refers to a set of technologies enabling the wireless data exchange between the vehicle and any other entity in its surrounding, like pedestrians (V2P), networks (V2N), vehicles (V2V) and infrastructure (V2I). This revolution is leading the transportation system towards a safer and more efficient way of travel. In facts, the association between all those partecipants will lead the creation of new vehicular network technologies for the automotive industry, and those are classified into 3 main groups: Road safety applications, Traffic efficiency and management applications, Infotainment applications.

These new technologies, wrapped into the so called *Intelligent Transportation System* (ITS), need to be verified and properly tested: due to their high development cost, the simulation tools play a key role in order to not to waste important resources.

ITS identifies all those systems that use technologies, communications and information processing to improve the current mobility experience enhancing the transportation safety, the mobility and the productivity of the transportation infrastructure. Major components of ITS are vehicle/user applications for localization/identification, information collection and exchange; road infrastructure, through which ITS can provide information, monitor and control road traffic and services provisioning. Finally, communication networks (Vehicular Ad hoc Networks – VANETs) that allow information transfer between vehicles as well as between vehicles and infrastructure.

Crucial for the Automotive Industry is to use Tool for the simulation of their product, and in the particular case of this thesis work studies, to simulate Urban Mobility and Networks. The goal of this thesis work is to create a module for a a open-source vehicular network simulation framework, MS-VAN3T, called IVI service, able to manage the generation, transmission and reception of the Infrastructure to Vehicle Messages (IVIMs). IVIMs are an Infrastructure-to-Vehicle (I2V) messages format conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency. Once the overall system it will have

been described and after a deep presentation of IVI messages, an example of its applications will be given in order to give to the reader a better understating of what this kind of service can do.

Acknowledgements

For this thesis work, firstly I would like to thank my supervisor Prof. Claudio Ettori Casetti, for this opportunity, Carlos Mateo Risma Carletti, Francesco Raviglione and Marco Malinverno, for their support and for their patience for the entire duration of the work. Then, I would like to thank all my family and my friends for their continuous support, especially my mother, this is all dedicated to her.

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Acronyms

ITS Intelligent Transportation System

C-ITS Cooperative Intelligent Transportation System

ITS-S ITS station

VANET Vehicular Ad-Hoc Network

V2X Vehicle-to-Everything

V2V Vehicle-to-Vehicle

V2I Vehicle-to-Infrastructure

I2V Infrastructure-to-Vehicle

V2P Vehicle-to-Pedestrian

V2N Vehicle-to-Networks

CA Cooperative Awareness

CAM Cooperative Awareness Message

DEN Decentralized Environmental Notification

DENM Decentralized Environmental Notification Message

IVI Infrastructure-to-Vehicle

IVIM Infrastructure-to-Vehicle Message

ETSI European Telecommunications Standards Institute

IEEE Institute of Electrical and Electronics Engineers

RSU Road Side Unit

OBU On Board Unit

3GPP 3rd Generation Partnership Project

DSRC Dedicated Short Range Communications

C-V2X Cellular Vehicle-to-Everything

WAVE Wireless Access in Vehicular Environments

TLC Traffic Light Control

GNSS Global Navigation Satellite System

GPS Global Positioning System

GPC GNSS Position Control

DOT Department of Transportation

BSM Basic Safety Message

SAE Society of Automotive Engineers

WSMP WAVE Short Message Protocol

WSM WAVE Short Message

LLC Logical Link Control

MAC Media Access Control

UDP User Datagram Protocol

TCPTransmission Control Protocol

IPv6 Internet Protocol version 6

SCH Service Channel

CCH Control Channel

WSA WAVE Service Advertisement

BSS Basic Service Set

OCB Outside the Context of BSS

CSMA/CA Carrier Sense Multiple Access with Collision Avoidance

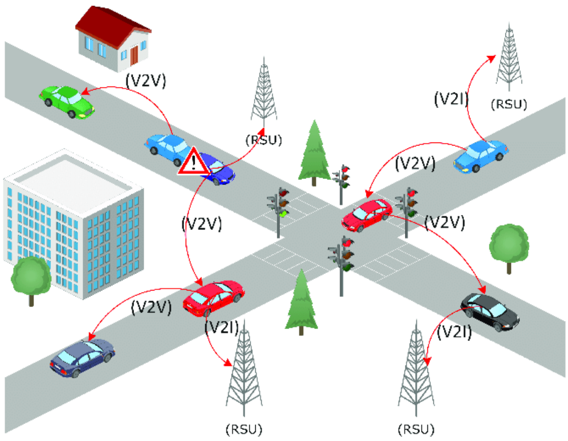
ProSe Proximity Services

D2D Device-to-Device

PDU Protocol Data Unit

Summary

In the smart-era in which we are, where social media and connected smart devices are of paramount importance, even the Automotive World is at the centre of a revolution. In last years, a huge progress in the network access technologies has taken place, which led giants of standardization like IEEE and ETSI to develop new applications in the so called Intelligent Transportation Systems (ITS). In particular, since when 3GPP officially standardized the C-V2X with its Release 14, the attention to these technologies skyrocked.

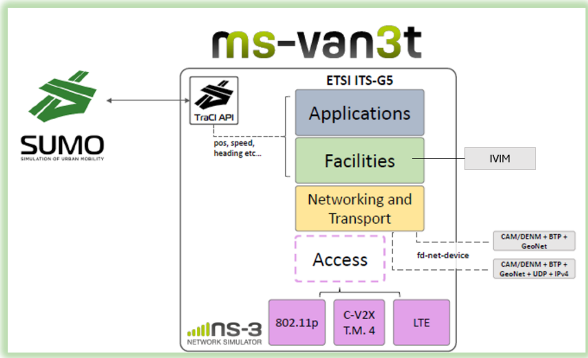


These new technologies need to be properly tested, verified and validated: due to their high development cost, the simulation tools play a key role in order to not waste important resources. In this thesis work, an overview of the vehicle networking technologies will be presented and the solution of the open source simulation framework MS-VAN3T will be given. MS-VAN3T allows the simulation of VANETs through the usage of the Simulation of Urban MObility (SUMO) traffic simulator. Its peculiarity is the possibility of creating scenarios using multiple communication stacks (MS) under a single repository.

The aim of this work is to leverage the MS-VAN3T simulating capability, developing a new module called 'IVI service'. The IVI service is the entity managing the generation, transmission and reception of infrastructured-related messages (IVIM) exchanged between Road Side Unit and vehicles, as defined by the ETSI TS 103 301 standard. IVIMs are messages conveying informations like road static or dynamic signage and road works warning.

V2X is an acronym that stands for Vehicle-to-Everything and it refers to a set of technologies permitting the exchange of data between the different road players. In particular, vehicles will be connected with all the surrounding entities, such as pedestrian (V2P), infrastructure (V2I) and other vehicles (V2V).

The communication between the users occurs using Vehicular Ad-Hoc Networks, known as VANETs.

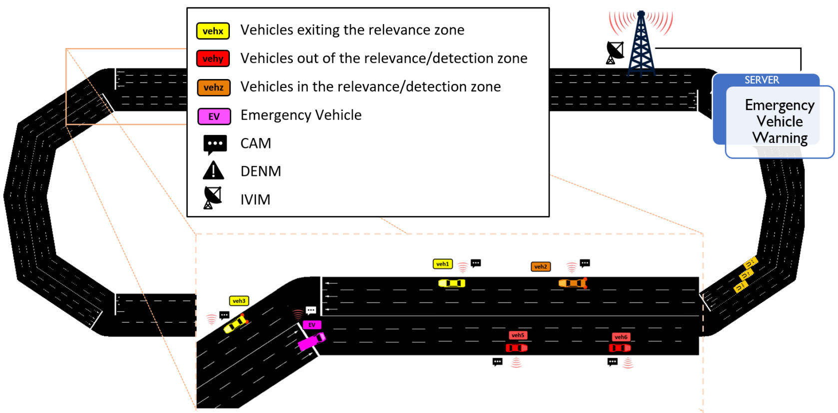


In the first chapter of this work, an overview about the Intelligent Transportation Systems will be provided. Then, in chapters 2 and 3, will be run a deeper analysis on the set of standards that regulate all the aspects of vehicular communications, focused on the ITS-G5 Facilities layer.

Once the state of the art is fully illustrated, in the fourth chapter the MS-VAN3T framework is descripted in detail and finally the IVI service is presented with all its features.

In the final chapter, in order to show the working procedure of the service and its efficiency, a testing application based on I2V communication called *Emergency Vehicle Warning* is developed. The scenario implies the presence of Emergency Vehicles due to an accident and vehicles running through an highway. This vehicles are warned by the IVI service of the situation, so they will start an anti-hindrance procedure suggested by the service.

In conclusion, an analysis of the application performance results will be taken, that will show how important might be the implementation of this infrastructure-based service.



Chapter 1

Introduction

Nowadays, the vehicle industries as a whole is in the middle of a revolution. In a quite near future the vehicles will be connected with all the possible players of transportation, thanks to the new technologies such as Vehicle-to-Everything (V2X) connection, and fully automated further in the future.

V2X refers to a set of technologies enabling the wireless data exchange between the vehicle and any other entity in its surrounding, like pedestrians (V2P), networks (V2N), vehicles (V2V) and infrastructure (V2I). This revolution is leading the transportation system towards a safer and more efficient way of travelling. V2V communication will permit vehicles to exchange safety messages, for example to avoid a forward collision or for a blind spot warning [1]. Moreover, a vehicle may learn from an infrastructure information like the geometry of an approaching intersection, the state of the signals at an intersection, and the existence of a hazard. In case a vehicle determines that exists a possibility of collision, the on-board system can take action to warn the driver, or even to assist in controlling the vehicle.

The association between all those participants will lead the creation of new vehicular network technologies for the automotive industry, and those are classified into 3 main groups:

- Road safety applications,
- Traffic efficiency and management applications,

- Infotainment applications [2].

These new technologies, wrapped into the so called *Intelligent Transportation System* (ITS), need to be verified and properly tested: due to their high development cost, the simulation tools play a key role in order to not waste important resources. In this thesis work, an overview of the vehicle networking technologies will be presented and the one solution of simulation framework will be given.

1.1 ITS

ITS identifies all those systems that use technologies, communications and information processing to improve the current mobility experience enhancing the transportation safety, the mobility and the productivity of the transportation infrastructure. ITS are vital to increase safety and tackle growing emission and congestion problems. They can make transport safer, more efficient and more sustainable by applying various information and communication technologies to all modes of passenger and freight transport. Moreover, the integration of existing technologies can create new services [3].

Major components of ITS are (1) vehicle and user applications aimed to localization/identification, for the collection of informations and its exchange; (2) road infrastructure, through which ITS can provide information, monitor and control road traffic, and (3) communication networks (Vehicular Ad hoc Networks – VANETs in section 1.2) that allow information transfer between vehicles as well as between vehicles and infrastructure (V2X-V2I-V2V).

The most important standardization organization are the Institute of Electrical and Electronics Engineers (IEEE), with its WAVE stack (Wireless Access in Vehicular Environment) and the European Telecommunications Standards Institute (ETSI), who developed the ITS-G5 stack.

In figure 1.1 it is shown a classification of the Use Cases for V2X communication. They span from non-safety to safety application, and each different situation has a different requirement in terms of Bandwidth, Latency and Availability. The Adaptive Cruise Control (ACC) is an example of Safety-feature that requires High Latency and High Reliability. The ACC is an Advanced Driver Assistance System (ADAS) that improves the Cruise Control (CC) features and aims at maintaining a set distance from the vehicle ahead, while the CC goals only at keeping constant the vehicle speed.

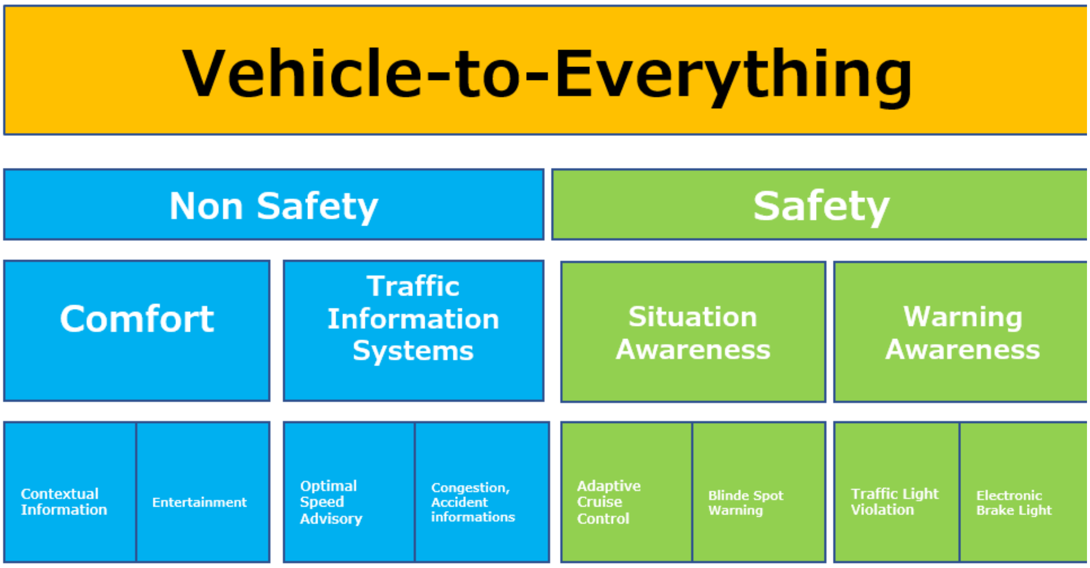
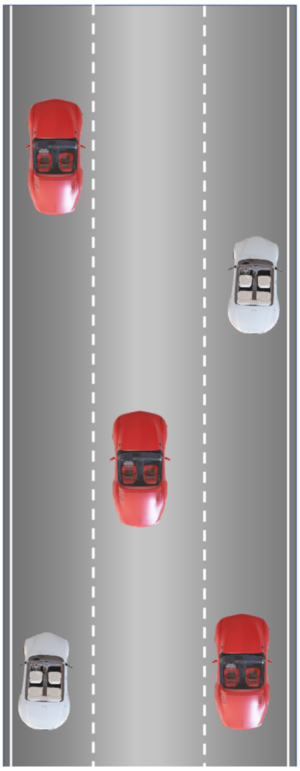


Figure 1.1: A Taxonomy of Use Cases.

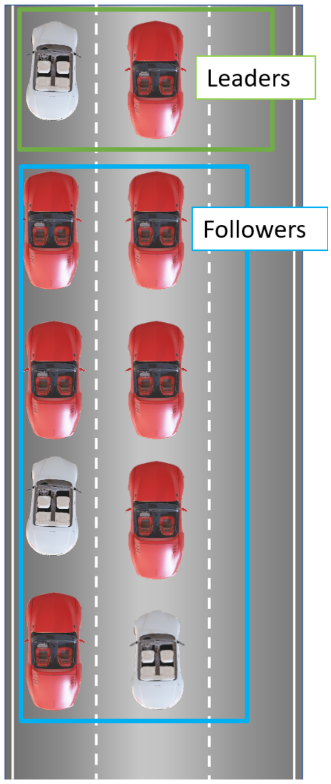
The overall ADAS technologies have the objective of improving the transport experience, with better reliability and efficiency. Another use case that is being developed and tested is *platooning*. A platoon is a group of vehicles proceeding in a closely linked manner, like a train with virtual strings attached between vehicles. Maintaining distance between vehicles needs the sharing of speed, heading and intentions. Platooning would be helpful due to the fact that distances between vehicles and fuel consumption would be reduced, road safety and road utilization increased.

Experimental results on Heavy Duty Vehicles (HDVs) Platooning show that by using preview information of the road ahead from the lead vehicle, the adaptive cruise controller can reduce the fuel consumption [4].

The communication between vehicles are important not only for the realization of systems like platoon, but even for the realization of Collision Avoidance applications.



(a) Without platoon



(b) Platoon

Figure 1.2: Highway with and without platooning.

Vehicles exchange messages with each other and, depending on the extracted information, each vehicle makes an autonomous decision. These messages contain a set of useful information about the sending vehicle such as position, speed, acceleration and heading, and are organized and encoded in the so-called Cooperative Awareness Messages (CAMs) standardized ETSI [5].

Another important example of ITS service is the the Traffic Light Control (TLC) service (figure 1.3). TLC service is in charge of managing the generation an the trandsmission of SREM (Signal Request Extended Message) messages and SSEM (Signal request Status Extended Message) messages. The TLC service supports prioritization of public transport and public safety vehicles, like ambulance, to traverse an intersection as fast as possible or using a higher priority than ordinary traffic participants as described in [6].

[6] also states the techicnal requirements for GNSS Positioning Correction (GPC) service, that uses positioning correction message for GNSS as defined by the RTCM (Radio

Technical Commission For Maritime Services), and the Infrastructure to Vehicle Information (IVI) service. In this thesis work a special attention to the IVI messages will be given. In order to introduce this concept, it can be stated that the In-Vehicle Information message (IVIM) is an I2V Message format conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency [7].

