FEDERAL UNIVERSITY OF PARÁ
INSTITUTE OF TECHNOLOGY
POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING

WELLINGTON VIANA LOBATO JUNIOR

PLATOON-BASED DRIVING PROTOCOL FOR MULTIMEDIA TRANSMISSION OVER VANET

DM 05/2019

UFPA / ITEC / PPGEE

Guamá University Campus

Belém - PA

2019

FEDERAL UNIVERSITY OF PARÁ
INSTITUTE OF TECHNOLOGY
POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING

WELLINGTON VIANA LOBATO JUNIOR

PLATOON-BASED DRIVING PROTOCOL FOR MULTIMEDIA TRANSMISSION OVER VANET

DM 05/2019

UFPA / ITEC / PPGEE

Guamá University Campus

Belém - PA

2019

FEDERAL UNIVERSITY OF PARÁ
INSTITUTE OF TECHNOLOGY
POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING

WELLINGTON VIANA LOBATO JUNIOR

PLATOON-BASED DRIVING PROTOCOL FOR MULTIMEDIA TRANSMISSION OVER VANET

Master's Thesis submitted to the judging panel at the Federal University of Pará as part of the requirements for obtaining a Master's Degree in Electrical Engineering in the area of Applied Computing.

UFPA / ITEC / PPGEE
Guamá University Campus
Belém - PA

2019

Dados Internacionais de Catalogação na Publicação (CIP)
Sistema de Bibliotecas da Universidade Federal do Pará

V614p Lobato, Wellington Viana Junior
Platoon-based Driving Protocol for Multimedia Transmission over VANET / Wellington Viana Lobato Junior. — 2019.
68 f. : il. color

Dissertação (Mestrado) - POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING (PPGEE), INSTITUTE OF TECHNOLOGY, FEDERAL UNIVERSITY OF PARÁ, Belém - PA, 2019.
Orientação: Prof. Dr. Denis Lima do Rosário
Coorientação: Prof. Dr. Leandro Aparecido Villas.

1. Platoon. 2. Video. 3. Quality of Experience. I. RosÃ¡rio, Denis Lima do, *orient.* II. Título

CDD 621.3821

UNIVERSIDADE FEDERAL DO PARÁ
INSTITUTO DE TECNOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA ELÉTRICA

"PLATOON-BASED DRIVING PROTOCOL FOR MULTIMEDIA TRANSMISSION OVER VANET"

AUTOR: **WELLINGTON VIANA LOBATO JÚNIOR**

DISSERTAÇÃO DE MESTRADO SUBMETIDA À BANCA EXAMINADORA APROVADA PELO COLEGIADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA ELÉTRICA, SENDO JULGADA ADEQUADA PARA A OBTENÇÃO DO GRAU DE MESTRE EM ENGENHARIA ELÉTRICA NA ÁREA DE COMPUTAÇÃO APLICADA.

APROVADA EM: 22/02/2019

BANCA EXAMINADORA:

Denis Lima do Rosário

Prof. Dr. Denis Lima do Rosário

(Orientador – PPGEE/UFPA)

Prof. Dr. Leandro Aparecido Villas

(Co-Orientador – UNICAMP)

Eduardo Cerqueira

Prof. Dr. Eduardo Coelho Cerqueira

(Avaliador Interno –PPGEE/UFPA)

Thais Lira Tavares dos Santos

Prof.ª Dr.ª Thais Lira Tavares dos Santos

(Avaliadora Externa ao Programa – GERCOM/UFPA)

Prof. Dr. Roger Kreutz Immich

(Avaliador Externo – UNICAMP)

VISTO:

Prof.ª Dr.ª Maria Emília de Lima Tostes

(Coordenadora do PPGEE/ITEC/UFPA)

Dedicated to my family. I could have never gone this far without their encouragement and help.

Acknowledgements

I would like to thank my family first: Wellinton Viana Lobato, Fatima de Oliveira Silva and Karina de Oliveira Lobato. Thanks to their support I am completing another stage of my academic life, I love you very much.

To my adviser Denis Lima do Rosario and to Professor Eduardo Coelho Cerqueira for believing in me, for all the advice you gave me, I believe I was very fortunate to have met the Group of Studies in Computer Networks (GERCOM) and met with people so inspiring, thanks to both I did an excellent scientific initiation and discovered my vocation for the research area. Thanks also to my friends and laboratory colleagues Iago Medeiros, Hugo Leonardo, Pedro Cumino, Felipe and Fábio Araújo, especially Joahannes Bruno (Time Pará !!!), for having helped me several times.

Thanks also to Professor Leandro Aparecido Villas for having welcomed me in Campinas and UNICAMP, thanks to his collaboration I have evolved as a researcher and a person. Thanks again to my new friends from the Computer Networking Laboratory (LRC), this involvement with new researchers was necessary to develop a more mature and conscious research.

I thank the Graduate Program in Electrical Engineering (PPGEE), the Federal University of Pará, for the opportunity to join the master's program in 2017. And the National Research Council (CNPQ) for having awarded the master's degree scholarship.

Lastly, I would like to thank everyone who truly wished for me.

"Fall seven times, stand up eight."
Japanese Proverb

Abstract

Abstract of Dissertation presented to UFPA as a partial fulfillment of the requirements for the degree of Master in Electrical engineering.

Advisor: Denis Lima do Rosário
Co-advisor: Leandro Aparecido Villas
Key words: Platoon; Video; Quality of Experience.

Vehicular Ad-hoc NETworks (VANETs) allow users, services, and vehicles to share information, and will change our life experience with new autonomous driving applications. Multimedia will be one of the core services in VANETs, and are becoming a reality in smart environments, ranging from safety and security traffic warnings to live entertainment and advertisement videos. However, VANETs have a dynamic network topology with short contact time, which leads to communication flaws and delays, increasing packet loss and decreasing the Quality of Experience (QoE) of transmitted videos. To cope with this, neighbor vehicles moving on the same direction and wishing to cooperate should form a platoon, where platoon members act as a relay node to forward video packets in autonomous VANETs. This master's dissertation introduces a Game Theory approach for Platoon-based driving (GT4P) for video dissemination services in urban and highway VANET scenarios. GT4P encourages the cooperation between neighbor vehicles by offering reward (money or coupon) for vehicles participating in the platoon. In this sense, GT4P establishes a platoon by taking into account vehicle direction, speed, distance, link quality, and travel path, which reduces the impact of vehicle mobility on the video transmission. Simulation results confirm the efficiency of GT4P for ensuring video transmissions with high QoE support compared to existing platoon-based driving protocols.

Resumo

Resumo da Dissertação apresentada à UFPA como parte dos requisitos necessários para obtenção do título de Mestre em Engenharia Elétrica.

Orientador: Denis Lima do Rosário
Coorientador: Leandro Aparecido Villas
Palavras-chave: Platoon; Video; Quality of Experience.

As Vehicular Ad-hoc NETworks (VANETs) permitem que usuários, serviços e veículos compartilhem informações e mudam nossa experiência de vida com novos aplicativos de condução autônoma. Conteúdo multimídia será um dos principais serviços das VANETs e está se tornando uma realidade em ambientes inteligentes, que vão desde avisos de tráfego de segurança e segurança até entretenimento ao vivo e vídeos de publicidade. No entanto, as VANETs possuem uma topologia de rede dinâmica com pouco tempo de contato, o que leva a falhas de comunicação e atrasos, aumentando a perda de pacotes e diminuindo a Qualidade da Experiência (QoE) dos vídeos transmitidos. Para lidar com isso, os veículos vizinhos que se movem na mesma direção e desejam cooperar devem formar um pelotão, onde os membros do pelotão atuam como um nó de retransmissão para encaminhar pacotes de vídeo em VANETs autônomas. Esta dissertação de mestrado introduz uma abordagem de teoria de jogos para a condução baseada em pelotão (GT4P) para serviços de disseminação de vídeo em cenários urbanos e rodoviários de VANET. O GT4P incentiva a cooperação entre os veículos vizinhos oferecendo recompensa (dinheiro ou cupom) para os veículos que participam do pelotão. Nesse sentido, o GT4P estabelece um pelotão levando em consideração a direção do veículo, a velocidade, a distância, a qualidade do link e o caminho de deslocamento, o que reduz o impacto da mobilidade do veículo na transmissão de vídeo. Os resultados da simulação confirmam a eficiência do GT4P para garantir transmissões de vídeo com alto suporte de QoE em comparação aos protocolos baseados em pelotão existentes.

Contents

List of Acronyms

ACC *Adaptive Cruise Control*

ACNL *Active Communication Node List*

ADAS *Advanced Driver Assistance Systems*

BDSC *Bidirectional Stable Communication*

BLR *BeaconLess Routing*

CACC *Cooperative Adaptive Cruise Control*

CW *Contention Window*

DFD *Dynamic Forwarding Delay*

DN *Destination Node*

DSRC *Dedicated Short-Range Communication*

FD *Furthest Distance*

GPS *Global Position System*

GT4P *Game Theory for Platoon*

IEEE *Institute of Electrical and Electronics Engineers*

LTE *Long Term Evolution*

LuST *Luxembourg SUMO Traffic*

OBU *On-Board Unit*

QoE *Quality of Experience*

QoS *Quality of Service*

RN *Relay Nodes*

ROI *Region Of Interest*

RSSI *Received signal strength indication*

RSU *Roadside Unit*

SN *Source Node*

SSIM *Structural Similarity*

SUMO *Simulation of Urban MObility*

V2H *Vehicle to Hybrid*

V2I *Vehicle to Infrastructure*

V2V *Vehicle to Vehicle*

V2V *Vehicle-to-Vehicle*

VANETs *Vehicular Ad-hoc NETworks*

VQM *Video Quality Metric*

WAVE *Wireless Access in Vehicular Environments*

List of Symbols

n	Number of Vehicles in the scenario
i	Individual Identity
G	Graph containing all the vehicles in the scenario
V	Set of vertices of the graph G
E	Set of edges of the graph G
v_i	Vehicle $\in V$
$N(v_i)$	Subset of all 1-hop neighbors
R_{max}	Radio Range
e_j	Communication link between vehicles
$w(e_j)$	Weight value for each link
P_i	Predefined travel path
S_i	Speed of v_i
S_{min}	Minimum speed of v_i
S_{max}	Maximum speed of v_i
L_i	Location of v_i
F_i	Forwarding nodes
$S_{platoon}$	Speed of the platoon leader
$P_{platoon}$	Travel path for platoon members
A	Set of available strategies

u_i	Reward of v_i for the strategy a_i
U	Set of reward functions of each vehicle v_i
C	Cost of v_i by deciding for the strategy a_i accept
a_i	Strategy of v_i
DC	List of candidates for RN
$dist$	Euclidean distance
α and β	Reward u_i coefficients
EI_i	Equality Index

List of Figures

List of Tables

CHAPTER 1

Introduction

This chapter introduces the key concepts about VANETs, summarizes the current challenges for video streaming over VANETs, introduces the main goal of this master thesis, shows the essential contributions, and outlines the course of the subsequent chapters.

1.1 Overview

VANETs allow moving vehicles to form self-organized ad-hoc networks without the need of permanent infrastructure [1]. In this way, VANETs provide communication exchange between vehicles, enabling autonomous vehicle communications and new use cases for enhanced safe driving at high vehicle speeds, harsh driving conditions, and cooperative driving. Besides the research efforts to increase VANETs connectivity, academy and industry partners have made efforts for autonomous driving [2]. This is because further enhancements of today's driver assistance, such as Adaptive Cruise Control (ACC) pave the way towards highly automated driving. In this context, platoon-based driving is one of the main forms of autonomous driving, since autonomous/semi-autonomous vehicles organize themselves, on the same lane, into a set called of platoon. Platoon can be defined as a group of vehicles that travel close to each other, and safely on the road, even at high speeds [3, 4].

In platoon-based driving, vehicles moving on the same direction and closer to each other could cooperate in establishing a platoon to mitigate some drawbacks [5]. This is because platoon-based driving provides an autonomous and cooperative driving pattern for a group of vehicles with a common path, where vehicles maintain a constant distance. The platooning protocol must control and manage the platoon, including formation, merging, splitting, and maintenance tasks [6]. Specifically, the platoon leader defines the speed and direction for platoon members, giving commands about when to accelerate or break. The platoon-based driving brings many benefits, such as more efficient information dissemination and sharing among platoon vehicles [7].

