UNIVERSIDAD DE TECNOLOGIA EXPERIMENTAL YACHAY

Escuela de Ciencias Matematicas y Computacionales

TITULO: Find Parameters to Obtain Optimal Connection Between RSU and Vehicles to Support Video Streaming Along the Road

Trabajo de integracion curricular presentado como requisito para la obtencion del titulo de Ingeniero en Tecnologias de la Informacion

Autor:

Estrella Baquero Marcos Fernando

Tutor:

Ph.D. - Pineda Arias Israel Gustavo

Co-tutor:

Ph.D. - Iza Paredes Cristhian Rene

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CI: 1723347900

Dedication

I dedicate this work mainly to my family, my mother, Lorena Baquero, for being the essential pillar and always showing me affection and love. To my father, Marcelo Estrella, despite our different thoughts, he has always been necessary support. To my life partner, Daniela Negrete, who has supported me at all times. Furthermore, to my son, Joaquin Fernando, my greatest gift in life and my reason for getting ahead.

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With all my heart.

Resumen

La población urbana es uno de los elementos fundamentales de una ciudad inteligente. Esta población es la única que puede fomentar el desarrollo de la ciudad y el nivel de comodidad de sus ciudadanos. Los Sistemas de Transporte Inteligentes son soluciones tecnológicas basadas en información, tecnología y telecomunicaciones diseñadas para mejorar la operación y seguridad del transporte. En los últimos años se han establecido diversas normativas acerca de los sistemas de transporte inteligente para controlar y promover su implementación en el sector del transporte por carretera y sus conexiones con otros medios de transporte.

Existen diversas aplicaciones relacionadas con las redes vehiculares. El crecimiento de esta área y los beneficios que puede producir para las organizaciones públicas y privadas hacen del estudio un auge constante. Algunos ejemplos de los beneficios son la seguridad, las aplicaciones comerciales, las aplicaciones de mejora de la comodidad y las aplicaciones productivas.

Internet se diseñó inicialmente para el tráfico de datos, proporcionando un canal impredecible y variable en el tiempo para el retraso, el ancho de banda y la pérdida de paquetes. Si bien las aplicaciones tolerantes al retardo pueden usar protocolos TCP que transforman el ancho de banda variable en el tiempo y la pérdida de paquetes en retrasos adicionales, en las aplicaciones de transmisión de audio y video, estos retrasos son intolerables. El uso de información multimedia ha sido posible, entre otros factores, gracias al crecimiento de las computadoras modernas y la tecnología de conexión a internet de banda ancha.

El número de personas que utilizan las carreteras para viajar a diferentes destinos ha crecido de manera exponencial, ya sea en sus vehículos, transporte público o privado y transporte de mercancías. Asimismo, situaciones como el cambio climático, la velocidad de los conductores y las irregularidades en las carreteras son inconvenientes que surgen al conducir. Algunas ocasiones provocan accidentes de tráfico.

Los ITS constituyen un esfuerzo global entre los gobiernos, la industria privada y los centros de investigación para aplicar las nuevas tecnologías de la comunicación para dar respuesta a los problemas globales. La innovación de tecnologías de este tipo consiste en la cantidad de información que son capaces de manejar al tener más agentes involucrados en la creación de un servicio de transporte.

Las redes de vehículos VANET son un tipo particular de redes móviles Ad-Hoc. Son parte del ITS, donde los nodos son vehículos en movimiento como automóviles y autobuses con capacidades de comunicación. Hay tres tipos de comunicación en una red: V2I, V2V y red híbrida. La red V2I consiste en la comunicación entre un nodo móvil o vehículo y un nodo de infraestructura o RSU. V2V es la comunicación entre dos vehículos. La red híbrida es la comunicación de un vehículo con la infraestructura utilizando uno o más vehículos.

La transmisión de video a través de VANET debe superar algunos desafíos, ya que dicha red es propensa a tener topologías dinámicas y enlaces entre nodos.

Para lograr la cooperación entre los elementos de comunicación y proporcionar una mayor funcionalidad, las comunicaciones inalámbricas dentro de los sistemas de transporte son esenciales a través del desarrollo de redes de vehículos. El acrónimo VANET (Vehicular Ad-hoc NETwork) define una red vehicular que consiste en vehículos en movimiento que crean redes altamente dinámicas. Los vehículos equipados con sistemas e infraestructura de comunicación inalámbrica están involucrados en esta implementación.

Los sistemas de comunicación en las redes ad-hoc de vehículos (VANET) se han convertido en un área importante de investigación. En los últimos años se han desarrollado tecnologías en diferentes áreas. En las tecnologías inalámbricas y el Internet de las cosas, la transmisión de video es una aplicación importante porque puede ofrecer muchos servicios valiosos a los conductores. Entre los beneficios a los que se puede acceder se encuentra compartir información sobre el tráfico, condiciones de la carretera, accidentes de tráfico, haciendo de cada vehículo una fuente de información que se puede conectar a la infraestructura de red (V2I) mediante Road Side Units (RSU). La transmisión de video sobre vehículos y el medio ambiente es una tarea complicada debido al elevado movimiento de los vehículos.

Este trabajo tiene como objetivo encontrar las mejores condiciones como velocidad del vehículo y ancho de banda para que la conexión entre la RSU y los vehículos sea óptima. Los análisis simulados de los algoritmos propuestos en las plataformas SUMO, OMNeT++ y Veins se proporcionan utilizando mapas de carreteras urbanas.

Finalmente, en base a los resultados. La comparación entre la descarga total esperada y la obtenida a través de la simulación es que la descarga total obtenida es menor a la descarga total esperada ya que se simula las pérdidas en el envío de paquetes; si el vehículo aumenta la velocidad, también aumenta la pérdida de paquetes. Por lo tanto, las curvas difieren a velocidades más altas. Además, la velocidad óptima seleccionada por los resultados en las Figuras cumplió con las limitaciones del escenario. Es la velocidad más alta que lo hace. Como resultado, el usuario obtiene una mejor calidad de experiencia porque descarga la mayor cantidad posible en un tiempo considerable.

Palabras Clave: transmision de video, sistemas inteligentes de transporte, RSU, banda ancha, etc.

Abstract

Urban population is one of the fundamental elements of a Smart City. This population is the only one that can foster the development of the city and the level of comfort of its citizens. Intelligent Transport Systems (ITS) are technological solutions based on information, technology, and telecommunications designed to improve transportation operation and safety. In recent years, various ITS regulations have been established to control and promote its implementation on the road transport sector and its connections with other transportation methods.

There are various applications related to vehicular networks. The growth of this area and the benefits that it can produce for public and private organizations make the study a constant boom. Some examples of the benefits are security, commercial applications, comfort enhancement applications, and productive applications.

The Internet was initially designed for data traffic, providing an unpredictable and time-varying channel for the delay, bandwidth, and packet loss. While delay-tolerant applications can use TCP protocols that transform time-varying bandwidth and packet loss into added delays, in audio streaming and video streaming applications, these delays are intolerable. The use of multimedia information has been possible, among other factors, thanks to the growth of modern computers and broadband internet connection technology.

The number of people who use the roads to travel to different destinations have grown exponentially, whether in their vehicles, public or private transport, and freight transport. Likewise, situations such as climate change, drivers' speed, and irregularities on the roads are inconveniences that arise when driving. Some occasions cause traffic accidents.

The ITS makes up a global effort among governments, private industry, and research centers to apply new communication technologies to provide answers to global problems. The innovation of technologies of this type consists of the amount of information they are capable of handling by having more agents involved in creating a transport service.

VANET vehicle networks are a particular type of Ad-Hoc mobile networks. They are part of the ITS, where the nodes are moving vehicles such as cars and buses with communication capabilities. There are three types of communication in a network: V2I, V2V, and hybrid network. V2I network consists of the communication between a mobile node or vehicle and an infrastructure node or RSU. V2V is the communication between two vehicles. The hybrid network is the communication of a vehicle with the infrastructure using one or more vehicles. The transmission of video streaming over VANETs must overcome some challenges since such a network is prone to having dynamic topologies and links between nodes.

To achieve cooperation among communication elements and provide greater functionality, wireless communications within transport systems are essential through vehicle network development. The acronym VANET (Vehicular Ad-hoc NETwork) defines a vehicular network consisting of moving vehicles that create highly dynamic networks. Vehicles equipped with wireless communication systems and infrastructure are involved in this deployment.

Communication systems in Vehicle Ad-hoc NETworks (VANET) have become an important area of research. In the last years, technologies have been developed in different areas. In wireless technologies and the Internet of Things, video streaming is an important application because it can offer many valuable services to drivers. Among the benefits that can be accessed is sharing information about traffic, road conditions, traffic accidents, making each vehicle a source of information that can connect to network infrastructure (V2I) using Road Side Units (RSU). Video streaming about vehicles and the environment is a complicated task due to the high vehicle movement.

This work aims to find the best conditions such as vehicle speed and bandwidth so that the connection between the RSU and the vehicles is optimal. Simulated analyzes of the proposed algorithms on SUMO, OMNeT++, and Veins platforms are provided using accurate urban road maps.

The results showed that the download size obtained through the simulation was smaller than the expected total download. The simulation includes the losses in sending of packages. Packet loss increases if the vehicle increases speed. Therefore, the curves differ at higher speeds of the vehicles. Also, the optimal speed, shown in the results, met the constraints of the scenario. The optimal speed is the highest speed that complies with the constraints. As a result, the user obtains a better quality of experience because he downloads as much as possible in a considerable time.

Keywords: video streaming, ITS, RSU, bandwidth, etc.

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Chapter 1

Introduction

1.1 Background

Smart cities worldwide are an innovation considered as a winning strategy to deal with severe urban problems such as traffic, pollution, and energy consumption. This concept attracts governments interest, optimizing the cities systems by making them more efficient. The possible applications of intelligent vehicles, such as vehicles connected to technologies, are very varied and cover a wide variety of different sectors [4].

The network cooperation within (Video Stream Networks) VSNs has a wide range of beneficial applications in a smart city. In the construction of a smart city, VANET networks are a type of Ad-Hoc NETworks or mobile networks of a wireless nature, composed of two types of nodes: static and mobile. Static nodes, also called infrastructures (I), are nodes located along the road with the name of (RSU). Their function is to send, receive or transmit packets in a signal range. Mobile nodes, also called vehicles (V), are nodes equipped with an (OBU) On-Board Unit to communicate with other vehicles or RSUs. This type of node can also send, receive, or transmit packets.

VANET applications depend on one or more types of communication. V2V communication depends on the number and location of vehicles, V2I communication depends on the number and location of RSUs, and I2I communication depends on the interconnection network between the RSUs [5].

The VANETs in smart cities will play an important role, offering security or multimedia services. A Smart City applies the Information Technology and Communications (TICs) in various fields, for example, networks that are connected with computerized systems comprised of a database, tracking, and decision-making algorithms to stimulate sustainable economic growth and high quality of life for citizens [6].

There are two types of VANET applications. The application that increases vehicle safety on the roads is called safety applications. Applications that provide value-added services, for example, entertainment, are called user applications [7].

1.1.1 Safety Applications

Safety applications in VANETs are essential because they must promptly react to their messages before their respective deadlines. For example, if a crash occurs, a node has to activate a safety event and send a beacon message which contains a vehicle's position and the direction of a vehicle to warn other nodes of the crash. According to the authors in [8], drivers are responsible for the most hazardous road accidents. So, safety applications aim to reduce accidents on the road, keeping people safe in the vehicle.

1.1.2 User Applications

In VANETs, the user applications allow online vehicle entertainments such as gaming, file sharing via the internet or the local Ad-hoc NETworks, and video streaming or video-on-demand to allow passengers to enjoy the trip. In this case, we focus on user applications, specifically video streaming. The video server is the static node or RSU, and the video receiver is the vehicle or mobile node.

1.2 Problem Statement

There is an explosive growth of mobile data traffic. It is expected that the mobile traffic will increase seven-fold from 2018 to 2023 [9]. Today, vehicle network (VANET) components are equipped with computerized modules and wireless devices to be part of an Intelligent Transportation System. This advances is due to the evolution of technology that has occurred in recent decades [10]. A vehicle is connected to a network that allows it to benefit from various services.

The automotive industries currently manufacture intelligent vehicles integrated with efficient storage, which has good computing power and can communicate with other devices. Passengers can also have the internet inside their vehicle using the emerging LTE mobile internet technology. However, these applications provide a clearer view to drivers and passengers if high-quality video is exchanged between nearby vehicles.

Based on the new Vehicle Network and Smart City standards, cities factors are mobility, sustainability, population, and the economy as fundamental axes. The deployment of new applications provides service to the population of the city. It causes a better quality of life in the field of transport for both drivers and occupants.

The ETSI intelligent transport system standard has standardized the architecture and communication protocols for an intelligent transport system. It must consider applications related to road safety, such as the connectivity of vehicles connected to the internet. Access to services on the web are daily aspects of our life; therefore, the information service to drivers and passengers through vehicles connection to the internet is one of the aspects of interest in-vehicle networks. Nowadays, users want to enjoy internet applications continuously, not only when they are at home or work. So due to the incorporation of intelligent devices in vehicles, research in info-training has become more critical. Currently, mobile technologies cover most communications and entertainment services, focusing their applications on a larger market. Although the use of services has not been saturated, development and attention to the extensive entertainment market.

Video streaming provides a clear view to the driver and increases traffic awareness for drivers of nearby vehicles. Therefore, establishing a network of these cameras can be helpful to capture traffic or vehicle accidents. Video communication applications between vehicles are also helpful in getting this emerging network quickly to market. Although video streaming through vehicle networks is advanced, it has become a space for research [11].

VANET networks have the primary function to monitor and control vehicular traffic using the V2V and V2I communication concepts. It sends messages in real-time to the vehicles between different lanes and guides them to take an alternative route avoiding traffic congestion. The benefits that VANET provides for smart cities, such as real-time information related to traffic congestion, the same that can be provided to people smart devices to organize their trajectories, are very beneficial in different aspects.

Some of the benefits of a VANET are sharing information about traffic, road conditions, traffic accidents making each vehicle a source of information connected to network infrastructure (V2I) using RSUs. Video streaming over a vehicular environment is a daunting task due to the high movement of vehicles [11]. However, the vehicle can access these benefits as long as it is within the communication range. It means when a vehicle is within the coverage range of the RSU. Then, when this vehicle goes out of coverage range, it enters an area out of its range, losing all means of communication with it.

The main concern of the video streaming in such highly dynamic environments is enhancing the Quality of Experience (QoE). One of the critical issues in VANET is the speed of vehicles. We want to maximize the total downloaded by each vehicle taking into account the time necessary for this. That is, maintain a balance between the total download and the required time to download the video. With this optimization, we want to improve vehicle users quality of experience, making each vehicle download enough data to reproduce the video along the entire road in a considerable time.

