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CICLO

XXVIII

A PROPOSAL OF EFFICIENT ROUTING TECHNIQUES AND INTELLIGENT VEHICULAR TRAFFIC MANAGEMENT IN THE SMART CITIES CONTEXT, THROUGH DISTRIBUTED WIRELESS NETWORKS

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To my parents, for their patience, support and everything.

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Cesare Sottile

Abstract

0.1 ENGLISH

In this thesis, the design of efficient techniques for routing protocol suitable to Vehicular Ad-hoc NETworks (VANETs) has been proposed. In particular, the aims of the proposed protocols are to reduce interference issues, due to the data transmissions in wireless environment. The proposed protocols use time series prediction models and also multi-objective metric, based on the evaluation of co-channel interference levels, end-to-end delay, and link duration probability along the different links from sources towards destinations. These parameters are modelled through an optimization problem. The key factors are to exploit the advantages available to the Standard 802.11p, based on a dynamic allocation mechanism of the DSRC spectrum, aimed at the reduction of the co-channel interference and the maximization of the link duration probability (two key issues in vehicular environments). Another topic discussed in this thesis is related to the smart vehicular traffic management through VANETs infrastructure and communications(V2I and V2V). A distributed algorithm with the aim to build less congested path for the vehicles in a urban scenario has been developed. It is also considered the problem regarding to enhance air quality around the cities reducing the vehicles CO2 emissions. There are different causes related to the CO2 emissions such as the average travelled time spent by vehicles inside the city and their average speed. Hence, with a better traffic management the average time spent by the vehicles in the city will be considerably reduced as

well as CO2 emissions. These results are demonstrated in a discrete event simulator by using also real traffic data.

0.2 ITALIANO

In questa tesi sono stati effettuati degli studi per la progettazione di tecniche efficienti di routing adatte ai protocolli dinamici per le reti ad-hoc veicolari (VANETs). In particolare, i protocolli di routing proposti, hanno come obiettivo quello di ridurre il problema delle interferenze, che si vengono a creare durante la trasmissione di dati da parte dei nodi che compongono la rete in un ambiente mobile, sfruttando i vantaggi che lo standard 802.11p mette a disposizione. Alcuni dei protocolli proposti fanno uso di modelli di previsione legati alle serie temporali ed anche metriche multi-obiettivo, basate sul calcolo dell'interferenza co-canale, ritardo end-to-end e la probabilitá della durata del link che compongono i cammini. Queste tre grandezze considerate, sono modellate attraverso un problema di ottimizzazione. Un secondo settore di interesse trattato in questa Tesi, legato alle strategie innovative di gestione del traffico veicolare nel contesto delle Smart-Cities. Sfruttando le potenzialit dellinfrastruttura delle reti VANETs, stato ideato ed implementato un algoritmo distribuito per ottenere una gestione efficiente del traffico veicolare in ambente urbano. L'obiettivo principale dell'algoritmo *è* quello di fornire passo-passo, ad ogni veicolo facente parte della simulazione, una rotta meno congestionata per arrivare a destinazione. Inoltre, *è* stato dimostrato mediante lutilizzo di un simulatore ad eventi discreti, che utilizzando tale algoritmo si ottengono riduzioni in termini di emissioni di CO_2, tempi di permanenza in citt da parte dei veicoli e di conseguenza anche un risparmio in termini di carburante.

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Chapter 1

Introduction

A city can be defined *Smart* when there are investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructures fuel sustainable economic growth and a high quality of life, with a wise management of natural resources through participatory governance.

A smart city may be seen as a complex infrastructure of system of systems. The use of information and communication technology to sense, analyse and integrate the key information of core systems in running cities. At the same time, smart city can make intelligent response to different kinds of needs (e.g. daily livelihood, environmental protection, public safety and city services, industrial and commercial activities).

Nowadays one of the hottest theme is the application of the newest technologies in road safety. Several proposals have been made and both US and European standardization institutes are working on them. Drivers are responsible of several accidents on the roads, therefore, applications based on the detection of dangerous behaviours are one of the many reasons why Vehicular Ad-Hoc Network (VANET) technology and its related standard have spread. In these last few years car manufactures and Governance Institutions invested in IEEE802.11p standard (for US) and ETSI ITS (for Europe) to increase active and passive safety systems. The European standardization process produced the Cooperative Awareness Message (CAM) format to continuously disseminate status information about a vehicle. CAM message is sent in a broadcast way to all nearby vehicles when a set of rules is met. Broadcasting of Safety Message

(BSM) approach introduced in USA, aims to calculate waiting time of each node based on local density and distance trying to reduce the number of unnecesary broadcasting message in Vanet environment. This algorithm is fully distributed, and it needs only local information collected by the nodes.

In this thesis, will be addressed issues regarding the efficiency of routing protocols suitable for networks that have strong mobility problems and algorithms design for the efficient management of vehicular traffic, exploiting the distributed wireless networks. Vehicular networks can provide support for ITS applications (Intelligent Transportation System), oriented to road safety and information services and entertainment. The main advantage is the absence of an infrastructure, typical of centralized networks, that makes them very scalable and adequate for highly-variable network topologies. On the other hand, communication protocols become very complex and, sometimes, signaling overhead may waste bandwidth availability.

Vehicular communication systems represent one of the most desirable technologies when the safety, efficiency, and comfort of everyday road travel need to be improved. VANETs provide wireless communication among vehicles and among vehicle and road-side units (RSU) equipments. Communication performance and Quality of Service (QoS) strongly depend on how the routing takes place in the network, on how protocol overhead affects the available bandwidth, and on how different channels are selected in order to minimize interference levels. When evaluating network topology through its routing table and, in the considered case, the availability of different available channels, a protocol may enhance the quality of communication. So, in this scenario, each node should select the best route in terms of QoS, not only considering a typical cost metric (bandwidth, delay, traffic load, or a combination of them), as in the classical multihop architecture, but also taking into account the benefits that can be obtained if different interference levels, that is different channels, are considered. QoS routing in multi-hop wireless networks is very challenging due to interferences among different transmissions, but VANETs offer the chance to reduce them since multiple simultaneous transmissions are possible.

In detail, a new routing protocol for interference reduction and link-duration enhancement is proposed for VANET environments, taking the advantage of a dynamic allocation of the Dedicated Short Range Communications (DSRC) spectrum, in order to reduce interference level among mobile nodes and to increase the overall link stability in the considered network. The proposed scheme can be integrated with different already-implemented routing protocols and its metric takes into account the best values of co-channel interference, link duration probability and the term of end-to-end delay. Regarding the data dissemination in vehicular networks, our protocol does this purpose through the mechanism of construction of the Minimum Spanning Tree (MST), in order to diffuse the messages to a large number of vehicles. We decided to use the MST technique to minimize the number of transmissions so as reducing interference due to transmissions of neighbouring vehicles. Spanning trees are widely used in communication networks as a mean for dissemination information from one node to all other ones and/or to collect information at a single designated node. So, this protocol aims to choose different channels along the path from a source to a destination, obtaining a global metric minimization for the considered connection.

Considering that the protocol overhead is an important issue to be addressed because several kinds of messages have to be used to activate active and passive safety systems in vehicular environment. This increment is caused by messages flooding. Taking care about these considerations we have designed a VANET protocol paying attention on overhead issues as well, by spreading information towards on-board safety system notifying messages to the drivers exploiting the OBU. Another important aspect of the traffic management that we considered is to enhance air quality around our cities reducing vehicles' CO_2 emissions. There are different causes related to the CO_2 emissions such as the average travelled time spent by vehicles inside the city and their average speed. Hence, with a better traffic management the average time spent by the vehicles in the city will be considerably reduced as well as CO_2 emissions. In order to demonstrate these results, we designed a full integration framework.

The thesis is organized as follow:

- in the Chapter 2 are described how the ICTs and the telecommunication systems are employed in the modern concept of Smart City and their application,

- in the Chapetr 3 are illustrated the most important Standards developed for Vehicular Ad-hoc NETworks,
- in the Chapter 4 is described a novel routing protocol for Vanets, based on predictive channel selection to build robust paths, from source node to the destination node,
- in the Chapter 5 is presented a multi-objective routing protocol for vehicular network, in order to increase the QoS in mobility environment,
- in the Chapter 6 is presented a Smart Traffic Management Protocol called SeaWave, in order to improve traffic situation in urban simulated scenario and also by using real traffic data.

Chapter 2

Information and Communication Technologies to support the Smart Cities

2.1 Definitions of Smart City

In recent years, the concept of "Smart City" is came out and may be linked to the world of the institutions (the European Union in the first place) and also to companies in the world of technological innovation and research centres of the most famous Universities of the world. This concept can also encompass different aspects of social life in our cities. In fact, in the literature there are some publications that focus more attention on the infrastructure ICT, other than studying the correlation between the accessibility of the ICT infrastructure and level of the development of a territory, and others that put more attention to the human and cultural capital and education. An early definition of Smart City that struck me is that of Hollands, which states that "a smart city must be able to use the ICT infrastructure to improve economic efficiency, to promote political, cultural and urban social development.

From this statement it can guess that the ICT infrastructure is an enabler and central factor to a successful project of the Smart City, thus related to support and improve the liveability of the human and cultural capital of a territory. Do not underestimate the economic aspect, because the Smart Cities are also born with the aim of increasing productivity and saving in consumption of raw materials both for the companies, the institutions and not least also for the citizens.

A further definition that we can consider, is related to the English city of Southampton, which sees in the Smart City, a chance to promote social inclusion in the utilities factor. Social inclusion is a goal pursued by both small towns than larger ones. In this context it is possible to find the plans of e-government systems and democratic participation of the city, seeing the participation of citizens in a way to empower them and make they part of city life. I consider important this last definition of the Smart City, because they were made several scientific publications, considering aspects related to the environment and eco-sustainability. For sustainability understood in terms of environmental and energy resources, and sustainability viewed as maintaining a competitive advantage in time sufficient to ensure a decent or better life for future generations.

Beyond the possible definitions, the term Smart City is associated mainly with the Information and Communication Technologies (ICT). ICT is the key to the implementation of a Smart City as they represent a key factor to support services for the citizen. Therefore, the ICTs are seen as a means through which convey information and services. Obviously, the ICT alone are not enough. When designing a Smart City, we must consider other peculiar factors relating to each city: the human and cultural capital.