In this scenario, users could record, share, and even watch real-time videos in their vehicles, creating new specialized services for these users, ranging from on-road multimedia safety and security to entertainment video flows [8]. For instance, an on-board event detection system on vehicles could identify an accident and disseminate real-time video via VANET to show the area of an accident to its peers [9, 10]. In addition, autonomous driving must consider a see-through system, which relies on live multimedia information of vehicles approaching from the opposite direction in order to facilitate safety assessment during overtaking maneuvers. For instance, it enables vehicles to detect hidden objects or get a more accurate view on what is happening within their environment [11, 12].

Platon-based driving bring benefits in many ways, such as, more efficient information dissemination and sharing. Specifically, platoon members could actively collaborate in the video transmission without route failures. Platoon is also a promising way to improve traffic efficiency, safety, reduce fuel consumption and CO_2 emissions by vehicles driving close to each other with the same speed [7]. However, platoon-based driving relies on active user participation, and on incentive mechanisms to encourage greater vehicles participation [13, 14]. For instance, monetary incentive is the most immediate method for service provider to reward vehicles that joined the platoon for transmitting the video with Quality of Experience (QoE) provisioning [15]. Coupons, virtual currency, or credit-based incentive are alternative ways to stimulate platoon-based driving for vehicles interested in consuming a given services with an attractive discount, *e.g.*, free movies. Hence, it is required to choose a set of vehicles that can provide video transmission with adequate QoE to join the platoon. In this sense, game theory provides a set of mathematical and technical tools for modelling situations involving conflict of interest between nodes (*i.e.*, vehicles) [16]. For instance, game theory copes with conflicts between two or more platoons by the same vehicle.

1.2 Motivation and Challenges

Video dissemination can be considered as an interesting use case for autonomous driving, since they can feed world sensors through a set of cameras, *e.g.*, dash, side-view, rear, and bird's eye view cameras. In this context, video dissemination over VANET requires QoE support to deliver video content with a minimal quality level based on user experience. QoE emphasizes end-to-end performance by taking into consideration the user satisfaction with the content player, where users expect to watch videos without any interruptions, ghosting, blocking, pixelization, freezing frames, and at a certain quality level no matter what changes may occur in the network conditions and VANET characteristics [17]. This is a hard task due to vehicles usually move at high speeds, leading to frequent disconnections and limiting the duration of Vehicle-to-Vehicle (V2V) communication to a few seconds [18].

Route video packets in V2V communications are a difficult task due to the frequent disconnections caused by vehicle mobility, and also bandwidth limitations of wireless technology. For instance, Uppoor and Fiore et al. [19] analyzed a large-scale mobility trace from Cologne-Germany, and concluded that contacts between pairs of vehicle are extremely short, *i.e.*, between 1 and 15 seconds. Hence, how to mitigate the influence of short contact time in V2V communications to avoid communication flaws, delays, and packet loss during video transmissions is still a challenging task [20].

In this context, vehicles moving on the same direction and closer with each other can cooperate to establish a platoon, avoiding communications flaws in the V2V communication [5]. In this sense, platoon members could actively collaborate in the video transmission without route failures. Specifically, platoon-based driving consider cooperation among vehicles with common interest to bring benefits in many ways, such as, more efficient information dissemination and sharing among platoon vehicles. Despite the benefits of platoon-based driving from a system point-of-view, vehicles have a selfish behavior, leading to platoon splitting and merging, as well as packet losses. For instance, vehicles may not be willing to join the platoon in order to help other vehicles by forwarding packets, since they consume computing, communicating, and fuel resources, as well as changing their travel time [14]. Selfish vehicles will try to join and quickly leave the platoon, in order to receive the reward without participating in the platoon for the video transmitting task.

The decision of joining still relies on the driver, who considers the benefits of joining the platoon while taking a longer route/time to reach the destination location. For the driver, joining the platoon can be encouraged through the use of monetary incentives. Based on this assumption, the decision to join the platoon can be treated as a conflict of interest situation. In this sense, the cooperative behavior can be enforced by means of a rewarding function to give incentives to vehicles participating in the platoon, since users tend to be selfish [13, 14]. The platoon must rely on incentive mechanisms to encourage the user (*i.e.*, vehicles) participation, where monetary incentive is the most immediate method to reward vehicles that joined the platoon for video transmission with QoE support [15]. For instance, platoon-based driving can be encouraged by offering discounts at local markets, free parking lots, free movies, priority for video consumption and network resources, among other profits [15, 21].

In this context, game theory is an effective tool to model and analyze an incentive mechanism, and also for inactivated nodes (*i.e.*, vehicles) to cooperate [15, 22]. Game theory approaches are divided into cooperative and non-cooperative games [16]. In the former, players can make commitments before starting the game. In the latter, players can not establish previous relationships before starting the game. In simultaneous games, the game interaction happens in a single step, while in sequential games, the interaction happens in a sequence of steps. In a platoon-base driving considering game theory, it is expected that each vehicle choose their strategy without having access to the strategy and without waiting for the decision of the other vehicles, *i.e.*, a non-cooperative and simultaneous game.

1.3 Objectives

This master's thesis presents a protocol for the formation of Platoon based on the Game Theory for video transmission with QoE support, called GT4P (Game Theory for Platoon). The GT4P consider Game Theory to decide which vehicles to participate in the platoon and will serves as a relay node. Cooperation between vehicles is guaranteed by means of a reward function, which guarantees a retribution for the platoon participants. The protocol select, to participate in the platoon, a set of vehicles that are moving in the same direction, with similar speeds and a suitable distance to disseminate the video, thus providing greater connectivity between vehicles.

We conducted simulations to evaluate the performance of the proposed protocol (GT4P) to disseminate videos at heterogeneous VANET scenarios (urban and highway) compared to other protocols based on literature. Thus, the objectives of this work include:

- A state-of-the-art bibliographical survey on the transmission of video in VANETs, as well as to understand the main challenges and limitations of this research area.
- A protocol for selecting the best relay nodes, based on mobility information, for multimedia applications in vehicular networks.
- A protocol of encouragement and treatment of selfish nodes.
- Evaluate the behaviour of proposed protocol and videos transmitted according to QoE / Quality of Service (QoS) metrics.

1.4 Contribution

This work has he following main contributions:

- Development of a protocol for video transmission using Game Theory for VANETs
- Advances the state-of-the-art on video transmission in VANETs
- Implements and evaluates the proposed GT4P
- Instigates the sharing of video content with QoS/QoE support in VANETs

1.5 Text Organization

The rest of this dissertation is organized following the ordering described below:

- Chapter 2: It presents fundamentals about VANETs. Video transmission concepts are explained in VANETs and which QoE metrics will be used in the evaluation of the protocol based on the literature. The chapter ends with the concept of Game Theory, as well as the definitions of the game as: Game, players, cost and balance.
- Chapter 3: It outlines existing works and their main drawbacks to provide video transmission over VANET with QoE support.
- Chapter 4: It details the proposed protocol. The chapter also presents how the Game Theory is built, the parameters used for the vehicles selection criteria to re-transmit the video packet to its destination and how it works.
- Chapter 5: It shows how the protocol are evaluated, which simulation scenario is used and which metrics will evaluate the results. Some use cases for applying the proposal are also described. All the parameters used are defined, as well as the simulators, videos transmitted and methodology used to carry out the experiments. In sequence, the results are discussed.
- Chapter 6: Concludes the current master's thesis, suggests the expected future works and presents the published work.

CHAPTER 2

Theoretical Reference

This chapter presents the main concepts about VANETs, their characteristics and main applications. Still in the context of VANETs, we discussed the operation of the platoon and their controller models. We also discussed about Game Theory, the concepts used in this master's thesis and how is the relationship between the selfish behaviour and Nash Equilibrium. Furthermore, the QoE concept and their evaluation metrics SSIM and VQM are explained for video transmission.

2.1 Veicular Ad Hoc Networks (VANETs)

Within mobile ad hoc networks (MANETs) there is a peculiar type of network called VANETs, where the nodes that make up this network are vehicles instead of smart phones. VANETs have similar characteristics with MANETs, such as short transmission range and low bandwidth. Each vehicle is equipped with a network device and uses the IEEE 802.11p standard to add Wireless Access in Vehicular Environments (WAVE).

Vehicular Ad Hoc Networks allow the exchange of information between vehicles and can aid in the behavior of drivers, increasing their safety and comfort in travel. This type of network provides a large number of applications that make use of multimedia content in real time. With time, the vehicles are becoming smarter and more useful with multiple network aspects, and can be treated as VANETs.

In VANETs it is possible for vehicles to consume large amounts of data, based on local and temporal relevance. For the nodes that make up the network it is important to search for the independent content of their network providers, to collaborate with the network using their resources and to enable services with the help of the infrastructures [23].

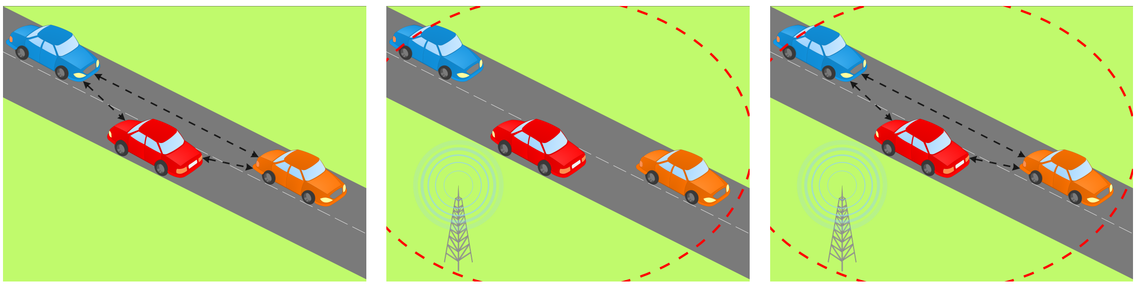
2.1.1 Characteristics

In VANETs, a node belonging to an ad hoc network has wireless interfaces that allow it to exchange information with other nodes, the network has autonomy to self-manage, this has brought the possibility of maintaining connections with several in the presence of an infrastructure for management of this network which increases the number of applications that can be thought for the most diverse scenarios.

These characteristics can basically work on three types of communication: V2V, V2I and V2H. A Vehicle to Vehicle (V2V), Figure 1(a), where all nodes communicate directly with each other and play the role of routers for forwarding multiple Relay Nodes (RNs) between a source (Sorce Node - SN) and a destination (Destination Node - DN). In this type of communication the connectivity between the nodes depends on the density of the network and how the vehicles are moving in the way, its mobility pattern, being possible through a network device installed on the vehicles called On-Board Unit (OBU) that connects to the Dedicated Short-Range Communication (DSRC) wireless network[24].

Another type of communication is the infrastructure, V2I, where the vehicles communicate with the infrastructure in the roads to be able to access the services as shown in Figure 1(b). In this type of communication it makes use of an external support infrastructure and gateways to provide Internet access and routing for the transmissions. This external infrastructure can be the so-called Roadside Unit (RSU) or the Long Term Evolution (LTE)[1].

There is still a last type of communication that uses the concepts of the two previous communications, known as hybrid or V2H. A node equipped with a network device may connect to another node ad hoc or communicate with an RSU to consume a given service, as shown in Figure 1(c). Hybrid communication is widely used in applications as it provides the union of services, a user can request multimedia content from the Internet while receiving information from other vehicles on the street.



(a) V2V Communications (b) V2I Communications (c) V2H Communications

Figure 1: Types of Communications in VANETs

2.1.2 Applications

The vehicles have users (drivers and passengers) who are the consumers for most applicatiorns. In the network, the vehicle plays as a collaborator node, sharing information with others vehicles. Based on that, the driver can take some advantage on assistance and safety applications for example, otherwise, passengers can consume entertainment applications. Further vehicles acts as RN and can propagate information even without when not covered by another infrastructure. There are some typical applications regarding VANETs. It can be used for driving assistance, safety, among other applications:

1. **Safety Applications** are responsible for increasing the safety of drivers, this type of application uses messages to warn about the conditions of the roads [25]. Within the safety applications, there are Advanced Driver Assistance Systems (ADAS) applications that consider collaboration between drivers and control systems, such collaboration takes place through the exchange of information between vehicles through the Ad Hoc Networks [26].