Video streaming provides a clear view to the driver and increases traffic awareness for drivers of nearby vehicles. Therefore, establishing a network of these cameras can be helpful to capture traffic or vehicle accidents. Vehicle-to-vehicle video communication applications are also helpful in quickly getting this emerging network to market. Although the transmission of video through vehicle networks is advanced, it has become a space for research. Unfortunately, there is no comprehensive survey to understand contemporary video streaming techniques fully. With the growing interest in video transmission through VANET, this document presents concise information on the background of vehicular networks, simulators, and especially the transmission and main tools used for video streaming in VANET.

The applications related to the VANET networks in security applications compose the basis of the development of vehicular networks. It offers an accident prevention system where there are real-time traffic applications destined for the real-time storage of traffic in the city, identifying possible traffic jams or conflict zones due to contamination or other agents. Accident notification applications give network users full awareness of the road state or an accident reported by the vehicle involved. Applications for traffic surveillance such as camera installations in RSU where information is transmitted in real-time provide an overview of the road. There are applications for the vehicle remote diagnosis where it can be used to forward or receive information related to the vehicle to an RSU that stores the vehicle status on an external server for further processing and presentation.

The video visualization applications in real-time allowing the user to access multimedia content related to the video and access the desired contents on demand. In route selection applications, they may suffer modifications due to traffic congestion or unexpected road conditions resulting from possible accidents or other events. For the standardization of technologies dedicated to vehicle networks, the IEEE 802.11p standard is used, which meets the high requirements such as the nodes high speed and the existence of a highly dynamic topology. The 802.11p protocol operates on the lower layers of the model: physical layer (PHY) and medium access layer (MAC). The network structure composed in the 802.11p standard by network nodes is of two types; OBU represents a vehicle equipped with a short-range communication radio, and the RSU is a device with a DSRC radio located on the roadside [12].

In this part, everything that respects the simulation of the problem will be explained. VANET simulation requires two types of simulation components: network and mobility. Then, three software are required, the first for network simulation, the second for mobility simulation, and the third one is software that integrates the previous simulators. There are many simulators, but this work uses Urban Mobility Simulation (SUMO) for mobility, OMNeT++ for the network, and VEINS that integrate the previous two.

The rest of this graduation project is structured as follows: Chapter 2 stands out to describe the theoretical framework where it is described in the depth of vehicle networks, VANET, network simulators, traffic simulators, video streaming, and protocols used in streaming video. Chapter 3 describes the state of the art based on the different works. Also, it includes the explanation of the mathematical models implemented in works where VANET networks and video streaming are used to facilitate access to users on the state of traffic in real-time and their subsequent communication with other vehicles. State of the art also includes routing protocols used for VANET showing significant performance in terms of the number of hops and delivery. Chapter 4 covers the methodology used to solve the problem by implementing the environment that simulates video transmission in a VANET. A mobility scenario is created in SUMO to program the nodes behavior (RSU and vehicles). The integration is carried out in OMNeT++, and the two previous simulators are integrated into VEINS. Chapter 5 presents a discussion of the different scenarios results where an optimal speed is established that maximizes the total download in Megabytes depending on the speed of the vehicle when it is in coverage or within the signal range of an RSU. Finally, chapter 6 includes conclusions of the work carried out, limitations, and future works.

1.3 Objectives

1.3.1 General Objective

- Optimize video streaming in Vehicular Ad-hoc networks using the Veins simulator.

1.3.2 Specific Objectives

- Describe the sending of packets/frames in video streaming from an RSU to a vehicle.

- Characterize the behavior of the RSUs and the vehicles in video streaming using simulation.

Chapter 2

Theoretical Framework

In this chapter, the theoretical framework describes vehicular networks, VANET simulators such as Veins, PARAMICS, TraNS, and NCTUns. It presents an overview of different network simulators such as OMNet++, NS-2, NS-3, iST/SWANS, and traffic simulators such as SUMO, VanetMobiSim, STRAW, and BonnMotion. It also explains the video streaming architecture and protocols used in video streaming.

2.1 Problem Modeling

The Roadside Unit (RSU) is an essential infrastructural static unit in VANET for collecting and analyzing traffic data or multimedia. RSUs assist vehicle's efficient and secure driving by relaying traffic data, broadcasting locally analyzed traffic data, and sending packets with video frames [13]. Thus, RSUs are supposed to be installed for maximizing data collection and distribution. An efficient RSU placement for maximizing vehicular network connectivity is inevitable for supporting real-time video streaming and instant responses to VANET elements.

In this communication process (video streaming) between the vehicle and the RSU (V2I), the RSU plays an essential role. It is in charge of sending the video to the vehicle by sending packets (frames) containing information about the group of pictures (GOP). The video codification compresses the information using the estimation techniques and movement compensation to eliminate the temporary redundancy between consecutive photograms [14].

The coded video stream is a succession of GOPs of a specific size. GOP always starts with an I-frame (Intra-coded frame or reference frame), also called ”keyframe.” The size of the GOP is the distance between two consecutive I-frames (e.g., IBBPBBPBBPBBPBBI means that the size of the GOP is 15). For this scenario, we have chosen to use the Star Wars movie with a size of 646MB in Figure 2.1 it can be seen in some frames.

```
# This trace was obtained from trace.eas.asu.edu
# Sequence: Star Wars 4
# Resolution: 352x288
# FPS: 30
# Encoder: H.265/HEVC 8.0
# Encoding type: Main, 3T, Delta 264C
# GoP pattern: G16B15
# Quantization parameters (I,P,B_avg): 10, N/A, 18
# Layer: 3
# Other:
# Frame Time [s] Type Size [Byte] PSNR-Y [dB] PSNR-U [dB] PSNR-V [dB] VQM (if exists)
0   0   I   211 188.1308    70.12836    70.12836
1   0.03333 B   13  188.1308    70.12836    70.12836
2   0.06667 B   18  188.1308    70.12836    70.12836
3   0.1 B   13  188.1308    70.12836    70.12836
4   0.13333 B   13  188.1308    70.12836    70.12836
5   0.16667 B   13  188.1308    70.12836    70.12836
6   0.2 B   18  188.1308    70.12836    70.12836
7   0.23333 B   13  188.1308    70.12836    70.12836
8   0.26667 B   20  188.1308    70.12836    70.12836
9   0.3 B   13  188.1308    70.12836    70.12836
10  0.33333 B   18  188.1308    70.12836    70.12836
11  0.36667 B   13  188.1308    70.12836    70.12836
12  0.4 B   13  188.1308    70.12836    70.12836
13  0.43333 B   13  188.1308    70.12836    70.12836
14  0.46667 B   18  188.1308    70.12836    70.12836
15  0.5 B   13  188.1308    70.12836    70.12836
16  0.53333 I   153 188.1308    70.12836    70.12836
17  0.56667 B   13  188.1308    70.12836    70.12836
18  0.6 B   18  188.1308    70.12836    70.12836
19  0.63333 B   13  188.1308    70.12836    70.12836
20  0.66667 B   13  188.1308    70.12836    70.12836
21  0.7 B   13  188.1308    70.12836    70.12836
22  0.73333 B   18  188.1308    70.12836    70.12836
23  0.76667 B   13  188.1308    70.12836    70.12836
24  0.8 B   20  188.1308    70.12836    70.12836
25  0.83333 B   13  188.1308    70.12836    70.12836
26  0.86667 B   18  188.1308    70.12836    70.12836
27  0.9 B   13  188.1308    70.12836    70.12836
28  0.93333 B   13  188.1308    70.12836    70.12836
29  0.96667 B   13  188.1308    70.12836    70.12836
30  1   B   18  188.1308    70.12836    70.12836
31  1.03333 B   13  188.1308    70.12836    70.12836
32  1.06667 I   153 188.1308    70.12836    70.12836
33  1.1 B   13  188.1308    70.12836    70.12836
34  1.13333 B   18  188.1308    70.12836    70.12836
35  1.16667 B   13  188.1308    70.12836    70.12836
36  1.2 B   13  188.1308    70.12836    70.12836
37  1.23333 B   13  188.1308    70.12836    70.12836
```

Figure 2.1: Frames of the video.

In paper [15], the authors formulated a unicast transmission platform operation in an optimization problem to maximize the average video quality received by users and minimize travel time while satisfying the restrictions.

2.2 VANET

VANET is a type of excellent interest network in recent years by researchers, standardization bodies, and developers. It has the potential to improve road safety, improve traffic and travel efficiency, and make transportation a more comfortable and efficient means for both drivers and passengers.

The construction of smart cities has become a fundamental objective to improve the management of urban flows that depend on Information and Communications Technologies (ICTs), where the focus is on implementing safer and more efficient roads. However, the advancement of wireless technologies and their application in automobiles makes it possible to use the intelligent transport system.

Vehicular wireless communications have received significant attention in recent years due to the unique characteristics that distinguish them from Mobile Ad-hoc NETworks (MANETs). A MANET includes its rapid adjustment to topology changes and its high mobility, allowing it to form a highly dynamic network.

VANETs are technology that uses vehicles as nodes to create a mobile network. This concept has taken on a significant role in the field of smart cities in order to increase safety among motorists. When implementing Ad-hoc NETwork, it is necessary to consider certain specific characteristics such as mobility, constant change, the exchange of information between vehicles, and the unlimited size of the network. Likewise, each vehicle must be implemented by a VANET device to form an Ad-hoc NETwork and transmit messages on the network. The main drawback is the instability of the network, which reduces its efficiency.

The collision warning system effectiveness in cars has been improved, allowing cross-communication between the nearby vehicles so the network can communicate packets of relevant information between them. For the maintenance of the nodes and the route, it is necessary to discover the route through the broadcast of messages, which is the main challenge of VANETs due to the vehicles dynamic behavior.

The VANET architecture consists of three domains: Domain in the vehicle is composed of one or multiple On-Board Units (OBU) and Advanced Driver Assistance Sensors (ADAS) such as cameras and actuators. Communication between these systems is usually hard-wired and based on the Controller Area Network (CAN) bus and vehicle power line communications.

The Ad-hoc NETwork contains vehicles equipped with OBUs and infrastructure units (RSU). The OBU is like a mobile node in an Ad-hoc NETwork, and the RSUs correspond to a static node. Communications for V2V and V2I are based on dedicated short-range communications planning (DSRC/802.11p).

The infrastructure mode refers to RSUs connected to the internet through some gateway. These MSW or other hosts located outside the road network are what make smart cities connected.

Figure 2.2 shows the vehicle OBUs that can connect to the internet through V2I communications. In the absence of RSUs or access points, OBUs can also communicate with each other and with the internet by using mobile devices radio networks.

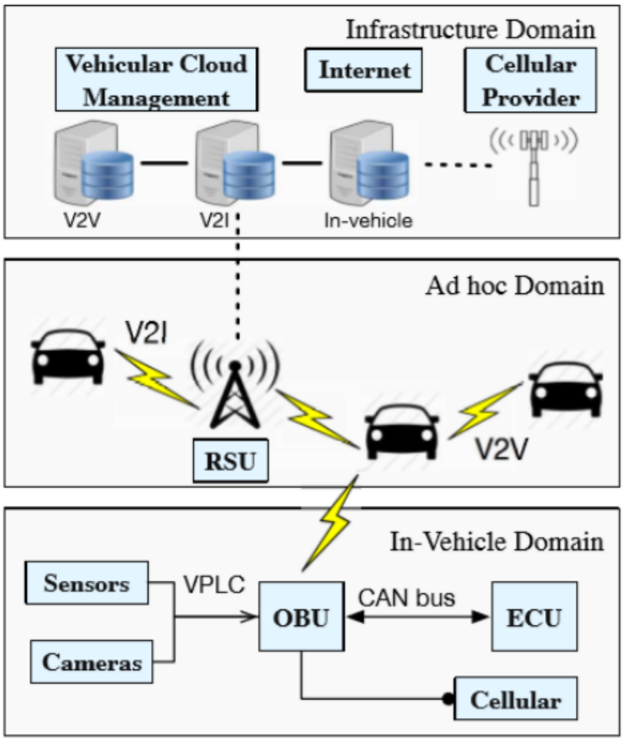

Figure 2.2: Architecture of a vehicle (OBU) to infraestructure (V2I) communication.

VANETs focus on short-range intercommunication with V2V and V2I architectures. The purpose is to connect when any car joins or leaves the network regions. Road journeys can be optimized using the IEEE 802.11p standard, which defines the physical and control layers of access to the medium, allowing vehicular communications.

The 802.11p standard defines the mode of interconnection between stations in limited areas using radio frequency as a transmission medium, which constitutes one of the most exciting standards for evolving interconnection technologies in local areas. The first version marks the beginning of technology with a great future. However, the need has arisen to communicate portable devices at high transmission rates.

Another standard involved in developing networks is IEEE 802.15.4, which focuses on providing a framework and the lowest levels for low-cost and low-power networks. It only provides the MAC and PHY layers, leaving the upper layers to develop according to market needs.

The development of a vehicular network is low-cost and low-speed communication between devices. It is not intended to compete with the more commonly used end-user-oriented systems such as IEEE 802.15.4. Costs are not as critical, and higher speeds are demanded. The concept of IEEE 802.15.4 is to provide communications over distances of up to 10 meters and with maximum data transfer rates of 250 kbps [16].

The IEEE 802.11p standard supports IP packets transmission and WAVE Short Messages (WSMs) since the IEEE 1609.3 standard defines a protocol for the VANET network layer called the WAVE or WSMP short message protocol. The messages sent by WSMP are called WAVE or WSM short messages. This type of message allows the exchange of information through a vehicular network. The number of overhead bytes in each message is small.

WSM messages contain information associated with data transmission, including WSMP protocol version, service provider identifier, PSID, data rate, transmission power, and channel number. The standard has multi-channel operation since one of its functions of the media access layer consists of prioritizing messages generated by security applications. Therefore, the 802.11p standard establishes an access mode channel access scheme, each associated with an independent channel and a different priority.

2.3 Simulators

There are three large groups of network simulators; isolated, integrated, and hybrid simulators. Isolated simulators are the first to propose those mobility models act together with network simulators, allowing the latter to load mobility scenarios. This type of simulators works with scenarios obtained from traffic simulators or complex mobility models that have to be previously generated.

Integrated simulators are an evolution opting for the substitution of both in a more straightforward off-the-shelf simulator used by some studies to approximate the 802.11p standard. In this way, an attempt is made to achieve mutual collaboration between the traffic generator and the network simulator at the expense of not using complex protocol stacks.