The term "smart" is understood as the intelligent use of resources of a territory, in almost cases are referred to energy. Very recently, major manufacturers and suppliers of energy services, are increasingly affecting the issue of energy sustainability. In this area work the "Smart Grids". They are born with the following purposes, today the city as well as being an energy consumer, will also become a producer (for example, by installing solar panels on their homes). Therefore, the Smart Grids have the task of managing efficiently and automated electrical system not only referring to the large centralized power plants, but distributed throughout the solar panels or wind turbines. Obviously, if we support what has been said now regarding the concept of sustainable energy, the goal of the Smart Cities will be to achieve self-sufficiency through the use of solutions with low environmental impact and low emission. Smart Cities are also proposed to solve problems related to the mobility of citizens. In fact, they are intended to maintain a careful management of the critical daily, with solutions that exploit the use of sensor networks and distributed wireless networks, which monitoring the state of the traffic in real-time, or the presence of accidents, in order to inform citizens and suggest them an alternative route, or invite their to postpone his commitments. Regarding the e-government, the idea on which the Smart Cities

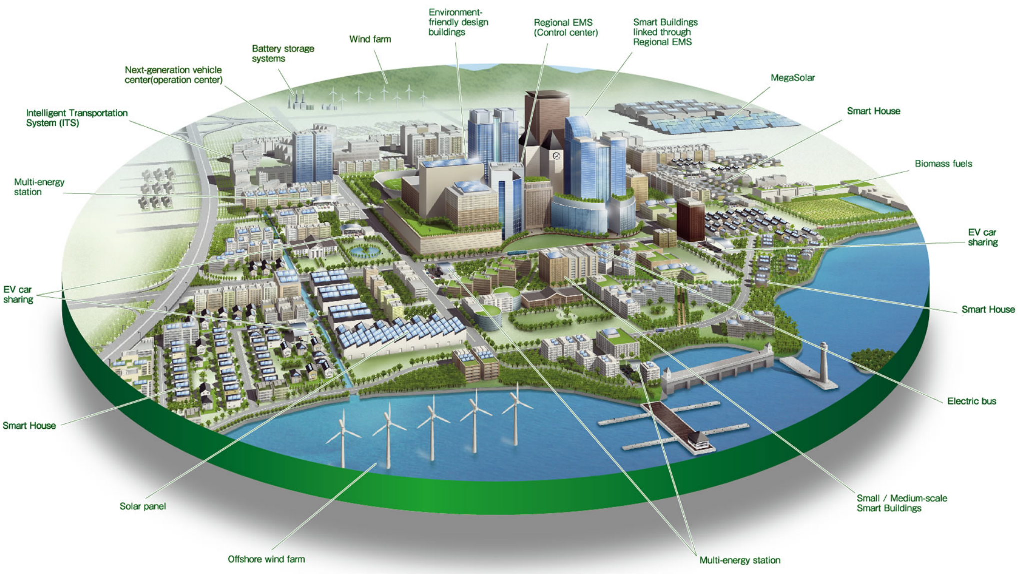

Figure 2.1: An example of Smart City

are based is to give the opportunity to citizens to be able to manage relationships with the public administration via Internet connection staying at home or at any place and time.

Finally, another aspect that has been developing recently is called "e-health". It aims to computerize the typical tools of Health (prescriptions, medical records, etc.), but also to create a system which, through the use of patient data, allowing to program properly the activities of hospitals or private health care; for example, having the ability to isolate any risk factors for the health of citizens.

2.2 The initiatives of the European Union

The topic of Smart Cities is treated by the European Union in a very strong and innovative manner, focusing on the potential of new initiatives to integrate different interventions and addressing and solving everyday the problems of the city. The concept of Smart cities ranks first in the Annual Programme of Work of 2012, drawn up by the European Commission; it focuses on the theme of cooperation between countries and EU Member States and is part of the Seventh Framework Programme for Research and Technological Development (2007-2013). The program has made available a budget of 50 billion of Euros, focusing on the great potential existing in the field of research and innovation. They are defined as key factors for competitiveness, employment, sustainable growth and social progress. As for the Seventh Framework Programme (FP7), it is divided into ten themes and the initiative of the Smart Cities is located on the fifth theme, that regarding on energy policies. The need to adapt energy systems more sustainable, less dependent on imported oil and based on a set of renewable energy resources, is the main goal to lead the European challenge to a high security of energy supplies and to begin to work concretely on the problem of climate change, in order to increase also the competitiveness of the European market. With the definition of the Horizon 2020 program, the European Union draws a clear path to emerge stronger from the crisis, making all member states more competitive and able to adapt to the growing challenges of globalization. To achieve this, have been set targets to be achieved by 2020:

- 75% of people aged between 20 and 64 years old must have a job;
- 3% of the EU's GDP should be invested in research and development;
- the goal of "20/20/20" on the environment and energy (to reduce emissions of greenhouse gases by at least 20% compared to the levels of the year 1990; 20% of final energy consumption from renewable energy and 20% improvement in energy efficiency);
- the drop out rate by students of secondary schools must be under 10% and at least 40% of the younger generation should have a tertiary degree;

Figure 2.2: Services that can be made in a Smart City

- to reduce by 20 million the number of people to be risk of poverty.

2.2.1 HORIZON 2020

Horizon 2020 stems from the awareness that the resources allocated by states and private companies to research and innovation decreased dramatically. Guilty before all the current crisis. Thus, Horizon 2020 aims to reduce the risk linked to research, and then directly fund research proposals from the world of institutions and individuals, whether it is large multinationals or to small and medium enterprises. To meet the needs of companies, in Horizon 2020 are provided mechanisms for simplify and speed up procedures for obtaining funding and a simplified accounting of expenses in order to ensure the recipient of financing the possibility of being able to focus on what really matters, that is research and innovation. Obviously a lot of attention is paid to the selection of the proposals with a careful ex-ante and an equally careful evaluation during and at the end of the project is made. The mechanism which is adopted in order to access funding from the community expects a response from interested parties to the "call". This is not generic call but issues related to the specific purpose, that the Europe 2020 Strategy want to pursue. Within Horizon 2020, and the FP7, there are already several calls regarding the Smart Cities, with a total budget of 449.5 million of Euros.

2.3 The Italian Smart Cities

Italy country had a different story compared to cases generally related to the cities in other European countries, about the phenomenon "Smart Cities". The main fault could be attributed both to the slowness in grasping the message of innovation that the general indifference. An indirect benefit that Italy could take is to assess weaknesses, problems and also the strengths of a strategy that changes according to the context of reference as these innovations require a fairly long period of running. The first major difference about other European cities is related to the concept of "City". In fact, pilot projects presented to the call of the European Smart cities and Communities for the italian city, refer to certain neighborhoods or areas, considered to be particularly interesting to accommodate advanced technology, to achieve the European objectives set out, among which we list: the reduction of CO_2 emissions, the design and development of new integrated systems, a new relationship between public and private entities and public awareness. The smart city concept begins to be formalized with the agreement between SMAU (International Exhibition of Information & Communication) and ANCI (National Association of Italian Municipalities); in which is established the "Italian Observatory on Smart cities" and also with the introduction from the Ministry of Education (MIUR) [1] the line of research: "Smart City as a strategy for the entire country". The most important purpose of the observatory is founded with the agreement SMAU-ANCI. It is to sensitize the public administrations on the issue of Smart Cities, trying to make easy the collaboration with the private sector or companies. The Observatory's goal is to understand how, through the use of the ICT, it can improve the quality of life in urban spaces, for example in terms of mobility, energy-saving policies, municipal waste management and citizen services. In the SMAU appointment, which took place in Milan on 20 October 2011, the participating administrations (the towns of Bologna, Genoa, Milan, Piacenza, Pisa, Prato, S. Giovanni in Persiceto, Venice and Turin), along with a few companies have signed a collaboration agreement to create observers for Smart cities, introducing innovative technologies and new models of management of administrative machinery. All this was intended to encourage cities to be open track project European Smart cities, to realize substantial cost savings and ready to face the challenge toward more sustainable cities. The SMAU-ANCI association has in the main aim also to facilitate direct contact between supply and demand, to entice the private sector to invest in urban areas well defined [2]. A known consulting company called Net-Consulting [3], states that the Italian cities are nowadays forced to chase the new concept of Smart City to not fall behind those European thus starting, the economic recovery is absolutely necessary in order to improve economic conditions and social rights of citizens. Net-Consulting provides also a definition of Smart City as follows: "A set of simple or complex solutions aimed on two objectives: the smart management of the services that is provided by the municipality and the implementation of critical projects in areas of the city as intelligent safety, traffic, youth marginalization, the economic attraction of a territory ".

For medium and small cities Italian was presented a new contract in Horizon 2020 project [4], where they have already joined in 1800 common to the Covenant on the Smart City development strategy. The issues that usually are being carried out are: spatial planning and housing stock (considering recovery actions of existing assets), upgrading of the urban environment and to invest in technology services, intelligent services for urban mobility, such as detectors of info-mobility for the efficient management of traffic and devices for video surveillance; regarding the spread of renewable energies are defined different campaigns for photovoltaic plants, building a smart grid and manage efficient disposal and waste recycling.

A final macro-area is dedicated, to the modernization and simplification of the administrative machine, with projects such as "e-government", which aim to create a new interaction between the citizen and the companies[5].

2.4 Ministry of Education, University and Research (MIUR) and Italian Player

The Italian government has developed a variety of programs and operational strategies, which address the development and the implementation of the Smart City concept. This strategy is considered a dual policy, as it points out, on the one hand, "the will to face the problems of great social importance, such as the reduction of emissions through clean technologies, intelligent infrastructures for mobility, the realization of urban models and homes more sustainable, more efficient health care, welfare fair and new technology for the ageing society and for people in conditions of difficulty", and on the other hand, "it is necessary to capitalize the efforts to improve the lives of citizens by increasing technological capacity, competitiveness and growth potential of the enterprises"[6]. A fundamental role has also the simplification decree of the article n.49 on the Italian Digital Agenda of 27 January 2012, strongly desired by Prime Minister Mario Monti. This Simplification Decree introduces important concepts and essentials for the realization of the strategic project on Smart Italian city. The objectives of the Digital Agenda Italian are [6]:

- the introduction of support to the growth of smart communities, in order to increase participation and awareness of citizens within the administrative machinery;
- Open data projects, to make public the information assets of the public administration and promote better interoperability;
- improve services to citizens through e-government projects, for an open and transparent public administration;
- dissemination and development of cloud computing architectures, connected to the activities of public administration;
- to develop channels of e-commerce to promote the use of new technologies; to simplify the access to the Internet for all citizens with broadband infrastructure or extra large in schools, universities, urban spaces and public places;

- finally, to develop e-learning projects for modernizing an educational system that is in step with the changes taking place in society.

In Italian territory, the most important companies of telecommunications, energy suppliers and Information Technology, have accepted the challenge of innovation in accordance with the ministerial programs. Enel company will play an important role for the realization of innovative distribution network, to achieve energy saving but also to decrease the cost of energy to the citizens. Enel has been assigned the role of manager of the electricity infrastructure. In this sense, it plans to ensure that systems of direct self-production and distribution of energy level also for the condominiums; systems that can be solar roofs or mini power plants and even structures with systems capable of storing the local energy, leaving to the consumers, the decision of its policies of energy consumption. Enel decides how much energy deliver outside, taking part, as well, to the electricity market. Telecom Italy about two years ago launched an initiative, on the Smart cities, called "Smart Town". This initiative provides the opportunity to make sustainable, from an economic and environmental point of view, the adoption of new intelligent services. The aim of Telecom Italy is to create new services, without change the approach to service. The project involves the integration of communication networks through applications that allow to have direct information on the users mobility, security and public lighting. Thus, it tends to improve the quality of the citizens' life and to distribute services especially to public administrations, as operators of the platform city.

IBM Italy instead will focus on the production of data management systems with their software. IBM wants to create an integrated heterogeneous management of data, to govern the phenomena that occur in the territory. IBM designed an Intelligent Operations Centre, which has the task of integrating the data coming from the sources, and to interpret them.

CISCO Italy focuses, instead, on the spread of broadband. The company's interest is to spread as much bandwidth as possible, having the necessary infrastructure to develop different devices, for example to realize the teleworking, which reduces travel as it is working at the CUD of Amsterdam.

We could be analyse many other companies, but even from this brief description, it is understood that the subject business-oriented needs to be managed by a metropolitan breath strategy to avoid falling into the error to have exclusively a high technology Smart City.

2.5 ICT applications for Smart Cities

The following section describes the main applications related to the world of ICT in various areas ranging from the domain of energy, environmental, living, transport and mobility.