2. **Advertising Applications** are responsible for disseminating advertisements and increasing sales of certain products, may indicate locations of establishments interesting to drivers, with the main objective to stimulate new costumers. Due to the long time that people spend inside the car ads messages' broadcast for vehicle passengers can be effective, and can bring commercial profits [27].

3. **Infotainment Applications** are related with multimedia content distribution. Many applications use video as main content in computer networks, people are consuming this kind of content anywhere, whether it's cell phones, personal computers, or even cars [28]. In this master's thesis this kind of application is the focus together with ADAS applications.

2.2 Game Theory

Game Theory specifies a game as a set of mathematical and technical tools for modeling situations involving conflict of interest and for modeling situations in which individuals make decisions seeking to maximize their gain (or minimize their losses), but the result of the game is obtained depending on the decisions of other players who also participate in the game. Game Theory is an area of economics that models games or activities that involve two or more decision makers (Players) interacting with each other [29].

The main approaches involving game theory are subdivided into cooperative games and non-cooperative games [16]. In non-cooperative games, players can not make compromises before starting the game. On the other hand, in cooperative games, players can establish previous relationships before starting the game, in addition to making compromises secured with the other players.

In simultaneous games, the process of interaction of the game happens in a single step, already in sequential games the interaction happens in a sequence of steps. Therefore, in the formation of a platoon, considering game theory, each player (vehicle) is expected to choose their strategy without having access to the strategy and without waiting for the decision of the other players, that is, a non-cooperative and simultaneous game [30].

In this way, we can visualize a game as a mathematical tool to model situations with several agents (called Players or Individuals) that make a decision (Strategy Call) in order to guarantee the best and best result for you (Maximize the gain or minimize the cost, also called payoff), which depends on the decision-making of other players who also play the game. A classic example is the Prisoners' Dilemma which is widely used in the state of the art as a game involving game theory [31].

In this context, protocols can be idealized by knowing the possible actions of each player within a situation. This protocol can deal with the selfish of each decision maker, always seeking to maximize their individual gain, which can cause a degradation in the quality of a particular service. The proposed GT4P protocol uses these concepts of Game Theory to minimize selfish behavior with an incentive mechanism based on the actions of the selected RN.

2.3 Quality of Experience

When it comes to assessing the quality of multimedia content, traditional QoS metrics are not accurate enough to describe the quality of the videos being streamed. Latency, delay variation, bit rate per second, and packet loss do not allow you to evaluate subjective aspects of the video content pertaining to the human experience [17]. To circumvent such a problem, QoE metrics, especially Structural SIMilarity (SSIM) and Video Quality Metric (VQM) are widely used.

2.3.1 Structural Similarity Index (SSIM)

SSIM is a method to measure the similarity between two images. The SSIM index can be seen as a measure of the quality of one of the images being compared, as long as the other image is the original. Evaluates the structural distortion of the video rather than an error in the transmission. It measures three basic components, luminance, contrast, and structural similarity and combines them into an end value that determines the quality of the test sequence [32].

The values extracted from the frame received by the user and the original frame are stored in separate vectors, being a vector for the luminosity, one for the contrast and another for the structure. Thus, the mean of each vector is obtained and the video quality indicative is generated by the combination of the three means. The value of SSIM is obtained through Equation 2.1.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{2.1}$$

Where: x it's the original video; y degraded video (transmitted); μ_x the average of x; μ_y the average of y; σ_x the standard deviation of x; σ_y the standard deviation of y; σ_{xy} the covariance of y; $L =$ the maximum value that can be assigned to each pixel; $k_1 =$ 0,01 e k_2 0,03, by default; $c_1 = (k_1 L)^2$ and $c_2 = (k_2 L)^2$ are constant. Finally, the SSIM results are presented in the interval $[0,1]$. The closer to 1 is the SSIM value, the better the video quality will be.

2.3.2 Video Quality Metric (VQM)

Taking into account characteristic features of the human visual system, VQM $\in [0,4]$ examines the received video according to perceptual damage. Extracts information from the original video and compares it with the information extracted from the degraded video. Among the information analyzed by VQM are: spatial, temporal and chrominance. The final quality estimate is provided by a linear combination of the measured parameters and the impact that such parameters exert on the human visual system [33].

The VQM calculation has 4 steps [34], described as follows:

1. Calibration: estimates and corrects the spatial and temporal change, as well as the contrast and brightness shift of the processed video sequence in relation to the original video sequence;

2. Extraction of quality resources: extracts a set of quality features that characterize perceptual changes in the spatial, temporal and chrominance properties of video streams using a mathematical function;

3. Quality Parameter Calculation: computes a set of quality parameters that describe perceptual changes in video quality, comparing the extracted resources of the processed video with those extracted from the original video;

4. VQM calculation: The metric is calculated using a linear combination of parameters calculated from previous steps.

As a final result, the values returned by VQM range from 0 (imperceptible defects between videos) to approximately 4 (extremely perceptible defects). Some studies show that VQM has a good correlation with subjective quality scores because it considers factors of the human visual system.

2.4 Chapter Conclusions

This Chapter explains the basics VANET concepts, their main characteristics, applications, challenges of the technology, and detailed several important characteristics regarding the platoon architecture and their controller models. The topic of Game Theory was also discussed in this Chapter and serves as a basis for a better understanding of this dissertation. The idea of QoE with their essential metrics SSIM, and VQM also were introduced, these QoE metrics are used in this work to evaluate the quality of the transmitted videos. The concepts presented in this chapter are essential to the development of this work.

CHAPTER 3

Related Work

This chapter aims to present the main works related to video transmission in urban scenarios and highways in VANETs. It describes the main characteristics and the functioning of each work in the process of selection of the best RN. One of the biggest concerns around platoon is the selection of the vehicles adequate to participate in the group and serve as a RN for information. Such problem is the task that every platoon protocol needs to tackle, because if the selection is not good, video packets can be lost before reaching the destination. In the following, we detail the analyzed platoon-based protocols evaluated in this paper. We also divide the existing works into platoon-based driving and routing protocols.

3.1 Routing Protocols

Braun et al. [35] introduced the concept of Dynamic Forwarding Delay (DFD) as the routing decision in BeaconLess Routing algorithm (BLR). Instead of continuous information exchange with the neighbouring nodes, each node makes the forwarding decision by computing the DFD value based on its current location and the neighbour location contained in the received packet. All receivers set a timer, and the one that first counts down to zero will be selected as relay node. Rosário et al. [36] proposed XLinGO, which considers cross-layer information to compute the DFD value, namely buffer size, link quality, location and energy. However, a VANET has a dynamic network topology with short contact time, which worsens the QoE of delivered videos via those protocols due to frequent disconnections. Quadros et al. [37] computed the Contention Window (CW) based on video parameters, location, and QoE information. However, a VANET has a dynamic network topology with short contact time, which worsens the QoE of delivered videos via those protocols due to frequent disconnections. The proposed protocol employs

QoE-indicators criterion that support the selection of the best next hop and switches to other routes as soon as lower quality is identified. Moreover, this protocol do not take into account metrics to increase the route duration during video transmission.

Chen et al. [38] considered game theory to form groups and offer incentives for the group members. This work can be used for decision-making in routing protocols, forcing the cooperation among network nodes. It considers the storage size of each vehicle to decide which vehicles participate in data transmission. The result shows that the incentive scheme provides effective stimulation for nodes to cooperate and prevents the degradation of system performance in VANETs with selfish nodes.

Gerla et al. [39] presented an approach using game theory to enforce forwarding nodes to apply network coding, the autors also presented a state of the art technologies and protocols for content distribution in VANETs. In the paper, video streaming was studied with particular attention to errors and packet losses. However, such works [38, 39] do not consider platoon establishment for video transmission.

3.2 Platoon-based Driving

Amoroso et al. [40] introduced Furthest Distance (FD), which considers a sender-oriented multi-hop relay selection algorithm. In FD every node computes a CW before forwarding a packet. The CW is calculated based on its current location and the neighbors' location contained in the received packet. In general, a lower CW means that the vehicle is closer to the destination, which increases the probability of such node to be selected for the platoon as the platoon leader. The FD goal is to minimize the number of hops between the source and the destination. We can observe the behavior of the FD in the Figure 2, where the (SN) selects the (RN) closest to the limit of the radius of communication and closer to the (DN):

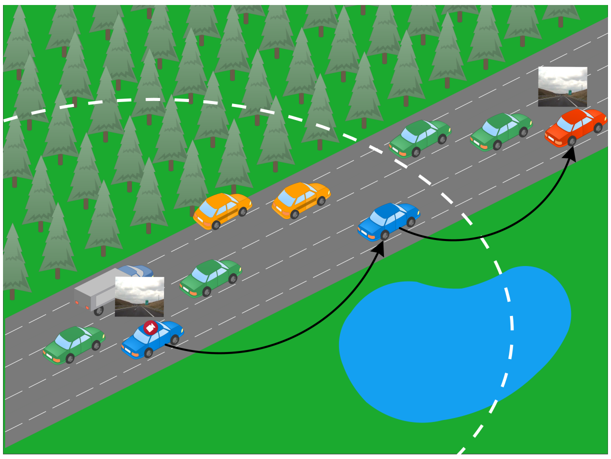


Figure 2: Behavior of the FD protocol

Bidirectional Stable Communication (BDSC), proposed by Rehman et al. [41], considers that each vehicle periodically broadcast a HELLO message, which contains three pieces of information: broadcaster ID, location information, and Active Communication Node List (ACNL). Specifically, the broadcaster ID refers to the source node MAC address of the Wi-Fi transceiver, while the location information refers to its current location coordinates. The ACNL is the most important component of the HELLO packets, since it keeps the recent information of the available single-hop vehicles, by constantly exchanging the HELLO packets.

Zhang et al. [42] proposed V-PADA, which is a novel vehicle-platoon-aware data access solution for VANETs. V-PAD is a platoon protocol that includes two components based on cost and efficiency to find the best vehicle to replicate data within the platoon, and also to analyze possible mobility anomalies that could affect data transmission.

Amoozadeh et al. [7] introduced a high-level design of a platoon management protocol that considers a centralized platoon coordination approach where the platoon leader coordinates all communications. The protocol consider three basic maneuvers: merge, split, and lane-change that is based on VANET and Cooperative Adaptive Cruise Control (CACC) vehicles. A set of micro-commands exchanged between vehicles leveraging IEEE 802.11p are used to accomplish the basic maneuvers, and the protocol operation is described in details using various finite state machines.

Jia et al. [5] takes into account vehicle mobility to establish a platoon, such as traffic flow, bandwidth, platoon speed and size, the autor also consider the probability distribution of platoon-based traffic flow, including inter-platoon spacing and interplatoon leader spacing, and investigated inter-platoon connectivity in a practical bi-directional highway scenario and evaluated the expected time of safety message delivery among platoons.

However, these protocols must provide incentives for vehicles to participate in the platoon, since those vehicles change their travel time, fuel consumption, and CO_2 emissions. In addition, Jia et al. consider that all vehicles within the platoon can communicate directly with each other, which means that the platoon communication length does not exceed one hop.

3.3 Chapter Conclusions

In this chapter, we present the state-of-the-art that relate to the proposal of this research. Each work seeks to guarantee an ideal selection of nodes that should forward a certain content. Based on the analysis of the related works, it is clear the need for more eficient protocols to transmit video information between vehicles, as well as the use of an incentive mechanism to increase node participation in packet transmission. Thus, Table 1 summarizes the main characteristics of each related work.