The most significant disadvantage of integrated simulators is the low quality of the network simulator, which causes their use to be limited in VANET network environments since they are unable to reproduce the behavior of protocols of this type of network, as well as that of the layers physical (PHY) and media access (MAC) using the 802.11p standard.

Hybrid simulators incorporate the development of an interface responsible for translating the instructions between the network simulator and the traffic generator. In this way, a hybrid union is achieved between both parties. The main advantage in using this type of simulators consists of the use they make of the benefits offered by both simulation tools. However, there is the disadvantage of the high computational cost that involves taking into account that a communication interface between simulators can lead to complex network development.

In this part, everything that respects the simulation of the problem will be explained. VANETs simulation requires two types of simulation components: Network and mobility. So, it is required three software, the first one for network simulation, the second one for mobility simulation, and the third software that integrates the previous simulators. There are many simulators, but in this work, we use Simulation of Urban MObility (SUMO) for mobility, OMNeT++ for networks, and Veins which integrate the previous two.

2.4 VANET Simulators

2.4.1 VEINS

Veins (Vehicles in Network Simulation) is an open-source hybrid simulator focused on simulating VANET networks. For its correct operation, it must use a mobility simulator (or traffic generator) and a network simulator.

The Veins simulator offers a set of models to simulate different V2V type communications, achieving the integration of the simulators previously exposed. In this case, the vehicles movement (generated by SUMO) is reflected in the movement of the nodes in the network simulator (OMNeT++).

In this way, the nodes can interact with the road traffic in a precise and straightforward way; therefore, it allows developing, analyzing, and evaluating applications aimed at ITS through vehicle networks.

This simulator main characteristics are the IEEE 802.11p IEEE 1609.4 DSRC/WAVE layers, the use of OpenStreetMap maps with a high level of speeds, crossings, among others, and the use of computer models to consider conflict zones due to the presence of buildings or other vehicles.

This simulator has two separate events queues. At regular intervals, the manager module triggers the execution of a one-time step of the traffic simulation, receives the resulting mobility trace, and triggers position updates for all modules it had instantiated [17].

Veins provides models that can serve as a modular framework for simulating applications. Each model is contained in one or more of what OMNeT++ terms a module, which can be instantiated in a running simulation to provide the required functionality. Figure 2.4 shows Veins modules and the integration of SUMO and OMNeT++. Each simulation in Veins is performed by executing two simulators in parallel: OMNeT++ (for network simulation) and SUMO (for road traffic simulation). Both simulators connect via a TCP socket. The protocol for this communication is the Traffic Control Interface (TraCI). This communication allows bidirectionally-coupled simulation of road traffic and network traffic. The movement of vehicles in the road traffic simulator SUMO is reflected as nodes movement in an OMNeT++ simulation [1].

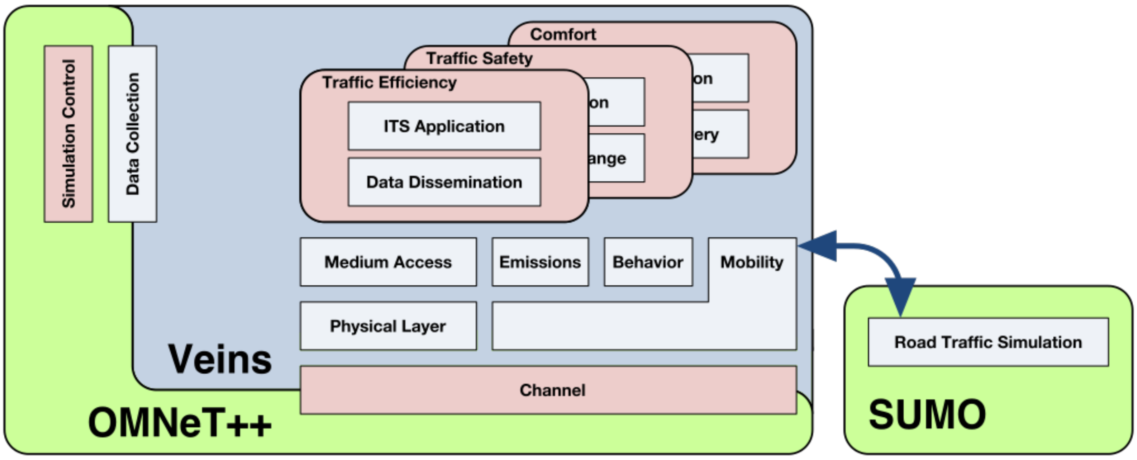

Figure 2.3: Modular structure of Veins. Source [1].

Veins includes some models like 802.11 that is tailored to use in vehicular networks, particularly IEEE 802.11p. This includes QoS channel access conforming to EDCA (that is, four queues with different access categories) and accurately captures frame timing, modulation and coding, and channel models [17]. It includes QoS channel access conforming to EDCA (four queues with different access categories). It accurately captures frame timing, modulation and coding, and channel models.

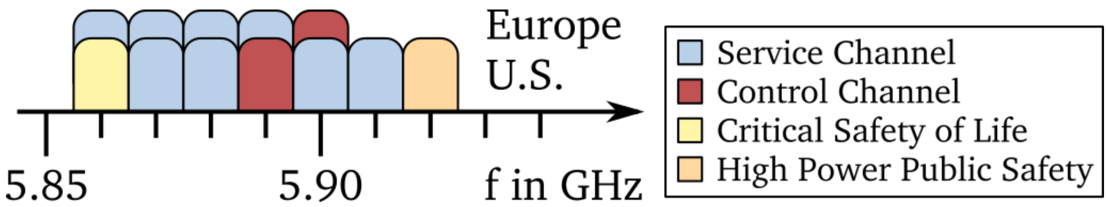

Figure 2.4: Model 802.11p used in Veins to include QoS channel. Source [1].

2.4.2 PARAMICS

It is an integrated simulator that works on Windows operating systems. It contains a series of tools that allow the analysis and design of vehicle networks. It can simulate the behavior of the different components of the traffic and present the result graphically in real-time. This simulator is capable of modeling in detail the physical layout of the nodes, taking into account public transport, particular nodes, road marking elements, and drivers behavior.

2.4.3 TraNS

TraNS (Traffic and Network Simulation Environment) is a hybrid simulator written in C++ and Java that works on Windows and Linux. It contains visualization tools that allow integrating the SUMO and NS-2 simulators to simulate VANET networks. The functionalities of TraNS are the use of TraCI (Traffic Control Interface). This simulator allows working together events such as accidents and the generation of possible random routes of vehicles, and the use of TIGER-type maps. In addition to the functionalities, it has two applications for VANET networks called Road Danger Warning and Dynamic Reroute.

2.4.4 NCTUns

The NCTUns (National Chiao Tung University Network Simulator) integrated simulator can simulate protocols of all types of wired and wireless networks. This simulator main feature is that it uses the Linux TCP/IP protocol stack to obtain precise simulation results, taking into account VANET network simulations simulating the 802.11p/609 WAVE protocol to establish V2V and V2I communications.

Below is a comparison of the different most essential simulation tools for their application to VANET networks. This subsection presents a comparative table between them.

It is highlighted that the OMNeT++ simulator has the main advantage in its modular structure, providing great extensibility to the projects that are developed on it and tending adequately to VANET networks.

In the same way, SUMO is the best solution since it is the tool that allows us to obtain a greater degree of detail when simulating VANET networks even though it performs the route calculation before starting the simulation itself.

Table 2.1 shows a comparison of characteristics between different VANET simulators. It helps us to select the simulator according to the study to be carried out.

Table 2.1: Comparison of features between different VANET simulators

	VEINS	PARAMICS	TraNS	NCTUns
Free	YES	YES	-	YES
Language	C++	C++ & Python	Java	C++
Platform	Windows & Linux	Windows	Windows & Linux	Linux
Supported Simulators	SUMO & OMNeT++	Traffic	SUMO & SN-2	Traffic & Net

2.5 Network Simulators

A network simulator is a software program that forms a network performance by analyzing the relations between the various network entities such as nodes, routers, links, and access points.

2.5.1 OMNeT++

The OMNeT++ network simulator is a C++ simulation library whose initial purpose was to develop simulators for all types of communication networks (wireless and wired). OMNeT++ has a public license that can be used only for academic purposes and a commercial use license from SimulCraft Inc.

Another characteristic of this simulator is its development integrated with Eclipse. It has a graphical simulation interface and a large number of tools that allow extending its initial functionality, such as real-time simulation, the use of databases, among others. The OMNeT++ network simulator works for different environments such as Windows, Linux, Mac OS X, among other Unix systems [12].

Domain-specific functionality, such as support for ad-hoc wireless networks, Internet protocols, performance modeling, and photonic networks, is provided by model frameworks developed as independent projects in OMNeT++. OMNeT++ offers an Eclipse-based IDE, a graphical runtime environment, and a host of other tools [17].

An OMNeT++ model contains modules. The active modules are called simple modules. These are grouped into compound modules, and messages can be sent via connections between modules or directly to their destination modules. Both compound and specific modules are instances of module types. Modules can have parameters. Parameters are mainly used to pass configuration data to simple modules and to help define the model topology. Parameters may take a string, numeric or Boolean values [18].

2.5.2 NS-2

NS-2 is a discrete event simulator currently used primarily in academia. It is expected to be replaced by SN3 in the coming years. This simulator written in C++ has an object-oriented TLC extension that can be used to execute scripts and the specification of aspects such as the network topology, avoiding unnecessary compilations when modifying the simulation parameters. Currently, there is no problem, and this solution involves degrading the performance of the entire simulation.

In this case, NS-2 allows simulations to be carried out, taking into account different parameters such as propagation and the protocols of the 802.11 standard, which allows obtaining a high degree of detail in the simulation of VANETs. One of this simulator main advantages is that the output provided can be used by other programs such as SUMO (traffic simulator) and allows integration between the two.

2.5.3 NS-3

The NS-3 simulator was funded by the NSF (U.S. National Science Foundation) to replace the NS-2 simulator. Being publicly available under the GNU GPLv2 license and has released its first version of the software. NS-3 was designed in C++, allowing the integration of some features implemented in the Python language. In this way, and unlike NS-2, TLCs use is not used, which implies that the traces of code developed for this simulator cannot be used by the new one. The network simulator makes up a set of libraries that combine with other external ones. NS-3 works on the command line with C++ and Python development tools.

2.5.4 JiST / SWANS

JiST (Java in Simulation Time) is a discrete event simulator that works on a virtual JAVA machine using the so-called virtual simulation. It is possible to optimize the time consumption, and the memory consumption spent in the simulation. This simulator is compiled with a standard Java compiler that allows it to run on a virtual machine without making any previous modifications.

SWANS is a network simulator used on JiST created to cover the needs of research in this field that other simulators could not cover. This simulator functionality is similar to that used in SN-2, having the ability to simulate more extensive networks, reducing, through the use of JiST, the memory and execution capabilities of standard network applications written in JAVA language.

Table 2.2 shows a comparison of characteristics between different network simulators. It helps us to select the simulator according to the study to be carried out.

Table 2.2: Comparison of features between different network simulators

	OMNeT++	NS-2	NS-3	JiST/SWANS
Free	YES	YES	YES	YES
Language	C++	C++	C++ & Python	Java
Platform	Windows Linux MAC	Windows Linux MAC	Windows Linux MAC	Windows Linux
Supported Simulators	VEINS	SUMO	SUMO	VISSIM

2.6 Traffic Simulators

2.6.1 SUMO

It is a free traffic simulator developed by the DRL (Dutsche Gesellschaft fur Luft and Raumfahrt) in C++ language, allowing to simulate microscopic traffic and vehicle movement based on its variables such as pedestrians and public transport. SUMO considers the different lanes of the roads, so it also implements lane changes of the vehicles and the behavior of the same in the crossings. One of the advantages it offers is the graphical user interface (GUI) that helps considerably develop scenarios, having no limits on the size of the network or the number of vehicles. Another advantage that it presents is that it can work on different operating systems. The disadvantage it presents is that it calculates the vehicles routes before starting the simulation, which makes it challenging to evaluate the V2V communication since it can change its course due to the movement of the vehicles along the highway [12].

SUMO is a microscopic simulator based on the individual emulation of each vehicle movement that participates in the stage. SUMO can adopt a different movement to each vehicle on the stage, making an environment closer to reality. Stefan Krauss develops the mathematical model that implements this microscopic behavior.

SUMO works in continuous space in the sense that at each discrete time instant of the simulation, each vehicle position is perfectly described. That is, the exact position of each vehicle can be known at any instant of the simulation. Vehicles arrive at their destination defined by the user or automatically via the shortest route.

In a scenario where multiple vehicles are involved depending on the simulation specifications, this could cause traffic congestion on the arterial streets of the digital map. In contrast, another of SUMO limitations is that having the routes of each vehicle preestablished in the simulation. It will be of great use of memory of the machine used without compression, which is quite aggravated in scenarios where many vehicles are used. It can also be highlighted that SUMO can be divided into small subprograms that work in conjunction. Each one has its function to carry out the final result [19].

SUMO allows for intermodal simulation, including pedestrians, and comes with a large set of tools for scenario creation [20]. Its main features include different vehicle types, single-vehicle routing, junction-based right-of-way rules, the hierarchy of junction types, an open GUI (Graphical User Interface), and dynamic routing [21].

2.6.2 VanetMobiSim

It is an extension of the framework used for vehicle simulation called CaniMobiSim (CANU Mobility Simulation Environment). It is implemented in JAVA as an independent application, allowing its use with almost any simulation tool dedicated to networks. VanetMobiSim stands out for its versatility in the use of both macroscopic and microscopic mobility models. VanietMobiSlim allows to import maps from the census office database in TIGER/Line format or generate randomly using the creation of zones from specific points. Therefore, it allows simulating roads with several lanes considering the signaling at intersections and traffic flows. It means traffic in both directions and speed limitations. It also allows the use of motion models that use V2V and V2I interactions to regulate vehicles speed, among other parameters.

2.6.3 STRAW

The free STRAW (Street Random Waypoint) traffic simulator, developed by AquaLab, is capable of simulating vehicles natural behavior with a high degree of detail thanks to the use of a mobility model based on the study of traffic in various cities. This simulator was designed to be used in conjunction with a discrete event simulator (JiST/SWANS network simulator). STRAW is advisable to download the Eclipse IDE and the TMRS Software, whose function is to convert TIGER (Topologically Integrated Geographic Encoding and Referencing) maps to a format compatible with this simulator.