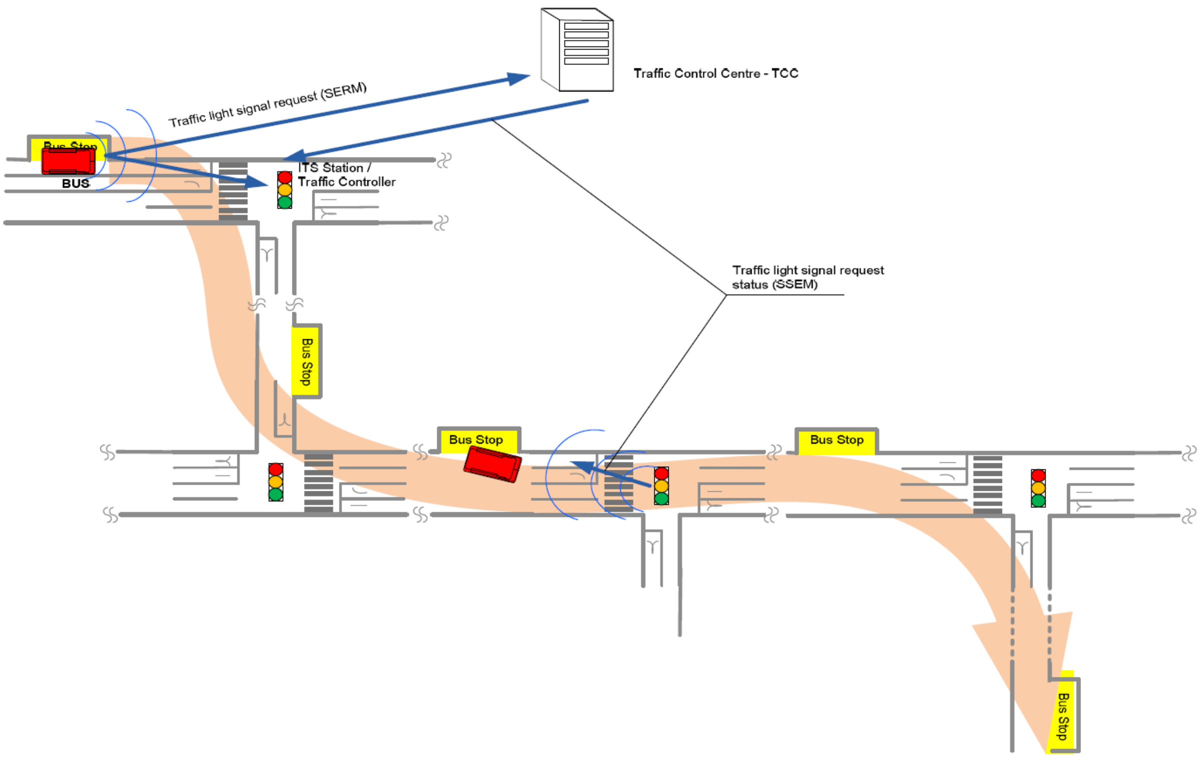


Figure 1.3: Example of TLC application.

1.2 VANETs

As introduced in the previous section, VANETs allow information transfer between vehicles as well as between vehicles and infrastructure (figure 1.4). VANET's were originally created as a variant of Mobile Ad-hoc NETworks (MANETs). Their main characteristics are the ability to deal with fast changes in the topology (due to the elevated speed of vehicles) and to provide ultra low latency.

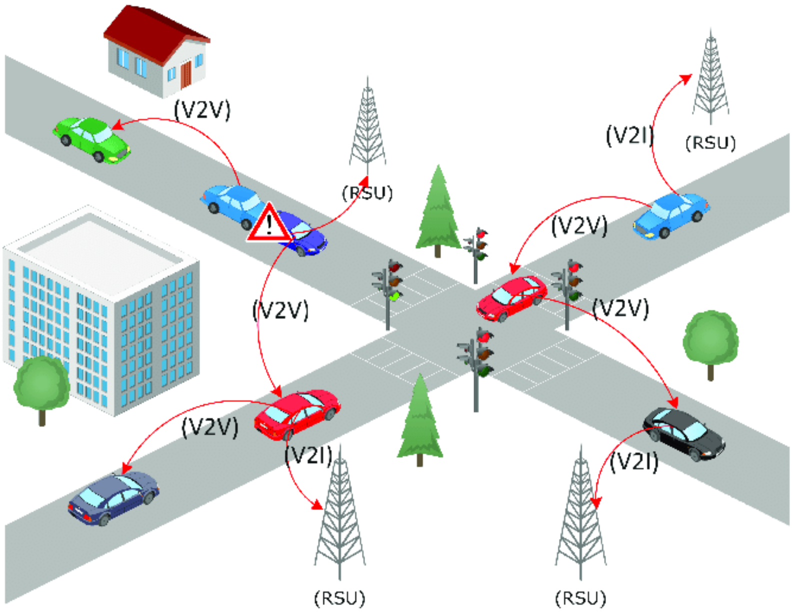


Figure 1.4: VANET-communication architecture [8].

VANET is a particular case of a wireless multihop network, which has the constraint of fast topology changes due to high node mobility. A wireless multi-hop network can be viewed as a set of nodes able to communicate with each other directly or beyond their transmission range by using nodes as relay points acting as routers. With the increasing number of vehicles equipped with computing technologies and wireless communication devices, intervehicle communication is becoming a promising field of research, standardization, and development. VANETs enable a wide range of applications, such as prevention of collisions, safety, blind crossing, dynamic route scheduling, real-time traffic condition monitoring, etc. Another important application for VANETs is providing Internet connectivity to vehicular nodes [9].

Vehicles must be equipped with On Board Units (OBU) to communicate with Road Side Units (RSU). Also GPS/DGPS receiver are required on board in order to get detailed positioning informations. In general, it is common to talk about the V2X communication, previously defined. Two main families of access technologies are at the base to make V2X possible: Dedicated Short Range Communication (DSRC), mainly developed by ETSI and IEEE, and Cellular Base Standard referred as C-V2X, developed by 3GPP only.

For the development of these communication technologies to thrive, from the beginning of this century the spectrum management organizations have made efforts to provide the vehicular communications with an exclusive band for ITS-based scopes [10]. In 1999, 75 MHz of spectrum in the 5.9 GHz frequency band has been allocated for DSRC applications by the the US Federal Communication Commission (FCC) [11]. Out of the 75 MHz spectrum, 5 MHz is reserved as the guard band and seven 10-MHz channels are defined as in shown in Figure 1.5. The available spectrum is configured into one control channel (CCH) and six service channels (SCHs). The CCH is reserved for carrying high-priority short messages or management data, while other data are transmitted on the SCHs. The pair of channels (channel 174 and 176, and channel 180 and 182) can be combined to form a single 20-MHz channel, channel 175 and 181 respectively. The channel number (CN) is derived by counting the number of 5-MHz spectrum in the frequency band from 5000 MHz to the center frequency f (CN) of the channel CN, i.e.,

$$f(CN) = 5000 + 5CN(MHz).$$

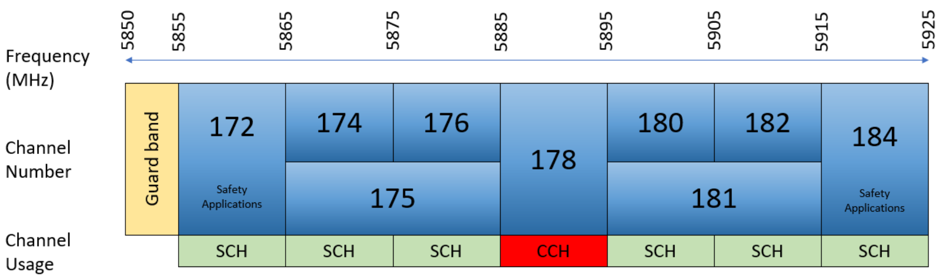


Figure 1.5: The DSRC Frequency Allocation in US.

For twenty years, the 5.9 GHz band (5.850-5.925 GHz) has been dedicated to intelligent transportation systems and vehicle safety, and in particular to DSRC. On November 18, 2020, the FCC unanimously approved a First Report and Order reallocating a majority of the 5.9 GHz band away from connected vehicle technologies. The Commission repurposed the lower 45 megahertz at 5.850-5.895 GHz for unlicensed commercial uses such as Wi-Fi.

The upper 30 megahertz of spectrum in the 5.895-5.925 GHz band is still designated for intelligent transportation systems, but the Commission has endorsed a new standard for automotive uses, C-V2X [12].

On the 5th of August 2008, the Commission Decision 2008/671/EC [13] legally forced European Union to use 5875–5905 MHz band for traffic safety-related applications. The European Conference of Postal and Telecommunications Administrations (CEPT) harmonization was applied by the European Communications Committee (ECC) Decision and indicates using 5905–5925 MHz for an extension of the ITS spectrum. The current spectrum allocation was designed following the technical recommendations TR 102 492-1 [14] and TR 102 492-2 [15], where 5855–5875 MHz is assigned for non-safety related applications, 5875–5885 MHz for roadsafety and traffic-efficiency applications, 5885–5905 MHz for critical road-safety applications, and 5905–5925 MHz for road-safety and traffic-efficiency applications [16].

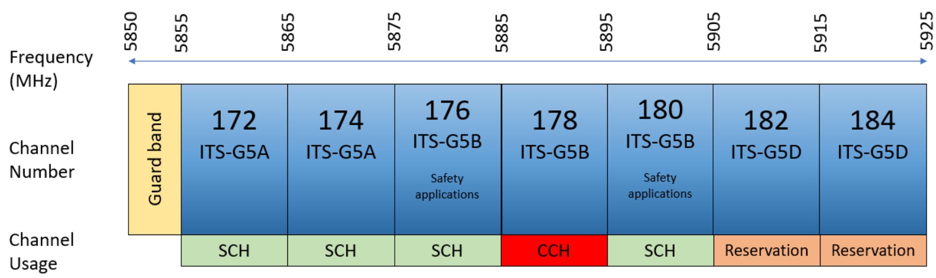


Figure 1.6: EU spectrum allocation for the 5.9 GHz band.

In the European scenario, the current spectrum allocation follows the already mentioned recommendation [14] and [15], in Figure 1.6. ITS-G5 introduced with the [17] a detailed SCH assignment through the definition of 4 types of channel:

- ITS-G5A: Channels 172 and 174, for non-safety related applications.
- ITS-G5B: Channels 176, 178 and 180, for safety related applications.
- ITS-G5C: Channels in the 5.6 GHz band, for infrastructure-based broadband radio access networks.

- description ITS-G5D: Channels 182 and 184 for future ITS applications. [8]

1.2.1 MS-VAN3T Overview

Crucial for the automotive industry is the use tools for the simulation of their products, and in the particular case of this thesis work studies, to simulate different urban mobility and networks scenarios. In order to improve the capability of new features implementation, a huge amount of time is indeed spent in the process of developing and testing a V2X application.

Amid the different possibilities, in this thesis, an open-source vehicular network simulation framework named MS-VAN3T is presented (Figure 1.7).

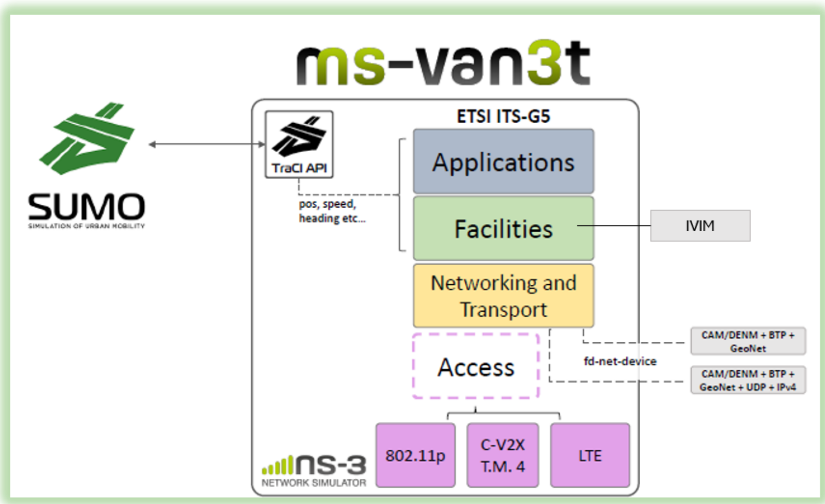


Figure 1.7: MS-VAN3T description [8].

MS-VAN3T stands for Multi-Stack framework for VANET application testing in ns-3. The access models supported by MS-VAN3T are:

- 802.11p for V2I and V2V;
- LTE for V2N;
- C-V2X in transmission mode 4 for V2V communication.

ns-3 is a descrete-event network simulator that takes care of all the communications between the nodes involved in the simulation. Furhtermore, the framework uses SUMO (Simulation of Urban MObility): an Open Source traffic simulator that allows the modelling of intermodal traffic systems, including road vehicles, public transport and pedestrians. More detailes about the framework will be given in chapter 4.2.

The goal of this thesis work is to create a module for the MS-VAN3T framework, called IVI service, able to manage the generation, transmission and reception of the IVI messages, and to provide data to ensure the correct functioning of the module through an application. The In-Vehicle Information Message (IVIM) is an I2V message format conveying information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency [7]. For the first phase of C-ITS deployment in Europe, C-Roads and the C2C-CC have agreed on adopting IVI profiling examples based on the IVI message format standardized in [18].

1.3 C-roads

The C-Roads Platform is a joint initiative of European States for testing and implementing cooperative intelligent transportation systems (C-ITS) in a harmonized and interoperable way. C-ITS services allow effective data exchange through wireless communication technologies between components and actors of the transport system to improve road safety and efficiency of transport. C-ITS pilot sites will be installed across the EU for testing and later operation of applications as recommended by the "C-ITS Platform" set up by the European Commission.

The main goal of the project is to implement and test, in real traffic conditions, cooperative systems based on V2X technologies, for trucks platooning, passenger cars Highway Chauffeur and combined scenarios of trucks and passenger cars. That implies the infrastructure upgrade and the integration of V2I C-ITS service and V2V information with vehicle control strategies [19].

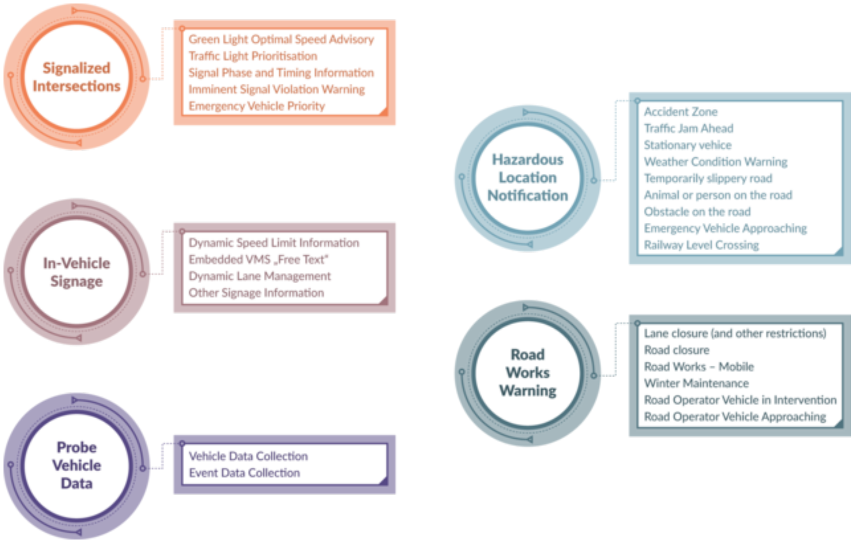


Figure 1.8: C-Roads programme [19].

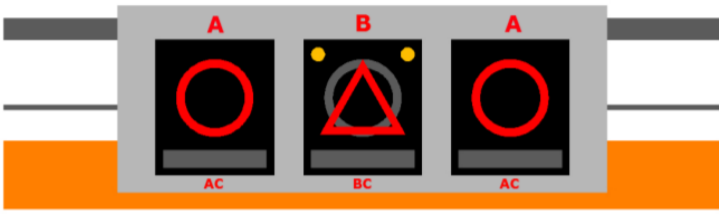


Figure 1.9: Example of VMS adopted in Austria for a two-lane highway [7].

Among the Use Cases that C-Road platform could bring to the C-ITS, there are the:

- In-Vehicle Signage, implementing

  Dynamic Speed Limit Information,

  Dynamic Lane Management,

  others;

- Road Works Warning,

  Lane closure (and restrictions),

  Road works,

  Road closure,

  Others.

C-Roads uses the In-Vehicle messages to transmit both static and dynamic road sign and message sign on highways, where static road signs referes to actual sign plates placed on the side of the road, whereas dynamic road signs are signs that indicate variable information. An example of dynamic road sign is the Variable Message Sign (VMS) mounted on a highway gantry, like the one in the Figure 1.9.

