Universidade de Aveiro Departamento de
Electrónica, Telecomunicações e Informática,
2014

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Ferreira Silva Mendes**

Gestor de Conectividade com Informação de Estações Fixas para melhorar as Comunicações entre Veículos

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"It always seems impossible until it's done"

— Nelson Mandela

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requesitos necessários à obtenção do grau de Mestre em Engenharia Electrónica e Telecomunicações, realizada sob a orientação científica da Professora Doutora Susana Isabel Barreto Sargento, Professora Associada do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro e co-orientação do Doutor André Cardote, Systems Engineers na VeniamWorks.

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Resumo

As comunicações sem fios têm sido alvo de uma pesquisa intensiva nos últimos tempos. Desde sempre, comunicar foi uma necessidade do homem, e hoje em dia essa necessidade é transversal a qualquer meio. Um dos ambientes em que as comunicações sem fios mais se desenvolveram nos últimos anos foi em ambientes de grande mobilidade. Para este tipo de ambientes foram criadas as redes veiculares que se caracterizam por uma grande mobilidade, topologia dinâmica e frequente perda de conectividade entre nós, o que torna a forma de gerir estas redes bastante complexa.

Num ambiente repleto de redes sem fios, especialmente em zonas urbanas torna-se crucial fazer uma boa escolha no momento de efectuar a ligação. Assim, para garantir ao utilizador a melhor experiência de ligação, é necesseçário a existência de um mecanismo capaz de efectuar essa decisão de uma forma informada. A melhor forma de efectuar a selecção entre as diversas redes disponíveis é introduzir no mecanismo de selecção a capacidade de prever a qualidade de cada ligação possível de ocorrência, utilizando para isso informação guardada das ligações ocorridas anteriormente.

Assim, é proposto o desenvolvimento de um mecanismo de selecção de redes, para eleger a melhor rede possível que se baseie, não só na informação disponvél a cada momento, mas também na informação recolhida através do histórico da qualidade de ligações. O mecanismo proposto baseia-se num processo que combina parâmetros das várias redes sem fios disponíveis para determinar a melhor ligação possível para os utilizadores.

Para observar as potencialidades deste novo mecanismo foram feitos alguns testes na estrada usando nas mesmas condições um mecanismo sem previsão e o mecanismo desenvolvido. Os resultados obtidos mostram as melhorias verificadas com a implementação deste mecanismo com previsão.

Abstract

Wireless communications have been subject of an intensive research in recent times. Communicating has always been a necessity of people, and nowadays it is transversal to people needs. In recent years, wireless communications have been developed better in highly mobile spaces. For this type of spaces, vehicular networks have been developed, that are characterized by a large mobility, dynamic topology and frequent loss of connectivity, which makes the way to manage these networks rather complex. In a crowded space of wireless networks, especially in suburban areas, it becomes crucial to make a good choice when performing the connection. Thus, to ensure the best connection experience, it is necessary the support of a mechanism that is able to make that choice in an informed way. The best way to make the selection between the different available networks is introducing the selection mechanism with the ability to predict the quality of each possible connection, using the stored information of connections previously occurred. This way, it is proposed the development of a selection mechanism to select the best possible network that is based, not only on information available at each moment, but also on the information gathered through the historical links. The mechanism proposed is based on a process that combines parameters of the various wireless networks available to determine the best connection possible for users. To observe the potential of this new mechanism, tests were performed on the road using the same conditions as the mechanism without any prediction and the developed mechanism. The results show the improvements with the implementation of this mechanism with prediction.

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Acronyms

ABC	Always Best Connected
AP	Access Point
ASV	Advanced Safety Vehicle
ATM	Asynchronous Transfer Mode
AU	Application Units
BCM	Basic Connection Manager
BSC	Base Station Controller
BTS	Base Transceiver Station
BW	Bandwidth
CCA	Cooperative Collision Avoidance
CCH	Channel
C2C-CC	Car-to-Car Communication Consortium
DHCP	Dedicated Host Configuration Protocol
DSRC	Dedicated Short-Range Communications
ETSI	European Telecommunications Standards Institute
EWM	Emergency Warning Messages
GPRS	General Packet Radio Service
GPS	Global System Position
GSM	Global System for Mobile Communications
HLR	Home Location Register
IEEE	Institute of Electrical and Electronics Engineers

IP	Internet Protocol
IVC	Inter Vehicle Communication
ISP	Internet Service Provider
ITS	Intelligent Transportation Systems
LMA	Local Mobility Anchor
LOS	Line-of-Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MADM	Multiple Attribute Decision Making
MANET	Mobile Ah-hoc Network
MCDM	Multiple Criteria Decision Making
MN	Mobile Node
MSC	Mobile Switching Center
OBU	On-board Unit
OSI	Open Systems Interconnection
PbVCM	Vanet Connection Manager with Prediction
PCM	Preference-based Connection Manager
PSTN	Public Switched Telephone Network
QoE	Quality-of-Experience
QoS	Quality of Service
RSU	Road Side Unit
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTT	Round-Trip Time
SAW	Simple Additive Weighting
SCH	Service Channel
SHF	Super High Frequency

STDMA	Self-Organized Time Division Multiple Access
UDP	User Data Protocol
UE	User Equipment
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
VANET	Vehicular ad-hoc Network
VCM	Vanet Connection Manager
VLR	Visitor Location Register
V2I	Vehicle to infrastructure
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular Environments
WiMax	Worldwide Interoperability for Microwave Access
WI-FI	IEEE 802.11 a/g/n
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network
ZOR	Zone of Relevance

Chapter 1

Introduction

1.1 Motivation

Currently, with the need that people have to be always online, the Wireless networks have increased their importance in people's lives over the years. According to Cisco's data [1], global mobile data traffic grew 81 percent in 2013. In the last years, mobile data traffic was about 18 times larger than the size of the whole Internet in 2000.

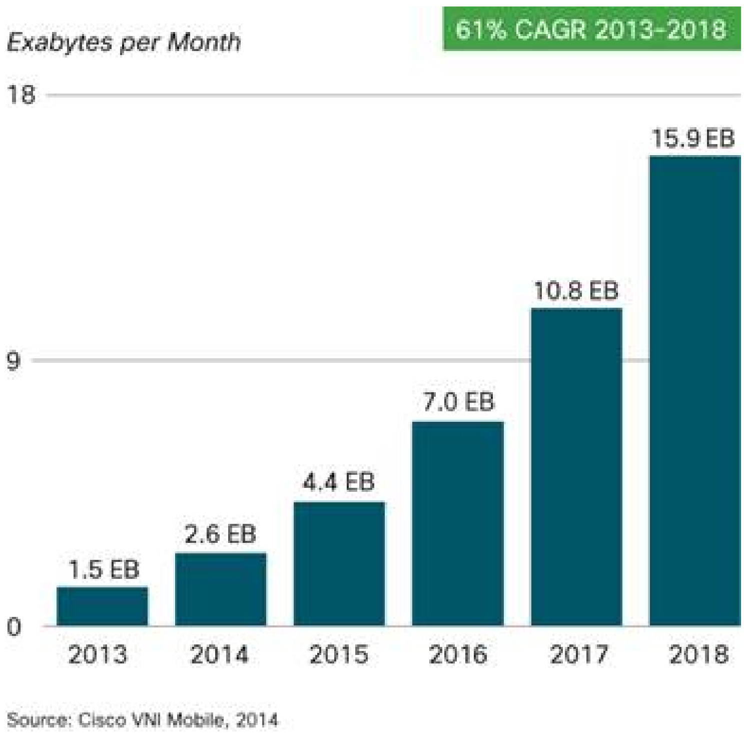

Figure 1.1: Cisco Mobile Applications Traffic Forecast [1]

The process of driving vehicles has been improved with the inclusion of new services, such as Global System Position (GPS), onboard computers, speed control and several sensors to prevent accidents or even improve the traction. With the increased use of these technologies, it is expected that in the near future, most of the vehicles on the roads will be capable of being connected to each other and to the internet.

The main purpose of communication between vehicles is to create safer roads, reducing the number of accidents, sharing messages to provide information about accidents or traffic congestion. Another purpose is to give the users comfortable travels providing internet access to all passengers and an improved driving experience.

The connection between vehicles and between vehicles and the infrastructure builds a Vehicular Ad-hoc Network (VANET). The concept used is similar to the one applied on ad-hoc network: vehicles act as mobile nodes carrying a device called On Board Unit (OBU), which has one or several wireless technologies, such as IEEE 802.11a/b/g (WI-FI), WAVE(IEEE 802.11p) or Long Term Evolution (LTE), and connects to other nearby nodes (vehicles) sharing contents or spreading messages. The nodes are also able to connect to stationary providers along the road, such as Institute of Electrical and Electronics Engineers (IEEE) 802.11p Road Side Units (RSUs) or WI-FI Access Points (APs), which will provide them access to the Internet. The communications will be done directly to the infrastructure or vehicle to vehicle as shown in the Figure 1.2

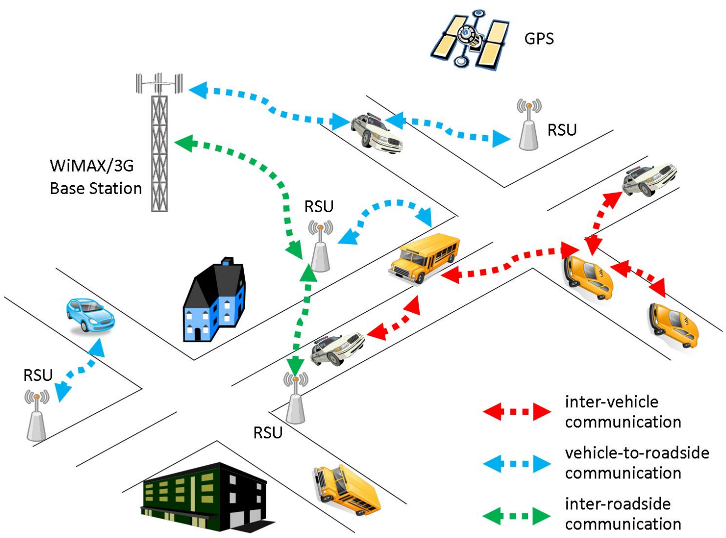

Figure 1.2: Communication schemes in vehicular networks [2]

With the deployment of VANETs, users will be a little closer to the main objective that is the Always Best Connected (ABC), since they will be able to be also connected on the move in the vehicles.

With the increase in the number of possible connections, it is more and more necessary to develop a connection manager more powerful that is able to choose, the best network from all available ones, and in the road, it is important to determine the best infrastructure to connect, through direct path or through multi-hop. All parameters are important to decide which network to choose and the history of each network can play a key role in building connection managers that one increasingly reliable.

1.2 Objectives

In the previous work, a decision mechanism that chooses the network to access the Internet in a dynamic way was implemented. This decision mechanism is called Vanet Connection Manager (VCM). Thus, a user in a vehicle when moving in the middle of an area with a high density of hotspots can have maximum stability on the link. The VCM created is capable to choose the best connection, between three types of technologies, IEEE 802.11p, Wi-Fi and cellular network, considering the selection parameters such as price, number of hops, expected connection time and Received Signal Strength Indicator (RSSI).

However, this mechanism considers that the information of stations is known only after coming into contact, which does not allow to use the network in the best way. This mechanism lacks the ability to anticipate the availability of a network, and to know before coming into contact with the network which has been the network behaviour. With this information, the mechanism will be able to know what type of connection it is expected in a certain network, and it can use that to chose between networks.

This dissertation will consider information of previous connections to the several stations to anticipate the connection decision. This dissertation aims to use data from previous connections, to understand how a particular network has behaved and then choose which network gives the best guarantees. Using the resources present in the OBU installed in the cars and anticipate which stations will be available along the way, it will help to get more detailed information.

In this work it is important to know that the OBUs in the cars have limited storage capacity and processing, so it will be necessary to check what information will be needed. Then, it is necessary to have this information in order to have an optimal compromise between the best network connection and the complexity of the decision process.

The objectives of this Dissertation are the following:

- Use the existent databases to build a new database with the required information. That information will be very useful to develop the new selection mechanism.

- Evaluate and analyse the amount of information needed to make a good prediction, and evaluate the impact on the OBU. Assessment of connections available to use to access this information

- Specification of a predictive mechanism for deciding which available network to choose.

- Implementation of a connection manager with the predictive information. This connection manager will be able to use the information stored in the databases to choose the best network available.

- Integration and test of the predictive handover mechanism between RSUs, that use IEEE 802.11p technology.

- Final test of the work, at a real vehicular network in the city of Porto.

1.3 Contributions

This Dissertation provided the following contributions:

- It identified the relevant parameters to provide a predictive connection manager with optimized performance;
- It developed a database that contains the information of the base stations to connect;
- It provides the request and transfer of information between the server and the OBU;
- It selects the best network to connect taking into account current conditions and past experience.
- Real platforms and tests were developed, both in the lab and in the city of Porto with real vehicles and road side units;
- Real experiments were performed in both platforms, and performance metrics were gathered and analysed to compare both connection managers, the base one and the predictive one.
- A paper entitled "Predictive Connection manager for Vehicular Networks" is submitted to IEEE ICC Workshop on on Dependable Vehicular Communications (DVC) 2015.

1.4 Organization

This Dissertation is organized in the following way:

- **Chapter 1** provides the contextualization of this Dissertation including the motivation, the proposed objectives and how the document is organized.

- **Chapter 2** provides an overview of wireless networks, cellular networks, Wi-Fi and IEEE 802.11p. This chapter also introduces an overview of the main concepts of VANETs, history, vehicular networks architectures and special characteristics, challenges, data dissemination and possible applications and services in VANETs. The final part of this chapter presents the related work in the available connection managers in the literature.

- **Chapter 3** describes and contextualizes the problem of connection management, and proposes a solution to address prediction in the vehicular network management.

- **Chapter 4** presents the developed implementation with the purpose of building the prediction mechanism in road environments.

- **Chapter 5** is the chapter that includes the results. First, it discusses the results of the tests in the laboratory, and then the ones in the road environment.

- **Chapter 6** is reserved to the conclusions related to the developed work in this dissertation, and also the improvements that are possible to perform, as future work, to continue and optimize this work.

Chapter 2

State of the art

2.1 Introduction

This chapter will present an overview of vehicular networks, with the main objective of framing the reader in the theme. The chapter organization is as follows.

Section 2.2 contains a summary of the wireless networks, considering the cellular networks, Wi-Fi and IEEE 802.11p.

Section 2.3 addresses vehicular networks: what are vehicular networks, how they have been developed over time, what are the potential architectures and how data is disseminated between vehicles. This section presents also the way communication is done in these networks, the architecture used, which applications and services are associated with such networks, and which developments are expected for vehicular networks.

Section 2.4 shows the work that has been developed over time in the connection management and in mobility prediction in wireless networks.

2.2 Wireless Networks

Nowadays, wireless technologies can be divided in three main groups:

- The wide area technologies, such as Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS) or LTE with a moderate bandwidth (BW);
- The local area technologies such as IEEE 802.11, the most popular standard [7];
- The personal area technologies, such as Bluetooth.

The wireless networks can be infrastructured or ad-hoc mode. For the first case, communication between mobile devices occurs via fixed nodes, such an Access Point (AP), thus being necessary to use infrastructure. In the second case, it is not necessary to use infrastructure because the network consists of mobile devices that communicate between each other, in a mobile ad-hoc networks (MANET) [8] [9].

2.2.1 Cellular Networks

A cellular network is a radio network distributed over land through cells, where each cell includes a fixed location transceiver known as base station. These cells together provide radio coverage over larger geographical areas.

Cellular networks give subscribers advanced features over alternative solutions, including increased capacity, small battery power usage, a larger geographical coverage area and reduced interference from other signals.

Cellular technology supports a hierarchical structure formed by the base transceiver station (BTS), mobile switching center (MSC), location registers and public switched telephone network (PSTN). The BTS enables cellular devices to make direct communication with mobile phones. The unit acts as a base station to route calls to the destination base center controller. The base station controller (BSC) coordinates with the MSC to interface with the landline-based PSTN, visitor location register (VLR), and home location register (HLR) to route the calls toward different base center controllers.