2.5.1 ICT applications in the Energy field

In the field of public lighting, it is possible to remotely control electric street lights through dedicated software (Remote Dimming and Control) that can adjust the light intensity depending on the conditions of a specific area, with energy savings up to 20%. It is also possible to take advantage of the widespread presence of street lights in the city to offer other services, such as free Wi-Fi or the monitoring of traffic, pollution and weather conditions, through the use of wide-area network (WAN). Among the best known examples, which include the Intelligent Lamppost installed in Malaga or those of Santander, they can independently adjust its brightness according to the brightness of the environment and the natural flow of traffic. The Smart Grid along with computer networks allow two-way commu-

Figure 2.3: Smart City Services to monitor the energy consumptions

nication of traditional electricity networks and effective integration of renewable energy sources. They represent the paradigm of the future in the production and distribution urban energy. These will be able to improve the management and distribution of electricity, thanks to constant monitoring of electricity consumption and the transformation of the consumer into a "pro-sumer" (producer / consumer). They will be able to sell the energy produced and actively participate in the energy market. This inevitably leads to reconsider the existing business models, focusing on the big players distributors of the service, so that they are also protected other players who have not longer a marginal role, thus achieving sustainable investments. Today, , there are still a series of barriers related to:

- standard, both in terms of semantics (data model) and syntax (protocol);
- lack of technological maturity, including also that the electric vehicles to be integrated;
- governance of the system;
- lack of expertise of the utilities of the ICT.

A key aspect behind the development of the Smart Grid is the presence of decentralized storage systems, which are essential for the network integration of the renewable energy sources.

Among the technologies enabling the Smart Grid there are: smart meters in the homes, the Advanced Metering Infrastructure (AMI), which allows to establish a channel of communication between the control system and information system; the Demand Side Management, it is a smart software capable of crossing in real-time supply and demand. Finally, the Micro Grids are defined as the points within the city energetically balanced such as hospitals, university campuses or shopping centers, which are able to produce an amount of energy at least equal to its consumptions.

In the field of renewable energy, the scenario changes a lot depending on the specific technology treated. Among all, the photovoltaic appears that more competitive in Italy, thanks to different reasons:

- in the last five years there was a reduction of over 50% of the investment costs in the construction of photovoltaic systems;

- the geographical position of Italy that allows optimal level of radiation;
- in recent years, there was an increase of the price of crude oil and therefore the energy (common aspect to all sources of renewable energy).

2.5.2 ICT applications in the Environment field

Sensor networks are revealed in this domain an indispensable factor in the monitoring of water, waste and pollution, with clear advantages over the entire planning cycle and the resulting productivity, thanks to a level of technological maturity already acquired. However, the spread remains low due to the high initial investment.

In water management, the Advanced Metering Infrastructures (AMIs) enable to promptly intervene on the possible failures or malfunctions in plumbing pumps.

An interesting experience in this area is made in Gothenburg City. Where, for the first time in Europe, they are thinking to replicate for the water control, the positive experience had in the energy field with the installation of 90,000 smart meters based on ZigBee communication infrastructure[7]. The AMI could also be

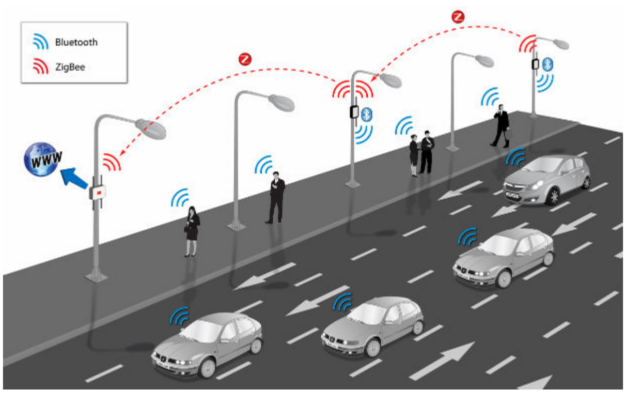

Figure 2.4: Network Infrastructure for the Smart City

used in waste management, and particularly to monitor in real-time of the filling level of the bins; so as to optimize also the path of the waste collection vehicles, such as is already in the city of Santander.

In the cities where it is already spread the door-to-door collection, the Radio Frequency Identification (RFID)technology can also used, to attach the low frequency tags on the waste bags the information of the provenance house. The ultimate goal would be to greater empowerment of the people on the subject, thanks to incentive mechanisms that go to reward good behaviour in terms of recycling.

The main limitations of this approach are given by:

- the need to have a system for collecting door-to-door, able to associate the waste to the user;
- difficulties to implement the projects proportionally to the population size of the city;
- inability to implement incentive mechanisms without a logic of payment service, based on tariff and non-tax type.

2.5.3 ICT applications in the Mobility and Transport field

In general, the transport in urban areas generates huge external costs attributable to:

- greenhouse gas (human health, agriculture, climate change, water availability);
- air pollutants (human health, damage to buildings, land, water);
- noise pollution (health, interventions on buildings, vibration);
- congestion (loss of time, health, inefficiency of the production system);
- security (quality of life, health, accident).

The mobility issue, which takes a central role in the Smart City, comprises two main areas of technology, one related to the Intelligent Transport Systems (ITS) and the second one to the development of alternative energy sources to oil, with particular reference to the electric.

The Internet-of-Things (IoT) will change the cars in hub able to exchange information with the outside world, for example with the road infrastructure (Vehicle-to-Infrastructure Communication) or other vehicles (Vehicle-to-Vehicle Communication). This will also facilitate the control systems or paid access in urban centres. The adoption of interoperable electronic ticketing will reduce

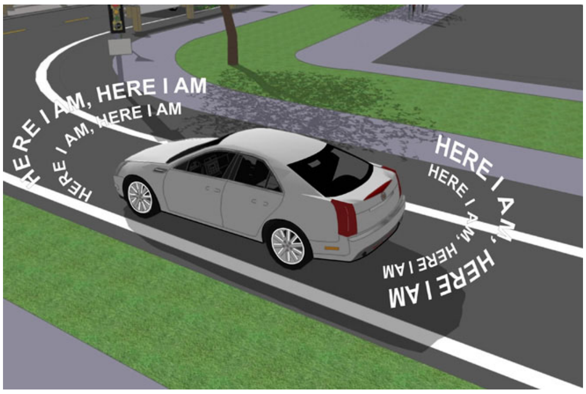

Figure 2.5: An example of ITS service

the costs associated with the issuance of the travel documents, facilitating a logic of dynamic pricing user targeted; as already happens in Tallinn City for several years, and ensure a more accurate monitoring of actual demand, which is essential to improve the supply. Even the spread of the alternative mobility systems as bike-sharing, car-sharing or car-pooling, is linked to the possibility to take advantage in the fast and simple way, for example through a unique services card.

Finally, the applications of the driver support in the search and reservation of parking [8][9] will help to reduce congestion in the city centres. For example, Streetline Company provides solutions that, through the use of technology infrastructure (parking sensors, smart parking meters and database), assist the user to find a parking spaces. Both the municipal authority for parking is private dealers pay therefore the application to be displayed on the user's query during the use of the service. Even traders are stakeholders of the system, because the parking produces positive externalities and they also could use the application, encouraging the customer to the purchase of its product through parking-pass.

It should also be underlined the presence of a double infrastructure level. The sensors and parking meters are in fact provided directly by the company, while mesh networks to connect them to be already present in the city, as well as an operator (e.g. a company of TLC) that manages it. The driver achieves greater individual productivity, while the city benefits from a reduction in traffic and CO2 emissions, thanks to dynamic pricing policies on public car parking, that line supply and demand. The same logic can be used also in city logistics for reservations the stopping places. In city-logistics on the one hand, it is trying to internalize the market price of the goods but the external costs now fall on the community, in the other to rationalize logistics flows. In addition, the Italian cities enjoy special features that make the theme of central importance of the Smart City, such as:

- dense city centres;
- historic centres to which access is difficult due to narrow roads;
- high presence of shops in central areas;
- strong presence of transport on own account [10];
- protection of the artistic heritage.

2.5.4 ICT applications in the Living field

In the health sector, are spreading solutions for monitoring the patient's health remotely. It is able to increase the level of service perceived by the user, while reducing the costs. In fact, there are devices that measure the vital signs of the user, and in case of anomalies in the data it will send through a domestic or a centralized hub to the nearest hospital, by using a simple smartphone.

The same technologies are also applicable to private care services to the most vulnerable category, such as the elderly. This could ensure also an increase of the efficiency / effectiveness level of the third sector. The Video-Guided, are beginning to emerge, particularly in Canada, or video conferencing consultation remotely through stethoscopes or digital cameras. Finally, the digitization of reservation systems, diagnostic images and related reports, databases and the creation of electronic health file, would lead to a substantial reduction in term of costs.

Chapter 3

Reference Standards for the Vehicular Ad-hoc NETworks

3.1 Introduction

There has been tremendous investment from government, academia and industry under the big umbrella of Intelligent Transport Systems (ITS), leading to the development of safety and traffic management technologies in vehicles and road infrastructure. Wireless vehicular communications and networking is a key enabling technology for future ITS services. The International Organization for Standardization (ISO) TC204 WG16 is developing a family of international standards and architecture on communications access for land mobiles (CALM). It is expected that the future CALM system will make use of a wide range of technologies including satellite, cellular (GSM, 3G and 4G/WiMAX), Wi-Fi wireless local area network (WLAN) and its wireless access in vehicular environments (WAVE) evolutions (IEEE802.11P and IEEE P1609), Bluetooth wireless personal area network (WPAN), mm-Wave, infrared and radio frequency identification (RFID). In addition, many sensing technologies such as radar, imaging and video processing will be integrated into the CALM architecture. Most of the communication technologies in the CALM family are borrowed from other mature applications, with the exception of the recently proposed WAVE standards on the dedicated short range communications (DSRC) frequency band. DSRC/WAVE is the only wireless technology that can potentially meet the extremely short latency requirement for road safety messaging and control. The unique feature of low latency secures the role of DSRC, as an essential communication technology, in future CALM networks that will make use of multi-radios on multi-bands. However, the current DSRC solutions are not fully field proven. There are significant DSRC-related social and technical challenges that have to be dealt with before large-scale deployment. There are two classes of devices in a WAVE system[11][12]: On-Board Unit (OBU) and Road-Side Unit (RSU). They are equivalent to the mobile station (MS) and Base Station (BS) in the cellular systems respectively. There are two classes of communications enabled by the OBUs and RSUs: vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). While a MS in the cellular environment normally communicates with another MS via the BS, the OBU in a vehicle normally directly communicates with other OBUs within the radio coverage area. This direct V2V communication reduces the message latency and low latency is an essential requirement for safety applications such as collision avoidance[13]. Another difference is that an OBU is more likely to be embedded and connected with other electronic systems of the vehicle via in-vehicle networking such as controller area network (CAN) and FlexRay, while a MS is normally detached from the CAN. In addition to improving safety, WAVE networks can play major roles in travel plan, traffic management, navigation, fleet and asset management, environment monitoring, logistics, congestion and emission reduction, toll collection, smart parking, emergency services and a wide range of other location-based services. WAVE networks have a set of technical challenges not encountered in other wireless networks. One challenge is to use WAVE technology in collision avoidance between fast moving vehicles. For example, it can be used to warn the drivers at the crossing between roads and railways if there is a danger of collision. In V2V communication, the relative velocity between two vehicles moving in the opposite direction is the sum of their individual speeds. In addition, such V2V communication system has to be robust in extremely abnormal situations, as accidents and collisions are less likely to happen in normal situations. One example of such an abnormal situation is when two cars are traveling on a narrow two-way street towards each other at fast speed. Therefore V2V communication has deal with much faster fading and much more Doppler frequency spread than any other wireless systems. On the other hand, most other wireless communication systems such as the Wi-Fi and cellular systems are designed to work in well anticipated and even controlled environments. Fundamentally WAVE networks have to be extremely robust as their failure may cause the loss of life and property. Some messages transmitted on a WAVE network have a tight latency requirement, and a decision based on delayed information could be quite harmful. The WAVE networks may operate in a wide range of hash environments. The density can vary from a few vehicles to perhaps tens of thousands of vehicles in the radio coverage area. To meet these challenging requirements, a WAVE solution must be scalable, robust, low-latency, high throughput and cognitive[14].