Table 1: Main Characteristics from Related Work

Protocols	Platoon Based	Incentive Based	QoE Evaluation
Braun et al.	no	no	yes
Rosário et al	no	no	yes
Amoroso et al.	yes	no	no
Rehman et al.	yes	no	no
Zhang et al.	yes	no	no
Amoozadeh et al.	yes	no	no
Jia et al.	yes	no	no
Quadros et al.	no	no	yes
Chen et al.	no	yes	no
Gerla et al.	no	yes	no
Current Proposal	yes	yes	yes

CHAPTER 4

Game Theory Approach for Platoon-based driving for Video transmission over VANET (GT4P)

This chapter describes the GT4P protocol, which considers game theory to enforce the cooperation between vehicles in order to form an efficient video-based platoon. GT4P protocol uses monetary rewards/credits/tokens to allocate/pay for the platoon vehicles according to their efforts in the video transmission process with QoE support. GT4P takes into account direction, speed, vehicle travel path, Received Signal Strength Indication (RSSI), and distance to select the platoon members, as shown in Figure 3. In addition, GT4P adjusts the distance between platoon members to reduce the effects of wireless communication on the packet loss. Platoon members collaborate with the video transmission by mitigating the effects of vehicle mobility with lower disconnections.

4.1 Network and System Model

We consider a VANET scenario composed of n vehicles (nodes) moving on a multi-lane urban or highway area, where each vehicle has an individual identity ($i \in [1, n]$). These vehicles are represented in a dynamic graph $G = (V, E)$, where the vertices $V = \{v_1, \cdots, v_n\}$ represent a finite set of vehicles, and edges $E = \{e_1, \cdots, e_m\}$ build a finite set of asymmetric wireless links between neighbor vehicles (v_i). We denote $N(v_i) \subset V$ as a subset of all 1-hop neighbors within the radio range R_{max} of a given vehicle v_i. Each link e_j has a weight value associated ($w(e_j)$), *i.e.*, link quality, such as the one provided by RSSI.

Each vehicle (v_i) moves towards a certain direction ($\overrightarrow{dir_i}$) following a predefined

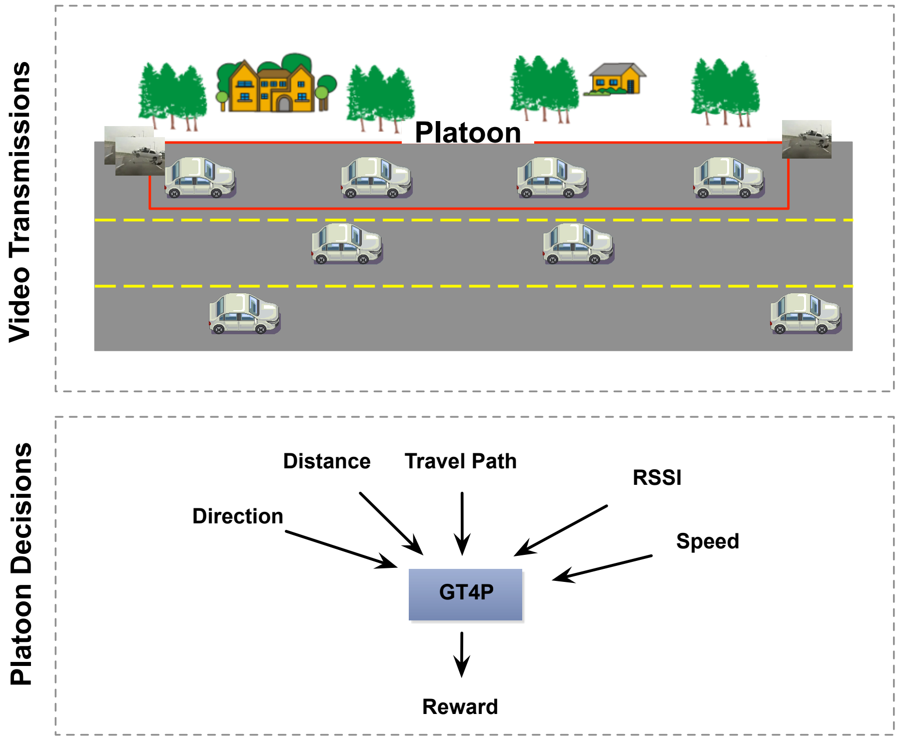


Figure 3: Platoon-based Driving Scenario

travel path P_i (a set of roads connected by intersections) with speed S_i ranging between a minimum (S_{min}), and a maximum (S_{max}) speed limit. Each vehicle v_i is aware of its own location $L_i(x, y)$ by means of positioning system, such as Global Position System (GPS). The location of the Destination Node (DN) $\subset V$ is provided by any update localization service, such as introduced by de Felice et al. [10]. Further, each vehicle v_i is equipped with an IEEE 802.11p-compliant radio transceiver, where each vehicle can communicate with its neighbors $N(v_i)$. Each vehicle v_i is also equipped with a multimedia encoder/decoder. For convenience of notation, we denote $SN \subset V$ (Source Node) as the node v_i responsible for capturing video flows and transmitting them to the DN via multiple forwarding nodes ($F_i \subset V$).

For the network model of this master thesi's, it was supposed a scenario of dissemination of video. The use case is an accident or disaster, where vehicles and first aid teams coming toward the collision area should receive the video of the accident. Video streaming on VANETs can be used to improve service during emergency situations such as road accidents. Videos recorded by neighboring vehicles can be used to enable paramedical teams in ambulances to prepare a more accurate care before they even reach the emergency room. Disseminated videos likewise can be used for motorists to check traffic conditions and assist in deciding the best routes. Finally, video treamings can also be used for passenger entertainment.

Regarding the video request, a safety alert message is transmitted through multi-hop communications. As introduced by de Felice et al. [10], the interested vehicle DN requests a video from a given vehicle SN via a video request message, which is forwarded towards the direction of the DN, not further on, and above all, not in other directions, since every message contains the SN and DN location information. The vehicle SN automatically switches its cameras on and starts recording and sharing the video content to the vehicle DN that can be located away. In this sense, the source vehicle SN must establish a platoon in order to use platoon vehicles for video dissemination.

In this work the ACC and CACC controllers were used to carry out the control of the platoon. The ACC system can use sensors to detect the distance between adjacent vehicles and autonomously maintain the speed and/or distance [6]. The control is based on sensor information presents in the vehicle, this technology is also regarded as a key component of intelligent cars [43]. As for the CACC system is an extension of the ACC controller, it's uses the VANETs to share information that helps in the decision making of the controller, as well as assist in the accuracy of the sensors present in the vehicles. In Figure 4 is shown an example of a platoon, we can also analyze the sharing of multimedia content of the conditions of the route, in this case it's present the See-Through System.

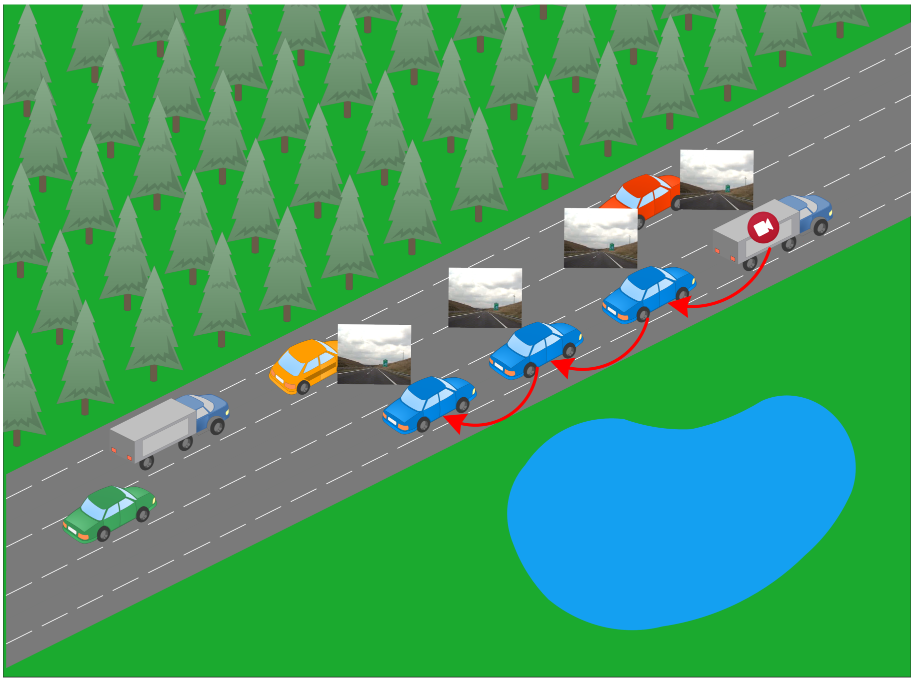


Figure 4: See-Through System in Platoon

The platoon leader defines the speed $S_{platoon}$ and the travel path $P_{platoon}$ for platoon members, exchanging commands about when to accelerate, slow down, or break. Through V2V wireless communication, a vehicle v_i could get information on the platoon leader and also from the vehicle in front, in order to know in advance what is happening at the head of the platoon and react promptly, avoiding instabilities that might lead to vehicle collisions [3].

The GT4P protocol considers two phases to form a platoon for video transmission. The communication phase finds a vehicle v_i to join the platoon based on travel path, direction, speed, distance, and link quality, by computing the reward function for each candidate vehicle to join the platoon. The mobility phase is responsible for maintaining a platoon during the video transmission. The GT4P protocol has the following assumptions.

- a non-cooperative and simultaneous game.
- selfishness means taking an action to maximize its own utility, which might lead to a given vehicle joining the platoon and subsequently leave it.
- every vehicles v_i can participate in the platoon.
- the platoon configuration is the column, also known as road trains.
- the platoon finishes after the video transmission.

4.2 GT4P Game Setting

We designed a non-cooperative and simultaneous game, since vehicles v_i choose their strategies without waiting and have access to the strategies of their neighbors $N(v_i)$. The cooperative behavior is enforced by means of a rewarding function to give incentive for vehicles joining the platoon. We described the game as $\{V, A, U\}$, where V means the set of vehicles, $A = \{a_1, a_2, a_3, ..., a_n\}$ denotes the set of available strategies $a_i \in \{0{,}1\}$ for each vehicle v_i.

- $a_i = 1$, action of *accept* to join the platoon;
- $a_i = 0$, action of *decline* to join the platoon.

The platoon vehicles have changing travel time, fuel consumption, and CO_2 emissions, and thus GT4P gives a reward u_i to enforce greater vehicle participation in the platoon. The set of reward functions of each vehicle v_i is represented by $U = \{u_1, u_2, u_3, ...u_n\}$, which depend on the set of strategies A. A given vehicle v_i receives a reward u_i and has a cost C by deciding for the strategy a_i accept. The cost C is related to the use of network resources, fuel consumption, CO_2 emissions, and changes in the travel time. On the other hand, a given vehicle v_i receives a reward u_i equal to zero by choosing the strategy a_i decline, as it will not be possible to join the platoon.

The GT4P communication phase involves the transmission of the advertisement (*adv*), *join*, acknowledgment (*ack*), and *end* messages. Establishment of a platoon starts as soon as a vehicle SN receives a request to capture and send a video for a given vehicle DN via multiple forwarding nodes F_i (*i.e.*, platoon members). In this sense, the vehicle SN broadcasts an *adv* message to its neighbours $N(SN)$ to start the platoon formation, and waits for the reception of *join* messages. The *adv* message contains SN speed S_{SN}, direction $\overrightarrow{dir_{SN}}$, and current location $L_{DN}(x, y)$, as well as DN location $L_{DN}(x, y)$ information.

Upon receiving an *adv* message, each SN neighbor $N(SN)$ must check if they are inside the SN Region Of Interest (ROI). GT4P considers the ROI of vehicle SN as the region located between the vehicles SN and DN with vehicle v_i moving on the same direction $\overrightarrow{dir_i}$ of vehicle SN. Hence, a given vehicle v_i within the ROI of SN selects a strategy a_i accept, since the GT4P ensures that such vehicle will receive a fair reward to pay for the costs to join the platoon. Then, vehicle v_i needs to announce its interest in joining the platoon by sending a *join* message, which contains current vehicle travel path P_i, location $L_i(x, y)$, speed S_i, and the RSSI $w(e_j)$ measured for the received *adv* message.