Cellular networks maintain information for tracking the location of their subscribers' mobile devices. In response, cellular devices are also equipped with the details of appropriate channels for signals from the cellular network systems.

A typical cell site offers geographical coverage between 9 and 21 miles. The base station is responsible for monitoring the level of the signals when a call is made from a mobile phone. When the user moves away from the geographical coverage area of the base station, the signal level may fall. This can cause a base station to make a request to the MSC to transfer the control to another base station that is receiving the strongest signal without notifying the subscriber; this phenomenon is called handover. Cellular networks often encounter environmental interruptions like a moving tower crane, overhead power cables, or the frequencies of other devices. Figure 2.1 represents an architecture of a GSM network.

2.2.2 Wi-Fi

Wi-Fi is a local area wireless technology that allows an electronic device to exchange data or connect to the Internet using 2.4 GHz Ultra High Frequency (UHF) and 5 GHz Super High Frequency (SHF) radio waves. The Wi-Fi Alliance defines Wi-Fi as any "wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 standards".

Many devices can use Wi-Fi, e.g., personal computers, video-game consoles, smartphones, some digital cameras, tablet computers and digital audio players. These can connect to a network resource such as the Internet via a wireless network AP. Such an AP (or hotspot) has a range of about 20 meters (66 feet) indoors and a larger range outdoors. Hotspot coverage can comprise an area as small as a single room with walls that block radio waves, or as large as many square kilometres achieved by using multiple overlapping access points.

The table 2.1 shows some standard of Wi-Fi technology and its characteristics.

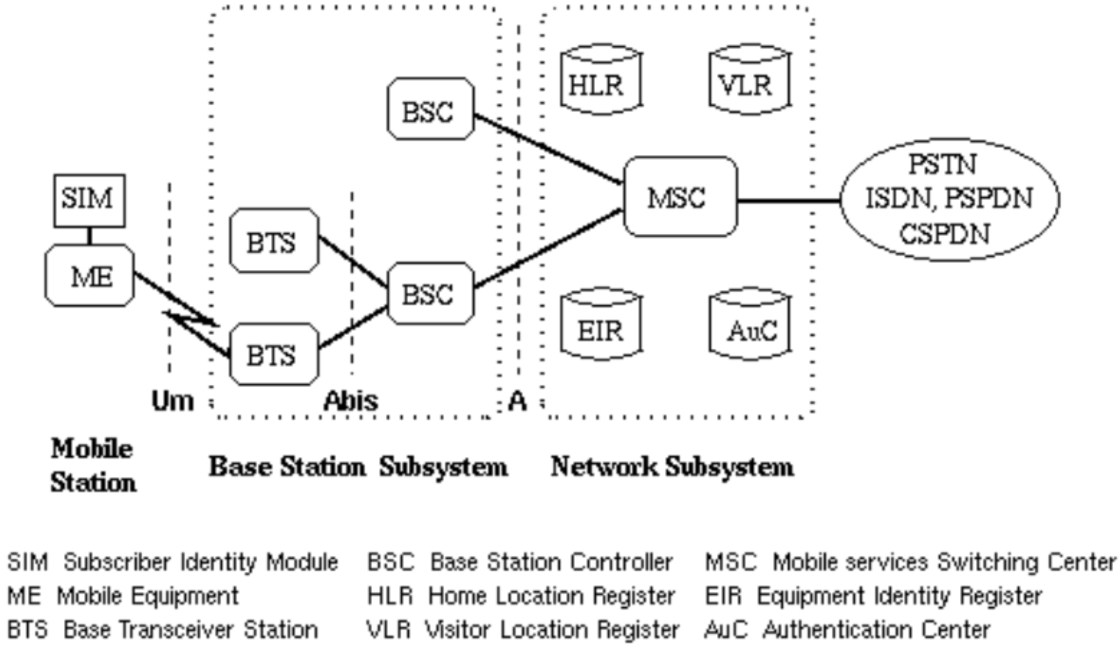

Figure 2.1: General architecture of a GSM network [3]

Realease Date	Standard	Band (GHz)	Bandwidth (MHz)	Modulation	Maximum Data rate
1997	802.11	2.4	20	DSSS, FHSS	2 Mbits/s
1999	802.11b	2.4	20	DSSS	11 Mbits/s
1999	802.11a	5	20	OFDM	54 Mbits/s
2003	802.11g	2.4	20	DSSS, OFDM	54 Mbits/s
2009	802.11n	2.4, 5	20, 40	OFDM	600 Mbits/s

Table 2.1: IEEE 802.11 standards [6]

2.2.3 IEEE 802.11p

The IEEE 802.11p standard is an approved amendment to the IEEE 802.11 standard for the communication between vehicles (V2V) and between vehicles and the roadside infrastructure (V2I), which is based on the 5.9 GHz band (5.85 to 5.925 GHz) [10].

The improvements in this technology make it ideal for use in vehicular networks due to the reduction of time in the authentication process before exchanging information.

The main changes in terms of physical layer in IEEE 802.11a are the use of 10Mhz channels in contrast to traditional 20Mhz, and also the level of frequency of 5.0GHz now for 5.9GHz [11].

In [12], it is possible to see that the IEEE 802.11p standard overcomes several issues, which are the inherent characteristics of VANETs, such as high mobility or frequent disconnecting.

In this type of network, there are two types of channels: control channel (CCH) and service channel (SCH). The CCH allows a WAVE device to exchange messages without the need of a pre-association, allowing the reception and the forwarding of messages very fast. The SCH sends and receives an IP data.

In [13] Bilstrup uses the Carrier Sense Multiple Access (CSMA) in a network with a large number of users, and the throughput of the communications falls around 80 percent. It also shows that the scheme Self-Organized Time Division Multiple Access (STDMA) for real-time data traffic between vehicles brings some improvement.

Neves et al. [14] studied the range in real scenarios of IEEE 802.11p, concluding that with Line-of-Sight (LOS) it is possible to reach communications around 450m, and with Non-Line-of-sight it is possible to reach communications around 140m.

In [15], Zhuang concluded that the speed of the vehicles have a large impact on the channel access by the Medium Access Control (MAC) layer, through the study of the mobility impact on the performance of the MAC layer in the scenario without RSUs.

2.3 Vehicular Networks

The area of inter-vehicle communication (IVC) has been subject of intensive studies, by researchers and the automotive industry in the last years. Their aim is to provide an intelligent transportation system (ITS) for drivers and passengers. Vehicular networks are then a new class of wireless networks. This type of networks, also known VANETs are created spontaneously between vehicles equipped with wireless interfaces, using short-range or medium-range communication systems. VANET is a type of mobile ad-hoc network (MANET), that provides communications between nearby vehicles and between vehicles and nearby fixed equipment on the roadside.

This section will give more details about vehicular networks.

2.3.1 Definition

Vehicular networks are formed between moving vehicles equipped with wireless interfaces that can allow the communication with different access network technologies as shown in Figure 2.2.

VANETs enable communications between nearby vehicles, but also between vehicles and nearby fixed equipments, usually called Road Side Units (RSUs). The vehicles, considered mobile nodes, need to be equipped with a On-Board Unit (OBU); this equipment, depicted in Figure 2.3, is responsible for sending and receiving information to the network. The static nodes in these networks are the RSUs and they are responsible to give access to the OBUs for the access to the internet.

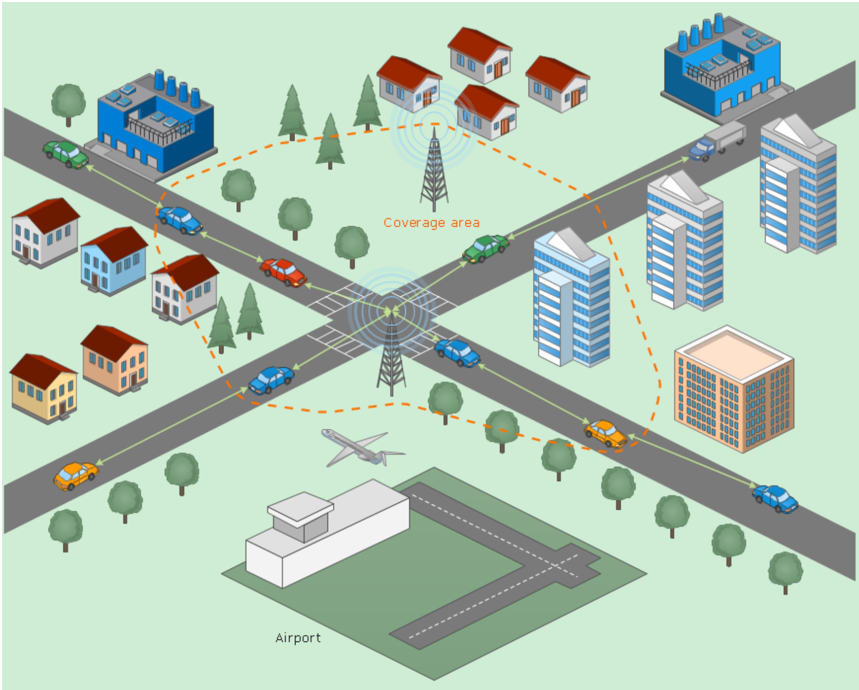

Figure 2.2: Vehicular Network

2.3.2 Special Characteristics of Vehicular Networks

The vehicular networks and its nodes are organized, like in MANETs, without a central authority. Then, the main difference between VANETs and MANETs are the vehicles and its special characteristics and behaviour [16]. The main special characteristics are:

- **Unlimited transmission power:** The power is not a problem to this kind of network as it is to the classic mobile ad-hoc or sensor networks. Taking into account that a node is a vehicle, it can provide to itself continuous power.

- **Higher computational capability:** As in the previous point, the vehicle can also provide a significant computing, communications and sensing capabilities.

- **Predictable mobility:** Unlike the classic ad-hoc networks, where to predict the mobility of nodes is almost impossible, in vehicular networks the movement of the nodes is restricted to an area, the roads. Using latest technologies like Global System Position (GPS), it is possible to obtain the instantaneous speed information as well as the direction of movement, which makes the trajectory of the node something predictable especially in highways.

- **Geographical communication:** In vehicular networks it is possible to send packets to a specific zone, according to a geographical address.

Figure 2.3: On-Board Unit (OBU)

2.3.3 Challenges

VANETs have some also challenges [17], such as:

- **Potentially large scale -** In most traditional ad-hoc networks it is normal to assume a limited network size, but vehicular networks lead to an extension over the entire road network and include a lot of participants.

- **High mobility -** The vehicular networks operate in a very dynamic environment, its nodes (vehicles) can move upper than 120km/h on highways, where the vehicle density is low. But in the city environments the nodes can move with low speeds, lower than 50km/h, and the vehicular density is usually large, especially during the rush hour.

- **Network topology and connectivity -** Vehicular networks are a very special type of networks, due to the constant movement of the nodes, where the topology and the connections between nodes change frequently. The connectivity of nodes will depend on the range of wireless links, and also on the number of vehicles on the road equipped with IEEE 802.11p.

- **Synchronization -** Every node in a vehicular network must be synchronized to access the channel on the same time. Using the GPS time, it is an easy way to solve this problem, but it can fail if the vehicle travel into a zone where there is no satellite coverage.

- **Extreme environments -** The vehicular networks must be able to operate in some different, but extreme environments. For example, in highways the vehicles speed is high, but the density is expected to be small. On the other hand, in the city the vehicle speed is very low, but the vehicle density is larger than in the highway.

- **Latency restrictions -** In this type of networks there are some messages that can not tolerate delays, the safety messages. A message about an accident must have share on vehicles with a reduced delay.

2.3.4 Addressing

In vehicular networks the applications need an addressing scheme. According to Moshin et al. [18], there are some requirements for internet Protocol (IP) addressing such as:

- There cannot be duplicate IP addresses;
- Every node must have an IP address;
- The IP address must only be assigned to a node while it is in the network.

According to [19] the addressing schemes can be divided in two types:

Fixed addressing means that each node has a fixed address assigned at the moment that it joins the network until the node leaves the network. This type of addressing scheme is the most common used in the internet and for ad-hoc networks.

Geographical addressing assigns a specific address to each node, and that address will change according to its movement and the local where it is. Some information can be attached to this address such as the heading, the speed and the type of vehicle.

The time to acquire an IP address must be very small because the connection time between VANET nodes is very reduced. In [20], Palazzi proposes a novel Leader-based scheme that exploits the topology of VANETs and a distributed Dynamic Host Configuration Protocol (DHCP) service to guarantee fast and stable address configuration. According to [21, 22], the “Best-Effort“, a quite common addressing scheme, is not the most suitable for real time applications due to the possibility of duplicate addresses. The authors proposed a detection mechanism to avoid the overhead.

2.3.5 Data Dissemination

The VANETs characteristics, such as high mobility of the nodes and dynamic topology, leads to several issues in terms of data dissemination. VANETs should be ready to operate in extreme environments, such as rural scenarios with low density of nodes and urban scenarios with high density of nodes. Thereby, it is important to develop algorithms for data transmission that guarantee the correct delivery of information. Data dissemination can be single-hop or multi-hop (see Figure 2.4)

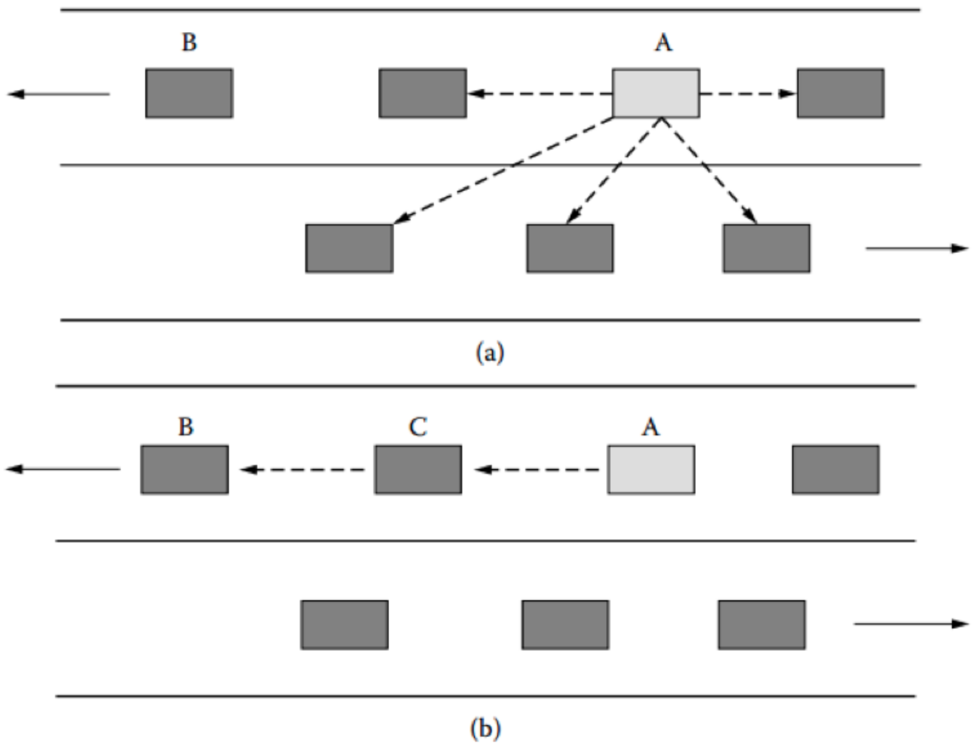

Figure 2.4: Single-hop (a) and Multi-hop (b) Data dissemination

Single-hop dissemination is implemented with the broadcast on the MAC layer, as it is shown in the Figure 2.4. The vehicle A sends the information to all other vehicles at its range, but the vehicle B cant receive that information. If in the range of the vehicle there is some RSU, single-hop disseminated is also used to improve the connection and the control of communication.

Multi-hop dissemination requires intermediate agents to act like relays between the sender and the receiver. As it is shown in Figure 2.4, vehicle C can relay the information received from vehicle A to the vehicle B, the receiver node. To use this type of data dissemination, it is necessary a mechanism for network routing. Also Hybrid variants have been proposed, where data is dissemination to the RSU by multi-hop and after the RSU sends data to the relevant vehicles using single-hop.