Chapter 2

VANET regulating standards

In the first chapter it has been introduced the composing technologies of Intelligent Transportation Systems. A particular attention to VANETs and their working spectrum has been given. In this second chapter, a more detailed focus will be given to the standards that regulate the communication.

Vehicles utilize a variety of wireless technologies to communicate with other devices and as already mentioned, there exist two main standard developers:

- ETSI and IEEE, with their Dedicated Short Range Communication (DSRC),
- 3GPP, with its Cellular Base Standard referred as C-V2X.

In section 1.2 have been described the differences between US and Europe regarding the spectrum division. In the following section, the characteristcs and diversity between the two standards will be presented.

2.1 DSRC standards

DSRC standards are designed to support a variety of applications based on vehicular communication. It is mainly developed to enable collision prevention applications that depend on frequent data exchanges among vehicles, and between vehicles and RSU. The U.S. Department of Transportation (DOT) has estimated that V2V communication based

Figure 2.1: DSRC vs C-V2X.

on DSRC can address up to 82% of all crashes in the United States involving unimpaired drivers, potentially saving thousands of lives and billions of dollar [1].

The term "Dedicated" refers to the U.S. Federal Communications Commission decision to allocate 75 MHz of spectrum in the 5.9 GHz frequency band for DSRC [20] [21]. Whereas, the term "Short Range" express the characteristic of this technology to be active inside a radius of hunderd of meters, differently from cellular based technologies, that take place over longer distances.

	IEEE (USA)	ETSI (UE)	SAE
UPPER LAYER	IEEE 1609.X-2016	ITS-G5	J2735
MAC LAYER	IEEE 802.11p → IEEE 802.11-2016		WAVE
PHYSICAL LAYER	IEEE 802.11p → IEEE 802.11-2016		

Figure 2.2: DSRC layers division.

As it can be noticed from Figure 2.2, DSRC is mainly composed by the Wireless Access in Vehicular Environments (WAVE) developed by IEEE and ITS-G5, issued by ETSI.

A further standard is responsible for DSRC, at the top of the stack: the SAE J2735 [22] Message Set Dictionary standard specifies a set of message formats that support a variety of vehicle-based applications. The most important of these is the Basic Safety Message (BSM), which conveys critical vehicle state information in support of V2V safety applications. They include information on vehicle position, speed, heading, brake status, and size [23]. BSMs are periodically broadcast by other similarly-equipped vehicles to track nearby vehicles and assess the risks of collision. SAE J2735 defines message syntax, but leaves other norms for V2V safety to be specified in the emerging SAE J2945.1 [24] communication minimum performance requirements standard. Among the topics to be addressed in SAE J2945.1 are BSM transmission rate and power, accuracy of BSM data elements, and channel congestion control.

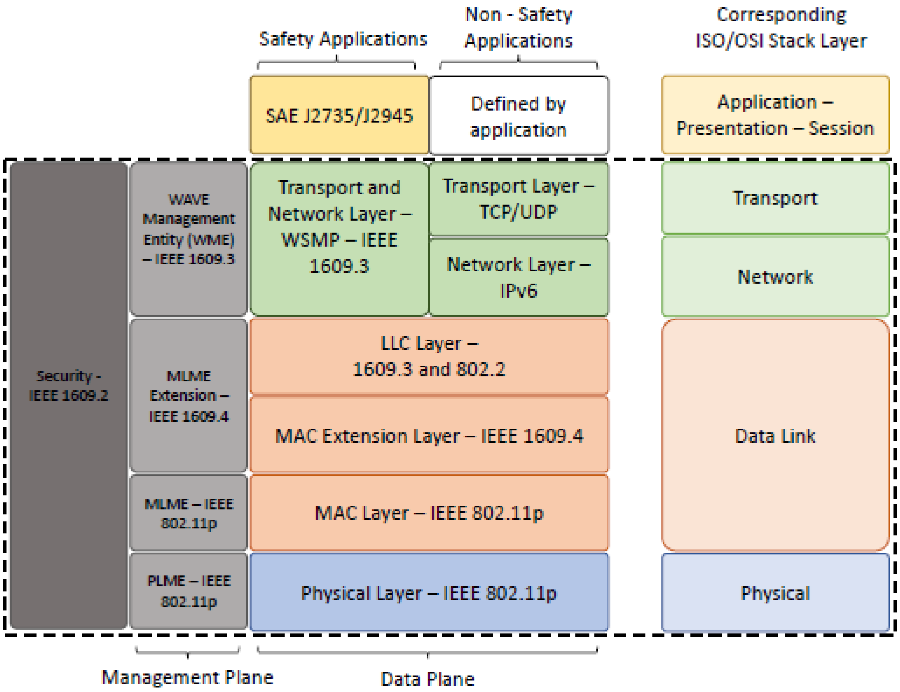


Figure 2.3: WAVE stack. [8]

2.1.1 WAVE

The WAVE stack different layers are based on different standards, how it is shown by Figure2.3. The IEEE's WAVE utilizes the 1609 family of standards [25] [26] [27] [28], 1609.4 for Channel Switching, 1609.3 for Network Services, including the WAVE Short Message Protocol WSMP, and 1609.2 for Security Services. Moreover, it uses IEEE 802.2 at the Logical Link Control layer (LLC), whereas at the MAC and Physical layer the IEEE 802.11p, based on the 802.11 (WiFi) standard.

For the other ISO/OSI stack layer, i.e OSI Application, Presentation and Session layers, WAVE does not expect any particular instruction, but the SAE standards provides a message layer for safety-related application, as described in the previous section.

Transport and Network Layers

Network and Transport layers are described partially by 1609.3 [27], that defines two different data-plane stacks that work concurrently and share the same Data Link and Physical layer: WSMP, carrying the WAVE Short Message (WSM) for safety-related application, and Internet Protocol version six (IPv6) stack, using either User Datagram Protocol (UDP) or Transmission Control Protocol (TCP) as transport medium. The reason for having two protocol stacks is to accommodate high-priority, time-sensitive communications, as well as more traditional and less demanding exchanges [29]. UDP provides port number addressing and a checksum not offered by WSMP. TCP provides port number addressing and end-to-end reliability through acknowledgements and selective retransmissions [30].

The usage of WSMP is aimed to enabling the application to send short messages and directly control the parameters of the radio source. In this way, it could be maximized the probability that all the implicated parties will receive the messages in time. Nevertheless, WSMP is not enough to support typical Internet applications, and these are required to attract private investment that would help spread, and ultimately reduce, the cost of implementing the systems; hence the inclusion of IPv6. Moreover, WSM may be sent on any channel, whereas IP traffic is only allowed on service channels (SCHs), so as to offload high-volume IP traffic from the control channel (CCH) [30].

Considering the Management-plane, specified in IEEE 1609.3 [27], the services are globally referred as the WAVE Management Entity (WME), and some of them are:

- Application registration
- Channel usage monitoring

- IPv6 configuration
- Received channel power indicator (RCPI) monitoring
- Management Information Base (MIB) maintenance [29].

Each application that want to use the WAVE application services needs a unique Provider Service Identifier (PSID). PSID is genereted when the application registers to the WME, and it is composed by the ProviderServiceInfo table, the UserServiceInfo table, and the ApplicationStatus table.

Another important feature of WME is the transmission and reception management of WAVE Service Advertisement (WSA) messages through WSMP. WSA are intended to carry information about one or more vehicular services offered in an area [8]. The Provider WME generates a WSA, which will be transmitted to potential application-service Users. The provider WME collects the application information describing the application-services being offered, previously registered in its MIB, and channel characteristics, also from the MIB, and inserts them into the WSA as Service Info [30].

Data-Link Layers

Moving to the lower zone of the stack, Data-link layers can now be analyzed. As already stated, the protocol stack distinguishes between the two upper stacks IPv6 and WSMP, and thery are distinguished by the Ethertype field. Ethertype is a 2-octet field in the LLC header, used to identify the networking protocol to be employed above the LLC protocol [30]. The Ethertype field is specified in IEEE 802.3 and its use in WAVE devices is specified in IEEE Std 1609.3 [27]. In particular, IEEE 1609.3 specifies the use of two Ethertype values one each networking protocol, indicating IPv6 and WSMP are 0x86DD and 0x88DC, respectively, as hexadecimal values. A WAVE device may support additional Ethertypes, but the WAVE standards do not describe the use of these Ethertypes and their associated protocols.

MAC and Physical Layers

Finally, moving further down along the stack, the lowest layer are the MAC layer and the Physical Layer. For these, the standard that is used is the 802.11p [31] [32].

The choice of this standard is validate from the fact that 802.11 is a stable standard, a characteristic required in order to guarantee vehicles made by different car manufacturers and differently located RSUs the ability to work together. Moreover, it is supported by a huge number of experts in the wireless communication technologies.

IEEE 802.11p is derived from the IEEE 802.11a version and it uses the Orthogonal Frequency Division Multiplexing (OFDM) like its primitive. In OFDM the signal is organized in time domain in OFDM "symbols", each carrying a signal spread over N sub-carriers 2.4.

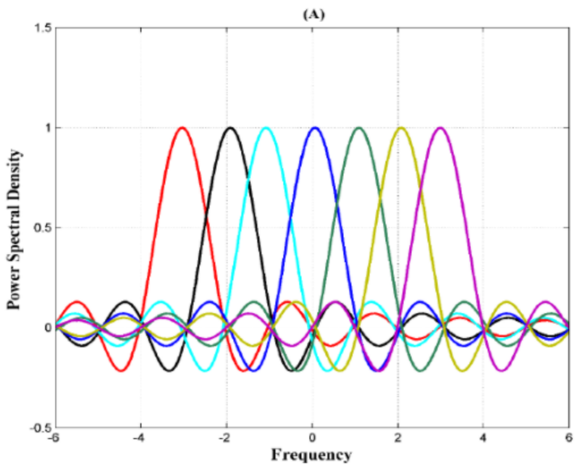


Figure 2.4: Orthogonal Frequency Division Multiplexing (OFDM). [33]

Each of this subcarrier is digitally modulated and the resulting number of bits-per-symbol (bps) is equal to $N \log_2 M$, where N is the number of subcarriers and M is the number of bits-per-waveform. Considering $N = 10$ and the 16 Quadrature Amplitude Modulation (16QAM), so $M = 16$, the result is $10 \log_2 16 = 60$ bps.

Differently from IEEE 802.11a that uses 20 MHz-wide channels, 802.11p uses seven 10 MHz-wide channels in the 5.850/5.925 GHz band 1.5. With this expedient, the standard results more robust against Doppler and Fading effects, because small channels means small overlap.

Consequently to the reduction of the channel width, all time paramaters are almost doubled with respect to 802.11a. The Data rate spans from 3 Mb/s, for Binary Phase-shift keying (BPSK), to 27 Mb/s, for the 64QAM. Other possibile modulation are Quaternary Phase Shift Keying (QPSK) and 16QAM.

In 2017, a new proposal has been carried: the IEEE NGV-IEEE 802.11bd [34]. Its design policy is the following one:

- Starting from the 802.11ac Physical layer, to increase the basic rate;
- Adapt it to the Outside the Context of a BSS (OCB) and High Mobility;
- Maintain backward compatibility with 82.11p.

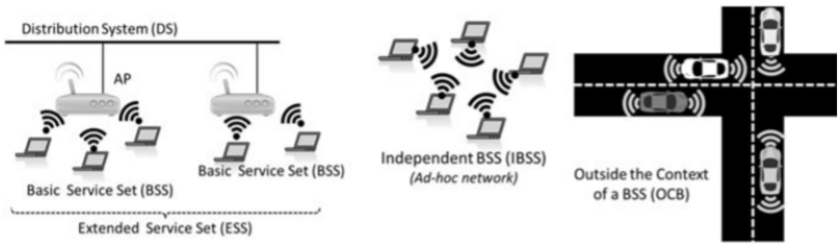


Figure 2.5: Outside the Context of BSS (OCB). [35]

As far as regards the MAC layer, we can refer to Lower MAC layer, in charge of channel access, and to upper MAC layer, for channel coordination.

The channel access is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This "listening while talking" method consists in the transmitting node verifing that channel is "idle", i.e. it is not traffic on the channel, before starting the transmission. If another node is transmitting, the first node runs a preocedure, called backoff procedure, in order to avoid collision.

Moreover, the lower MAC layer includes some features of the 802.11e standard:

- No BSS established: OCB, in Figure 2.5. In this way, a data frame can be sent to either an individual or a group destination MAC address [35];

- Contention-based;
- Enhanced Distributed Channel Access (EDCA) protocol, so it presents different priority levels :

  AC_BK: Background (lowest);

  AC_BE: Best Effort;

  AC_VI: Video;

  AC_VO: Voice (higher).

The channel regulation is regulated by IEEE 1609.4. As previously stated, there exist two channel type: Control Channel (CCH) and Service Channel (SCH). The first one is used for service advertisement, whereas the latter is used for every type of services and messages. The default CCH is the 178, like in Figure 1.5 and 1.6. The standards provides three possibile switching modes: continuous, alternating and immediate channel access, described in Figure 2.6.

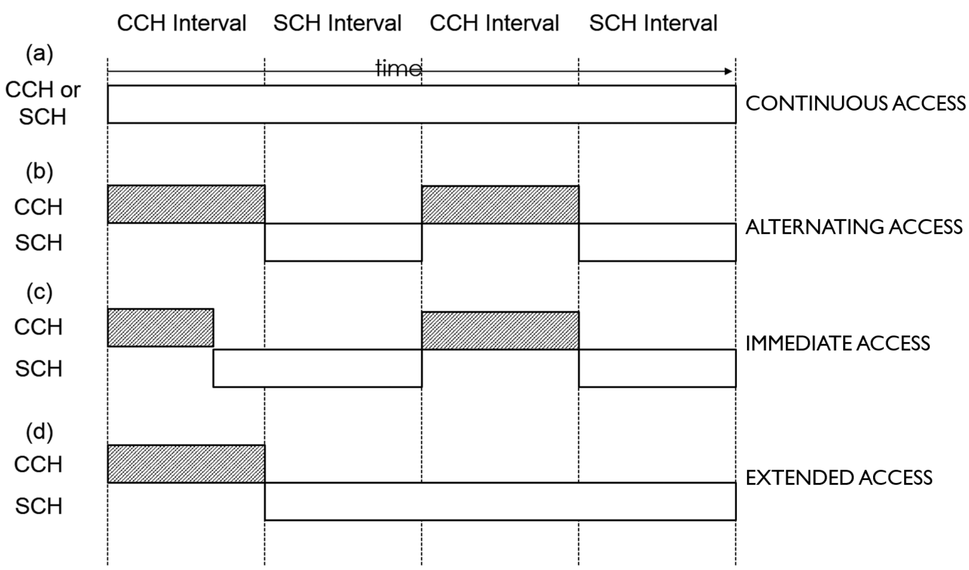


Figure 2.6: Switching modes for SCH and CCH. [35]

2.1.2 ITS-G5

In the Europe, ETSI developed the DSRC standard profile for European market, called ITS-G5, defined in [17].

As highlighted by [36], one of the main objective of ETSI ITS-G5 is to integrate new access technologies such as LTE-V2X.

The protocol stack of this set of standard is shown in Figure 2.7 below.

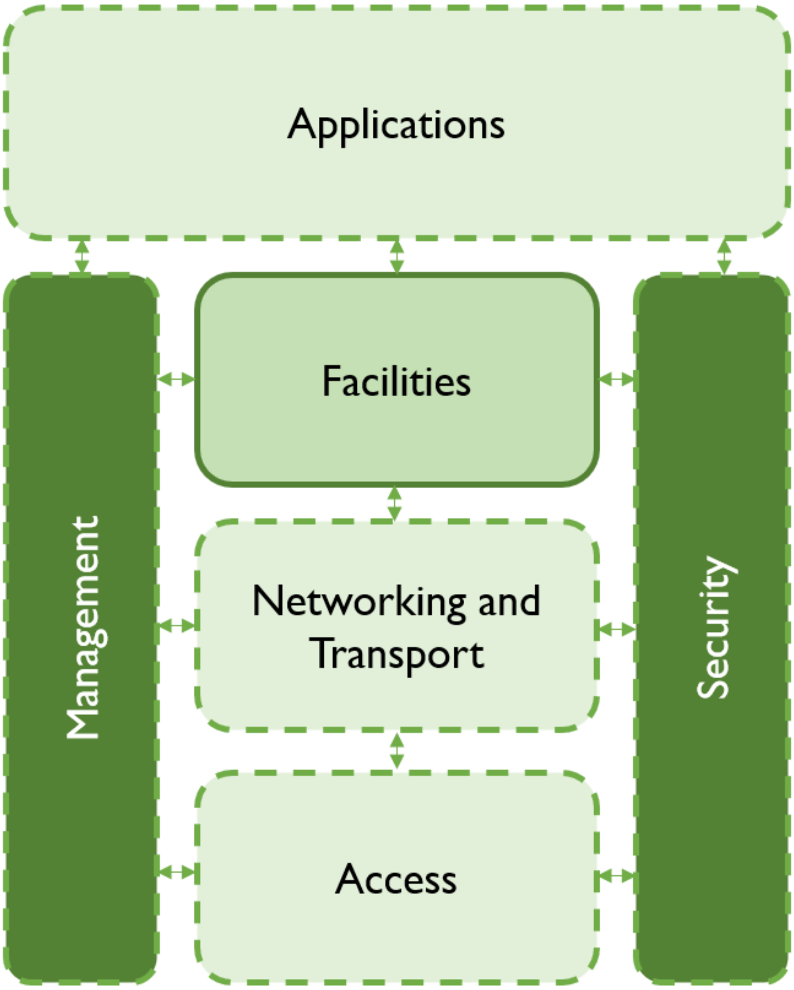


Figure 2.7: ITS-G5 protocol stack.