2.6.4 BonnMotion

This software is free and implemented by the University of Bonn in Germany, which allows analyzing mobility scenarios, being one of the most widespread for the study of MANET networks. One of the advantages of using this simulator is the interoperability of the traffic scenarios created with simulators such as NS-2, NS3, or MiXim. It is possible thanks to the fact that BonnMotion saves the routes drawn by the nodes following the node and link model. Another advantage of BonnMotion is that it can be used on any platform with a JRE compatible with the JAVA Oracle 1.8 version, thus allowing its use on both OS X, Linux, and Windows.

Table 2.3 shows a comparison of characteristics between different traffic simulators. It helps us to select the simulator according to the study to be carried out.

Table 2.3: Comparison of features between different traffic simulators

	SUMO	VanetMobiSlim	STRAW	BonnMotion
Free	YES	YES	YES	YES
Language	C++	Java	-	Java
GUI	YES	YES	NO	YES
Using real maps	YES	YES	YES	YES
Multi-lane roads	YES	YES	YES	NO
Direction of traffic	YES	YES	YES	NO
Pedestrian movement	YES	NO	NO	NO
Vehicle types	YES	NO	NO	NO
Intersection management	YES	YES	-	NO
Signaling	YES	YES	YES	NO

2.7 Video Streaming

The basic architecture of a video streaming system does not vary substantially, as shown in Fig. 2.5. Once encoded and compressed, the video and audio information are stored on the server. When the client requests to receive compressed video and audio, the QoS control module adapts the audio and video streams according to the network characteristics and the level of QoS that negotiates the resources necessary for transmission with the network [2].

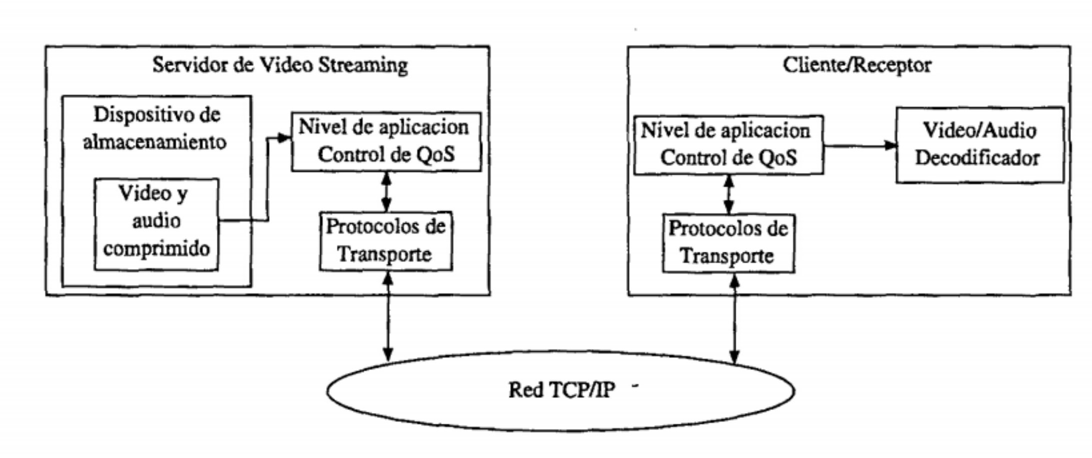

Figure 2.5: Video streaming system basis architecture. Source [2].

The characteristics of the network and the services offered by it determine the different strategies in the transmission of video to maintain minimum levels of quality in the receiver. If the network provides only the best-effort delivery service using techniques to minimize the effect of delay variations, the transmission rate's control, and instants of congestion, to adapt to these conditions. Therefore, the impact of bandwidth variations, delay variations, and packet losses on the video transmission is minimal.

If the network provides QoS services, it is possible to combine the different types of QoS services provided by the network with the different scalable video coding techniques to obtain a transmission strategy that allows maintaining the minimum quality levels in reception.

The video streaming service is the transmission of video for real-time playback. The video stream is received continuously by the final user while the video provider delivers it. Downloading the file generates very high transfer times due to the size of the files. This type of system tolerates a certain level of losses. It is translated as outages, so if they do not occur in long-duration bursts or the loss of several frames, principally I frame (Fig. 2.6), the effect may go unnoticed. Therefore, if the losses are infrequent, the final user only perceives small unavailabilities, which do not alter his general impression.

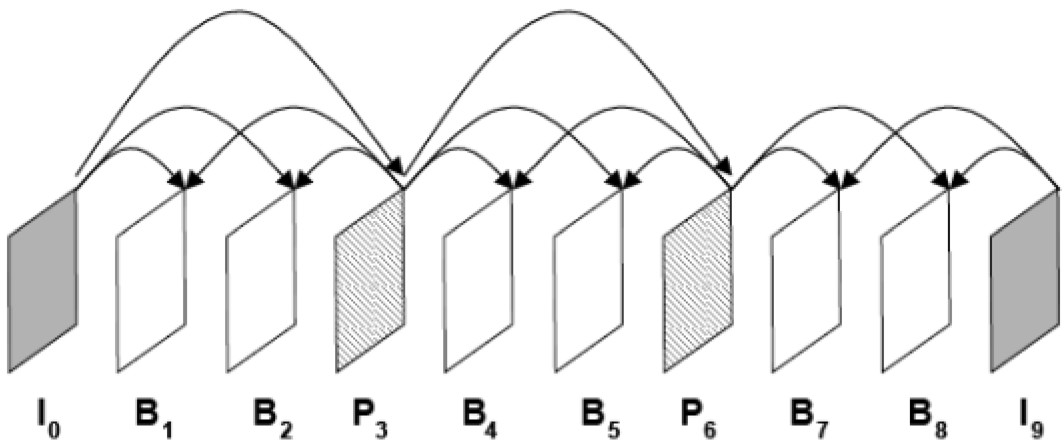

Figure 2.6: Dependencies between frames (MPEG). Source [2].

Video compression techniques basis on taking advantage of the similarities that exist between frames of a sequence. The temporary redundancy in consecutive frames is because they usually contain the same objects, although possibly displaced. A video sequence is a group of images or frames that can be encoded as independent images. An essential factor for the right prediction is found in the correct estimation of the movement. The frames classify into three different categories type I frame (Intra-coded-frame), where the frames are coded independently from the rest; P-type frames (predictively coded frame), where the frame is coded according to the frame above and B-type frames (bi-directionally predicted frame).The following table 2.4 shows the different frames characteristics according to their type.

Table 2.4: Comparison of features between frame types

Frame type	Frame I	Frame P	Frame B
Compression ratio	Come down	Good	Excellent
Amount of information	Quite	Little	Minimum
Number of frames	One per GOP	There may be sereval	There may be quite a few
Consequence of loss of the frame	No frame of all that GOP can be decoded	Impossible to decode the remaining frames of the GOP	No impact on other pictures

2.7.1 IMGPG4 Format

MPEG-4, called ISO / IEC 14496, is a standard developed by the MPEG group to represent and deliver multimedia information on a wide variety of transport protocols. Interactive management includes video streaming, audio-video representation, and system functionalities such as multiplexing, synchronization, and an object-oriented descriptor framework. Based on the large number of features that make up the MPEG-4 standard, not all are available in all implementations.

The MP4 file is made up of container structures, also called atomic ones, containing other lower-level atoms. The atoms are made up of an 8-byte header that indicates the container length and the type of atom it is. Multimedia data is stored in the top-level atom of type mdat (media data). This data can be of any type: text, audio, voice, synthetic images, among others.

2.7.2 RTP/RTCP

Real-Time Protocol and Real-Time Control Protocol are two complementary and session-level protocols that transport data streams in real-time over unicast or multicast networks such as streaming systems. Given the data instantaneous nature, the retransmission of the emitted packets would suppose that the receiver discarded them for arriving out of time. Therefore the transport protocol used is UDP. (User Datagram Protocol). An RTP session uses two consecutive ports. The first pair port transmits RTP packets, that is, data encapsulated in RTP packets. The second contains the RTCP packets that provide a feedback mechanism to report the data distribution quality. For the audio-video transmission, each stream is broadcast by a different RTP session, so 4 UDP ports are required [22].

2.8 Video Streaming Protocols

2.8.1 Video Streaming in Vehicle Networks

Video streaming communication is designed to provide an excellent benefit for traffic management. In the long term, it will be possible to transmit multimedia data such as images or short clips of floods, fires, earthquakes, among others. The driver will be able to make decisions based on his priorities. During emergencies, this will speed up the assistance process or evacuation procedures and improve vehicular navigation safety. Video streaming on vehicle networks can also provide value-added entertainment.

Despite high connectivity, applications deal with various challenges due to transmission, coverage area, video quality requirements, and highly dynamic topologies. The protocols routing decisions must adapt to these conditions and comply with certain specific requirements of QoS (Quality of Service) and QoE (Quality of Experience). The delay transmission should not exceed 10 seconds, or the packet loss should not exceed 5%. Although video broadcasting involves higher bandwidth, it should not be exaggerated and transmit overwhelming amounts of data. The BER in a wireless transmission threshold values indicates "very poor" to "excellent" video quality. These values are between $> 1x10e - 3$ to $< 1x10e - 4$.

VANETs must have the ability to ensure delivery of video streaming from source to destination and provide smooth, near-real-time playback. High vehicle speeds, rapidly changing traffic density, lossy wireless links, and other road factors make it challenging to find a stable end-to-end path for video packet delivery. Some of the streaming video protocols are detailed below.

2.8.2 An Application-Centric Inter-Vehicle Routing Protocol

This protocol tries to transmit on the path with the fewest hops. It is used for the transmission of video in real-time through the VANET network in urban settings. This routing protocol is based on exchanging information between the application layer and the network layer to select the path that minimizes the frame distortion function of the application layer using error probability in point-to-point transmission. The routing design considers the spatial distribution of traffic and the probability of connectivity for VANET scenarios. The goal is to maximize the end-user peak signal-to-noise ratio of the received video frame. The vehicle at each hop uses a decoding and forwarding scheme to transmit the packets to the next-hop without amplifying noise effects. The vehicle transmission of the packages first selects a subset of candidate vehicles to forward their packages.

This protocol is based on the topology that transmits video packets to the target vehicle through multi-hop communication. The intermediate vehicles interact with a jump communication to relay the video packets to the destination vehicle. The switching of transmission between RSUs during a video session is controlled by an access router that controls multiple RSUs. Suppose the vehicle leaves the coverage range of an AR (Access Router). In that case, a handover occurs, and a new Ar controls the transmission through a set of RSUs, which cover the target vehicle current location. The vehicular network is based on the 5.9GHz standard for short-range communications. Each vehicle is transmitting information about its position, current time, direction, speed, acceleration, and traffic events to its neighbors.

The mobility model used to extract the connectivity between two vehicles and formulate the QoS and determine its optimization is An Application Centric Inter-Vehicle Routing Protocol. The probability of connectivity is defined as the probability that the vehicles along the streets can communicate through a radio link. This protocol focuses on the characteristics of geographic routing protocols since they are more suitable for VANETs.

2.8.3 A Reliable Beaconless Routing Protocol for VANETs (RBRP)

The RBRP protocol is used for unicast forwarding packets without the help of beacons. The RBRP proposes a self-adaptive forwarding zone to avoid multipoint broadcasting. The critical points in RBRP are the definition of the forwarding zone and the timeout algorithm. The choice of the direction of the forwarding zone is based on the destination location and the direction of movement of the current sender. The size of the forwarding area can be adjusted according to the density of traffic. The direction of movement of the current node is the direction coordinate reference Fig. 2.7, the angle between the reference direction and the line connecting the emitter and the destination. Suppose the absolute value of the angle is less than 90 degrees. In that case, the direction of the return zone is the same as the reference direction. Finally, θ is the opening angle of the forwarding zone (yellow zone).

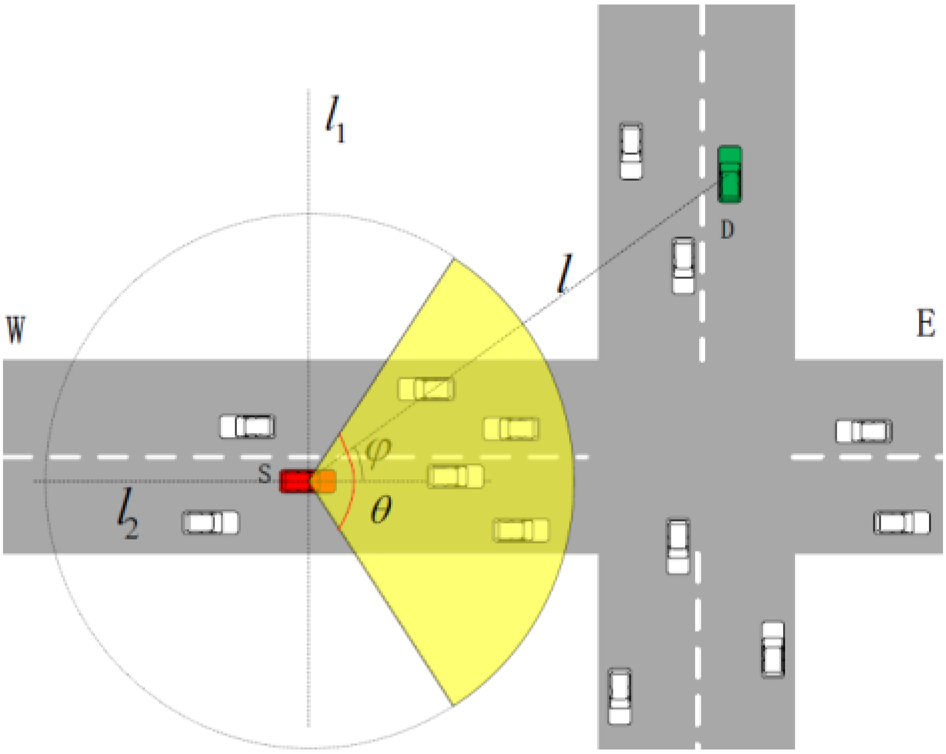

Figure 2.7: Forwarding area of the current node and line to connect the sending node and receiving node. Source [3].

The timeout determines the priority of the nodes in the forwarding zone. The main idea of RBRP is that the sender determines if the distance from him to the destination is less than the communication range R. If the sender determines that the destination is less, it sends the packets and ends the delivery. Otherwise, the sender adds in the packets the information of its destination location, destination ID, emission time, and angle of the node forwarding zone. On the other hand, the receivers record the reception time individually. According to the contention scheme, the nodes in the forwarding zone calculate the timeout and compete for the right to forward the packets while the nodes outside the forwarding zone discard the packets.