3.2 Physical parameters of the different reference standards

In United States, 75 MHz of spectrum in the 5.9 GHz frequency band has been allocated for Dedicated Short Range Communications (DSRC) applications. Out of the 75 MHz spectrum, 5 MHz is reserved as the guard band and seven 10 MHz channels are defined as in shown in Fig. 3.1. The available spectrum is configured into 1 control channel (CCH) and 6 service channels (SCHs). The CCH is reserved for carrying high-priority short messages or management data, while other data are transmitted on the SCHs. The pair of channels (channel 174 and 176, and channel 180 and 182) can be combined to form a single 20-MHz channel, channel 175 and 181 respectively. The channel number, indicated with (ch_n), is derived by counting the number of 5-MHz spectrum in the frequency band from 5 GHz to the center frequency $f(ch_n)$ of the channel ch_n, as following:

$$f(ch_n) = 5[GHz] + ch_n[GHz] \tag{3.1}$$

In terms of transmitter (TX) power, four classes of devices have been defined whose maximum TX power ranges from 0 dBm to 28.8 dBm. The associated coverage distance by a single radio link depends on the channel environment, the TX power and the Modulation and Coding Schemes (MCS) used. This distance is between 10 meters to 1 kilometer. The details of OBU and RSU TX limits of equivalent isotropically radiated power (EIRP) also depend on the operating ch_n channel and its applications. It is worth noting that the current FCC code of federation regulations (CFR) heavily refers to the American Society for Testing and Materials (ASTM) standard E2213-03, while the industry is adopting the IEEE802.11P and IEEE 1609 standard. The IEEE standard on the other hand refers to the FCC CFR for regulatory requirements. This means that implementers should address the channel and power limit defined in the ASTM standard. In detail, FCC CFR specifies that the channel 172 and 184 commonly shall be used for Public Safety Applications, as shown in [15]; this requirement is not fully compatible with the current IEEE1609.4, where multi-channel operation it is more natural to use channel 178 (i.e., the CCH) for such applications. Other than some minor differences in power level and spectrum mask requirements, ASTM standard E2213-03 and IEEE802.11P are both based on IEEE802.11A and they are effectively compatible.

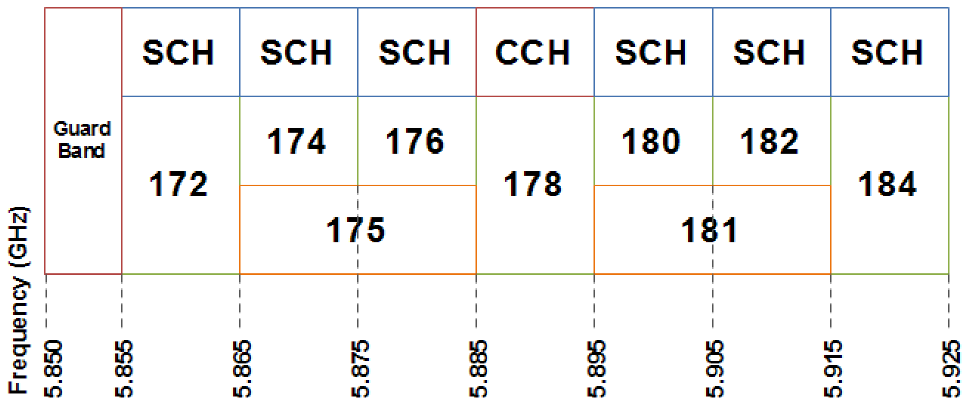

Figure 3.1: The DSRC Frequency Allocation in United States

Other frequency bands have also been used for DSRC applications even before the 5.9 GHz band allocation. They were typically used for highway or city central business district (CBD) toll collection. Of particular interest are the frequency bands defined in Table 1. It is worth noting that the DSRC regulatory requirements in many parts of the world are in the process of being finalized. There is a chance that similar spectrum allocation and requirements will be adopted World

Table 3.1: Spectrum Allocation for WAVE/DSRC Applications

Country	Frequency (GHz)	Reference Documents
North America	0.902-0.928, 5.850-5.925	FCC 47 CFR
ITU-R (ISM band)	5.725-5.875	Article 5 of Radio Regulations
Europe	5.795-5.815, 5.855/5.875-5.905/5.925	ETS 202-663, ETSI EN 302-571, ETSI EN 301-893
Japan	0.715-0.725, 5.770-5.850	MIC EO Article 49

Wide for DSRC applications. Spectrum harmonization is desirable for global inter-operability and low-cost DSRC services.

3.2.1 DSRC/WAVE Standards

Collectively the IEEE 1609 family, IEEE802.11p and the Society of Automotive Engineers (SAE) J2735[16] form the key parts of the currently proposed WAVE protocol stack. The WAVE protocol architecture with its major components is shown in Fig. 3.2, and they are summarized as follows.

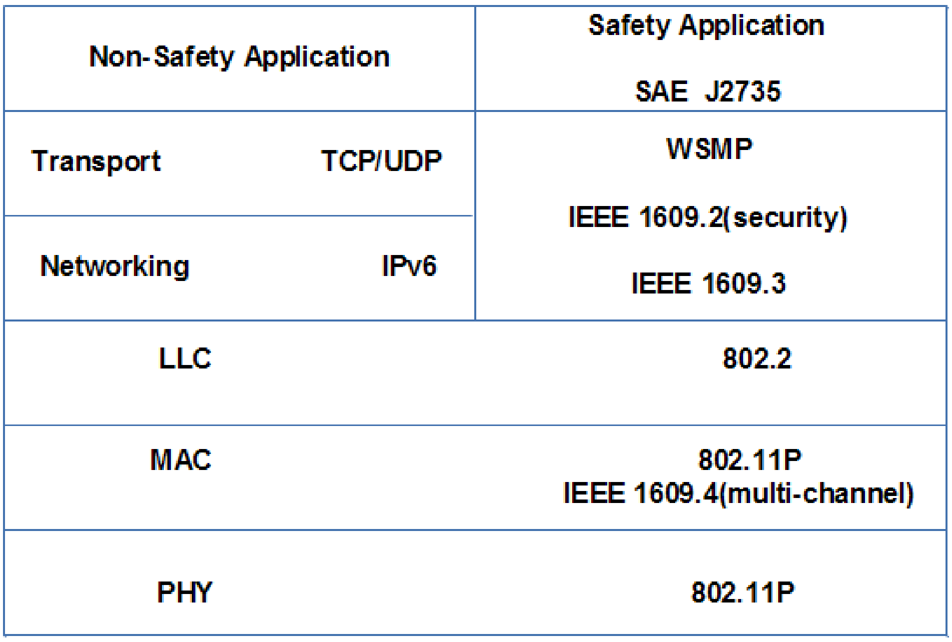

Figure 3.2: The WAVE Protocol Stack and Its Associated Standards

- IEEE P1609.0 Draft Standard for Wireless Access in Vehicular Environments (WAVE) -Architecture
- IEEE 1609.1 Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager
- IEEE 1609.2 Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) - Security Services for Applications and Management Messages
- IEEE 1609.3 Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services
- IEEE 1609.4 Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operations
- IEEE P1609.11 Over-the-Air Data Exchange Protocol for Intelligent Transportation Systems (ITS)
- IEEE802.11p Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications - Amendment: Wireless Access in Vehicular Environments

3.2.2 The WAVE Physical Layer (PHY)

The current FCC CFR still refers the ASTM E2213 as the PHY standard. ASTM E2213 was published in 2003, and was based on the IEEE 802.11A OFDM PHY. Since 2007 IEEE has consolidated all older versions of the PHY and the MAC into the IEEE 802.112007 edition. IEEE 802.11P [17] is an amendment to IEEE 802.11-2007 for WAVE applications. Compared to IEEE802.11-2007 [18], minimum change has been proposed in IEEE802.11P. In particular, IEEE802.11P only adopts the OFDM PHY on 10 MHz channels in the 5.9 GHz frequency band. On the other hand, the Wi-Fi industry normally implements the OFDM PHY on the 20 MHz channels, even though 5/10/20 MHz channels have been specified in IEEE802.11-2007. Compared to the 20 MHz Wi-Fi OFDM PHY, the subcarrier spacing and the supported data rate of IEE802.11P are halved while its symbol

Table 3.2: Comparison of WAVE and Wi-Fi OFDM Parameters

Parameters	**WAVE Std**	**WI-FI Std**
Frequency Band	5.9 GHz	5/2.4 GHz
Channel Bandwidth	10 MHz	20 MHz
Supported Data Rate (Mbps)	3, 4.5, 6, 9, 12, 18, 24 and 27	6, 9, 12, 18, 24, 36, 48 and 54
Modulation	BPSK, QPSK, 16QAM and 64QAM	Same as WAVE
Channel Coding	Convolutional coding rate: 1/2, 2/3 and 3/4	Same as WAVE
No. of Data Subcarriers	4	Same as WAVE
No. of Pilot Subcarriers	12	Same as WAVE
No. of Virtual Subcarriers	64	Same as WAVE
FFT/IFFT Interval	6.4 S	3.2 S
Subcarrier Spacing	0.15625 MHz	0.3125 MHz
CP Interval	1.6 S	0.8 S
OFDM Symbol Interval	8 S	4 S

interval including cyclic prefix (CP) is doubled. Other parameter comparisons are shown in Table 3.2. In addition, IEEE802.11P requires the signal spectrum to decay faster to further reduce the adjacent channel interference. Different T_X filtering may impact other T_X performances such as Error Vector Magnitude (EVM) to which a designer should pay attention.

The receiver design is typically out of the scope of the standard specification. However, due to significantly different channel environments, it is expected that a WAVE receiver may attract special design considerations. Compared to Wi-Fi OFDM receivers, the WAVE receivers have to deal with much higher Doppler spread which causes Inter-Carrier Interference (ICI). The fact that the sub-carrier spacing has been halved means that the WAVE OFDM receiver is more sensitive to carrier frequency offset and Doppler shift. Due to the higher Doppler spread and higher multipath delay spread, the channel coherence bandwidth and channel coherence time become smaller, or in other words, the channel becomes more frequency/selective and faster fading.

3.2.3 WAVE Medium Access Control

In the architecture of IEEE802.11 networks, three kinds of service set (SS) are defined: basic service set (BSS), independent BSS (IBSS) and extended service set (ESS). The IBSS is formed by stations (STAs) without infrastructure, generally called an ad-hoc network. A BSS includes an access point (AP) that behaves as the controller/master STA. The ESS is the union of two or more BSSs connected by a distribution system (DS). A STA in the IBSS acting as the controller or the access point (AP) in the BSS periodically broadcasts a beacon that contains the service set ID (SSID) and other information. Other STAs in the SS receives the beacon and synchronize their time and frequency with those contained in the beacon. STAs can communicate with each other only if they are the members of the same SS. The same architecture of SS can be used for WAVE applications. However, forming a SS takes several steps including time and frequency synchronization, authentication and association. These steps take a time interval that is not affordable in some safety applications. In a vehicle traffic flow, two vehicles may be within the reach of the wireless link for less than a second. To minimize the message latency, a mode called outside the context of BSS (OCB) is introduced. The OCB mode applies to any two or more devices within the coverage area of a single radio link. A STA in OCB mode can send and receive data and control frames any time without forming or being a member of any SS. While enjoying the benefit of low-latency, the OCB mode does not receive the authentication, association or data confidentiality services on the MAC layer. The equivalent services have partially been moved to the higher layer as defined in IEEE1609.2. From the receivers point of view, care must be taken on frequency synchronization. Currently IEEE802.11P does not specify a different frequency accuracy for the WAVE transceiver oscillators. In IEEE802.11-2007, the frequency accuracy is specified to be 20 ppm, i.e., the maximum frequency difference between the T_X and R_X oscillator frequencies can be up to 40 ppm. For example, the center frequency difference of transceivers operating on channel 184 could be as high as $5920*40*10^{-6} = 0.2368$ MHz, greater than the sub-carrier spacing of 0.15625 MHz. Without good frequency correction, the receiver error rate cannot be guaranteed even if the signal to noise ratio (SNR) is high. The preamble can be used to estimate the frequency offset. It is likely that WAVE radios may have access to other more accurate frequency sources such as the frequency derived from the GPS signal. The WAVE standard also support a timing advertisement frame, which can replace some of the features lost due to the lack of periodically sent SS beacon. To transmit a frame either as a member of a SS or in OCB mode, the STA shall compete for the channel using the IEEE802.11 carrier sense multiple access/collision avoidance (CSMA/CA) mechanism. Another major MAC layer extension for WAVE applications is the multi-channel operation defined by IEEE1609.4. This extension makes use of the concept of frequency/time division multiple access (FDMA/TDMA), where the 7 FDMA channel frequencies are as shown in Fig. 3.1. The TDMA channel is shown in Fig. 3.3. The time is divided into repetitive periods of 100 ms. During each 100ms, 50 ms is allocated to CCH and another 50 ms is allocated for SCH, including 4 ms guarding interval (GI) for switching between CCH and SCH. The motivation is to accommodate single-channel radios in the WAVE system to access both CCH and SCH services. A single-channel radio is defined as a radio that can either transmit or receive on a single 10-MHz channel but not simultaneously. On the CCH frequency (i.e., channel 178) and during CCH time (i.e., the 46 ms), only two kinds of messages can be sent: Short messages, primarily for safety applications, as defined by the WAVE short message protocol (WSMP). WAVE service advertisement (WSA) messages used to announce the services available on other SCH frequency channels.