The information can be disseminated in unicast, multicast or broadcast. In the unicast case there is one sender and one receiver of the data. The unicast is used for entertainment applications. When there are a group of vehicles to receive the date, that type of dissemination is called multicast. It is used for example to send information to a specific zone involving several vehicles. The broadcast is used when some node wants to send information to all vehicles at the range, for example safety messages. Sometimes some safety messages are necessary in a specific zone. Kremer et al. [23] creates a concept of Zone of Relevance (ZOR) that consists in the creation of a zone where the message is important to be delivered, and only vehicles in that zone receive it.

2.3.6 Applications and Services

Vehicular applications can be divided in safety, traffic efficiency and comfort applications with several technologies involved [4].

2.3.6.1 Safety Applications

Thys type of applications was created to avoid accidents and loss of life of the drivers and passengers of the vehicle. The biggest characteristic for safety applications is that data should be disseminated fast and with low delay to a large number of vehicles in a certain ZOR. The safety applications can be divided in Cooperative Collision Avoidance and Emergency Warning Message.

- **Cooperative Collision Avoidance (CCA)**

  In cooperative collision avoidance applications, vehicles communicate to identify a collision in order to give to the drivers some time to take a proper decision. In [24] Biswas concluded that safety messages can not have more than 10ms of delay to be efficient. Thus, the V2V communication is the proper solution due to the reduced delivery time of the messages. In the Figure 2.5 it is presented an example of safety messages. An accident occurred and that information is sent to the RSU and the closer vehicles.

- **Emergency Warning Message (EWM)**

  The main objective of an emergency warning message application is to disseminate warning information to the vehicles in the relevant area. These messages can be very important, since they are able to warn drivers of dangers on the road, prevent many accidents and save human lives. These applications require that messages remain available for a certain amount of time [25]. Emergency warning messages can be differentiated in two categories, instantaneous and permanent messages.

  The **instantaneous EWM** informs other vehicles about an accident or an anomalous situation, and then, the warning message is addressed to all vehicles of that zone of relevance (ZOR). These messages are not available for a long time.

  The **permanent EWM** aims to warn drivers about dangerous road conditions. In order to be effective they have to be available for long time to inform approaching vehicles in that ZOR, and then vehicles take responsibility for warning neighbour vehicles coming into that ZOR as it is illustrated in figure 2.6.

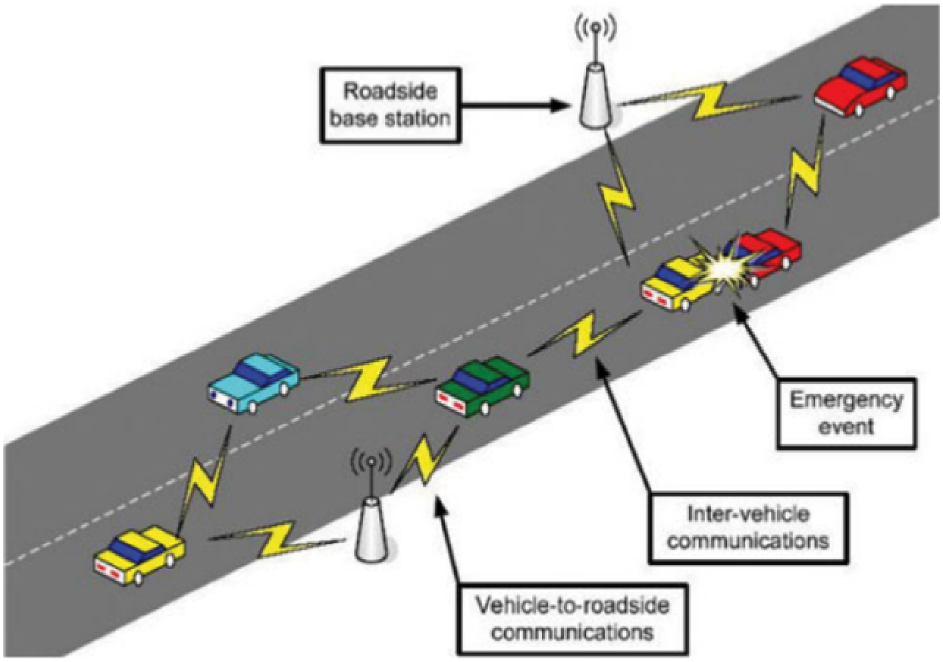

Figure 2.5: Safety Applications [4]

As low density scenarios have low connectivity, in order to guarantee the delivery of the permanent EWM, Maihofer [26] proposed a central server responsible to disseminate information to the ZOR. Therefore, vehicles would send an EWM to the responsible unit of that ZOR via cellular network.

2.3.6.2 Road Traffic Management

Road traffic management applications are important to improve the traffic flow. It would make fastest trips and also reduce the traffic jams. The real-time is the main difference between road traffic management applications and safety applications. The road traffic management applications can be divided into: Traffic Monitoring and Intersection Assistance.

- **Traffic Monitoring**

  This type of application can provide a traffic information for a certain area around the current location of the vehicle, [27, 28, 29]. The roads are divided into segments, as it is shown in Figure 2.7, where the vehicles gather information in the segment and they share that information into the ZOR. This information improves the efficiency of the mobile navigations [30].

- **Intersection Assistance**

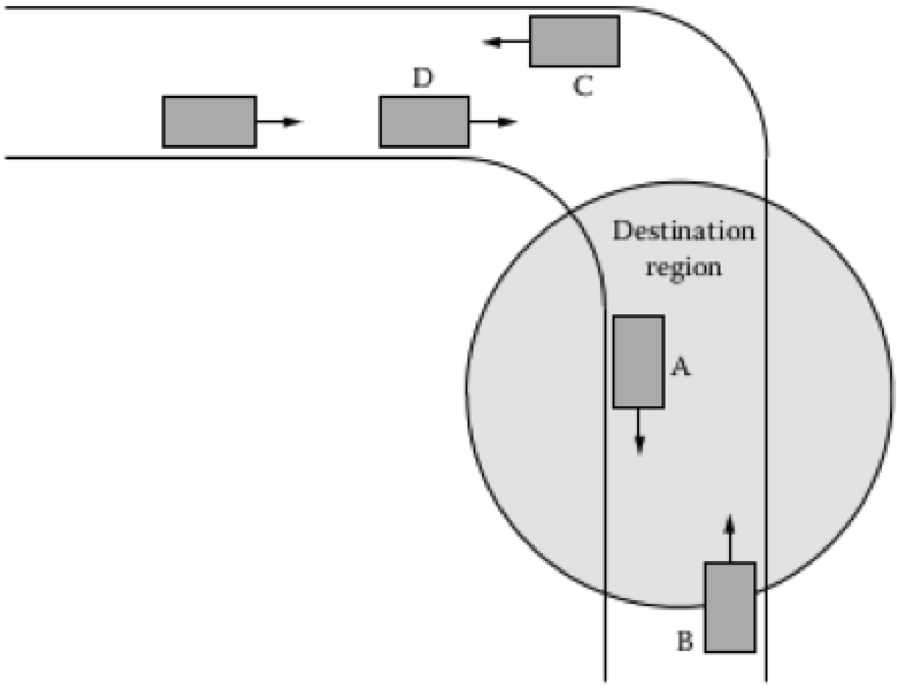

Figure 2.6: Permanent Geocasting [5]

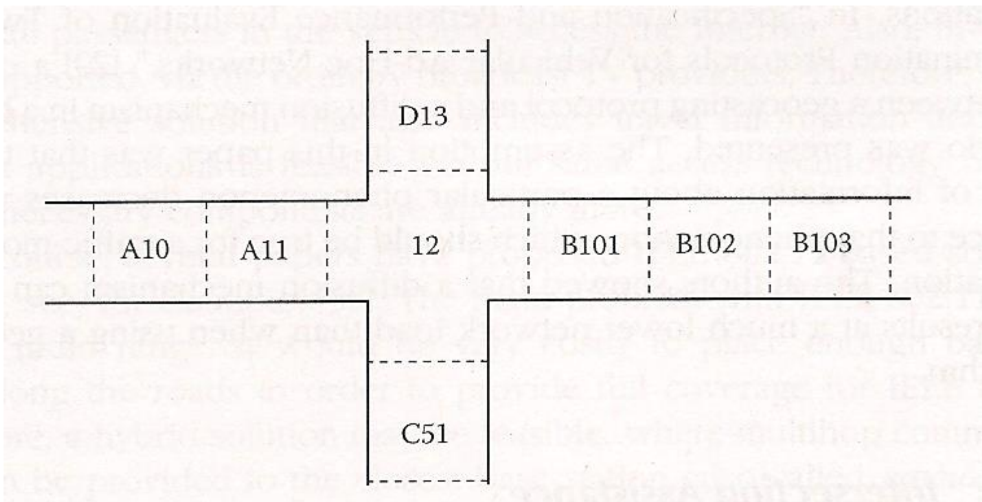

Figure 2.7: A digital map with road segment identifiers [5].

This zone in the roads is a critical zone, since many accidents occur there. The objective of intersection assistance applications is to assist drivers at the intersections [31], in order to avoid collisions with other vehicles [32, 33], or pedestrians [34]. Comparing, the IEEE 802.11 is better than Bluetooth technology to use in intersections, due to its applicability to a broader range of applications. These applications could be, for example, communicating with traffic lights, to improve the performance, in emergency situations and also when the traffic density is low.

2.3.6.3 Comfort Applications

Comfort applications were created to make the time spent in the vehicle more interesting for drivers and passengers. Some technologies can be incorporated to give internet access inside the vehicle, such as cellular networks (GPRS, UMTS, LTE), IEEE 8902.11a/b/g, WiMax and IEEE 802.11p.

Service announcements made by restaurants, hotels or tourist points are examples of information that vehicle users could receive when crossing certain area [7].

2.4 Related Work on Connection Management and Prediction

This section presents the related work in the area, emphasizing the concepts of connection management, network selection and prediction in wireless networks.

2.4.1 Connection Management

Network selection has been studied for scenarios with no mobility, or low mobility but when the subject is high mobility, VANETs, the scenario becomes substantially different. The concept "Always Best Connected" [35] makes sense when the user wants to enjoy his connection independently of the environment. This concept combines two related ideas, the full time connectivity and the selection of the best access technology. The VANETs environment brings a necessity of a selection mechanism to help the users to choose the best connection available.

To see which is the best connection is quite difficult due to the number of the variables involved in the decision process and the limited time to make the decision. It is necessary to take into account several factors as available networks, coverage area, applications requirements and more characteristics of the networks. The biggest difficulty in the decision is the high mobility. To solve this, the algorithms should be optimized.

Kosmides et al. [36] focused on the network selection when the users are equipped with multimode terminals. Also in [37], Kikilis identified some aspects of access selection and formulate network selection as an optimization problem. Bari in [38] proposed a decision process, for network selection, that combines non-compensatory and compensatory Multiple Attribute Decision Making (MADM) algorithms, which was taken into account like the best service delivered to the terminal.

Other authors developed studies on this topic: Shen [39] proposed a selection network mechanism based in multiple Quality-of-Experience (QoE) criterion, and Marti in [40] proposed a mechanism based on the users preferences, network conditions and also the service requirements.

Niyato et al. [41] studied the dynamics of network selection in heterogeneous wireless networks, through an evolutionary game approach. The authors proposed two ways for network selection: an alghorithm that uses the information from all users in the same service area, and an algorithm able to learn the performance and price of different networks by interaction.

The network selection is not the only problem that has been studied, Benslimare [42], proposed a heterogeneous integration of VANET and 3G networks using mobile gateways. The authors proposed a solution for gateway selection, advertisement and discovery that integrates 3G/UMTS networks with VANETs, to reduce the time without connection.

In [43], Setiawan et al. proposed a mechanism to select a gateway using multiple node metrics such as the remaining energy, mobility and the number of hops to connect MANETs with infrastructure networks. The authors used a Multiple Criteria Decision Making (MCDM) method called Simple Additive Weighting (SAW), to optimize the selection mechanism in order to choose the optimal gateway node.

Leung et al. [44] proposed a new server and a packet relay to minimize the rate of server hand-offs, by relaying location update packets towards the server that has the highest possibility to keep the connection. The authors also proposed a decision that takes into account a tolerable delay and cost.

Zhang et al. [45] proposed a network-controlled group handover scheme in heterogeneous vehicular networks, with the main purpose to maximize the system throughput and to minimize the system latency cost.

Baldessari et al. [46] proposed a solution that provides dynamic connectivity management for vehicular communications. The authors used a criteria based model to achieve the optimal path: the number of wireless hops between nodes and the geographical distance between them. The main differences between this solution and our solutions are: the number of criteria, but the mainly difference is that our solution has a predictive side, and it is capable to know which networks are in the area and what is the best network option.

Network selection mechanisms for areas with low mobility have been studied, and many solutions have been proposed. But, in high mobility scenarios, to make a good network selection mechanism is more complicated. The specific characteristics of VANETs turn that mechanism into a complex problem.

During the last year Carreira et al. [47] proposed a network selection mechanism able to work in high mobility scenarios. This mechanism takes into account some characteristics of the VANET nodes such as speed and location, price, number of hops, RSSI amd expected contact time. Another problem solved by the authors was the network selection between different types of networks: Wi-FI, cellular network and IEEE 802.11p.

This work identified what type of networks and what parameter values give the best performance in vehicular networks, and which are the optimal weights for each parameter during the selection process. At the end of the selection process, the node receives the best network available and it starts the connection process.

This work is the base of the work developed in this dissertation. We will improve the previous network selection mechanism: the proposed network selection mechanism will be able to use not only the available information, but also some predictive information to know which has been the performance of each network during the time.

2.4.2 Prediction in Wireless Networks

Prediction in Wireless networks have also been investigated over time. In [48] Bargui proposed a predictive gateway selection scheme, using the vehicle movement parameters to select the way with the longest lifetime by predicting the future connections. This will help to have more stable routes and increases the connection quality.

William Su in [49] used the mobility prediction to anticipate the changes of topology and perform rerouting, before the route breaks. They applied the prediction mechanism to some of the representatives of the wireless ad-hoc routing family, an unicast routing protocol, a distance vector routing protocol and a multicast routing protocol, concluding that routes that stay connected for longest are chosen when it is utilised the mobility prediction. In the simulation, with mobility prediction, more packets were delivered to the destination.

2.5 Summary

In this chapter it was provided an overview of vehicular networks based on the information available in the literature.

First we showed some of the most important wireless networks in vehicular networks, such as, cellular networks, Wi-Fi and IEEE 802.11p networks.

Then, we focused on vehicular networks, its specific characteristics and its technical challenges. It was also presented three types of architectures for VANETs deployment: ad-hoc, WLAN/cellular and hybrid. Posteriorly, it was analysed the addressing and data dissemination schemes.

Finally, the work that has been developed in the scope of this dissertation was presented, including the connection management and also the prediction in wireless networks.

Chapter 3

Prediction Network Mechanism

3.1 Introduction

This chapter will address all necessary steps to make the prediction of the best connection from the time the data is stored in the database until the process of choosing the best network.

Section 3.2 presents a description of the problem of connection management in vehicular networks, while section 3.3 describes the solution presented in this dissertation. The proposal will be discussed in more detail in section 3.4, where the whole process will be described: how to select the most relevant information, how the vehicle will request the information and how the comparison between the information will be done, are some of the problems discussed in this section.

The prediction decision is presented in section 3.5, where we will present the connection manager and the changes that will be made.

3.2 Problem Statement

The high mobility in vehicular networks makes these have very special characteristics, such as changing between available networks with a very high frequency. The time spent to switch between available networks is determinant to raise the quality of service, since no one wants to lose connection, even for a limited time. Thus, the network selection mechanism has been developed to decrease the decision time, because this time is crucial in the performance of the system.

The decision mechanism between different networks in VCM, just starts the decision process after performing a scan of available networks and analysing the quality parameters of the networks. The traditional mechanisms only make decisions according to the signal quality of the link and they do not care about mobility, for example.