As it can be noticed, architecture of the stack [37] is organized in four horizontal layers plus two vertical layers:

- ITS Application Layer, defined in [38] [39] [40];

- ITS Facilities Layer, a peculiarity of this set of standards, defined in [41] [42] [43] [6]. Here are defined some important V2X messages, namely Cooperative Awareness (CA), Decentralized Environmental Notification (DEN) and Infrastructure to Vehicle (IVI) messages. A further analysis of this services will be given in chapters 3 and 4.

- ITS Networking and Transport Layer, defined in [44] [45] [46] [47] [48].

- ITS Access Layer, defined in [17], that it contains the guidelines for MAC and Physical layers, and in [49] [50], where the Decentralized Congestion Control (DCC) is defined. As access techonologies, ITS-G5 uses the already mentioned IEEE 802.11p like WAVE, but extended with the support of LTE-V2X [17].

- ITS Management Entity defined in [46].

- ITS Security Entity, defined in [46].

ETSI ITS-G5 introduces a detailed service channel assignment, defined as follows:

- ITS-G5A from 5875 to 5905 MHz (channels 176-178-180),for safety applications, like collision avoidance ;

- ITS-G5B, from 5855 to 5875 MHz (channels 172-174), for non-safety applictions like entertainment and localization;

- ITS-G5C, infrastructure-based broadband radio access networks, around 5.6 GHz;

- ITS-G5D, from 5905 to 5925 MHZ (channels 182-184).

Decentralized Congestion Control

One core feature of ETSI ITS-G5 is the Decentralized Congestion Control (DCC) [49] [50]. The idea is to reduce the traffic congestion, so each node, i.e. each vehicle, is classified in three states: Relaxed, Active or Restricted. Corresponding to each state, some EDCA parameters are associated, like Transmit Power and Carrier Sense Threshold. Vehicles in areas with higher node densities, use a reduced power level, hence communicate over shorter ranges. In Figure 2.8 an example of state changes.

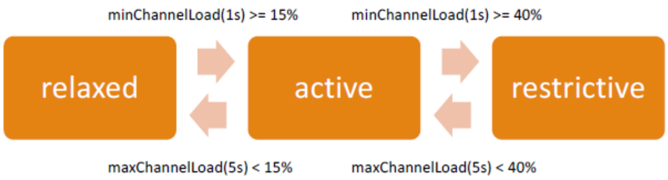


Figure 2.8: Example of state changes.

2.2 C-V2X protocols

Cellular Vehicle-to-Everythyng (C-V2X) standard is developed by 3GPP and it is based on cellular networks communication, like Long Term Evolution (LTE) and 5G.

Cellular networks can be defined as a wireless network using as geographical area an area covered by tessellation through adjacent/overlapping zones, referred as cells.

This cells correspond to the area covered by the antenna of a base station.

C-V2X is described in 3GPP Release 14 [51], and its features can be summarized as follows:

- it uses the new Device-to-Device (D2D) PC5 sidelink interface (5.9 GHz)[52], so it does not need a SIM, carrier access or licensed spectrum;
- it does not require an infrastructure;
- it is not contention based, so no CSMA/CA;
- it has better performance with respect to 802.11p, i.e. it is more robust at the same range;
- layers higher than Physical and MAC are almost identical to DSRC protocol.

To allow the communiction, two different links are used (Figure 2.9):

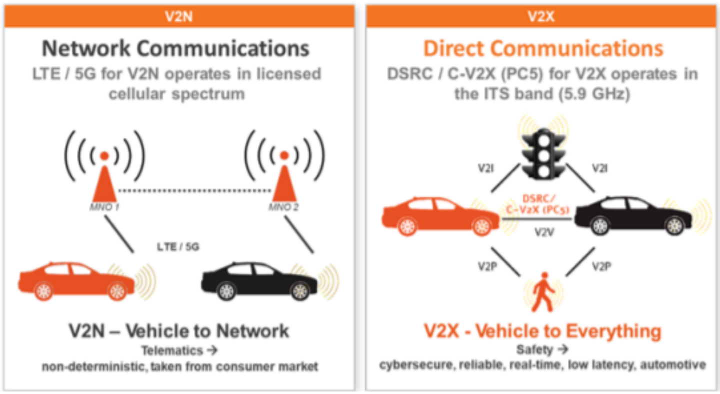


Figure 2.9: C-V2X PC5 and Uu links [53]

- Direct communication, for V2V, V2I and V2P, using the PC5 interface, that directly connects the User Equipments (UEs) so that the message from one UE is direclty received by the other UEs around the transmitter. The communication is supported using sidelink when the UE is inside LTE network coverage (so called Mode 3), and also when the UE is out of network coverage (Mode 4) [10]. Direct link operates in the unlicensed 5.9GHz [53].

- Network communication, using the LTE-Uu interface. Uu connects the UEs with the Evolved-UTRAN NodeB (eNB), i.e. the base station in LTE networks. The UE may receive V2X messages (either unicast or broadcast) via downlink, while transmitting V2X messages via uplink. Differently from communications over PC5, communications over LTE-Uu are only supported when the UE is inside network coverage [10].

As explained in section 1.2, in Europe C-V2X and 802.11p can coexist, but in USA, FCC approved in November 2010 the exclusive usage of upper 5.9 GHz band by C-V2X [12]. Although the standardization C-V2X was completed with Release 14, the D2D communication has been of feature of LTE since Release 12, referred as Proximity Services (ProSe). It was addressed only for Public Safety services, like for instance a lack of communication in case of natural disaster. At a later time, Release 14 has enhanced the PC5 for vehicular cases, specifically for high speed and high density.

Chapter 3

ETSI ITS-G5 Facilities Layer

In chaper 2 a detailed description of the standards regulating the Vehicle-to-Everything communication has been provided. In particular, it has been highlighted how ITS Station (ITS-S) can communicate using the DSRC standards like WAVE and ITS-G5 or the cellular-based C-V2X standard. In this chapter, further attention to the ETSI ITS-G5 standard will be given.

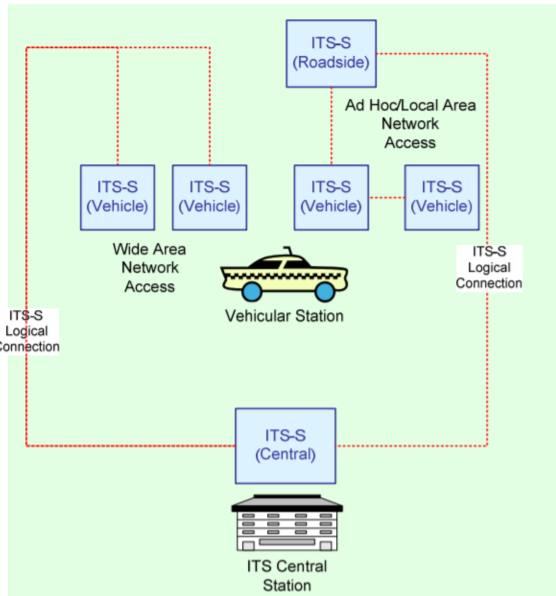


Figure 3.1: ITS environment overview [54]

In [37] four type of ITS station have been defined (Figure 3.1 [54]):

- Central ITS-S, providing centralized ITS apps. It may require a further connection with backend system, for instance via Internet;

- Road Side ITS-S, providing ITS applications from the side of the road;
- Vehicle ITS-S, providing applications to drivers and/or passengers;
- Personal ITS-S, providing applications to personal and nomadic devices.

All of this categories, might contain grouping of Applications or Facilities for deployment and performance requirements. In Figure 3.2 it is showed the ITS-S architecture provided by the standard, already presented as ITS-G5 protocol stack in section 2.1.2.

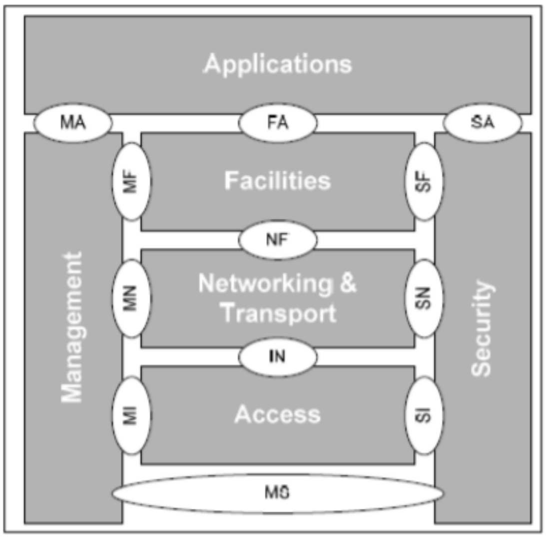


Figure 3.2: ITS station reference architecture. [54]

Aim of this thesis work is to develop the IVI basic service module for a network simulator. Before starting talking about the IVI messages, it could be important provide an overview of the composition of the Facilities layer, in witch IVIMs are located.

3.1 Facilities

As the technical specification [54] states "an ITS application make use of the facilities and communication capacities provided by the ITS-S". [55] defined three types of application: road safety, traffic efficiency and other applications. Moreover, [55] provides the complete list of Basic Set of Applications (BSA). The Facilities layer is an intermediate layer located in the middle between the Networking and Transport Layer and the Application layer, composed of sets of facilities supporting the BSA. Like it can be noticed from Figure 3.3, facilities can be divided into two categories: Common facilities and Domain facilities. Whereas, considering the functionalities provided by the facilities, they can be differentiated in four types: Application support, Information support, Communication support and Management facilities.

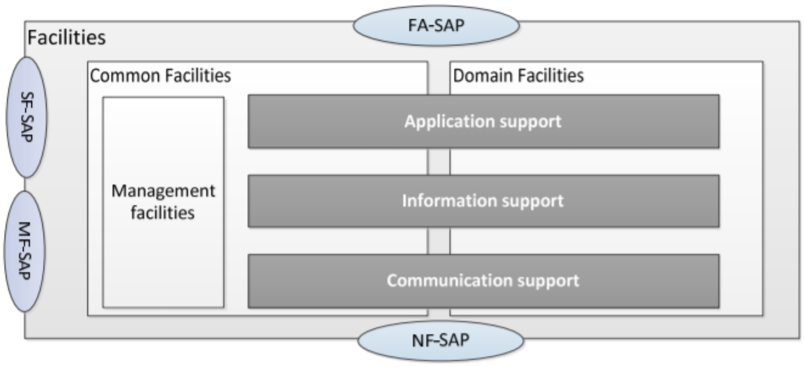


Figure 3.3: Facilities layer functional architecture. [54]

The Common facilities are the ones providing the basic services to support the ITS-S reliability and BSA interoperability, like positioning and time services. Domain facilities provide functions and services for several (or one) specific BSA application like DEN basic service for cooperative road hazard warning apps. They could be optional or not used for other applications.

Facilities that supply common services and/or functionalities for the BSA execution are considered Application Support facilities, such that CA basic service and DEN basic service. On the other hand, the ones providing commond data and database management functionalities are the Information Support facilities. An example of this is the Local Dynamic Map (LDM). Finally, the Communication support facilities supply services for communications and session managament, and the Management facilities are the ones that are interconnected with the Security or with the Management entity of the station.

A given example of Information support facility is the Local Dynamic Map, defined in

[55]. LDM is relevant for vehicle, personal and road-side stations and it is a database providing a representation of the situation around the ITS-S, based on the received messages like CAM and DENM.

ITS-G5 provides services not present in IEEE WAVE, like the Communication support facilities. These kind of facilities provide future-proof lower-layer independece, allowing the usage of different access technologies like 802.11p, Visibile Light Communication (VLC) and LTE, and networking protocol.

In ITS-G5 Application Support facilities, several application support messages are exchanged. The most important are:

- Periodically sent CAM, corresponding to the BSM standardized by SAE [23];
- Event-driven DENM;
- the already mentioned IVIM;
- Service Announcement Message (SAM);

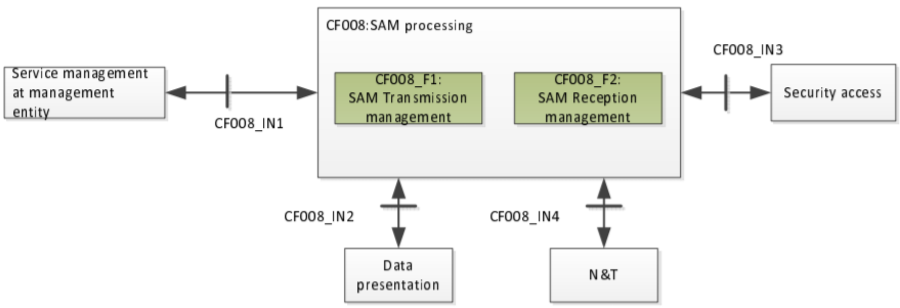


Figure 3.4: SAM functional block diagram. [54]

SAMs are messages sent on the Control Channel in order to advertise services offered on Service Channels, and they are similar to the WAVE Service Announcement (WSA). In other words, SAMs include informations regarding the provided service, the communication access technologies and other informations enabling the access to the services.

Every time a SAM is received, the corresponding processing facility decodes the message and sends its content to the managament layer that communicate with the correlated application. The block diagram of SAM processing is shown in Figure 3.4.

Messages like CAM, DENM and IVIM need a deeper description given in the following sections.

3.1.1 CAM

The Cooperative Awareness Basic Service, defined in [42], it is a facility entity that operates the CAM, which is a message designed for time-critical road safety purpose [56]. This message provides to the surrounding nodes status informations, including position, heading, speed, stationID and it is send periodically, up to 10 Hz. CAM is a safety message, sent on CCH, and several safety applications realy on it, like Rear end collision and Intersection assistsance. CAM aim is, indeed, to prevent a risk of collision. Upon reception and interpretation of these status messages the receiving ITS-S can create the previously defined LDM [57].

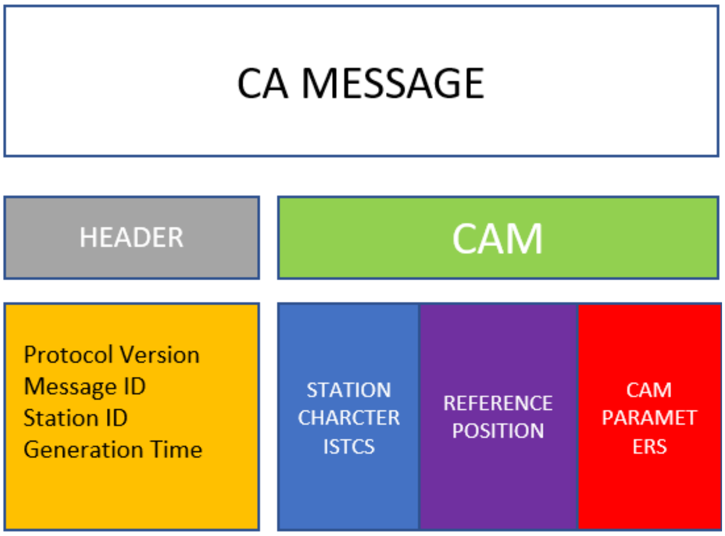


Figure 3.5: CAM structure.

In Figure 3.5 is presented a simplified structure of the CA message.

In the showed structure not all the extra optional fields have been considered. Apart from management fields, like the message identifier (0 in case for CAM), the specific information is contained in the body.

A serious problem of networks is the channel congestion. To avoid this issue, the CAM is triggered only when the following set of rules is met:

- The current heading of the vehicle is at least 4° different from the heading in the CAM, **or**
- the current position of the vehicle is different at least $4[m]$ from the position in the last CAM, **or**
- the current position of the vehicle is different at least $0.5[m/s]$ from the position in the last CAM, **or**
- the last CAM was sent 1[s] earlier.

CAM messages are generated and broadcasted by the Vehicle ITS-S through an access technology like IEEE 802.11p wireless interface. Roadside ITS-S within the cover-age area will receive the CAM messages and forward them to the Central ITS-S. Finally, the Central ITS-S application support decodes CAM messages and the status information contained within the CAM message about the vehicle is made available to ITS applications [58].