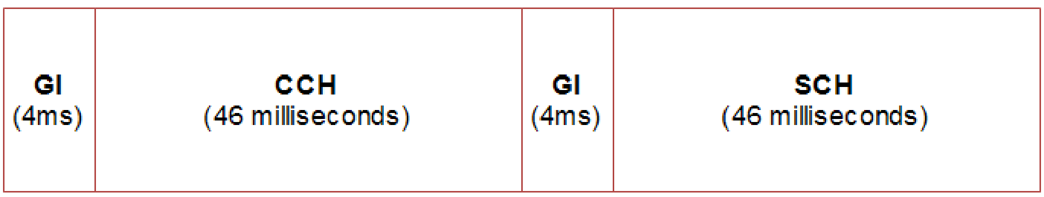

Figure 3.3: The TDMA Extension of WAVE MAC

A single-channel radio can switch to other SCH frequencies for services during the SCH time and switch back to the CCH frequency during the CCH time for sending or receiving safety and other critical messages. The TDMA extension does not mean that the channels are idle for about 50% of the time. All SCHs can be active all the time to exchange service data and the CCH channel can be active all the tine to exchange control, management and other short messages. Practically it does mean a loss of time for safety messages sent on the CCH frequency. It cannot be guaranteed that all other STAs shall be listening on the CCH frequency during the SCH time, and as such safety messages sent on the CCH frequency during SCH time can be ineffective. Therefore it would be desirable to concentrate all safety messages on the CCH frequency and during CCH time, i.e., only 460 ms out of a second. This represents a capacity reduction for safety messages.

3.2.4 The WAVE WSMP

In addition to the standard IPv6 networking protocols operating over the SCHs, a WAVE-specific protocol called WSMP has been developed to carry messages on both the CCH and the SCHs. Unlike the standard IP protocol, the WSMP allows the applications to directly control the lower-layer parameters such as transmit power, data rate, channel number and receiver MAC addresses. To further shorten the latency, WSMP over the CCH can skip the steps for forming a WAVE BSS (WBSS) that delivers IP and WAVE short message (WSM) traffic on the SCHs. The primary motivation for developing the WSMP is to reduce the overload. A WSMP packet is shown in Fig. 3.4. The overhead is 11 bytes, compared to a minimum of 52 bytes of a UDP/IPv6 packet. If a device receives a WSMP packet that has a WSM Version number not supported by the device, the received WSMP packet shall be discarded.

WSM Version (8 bits)	Security Type (8 bits)	Channel Number (8 bits)	Data Rate (8 bits)	TX Power (8 bits)	PSID (32 bits)	Length (16 bits)	WSM Data (Variable)

Figure 3.4: The TDMA Extension of WAVE Medium Access Control

The Security Type identifies if the packet is Unsecured, Signed or Encrypted. The Channel Number, Data Rate and T_X Power allow the WSMP to directly control the radio parameters. The purpose of the provider service ID (PSID) field serves the similar role as the port number of the UDP/TCP packet, i.e., to identify the application that will process the WSM Data. The Length field indicates the number of bytes in the WSM Date, which might have been security-protected as specified in IEEE1609.2.

3.3 Continuous Air-interface, Long and Medium Range (CALM)

CALM [19] is launched by the International Organization for Standardization (ISO) in 2003, and promoted by the more recently created industry association (The CALM Forum), to develop a new family of ITS standards with the overall branding of Continuous Air-interface, Long and Medium range (CALM). The aim of CALM is to provide wide area communications to support ITS applications that work equally well on a variety of different network platforms, including Second Generation (2G) mobile (e.g., GSM/GPRS), 3G (IMT-2000 e.g., W-CDMA/CDMA 1x EV-DO) 4G (IMT-Advanced), as well as satellite, microwave, millimetre wave, infrared, WiMAX and short-range technologies like Wi-Fi. The decision on which platform to use in a particular country or for a given application would then be based on logical selection of pre-set criteria (e.g., what platform is cheapest, offers highest performance, has the greatest level of coverage, and what communication equipment is available in the vehicle) to make the best use of resources. Thus, CALM is intended to be platform-independent, and therefore to avoid the battles over regional standards that have dogged existing ITS standards like DSRC.

Figure 3.5: CALM Standard logo

CALM was developed by Working Group 16 of Technical Committee 204 of the ISO, chaired by Russ Shields (Ygomi LLC, USA). The work is closely coordinated with other standards development organizations including ETSI and IEEE as well as ITU [20]. Working Group 16 has 7 sub-working groups and is currently working on nearly 20 different CALM-related standards. The main characteristics of CALM[21] are:

- Allows for continuous (or quasi-continuous) communications, in three main modes of operation: Vehicle-Infrastructure; Vehicle-Vehicle; and Infrastructure-Infrastructure.
- Inter-operability and seamless handover between networks and applications.
- Based on Internet Protocol. In its initial specification, CALM used Internet Protocol version 6 (IPv6) exclusively. However, in order to meet the requirement for very fast short communications in time-critical safety situations, such as C2C applications (e.g., collision avoidance), a non-IP solution with lower processing overhead and lower latency may be more suitable, and this is incorporated in the new specification (CALM Fast).
- A single global architecture which is compatible with existing ITS standards (e.g., DSRC) and wireless standards (e.g., GSM/GPRS) and which can anticipate future ones.
- Platform-independent support for multiple radio communication network platforms. For instance, the basic CALM system architecture (ISO 27217) foresees support for 10 main categories of network, and 22 different sub-categories, each of which would need a different Service Access Protocol (SAP).

While it is evident that not every CALM implementation would need to support all of these different network platforms, the intention is to develop SAPs for each of them within the overall architecture. This multi-platform support is essential if the standard is to be global, to permit roaming and to permit seamless interworking. Specific implementations of the standard may be customized by manufacturers to suit local conditions, market segment (e.g., compacts cars vs. luxury models), and with pre-set usage profiles (e.g., using lowest cost network for high bandwidth applications), and the possibility for seamless roaming between different service environments (e.g., urban/rural, high-speed/slow-speed/stationary) as well as between countries. CALM may be implemented in a specific device (e.g., a receiver and screen, as illustrated in Figure 3.6) or as a support for a particular service. The typical life cycle of a car, at 10-20 years, is much longer than that of a mobile phone, which can be as little as 18 months. For that reason, a technology and service-neutral approach is essential for CALM.

Figure 3.6: Example of a two part solution for in-vehicle implementation of CALM

CALM is intended to provide a standardized set of air interface protocols for ITS applications, using multiple network platforms. These include:

- 2G mobile systems, including GSM/GPRS, which are the most widely deployed mobile network worldwide;
- 3G (IMT-2000) mobile systems, including W-CDMA and CDMA 1x EVDO;
- Infrared;

- Wireless LAN systems, including the IEEE 802.11 series;
- Millimetre wave systems, including radar;
- DSRC, including national and regional implementations;
- Wireless MAN systems, including WiMAX;
- Broadcast signals, including GPS and Digital Audio Broadcasting (DAB);
- Personal Area Networks (PAN) including UWB and Bluetooth;
- Fixed-line networks (for infrastructure to infrastructure communications), including Fibre and Ethernet.

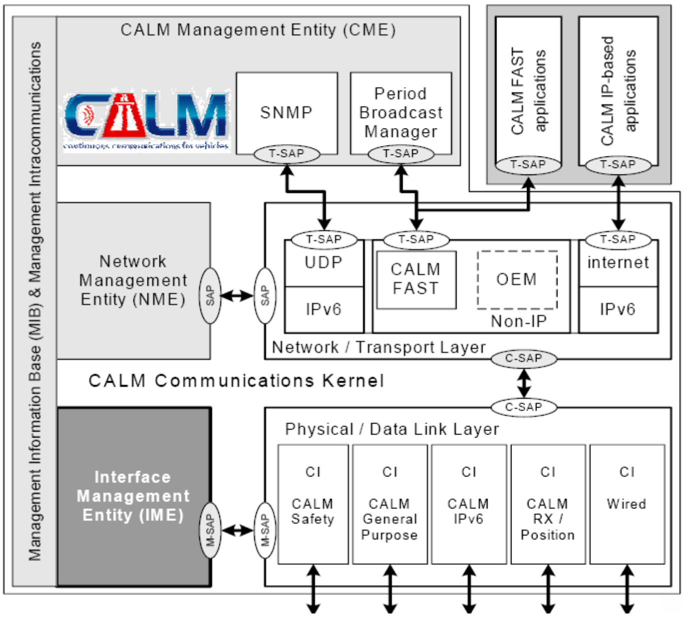

Figure 3.7: CALM General Architecture

The main criticism of CALM is to support so many different networks, it ends up with a bewildering array of possibilities and an over-complex management stack. However, if CALM is to reconcile the North American-originated

WAVE standards, the European C2C-CC standards and the Japanese implementation of DSRC, then it will have to accommodate, for instance, non-IP communications for short-range use. But while the overall enabling architecture for CALM is complex, only a subset will be implemented in any given vehicle, so it is not as daunting as perhaps it first seems. The likely future direction seems to be a flexible CALM architecture and a division of labour among different organizations, with ETSI, for instance, working on test suites while basic research and testing is being carried out by an EU-financed research project, Cooperative Vehicular Infrastructure Systems (CVIS), together with sister projects SafeSpot and Coopers. This is reflected in the new (2007) merged CALM architecture. CALM represents an ambitious attempt to provide a platform for a wide range of future communications requirements for intelligent transport systems. As such it cuts across several ongoing standards-making efforts, including those of the ITU, such as NGN. While the work is still ongoing, it is hard to judge the likely level of commercial acceptance and, for the moment at least, not all the major car manufacturers are engaged in the project. Nevertheless, the commercial success of satellite navigation systems suggests that this could become a major future market opportunity.