The Wi-Fi technology has grown steadily, and the number of hotspots in the cities is now large. But, when the moving cars want to connect in this technology, some problems arise. Vehicular communication cannot completely rely on Wi-Fi technology, due to the time consumed in the association process (2-3 seconds) and the small range which is around 100m, leading that the useful communication time between one vehicle and an infrastructure unit becomes too short.

The high mobility of the nodes of the vehicular networks increases the dynamic of the wireless medium, and consequently, the motion states in which they can be classified. For example, Wi-Fi technology could be an option for a vehicle with low speed, but it is no longer an option when the vehicle moves with high speed.

With the creation of a mechanism to predict the following possible available networks, we can choose the best one in advance, and prepare the connection to these networks even before they are available. So, when they are available, the time spent in the connection will be lower.

Another problem present in the traditional selection mechanisms is that they do not take into account other parameters beyond the signal power, and sometimes the connection can be done by choosing the best network at the time, and not the one that ensures the best quality of connection. It would be quite interesting to know how each network behaves for a given area.

The ideal network selection mechanism must be able to choose the best connection available in a certain area, according to the historical of each network. That means not only the choice of the best available technology given the best connection, but the best network is the one that gives best performance to the connection over time. This new network selection mechanism must be able to work in real scenarios, in Porto, where there is an IEEE 802.11p already installed, similar to the one in Figure 3.1.

The proposed solution is presented in the next section.

3.3 Proposed Solution

Due to the special characteristics of vehicular networks, as mentioned above, the decision of the network selection mechanism along a route should be as fast as possible, and always choosing the best network in terms of the route. Therefore, it is important to know the networks to which we can connect, along with the route, and to know their historic in terms of previous connections and their quality. With this information, the network selection mechanism can choose the best network using several factors and not only the signal power.

When there is a connection between an OBU and an available access point or RSU, every second it is sent to the server information about this connection, such as RSSI, throughput, the location of the OBU, and several metrics that characterize the connection over the time. This information is stored in a database. This database will be the point of departure of this work, since with the amount of information about the connections, we will be able to analyse the location of these connections and their characteristics.

Therefore, knowing the location of a certain OBU and its movement, it is possible to send which networks are present on the route and the historic performance of previous connections. Once it has this information, the OBU can choose the best network, not only

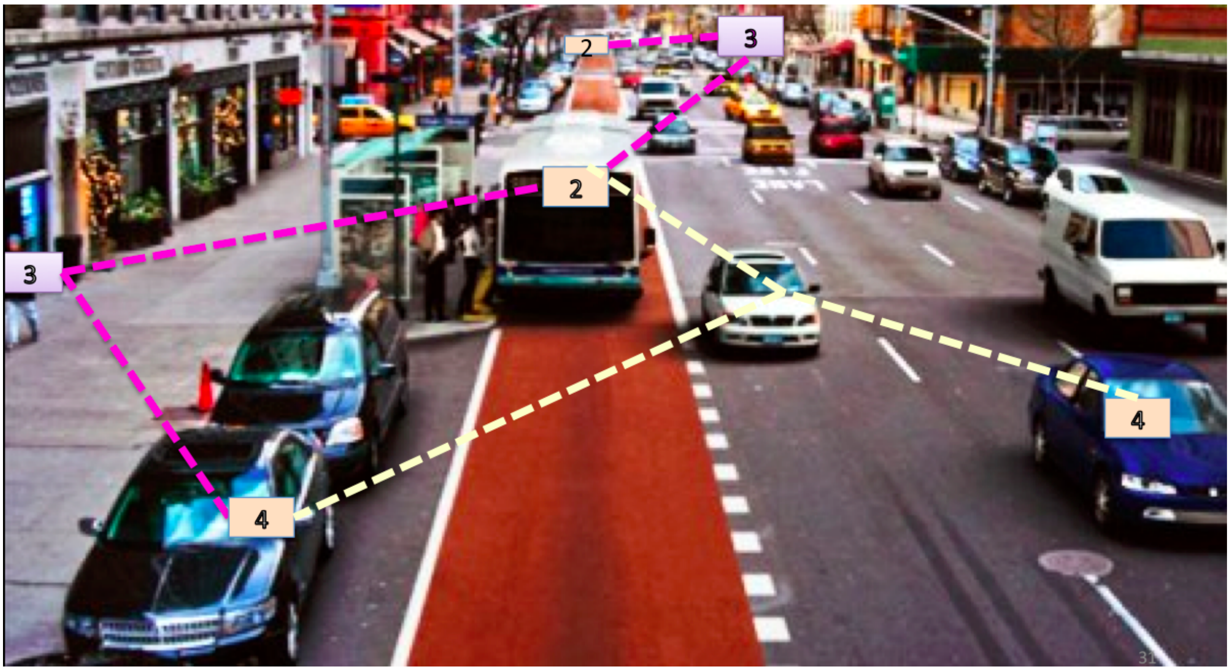

Figure 3.1: Example of the environment

using the available information, but also with the previous information, to predict what will be the best attachment point.

In the scheme of Figure 3.2, it is shown an example of the information that each OBU may contain to perform the decision.

The selection mechanism will be more complex, but more reliable to choose always the best connection.

3.4 Decision Process

This section describes the decision process, which consists of three distinct parts. Then, this work will be divided into three areas, such as:

- **The database**

  The work on the database aggregates the type of information that needs to be stored when a connection is established. This work consists in creating databases to arrange and simplify the use of information that will be used in this process. The creation of databases, optimized for a specific process, will lead to an improvement on the time spent to get a specific type of information.

- **Request and transfer of information to the OBU**

  This is an important part of the work. As we know, an OBU has very limited memory and processing. It is in this second part of the work that we will study

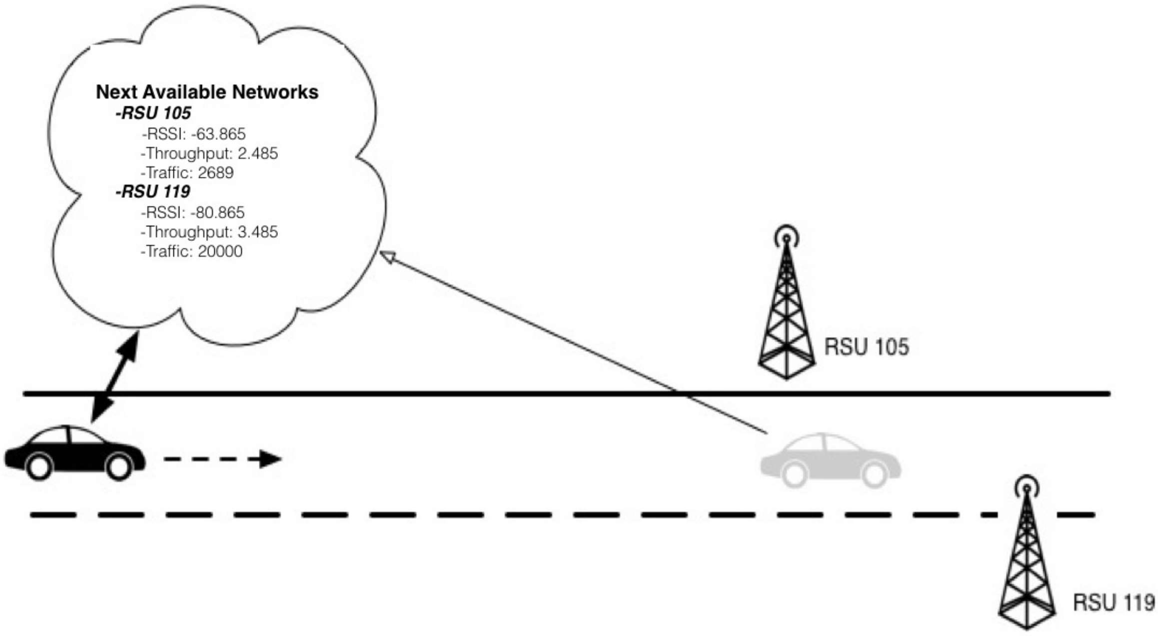

Figure 3.2: Proposed Solution

how the exchange of information will be done, such as what information will be transmitted, when information will be communicated, and which equipment does most of the processing.

- **Selection of the best network**

  When the OBU has access to all networks that can be found in the route, and knows the performance of the connections, the OBU is ready to choose the best network. In this part of the work, a mechanism able to choose the best network will be developed. This mechanism does not opt for the best available network with the best signal strength, but it will use all information that it is available. The information of previous connections will provide information prediction to the decision process, and makes the decision process more reliable.

3.4.1 City Mapping

To predict positions, whether from the vehicle or even from the hotspots, the system needs a reference point. In this work, the city was divided into cells as shown in Fig. 3.3.

Thereby, it is easy locate a vehicle in the city and broadcast to the vehicle all the information needed during the journey.

The cells have a number in the horizontal and vertical starting at 0:0.

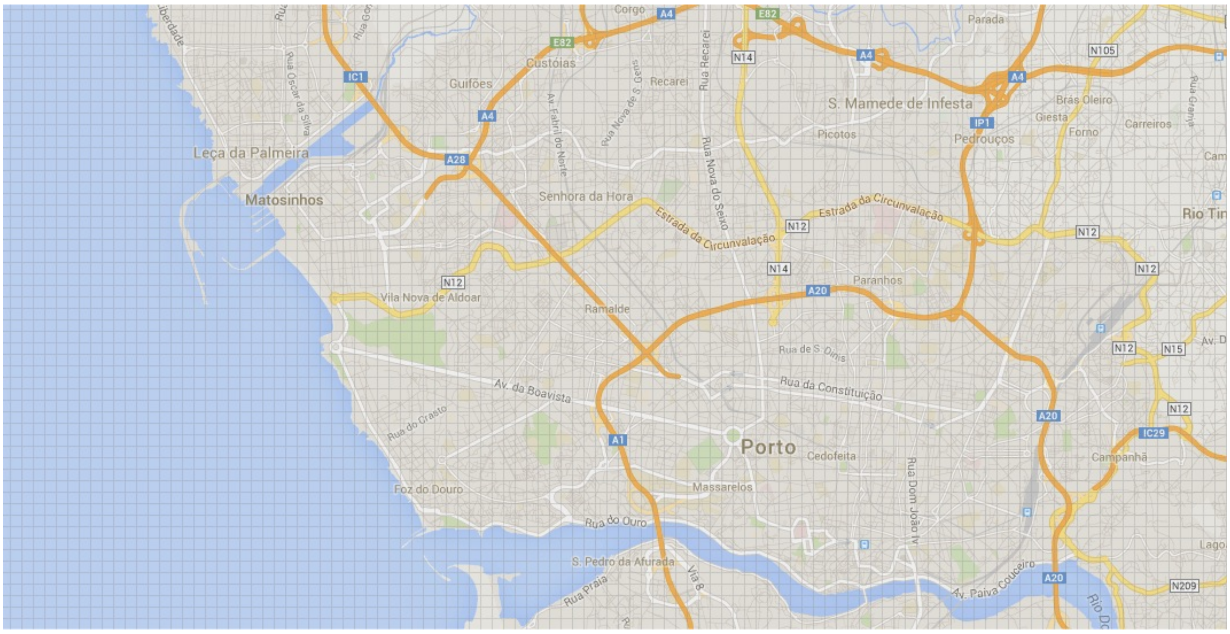

Figure 3.3: City map divided in cells

3.4.2 RSU Mapping

The mapping of RSUs is a complement to the mapping described above.

In each cell, there was a connection between an OBU and an RSU, this connection information is stored within the cell, as shown in Figure 3.4. When there are multiple connections in the cell, it is made an average of the values.

This is an essential part the work. This information is used by the network selection mechanism. It is also this information that will be sent to the OBU in order to inform which are the networks available and its characteristics.

In the following section we will study what is the most relevant information about the connections that we need to store and send to the OBU.

3.4.3 Information in the OBU

For the OBU to have available all information required to make the best choice between different networks, it is necessary to receive the information from the server. The process of receiving this information involves four states:

- **The OBU collects information about the vehicle**

  The OBU collects information from GPS, speed, heading, latitude and longitude, and these parameters are sent to the server.

- **The OBU makes a request to the server**

Figure 3.4: Mapping city and RSU

The OBU joins the collected information and makes a request to the server to get the networks present in its vicinity.

- **The server receives the request and calculates the response**

  The server receives all the information from the OBU, and then calculates which are the relevant cells. From the relevant cells, the information that is sent to the OBU is the one of the cells with available connections.

- **The server sends the response**

  After being calculated, the relevant information is sent to the OBU to use in the best network selection.

This process occurs only when the OBU sends a request to a server. This happens always when the OBU changes the route in 90 degrees or when the OBU moves away more then 500 meters, from the last place where the request occurred.

3.4.4 Choosing the information

When a connection between OBU and RSU happens, there is a large set of infomation saved in a database. If we want to use that information in the network selection mechanism, we need to filter and separate the important information so that the decision process is simple and is not overloaded by giant databases. Then, only the important information will be sent to the OBU.

As we know, the OBU has a very limited memory and the information to be stored, even temporally, must be very relevant and very useful to the selection mechanism. Moreover, the decision approach needs to be done fast, and the information needs to be processed in such a way that makes the decision process very simple.

The previous work on VCM, in order to choose the best network among the available networks, were used criteria such as **Price**, **RSS**, **expected contact time** and **Number of Hops**. This dissertation takes into account the historical information about the networks. Then, it is different to use criteria for available networks or for information of previous connections.

We must use criteria that characterizes the connections to know if those connections were of good or bad performance. Therefore, in this dissertation, it will be used criteria such as **RSSI, throughput** and **traffic**, which will be better explained in the following sub-section.

The price is not necessary in this work because it is not considered the cellular network. Also, the number of hops criterion is unnecessary, since it is impossible to predict the existence of a vehicle to serve as a hotspot; it is only possible to do this for fixed hotspots, and so the number of hops will always be one.

In the next sub-sections it will be presented the chosen criteria.

3.4.4.1 RSSI

The RSSI is the received signal strength in wireless environments. With the increase of this value, the received signal strength increases as well. Therefore, there is an improvement of the signal quality. This criterion will be quite important to know how the links have behaved in a certain area, and to know the expected signal quality for this area.

3.4.4.2 Throughput

Throughput refers to how much data can be transferred from one location to another in a certain period of time. It is used to measure the performance of the network connections to access the infrastructure.

3.4.4.3 Traffic

Traffic is another criteria that qualifies the connection. The traffic is a metric that quantifies the amount of information received in the OBU from a network in a certain area.

3.4.5 Comparison between predictive information and Available information

The information received from the server, that includes the predication of networks available and its quality, has to be complemented with the information available at that time. The information of available networks, sent by the server to the OBU, is an average of all the connections that have happened before. However, at a certain instant, the connection might not be available. As we know, vehicular networks have the particularity to be very unstable, since their nodes are constantly changing as well as the environment. For example, a truck stopped next to the RSU is enough to behave as an obstacle for this connection to not be available to a vehicle, and this vehicle will continue to receive information from the server that there is a good connection in this area through that RSU. Therefore, prediction information and available information must be linked, so with this information, the best option will be chosen without considering temporary non-existent connections.

3.5 Connection Manager

The development of an improved connection manager belongs to the part three of this work. This is an important part, as it is in this part that it will be chosen the best network.

This part will join all the work done so far.

The improvement we include in the connection manager is the prediction. Depending on what has happened in previous connections, we can choose a more stable network instead of choosing the one with better RSSI at that moment.

To have a choice based on that prediction, the VCM uses, as we have seen, certain criteria. These criteria are related to previous connections, but also in relation to the networks that are available at certain moment.

As we can see in the Figure 3.5, to choose the best connection between the network 1 and network 2, we consider available information and predictive information. The criteria for the available information is only the RSSI, while to the predictive information we use the RSSI, throughput and traffic to know which network had better performance over time.