2.8.4 QoE-aware Routing for video Streaming over VANETs

The routing protocol is based on the quality of the experience for streaming video through VANETs. The most popular routing protocols are AODV (Ad-Hoc On-Demand Distance Vector Routing) and OLSR (Optimized Link State Routing). To evaluate the video perception in real-time, the PSQA (Pseudo-Subjective Quality Assessment) is used, which is based on statistical learning using the random neural network of oriented networks as income, giving the corresponding MOS as output. QoE-aware routing is intended for mesh networks where each node in the network uses reinforcement learning to select the path.

2.8.5 Opportunistic Vehicular Routing: Opportunistic Multicast for Emergency Video Streaming.

Dissemination of information such as short clips, floods, fire, earthquake damage is an emergency that must take place within minutes of the accident before police and news helicopters intervene at the scene. The emission must be efficient and light so as not to congest the network. The information must be reliable to all the vehicles involved so that actions can be coordinated. Finally, video delivery in emergencies should not be based on fixed infrastructure because, in an earthquake, cellular base stations can be affected.

In multi-hop broadcast, packets can become corrupted and lost due to environmental interference. For this, it is proposed to combine path diversity and a network coding strategy. The strategy must consider scenarios where cars can form platoons like in Fig. 2.8. Therefore, the information will have delays until arriving from the first platoon to the second. To mitigate this challenge, a data mule approach is used to take advantage of oncoming vehicles. Figure 2.8 the platoons Pr1 and Pr2 behave like data mules if the road has several lanes in both directions. The vehicles will pick up, transport, and retransmit the packets.

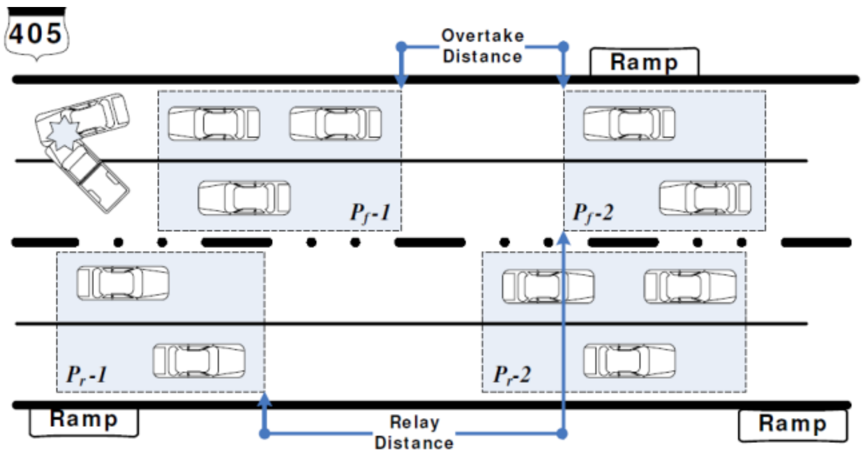

Figure 2.8: Retransision model where cars form platoons. Source [3].

2.8.6 Opportunistic Routing for Live Video Streaming in Vehicular Ad-Hoc Networks

The protocol takes interference into account and formulates a distortion model in LVS (Live Video Streaming) delivered over VANETs. In this model, a method is designed for the optimal selection of the repeater node; through this method, predicting the minimum distortion rate of video transmission can be calculated along each road segment.

The central part of the protocol is to consider the delay of the video streaming. To achieve that, a new algorithm is adapted that makes the vehicles change their delivery mode adaptively. Therefore, the forwarding of video packets creates a strategy called opportunistic. The protocol will consider the interference and the delivery time of the packets relating to the error and the packet delay. If the vehicle can deliver the package, it will decide whether or not to deliver it based on the calculation of the distortion at the delivery of the package [3].

In conclusion, VANET networks have been of great interest in recent years because they allow to enhance and increase road safety and travel efficiency, making transport a more comfortable and efficient means for drivers and passengers. The Ad-Hoc network is used from the information search, which is made up of vehicles equipped with OBUs and RSU infrastructure units. The 802.11p standard is the one that defines the interconnection modality between stations that allows communication through IP packets. The simulators used for this work are the SUMO traffic simulator and the OMNeT++ network simulator, used in real-time and used to download streaming video.

Chapter 3

State of the Art

This chapter state of the art describes the different works found in the implementation of RSU in urban or suburban roads and its optimization in relation to coverage time. Also, explain The mathematical models implemented in works where VANET networks and video streaming are used to facilitate users access to traffic in real-time and their communication with other vehicles.

3.1 VANETs and RSU

Wang et al. [23] studied the RSU implementation problem on urban or suburban roads of an Ad-hoc Vehicular NETwork (VANET). To optimize the RSU implementation, the centrality-based implementation approach progressively improves the efficiency of the RSU implementation in terms of coverage time ratio compared to the random implementation approach.

Mahmood and Horváth [24] considered the speed of messages propagation on the road, where the messages can be exchanged between vehicles and between the roadside infrastructure and vehicles. The results obtained make it possible to determine the optimal distance between road units (RSU) and calculate the effect of speed restrictions on the message propagation.

Shareeda et al. [25] proposed an RSU position strategy based on GA, which mechanically finalizes the best RSU position to increase the number of BSM messages received from a vehicle in any route from a city map. This shows the RSU region optimization based on GA and efficiently selects RSU locations on hard vehicular access places.

Xue et al. [26] focused on providing VANET with an optimal RSU implementation to improve the RSU connectivity of communication by covering most of the vehicles on the road with a minimum number of RSU. The results show that the CMCS scheme can guarantee the RSU acceptable yield by implementing 8 RSU and 7 RSU in the 400m and 500m transmission. The scheme allows identifying optimal RSU locations with high-yield communications connectivity.

The 5GAA association [27] focused on mobile networks and cellular coverage is constantly evolving and improving. Mobile networks support a lot of services that are beneficial to today society and industries. The services provided range from automotive infotainment, remote telecommuting, and ordinary voice call to ITS services such as enhanced safety, traffic efficiency, autonomous driving enablement services, mobility as a Service (MaaS), enhanced logistics, efficient road maintenance and operations, and auto accidents. The study considered that these services could be delivered with direct V2I communication (vehicle to infrastructure) to locally located RSUs, or with V2N2I communication (vehicle to the network to infrastructure) through a cellular network connection to interface more traffic management centers. This will highlight the complementarity between long-range cellular technologies such as mobile networks, which use the cellular interface (Uu), and side link technologies (PC5).

Zhao et al. [28] proposed a vehicle mobility prediction module to estimate future connected road units (RSU) using data traces collected from a real-world VANET tested deployed in the city of Porto, Portugal. It also designs a 3-tier caching mechanism and OTT content popularity estimation scheme to forecast content requests distribution. It was implementing a learning-based algorithm to proactively preload user content into VANET edge caching on RSUs, using a prototype in the Raspberry Pi emulating RSU nodes to test the system functionality.

Abenza et al. [29] introduced a simulation framework called Video Delivery Simulation Framework over Vehicular Networks (VDSF-VN). This framework is intended to enable research on VANET video streaming through simulation. This work includes several command-line programs and uses other utilities provided by the SUMO and OMNet ++ simulators. However, the user only needs to use two graphics applications: GatcomSUMO and GatcomVideo. In particular, the time required to encode video sequences and run simulations, which are tasks that require much time to launch the jobs in parallel, is substantially reduced, thus reducing the effort involved in viewing the results obtained, since it allows the user to define and generate charts within your interface and combine other collected statistics.

3.2 Video Streaming

Liu et al. [30] showed a mathematical model and transmission delay analysis in VANET based on clusters along the road. The results show that alert messages could be transmitted to the RSUs within a determined delay. For any density traffic flow, the relationship between the transmission range and the groups that connect the probability could be obtained using the curve fits method.

Begin et al. [31] proposed the calculation of the yield of a VoD service based on IEE 802.11p for connected vehicles which travel along the road using a probabilistic approach to show the mobility of vehicles and deliver estimates of the achieved yield of vehicles and interruption times in video playing. This allows the better yield to block politics when they have the lowest transmission rates temporarily. Thus all vehicles can benefit from higher yield.

Sánchez [12] showed a study to improve traffic conditions in urban areas carried out in Gijón, with the capacity to reduce traffic jams. The system is based on the use of vehicular communications and fuzzy logic to detect vehicular traffic jams. The system is carried out using VANET networks through communications between vehicles and between vehicles and infrastructure. Direct WiFi is also applied, which facilitated access to users on the state of traffic in real-time and their subsequent communication with other vehicles.

Ghafoor [11] showed a complete review on the new direction of research on video transmission through VANET. Based on the result of the review, VANET efficient and adaptive video transmission protocols are presented. It highlights the practical implementation, which verifies the assumptions made in the simulation and provides credibility to the results obtained from the simulation and mathematics. Therefore, conducting experiments is considered a more realistic vehicular environment.

3.3 Protocols in Vehicular Networks

Herrera [32] analyzed the basic paradigms of the VEINS components (OMNeT++, SUMO, and the TraCI module) and provided a study about the characteristics of two scenarios (urban and road). Based on the conclusions, to select the probability threshold value, the characteristic of the scenario and the number of nodes must be considered. If the value is too small, the number of relay nodes is small, suitable for the network. Finally, the probability technique works better on roads than in urban environments.

Gazori and Mirjalily [33] introduced the performance enhancement of existing routing protocols based on geographic routing based on the backbone structure. It proposes an algorithm that uses bridges for route evaluation instead of using mobile vehicles, which avoids network failures in the route selection process. The proposal evaluates the routes by exchanging control packets between bridge nodes, selecting the least number of hops and maximum connectivity. The simulation results show that there is a significant improvement in network performance. Alternative bridges reduce latency and congestion on the average network. Therefore, by increasing the packet generation rates, the proposed algorithm performs better than the SCRP protocol due to less congestion in the network.

Liro [34] investigated the conditions in which V2X-based vehicle networks should be implemented as an essential way to transport Internet traffic. Expanding cellular network capacity alone may not be the most cost-effective way to cope with the mobile Internet present and future growth. It also examines whether V2X-based networks should be implemented to supplement cellular capacity. We address this issue by evaluating the cost-effectiveness of offloading Internet traffic that would otherwise be carried over cellular infrastructure to V2X-based networks. Other criteria are evaluated, such as cost savings for governments or spectrum efficiency, depending on the scenarios. The assessment is performed under various conditions of population density, V2X device penetration, Internet traffic data rates, V2X costs, cellular spectra and allocated bandwidth for cellular networks, and spectrum efficiency of cellular technology.

Balico [35] proposed a new VANET routing algorithm that uses knowledge of vehicles predicted locations to improve routing performance in several ways. Routing is path-based for VANET. Knowledge of predicted future vehicle locations and a digital map are leveraged as metrics to forward data packets without the need to exchange any control messages. The results obtained show different VANET scenarios and the benefits of using the vehicles predicted locations as a metric for data communication.

Zhu et al. [36] have investigated the geographic routing protocol for multilevel VANET. We have revealed the impacts of the multilevel structure using an outdoor transmission experiment and stochastic analysis. The measured data has indicated that the wireless transmission range showed a dramatic degradation in communication between levels. Furthermore, we have shown that the probability of connectivity decreased without considering the degradation in the multilevel VANET. Furthermore, routing protocols based on the GF algorithm suffer significant performance reductions regarding the number of hops and delivery ratio.

Mosaarab et al. [37] used the proper data exchange method, such as network encryption, which has the most negligible computational load on the network, which is an essential factor in the optimal use of the limited power of nodes in a wireless network. This job also uses frame blending through neighbor buffer status and AHP methods. The simulation results show that due to the reduction in the number of packets transmitted on the network, parameters such as congestion and point-to-point delay are significantly reduced, and vehicles experience higher video quality than other methods.

Kraizewicz [38] the road networks of the city of Madhubani have been integrated into SUMO. They were using the open street map to create maps of the city road network. According to the traffic data, the various road networks and vehicles on the highway have been taken as input and simulated in SUMO. Through this simulation, better planning of traffic signs has also been discussed. It concludes that the integration of roads and transport is not adequate on a large scale as it does not have multi-modal transport facilities.

Reñé [39] focused on real-time information and entertainment services from vehicular to infrastructure (V2I). Among the main contributions is a new V2I communications test framework to test infotainment services quickly. The analysis of the implementation of infotainment video services in vehicular networks using mobility protocols and better performance for all information and entertainment services based on TCP in a vehicular scenario with transfers are tested. Based on the network operators income, it is evaluated as the network layer transfers that may limit the implementation of a video transmission service. Finally, we develop a new TCP architecture to improve performance during transfers. Most of the infotainment services in ITS are based on TCP, one of the leading internet protocols. However, this work demonstrates that handover management is a critical problem to address and especially relevant for multimedia applications and services with real-time requirements.

In this chapter, it is concluded that the arduous research about state of the art also provides a rigorous sample of the different contributions from 5 years ago about VANET networks that include routing protocols used for VANET and its implementation of RSU on urban roads, as well as mathematical models implemented to improve the optimization and use of video streaming, thus facilitating access in real-time and showing significant performance in terms of several hops and delivery.

Chapter 4

Methodology

This chapter describes the methodology used to develop the work where the video streaming transmission is simulated in a VANET. The traffic and network simulators described in chapter 2 intervene and integrate the SUMO and OMNeT++ simulators in Veins. The description of the problem, the design of algorithms, their implementation, parameters used for the simulation of the video transmission with their respective optimization to solve the optimization problem.

4.1 Phases of Problem Solving

The first step is to implement the environment that simulates the video streaming in VANET. It refers to creating the mobility scenario in SUMO, programing the nodes (RSUs and vehicles) in OMNeT++, and integrating the previous two simulators in Veins.

The second step is to simulate the environment with vehicles traveling at different speeds and compare if the total download obtained by the vehicle is similar (less or equal) to the value of total download calculated by the Equation 4.1

The next step is to graph the total download results in the function of the vehicle speed in coverage with different bitrate (3, 6, 9, and 18 Mbps) and taking into account the constraints of the scenario.

The last step is to choose the optimal speed in coverage based on the graphs obtained in the previous step. This speed must satisfy all restrictions and must guarantee that the vehicle will not be left without service at any time on the highway.

4.1.1 Description of the Problem

The problem is to find the most optimal speed that provides a reasonable quality of service and quality of experience, which means that vehicle users do not lose signal and can watch the video without interruptions or loss of scenes. Also, it is necessary to consider the time that requires the vehicle to pass the highway. This time should not be very long because this lowers the quality of experience for users.

4.1.2 Algorithm Design

The algorithm design consists of two parts. The first part is the programming of the infrastructure nodes or RSUs when a vehicle is in coverage when a vehicle comes in and comes out of coverage. The second part is the programming of the vehicles or nodes behavior when it is in coverage when it comes in and comes out of coverage.