3.4 Cooperative Awareness Messages (CAM) Protocol

The Cooperative Awareness Messages (CAMs) [22] are distributed within the ITS-G5 (802.11p) network and provide information of presence, positions as well as basic status of communicating ITS stations to neighbouring ITS stations that are located within a single hop distance. All ITS stations shall be able to generate, send and receive CAMs, as long as they participate in V2X networks. By receiving CAMs, the ITS station is aware of other stations in its neighbourhood area as well as their positions, movement, basic attributes and basic sensor information. At receiver side, reasonable efforts can be taken to evaluate the relevance of the messages and the information. This allows ITS stations to get information about its situation and act accordingly. Information distributed by

CAM Management is commonly used by related use cases and therefore the CAM Management is a mandatory facility. The Approaching Emergency Vehicle and Slow Vehicle Warning are just two use cases which benefit from CAM. Within the ITS Station Reference Architecture, the CAM Management belongs to the Facilities Application Support and more detailed it is assigned to the Messages Management (see Figure 3.8).

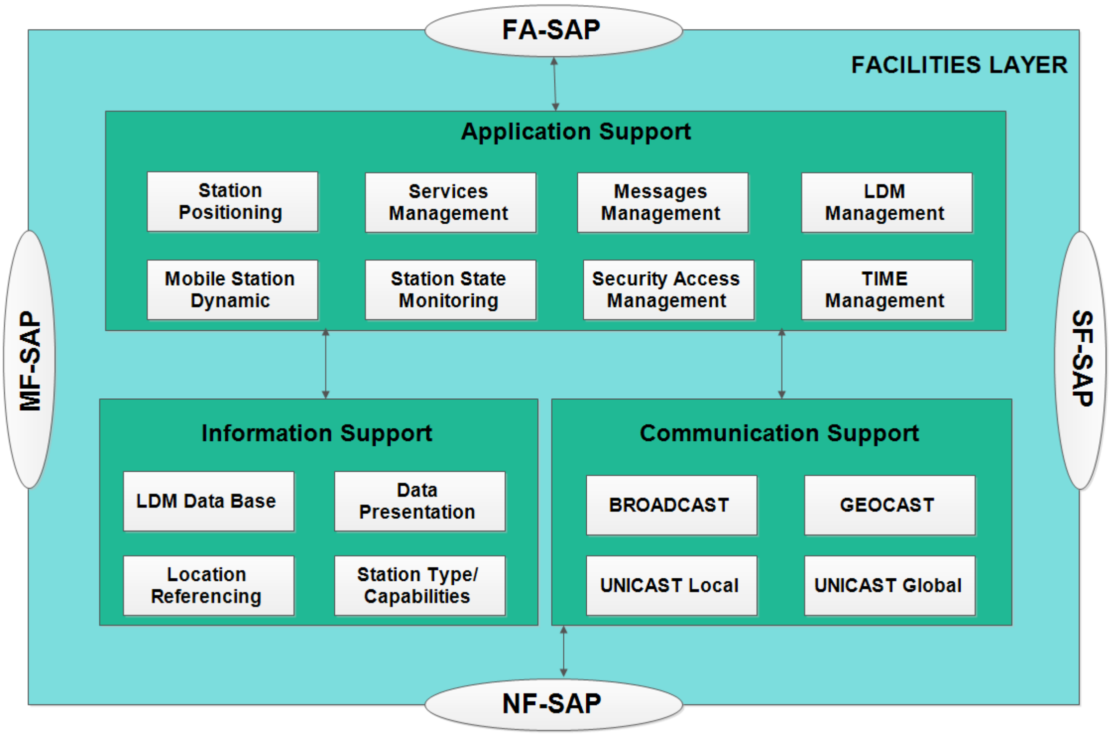

Figure 3.8: Facilities Layer Architecture

3.4.1 Timing Requirements

Some use cases require high frequency in order to ensure low reception latency after first contact. In this case DENM with situation specific communication attributes shall be used. These communication attributes might include forwarding. In Table 3.3 is shown the BSA use cases based on CAMs and the corresponding timing requirements.

Table 3.3: Overview Use Cases based on CAM

Use Cases	**min Latency (ms)**	**min Frequency (Hz)**
Speed Limits Notification	100	1 to 10
Slow Vehicle Indication	100	2
Motorcycle Approaching Indication	100	2
Traffic Light Optimal Speed Advisory	100	2
Emergency Vehicle Warning	100	10
Intersection Collision Warning	100	10
Collision Risk Warning	100	10

CAMs messages are generated by the CAM Management and passed to lower layers between a minimum time interval CAM generations setted from 0,1 second and a maximum time interval CAM generations setted to 1 second. The system shall ensure that processing time of CAM construction does not exceed 50 ms. If no other channel load is present, the system transmission time between message construction and message being sent shall neither exceed 50 ms.

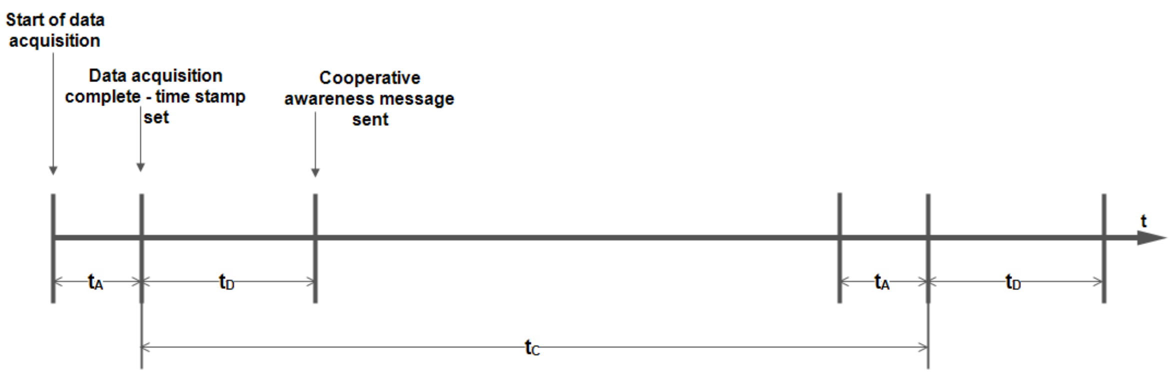

Figure 3.9: Time requirements for CAM generation and CAM processing

The above requirements are fixed as t_A and t_D are $\leq$ 50 ms.

3.4.2 Interfaces

The CAM Management[23] is application independent. For this reason there is no interface to applications. But the CAM Management has interfaces to

Data Provisioning Services such as: Station State Monitoring Interface (provides current static state of ITS stations), Time Management Interface(provides global time reference for time stamping), Mobile Station Dynamic Monitoring Interface (provides real time kinematics of ITS stations) and LDM Management.

Chapter 4

A Predictive Cross-layered Interference Management in a Multichannel MAC with Reactive Routing in VANET

In this chapter, an interference aware metric is proposed in order to reduce the level of interference between each pair of nodes at the MAC and routing layer. In particular, this metric with a prediction algorithm is proposed to work in a cross-layered MAC and an on-demand routing scheme in multi-radio vehicular networks, wherein each node is equipped with two multi-channel radio interfaces. The proposed metric is based on the maximization of the average Signal-to-Interference Ratio (SIR) level of the connection between source and destination. In order to relieve the effects of the co-channel interference perceived by mobile nodes, transmission channels are switched on a basis of a periodical SIR evaluation. The proposed solution has been integrated with an on-demand routing scheme but it can be applied to other routing strategies. Three on-demand interference aware routing schemes integrating IEEE 802.11p Multi-channel MAC have been tested to assess the benefits of the novel metric applied to a vehicular context. NS-3 has been used for implementing and testing the proposed idea, and significant performance improvements were obtained: in particular, the proposed policy has resulted in an enhancement of network performance in terms of throughput and packet delivery ratio.

4.1 Interference Management in a Cross-Layered View

In this section, The attention is focused on the interference management at routing and MAC layers on VANET in order to reduce packet dropping and improve communication quality. At MAC layer each node (vehicle) estimates the local interference on its channels whereas the routing layer is able to estimate a path interference. It is assumed that the channel router of the WAVE MAC layer (as illustrated in fig. 4.1) is able to analyze the LLC data unit in order to choose the right priority queue. As introduced and explained in [24], we considered that each VANET node has two interfaces (transceivers): the first (transceiver1), which is always tuned to the control channel (CCH) and the second one (transceiver2), which can be tuned to any of the 6 service channels (SCH) [24]. Using the information carried out in the messages sent and received on CCH, in each time slot a node can switch on a selected service channel, as will demonstrate in section 4.1.4.

4.1.1 Proposal summary

The basic idea consists in the evaluation of the SIR level on each available channel for each node of the network and each path from a source to a destination is built-up maximizing the obtained level of SIR on each point-to-point link. In addition, a SIR prediction algorithm is introduced in order to take into account how the SIR values change in time, having the possibility to know a-priori which link will be the best in terms of SIR level. The MAC layer is able to perform a dynamic channel switching in order to balance interference among the available channels. Moreover, the interference estimation algorithm is able to compute a smoothed interference value in order to offer a stable measure to select the best path among source-destination pairs. In the following, the math formulation, the problem

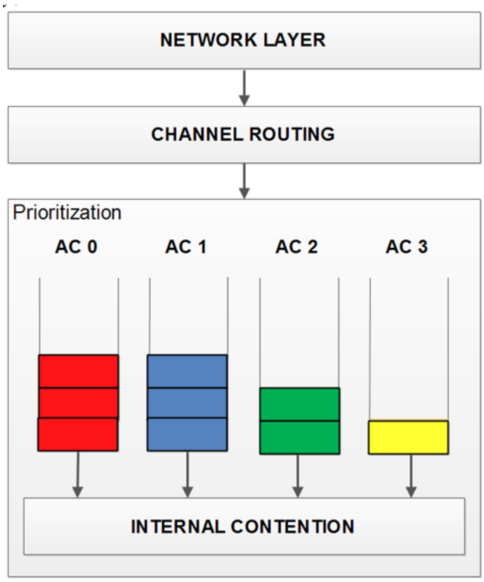

Figure 4.1: Multi-channel EDCA extension for WAVE specifications.

statement and the modification at MAC and routing layer are proposed in order to obtain advantage from a cross-layered view in interference management.

The list of symbols adopted in the math formulation and metric definition are shown in the tables 4.1 and 4.2.

4.1.2 Problem Statement in Interference Management at routing layer

Let $G =< V, E >$ be the graph G associated with the considered VANET topology, $V = n_0, \dots, n_W$ the set of vertexes with $|V| = W$, let $E = \{(n_0, n_1)_1, (n_1, n_m)_2, \dots, (n_j, n_D)_M\}$ be the set of edges with $|E| = M$. Let $n_S \in V$ be a source node that has to transmit a certain amount of packets to a destination $n_D \in V$ $P_k(n_S, n_D)$ the $k - th$ route from n_S to n_D, composed by a sequence of edges $(n_S, n_1), \dots, (n_r, n_D)$. Let $N(n_s) = n_1, \dots, n_I$ be the set of neighbour nodes of n_S so that $\overline{(n_S, n_i)} < r$, $\forall n_j \in N(n_S)$, r is radio coverage radius of each node $n_j \in V$ and $\|N(n_S)\| = I$. Let CH be the set of available transmission channels for each node in the considered scenario, so $CH = \{172, 174, 176, 180, 182, 184\}$ and $\|CH\| = C = 6$ (channel 178 is disregarded because it is used only for