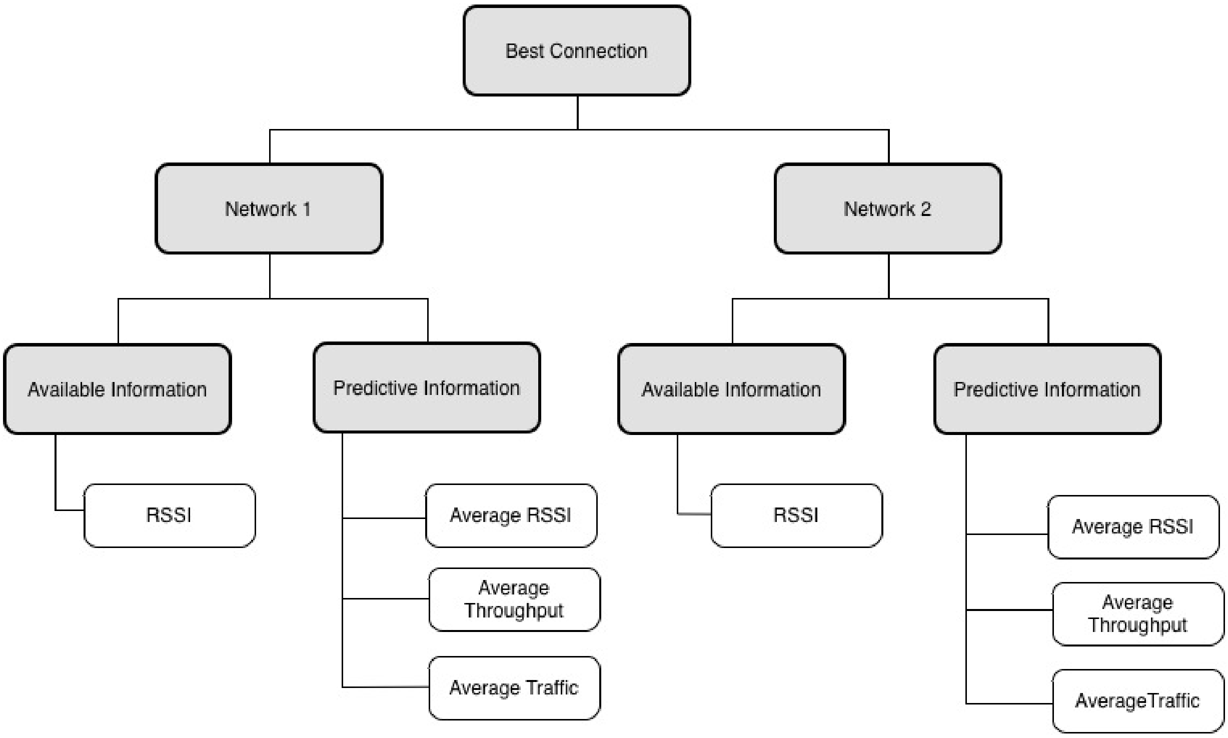

Figure 3.5: Selecting the best connection

3.6 Summary

This Chapter described the proposed solution and the work to be performed.

In conclusion, the work to be performed will involve mapping the city, divided into cells with a particular area, where in each cell we have information of previous connections, such as RSSI and throughput. The features present in each cell will concern with RSU available signal at that location.

Another phase of the work is the filtering and transfer of existing information, the process in the server and how the information will be used in the OBU. After choosing the most relevant information, the comparison between the information provided and available at all times, is performed by each OBU.

Finally, the process for the connection manager to make the decision between networks takes us to the last phase of the proposed work.

Chapter 4

Implementation

4.1 Introdution

After a more detailed description of the problem and its resolution in the previous chapter, this chapter will address how this solution will be implemented to a more technical and deeper level.

Section 4.2 will address the work performed in the database, the databases created and the information that has been used.

Section 4.3 will present the implementation required at the OBU level, the interaction between the server and the OBU and the information transferred between them.

As in the previous section, it is also important to know the processing at the server level, the interaction with the OBU and the information transferred. This will be discussed in section 4.4.

In Section 4.5, it is presented the way VCM is implemented with the predicted information. This decision process is performed in the OBU.

Finally, a concise summary is presented in the end of the chapter.

4.2 DataBase

The database created with the information of the connections that have occurred will be the basis for all the work.

When there is an OBU to RSU connection, several pieces of information that qualify this connection are stored in a database. Using this information, we will make it possible to predict the characteristics of a given connection.

4.2.1 DataBase of RSUs

This database will be called map_RSU and it will be filled using two databases that already exist, and which will be updated over time. This database aims to gather in a single database all the information necessary for the creation of the historical connections.

Two databases will be necessary. The first gives us parameters as the location using latitude and longitude, the RSSI and the traffic of each connection. The other databases give us the throughput.

To get RSSI values between -95 and 0, it is necessary to subtract 95, the value in the database.

$$RSSI = RSSIRec - 95 \tag{4.1}$$

With all these parameters, the map_RSU database is created with the following parameters: obu_id, rsu_id, gpsTime, latitude, longitude, RSSI and throughput as shown in Figure 4.1

Column	Type	Collation	Attributes	Null	Default	Extra
node_id	int(10)		UNSIGNED	Yes	*NULL*	
rsu_id	int(10)		UNSIGNED	Yes	*NULL*	
gpsTime	datetime			Yes	*NULL*	
latitude	decimal(9,6)			Yes	*NULL*	
longitude	decimal(9,6)			Yes	*NULL*	
rssi	decimal(6,3)			Yes	*NULL*	
throughput	decimal(6,4)		UNSIGNED	Yes	*NULL*	
traffic	decimal(6,4)			Yes	*NULL*	

Figure 4.1: mapRSU DataBase

4.2.2 DataBase of Existing Networks

Using the database described in the previous section, another database, with the mapping of existing networks, will be created in the city. This database will be regularly updated, so it was developed a program in python for this purpose.

This program has the function of dividing the city of Porto into cells with 100m aside. In each cell there are several entries, and each entry refers to a connection.

The program starts by analysing and storing in a variable all RSUs presented in the database. For each connection and for each RSU, the program finds the cell where the connection has taken place, using the latitude and the longitude. In each cell, it is made an average of the throughput, RSSI and traffic for the whole connections that take place in that cell.

The resulting database is shown in figure 4.2, with information of the connections made with the specific RSU.

#	Column	Type	Collation	Attributes	Null	Default	Extra
1	**RSU_id**	int(10)		UNSIGNED	Yes	*NULL*	
2	**Longitude_pos**	int(10)		UNSIGNED	Yes	*NULL*	
3	**Latitude_pos**	int(10)		UNSIGNED	Yes	*NULL*	
4	**rssi**	float			Yes	*NULL*	
5	**throughput**	float			Yes	*NULL*	
6	**traffic**	float			Yes	*NULL*	

Figure 4.2: mapRSU DataBase

4.3 OBU Request

For the OBU to know which networks it can find in its path, it has to ask for this information to the server that knows all information about the networks presented in the databases. The request is sent with information needed for the server to calculate the locations of interest to the OBU. Position (latitude and longitude), speed and heading, are the parameters sent along with the request to the server. These parameters are taken by GPS information.

The process of request for information by the OBU is not done indiscriminately. Whenever there is a request, there is the expense of internet traffic and this has costs. Therefore, the request process will have some rules: there is a request from the OBU to the server, whenever the OBU is 500m from the site of the last request, or when the OBU makes a change of direction of 45 degrees also in relation to the direction that it had in the last request. The process is shown in Figure 4.3.

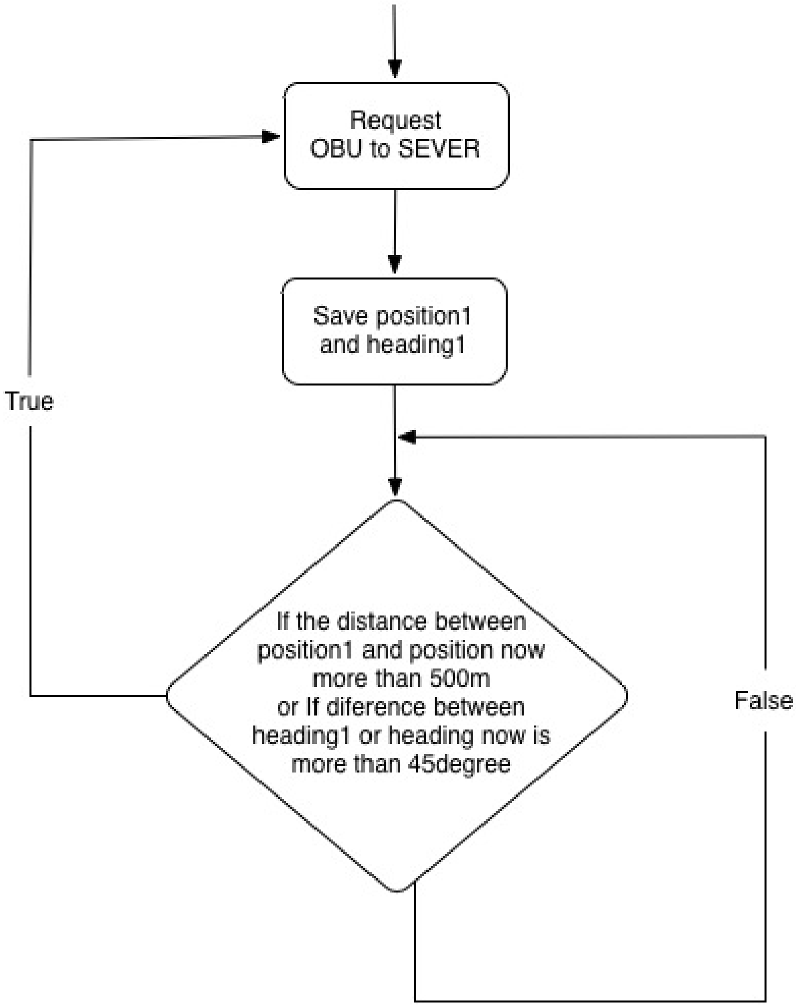

Figure 4.3: OBU Request Process

4.4 Implementation on the Server

When the server receives a request from the OBU, it sends the information to the OBU about relevant cells, depending on the parameters received by the server.

The server will calculate a certain area, and all information of the cells within that area will be sent to the OBU. The relevant area will vary depending on the vehicle speed.

- Up to 30km/h, the area is a circle with a 500m radius;
- Between 30 and 50km/h, the area is a circle with a 1000m radius;
- Between 50 and 70km/h, the area is a circle with a 1500m radius;
- More than 70km/h, the area is a circle with a 2000m radius;

With the heading received in the request, we increase 45 degrees and also subtract 45 degrees and we obtain a well-defined area as shown in the figure 4.4

After we calculate the latitude and longitude for each vertex of the relevance zone, we just find the vertex cell and the relevant cells are all cells inside the vertex, as also shown in figure 4.4.

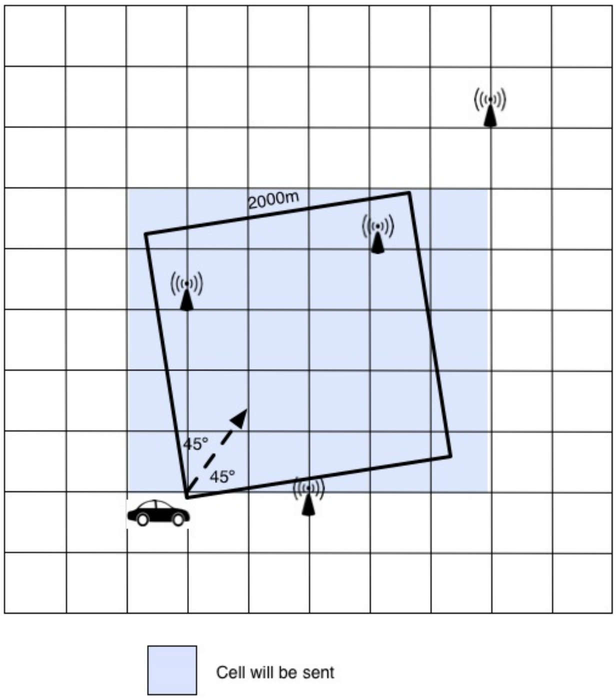

Figure 4.4: Diagram of the relevant cells

The relevant information of the cells is sent to the OBU by a file in *json* format.

4.5 Vanet Connection Manager with Prediction, Pb-VCM

The implementation uses an application installed in each OBU. This application provides to all vehicles the necessary intelligence for choosing the best network available in every moment. For that, this application analyses the environment and receives all information from each network available. This information is processed and the connection manager decides, according to priority values, what is the best connection.

This dissertation will add to the VCM the information to perform prediction of the best connection. It is possible that the VCM chooses a network with a lower signal in a certain place, because the network performance is predicted to be better. The VCM receives that information through the database.

```
{
    “id”: 481,
    “posicao”: [
        102,
        63
    ]
    “rssi”: -91.5902
    “traffic”: 1254
    “throughput”: 4.3600
},
{
    “id”: 481,
    “posicao”: [
        103,
        63
    ]
    “rssi”: -88.667
    “traffic”: 20561
    “throughput”: 3.7900
},
```


Figure 4.5: *json* file sent by the server to the OBU

4.5.1 Implementation of PbVCM

In the implementation of the new VCM, PbVCM it is used as a base a VCM already developed. This VCM is responsible for choosing the best network available: it performs a scan of available networks, then it compares the various RSSI, and then it finds the network with the best signal, and the OBU is connected to that network.

In the implementation of VCM with prediction, the main difference focuses on the choice of the best network, since this time it will consider the past behaviour of networks in advance, stored in the database.

4.5.1.1 The Existing Vanet Connection Manager

The existing VCM performs a scan using the “getAvailable” command. With this information, the next step is to learn from all available networks, which one has the best RSSI value. The VCM only compares the RSSI values of available networks, and the network that has the highest RSSI value will be the choice for the connection.

4.5.1.2 The New Vanet Connection Manager, PbVCM

The PbVCM developed in this dissertation has, as main difference, the process to choose the network. While at first the choice was made to use only the RSSI, in addition to the RSSI available at the time, we now take into account the RSSI, throughput and traffic parameters of the previous connections in the same area, and predictively by choosing the best one.

4.5.1.3 Choosing the best Network

In the choice of the best network we have several parameters. As studied in [47], weights to each parameter will be assigned according to their behaviour at each site.

In the following tables, the weights of each criterion are presented. This are the weights used in PbVCM.

RSSI	RSSI ratings
>-47	1
<= -47 and >-59	1/2
<= -59 and >-71	1/3
<= -71 and >-83	1/4
<= -83	1/5

Table 4.1: IEEE 802.11p RSSI ratings

Traffic (mbps)	Traffic ratings
>3	1
<= 3 and >1	1/2
<= 1 and >0.5	1/3
<= 0.5 and >0.1	1/4
<= 0,1	1/5

Table 4.2: IEEE 802.11p Traffic ratings

Throughput (mbps)	Traffic ratings
>3.5	1
<= 3.5 and >2.5	1/2
<= 2.5 and >1.5	1/3
<= 1.5 and >0.5	1/4
<= 0.5	1/5

Table 4.3: IEEE 802.11p Throughput ratings

The ratings present in previous tables were not chosen at random. For all criteria a study database was done, to determine which is the range of values presented. After knowing this interval, it was only necessary to divide the interval in five different ratings. The number of entries present in each rating were taken into account and this is why we do not have a linear division of intervals.

Note that the ratings used for RSSI available were the same used in predictive RSSI.

After the calculation of the weights in each criterion, it is time to calculate the total performance of the network using in the following formula.

$$\begin{aligned} Networkweight = RSSIAvailableRating * 0,3 + RSSIRating * 0,233 \\ + ThroughputRating * 0,233 + TrafficRating * 0,233 \end{aligned} \tag{4.2}$$

As we checked out in the previous formula, we have two types of information, available, and predictive. The information available comprises only one criterion RSSI, which has a total weight in the decision of 30%. The predictive information has three criteria RSSI, throughput and traffic each with 23.3% weight in the decision, which gives a total weight of approximately 70% in the final decision for a predictive information.

These weights were chosen to enhance the criteria with predective information. However, just doing some lab tests we come to the final weights, described above.

4.6 Summary

In this chapter it is presented the implementation for the proposed solution explained in the previous chapter. First, it was showed the importance of the database in this work. The work done to build the database is presented, from the study of existing databases to the creation of new databases.

After being treated all the information, it was necessary to make the communication between OBU and server to exchange information. This subject is treated in sections 4.3 and 4.4, where it is described how the reception of the information on the OBU is performed.