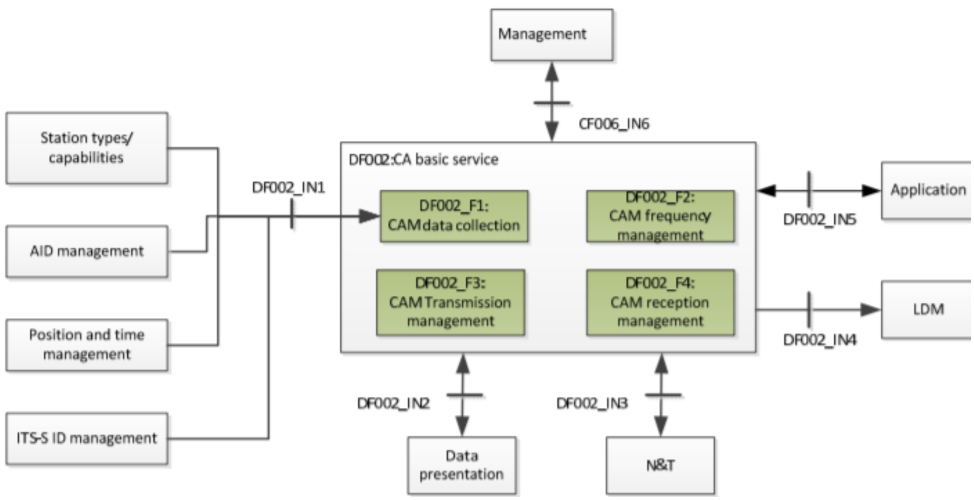


Figure 3.6: CA basic service functional block diagram [54].

3.1.2 DENM

Decentralized Environmental Notification Basic Service, defined in [42], it is a facility entity that provides the dissemination of DEN messages. DENMs are event-based messages describing the specific events occurring in a potentially dangerous area. It is used to report about traffic hazards [56]. They are triggered only when an event like Accident, Imminent collision, Tail end of jam occurs. DENMs relay is based on Area, Road topology and Driving direction.

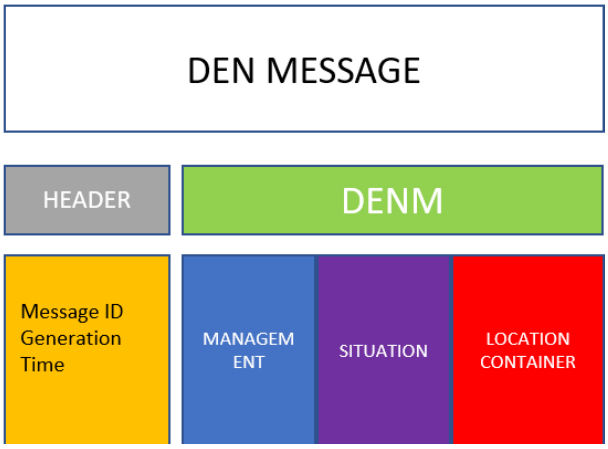


Figure 3.7: DENM structure.

A very simplified model of DENM structure is presented in Figure 3.7.

Differently from CAMs, DENMs are generated by the Central ITS sequently to a request from one of the ITS application for the notification of a road event like the ones previously described [58]. The application provides data about attributes of the detected event, such as event type, event duration, and destination area of the DENM dissemination to the DEN basic service, responsible for the DENM contruction.

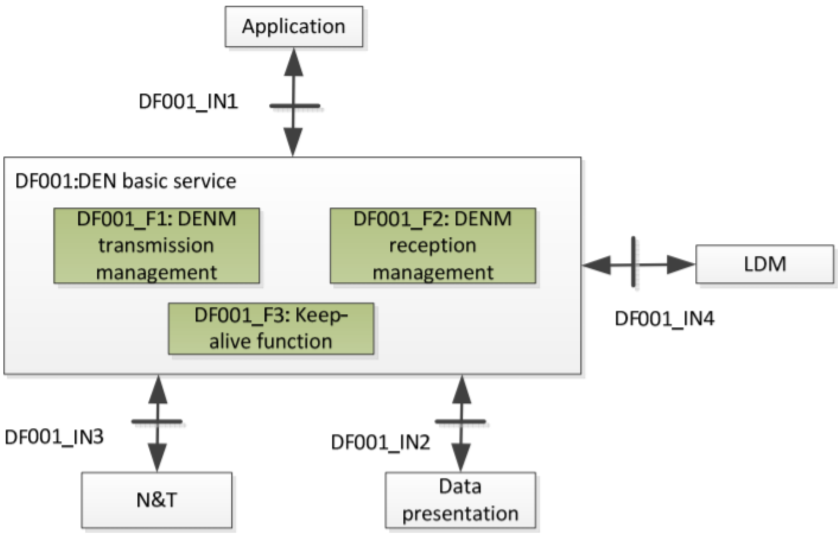


Figure 3.8: DEN basic service functional block diagram. [54]

At the receiver side, the informations are provided to ITS application using Application Programming Interface (API) or LDM. The DENM protocol establishes the discarding of outdated messages. The functional block diagram of DEN basic service is illustred in Figure 3.8.

3.2 IVIM

This thesis work is based on the usage of the IVI messages, so a deep analysis now is provided.

The Infrastructure-to-vehicle message (IVIM) is a message exchanged between road side ITS-S or central ITS-S and vehicles providing information about infrastructure-based traffic services needed for the implementation of use cases focusing on road safety and traffic efficiency [7].

C-Roads uses this message for conveying static and dynamic road sign information. The road side information could include static or dynamic signage details. Static signage information is information like speed limit and school zone delimitation, whereas the dynamic ones are provided by the Variable Message Sign (VMS), mentioned in the first chapter.

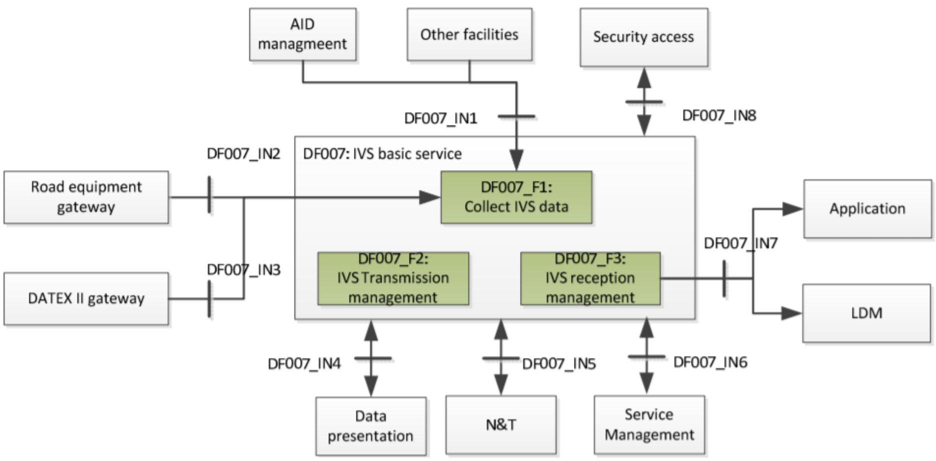


Figure 3.9: IVS basic service functional block diagram. [54]

If a central station is providing the informations, a traffic operator could manage and send in real time the In-Vehicle Signage (IVS) data to a vehicle ITS-S. The IVS basic service is the domain facility constructing the message with the obtained details and transmitting (maybe firstly announcing the availability of the information through a SAM) to the approaching vehicle. The receiving station provide the content of the message to an ITS application: in order to complete a proper reception of the IVS data, the ITS has to interact with the management layer [54]. The functional scheme of the IVS basic service can be referred to Figure 3.9.

The IVIM format is standardized in [18], while the message transmission is operated according to the indications of the standard [6].

In the following Figure 3.10, a simplified structure of the IVI message is illustrated.

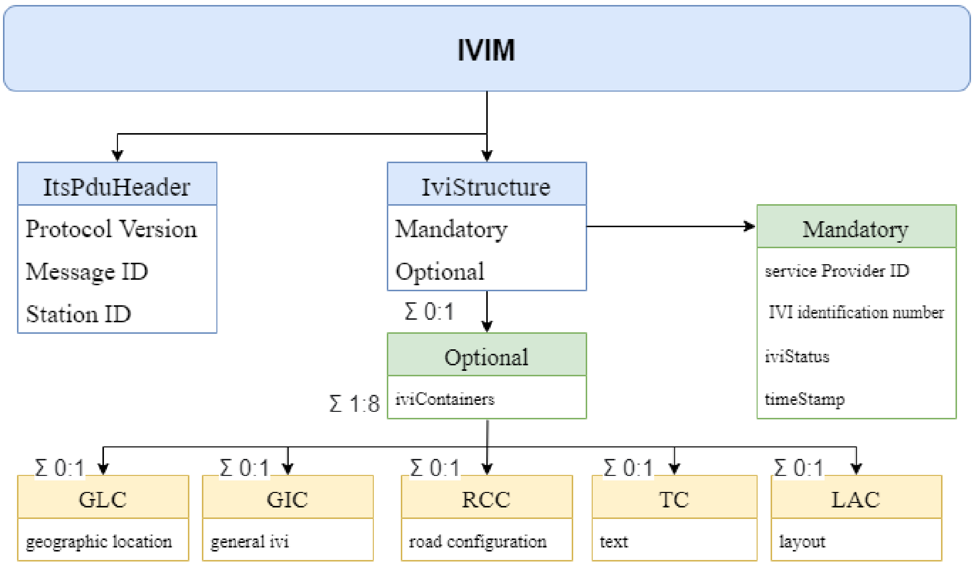


Figure 3.10: IVIM structure.

As [18] states, the IVI structure is intended to be encapsulated using an appropriate ITS Common Header like *ItsPduHeader* defined in [59], where PDU stands for Protocol Data Unit. Its content is specified in and it includes:

- protocolVerison;
- messageID, intended as the type of payload content, in case of IVIM is equal to 6;
- stationID, i.e the identifier of the ITS-S generating the message.

The IVI structure must be equipped with a mandatory container called IVI Management Container. This provides a receiving station with the minimum to handle the IVIM and decide its further processing. The mandatory elements that must be provided are the following:

- serviceProviderId, that identifies the organization providing the IVI;
- iviIdentificationNumber, assigned by the service provider, should be retained as long as the IVI structure exists;
- iviStatus, indicating the status of the message among *new, update, cancellation and negation*.

The definition of any actions for IVI handling is defined in [6].

Beside the mandatory container, the message may be equipped with at maximum eight optional containers. They can be differentiated into two categories: Location containers and Application containers. The location containers have inside informations about the zones in order to support the application containers. To this category belong the Geographic Location Container (GLC) and the Map Location Container (MLC).

GLC is made up of a common content, the *referencePosition*, indicating a suitable position used as reference, and the repetition of n-parts which define the zones with reference to that referencePosition. Each *zone* must be indicated with a unique *zoneId*.

MLC is built up with a *reference* to a MAP and n parts indicating the related zones, with the corresponding *zoneId*.

Their aim is to define the zones referred in the application containers.

The IVI application containers are needed in order to provide informations for a specific situation. Application containers are:

- General IVI Container (GIC), which supports services such as IVS and Road Works Working (RWW);
- Road Configuration Container (RCC), in charge of the transmission of the road in terms of lanes and lane-type;

- Text Container (TC), to transmit text and/or images;
- Layout Container (LAC), providing informations about the potential layout of the IVI;
- Automated Vehicle and Road Surface container are extension of the existing Ivi-Container. [18]

As far as regards the GIC, in its structure it contains the definition of the zone indicated inside the GLC. For example, it contains the *detectionZoneIds* and the *relevanceZoneIds* associated to specific message. The Relevance Zone is the area where a signage is applicable. Differently, a Detection Zone is the area in which the vehicle ITS-S must be informed because is approaching the relevance area. Its presence is important in order to guarantee that the Relevance zone is collectly detected: if a vehicle is moving inside the detection area, the receiving station will prepare for the entry in the zone were the signage is valid.

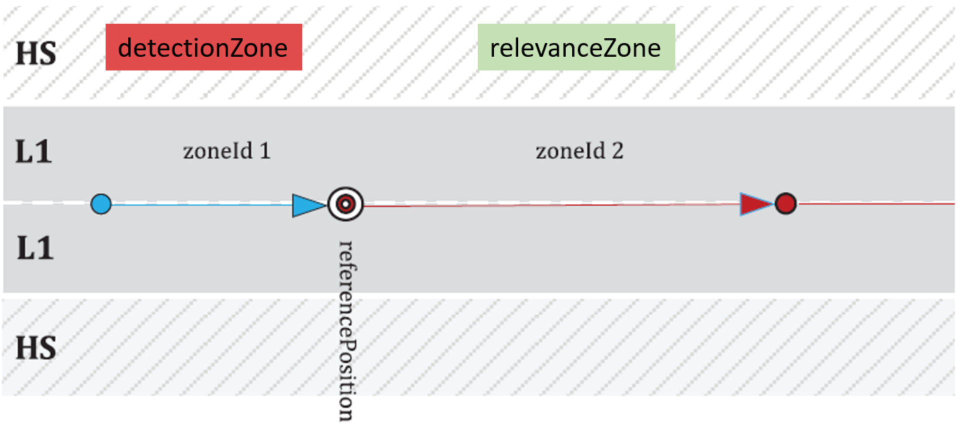


Figure 3.11: Example of Relevance and Detection Zone. [18]

The GLC it contains another important element, the *roadSignCode*. This specific data frame is a ordered list of applicable road sign codes, according to the catalogue. [18]

For the development of the IVI service, the indication to be followed are indicated in [6]. It is "one instantation of the infrastructure services to manage the generation, transmission and reception of the IVIM messages" [6]. As already stated, the IVIM convey informations about static or dynamic road signs, road works and it is made up of mandatory and optional entities. It is important to notice that the service must provide either the reception and the transmission of the message.

To better understand how to develop the IVI service, a brief description of the GeoNetworking and Basic Transport Protocol must be provided.

3.3 GeoNet and BTP

The usage of BTP is important since it is responsible for enabling the protocol entities at the Facility layer in order to access the services provided by the GeoNetworking layer [60]. More precisely, it provides an end-to-end connection-less transport service in the network, with the main purpose of multiplexing different messages, like CAM and DENM, processed at the Facilities layer.

The BTP message processing is based on the so called ports. A port is an entity that represents a communication endpoint that identifies the ITS Facilities layer service at the source or the destination. The GeoNetworking protocol transports the packets among the ITS stations and the BTP protocol delivers the packet to the entities at the ITS Facilities layer.

Since it has a 4-byte protocol header and requires a minimal processing, BTP is considered a lightweight protocol. On the other end, packets can arrive out-of-order or can be lost, since their transmission in unreliable. It follows the BTP packet structure.

Figure 3.12: BTP structure. [60]

In VANETs, GeoNet enambles wireless communication (maybe using ITS-G5) among vehicles and among vehicles and fixed stations along the roads. Its relevant feature is that provides communication in mobile environments without the usage of a coordinating infrastructure. Since it was meant for general mobile ad hoc networks, GeoNet can also be regarded as a family of protocols based on on the usage of geographical positions for addressing and transport of data packets in different types of networks [44].

The usage of the GeoNetworking is propedeutic for the specific requirements of the vehicular enovironment. The protocol is able to meet its requests since it is well developed for highly mobile network nodes and frequent changes. In addition, thanks to its flexibility, GeoNet can span between several application requirements, meeting the needs for infotainment, traffic efficiency and road safety.

GeoNet is able to send data packets to a node, or to multiple node, using its position or geographical region. This is different from what usually happens in conventional networks, where to a node is associated a unique name, such as the IP address. The way messages can be exchanged between nodes that are not within a radio range is established by three Routing Algorithms, as follows:

- GeoUnicast: To send a packet, the transmitting node firstly determines the destination's position and then forwards the packet to another node closer to the target, which in turn will re-forward the packet until the destination is reached (Figure 3.13).

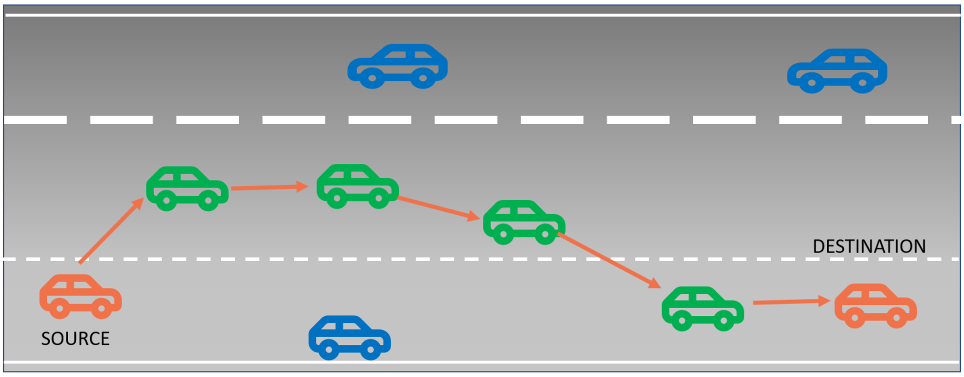


Figure 3.13: GeoUnicast.

- GeoBroadcast: the destination is not a node but an area. The packet is forwarded "hop-by-hop" antil it reaches the destination. The packet is rebroadcasted from the nodes inside the area (Figure 3.14). If this it does not happen, GeoBroadcast is referred to as GeoAnycast.