The pseudocode that shows the behavior of the RSUs is the following:

Algorithm 1 Behavior of RSU

```
procedure RSUs PROCEDURE
    load the movie
    initialize variables
    wait for request video streaming message
    if a video streaming message arrives then
        check the last frame received of the vehicle
    return a video streaming confirmation message and schedule the sending of packets
    while a vehicle is in coverage do
        send video frames and packets
```

The pseudocode that shows the behavior of the vehicles is the following:

Algorithm 2 Behavior of vehicles

```
procedure VEHICLES PROCEDURE
    initialize variables
    start the highway at full speed
    if a vehicle enters in RSU coverage then
        send video streaming message (request video on demand) and reduce the speed
    while a vehicle is in coverage of an RSU do
        receive video frames and packets and reproduce it
```

4.1.3 Implementation

For the implementation, it is necessary to implement the highway part in SUMO and the vehicular network programming in OMNeT++.

To implement the highway, it is necessary to manually create the node file containing two nodes, one located at the beginning position (0km) and the other at 10km, which is the extension of the highway, edge file that defines the connect node to form links. In this case, the 10km highway and route file contain the types of vehicles and the routes allowed in the network. All these files are in XML format.

The netconvert command uses the node file and edge file to generate the net file containing the information about the network. It is necessary to create the sumocfg file with the rou file and the net file as inputs. This file contains the parameters for a traffic simulation in XML format and detailed information about the simulation. The scenario implemented in Veins is in Figure 4.1.

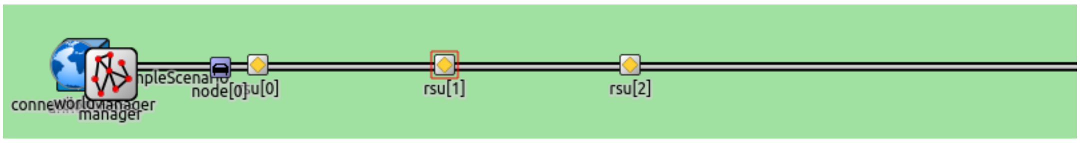

Figure 4.1: Simulation scenario in VEINS with the respective modules and nodes.

To implement the programming of the vehicular network in OMNeT++, it is divided into two parts: the programming of the behavior of the RSUs and the second the programming of the vehicles behavior. So the programming of the behavior of the RSUs has the following functions:

- Initialize function: This function initializes the variables, reads the video trace and stores it in each RSU.
- onBSM function: This function update the RSU neighbor table when it receive a beacon message.
- onDRV function: It is activated or executed when a message of type ReqVod arrives which means Request Video on Demand and is sent by the vehicles. This function calls another function to send a confirmation message to the vehicles that the ReqVod message has been received. Also schedules the sending of frames/packages and schedules the stop of sending frames/packages.
- handleSelfMsg function: It is activated when a message arrives scheduled by the RSU itself. This function check the type of the message and depending on the type it executes certain actions. For example, if a SEND_VIDEO_EVT message arrives, it process the stream request and send the stream data.
- sendMessage function: This function prepares the message, sets the name and sends the message.
- processStreamRequest function: This function receive as arguments the message, the last frame received and the id of the vehicle. Also it schedules the start of frame and the transmition of packets.
- readFrameData function: This function read frame data from the vector and trigger packet transmission.
- sendStreamData function: This function generate and send a packet.
- sendVMessage function: This function prepare the video stream message and sends it to the vehicle with a delay.

In Figure 4.2 it can be seen an image from the simulators which describes the sending of Video stream packets from the RSU to a vehicle

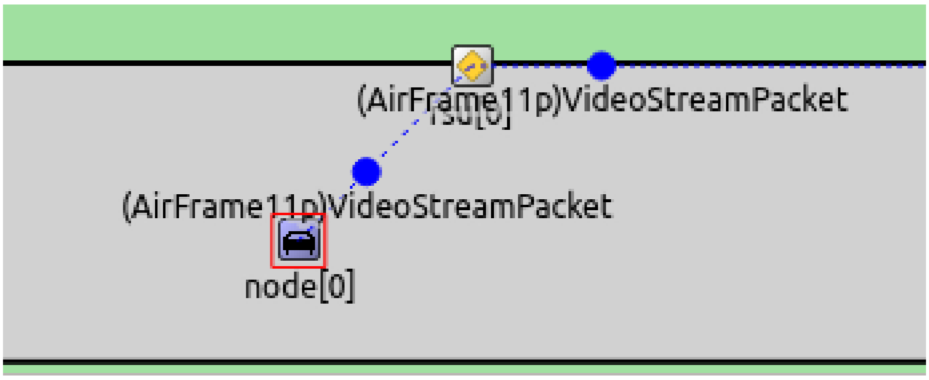

Figure 4.2: RSU sending a video stream packet to a vehicle.

The programming of the behavior of the vehicles has the following functions:

- initialize function: This function initializes the variables.
- finish function: This function generates text files with the statistics obtained by the vehicle.
- onBSM function: This function update the vehicle neighbor table when it receive a beacon message.
- onDRV function: This function it is activated when the confirmation arrives that the ReqVod message arrived at a RSU and initialize the statistics.
- onVSM function: This function it is activated when a video stream message arrives.
- handleSelfMsg function: It is activated when a message arrives scheduled by the vehicle itself. This function check the type of the message and depending on the type it executes certain actions. For example, if a END_RSUSERVICE_EVT message arrives, it means that the vehicle is out of coverage and finish the statistics.
- sendMessage function: This function prepares the ReqVod message, sets the name and sends the message to the RSU.
- handlePositionUpdate function: This function is executed for each meter that the vehicle advances.
- requestServiceToRSU function: This function checks if the vehicle is in coverage and if the ReqVod message has been sent only once
- recvStream function: This function get packet fields and check if a frame was received complete or not. Also keep track of frame loss.
- frameEncodingNumber function: This function receives as argument the number of frame, the number of B frames and the frametype.

- LogToFile function: This function creates a text file with the information about the frames and packets received for the vehicle.
- statisticsRSUIn function: This function is activated when the vehicle is in coverage and it set the variables.
- statisticsRSUOut function: This function is activated when the vehicle is out of coverage and it set the variables with the current values.
- queueBuffer function: This function simulates a buffer in the vehicle for video playback.
- sourceBuffer function: This function add video stream messages to queue.
- sinkBuffer function: This function checks the lifetime of a message.

4.2 Experimentation of Video Streaming Simulation

To validate the optimal speed is required a highway of D = 10km, with the number of RSUs N = 3 located in 2.5km, 5km and 7.5km respectively.The highway scenario is a bidirectional road, straight, and has multiple tracks. RSUs are located along the road as shown in Fig. 4.3.

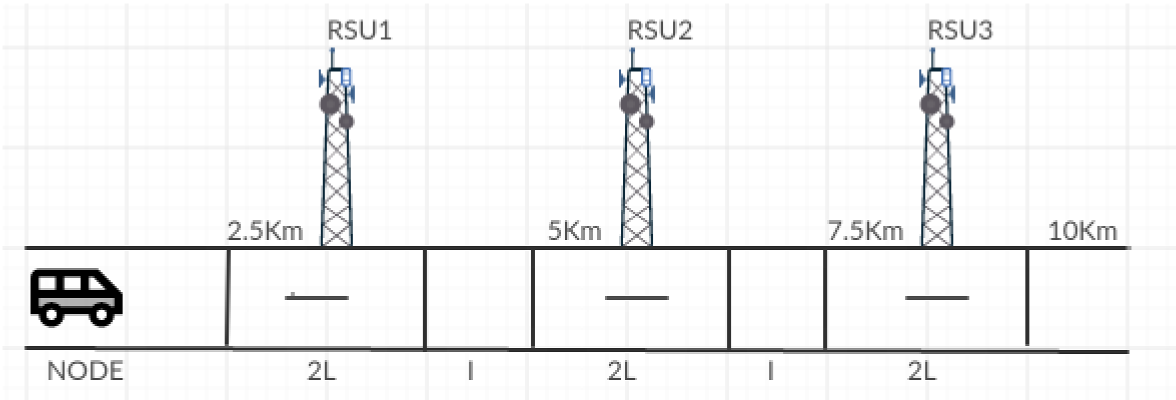

Figure 4.3: Highway scenario of the simulation. The input parameters used are found in Table 4.1.

Equation 4.1 describes the total download in the function of the bitrate and speed when it covers the RSU signal. The bitrate is directly proportional to the total download because if the bitrate increases, the total download increases. On the other hand, the speed in coverage is inversely proportional to the total download.

$$\text{Total download } [MB] = \frac{2 \cdot L}{v_i} \cdot \frac{B[Mbps]}{8} \tag{4.1}$$

$$\text{Time spend by vehicle in RSU[sec]} = \frac{2 \cdot L}{v_i} \tag{4.2}$$

The constraints are an essential part because the optimal speed has to accomplish all the constraints. The constraints, in this case, ensure that the user of the vehicle is never left without service. This means that it has enough video in the buffer when the vehicle is out of the RSU signal range coverage. The video image does not stop.

- $\frac{r_i}{B} \geq 2L/v_1 + I/V$ = enough data for the first hop
- T = E2E delay (sec) = $T = \sum_{i=1}^{N-1} \frac{2L}{w} + (N-1) \cdot \frac{1}{V}$
- $\frac{r_1+r_2}{B} \geq 2L/v_1 + 2L/v_2 + 2I/V$ = enough data for the first two hops
- $\frac{\sum_{i=1}^{N-1} r_i}{B} \geq 2L \sum_{i=1}^{N-1} \frac{1}{v_i} + (N-1)\frac{1}{V}$ = enough data for the whole set of hops
- $\forall j \in [1, N-1], \frac{\Sigma_{i-1}^{j} r_i}{B} \geq 2L \sum_{i=1}^{j} \frac{1}{v_i} + j\frac{1}{V}$ = enough data for the first j hops

4.2.1 Input Parameters

For simulation purposes, a 2.5Km distance is established for the location of the 3 RSUs and a maximum speed of $90Km/h$, and an initial speed of 36Km / h. Next, the simulation parameters are detailed, which are explained in Table 4.1. The number of RSUs, the distance used in Km, the signal range, video size, and the maximum speed used are established.

- N = number of RSUs
- D = end-to-end distance $E2E$(km)
- L = signal range ($\sim$ 500m)
- M = size of the video (MB)
- V = (max) velocity of a vehicle (km/h)

Table 4.1: Input parameters used in the video streaming simulation

N	number of RSUs	3
D	E2E distance (m)	10
L	signal range ($\sim$ 500m)	520
B	bitrate (Mbps)	6
M	size of the video (MB)	646.7872
V	(max) velocity of a vehicle (km/h)	90
vi	velocity of a vehicle (km/h)	36
I	inter-RSU coverage distance (km)	1.5

4.2.2 Assumptions

Vehicles can be moved whenever they want, as mentioned before, the RSUs are uniformly located so that they can be stored on D Movies in each RSU. The downlink uses the IEEE 802.11p standard which is one of the most viable communication standards for its high node speed.

- Downlink using IEEE 802.11p
- RSUs uniformly distributed over D Movies are stored on each RSU
- Vehicles can always move at speed V whenever the y want while it is possible

4.2.3 Intermediate Parameters

Vehicles can be moved whenever they want. As mentioned before, the RSUs are uniformly located to be stored on D Movies in each RSU. The downlink uses the IEEE 802.11p standard, one of the most viable communication standards for its high node speed.

- I = inter-RSU coverage distance (km) = I
- s = time without connection = I/V(sec)
- $r_i(v_i, n_k)$ = (estimated) amount of data downloaded in the k -th RSU given the velocity of vehicle i is v_i and the number of vehicles in the cell is n_k

In this chapter, it is concluded that for simulation purposes, the location of the RSUs was established at 2.5Km distance. For the validation, a road of 10Km distance is required. Consequently, 3 RSUs were placed, with the maximum speed of $90Km/h$ per part of vehicles and an initial speed of $12.09Km/h$. The different speeds are used to compare the obtained download and the calculated download by the equation.

Chapter 5

Results and Discussion

This chapter shows the results obtained in the simulation and compares these results with the expected results. It presents an extensive analysis of figures with different bitrate and constraints in each case. The optimal speed was chosen as the maximum speed that complies with the restrictions to guarantee the QoS service quality. Finally, the validation of a simulation is made with the optimal speed.

To find the optimal speed that maximizes the total download, but in a reasonable time, it is required to analyze many Figures. Figures 5.1, 5.2, 5.3 and 5.4 show the total download in Mega Bytes [MB] in function of the speed of the vehicle in meters per second [m/s] when it is in coverage or inside the signal range of an RSU.

Figure 5.1 shows the total download of a vehicle when the bitrate is $3Mbps$. It is the least of all. The constraint calculated by Equation 4.2 is $60MB$. It means that the vehicle needs to download at least $60MB$ in each RSU to ensure that it is provided with service on the highway. Other constraints are the minimum and maximum speed, $36km/h$ and $90km/h$, respectively.

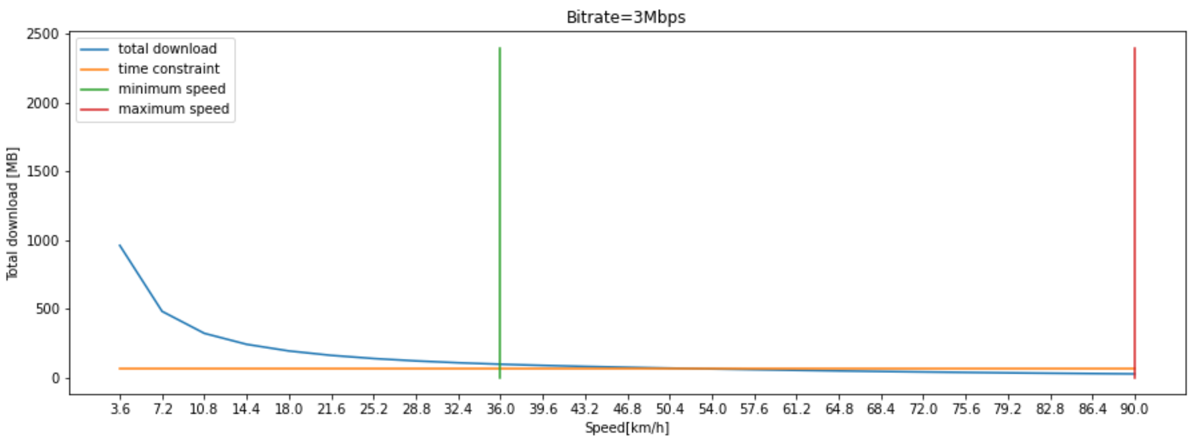

Figure 5.1: Constraints and total download of a vehicle with transmission bitrate= $3Mbps$.