Lastly, it was described the decision process of the network selection mechanism. It was described how the weights were assigned to each parameter to provide good decision between networks, as well as the differences when compared to the existing VCM.

After the implementation, in the next chapter it will be presented the results obtained in the real scenario. These results are a comparison between the ones of the existing VCM and the ones of the PbVCM developed in this Dissertation.

Chapter 5

Results

5.1 Introduction

This chapter tests and evaluates the performance of the new Prediction based VCM (PbVCM).

In section 5.2 it is shown how, in the laboratory, the PbVCM is tested, before being tested in real scenarios.

In section 5.3 it is depicted the scenario deployed in the real world tests. In the different subsections, it is detailed the equipment used in the tests, the metrics to evaluate and the results.

Lastly, section 5.4 presents an overview of the topics described.

5.2 Laboratory Tests

After the deployment is completed, it is necessary to make sure that everything is operating correctly, and it is possible to take all the necessary results. We will start with a set of tests in the laboratory before going to the real scenario.

Since this work is based in the information presented in the database that contains the information of links on the road, to test this solution in the laboratory is difficult. Thus, it is necessary to test the three parts of this work separately: the work on the database, the transmission of information between the server and the OBU, and the decision of the PbVCM in the OBU.

The test of the database was done easily but with much time spent. The main concern was to know if the datadases created were being filled correctly. Each cell in the created database has been filled with the information of the connections that occurred in that area. In the code, several tests were made to analyse the information inserted in the database in different situations.

In the mechanism responsible for requesting and sending the information to the OBU, it was necessary to test if the information was requested at the right time, and if this information was correct. The information must be requested every 500 meters and when the heading varied 45 degrees. Using a car, it was checked that everything was working properly.

Finally, the PbVCM was tested by checking if the choice of the best RSU was well taken. Some lines were added in the *json* file to simulate a history of connections to these RSU, as shown in figure 5.1. Thus, as can be seen in Figure 5.2, it is chosen the best RSU, based on the information contained in the *json* file and the available RSSI.


```
{
    "id": 555,
    "posicao": [
        300,
        300
    ]
    "rssi": -50.0
    "traffic": 2689
    "throughput": 4.3600
},
{
    "id": 555,
    "posicao": [
        300,
        300
    ]
    "rssi": -80.0
    "traffic": 20000
    "throughput": 3.7900
}
```


Figure 5.1: Necessary information in the *json* file.

```
Candidate (RSU): 555; Priority: 0.650000; P_RSSI: -23.000000; P_HOP: 0.000000

Candidate (RSU): 555; Priority: 0.650000; P_RSSI: -23.000000; P_HOP: 0.000000

BEST RSU —> 555 -35 0 p r 555
```

Figure 5.2: PbVCM results in the laboratory

5.3 Real Testbed Scenarios

The tests on a real scenario were made in Porto, where the company VeniamWorks, together with Institute of Telecommunications, University of Aveiro and University of Porto, have already implemented a vehicular network. The network is composed by a set of RSUs scattered around the city, 400 buses working as OBUs and 20 garbage containers working also as OBUs.

To better use the network capabilities, it is followed a default route to the tests. The route used is shown in the figure 5.3.

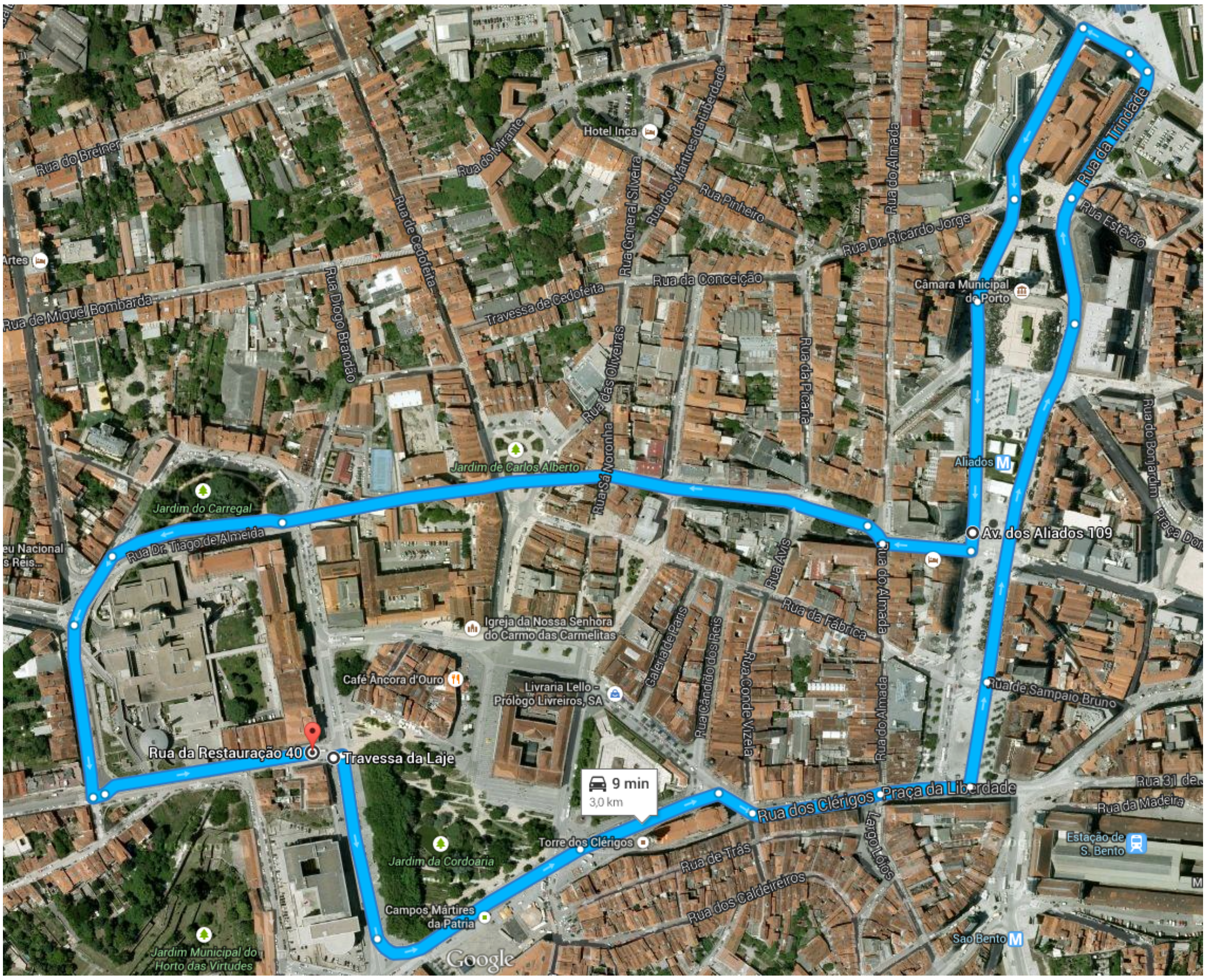

Figure 5.3: Route used in the pratical tests

This route crosses areas in the center of Porto, such as Aliados, Trindade, Reitoria da Universidade do Porto, Hospital de Santo António and Torre dos Clérigos. All these areas have RSUs installed, which were used to conduct the tests, with the establishment of links between OBUs.

Before going to the road, it was necessary to fill the database. It was used the information of the connections that happened during the previous two months. The information was comprised of 2500k entries, and it was intriduced in the database the day before the experiment. The database created in this work must be updated, and this update must be done at least once per day.

If the database is continuously updated, it is avoided that the RSUs will always have the same performance. The performance of each RSUs will vary, at least, from day by day.

It is important to mention the way some data were saved and processed. The traffic criteria, used in the selection process, is the amount of download and upload data through IEEE 802.11p and it is generated using loading tests (IPERF programs running on OBUs to generate traffic). It is possible to know the amount of traffic generated by each RSU, by analysing the traffic in terms of technology and interface. The throughput, besides being used in the selection mechanism, is also one of our criteria in the results. This criteria is calculated using wbest [50], a tool that estimates the bandwidth in wireless networks without interfering with the existent traffic. The delays, used in the results, are calculated through IP pings.

5.3.1 Equipment Used

For the tests on the road, the following equipment was needed. A vehicle moves along the road with two OBUs, illustrated in figure 2.3, one with the old VCM installed and the other with the PbVCM, developed during this dissertation. Other equipment used were batteries to turn on both OBUs, and the RSUs were already present on the road.

5.3.2 Evaluated Metrics

To make a comparison between both VCM and PbVCM, we used the following metrics to qualify the practical tests.

- **Connectivity Duration**

  The Connectivity Duration is the duration of each connection made between the OBU and the RSU.

- **RSU - OBU Single-Hop Distance**

  The RSU - OBU Single-Hop Distance is the distance between the OBU and the RSU where the connection was established.

- **Last OBU RSSI Single-Hop Connections**

  The Last OBU RSSI Single-Hop Connections is a metric that quantifies the RSSI in each link between the OBU and the RSU.

- **RSU - OBU Round-Trip Time (RTT) Single-Hop Connections**

  The RSU - OBU RTT Single-Hop Connections is the time spent on the round trip of each packet between the OBU and the RSU.

- **RSU - Last OBU Throughput Single-Hop Connections**

  The RSU - Last OBU Throughput Single-Hop Connections is a metric that quantifies the throughput of each link between the OBU and the RSU.

- **Local Mobility Anchor (LMA) - OBU RTT Single-Hop Connections**

  The LMA - OBU RTT Single-Hop Connections is the time spent on the round trip of each packet between the OBU and the LMA.

- **IEEE 802.11p Handover Latency Single-Hop Connections**

  The IEEE 802.11p Handover Latency Single-Hop Connections is the time spent to make a handover between 2 RSUs with IEEE 802.11p technology.

5.3.3 Real Scenario Experiment Results

The road tests were conducted with the use of two OBUs, as was said above, one OBU with old VCM, and another with PbVCM developed in this dissertation, to compare the results achieved with both connection managers. Therefore, the results will be presented through graphs that evaluate each metric.

The OBU 639 is the one that contains the old VCM, and the OBU 666 is the one that contains the PbVCM developed in this dissertation.

These tests were made in a real road in the city, so there are always several situations that we can not control. The speed, for example, is extremely variable and the time spent doing the circuit is also variable. But, in general, the test was made without incidents.

For the PbVCM the test lasted 4 hours, and for the VCM the test lasted 3 hours, the route followed was the same for both. The average speed to the PbVCM was 9.9 m/s and the one of VCM was 8.9 m/s.

5.3.3.1 Type of connectivity

This metric shows the percentage of time that each technology, IEEE 802.11p and cellular, has been turning on during the experience.

The most favourable case in this metric is a high percentage of the time where it is used the IEEE 802.11p technology because, when compared with cellular technology, the IEEE 802.11p costs are reportedly reduced.

Figures 5.4 and 5.5 show the percentage of time each OBU spent in each technology. In the legend of the figures we can observe that connections through IEEE 802.11p were made near the RSUs, which means where it is supposed to be IEEE 802.11p connection.

However, whenever the OBUs are considered near the RSUs, only 359 of the 1520 sec the connections were made through cellular.

Comparing the graphs in figures 5.4 and 5.5, we can see that in the PbVCM 31 % of the connections near the RSUs were made using cellular network, and in the VCM only 17 % of the connections were through cellular. These results are easy to explain, because the first experiment was performed with the PbVCM in which there were a few stops in zones without IEEE 802.11p coverage, thus increasing the time of the cellular. To prove that, we can look at the bar in graph 5.7 that shows that there were cellular connections which lasted between 10 and 20 minutes.

We can also conclude that only near the RSUs there are connections using IEEE 802.11p technology for both OBUs.

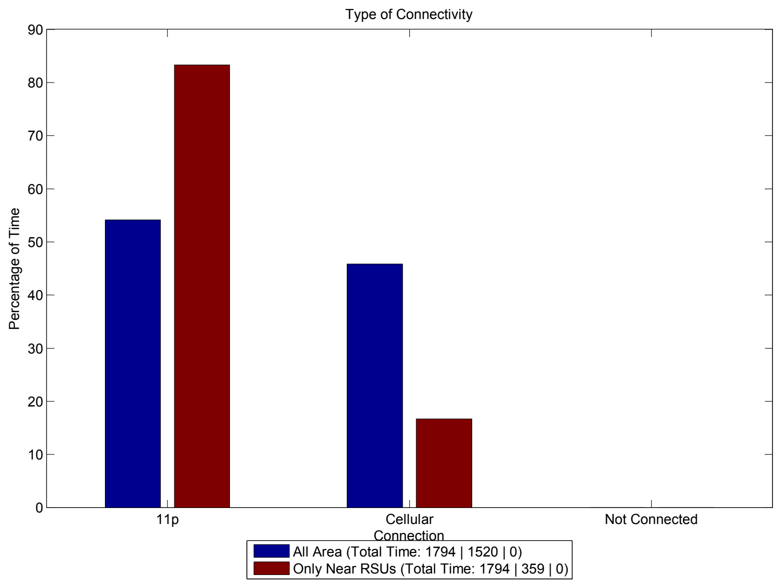

Figure 5.4: VCM - Type of Connectivity

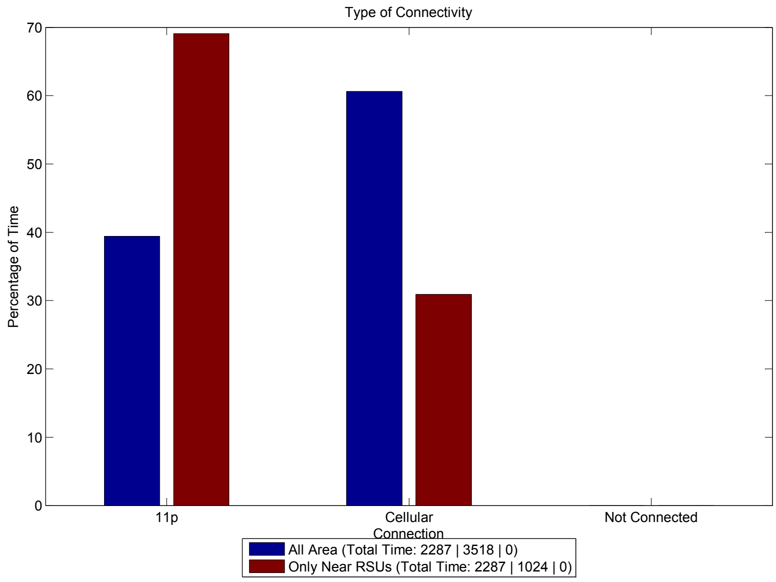

Figure 5.5: PbVCM - Type of Connectivity

5.3.3.2 Connectivity Duration

This metric shows the duration of each connection while the above showed the percentage of time in each technology. With the changes made, it is expected that the time of each connection increases. In other words, it is expected that the PbVCM connections will be of longer duration than the ones of VCM in the IEEE 802.11p technology.

The graphics 5.6 and 5.7 show the duration of each connection for both OBUs. First of all, we can see directly that the average duration is larger in the PbVCM, 144.4 seconds against 140.8 seconds in the VCM.

The PbVCM is using the historic information to decide between networks. The best network will be the one that has had the best performance. A network with more traffic sent or better throughput is expected to have a connection time also larger.

If we analyse the graphics in detail, we can see an increase in the bar [0,5]min for the PbVCM. In the IEEE 802.11p technology most of connections last around 2,4 seconds.

The difference between both selection mechanisms is not high but we can see some improvements.