Table 4.1: Symbols adopted for metric definition

$G =< V, E >$	The graph associated with the considered VANET topology
$V = \{n_1, \ldots, n_W\}$	The set of vertexes, cardinality W
$E = \{(n_0, n_1), \ldots, (n_{M1}, n_M)\}$	The set of edges, cardinality M
$n_S \in V, n_D \in V$	Source node and Destination node
$P_k(n_S, n_D)$	The k-th route from node n_S to node n_D
$N(n_j) = n_{j1}, \ldots, n_{jT}$	The set of n_{jl} nodes that are neighbours of node n_j, with $\|N(n_j)\|$=T and $l = 1, \ldots, T$
r	Coverage radius
$P(n_S, n_D)$	The set of all the possible Paths from node n_S to node n_D, cardinality K
$n_{p,k}$	$p - th$ node on the $k - th$ path from a generic couple of source/destination n_S, n_D
CH	The set of available transmission channels, cardinality C
$ch_c \in CH$	The generic transmission channel
$MAX\_SIR_{nm,k}$	The best available SIR value available on node n_m belonging to $k - th$ path
$P_{opt}(n_S, n_D)$	The best path in terms of interference (eq. 4.2) from node n_S to node n_D
SIR_{nm}, ch_c	The SIR value on channel ch_c for node n_m (eq. 4.3)
P_t	Transmission power (assumed to be the same for each node)
$P_r(ch_c, n_j)$	The received power on generic node n_m on channel ch_c due to the transmission of node $n_j \in Neigh(n_m)$ (eq. 4.5)
$d(n_m, n_j)$	The distance between node n_m and node n_j
η	Reflection coefficient
h	Antenna height

Table 4.2: Continuation of the Symbols adopted for metric definition

$\lambda(ch_c)$	The wavelength related to the carrier frequency of channel ch_c
γ	Path-loss factor
T_r	Periodical refresh time
T_p	Periodical probes-sending time
δ	The minimum SIR level that must be granted on each selected channel
$SIR_{nm,chc}(n)$	The sequence of SIR values observed on a given channel ch_c (eq. 4.6)
$\vec{\theta^*}$	Optimal coefficient vector for RLS algorithm (eq. 4.7)
$\vec{u}(n)$	The input vector for eq.6 of the RLS algorithm (eq.4.8)
$\hat{\vec{\theta}}(n)$	Estimated parameters vector for the RLS algorithm (eq. 4.9, eq. 4.11)
λ	Forgetting factor for the RLS algorithm
$\vec{k}(n)$	The gain vector for the RLS algorithm (eq. 4.10)
$P(n)$	The input inverse correlation matrix of the RLS algorithm (eq. 4.12)
$d(n)$	The desired output for the RLS algorithm
SIR_PROBES_h	The average instantaneous SIR on $Path_{opt}(n_S, n_D)$ at the $h-th$ step (eq. 4.13)
SIR_PROBES_k	The value of SIR contained in the $k-th$ received PREP packet
D	The input threshold used to consider a degradation of SIR
$SIR_{nm,chc}(n+1)$	Predicted $(n+1)-th$ SIR value (eq. 4.15)
α	Smoothing factor

signaling purposes). To provide a specific scheme where interference aware procedures and metrics are introduced, let us refer to a generic on-demand scheme where two messages are used: *RREQ* (broadcast) to request a path from source to destination, and *RREP* (unicast) to answer on the reverse path forwarding from destination to source. In this view, before formulating the path optimization problem, we explain the path discovery strategy. The proposal can be applied also to other routing schemes using the mechanisms that it will explain in the next paragraphs. During the *Path Discovery* (PD) procedure of the proposed Interference-Aware Reactive (IAR) scheme, the source node n_S, unaware of the best path toward n_D in terms of SIR, broadcasts *RREQ* packets to its neighbors $N(n_S)$ in order to know the set of all the possible paths to n_D: $P(n_S, n_D) = P_1(n_S, n_D), \ldots, P_K(n_S, n_D)$, with $\|P(n_S, n_D)\| = K$. Without loss of generality we hypothesize that G is a connected graph, so $K \geq 1$ for each couple n_S, $n_D \in V$. Each neighbor node $n_i \in N(n_S)$ will forward the *RREQ* packet to its neighbors $N(n_i)$, until the *RREQ* packet reaches the destination node n_D. After receiving the RREQ packet the destination will forward towards the source on the reverse path forwarding the RREP packet. In this case, the previous hop of the destination node $n_{p,k}$ (it represents the $p-th$ node on the $k-th$ path) $P_K(n_S, n_D)$ with $p = \|P_k(n_S, n_D)\| - 1$ will compute the maximum local SIR perceived on its channels such as shown in fig. 4.3. In particular, the node $n_{p,k}$ scans all the available channels ch_i with $i = 1, \ldots, 6$ to find the one that guarantees the best local SIR (see the sub-section 4.1.3).

Then, the node inserts this pre-computed SIR inside *RREP* packet. At this point, the *RREP* packet is sent back to the previous hop on the *reverse path forwarding* such as on-demand routing schemes for MANET; each previous hop receives the *RREP*, evaluates its *maximum local* SIR and modifies the SIR field of the *RREP* packet with the *min value*; the local min SIR is executed by each intermediate node $n_{m,k}$ on $P_k(n_S, n_D)$, computing the minimum value between the local SIR perceived and the SIR value carried by the *RREP* packet such as shown in fig. 4.2. If at source node n_S arrives k *RREP* packets meaning that k routes have been discovered, the best path in terms of interference by the

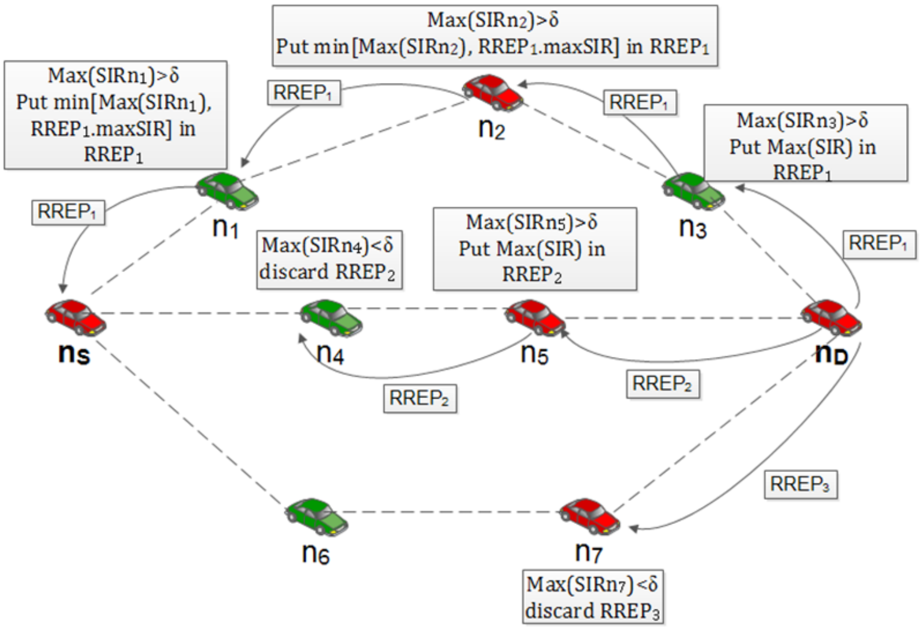

Figure 4.2: Path Discovery (PD) procedure in IAR protocol and SIR computation.

following relation:

$$P_{opt} = \{P_i(n_S, n_D)/i = index\{\max_j(MIN\_SIR)_j\}, j = 1, \dots, k\} \tag{4.1}$$

s.t.

$$MAX\_SIR_K(n_j) \geq \delta, \ with \ j = 1, \dots, \|P_k(n_S, n_D)\| - 1 \tag{4.2}$$

where δ is the minimum SIR threshold that should be guaranteed. The k term, is the number of discovered paths from source n_S to destination n_D, MIN_SIR_j is the minimum SIR registered on a link of a path $j-th$ between n_S and n_D. Figure 4.3 shows an example of IAR *PD* procedure for node n_S, which needs to communicate with node n_D: in this case K=3, $P(n_S, n_D) = \{P_1(n_S, n_D)P_2(n_S, n_D)P_3(n_S, n_D)\} = \{\{(n_S, n_A), (n_A, n_D)\}, \{(n_S, n_B), (n_B, n_E), (n_E, n_D)\}, \{(n_S, n_C), (n_C, n_D)\}\}$.

At the end of the *PD* procedure, the node n_S will receive 3 *RREP* packets, containing the $MIN\_SIR_1 = 9$, $MIN\_SIR_2 = 16$ and $MIN\_SIR_3 = 8$ values

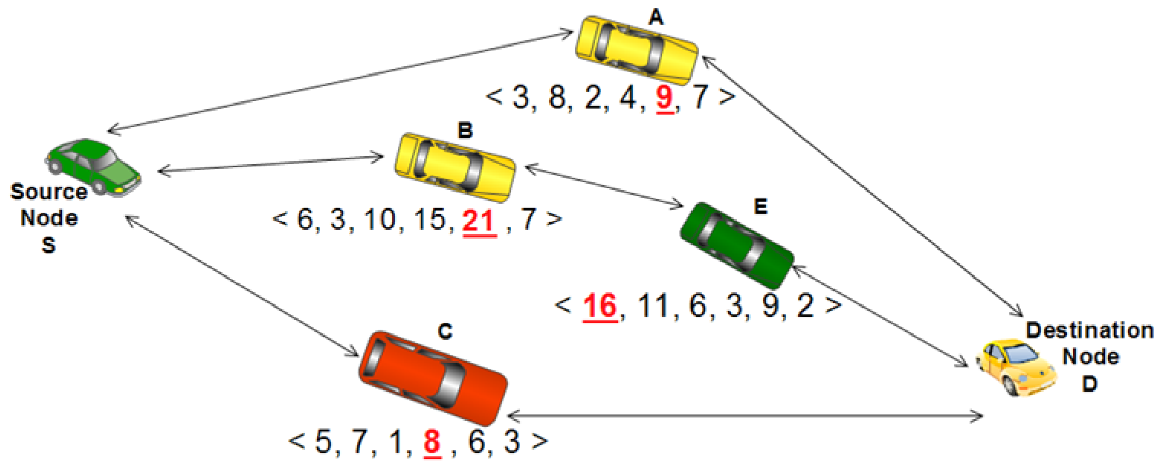

Figure 4.3: PD (Path Discovery) procedure in IAR protocol.

respectively. The optimal path P_{opt} is $P_2(n_S, n_D)$ because it is the path that maximize the min SIR value. In the case in which more paths have the same best SIR value, the algorithm will select among these best paths the shortest one.

4.1.3 SIR evaluation on multi-channel MAC

As seen in the previous section, each intermediate node n_m on the $k-th$ path, $n_{m,k}$, needs to estimate the current value of SIR on the generic channel $ch_c \in CH$. This operation can be executed by defining the SIR as a function of the transmitted and received signal power, subject to radio propagation conditions. In particular, the SIR value on channel ch_c, for node n_m is:

$$SIR_{n_m,ch_c} = \frac{P_t}{\sum_{j=0}^{\|N(n_m)\|-1} P_r(ch_c, n_j)} \tag{4.3}$$

where P_t is the transmission power (without loss of generality it is assumed that P_t is the same for each user and for each channel as defined by the standard, so $P_t(ch_c, n_m) = P_t$, $\forall n_m \in V$ and $\forall ch_c \in CH$) and $P_r(ch_c, n_j)$ is the received signal power of node n_m on channel ch_c due to the transmission of node $n_j \in N(n_m)$. At this point, it can be written that:

$$MAX\_SIR_K(n_m) = \{SIR_{Ch_j}/i = index\{\max_j(SIR_{n_m,ch_j})\}\} \ , with\ j = 1, \ldots, 6. \tag{4.4}$$

So, the value of SIR obtained by eq. 4.4 is the one that each intermediary node n_m will use to fill the SIR field of $RREP$ packets. Nowadays, each vehicular node has the possibility to evaluate the received power via hardware, but for our simulation purposes an analytical expression for $P_r(ch_c, n_j)$ in eq. 4.3 is mandatory. With this aim, we based the propagation modeling on the two-ray model for vehicular environment[25], so for a node n$_m$ it can be written that:

$$P_r(ch_c, n_j) = \frac{P_t}{\frac{16\pi^2(d(n_m,n_j)^\gamma)}{(\lambda(ch_c))^\gamma}}[1 + \eta^2 + 2\cos(\frac{4\pi h^2}{d(n_m, n_j)\lambda(ch_c)})] \tag{4.5}$$

where P_t is the transmitted power, $d(n_m, n_j)$ is the distance between n_m and the neighbor n_j, η is the reflection coefficient (related to the road surface), h is the height of the antenna, $\lambda(ch_c)$ is the wavelength related to the carrier frequency of channel ch_c and n_j is the path-loss factor[25].