Figure 5.2 shows the total download of a vehicle when the bitrate is $6Mbps$. The constraint calculated by Equation 4.2 is $120MB$. It means that the vehicle needs to download at least $120MB$ in each RSU to ensure that it has served with video on the entire highway.

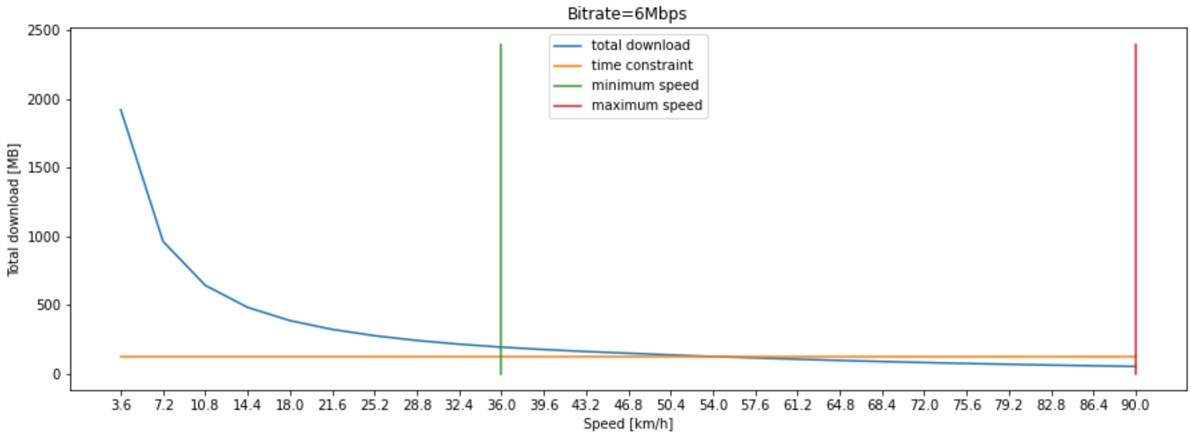

Figure 5.2: Constraints and total download of a vehicle with transmission bitrate= $6Mbps$.

Figure 5.3 shows the total download of a vehicle when the bitrate is $9Mbps$. The constraint calculated by Equation 4.2 is $180MB$. It means that the vehicle needs to download at least $180MB$ in each RSU to ensure that it has served on the $10km$ of the highway.

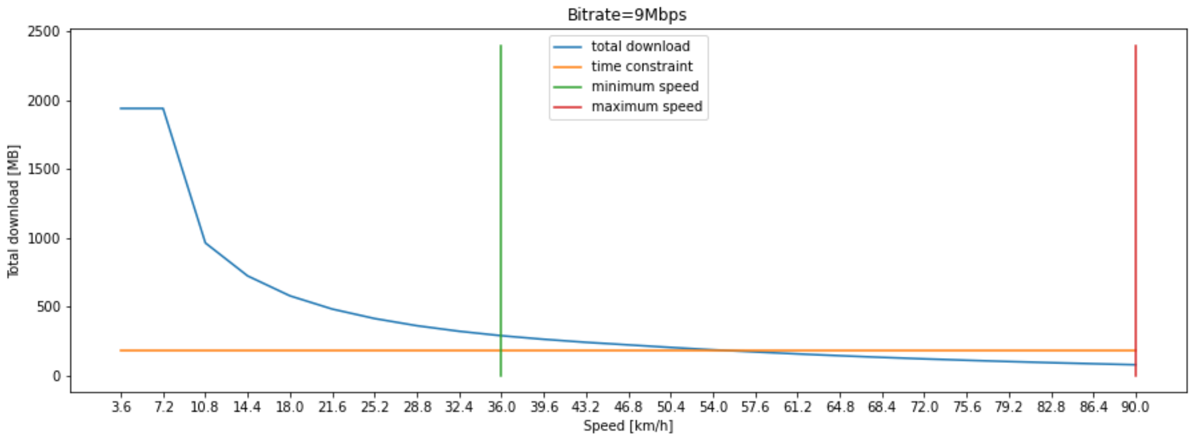

Figure 5.3: Constraints and total download of a vehicle with transmission $bitrate = 9Mbps$.

Figure 5.4 shows the total download of a vehicle when the bitrate is $18Mbps$. The constraint calculated by Equation 4.2 is $360MB$. It means that the vehicle needs to download at least $360MB$ in each RSU to ensure that it has served on the $10km$ of the highway.

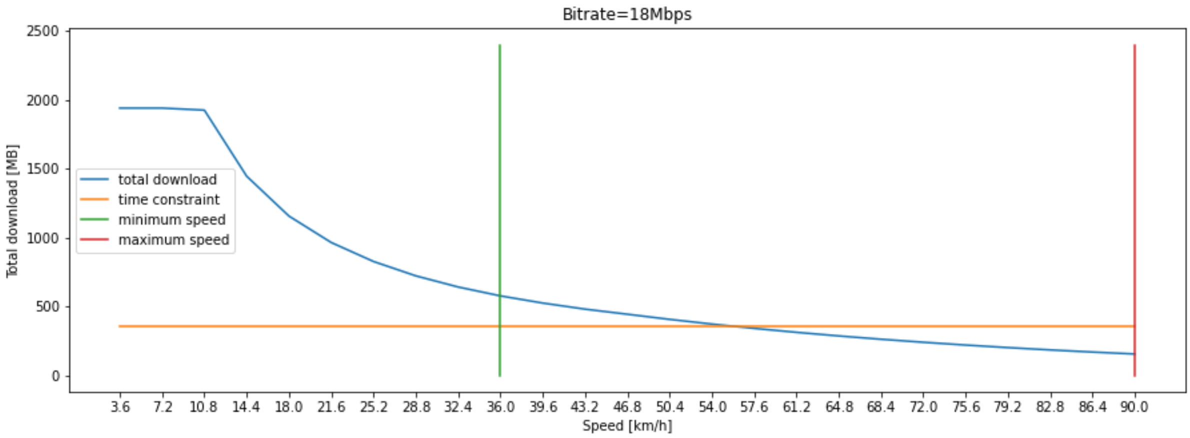

Figure 5.4: Constraints and total download of a vehicle with transmission bitrate= $18Mbps$.

The previous four figures show a decreasing function. It means the speed of the vehicle is inversely proportional to the total download. If the speed of the vehicle increases, the total download is less and vice versa.

Figure 5.5 shows the speed in function of distance. In this case, the vehicle goes at the maximum speed of $25m/s$ when it is not in coverage. It means out of the signal range of any RSU. On the other hand, the vehicle goes at a minimum speed 10 m/s when it is in coverage. It means inside of the signal range of any RSU. The highway has 3 RSUs located at $2500m, 5000m$, and $7500m$. For this reason, the vehicle goes at the minimum speed three times. It occurs for $1000m$ or $1km$ because the signal range is $500m$ in a radius.

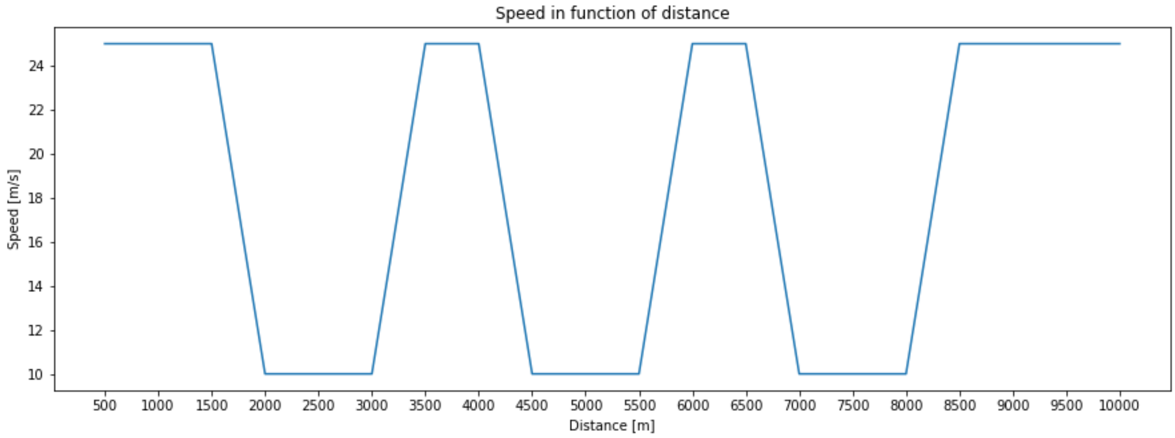

Figure 5.5: Speed of a vehicle when it is in coverage and out coverage of the RSU signal range. It means speed in function of distance.

Figure 5.6 shows the speed in function of the time spend for a vehicle when it is in coverage for approximately one kilometer. It is a decreasing function because the speed is inversely proportional to time. It means faster speed, less time, and vice versa.

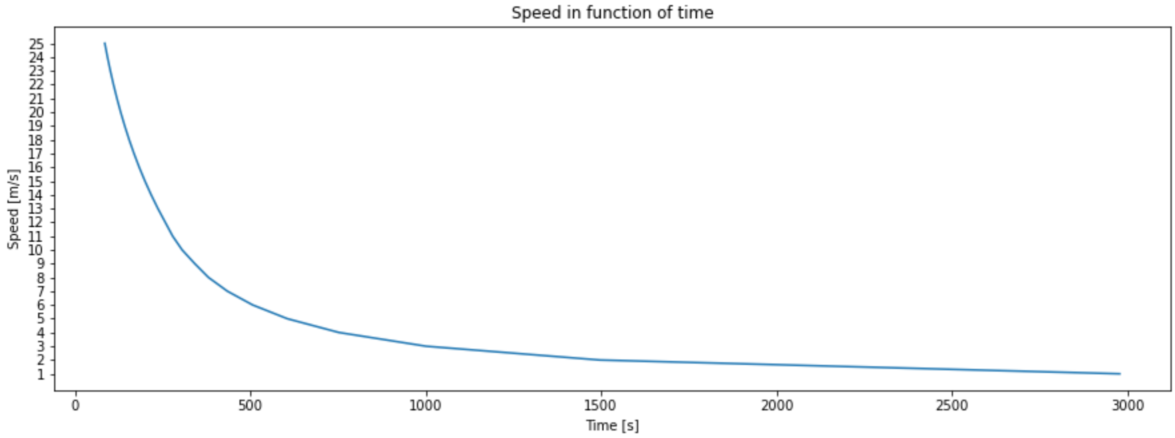

Figure 5.6: Speed of a vehicle in function of time required to enter and exit of the RSU coverage range.

Figure 5.7 shows a comparison between the expected and obtained total download. The obtained results are from the VEINS simulations, and the expected results are calculated by Equation 4.1. The results obtained by the simulation are lower than expected. This is because the simulator also simulates losses in sending packages. If the vehicle increases the speed, the loss of packages also increases. These are the reasons why both functions or curves differ at higher speeds.

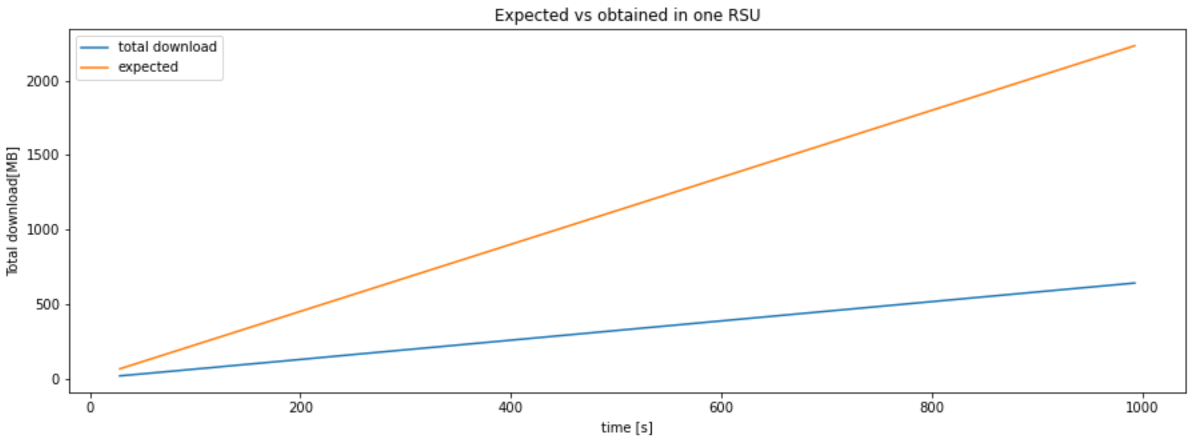

Figure 5.7: Comparison of total download for a vehicle between the expected mathematically and the obtained in the simulation.

Figure 5.8 shows the total download of a vehicle in an RSU in a scenario with a different number of vehicles and varying the bitrate in each scenario. The speed of the vehicles is a minimum $10m/s$.

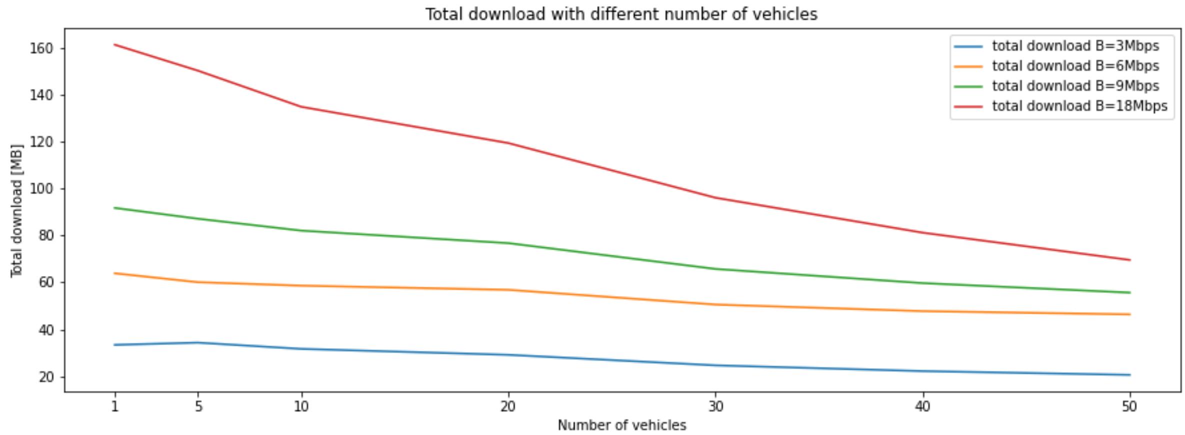

Figure 5.8: Total download of a vehicle obtained in the simulations with different number of vehicles.