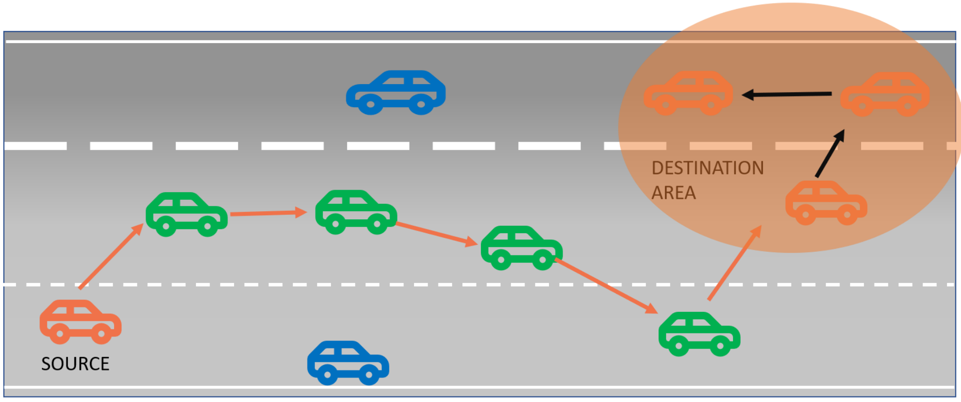


Figure 3.14: GeoBroadcast.

- Topologically-scoped broadcast: the rebroadcasting process is limited to only the nodes inside the n-hop neighbourhood. May be single-hop, like in the case of CA service messages. (Figure 3.15)

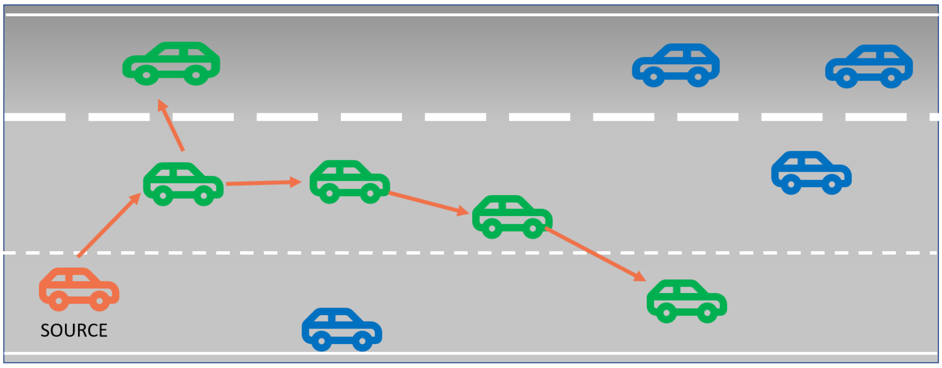


Figure 3.15: Topologically-scoped broadcasts.

In the following Figure 3.16 is showed the GeoNetworking packet structure [47].

Figure 3.16: GeoNetworking packet structure.

Chapter 4

IVI service

4.1 Simulation tools

In the first three chapters has been provided an overview of avariety of ITS aspects. A complete description of the standards regulating the communication has been provided with a particular attention to the ETSI ITS-G5 Facilities layer. As already stated, the basis of this thesis work are put onto two players: the IVIM basic service and the vehicular network simulation framework MS-VAN3T.

Into an industrial world as the Automotive which importantly evolves every microsecond, simulation tools are crucial in order to ensure an improvement of manufactoring processes. They provide the validation and the evaluation of the performances of systems. The goal of simulating a system isimitate its behaviour in time, artificially recreating its dynamics and evolution. To save CPU time, often are modelled only the events that actually affect the system states, thus discrete-time simulation are performed. The istantaneous time occurances at which the system state changes are the events: if the system is evaluated at time of event 'k', the next evaluation will be taken a time of event 'k+1'. Event-scheduling consists into building a list of future operation and decide at witch future point the event must occur.

Regarding vehicular networks simulation frameworks, one Open-Source solution is the

Veins simulation framework. It provides several models executed by the event-based network simulator OMNeT++ interaction with the road traffic simulator SUMO [61].

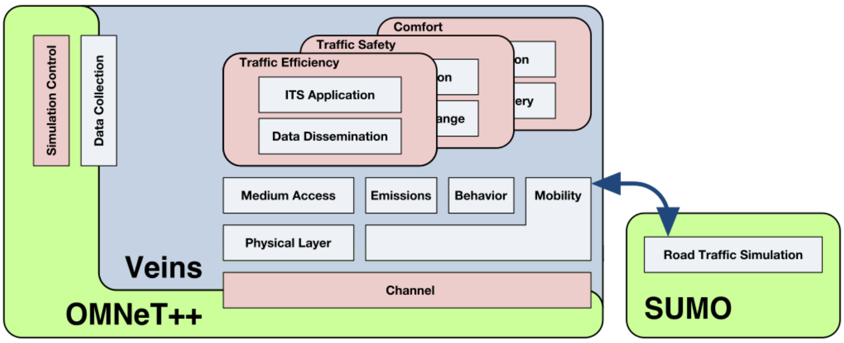


Figure 4.1: Veins architecture. [61]

Movement of vehicles in the road traffic simulator SUMO is reflected as movement of nodes in an OMNeT++ simulation. This nodes can interact with each other while the traffic simulation is still running, for example to simulate the influence of V2X communication on road traffic. Moreover, Veins features the bidirectional coupling between SUMO and OMNeT++ using the Traffic Control Interface (TraCI) [62].

4.2 MS-VAN3T

MS-VAN3T (Multi-Stack framework for VANET applications testing in ns-3) is an Open-Source vehicular network for the simulation of VANETs through the usage of ns-3 and SUMO. In particular, in consists in ns-3 modules to build and simulate ETSI-compliant VANET (V2X) applications using SUMO and ns-3 itself, with the possibility of easily switching communication technologies models [63]. This two systems can be defined as follows:

- ns-3: network simulator 3 (v3.33) is a discrete-event network simulator, aimed primarily for research and educational purposes [64].
- SUMO: Simulation of Urban mobility (v1.8.0) is an open-source traffic simulation suite. It allows modelling of intermodal traffic systems like vehicles, public transport and pedestrians.

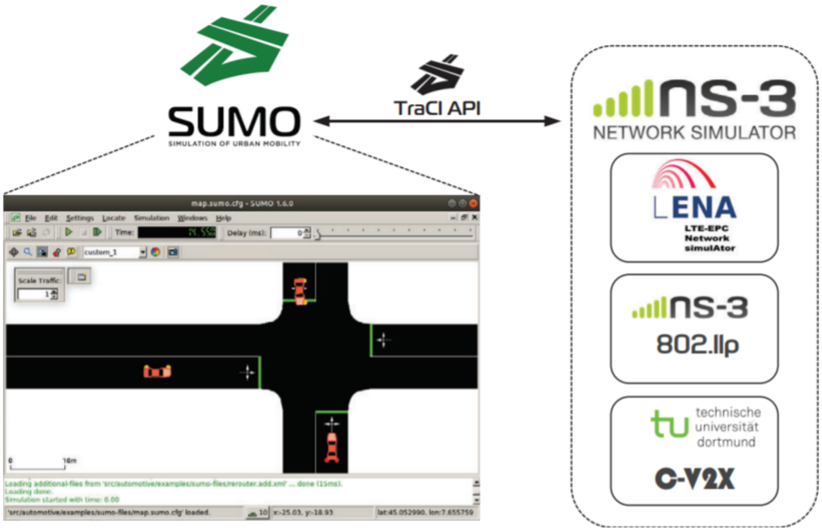


Figure 4.2: MS-VAN3T architecture. [63]

A special ms-van3t feature is the possibility of removing SUMO from the loop and using real GPS trace to manage mobility [63].

At the time of writing, ms-van3t supports the following access models:

- 802.11p for V2V and V2I communications;
- LTE for V2N communication (LENA);
- C-V2X in transmission mode 4 for V2V communications.

The development of the IVI service aims at leveraging the potential of ms-van3t, starting from the already implemented CAM and DENM basic services. These are developed in order to support the distribution and processing of CAM, DENM and IVI message. The messages generated in ns-3 can thus be received and decoded by real V2X devices, which in turn can interact with simulated entities. The standard-compliant facilites manage the transmission and reception the messages. In Figure 4.3 the logic of this two services is presented. To encode them, the ASN.1 is used: this tool allows the representation of complex data structures, described in detail in section 4.3.2.

Least but not last, ms-van3t proposes two sample applications: Area speed advisor, for V2I/V2N application, and Emergency vehicle alert, for V2V application.

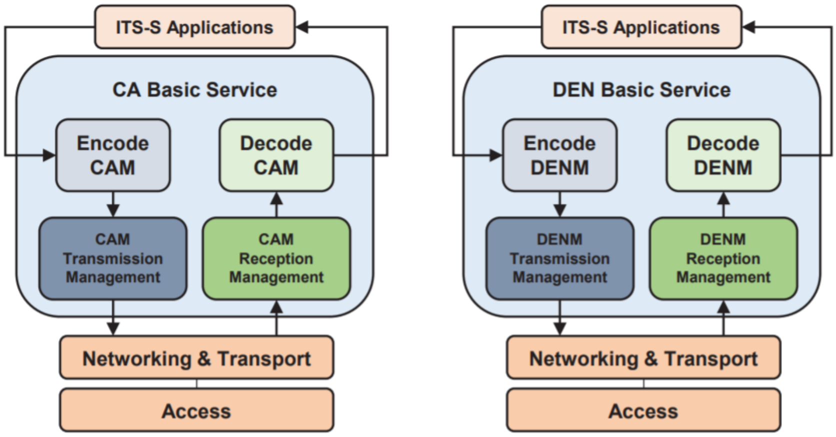


Figure 4.3: : CA and DEN Basic Services implemented inside an ITS-S. [62]

ns-3

The key reason of why is used ns-3 is that has been developed to provide an open, extensible network simulation platform. The simulator supplies several model of how packet data networks work and perform. Moreover, it provides a simulation engine for users to conduct simulation experiments. The model set is previously focused on how Internet protocols and networks work, but ns-3 model can be used to model non-Internet-based systems [65].

ns-3 also supports a real-time scheduler that facilitates a number of "simulation-in-the-loop" use cases for interacting with real systems. For instance, users can emit and receive ns-3-generated packets on real network devices, and ns-3 can serve as an interconnection framework to add link effects between virtual machines [64].

Differently from other simulation platforms, providing users with a single integrated graphical interface environment in which all tasks are carried out, ns-3 is modular. In fact, ns-3 is developed as a set of libraries that can be together and with other ones.

The simulator is primarely used on Linux systems and the users should expect to work at the command line using C++/Python software development tools.

SUMO

Since SUMO is concerned about micro-movements of cars, it can be considered as a road traffic time discrete microsimulation tool. Included with SUMO is a wealth of supporting tools which automate core tasks for the creation, the execution and evaluation of traffic simulations, such as network import, route calculations, visualization and emission calculation. SUMO can be enhanced with custom models and provides various APIs to remotely control the simulation [66]. Among the application contained in the SUMO package there are sumo, sumo-gui, netedit and others. The TraCI interface has been used to couple the SUMO functionalities with ns-3.

Traffic Control Interface - TraCI

TraCI stands for Traffic Control Interface and it allows to retrive values of simulated objects and to manipulate their behaviour "on-line".

To provide access to SUMO, TraCI uses a TCP based client/server architecture. Morover, it offers a set of control-related commands in order to complete the different operations, such as perform a simulation step or close the connection.

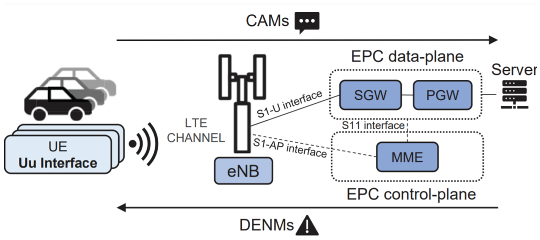
4.2.1 Communication models

As introduced earlier, ms-van3t supports different access technologies. In case of V2I/V2N situation, two communication models can be used to link the vehicles with a centralized service:

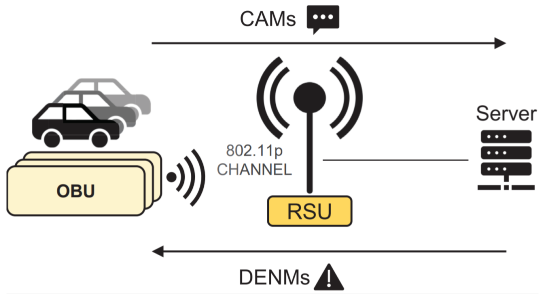
1. LTE, using LENA. It consists in a classic LTE network where the vehicles act as User Equipments connected to the eNodeB. This case can be referred as V2N, since the UE is connected to a service provider that can be ideally everywhere in the Internet (Figure 4.4a);

2. 802.11p using the WAVE model provided by ns-3. Here, vehicles equipped with On-Board Units communicate with a remote host located behind a Road Side Unit.

This case can be definite as a V2I communication (Figure 4.4b).

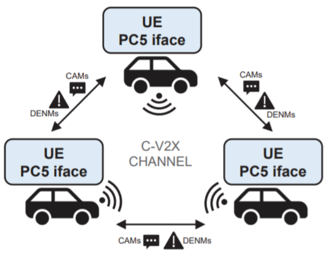


(a) V2N LTE-based.

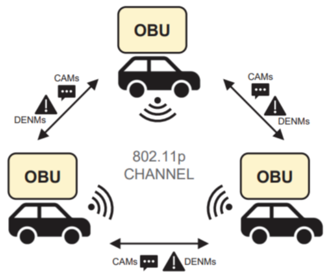


(b) V2I 802.11p WAVE-based.

Figure 4.4: V2I/V2N Communication Models.[62]



(a) V2V C-V2X-mode-4-based.



(b) V2V 802.11p WAVE-based.

Figure 4.5: V2V Communication Models.[62]

Considering the V2V models, where vechicles broadcast CAMs and DENMs directly among themselves, the two configuration available are:

1. C-V2X mode 4, where vehicles communicate using the PC5 interface through sidelink (SL), without eNB. (Figure 4.5a)

2. 802.11p using WAVE. Differently from the case of V2I, here CAMs and DENMs are exchanged between vehicles and are not sent to an RSU. (Figure 4.5b)

4.2.2 Application samples

The framework presents two sample application, one for the V2I/V2N case and one for the V2V situation.

The first case is presented into the Area Speed Advisor application (Figure 4.6). The core logic is to create two different zones inside the map: the central one, with a maximum allowed speed equal to 25 km/h, and the outer one, where vehicles are allowed to increase their speed up to 100 km/h.

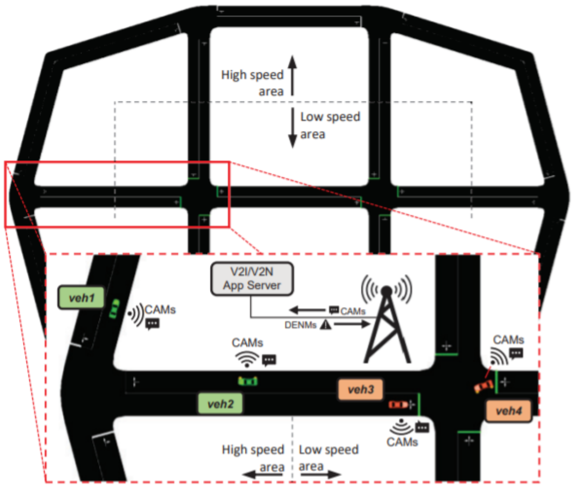


Figure 4.6: Area Speed Advisor sample application. [62]

The server receives the CAMs from the vehicles so that could monitor their position and advise them about the speed limit in the area in which they are. When a vehicle changes zone, the server it sends a DENM message in order to warn the driver about the different limitation. How it can be noticed from the SUMO-GUI capture in Figure 4.6, the vehicles in the inner area are red colored, whereas the ones moving into the outer zone change their color to green.

As regards the V2V, the framework offers and application named Emergency Vehicle Alert. In this scenario, two Emergency Vehicle (EV), like ambulances or a police cars, are present and sending DENM to the vehicles in their surrounding.

Whenever a normal vehicle receives a DENM, it will try to limit its impediment to the EV: if it is travelling on the same lane as the EV, it will try to change lane. If this is not possible, the vehicle will run faster and try to perform a lane merge maneuver as soon as possible (green colored). Whereas, if it is on a different lane, it will simply slow down (orange colored). With this procedure, the EV will be able to overtake a normal vehicle without being forced to reduce its speed.