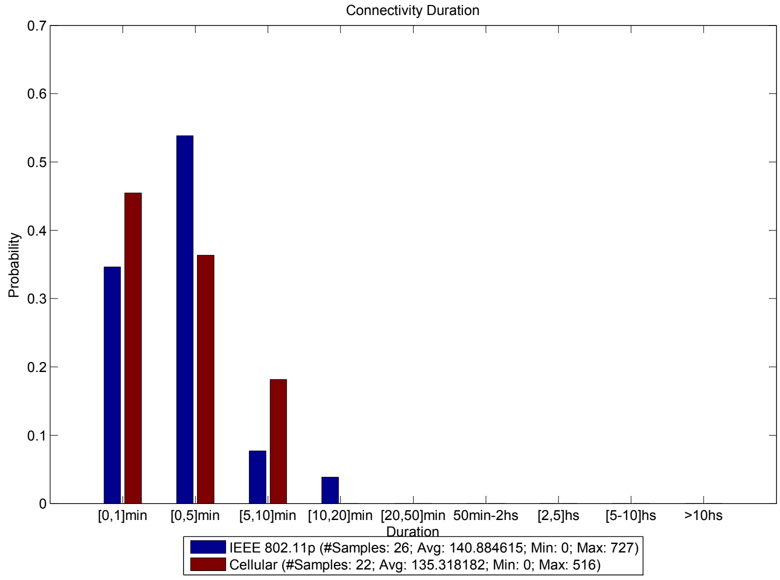

Figure 5.6: VCM - Connectivity Duration

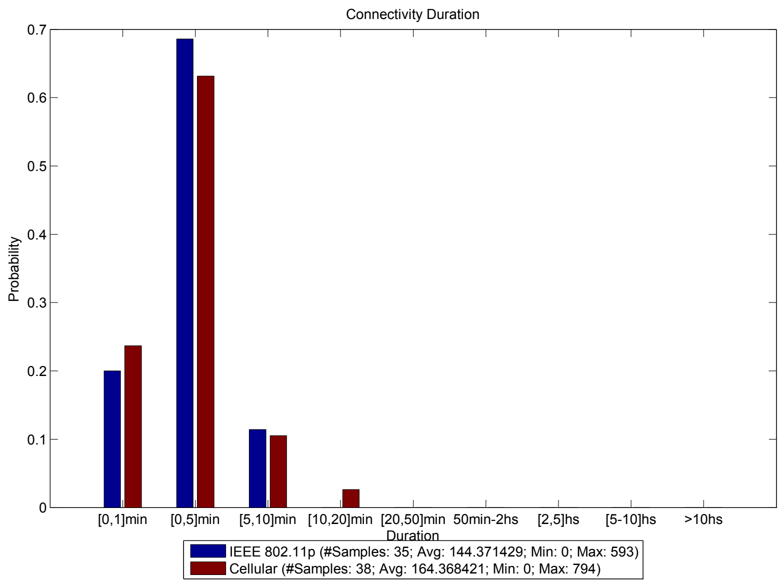

Figure 5.7: PbVCM - Connectivity Duration

5.3.3.3 RSU - OBU Single-Hop Distance

This metric shows the distance between OBUs and RSUs where the connection was established. It is an important metric to understand the differences between both VCMs. With the PbVCM, when the OBU tries to connect to an RSU, it takes into account not only the information available, but also the information present in databases, which refers to links that have already been established in previous times. Although this is a metric that is closely related to the characteristics of the land and the place where the RSUs are, it is expected some changes in the results of both VCMs.

With the PbVCM, we can expect an increase of the distance, because now the PbVCM uses more than the available RSSI.

Observing the graphs in figures 5.8 and 5.9 relating to VCM and PbVCM, it is possible to verify the changes. The biggest change is the existence of the occurrence of multiple connections to RSUs more than 600 meters away. This is true for the PbVCM but not for VCM, because the priority between networks changes. For example, if we have two netwoks available and the network 1 has a better RSSI but the network 2 has had much better performance in the previous connections, the PbVCM will choose the network 2, which although may not have the best RSSI, may be further away, it has the overall best performance.

In general, the distance increases when the OBU contains the PbVCM.

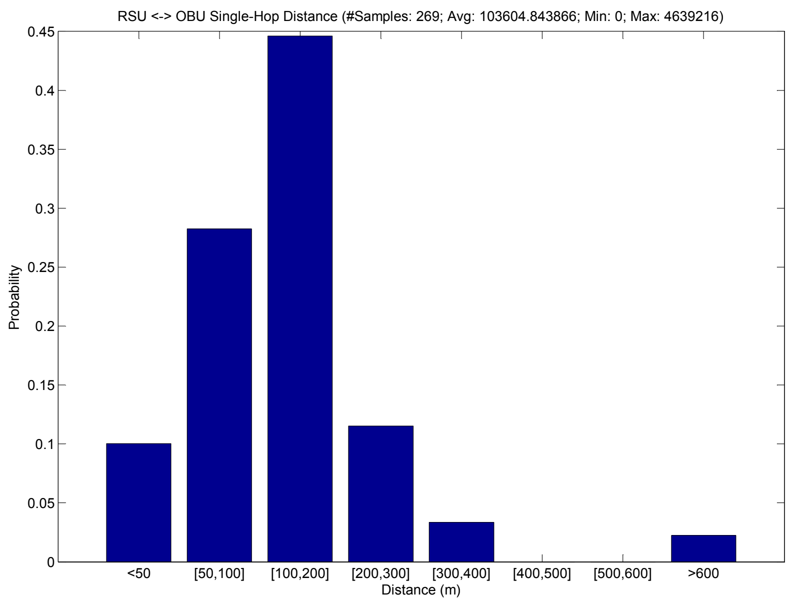

Figure 5.8: VCM - RSU - OBU Single-Hop Distance

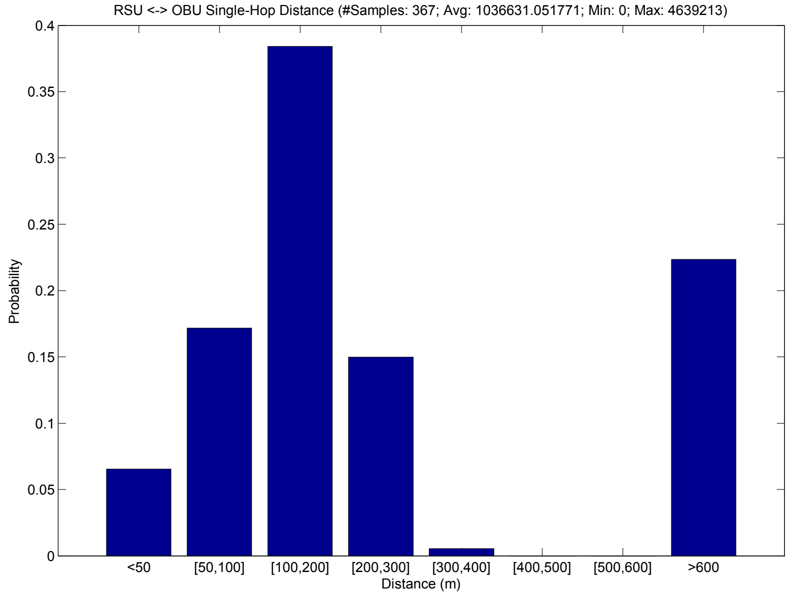

Figure 5.9: PbVCM - RSU - OBU Single-Hop Distance

5.3.3.4 OBU RSSI Connections

The RSSI is always a factor to be taken into account when referring to wireless networks. This metric is a measurement of the power present in a received radio signal. Therefore, it is important to understand how is the behaviour of the RSSI in both cases.

If we think about PbVCM, it is to conclude that the RSSI during the connection can get worse, because the mechanism can choose a network with lower RSSI. As we already said, wit PbVCM the RSSI is not the only parameter.

Analysing the graphs of figures 5.10 and 5.11, we can see that the average RSSI decreased, but in general the RSSI does not change so much between both OBUs. In this case, it is very positive that this has occurred, since we can state that the RSSI is no longer the strongest and only factor of decision.

Moreover, the decisions taken by the PbVCM do not have an impact on the RSSI experienced in the connections.

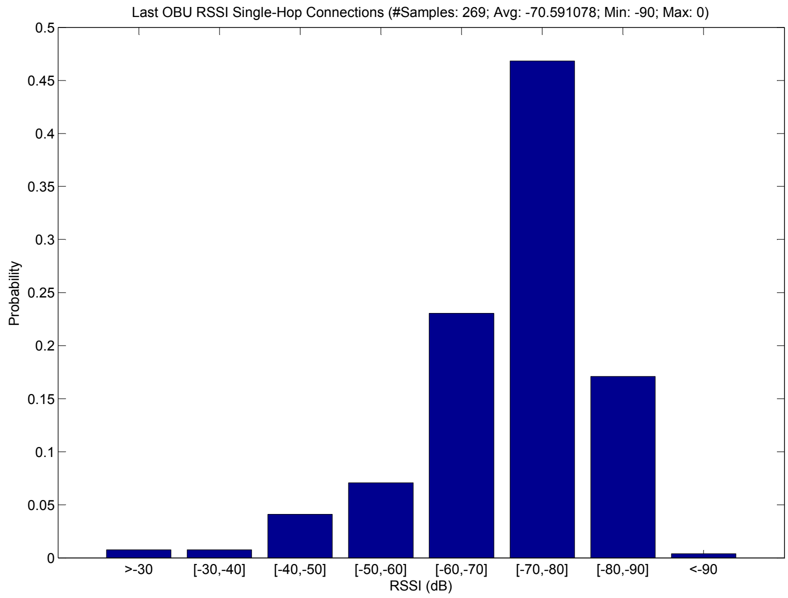

Figure 5.10: VCM - RSSI Connections

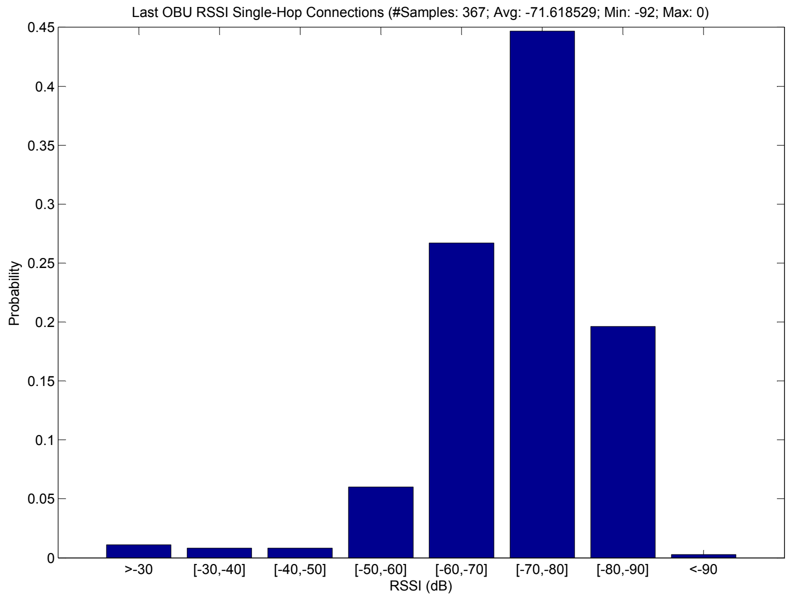

Figure 5.11: PbVCM - RSSI Connections

5.3.3.5 Last OBU Throughput Single-Hop Connections

The throughput is the amount of data transferred from one place to another in a specified amount of time. Thus, this is a very important metric. Taking into account that the throughput is also used to select the best connection, it can be expected to improve the throughput values for the PbVCM. In the PbVCM, the average throughput of each RSU is taken into account.

When analysing the graphs shown in the figures 5.12 and 5.13, we observe that the throughput on the PbVCM's connections is improved, with almost 60 percent of the connections with a throughput above 8Mb/s, while in VCM there is a larger percentage of throughput between 6 and 8Mb/s.

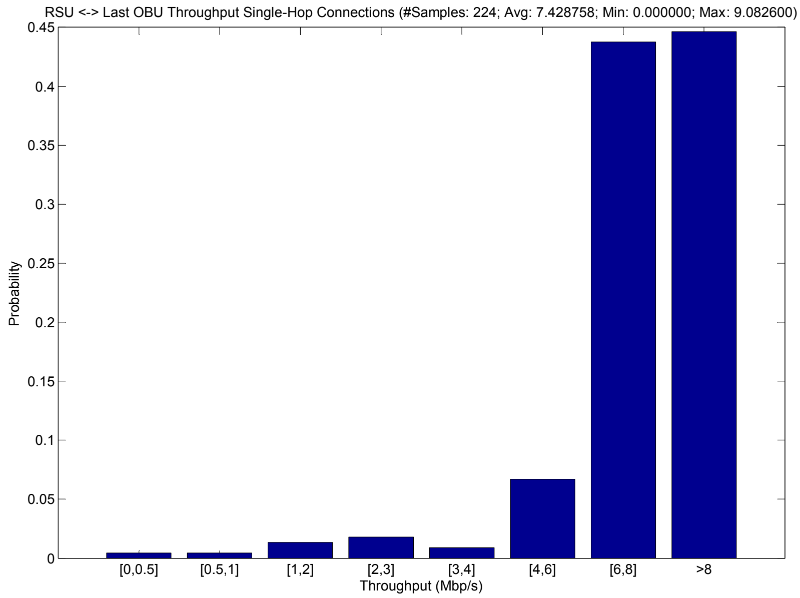

Figure 5.12: VCM - Throughput Single-Hop Connections

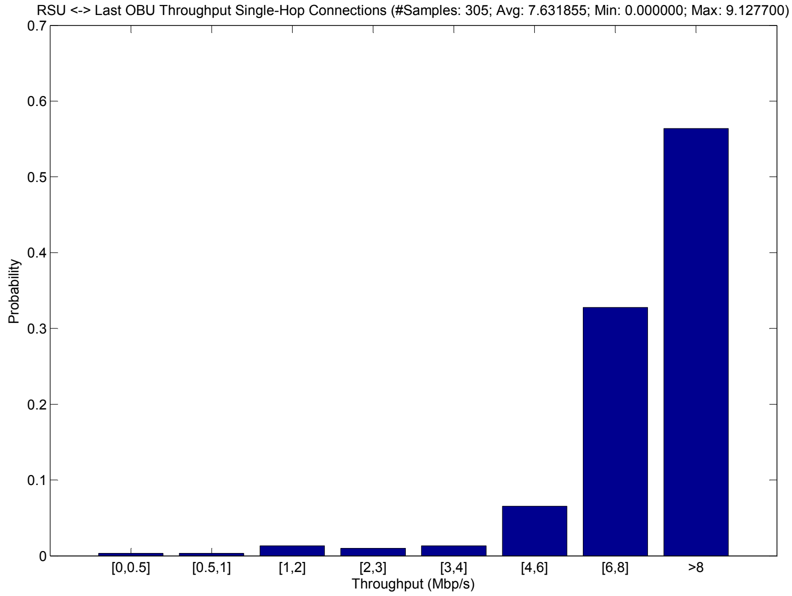

Figure 5.13: PbVCM - Throughput Single-Hop Connections

5.3.3.6 IEEE 802.11p Handover Latency Single-Hop Connections

The work in this dissertation and the improvement of the VCM, did not include any change in the way handovers were made. However, this metric will serve to verify that effect of the new PbVCM in the latency of handovers.

Observing the graphics 5.14 and 5.15, we can see some differences, the main difference is the average latency that is 16.5 ms in the old VCM and 10.6 ms in the PbVCM. As we said previously, it was not expected to improve this metric, but choosing better the network decreases the latency of handovers.

The number of bars can be explained with the more samples present in the PbVCM experience.