Figure 5.9 shows the packet loss of a vehicle in a scenario with a different number of vehicles and varying the bitrate in each scenario. The speed of the vehicles is a minimum $10m/s$.

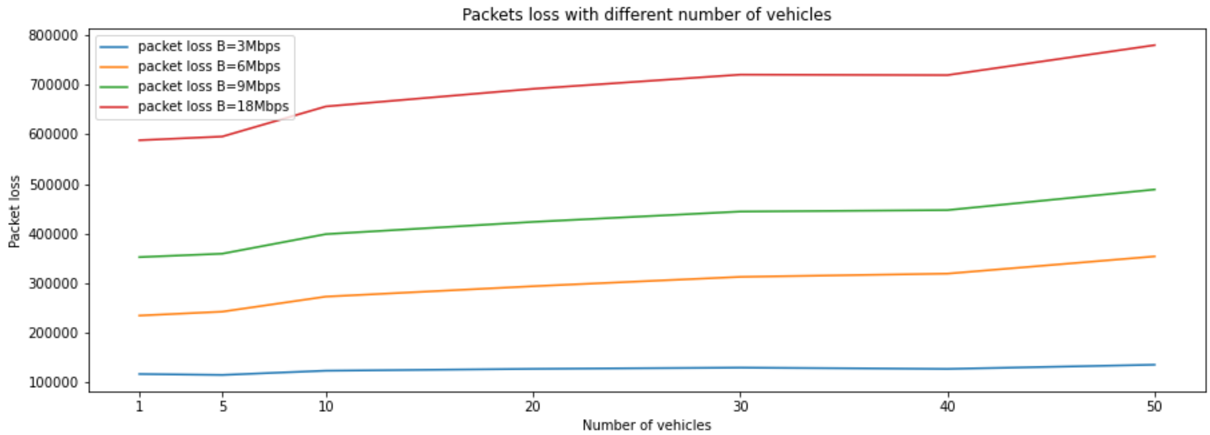

Figure 5.9: Packet loss of a vehicle obtained in the simulations with different number of vehicles.

As we can see in Figures 5.1, 5.2, 5.3 and 5.4 show the total download in MegaBytes in function of the speed of the vehicle in meters per second [m/s] with the respective constraints in each case. So we choose the optimal speed as the maximum speed, which accomplishes the constraints to guarantee the quality of service QoS.

We select the optimal speed as $14m/s$ for all different bit rates and present the following tables validation. These tables show some results obtained in the simulation like bitrate, speed of the vehicle, time spend inside RSU coverage, and total download. Also, these tables compare a comparison between the obtained results in simulations and the calculated results mathematically.

Table 5.1: Bitrate validation in RSU_0 with the optimal speed. Comparison between expected mathematically and obtained in the simulation.

Model	B[Mbps]	Speed[m/s]	RSU time[s]	Service dist.[km]	T. Download[MB]
Math.	3	14	73.92642	1.026	27.7224075
Sim.	3	14	73.92642	1.026	23.788
Math.	6	14	73.92492	1.026	55.44369
Sim.	6	14	73.92492	1.026	46.0695
Math.	9	14	73.9266	1.026	83.16742
Sim.	9	14	73.9266	1.026	65.748
Math.	18	14	73.9246	1.026	166.33035
Sim.	18	14	73.9246	1.026	117.085

Table 5.2: Bitrate validation in RSU_1 with the optimal speed. Comparison between expected mathematically and obtained in the simulation.

Model	B[Mbps]	Speed[m/s]	RSU time[s]	Service dist.[km]	T. Download[MB]
Math.	3	14	73.92271	1.026	27.72101625
Sim.	3	14	73.92271	1.026	24.3408
Math.	6	14	73.92415	1.026	55.44311
Sim.	6	14	73.92415	1.026	46.2197
Math.	9	14	73.9228	1.026	83.1699
Sim.	9	14	73.9228	1.026	66.517
Math.	18	14	73.9266	1.026	166.33485
Sim.	18	14	73.9266	1.026	117.093

Table 5.3: Bitrate validation in RSU_2 with the optimal speed. Comparison between expected mathematically and obtained in the simulation.

Model	B[Mbps]	Speed[m/s]	RSU time[s]	Service dist.[km]	T. Download[MB]
Math.	3	14	73.92243	1.026	27.720911
Sim.	3	14	73.92243	1.026	24.1794
Math.	6	14	73.91948	1.026	55.4355
Sim.	6	14	73.91948	1.026	46.4158
Math.	9	14	73.9198	1.026	83.159775
Sim.	9	14	73.9198	1.026	66.601
Math.	18	14	73.9241	1.026	166.329
Sim.	18	14	73.9241	1.026	117.0884

5.1 Experimental Environment

The experiment was carried out on a personal laptop. This computer is equipped with 4GB of RAM, a x86_64 Intel(R) Celeron(R) CPU 877 @ 1.40GHz, Ubuntu 18.04.5 LTS (Bionic Beaver) operating system with a Linux Kernel 4.15.

The software environment includes SUMO v1.2.0 as traffic simulator, OMNeT++ v5.6 as network simulator, and Veins v5.0 as VANET simulator.

Chapter 6

Conclusions

Based on an exhaustive review of different simulators used in the implementation of vehicle networks, OMNeT++ was identified as a suitable network simulator and SUMO as a traffic simulator. We can conclude that simulation is a fundamental tool for planning, designing, analyzing, and evaluation of video streaming techniques. This type of research allows vehicles to take advantage of communication capabilities under appropriate standards such as the IEEE 802.11p. This standard provides road safety, traffic management and offers information and entertainment services. At present, this kind of system deployment is not yet feasible due to the lack of security guarantees and the significant cost that it would take to implementing this kind of technology.

In the literature review regarding VANET networks, it can be expressed that they are a fundamental basis in mobility applications focused on smart cities. Sustainable mobility through the progressive incorporation of ecological vehicles and the acceptance of alternative solutions promotes realizing studies on mobility in the city or those developed by applying new technological solutions. Sustainability is one of the essential factors for the proper care and conditions for an environment quality of life. Therefore, citizens have the right to enjoy adequate and safe environments. In this sense, there are various methods to promote public participation within a Smart City environment.

The technological innovation of this type of system lays in the amount of information they are capable of handling by having more agents involved in creating a transport service. For this reason, vehicle networks search for solutions to the problems of passenger safety and traffic congestion. In addition to improving the comfort and information received by drivers and passengers, cooperation among the mentioned before agents can be achieved.

In the applications related to vehicle networks, there are security applications where new accident prevention systems and real-time traffic information are offered to the community. There are also applications to improve the transfer of messages and accident notifications. These applications give network users full awareness of the state of the road by continuous reporting on events. Commercial applications are focused on the services offered by third parties to generate income for a particular company. Within these applications, there is the remote diagnosis of the vehicle, which sends information related to it. The vast majority of people use GPS navigation applications where it is possible to visualize digitally and download maps in real-time that may be useful to users.

Comfort applications offer information to the user to regularly improve their driving level, such as road route selection, where they report any change due to traffic congestion. Productive applications are those where there is a purpose for users and society benefit using the multimodal approach that allows vehicles to transmit information to another vehicle

One type of communication found was the vehicle-to-vehicle (V2V) investigation in a spontaneous ad-hoc way, which allows the exchange of valuable information with other vehicles through the detection or notification of accidents or works as well as other susceptible services of the use of this type of communication. However, the investigation took into account vehicle-to-infrastructure communication. It is carried out between vehicles and the stations located on the side of the road (RSUs) to exchange information about road conditions and notices for the infrastructure. This type of communication is also used as a link for data exchange with external networks such as the Internet.

Road safety applications constitute one of the most fundamental approaches in-vehicle networks and intelligent transport systems; its main objective is to save lives and reduce the number of road accidents or reduce the impact, reducing collisions between vehicles or between vehicles and pedestrians.

During the previous fifth chapters of this thesis, an extensive study has been carried out about the transmission of video streaming in mobile networks. The benefits of VANET video streaming applications with their respective advantages have been presented.

The VANET is a wireless network for moving vehicles, enabling connectivity between infrastructure nodes or vehicular nodes. It provides some benefits like security, commercial applications, comfort enhancement applications, and productive applications.

Simulation is helpful to study the behavior of each node in VANET. For this, it is crucial to make the simulation as close to reality as possible. It is possible with the help of some frameworks designed for VANETs. To simulate a VANET, a network modeling module (communication between nodes) and another traffic mobility simulator are required. For this study, we chose VEINS, a hybrid simulator based on OMNeT++ (network simulator) and SUMO (traffic simulator). VEINS connects the two above using a real-time communication system called TraCI.

Vehicle networks allow evaluating different aspects such as the design process, VANET planning, algorithms, and network protocols to have an efficient communication channel. Through simulation, it is possible to define the parameters necessary for developing V2X applications and estimate their performance in realistic scenarios based on mobility models.

Intelligent Transportation Systems (ITS) promise a new generation to help people in an organized way, allowing drivers to be connected to a communications network throughout the journey while keeping the user informed about the different circumstances that exist on the road.

In networks where the transmission is through video streaming, they provide significant benefit for long-term traffic management where multimedia data such as images, short clips, earthquake accidents, among others, are transmitted. Knowing the current situation, the driver will be able to make decisions based on his priorities during emergencies, which helps with the process of improving the safety of vehicular navigation. However, with the high connectivity that the coverage area presents, the video quality requirements, and highly dynamic topologies, routing of the protocols must be taken into account to adapt to the conditions and meet certain specific QoS and QoE requirements. Similarly, VANETs must have the ability to guarantee the delivery of streaming video from the source to the destination point and provide smooth playback in real-time.

There are various protocols used in video streaming. The application-centric inter-vehicle routing protocol is used in urban scenarios where the routing protocol is based on exchanging information between the application layer and the network layer. It allows selecting the path that minimizes the application layer frame distortion function through the use of the error probability in the point-to-point transmission. Its routing design must be taken into account for the spatial distribution of traffic and the probability of VANET scenarios connectivity.

Another protocol is RBRP (Realibe Beaconless Routing Protocol for VANETs), which is used to forward unicast packets without beacons. The critical points in RBRP are the definition of the forwarding zone and the time-out algorithm. The choice of the direction of the forwarding zone is based not only on the location of the destination but also on the direction of the current sender movement. Likewise, the routing protocol based on the quality of the streaming video experience through VANET is known as AODV (Ad-Hoc On-Demand Distance Vector Routing). ORLS (Optimized Link State Routing) serves to evaluate the perception of the video in real-time. The dissemination of information with short clips, floods are emergencies which must be updated in minutes from the moment the accident occurs long before the police and news reporters arrive. The information must be reliable to all the vehicles involved so that actions can be coordinated. Finally, the video delivery on emergencies should not be based on fixed infrastructure since, in the event of an earthquake or major catastrophe, the cellular base stations may be affected.

Based on the research carried out, it is concluded that the video transmission of Ad-Hoc Vehicle Networks (VANET) is an attractive application that provides many valuable services for drivers, contributing a significant amount of traffic. However, modifications are still required to the algorithms related to packet delay and loss. The implementation of video services in-vehicle networks is used through mobility protocols. And information services based on TCP in a vehicular scenario with transfers can limit a streaming video service performance.

The results obtained from the Veins simulations showed that the data transferred was less than the expected mathematical value due to the losses of sent packets. If the vehicle increases its speed, the loss of packets also increases. This is the reason why curves differ at high speeds.

In Figure 5.1, the bit rate is $3Mbps$. The restriction, in this case, is $60MB$. Therefore, the vehicle needs to download at least $60MB$ on each RSU to ensure the vehicle has continuous service on the road.

The restriction in Figure 5.2 is $120MB$ and has a bit rate of $6Mbps$. Therefore, the vehicle needs $120MB$ in each RSU to ensure that the vehicle has road service.

The restriction in Figure 5.3 is $180MB$ and has a bit rate of $9Mbps$. Therefore, at least $180MB$ needs to be downloaded to ensure the vehicle has road service.

The bit rate in Figure 5.4 is $18Mbps$ and has a $360MB$ restriction. Therefore, the vehicle needs at least $360MB$ in each RSU to ensure the vehicle has road service.

The speed shown in Figure 5.6 is a function of the time taken by a vehicle when it is in coverage for one kilometer. The function is decreasing because speed is inversely proportional to time.

In Figure 5.5, the speed in function of distance, when there is no coverage, or it is outside the signal range of any RSU, it is $25m/s$, and within the coverage range, it is

$10m/s$. For this reason, it can be seen that the graph shows three minimum speeds during 1000m.

The results obtained from the simulations carried out in Veins, and the expected results are calculated using equation 4.1. In the results shown on Figure 5.7, it can be seen the comparison between the expected total download and the obtained, where the results obtained through the simulation are lower than expected because it simulates the losses in the sending of packages. If the vehicle increases speed, the loss of packages also increases. Therefore, the curves differ at higher speeds.

In Figure 5.8 it is possible to see the total download of a vehicle in an RSU where a scenario with a different number of vehicles and varying the bit rate in each scenario is shown. The speed of the vehicles is a minimum of $10m/s$.

The packet loss that a vehicle has can be visualized in Figure 5.9. There are different numbers of vehicles and variations of the bit rate in each scenario. Likewise, the speed of the vehicles is a minimum of $10m/s$.

.It is concluded that the optimal speed as the maximum speed that complies with the limitations to guarantee the quality of the QoS service is $14m/s$ for all the different bit rates. The validation of these are found in tables 5.1, 5.2, and 5.3.

6.1 Limitations

The most important limitation in this job is CPU resources. It is a complete simulation of a full VANET, so these simulations use many computational resources. The simulations take a long time and depend on the number of vehicles and their speed. Therefore, it is recommended to use a computer with good RAM resources to study vehicle networks.

Another limitation that We found was the little information on related topics. Few articles related to the topic as there was RSU, VANET, but no download optimization based on vehicle speed.

Another significant limitation is that the bit rate is not adaptive. It means that the bit rate is going to be constant all the time. It does not apply in real life, so to make the study more complex, the adaptive bit rate must be added. To complete the study, it is necessary to apply it in a city with more streets, intersections, and more simulation parameters.

6.2 Future Work

In this part, we present the objectives proposed as future work. The objectives complement this thesis and make it more similar and applicable to the real world.

- Perform simulations in a CPU with more computational resources.
- Implement video streaming in another simulator to compare the results and the effectiveness of each simulator.
- Use optimization techniques to determine which is the best technique for this problem.
- Perform simulations with an adaptive bit rate to make it more similar to reality.

- Simulate video streaming in another scenario, that is, make a complete study in a city with more RSUs, more streets, and more nodes to apply to a specific region.

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