For each *join* reception, vehicle SN saves the values contained in the *join* message in a candidate list DC. As soon as the *join* reception finishes, vehicle SN computes the reward u_i for each candidate in the list DC based on Eq. (4.1). Specifically, GT4P considers the following information for computing the reward u_i, namely, source node SN and vehicle v_i speed information (*i.e.*, S_i and S_{SN}), the Euclidean distance ($dist_{SN,v_i}$ $\in R_{max}$) between SN and v_i, the link quality $w(e_j)$ measured by the vehicle v_i in the reception of *adv* message, and the similarity between travel path P_i for vehicles SN and v_i, called the Equality Index (EI_i). The reward u_i includes coefficients (α and β) to give different priority to each metric depending on the application requirements. The sum of the coefficients (α and β) is equal to 1. We considers that both metrics have the same degree of importance, and thus we set these values equals to 0.5, representing an importance of 50%.

$$u_i = \min_{i \in C}\{|\alpha \times \frac{(|d_{SN,v_i} - 0.33 \times R_{max}| \times max(S_{SN}, S_i)}{min(S_{SN}, S_i) + 1} + \beta \times \frac{w(e_j)}{(EI_i \times max(w(e_j))) + 0.01}|\} \quad (4.1)$$

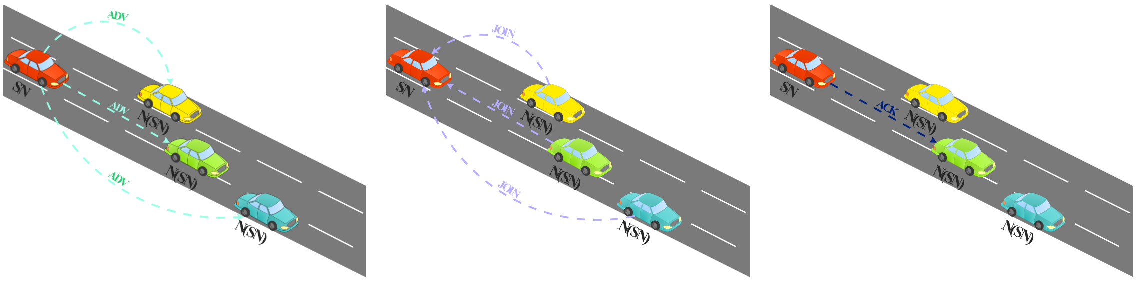
Equality Index $EI_i \in$ [0,1] is computed based on Eq. (4.2), which takes into account the number of equal roads $count_i$ in both travel paths P_i and $P_{platoon}$, and the total number of roads $|P_{platoon}|$ in the platoon travel path $P_{platoon}$. In this way, identical travel paths result in Equality Index EI_i equal to 1, while different travel paths result in Equality Index EI_i equal to 0. This avoids selfish behavior by giving higher incentives for vehicles that change their travel path more without leaving the platoon, since such vehicles have a higher fuel consumption and longer travel time.

$$EI_i = \frac{count_i}{|P_{platoon}|} \quad (4.2)$$

Vehicle SN chooses the vehicle v_i with the lowest reward u_i value for joining the platoon. This is because such vehicle received the *adv* message with higher RSSI, closer to the ideal distance between platoon vehicles, as well as similar speed and travel path. We consider that each platoon vehicle must be separated by 2/3 of the radio range R_{max}. Based on setup simulations, this distance is considered appropriate for video transmission with adequate QoE, since smaller distances increase the number of hops. On the other hand, higher distances cause disconnections due to radio range R_{max} dynamically changed by shadowing effects, attenuation from buildings, etc [44].

Finally, SN sends an *ack* message to the vehicle v_i chosen to join the platoon.

In this way, the GT4P protocol provides video dissemination with adequate QoE, while avoiding that platoon vehicles have their travel time, fuel consumption, and CO_2 emissions greatly changed. The GT4P protocol considers that platoon vehicles forward video packets between vehicles SN and DN, collaborating to video transmission with less disconnections. Once vehicle v_i receives the *ack* message, it starts the mobility phases by changing its speed S_i to the speed of S_{SN}. Afterwards, v_i becomes the new platoon leader (*i.e.*, SN), and the algorithm continues until the packet reaches the DN. We can observe the detailed operation of GT4P in Figure 5.



(a) ADV Phase (b) JOIN Phase (c) ACK Phase

Figure 5: Phases of the operation of the GT4P protocol

As soon as the DN joins the platoon, it has to send an *end* message for all platoon members. This message helps to keep all platoon members driving by the same travel path with the same speed. This message also contains all platoon members location, which helps to keep all platoon members with same distance between each other. Specifically, platoon vehicles separated by distances longer than 2/3 of the radio range R_{max} must have to adjust their distances, since long distance leads to packet losses due to the unreliability of the wireless channel. By doing this, GT4P reduces packet loss and disconnections caused by long distance between vehicles in a V2V wireless communication. Algorithm 1 introduces the main operations performed by GT4P that form a platoon.

4.3 Chapter Conclusions

We highlight the elements implementation In this chapter the GT4P was presented. The behavior of the protocol is discussed, as well as the selection of the RNs and the incentive mechanism applied to decrease the amount of selfishness. The RN selection metrics are presented, together with the protocol algorithm, with a focus on selecting the best RNs to participate in the platoon and transmit the video with QoE guarantees. The GT4P functions and the algorithm was detailed for a better understanding of its operation.

Algorithm 1: GT4P Description

begin
    Event: Begining the Platoon
    adv.Location $\leftarrow L_i(x, y)$
    adv.DNLocation $L_{DN}(x, y)$
    adv.Speed $\leftarrow S_i$
    adv.Direction $\leftarrow \overrightarrow{dir_{SN}}$
    adv.Source $\leftarrow v_i$
    broadcast(adv)
    Event: Platoon Decision
    compute u_i, $\forall i \in C$
    id $\leftarrow \min(u_i), \forall i \in C$
    ack.Speed $\leftarrow S_{SN}$
    unicast(ack, id)
    Receive: adv
    if *inside ROI* **then**
        join.Source $\leftarrow v_i$
        join.RSSI $\leftarrow$ RSSI
        join.Path $\leftarrow P_i$
        join.Location $\leftarrow L_i(x, y)$
        join.Speed $\leftarrow S_i$
        unicast(join, adv.Source)
    Receive: join
    Add all information of join message into a candidate list DC
    Receive: ack
    v_i become part of the platoon
    $S_i \leftarrow$ ack.Speed
    Start the platoon with $N(v_i)$

CHAPTER 5

Evaluation

This chapter describes the methodology and metrics used to evaluate the quality level of transmitted videos through GT4P, FD, BDSC, and Platoon to VANET (P2V) protocols. Afterwards, we evaluate the impact of the density of different nodes on the QoE of videos transmitted in an urban scenario.We also analyze the impact of videos with different characteristics transmitted in a highway scenario.

5.1 Scenario Description

We performed the simulation by using Veins a OMNeT++ framework, which implements the standard IEEE 802.11p protocol stack for vehicle communication and an obstacle model for signal attenuation. For the simulation of traffic and vehicle mobility, it is employed the Simulation of Urban MObility (SUMO), *i.e.*, an open source traffic simulator to model and to manipulate objects in the road scenario. This allows us to reproduce the desired vehicle movements with random cruise speed and V2V interactions based on empirical data. We conducted 33 simulation runs with different randomly generated seeds, and the results present values with a confidence interval of 95%.

The vehicles are equipped with IEEE 802.11p radio (18 Mbit/s) with transmission power of 1.6 mW, and thus these parameters, together with the two-ray ground propagation model, provide a transmission range R_{max} of 250 m. We have different distances between vehicles DN and SN, where the maximum distance is 750 m to provide a hop count limit, such as proposed by de Felice et al. [10]. We conducted simulations by transmitting video sequences with different motion and complexity levels, *i.e.*, Akiyo, Container, Hall, the initial 300 and 600 frames of Highway, News, Paris, Sign, and Silent, downloaded from the video trace library [45], in Figure 6 we can observe frames collected from the videos used to perform the simulations. Those videos have duration between 10 and 20 seconds, encoded with a H.264 codec at 300 kbps, 30 frames per second, and common intermediate format (352 x 288 pixels). The decoder uses a Frame-Copy method as error concealment, replacing each lost frame with the last received one to reduce frame loss and maintain video quality. We performed simulations both in an urban and a highway scenario.

(a) Akio

(b) Container

(c) Hall

(d) Highway

(e) News

(f) Paris

(g) Sign

(h) Silent

Figure 6: Frames collected from the videos used in simulations

For the highway scenario, we considered the Luxembourg SUMO Traffic (LuST) [46], which provides 26 hours of mobility simulation for the city of Luxembourg using the traffic simulator SUMO. LuST has mobility information with multiple vehicles, routes, and road length. The vehicles used in the simulation share the same characteristics, such as size, mean and standard deviation speed. We considered the vehicle for the highways of LuST scenario, which covers an area of 156 km^2 and 932 km of roads. Vehicle SN transmitted videos at a random time, following a Poisson distribution.

For the urban scenario, we considered the Manhattan Grid scenario, composed of ten evenly-spaced double-lane streets in an area of 1 km^2. The simulations run for

1000 seconds (s), where the vehicle SN sends the video at any time after the initial 100 s and before the last 100 s. We also considered the signal attenuation effects caused by buildings, where we assume that each block has a 80m x 80m obstacle, which represents high-rise buildings. In order to quantify the traffic evolution in this scenario, we defined the vehicle density between 200 and 400 vehicles/km^2. The speed of the vehicles respect the limits imposed by the urban scenario, having a maximum of 13.9 m/s in each lane. Table 2 summarizes the main simulation parameters used for the Manhattan Grid and Luxembourg scenarios.

Table 2: Simulation Parameters

Parameters	Manhattan Scenario	Luxembourg Scenario
Simulation Area	1 km^2	155.95 km^2
Simulation Time	800 s	3000 s
Vehicle Speed	13.9 m/s	Mean: 13.84 m/s (St.Dev: 5.27)
Vehicle Density	200, 300, and 400 vehicles/km^2	287034 vehicles
Transmission Power	1.6 mW	
Transmission Range	250m	
Bit Rate	18 Mbit/s	
Data Message Size	1024 Bytes	
MAC Layer	IEEE802.11p	
Video Sequences	Akiyo, Container, Hall, Highway(300 Frames and 600 Frames), News, Paris, Sign, and Silent	
Video Characteristics	H.264, 30fps, 352x288 pixels	

In terms of video quality evaluation, QoS schemes alone are not enough to assess the quality level of multimedia applications, because they fail in capturing subjective aspects of video content related to human experience [17]. In this context, QoE metrics overcome those limitations, and thus we consider a set well-known QoE objective metrics, namely Structural Similarity (SSIM) and Video Quality Metric (VQM). SSIM $\in$ [0,1] is based on a frame-by-frame assessment of three video components, i.e., luminance, contrast, and structural similarity. Higher SSIM value means better video quality. On the other hand, VQM $\in$ [0,4] measures the "perception damage" of video experienced based on features of the human visual system, namely blurring, noise, color distortion and distortion blocks. The VQM values being closer to zero means a video with a better quality. We used the MSU Video Quality Measurement Tool (VQMT) to measure the SSIM and VQM values for each transmitted video.

We conducted simulations with different platoon based protocols for video dissemination over VANET scenario, in order to compare the results in terms of video quality level of transmitted videos.

- **FD** follows the FD description [40], where it only considers geographical information to compute the distance between the vehicle, and the protocol selects the further node as a RN.
- **BDSC** follows the BDSC description [41],the location and a link quality estimate is used to select the best RN. However, there is a long delay in the network to make this estimate. This dynamics of choice delays the transmission of content.

- **P2V** follows our initial GT4P definition [21, 47], wich selects platoon vehicles based on direction, speeds, and distance, which participate in the video transmission with QoE support. P2V considers game theory for decision making and to decide about conflict situations between two or more platoon by the same vehicle during video transmission.

- **GT4P** follows all the GT4P description and operation principles, such as introduced in Chapter 4. GT4P considers it a non cooperative game, where cooperative behaviour is enforced by means of a rewarding function to give incentive for vehicles participating in the platoon, which is actively collaborating with the video transmission with QoE support. The GT4P protocol chooses vehicles to form a platoon based on direction, speed, distance, link quality, and vehicle travel path. In this sense, GT4P selects a vehicle to join the platoon with similar speed and travel path compared to the platoon, suitable link quality, and closer to a predefined distance between platoon members.