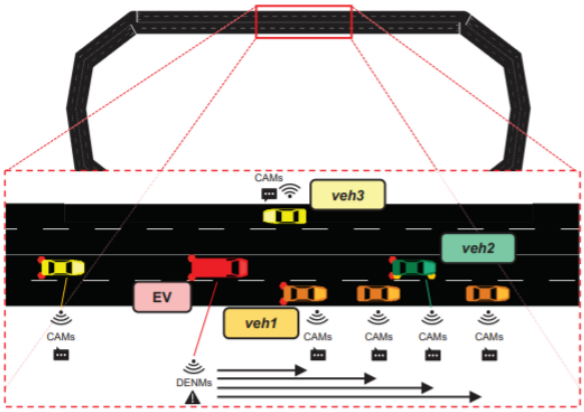


Figure 4.7: Emergency Vehicle Alert sample application. [62]

In this urban scenario, normal vehicles have a maximum speed varying between 30 km/h and 60 km/h whereas EVs can travel up to 75 km/h.

4.3 IVI Service development

Coming to the core of this thesis work, the IVI service has been developed in the just described ms-van3t framework. The main directives of the standard [6] for the IVI service can be summed up in the following table.

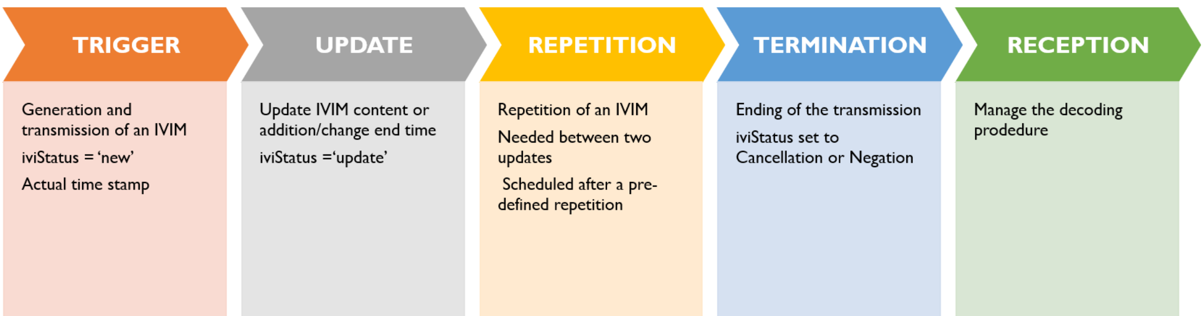


Figure 4.8: IVI service directives.

The iviIdentificationNumber, defined in chapter 3.2, enables the IVIM identification. Each time a new message is generated, a new ID shall be assigned by the service. Each iviIdentificationNumber is linked to the organization providing the service. The process responsible for generating and transmitting the IVIM is the *trigger process*. When this process is called, the iviStatus must be set to "new". When the content of the message needs to be updated, the process *update* is called. This process is used also to change or to add the end-time to the IVIM. The timeStamp must be set to the last change information content if the iviStatus is set to "update", or to the generation time if the iviStatus is set to "new". In order to let new ITS stations entering the Minimum Dissemination Area (MDA) receive the IVIM, an IVIM shall be repeated at a pre-defined repetion interval. This *repetition* process shall be activated by the ITS-S application. The IVI service termination indicates the end of the validity of the IVI service. IVI service termination can be referred either at the ending of transmission, at an application cancelation or at an application negation: a Cancellation of the IVI service can only be provided by the organization that originally provided the IVI service; a Negation of the IVI service can be provided by other organizations. The iviStatus will be set respectivelly to "cancellation" or to "negation".

In addition to this, [6] provides the requirements for short-range and long-range communication. In order to send the message, a packet is created, and passed to the BTP (Basic Transport Protocol, described in chapter 3.3) module with the required BTP type and destination port, i.e. for IVIM is equal to 2006.

4.3.1 iviData

In order to simplify packet data encapsulation procedure, an iviData class has been created. This class is made up as an IVIM-like structure and allows the filling of the IVIM messages to be easier and efficient for the user. For instance, the class offers a function called `<<iviData::setOptionalPresent(bool,bool,bool,bool,bool)>>` which allows to set the presence (or not) of optional containers.

Moreover, this class provides functions not only for the setting of the class elements, but functions to retrieve its content as well. For example:

- `iviData::setIvimHeader(messageID,protocolVersion,stationID)` allows the

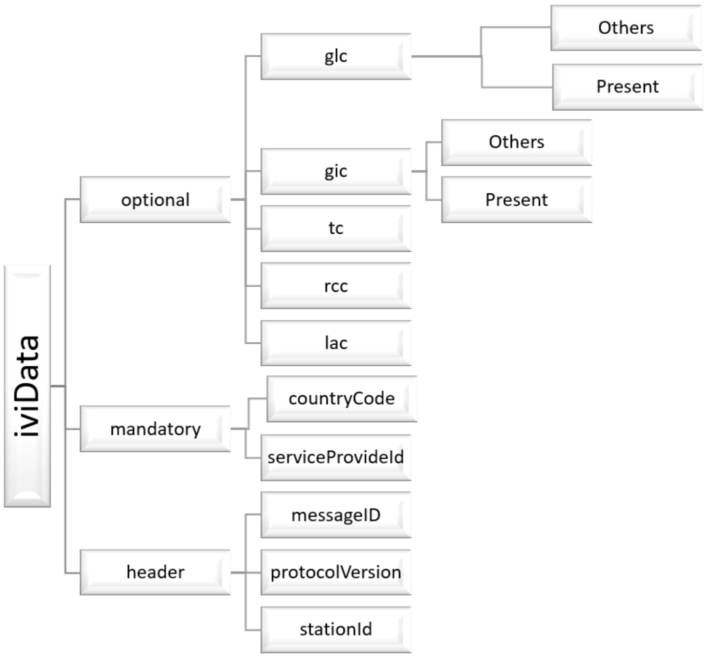


Figure 4.9: IVI service directives.

setting of the header;

- `iviData::getIvimHeader()` retreives the header content.

How it can be assumed, this new class facilitates both the encoding and decoding process.

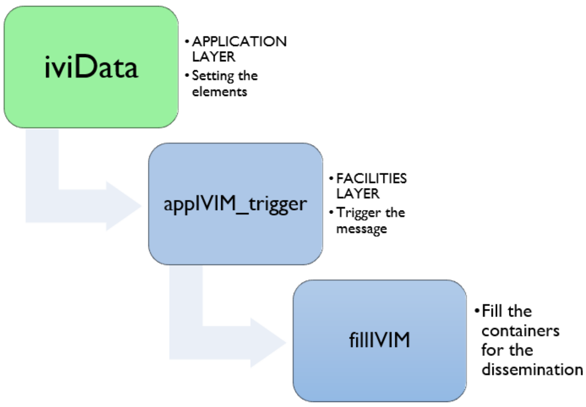


Figure 4.10: Transmission process.

When the user want to use the IVI service in order to disseminate a message, the first thing to be done is to fill at application layer an iviData object using the functions offered by the class. Upon reaching the completion of the object, it is passed to the Facilities layer, where the `iviService::appIVIM_trigger` function is responsible for the encoding procedure and for starting the dissemination. Before that, the `iviService::appIVIM_trigger` function in turn calls a function called `iviService::fillIVIM` to properly prepare the packet.

On the other hand, when an IVIM is received, the BTP module calls the `iviService::receiveIVIM` this operation is in charge of decoding the packet creating a `decodedIvim` object using the functions provided by the tool asn1cpp, illustrated in section 4.3.2. In a similar fashion to what happens for the transmission, the IVIM is converted into an iviData structure to easily use its informations.

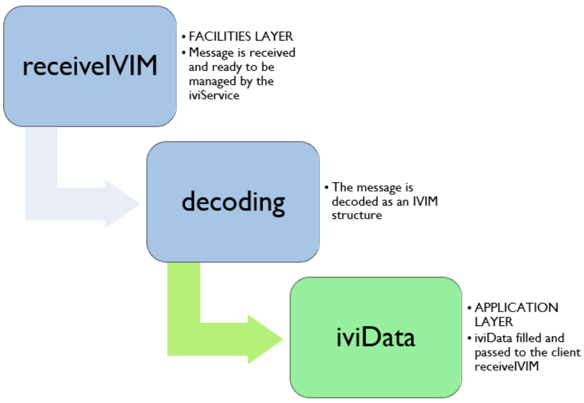


Figure 4.11: Transmission process.

In Figure 4.12 an example of the overall procedure is showed. How it can be noticed, in order to encapsulate the information the several function and structures offered by the iviData class are used. Later, to verify the correct transmission, a packet capture file can be generated from ms-van3t. The packet capture can be proccesed using WireShark and as it can be seen from the header, the message is properly disseminated. At the receiver side, the "Application output example" section shows the text extracted from the packet, feature available thanks to the TextContainer of IVIMs.

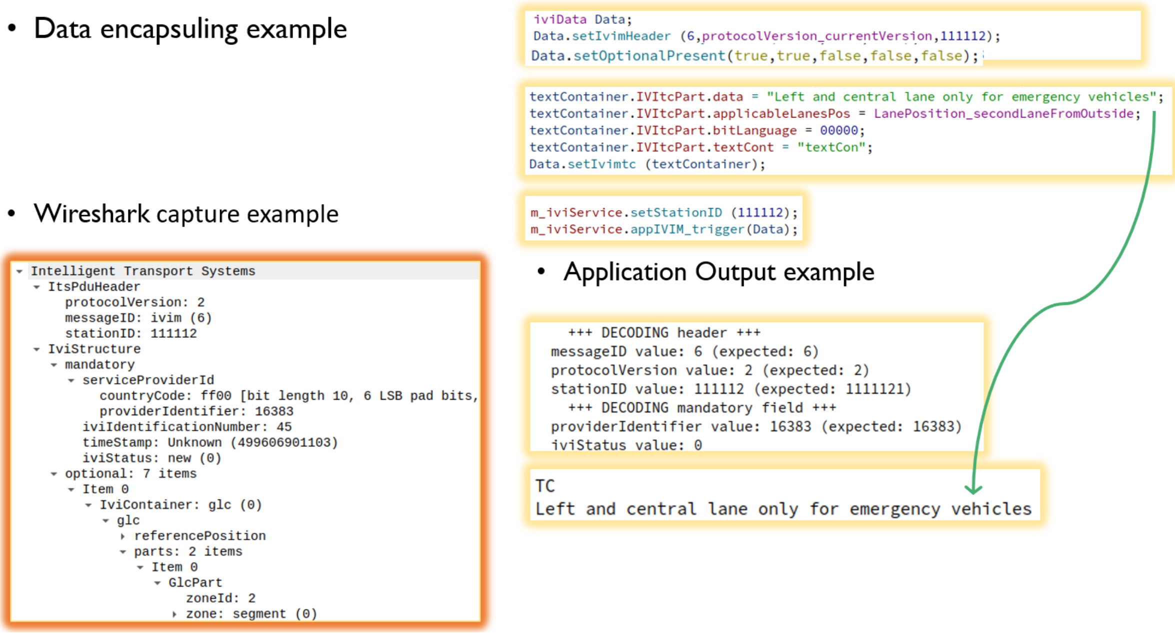


Figure 4.12: IVI management example: the iviData is set (upper-right picture); the packet is extracted using WireShark, as it is showed in the lower-left picture; the TextContainer content is printed and read through the Application Output (lower-right image).

4.3.2 ASN.1 and asn1cpp support

Before concluding the IVI service description, a note must be provided: in order to properly set all the fields present on IVIMs, Abstract Syntax Notation number One (ASN.1) notation has been used and for which the asn1cpp tool [69] has been chosen for its handling.

ASN.1 is a formal file used for descrbing data transmitted by telecommunications protocols, regardless of language implementation and physical representation of this data, whatever the application, whether complex or very simple [67]. This notation provides basic types like integers (INTEGER) booleans (BOOLEAN) and bit strings (BIT STRING), and offers the possibility to define constructed types such as structure (SEQUENCE), lists (SEQUENCE OF) and choice between types (CHOICE).

For the development of the iviService, a set of ASN.1 files have been provided by the standard. In order to generate all the data types useful for the IVIM encapsulation, the ASN.1 to C compiler (ASN.1c) has been used. This compiler takes the ASN.1 module files and generates the C++ compatible C source code [68].

The usage of asn1cpp tool is due to its capability to simplify the procedure of setting all the message fields. In fact, it provides several useful functions for this purpose.

For example, in order to declare a new asn1cpp sequence, the `asn1cpp::MakeSeq(asn1cpp:TYPE_descriptor_t)` function it is used. Whereas, to set a value inside a specific field it can be used the `asn1cpp::setField(Field,Value)` function. In case an ASN.1 SEQUENCE OF field has to be set, firstly the corresponding asn1cpp sequence must be declared, then the element of the list can be set. When the setting of its element is completed, the List is "pushed" into its field in the following way: `asn1cpp::sequenceof::pushList(ListField,ListValue)`.

To clarify the logic, it is considered for example the deltaPosition (Figure 4.13) setting procedure. To start with, the containers are created, from *ivim* to *deltaPosition*. Then, all the needed fields are set, like the *latitude* and *longitude* and only after this, each sequence is inserted inside the outer one. A code example is proposed:

```
//Creating the IVIM sequence and the IVI container sequence
auto ivim = asn1cpp::MakeSeq(IVIM);
auto iviCont = asn1cpp::MakeSeq(IviContainer);
//To create the glc container, firstly must set its presence
asn1cpp::setField(iviCont->present, IviContainer\_PR\_glc);
auto glc = asn1cpp::MakeSeq(GeographicalLocationContainer);
// glcPart,glcZone and delPos sequence are created
auto glcPart = asn1cpp::MakeSeq(GlcPart);
auto glcZone = asn1cpp::MakeSeq(Zone);
auto delPos = asn1cpp::MakeSeq(DeltaPosition);
//Once all the containers are created, the fields are set
//starting from the inner ones, i.e. deltaLatitude and deltaLongitude
asn1cpp::setField(delPos->deltaLongitude, delLonValue);
asn1cpp::setField(delPos->deltaLatitude, delLatValue);
//The containers previously created are now filled
```

```
//moving from the inner one (deltaPoistion) to the outer (ivim)
asn1cpp::sequenceof::pushList(glcZone->choice.segment.line.
        choice.deltaPosition,delPos);
asn1cpp::setField(glcPart->zone, glcZone);
asn1cpp::sequenceof::pushList(glc->parts,glcPart);
asn1cpp::setField(iviCont->choice.glc, glc);
asn1cpp::sequenceof::pushList(ivim->ivi.optional,iviCont);
```

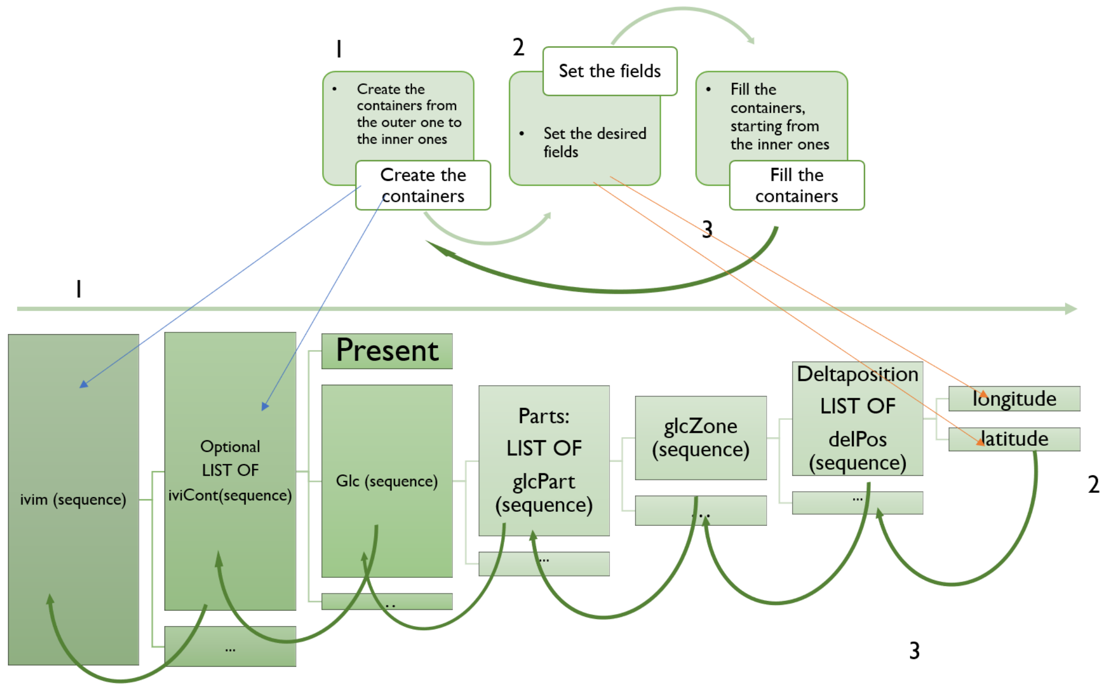


Figure 4.13: DeltaPosition setting process.