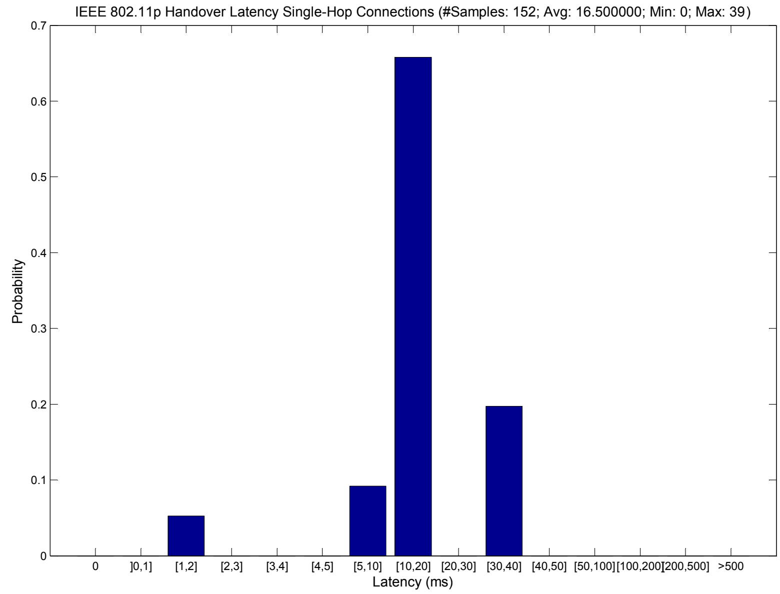

Figure 5.14: VCM - Handover Latency

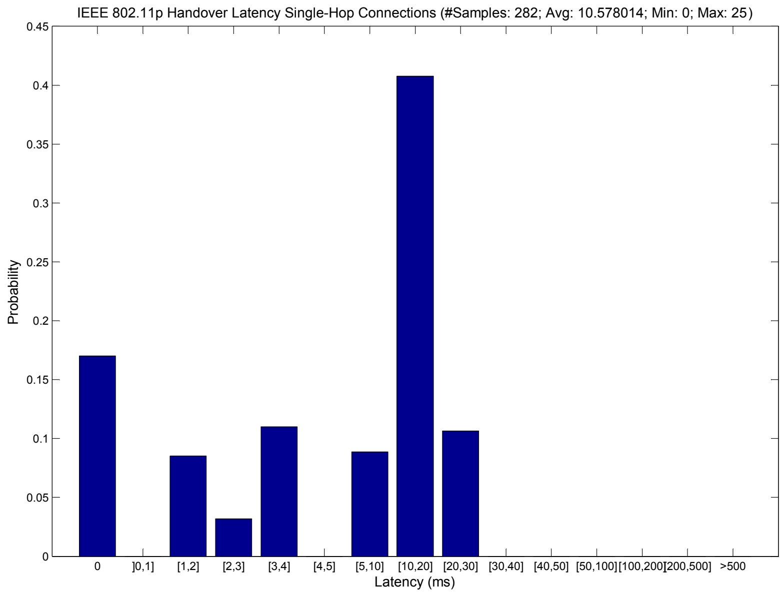

Figure 5.15: PbVCM - Handover Latency

5.3.3.7 RSU - OBU RTT Single-Hop Connections and LMA - OBU RTT Single-Hop Connections

In this section we join two metrics, since they are very similar. Like the previously metric in the last topic, the improvements of the VCM did not include any direct change in the RTT from OBU to RSU, or in the RTT from OBU to LMA. Therefore, these metrics are considered just to verify if some changes happened with the introduction of the PbVCM.

When we observe the graphics 5.16 and 5.17, we can see a very similar RTT average in both VCMs, most of connections have a RTT between 1 and 2 ms. Comparing both graphics we can see that there are not relevant changes.

In the graphics 5.18 and 5.19, we also observe that there are not relevant changes. The average RTT in the VCM is 5.4 ms, and the PbVCM is 6.2 ms, so they are very similar. Analysing the graphics, we can see that most of connections have a RTT between 4 and 5 ms.

We can conclude, as expected, that these metrics do not have relevant changes.

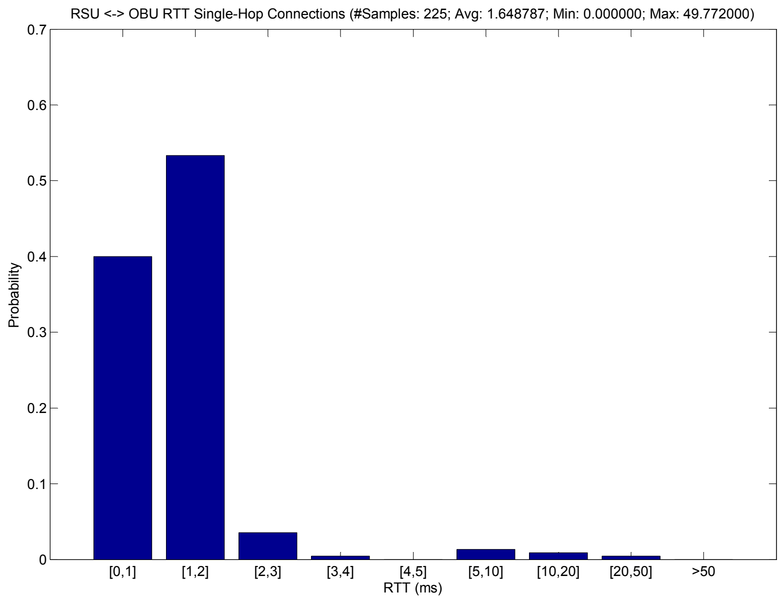

Figure 5.16: VCM - RSU - OBU RTT Single-Hop Connections

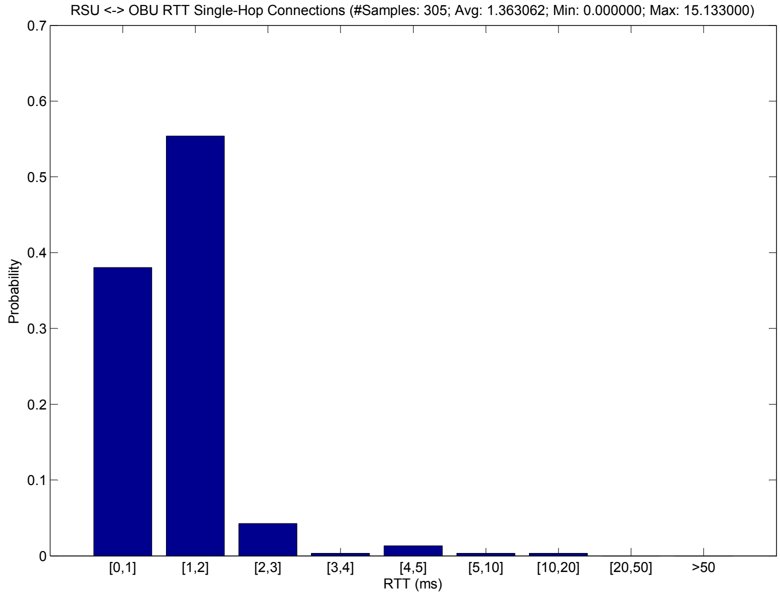

Figure 5.17: PbVCM - RSU - OBU RTT Single-Hop Connections

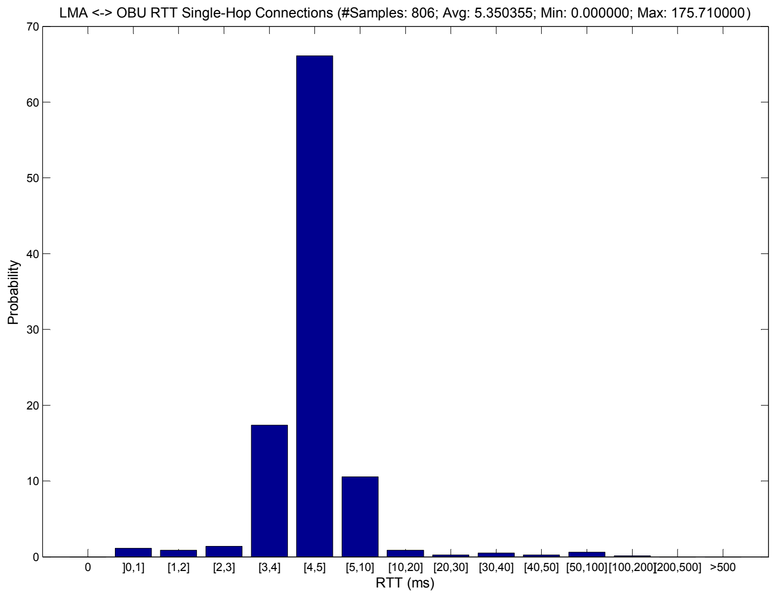

Figure 5.18: VCM - LMA - OBU RTT Single-Hop Connections

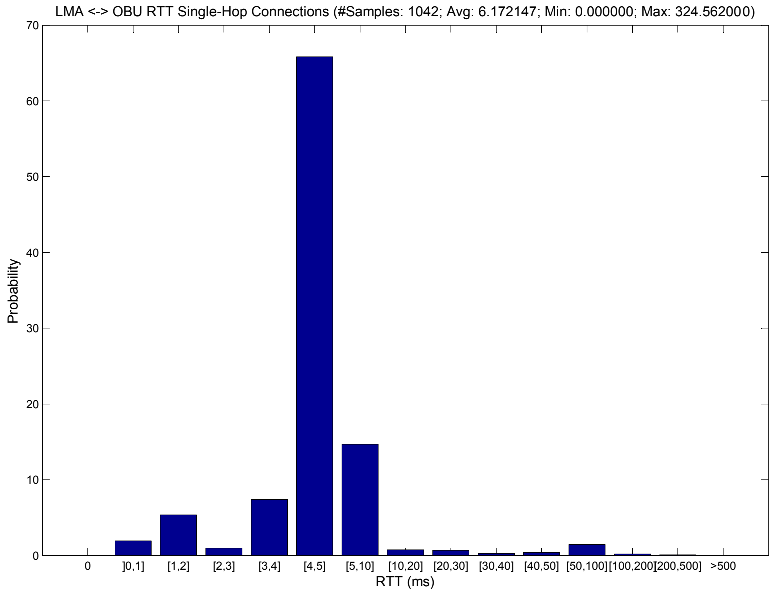

Figure 5.19: PbVCM - LMA - OBU RTT Single-Hop Connections

5.3.3.8 Number of Handovers

The number of handovers is an important metric because, the lower they are, more stable will be the connection.

Since the PbVCM chooses the network taking into account the performance that the network has had, it is expected that the selected network has larger stability, so we expect a lower numbers of handovers.

The graphic in 5.20 shows the number of handovers for both OBUs during the test in real world scenario. Each bar represents the number of handovers that happened during a certain session, during the test in real world scenario.

Analysing the graphic, we can see that, for PbVCM, the maximum number of handovers in one session was 7, and in the VCM the maximum number of handovers was 16. For each session we can see that the number of handovers are always larger in VCM.

We can conclude that the results in this metric are within the expected.

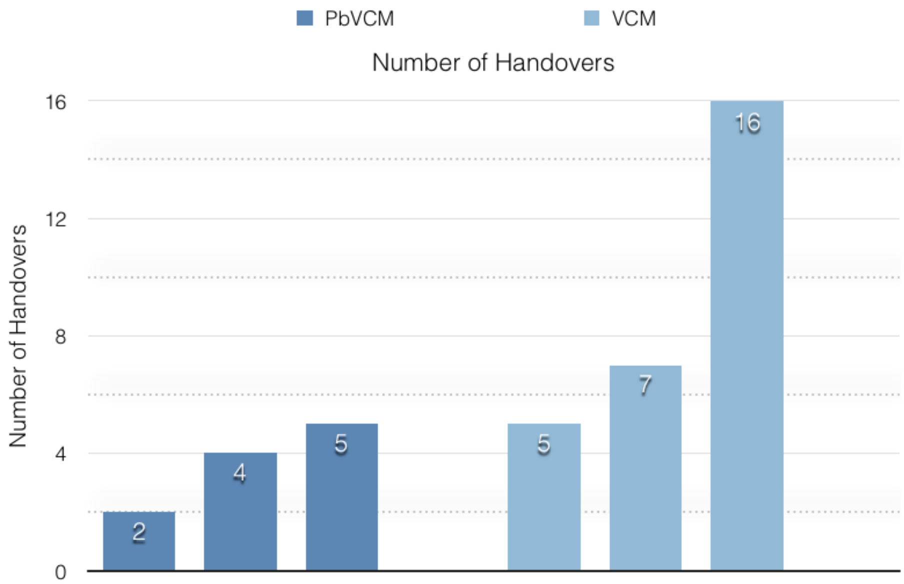

Figure 5.20: Number of Handovers for each OBU

After introducing all the results, we are able to draw some conclusions about the behaviour of the PbVCM.

The PbVCM is a mechanism that tries to improve the way the network selection is made. With the development of the PbVCM, we try to choose always the most stable network available.

With the analysis of the results we can conclude that there were improvements with the development of PbVCM. The key metrics for this analysis were: **Connectivity Duration**, **Throughput** and **Number of Handovers**. As we have seen, there was an improvement in these metrics when comparing the PbVCM and VCM.

Therefore, in general the connections are more stable when we were using the PbVCM as a selection mechanism.

5.4 Summary

In this chapter, it has been shown and explained the overall results in both laboratory and real scenarios.

First, it was presented the laboratory tests and the main results. The laboratory tests had three distinct states: to test the work on the database, the transmission of information between the server and the OBU, and the decision of the PbVCM in the OBU.

After the laboratory tests, the real scenario tests were performed, in the road.

With the results presented in section 5.3.3, we can conclude that with the PbVCM the chosen network was more stable. Therefore, we can say that the PbVCM improve the way the networks are chosen.

Chapter 6

Conclusion and Future Work

6.1 Conclusion

The special characteristics of vehicular networks, such as high mobility, dynamic topology and frequent loss of connectivity makes the decision of connection in networks a challenge aspect, but that is an essential part of VANETs.

Nowadays we live in a crowded wireless environment; for example in urban areas, there is a overlap of multiple networks and technologies; therefore it is important to have a reliably selection network mechanism. It must be capable to choose the best network to give the user always the best connection.

Many mechanisms have been developed in the literature, as it is showed in this dissertation. Some do not take into account the high mobility of the nodes in such networks, others were not able to decide on a network IEEE 802.11p. But, until now, there are no mechanisms that are able to povide an efficient decision mechanism in VANET with historical information of previous connections.

In this dissertation it was developed a new VCM, the PbVCM. With the PbVCM the decision of the best technology and network takes into account the predictive information, and it uses that information and the available information to make better decisions. The PbVCM uses criteria such as RSSI, throughput and traffic to compute which has been the best network in a certain area. With that information and also with the available information at a specific time, the PbVCM can choose the best network to prevent loss of connection and to reduce the number of handovers.

After some research work, we concluded that the development of this dissertation would have three phases:

1. **The database filtering**
2. **Request and transfer of information between the server and the OBU**
3. **Selection of the best network**

When the OBU already has all the information necessary to make the decision, based on previous work, it is chosen the weights to assign for each decision parameter.

With the network selection mechanism developed, some tests were done in the laboratory to conclude that everything was working as expected.

Finally, to draw conclusions about the developed PbVCM, we performed tests in a real road scenario. During a day it was tested in Porto the mechanism developed in this dissertation, and different metrics were evaluated. On the metrics such as **Connectivity Duration**, **RSU - OBU Distance** and even **The Throughput Connection**, there was a significant improvement between the old connection manager, VCM, and the developed PbVCM.

With respect to metrics such as **The RSSI of Connections**, **The Latency of Handovers** and **The RTT to the LMA and to the RSU**, the desired result was achieved. In all these metrics it was expected to keep their values, when we compare the results between the two VCMs. In general, we can conclude that the results are as expected and provided certain improvements in the network.

Vehicular networks are constantly changing so, until the concept of Always connected becomes a reality, there is still much to do. However, this dissertation has completed one more step to reach the overall goal: "have an increasingly technological world adapted to our needs".

6.2 Future Work

Vehicular networks as has often been said are constantly evolving so, there are several areas that can be worked in the future:

- **Using GPS navigation**

  The use of GPS makes the journey, to be made, clear. Whenever a route is added in GPS it is also searched a route of networks where the vehicle will bind along the way. Whenever there is an update of the route, there is also an update of the networks that will provide a connection. The whole process would be done by the server, and the OBU would only receive the information about the networks that would connect.

- **Inter-technology**

  With the increasing number of Wi-Fi hotspots especially in cities, the IEEE 802.11g technology can be very important in vehicular networks. However, the high time required for authentication remains an obstacle. The development of a mechanism like the one developed in this dissertation but with the inclusion of technology IEEE 802.11g technology would be a real asset to this type of networks.

- **Studying a way to not use available information**

  If whenever it is necessary to establish a connection to a given network, we have to check the available networks, the mechanisms of prediction will not work. The creation of a mechanism that would guarantee the existence of certain network at a given site would be very important. The time to scan the environment, it would be very useful in links to the IEEE 802.11g technology.

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