5.2 Simulation Results for Urban Scenario

Figure 7 shows the SSIM of videos transmitted via FD, BDSC, P2V, and GT4P protocols in an urban VANET scenario with different vehicle density. By analyzing the results of Figure 7, we conclude that SSIM of videos delivered by GT4P protocol increases as soon as vehicle density increases. This is because the protocol has more candidate vehicles to join the platoon, improving the platoon decision. In addition, the GT4P protocol delivered videos with SSIM 6%, 54%, and 44% higher compared to P2V, BDSC, and FD, respectively. This is because GT4P established a platoon by selecting vehicles with similar speed, appropriate distance between platoon members, similar travel path, and good link quality, as well as GT4P adjusts the distance between platoon members. This platoon selection provides a reliable V2V communication during the video transmission by mitigating the effects of vehicle mobility to avoid communication flaws, delays, void area, and packet loss.

FD has poor performance due to its behavior of selecting each platoon member, *i.e.*, it selects the furthest candidate vehicle to join the platoon. Due to the unreliability of wireless channels, the most distant node might suffer from a bad connection, increasing the packet loss ratio for FD. On the other hand, BDSC has an even worse SSIM result, due to the link quality estimation performed by the platoon leader to select each platoon member, which takes 0.5 seconds. This increases the delay for BDSC decision-making, and also leads to packet loss in a real-time video transmission. Finally, P2V delivered videos with high SSIM compared to FD and BDSC, since it establishes a platoon by selecting platoon members with similar speeds and appropriate distance to forward video packets, which reduces the packet loss. However, videos delivered by P2V have lower SSIM compared to GT4P, since P2V does not consider vehicle travel path and RSSI to select the platoon members. In addition, P2V does not enforce that platoon members

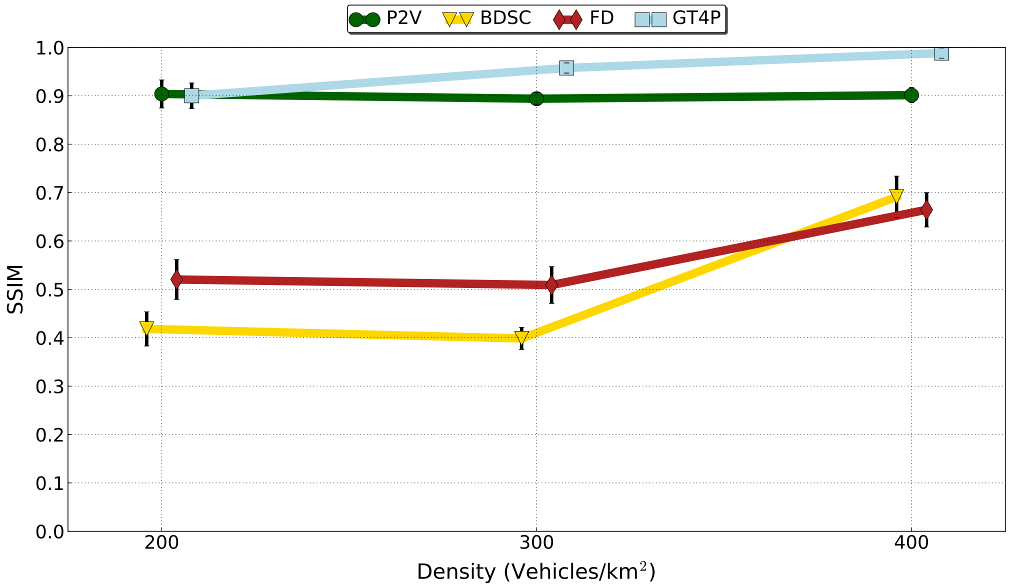


Figure 7: SSIM for Videos Transmitted by Different Platoon-based Driving protocol in an Urban Scenario Composed of Different Number of Vehicles

keep a given distance between platoon members in order to enables a reliable V2V wireless communication.

Figure 8 shows the VQM for videos delivered via FD, BDSC, P2V, and GT4P protocols in an urban VANET scenario with different number of vehicles. In contrast to SSIM values, low VQM values means higher video quality level. The VQM results confirm the benefits of GT4P to transmit videos with QoE support, by establishing a platooning to avoid the effects of vehicle mobility on the QoE. For instance, GT4P transmitted video packets with a reduced frame loss rate, protecting priority frames in congestion and link error periods, since video streaming is composed of a sequence of frames with different importance based on user experience [48]. GT4P reduced the frame loss rate by 40%, 44%, and 4% compared to video transmission via FD, BDSC, and P2V, respectively.

Figure 9 shows the delay for videos delivered via FD, BDSC, P2V, and GT4P protocols in an urban VANET scenario with different vehicle density. We can conclude that BDSC has a higher delay compared to FD, P2V, and GT4P protocols, since in BDSC each platoon member computes link quality estimation, which takes 0.5 seconds, increasing the delay for decision-making, and also to forward video packets. On the other hand, FD, P2V, and GT4P protocols do not introduce any additional delay in the video transmission.

We selected a random frame (*i.e.*, Frame #150) from the Silent video sequence transmitted by each platoon protocol to show the impact of transmitting video streams from the user's perspective, as displayed in Figure 10. Specifically, Frame #150 from the Silent video sequence shows a news report in sign language, which could be related to a report on the road traffic conditions. This frame transmitted via GT4P has a low distortion compared to the original frame, by comparing Figures 10(a) and 10(b). On the

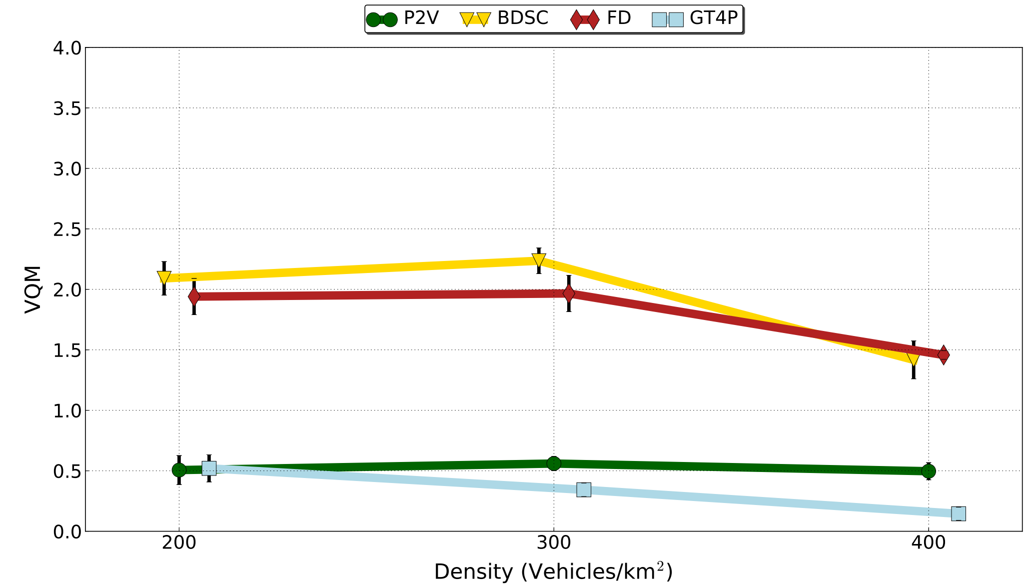


Figure 8: VQM for Videos Transmitted by Different Platoon-based Driving protocol in an Urban Scenario Composed of Different Number of Vehicles

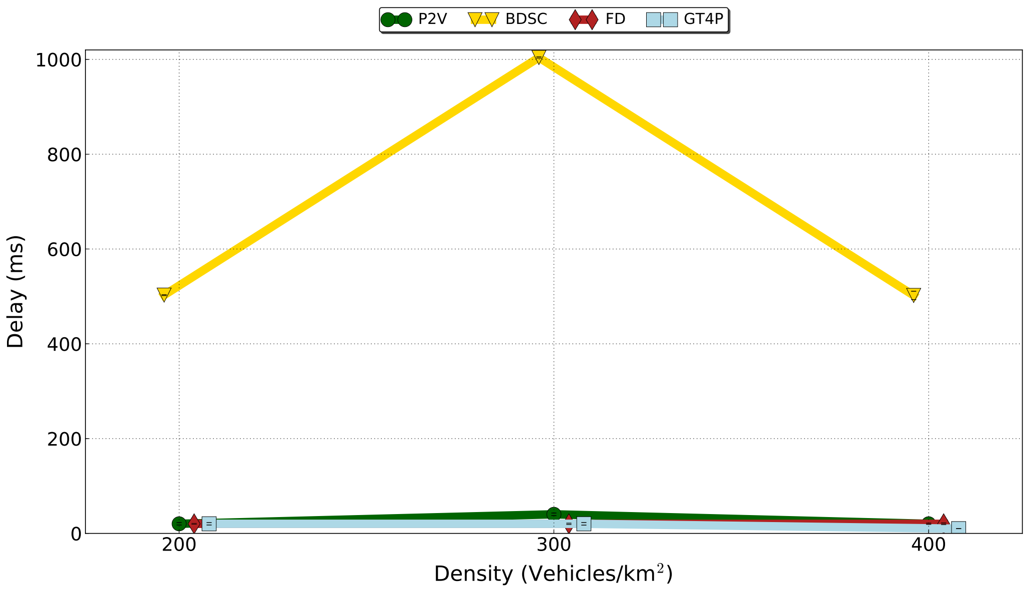
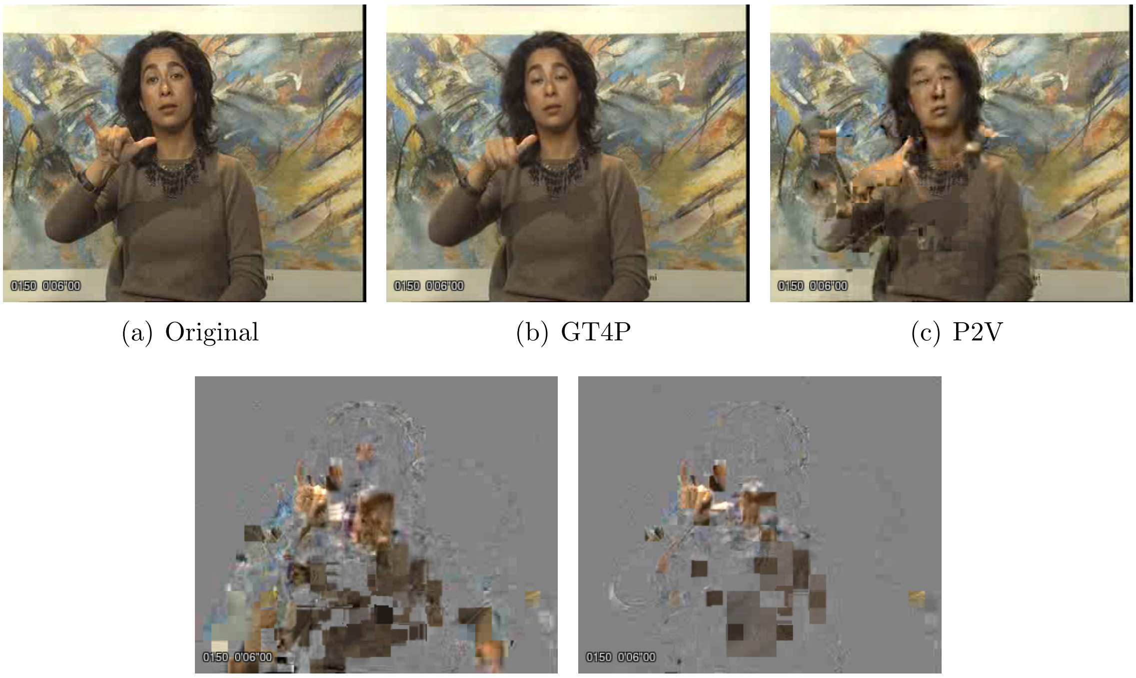


Figure 9: Delay for Videos Transmitted by Different Platoon-based Driving protocol in an Urban Scenario Composed of Different Number of Vehicles

other hand, the videos delivered by P2V, FD, and BDSC protocols are very deteriorated, as shown in Figures 10(c), 10(d), and 10(e), respectively. This is because this frame was lost, and also many previous ones, making it impossible to reconstruct based on the previously received frames. This makes the benefits of the GT4P protocol for video transmission evident.