Regarding the decoding procedure, the logic is quite similar, but the main functions to be used are:

- `asn1cpp::sequenceof::getSeq(Field,ASN1CPP_ASN_type,indexOftheList)`, in case of a List;
- `asn1cpp::getSeq(Field,ASN1CPP_ASN_type)`, in case of a sequence;
- *type_t* `fieldName = asn1cpp::getField(Field,type_t)`, in case of a simple element of type *type_t*, such as *long*, *uint8_t*, which are the ones used to set the iviData.

Chapter 5

Testing Application

In the previous chapter it has been provided an overview about the simulation tools, especially what regards the ms-van3t framework. Then, the structure of the developed IVI service and its functionalities have been illustrated. The following step is to validate the work for which a new application has been developed and tested on MS-VAN3T. This is possible thanks to the flexibility of the framework that allows the development and testing of a wide number of types of applications.

5.1 I2V Emergency Vehicle Warning

As already explained, the IVIM is a message set to be disseminated by an infrastructure, e.g. a RSU. The purpose of this message is to convey information like the state of the road, static or dynamic signages, to the users of the transportation systems like vehicles.

In case of emergency, like an accident involving more than one car, it is really important for law enforcement and health workers to reach as soon as possibile the accident location. Nevertheless, the presence of other vehicles could represent a hindrance for the emergency vehicles (EVs) trying to reach who needs help or to bring them to the nearest hospital. The conception of the *Emergency Vehicle Warning* application put its basis on this situation. The idea is the following one:

- Because of an accident, several emergency vehicles are running through an highway;
- To warn the other vehicles of this EV presence, an IVIM is triggered by an RSU placed on a portion of the road where the simulated crash happened;
- The message contains informations about the particular situation and where its content is valid;

The map used for the application is similar to the one provided by the *Emergency Vehicle Alert* ms-van3t sample application (described in section 4.2.2), the only difference is the presence of three lanes instead of two. The scenario is illustred in Figure 5.1.

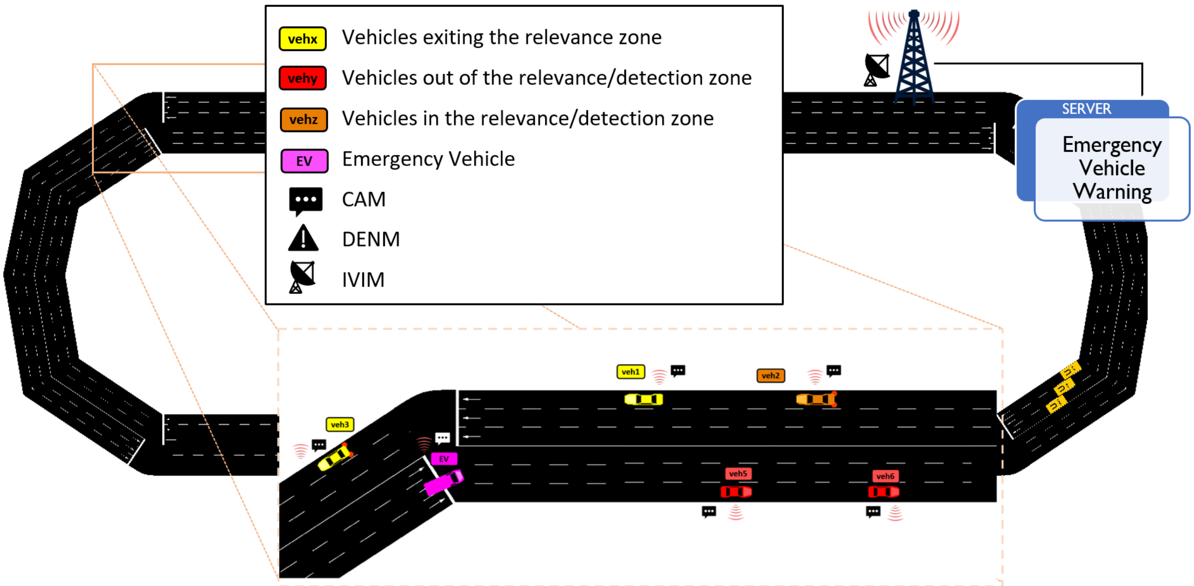


Figure 5.1: Emergency Vehicle Warning scenario.

IVIM content

The principal important information contained by the IVIM are inserted in the table 5.1. In Figure 5.2 a graphical explanation on how *referencePosition* and *deltaPosition* are evaluated. For the *stationID* and *serviceProviderID* fictitious data have been chosen. Another important clarification is that according to the standard referencePosition and deltaPosition must be expressed in tenths of microDegree, so in order to process them, the data must be converted in the proper reference system.

HEADER	protocolVersion = 2;	
	messageID = ivim (6)	
	stationID = 777888999	
MANDATORY	serviceProviderId = 16383	
	iviStatus = new (0)	
	iviIdentification number = 0	
	timeStamp	
OPTIONAL: glc	referencePosition	
	deltaPosition1	zoneID = 1 laneWidth = 9
	deltaPosition2	zoneID = 2 laneWidth = 9
OPTIONAL: gic	detectionZoneId = 1	
	relevanceZoneId = 2	
	ISO14823code = 13659	Attribute: Max speed 30 kmph
OPTIONAL: tc	detectionZoneId = 1	
	relevanceZoneId = 2	
	Data = Left and central lane only for emergency vehicles	

Table 5.1: Ivim content.

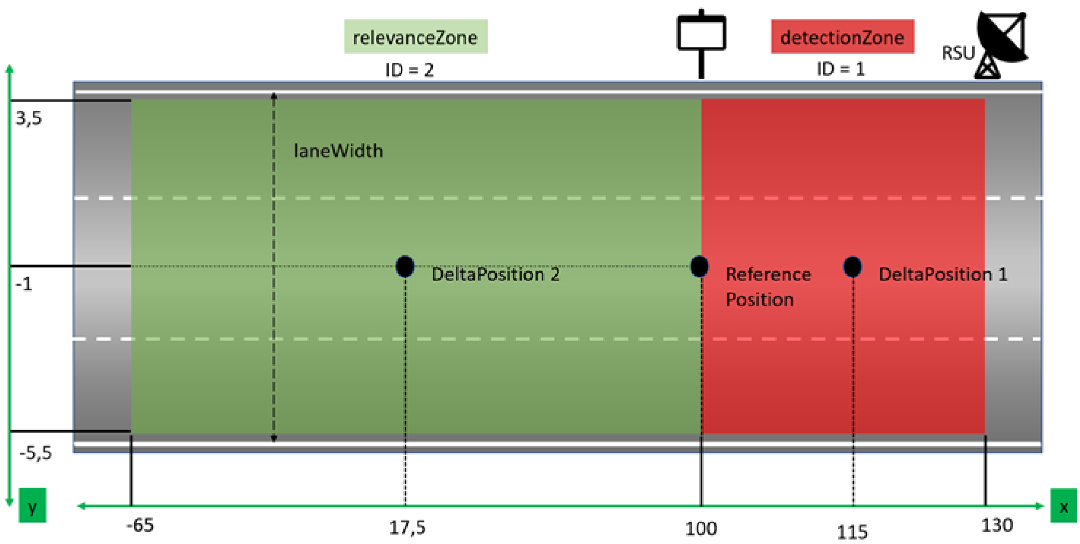


Figure 5.2: EVW relevanceZone and detectionZone.

The logic of the application establishes that when an approaching vehicle receives an IVIM (red coloured in Figure 5.1), the first thing that the client (i.e. the vehicles) must check is if the vehicle is an emergency vehicle or not. In the second case, if the vehicle is inside the detectionZone or the relevanceZone (orange colored cars in Figure 5.1) in a lane different from the righter one, it must perform a "laneChange" maneuver. A `checkRelevanceZone()` function is scheduled by the client after 3 seconds in order to check if the vehicle is still inside the relevanceZone: if true, another check is scheduled after 3 seconds, on the contrary, if false the vehicle is free to move as it prefers and its color changes to yellow. In parallel to the color setting, when the cars are running through the relevanceZone a new max speed limit is set equal to $30km/h$, according to the *RS ISOCode 14823* [70] indication, to reduce the possibility of an accident due to high velocity.

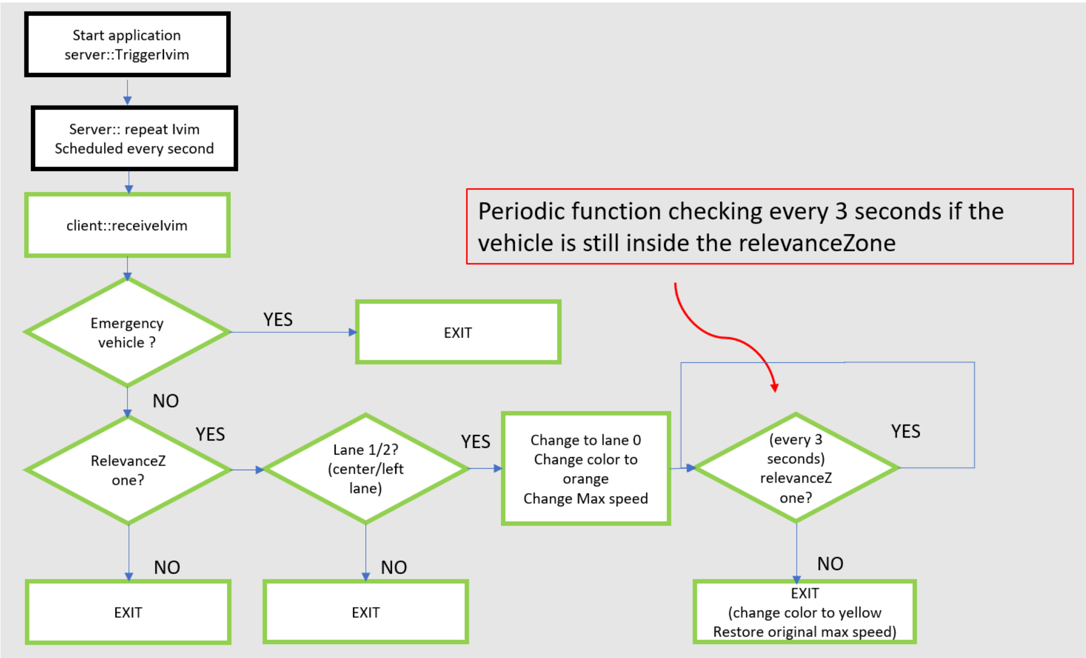


Figure 5.3: EVW logic flowchart.

In Figure 5.4 is shown a WireShark capture that provides the disseminated IVIM content. As it can be noticed, the information is correctly encapsulated and sent over the network. In the picture it has been put in evidence the correspondace of the IDs for the zone in the different containers. Moreover, to verify the correct signage information reception, a capture from the Client Application Output has been considered (Figure 5.5), like in the example of vehicle 1, coloured in yellow in Figure 5.1 .

In order to provide a proof of the good performances of this application, a test in the following conditions has been taken:

- 4 Emergency Vehicles running through the railway;

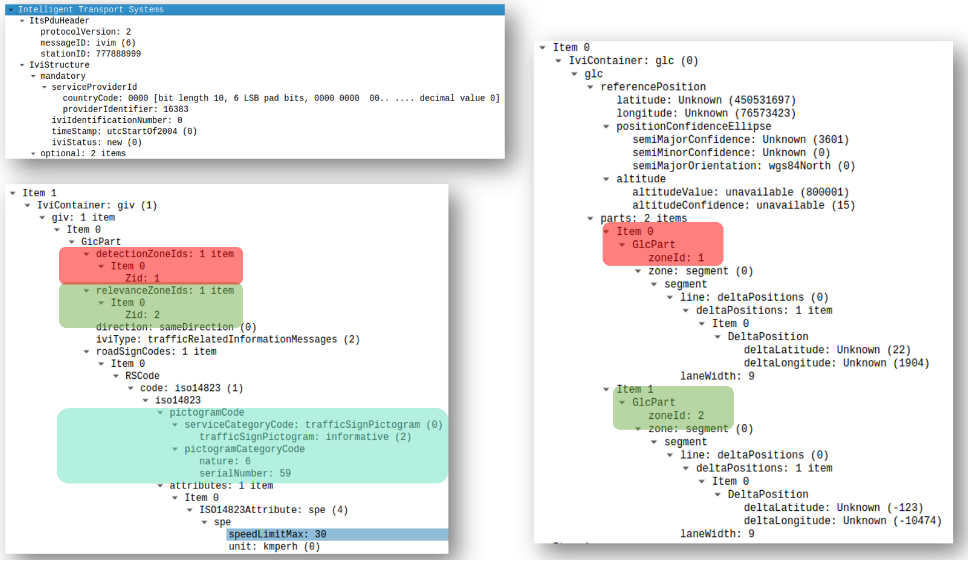


Figure 5.4: Wireshark capture.

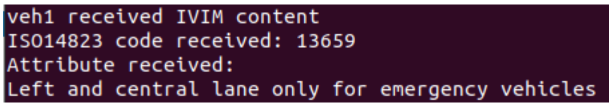


Figure 5.5: Vehicle 1 application output.

- Simulation time equal to 300 seconds;
- Total number of vehicles from 10 to 50, increasing by 5 vehicles each time;

Each simulation has been run 10 times, each with different initial condition in terms of vehicle route (i.e. the path taken by the cars), except for the EVs that always run in the outer ring. A comparison of the results obtained firstly enabling and then disabling the *Emergency Vehicle Warning application* are illustrated in Figure 5.6.

5.2 Results

From the plots in Figure 5.6, the benefits of the application are quite evident: except from the case of 15 vehicles, where the mean speed value is $1.2Km/h$ slower with the algorithm, the usage of the application is important to let the emergency vehicle run faster. In particular, the advantages of this algorithm are evident in case of a number of vehicles larger then 30, which actually is the intended working zone for this application:

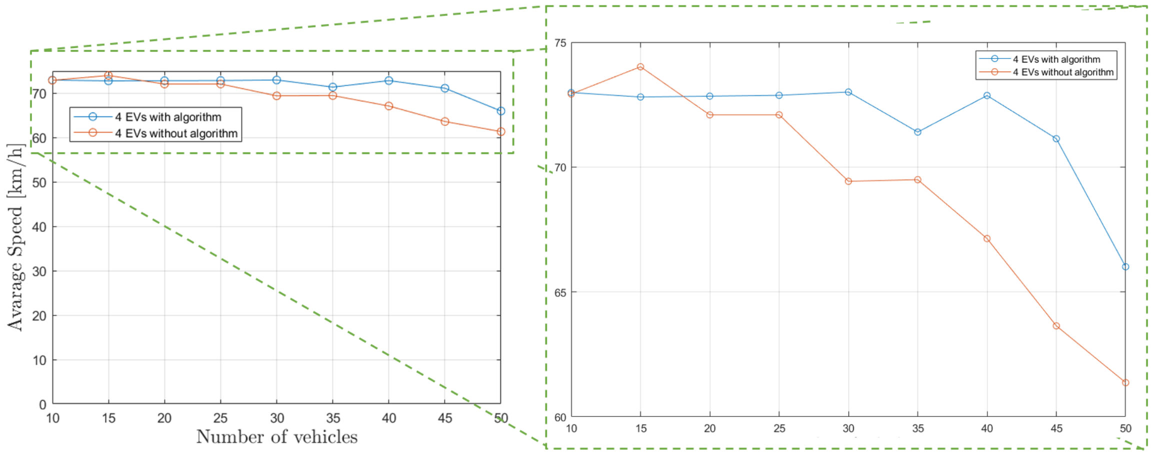


Figure 5.6: Emergency Vehicle Warning performances.

the slowdown due to a traffic congestion may evolve in huge issues for those in need, but thanks to this application the EVs could run up to $8.5Km/h$ faster as in the case of 45 vehicles ($71.14Km/h$ vs $63.64Km/h$), which would translate on a larger number of lives saved.

Chapter 6

Conclusions and Future Works

In the smart-era in which we are, where connected smart devices are of paramount importance, even the automotive world is at the centre of a revolution. In last years, a huge process in the network access technologies has taken place place, leding giants of standardization like IEEE and ETSI to develop new applications. This thesis work has focused on such new applications provided by the so called ITS. In the first chapter, an overview of what this systems are concerned has been provided.

Then, in chapter 2, a deeper analysis on the standards that regulate all the aspects of vehicular communication over the networks, focusing on the cellular based standard C-V2X, developed by 3GPP, and on the DSRC standards WAVE and ITS-G5, developed respectively by ETSI and IEEE.

The core of this thesis work is a module of the open-source framework MS-VAN3T that implements the IVI service, described in chapter 4, providing the management of an Infastructure based message referred to IVIM. The structure of this message and the context around it, i.e. the ITS-G5 facilities layer, is widely illustrated in chapter 4.

Finally, in chapter 5 a description is provided about an application showing the benefits of using the IVI service. As far as it can be assumed from the results, the efficiency of the traffic is leveraged by an application installed in a RSU conveying the vehicles running through highway, the presence of a zone dedicated to the approaching emergency vehicles.

As future works, further development of the IVI service will complete the service with all the features requested by the ETSI standards [6] [70] that are not already implemented, like several optional fields in the different containers. Concurrently to the IVI service, even the iviData class should be completed.

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