(a) Original (b) GT4P (c) P2V

(d) FD (e) BDSC

Figure 10: Frame #150 from the Silent Video Transmitted via Different Platoon-based Driving Protocols in Manhattan Grid Scenario

5.3 Simulation Results for Highway Scenario

Figure 11 shows the SSIM for videos with different motion and complexity levels transmitted via FD, BDSC, P2V, and GT4P protocols in a highway VANET scenario. By analyzing the results of Figure 11, we conclude that GT4P delivered videos with high SSIM compared to FD, BDSC, and P2V, regardless of video motion and complexity levels. For instance, videos delivered by GT4P have SSIM values closer to 1. On the other hand, videos delivered by P2V, BDSC, and FD reduced the SSIM in 11%, 60% and 48% compared to GT4P, respectively. This is because GT4P established a platoon by selecting vehicles with similar speeds, appropriate distance between platoon members, similar travel path, and good link quality. These results confirm that GT4P also delivers video with good quality level in a highway scenario. The different video assessment values are due to the unique characteristics of each video sequence, where small differences in motion and complexity level can influence the obtained values [49]. In this way, it is important to perform the experiments with different video characteristics.

Figure 12 shows the QoE measured by means of VQM for videos with different motion and complexity levels transmitted via FD, BDSC, P2V, and GT4P protocols in a highway VANET scenario. Once again, the VQM results confirm the benefits of GT4P to transmit videos with QoE support, by establishing a platoon to avoid the effects of vehicle mobility on the video quality.

We selected a random frame (*i.e.*, Frame #30) from the Highway video sequence

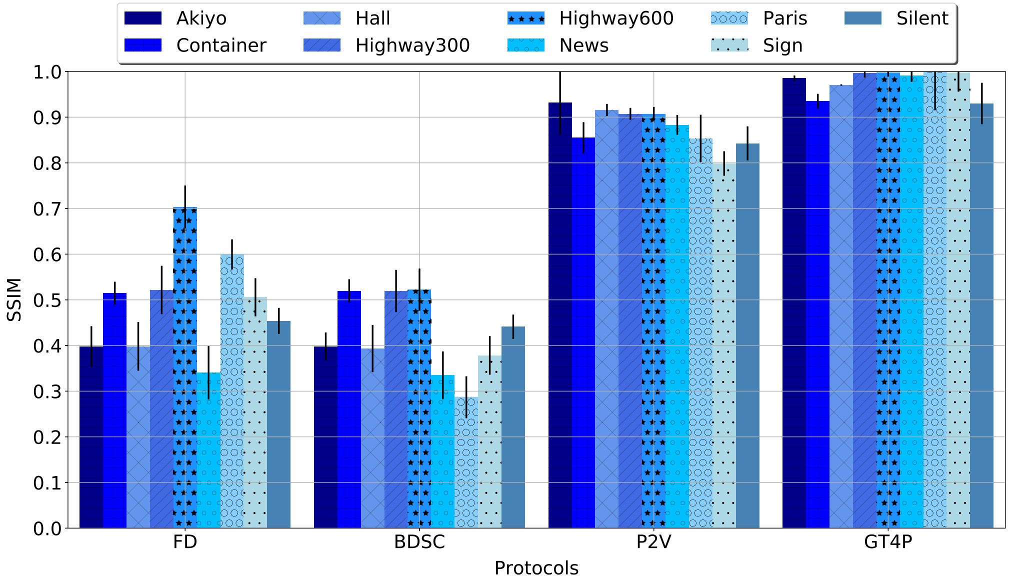


Figure 11: SSIM for Each Video transmitted via Different Platoon-based Driving protocol in a Highway Scenario

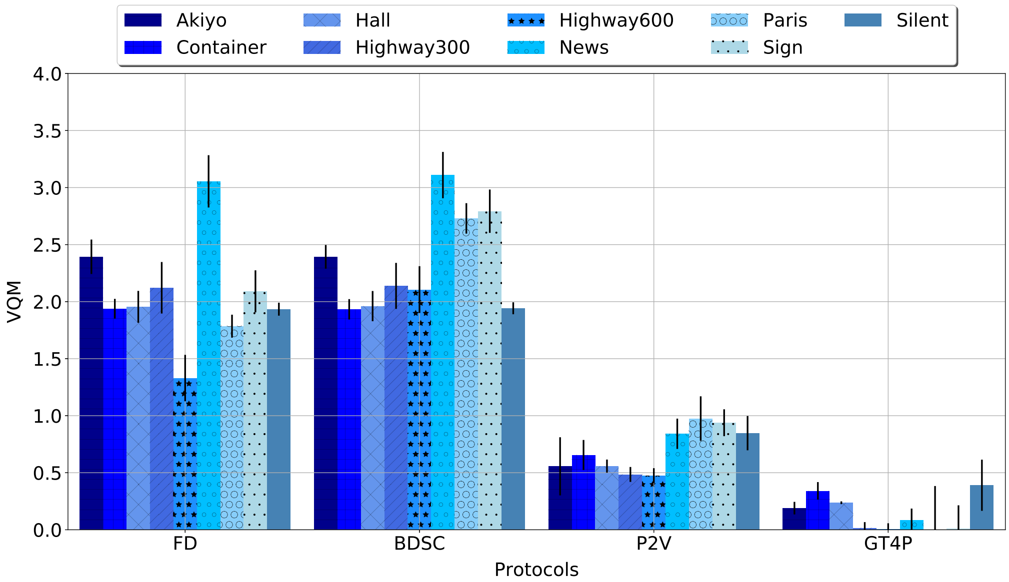


Figure 12: VQM for Each Video transmitted via Different Platoon-based Driving protocol in a Highway Scenario

transmitted by each platoon protocol to show the impact of transmitting video streams from the standpoint of the end-user, as shown in Figure 13. Specifically, Frame #30 from the Highway video sequence was collected in a car driving in a highway. This frame transmitted via GT4P has the same quality compared to the original frame, which makes the benefits of the GT4P protocol for video transmission evident. On the other hand, this frame delivered by P2V has a few distortions compared to the original frame. Finally, the video delivered by FD and BDSC protocols are very deteriorated compared to the original frame, which makes it impossible to analyze anything from the frame. This is because this frame was lost, and also many previous ones, making it impossible to reconstruct based on the previously received frames.

(a) Original

(b) GT4P

(c) P2V

(d) FD

(e) BDSC

Figure 13: Frame #30 from Highway Video Sequence Transmitted via Different Platoon-based Driving Protocols in the Luxembourg Scenario

5.4 Chapter Conclusions

This chapter described the evaluation methodology to evaluate GT4P. The behavior of the protocol was evaluated in two distinct scenarios considering different characteristics of VANETs. The simulation parameters were described, as well as all the tools and scenarios used. From the simulations obtained, it was proved that GT4P achieves better QoE values compared with other protocols, with different vehicular densities and videos.

CHAPTER 6

Conclusion

This dissertation presented a comparative analysis of video transmission in VANETs. Several applications in VANETs require videos to be transmitted over the network with QoE guarantees. As it is shown in the literature, this is a challenging task due to the specific characteristics of the VANETs, such as the constant change in the topological structure of the network, caused by the short contact time between the vehicles and the highly dynamic mobility. To solve these challenges, the GT4P platton-based driving protocol was presented to select the best RN and high QoE video transmission, which maintains a high quality perception of the videos received by the user.

GT4P mitigates the problems related to frequent disconnections caused by high vehicle mobility by establishing a platoon based on vehicle direction, speed, distance, RSSI, and travel path. In addition, the GT4P protocol enforces that platoon vehicles keep a given distance to mitigate route failures and packet loss. Te GT4P protocol considers a non cooperative and simultaneous game, where the cooperative behavior is enforced by means of a rewarding function to give incentive for vehicles to join the platoon. In this way, GT4P increases the connectivity between vehicles, reducing the packet loss during video transmission.

The simulations were executed in two different scenarios: Urban Scenario and Highway Scenario. Density, distance between vehicles and different videos were defined as factors for the analysis of protocol behavior. Thus, in the urban scenario, densities ranging from 200, 300 and 400 vehicles/km^2 were used. A total of 9 videos with different characteristics were used to simulate the transmissions between SN and DN, each video contained different patterns of movement and coloring, which influences the perception of the user.

From our performance evaluation analysis, we identified that the GT4P protocol delivered videos with QoE 10%, 60%, and 50% higher than videos delivered by P2V, BDSC, and FD, respectively. This is because GT4P establishes a platoon by taking into account vehicle direction, speed, distance, link quality, and travel path, which reduces the impact of vehicle mobility on the video transmission. Hence, simulation results show the efficiency of the GT4P compared to P2V, BDSC, and FD protocols to ensure video dissemination with satisfactory QoE in highway and urban scenarios.

Future work that can be developed from this research includes:

- Add new metrics for RN selection;
- Analyze behavior with longer and high-definition videos;
- Consider other transmission technologies for RN selection, for example Visible Light Communication, as well as analyzes the performance in a heterogeneous scenario;
- Compare the performance of GT4P with other routing protocols specific to video transmission.

6.1 Academical Production

The results obtained in this dissertation were published in the following events:

1. **LOBATO, W.**; ROSARIO, D.; GERLA, M.;CERQUEIRA, E. ;VILLAS, L. A.“Platoon-based Driving Protocol based on Game Theory for Multimedia Transmission over VANET”. In *2017 IEEE Global Communications Conference (GLOBECOM)*, Singapore, Singapore, Dec 2017. [50]

2. **LOBATO, W.**; ROSARIO, D.;VILLAS, L. A.; CERQUEIRA, E.“Mecanismo para Cooperação e Coligação de Veículos Baseado na Teoria dos Jogos para Transmissão de Vídeos em VANETs”. In *2017 16º WORKSHOP EM DESEMPENHO DE SISTEMAS COMPUTACIONAIS E DE COMUNICAÇÃO (WPERFORMANCE 2017)*, Porto Alegre, BRAZIL, July 2017. [51]

3. MEDEIROS, I.; **LOBATO, W.**; ROSARIO, D.; CERQUEIRA, E. ;VILLAS, L. A.“A comparative analysis of platoon-based driving protocols for video dissemination over VANETs”. In *2018 IEEE International Conference on Communications Workshops (ICC Workshops): 5G and Cooperative Autonomous Driving (ICC 2018 Workshop - 5G/Auto Dr)*, Kansas City, USA, May 2018. [52]

4. **LOBATO, W.**; ROSARIO, D.; CERQUEIRA, E. ;VILLAS, L. A; GERLA, M.“A Game Theory Approach for Platoon-Based Driving for Multimedia Transmission in VANETs”. In *2018 Wireless Communications and Mobile Computing)*, Hindawi, July 2018. [47]

5. **LOBATO, W.**; COSTA, J.; CERQUEIRA, E. "Avaliação Exploratória da Disseminação de Vídeos para Aplicações *See-Through* em Redes Veiculares". In: *Anais do XXIII Workshop de Gerência e Operação de Redes e Serviços (WGRS) - XXXVI Simpósio Brasileiro de Redes de Computadores e Sistemas Distribuídos*. Campos do Jordão, SP. WGRS - 2018. [53]

References

[1] F. Cunha, L. Villas, A. Boukerche, G. Maia, A. Viana, R. A. Mini, and A. A. Loureiro, "Data Communication in VANETs: Protocols, Applications and Challenges," *Ad Hoc Networks*, vol. 44, pp. 90–103, 2016.

[2] S. Fürst and M. Bechter, "AUTOSAR for Connected and Autonomous Vehicles: The AUTOSAR Adaptive Platform," in *Proceedings of the 46th Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshop (DSN-W)*. IEEE, June 2016, pp. 215–217.

[3] C. Campolo, A. Molinaro, and R. Scopigno, "From Today's VANETs to Tomorrow's Planning and the Bets for the Day After," *Vehicular Communications*, vol. 2, no. 3, pp. 158–171, 2015.

[4] H. Peng, D. Li, K. Abboud, H. Zhou, H. Zhao, W. Zhuang, and X. S. Shen, "Performance Analysis of IEEE 802.11 p DCF for Multiplatooning Communications With Autonomous Vehicles," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 3, pp. 2485–2498, 2017.

[5] D. Jia, K. Lu, and J. Wang, "On the Network Connectivity of Platoon-based Vehicular Cyber-physical Systems," *Transportation Research Part C: Emerging Technologies*, vol. 40, pp. 215–230, 2014.

[6] D. Jia, K. Lu, J. Wang, X. Zhang, and X. Shen, "A Survey on Platoon-based Vehicular Cyber-Physical Systems," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 1, pp. 263–284, 2016.

[7] M. Amoozadeh, H. Deng, C.-N. Chuah, H. M. Zhang, and D. Ghosal, "Platoon Management with Cooperative Adaptive Cruise Control Enabled by VANET," *Vehicular Communications*, vol. 2, no. 2, pp. 110–123, 2015.

[8] C. Quadros, A. Santos, M. Gerla, and E. Cerqueira, "QoE-driven Dissemination of Real-Time Videos over Vehicular Networks," *Computer Communications*, vol. 91, pp. 133–147, 2016.

[9] F. A. Silva, A. Boukerche, T. R. Silva, L. B. Ruiz, E. Cerqueira, and A. A. Loureiro, "Vehicular Networks: a New Challenge for Content-Delivery-based Applications," *ACM Computing Surveys*, vol. 49, no. 1, p. 11, 2016.

[10] M. De Felice, E. Cerqueira, A. Melo, M. Gerla, F. Cuomo, and A. Baiocchi, "A Distributed Beaconless Routing Protocol for Real-time Video Dissemination in Multimedia VANETs," *Computer Communications*, vol. 58, pp. 40–52, 2015.

[11] B. Zhang, E. S. Wilschut, D. M. Willemsen, T. Alkim, and M. H. Martens, "The Effect of See-Through Truck on Driver Monitoring Patterns and Responses to Critical Events in Truck Platooning," in *Proceedings of the International Conference on Applied Human Factors and Ergonomics.* Springer, 2017, pp. 842–852.

[12] C. Olaverri-Monreal, P. Gomes, R. Fernandes, F. Vieira, and M. Ferreira, "The See-Through System: A VANET-enabled Assistant for Overtaking Maneuvers," in *Proceedings of the IEEE Intelligent Vehicles Symposium (IV).* IEEE, 2010, pp. 123–128.

[13] J. Liu, X. Wang, G. Yue, and S. Shen, "Data sharing in vanets based on evolutionary fuzzy game," *Future Generation Computer Systems*, vol. 81, pp. 141–155, 2018.

[14] C. Wu, M. Gerla, and N. Mastronarde, "Incentive driven lte content distribution in vanets," in *Proceedings of the 14th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET).* IEEE, 2015, pp. 1–8.

[15] Y. Wang and X. Lin, "User-provided Networking for QoE Provisioning in Mobile Networks," *IEEE Wireless Communications*, vol. 22, no. 4, pp. 26–33, 2015.

[16] Z. Hu, Z. Zheng, T. Wang, L. Song, and X. Li, "Game Theoretic Approaches for Wireless Proactive Caching," *IEEE Communications Magazine*, vol. 54, no. 8, pp. 37–43, 2016.

[17] E. Liotou, D. Tsolkas, N. Passas, and L. Merakos, "Quality of Experience Management in Mobile Cellular Networks: Key Issues and Design Challenges," *IEEE Communications Magazine*, vol. 53, no. 7, pp. 145–153, 2015.

[18] C. Rezende, H. S. Ramos, R. W. Pazzi, A. Boukerche, A. C. Frery, and A. A. Loureiro, "VIRTUS: A resilient location-aware video unicast scheme for vehicular networks," in *Proceedings of the IEEE International Conference on Communications (ICC).* IEEE, 2012, pp. 698–702.

[19] S. Uppoor and M. Fiore, "Insights on Metropolitan-scale Vehicular Mobility from a Networking Perspective," in *Proceedings of the 4th ACM international workshop on Hot topics in planet-scale measurement.* ACM, 2012, pp. 39–44.

[20] J. Liu, J. Wan, Q. Wang, P. Deng, K. Zhou, and Y. Qiao, "A Survey on Position-based Routing for Vehicular Ad Hoc Networks," *Telecommunication Systems*, vol. 62, no. 1, pp. 15–30, 2016.

[21] W. Lobato Junior, D. Rosario, L. Villas, and M. Gerla, "Platoon-based Driving Protocol based on Game Theory for Multimedia Transmission over VANET," in *Proceedings of the IEEE Global Communications Conference*, 2017, pp. 1–8.

[22] D. Al-Terri, H. Otrok, H. Barada, M. Al-Qutayri, and Y. Al Hammadi, "Cooperative based Tit-for-Tat Strategies to Retaliate Against Rreedy Behavior in VANETs," *Computer Communications*, vol. 104, pp. 108–118, 2017.

[23] E. Lee, E.-K. Lee, M. Gerla, and S. Y. Oh, "Vehicular cloud networking: architecture and design principles," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 148–155, 2014.

[24] F. Bai and H. Krishnan, "Reliability analysis of dsrc wireless communication for vehicle safety applications," in *Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE.* IEEE, 2006, pp. 355–362.

[25] B. Deng and X. Zhang, "Car networking application in vehicle safety," in *Advanced Research and Technology in Industry Applications (WARTIA), 2014 IEEE Workshop on.* IEEE, 2014, pp. 834–837.

[26] J. Wang, G. Zhang, R. Wang, S. C. Schnelle, and J. Wang, "A gain-scheduling driver assistance trajectory-following algorithm considering different driver steering characteristics," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 5, pp. 1097–1108, 2017.

[27] C. Wang, Y. Chen, X. Cheng, and X. Fan, "Ads dissemination in vehicular ad hoc networks," in *Communications (ICC), 2015 IEEE International Conference on.* IEEE, 2015, pp. 3640–3645.

[28] I. Cisco, "Cisco visual networking index: Forecast and methodology, 2011–2016," *CISCO White paper*, vol. 518, 2012.

[29] R. Fiani, *Teoria dos jogos.* Elsevier Brasil, 2006.

[30] Z. Han, D. Niyato, W. Saad, T. Başar, and A. Hjørungnes, *Game theory in wireless and communication networks: theory, models, and applications.* Cambridge University Press, 2012.

[31] Y. Shoham and K. Leyton-Brown, *Multiagent systems: Algorithmic, game-theoretic, and logical foundations.* Cambridge University Press, 2008.

[32] M. Uhrina, J. Bienik, and M. Vaculik, "Coding efficiency of hevc/h. 265 and vp9 compression standards for high resolutions," in *2016 26th International Conference Radioelektronika (RADIOELEKTRONIKA).* IEEE, 2016, pp. 419–423.

[33] T. K. Tan, R. Weerakkody, M. Mrak, N. Ramzan, V. Baroncini, J.-R. Ohm, and G. J. Sullivan, "Video quality evaluation methodology and verification testing of hevc compression performance," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 26, no. 1, pp. 76–90, 2016.

[34] Y. Wang, "Survey of objective video quality measurements," 2006.

[35] T. Braun, M. Heissenbüttel, and T. Roth, "Performance of the Beacon-less Routing Protocol in Realistic Scenarios," *Ad Hoc Network*, vol. 8, no. 1, pp. 96–107, jan. 2010.

[36] D. Rosário, Z. Zhao, A. Santos, T. Braun, and E. Cerqueira, "A Beaconless Opportunistic Routing based on a Cross-layer Approach for Efficient Video Dissemination in Mobile Multimedia IoT Applications," *Computer communications*, vol. 45, no. 1, pp. 21–31, 2014.

[37] C. Quadros, E. Cerqueira, A. Santos, J. Lim, and M. Gerla, "Beacon-less Video Streaming Management for VANETs Based on QoE and Link-quality," in *Proceedings of the IFIP/IEEE International Symposium on Integrated Network Management (IM)*. IEEE, 2015, pp. 191–198.

[38] T. Chen, L. Wu, F. Wu, and S. Zhong, "Stimulating Cooperation in Vehicular Ad Hoc Networks: a Coalitional Game Theoretic Approach," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 2, pp. 566–579, 2011.

[39] M. Gerla, C. Wu, G. Pau, and X. Zhu, "Content Distribution in VANETs," *Vehicular Communications*, vol. 1, no. 1, pp. 3–12, 2014.

[40] A. Amoroso, G. Marfia, and M. Roccetti, "Going Realistic and Optimal: A Distributed Multi-Hop Broadcast Algorithm for Vehicular Safety," *Computer Networks*, vol. 55, no. 10, pp. 2504–2519, 2011.

[41] O. Rehman, M. Ould-Khaoua, and H. Bourdoucen, "An adaptive relay nodes selection scheme for multi-hop broadcast in vanets," *Computer Communications*, vol. 87, pp. 76–90, 2016.

[42] Y. Zhang and G. Cao, "V-PADA: Vehicle-Platoon-Aware Data Access in VANETs," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 5, pp. 2326–2339, 2011.

[43] A. Vahidi and A. Eskandarian, "Research advances in intelligent collision avoidance and adaptive cruise control," *IEEE transactions on intelligent transportation systems*, vol. 4, no. 3, pp. 143–153, 2003.

[44] D. Rosário, Z. Zhao, A. Santos, T. Braun, and E. Cerqueira, "A Beaconless Opportunistic Routing based on a Cross-layer Approach for Efficient Video Dissemination in Mobile Multimedia IoT Applications," *Computer communications*, vol. 45, no. 1, pp. 21–31, 2014.

[45] V. Library, "YUV Video Sequence Library," http://trace.eas.asu.edu/yuv/ Dez. 2016.

[46] L. Codeca, R. Frank, and T. Engel, "Luxembourg sumo traffic (lust) scenario: 24 hours of mobility for vehicular networking research," in *Proceedings of the IEEE Vehicular Networking Conference (VNC)*, Dec 2015, pp. 1–8.

[47] W. L. Junior, D. Rosário, E. Cerqueira, L. A. Villas, and M. Gerla, "A game theory approach for platoon-based driving for multimedia transmission in vanets," *Wireless Communications and Mobile Computing*, vol. 2018, 2018.

[48] J. Greengrass, J. Evans, and A. C. Begen, "Not All Packets are Equal, Part 2: The Impact of Network Packet Loss on Video Quality," *IEEE Internet Computing*, vol. 13, no. 2, pp. 74–82, 2009.

[49] R. Immich, E. Cerqueira, and M. Curado, "Adaptive Video-aware FEC-based Mechanism with Unequal Error Protection Scheme," in *Proceedings of the 28th annual ACM symposium on applied computing (SAC).* ACM, 2013, pp. 981–988.

[50] W. Lobato, D. Rosario, M. Gerla, and L. A. Villas, "Platoon-based driving protocol based on game theory for multimedia transmission over vanet," in *GLOBECOM 2017-2017 IEEE Global Communications Conference.* IEEE, 2017, pp. 1–6.

[51] W. L. Junior, D. Rosário, L. A. Villas, and E. Cerqueira, "Mecanismo para cooperação e coligação de veículos baseado na teoria dos jogos para transmissão de vídeos em vanets," in *16º Workshop em Desempenho de Sistemas Computacionais e de Comunicação (WPerformance 2017)*, vol. 16, no. 1/2017. SBC, 2017.

[52] I. Medeiros, W. Lobato Junior, D. Rosário, E. Cerqueira, TorstenBraun, and L. A. Villas, "A Comparative Analysis of Platoon-based Driving Protocols for Video Dissemination over VANETs," in *Proceedings of the IEEE International Conference on Communications Workshops (ICC Workshops): 5G and Cooperative Autonomous Driving*, Kansas City, USA, May 2018.

[53] W. L. Junior, J. Costa, and E. Cerqueira, "Avaliação exploratória da disseminação de vídeos para aplicações see-through em redes veiculares," in *Anais do XXIII Workshop de Gerência e Operação de Redes e Serviços (WGRS-SBRC 2018)*, vol. 23. SBC, 2018.