4.1.4 Dynamic Channel Switching Procedure

In order to ensure a good quality on the transmission path from n_S to n_D , a channel refreshing mechanism is also provided. Once a generic node $nm \in V$ has chosen the optimal channel in terms of interference, the associated SIR value has to be periodically refreshed (let us indicate the refresh time as T_r) in order to know if it can be still considered as the best SIR value for the transmission: if the refreshed SIR value falls below a lower-bound, then the node has to start a dynamic channel switching procedure for the selection of a new transmission channel with a better SIR value. The transmitter node will advertise the receiving neighbour node $n_n \in V$ with a Change-REQuest ($CREQ$) packet about the switching on a new channel: the $CREQ$ packet is similar to the $RREQ$ packet and contains the $Chan$ and SIR fields, which indicate the new transmission channel and the associated SIR value respectively. The receiving node n_n will reply with a Change-REPly message ($CREP$), in order to send to the transmitting node the

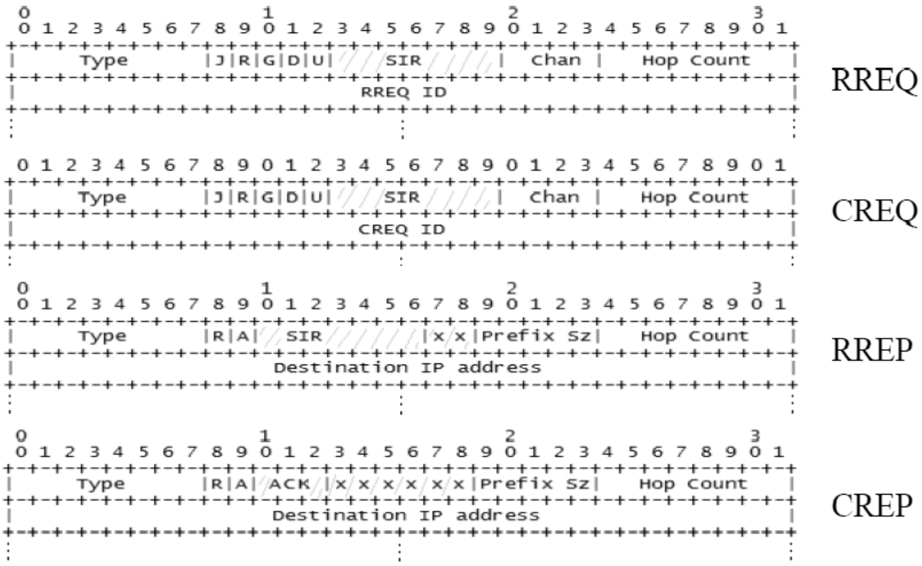

Figure 4.4: Signaling packets in IAR Protocol

acknowledgement of the $CREQ$ packet. Figure 4.4 shows the structure of $CREQ$ and $CREP$ packets on the right side. Figure 4.5 contains the flow diagram of the updating procedure, executed every T_r seconds by the generic node n_m that is currently transmitting on channel ch_c to the receiving node n_n: let $N(n_m)$ denote the number of neighbour nodes of n_m and δ is an input threshold that represents the minimum SIR level that must be granted on each selected channel. The value of SIR on the current channel ch_c must be greater than δ; if this is not satisfied, the channel has to be updated, so for each available channel the SIR value has to be evaluated, in order to find the new one, let us indicate it with ch_b, associated with an acceptable SIR level. At this point the transmitting node n_m can send to n_n the $CREQ$ packet containing the information about channel ch_b and its associated SIR value. Node n_n will reply with a $CREP$ packet as acknowledgement.

4.1.5 Predictive Interference Metric

IAR protocol, is based on the instantaneous evaluation of SIR levels on different available transmission channels. Since the degradation conditions on the channels

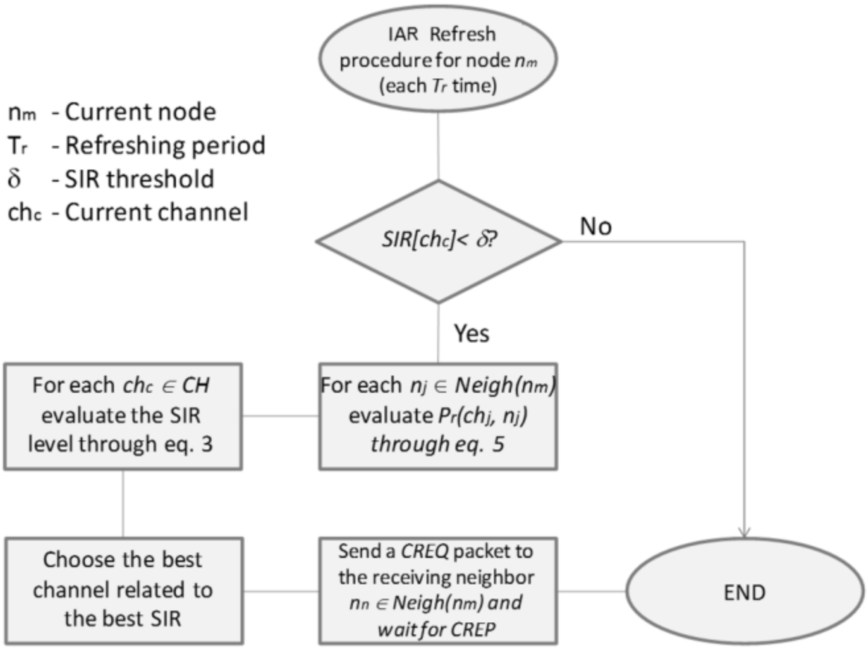

Figure 4.5: Threshold-based dynamic channel refresh procedure.

change quickly on the basis of nodes mobility and propagation conditions (fading, shadowing, Doppler-shift, etc.). In this way, the choice of a path is not made only considering instantaneous values of SIR, but considering the future evolution of channel conditions in a particular time period. So, a predictive version of the IAR protocol is proposed. In the next section, the enhancements due to the introduction of a predictive algorithm are shown. The Predictive IAR protocol ($PIAR$) chooses a path from a source n_S to a destination n_D on the basis of the best predicted average SIR value, and not on the basis of instantaneous evaluations (IAR). The equations and mechanisms used in IAR are still effective, but instantaneous SIR values are replaced by predicted ones. In order to make the prediction, the adaptive filter theory has been employed [26]: the sequence of SIR values observed on a given channel ch_c has been considered to be an $N-th$ order Auto Regressive (AR) process (a time series in particular) $SIR_{nm,chc}(n)$ defined as:

$$SIR_{n_m,ch_c}(n) = \theta_1^* SIR_{n_m,ch_c}(n-1) + \theta_2^* SIR_{n_m,ch_c}(n-2) + \ldots + \theta_N^* SIR_{n_m,ch_c}(n-N) \quad (4.6)$$

and it is based on the general assumption that the value of the process at time unit n is a linear function of previous N values. Basing our treatment on the theory of [26], it can be written that the unknown optimal coefficients vector is:

$$\vec{\theta^*} = [\theta_1^*, \theta_2^*, \ldots, \theta_N^*]^T \quad (4.7)$$

and in the $n-th$ time unit an input vector $\vec{u}(n)$ is defined as:

$$\vec{u}(n) = [SIR_{n_m,ch_c}(n-1), SIR_{n_m,ch_c}(n-2), \ldots, SIR_{n_m,ch_c}(n-N)]^T \quad (4.8)$$

If the estimated parameters vector is indicated with:

$$\hat{\vec{\theta}}(n) = [\hat{\vec{\theta}}_1(n), \hat{\vec{\theta}}_2(n), \ldots, \hat{\vec{\theta}}_N(n)]^T \quad (4.9)$$

then the estimation of the optimal $\vec{\theta^*}$ vector can be made through the Recursive Least Squares (RLS) algorithm [27], in the following way:

$$\hat{k}(n) = \frac{\lambda^{-1} P(n-1)\vec{u}(n)}{1 + \lambda^{-1}\vec{u}^T(n) P(n-1)\vec{u}(n)} \quad (4.10)$$

$$\hat{\vec{\theta}}(n) = \hat{\vec{\theta}}(n-1) + \hat{k}(n)(d(n) - \hat{\vec{\theta}}^T(n-1)\vec{u}(n)) \quad (4.11)$$

$$P(n) = \lambda^{-1} P(n-1) - \lambda^{-1}\hat{k}(n)\hat{u}^T(n) P(n-1) \quad (4.12)$$

Where λ is the forgetting factor, $P(n)$ represents the input inverse correlation matrix, $\hat{k}(n)$ is the gain vector, $d(n)$ is the desired output ($d(n) = SIR_{nm,chc}(n)$); as initial condition n=0, $\hat{\vec{\theta}}(0) = 0$ and $P(0) = \varepsilon^{-1} I$ where I is the identity matrix and ε is an arbitrary, positive and tending to zero constant.

Figure 4.6 illustrates an example of the effectiveness of the RLS prediction

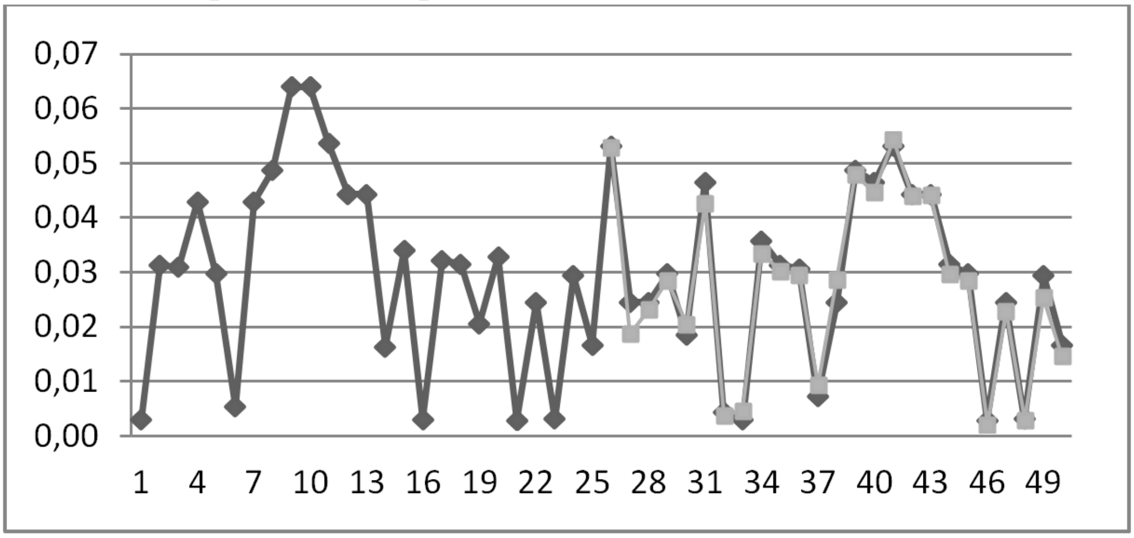

Figure 4.6: Predicted SIR values with N=25 and M=10.

of the SIR process for $N = 25$ and $M = 10$ (M is the number of future values predicted on the basis of the previous N ones). As indicated in the next section, N has been fixed to 25 and the obtained values of SIR are normalized respect to 10^{10} in order to offer a better visibility of curves. Moreover, further graphics with different N and M values are not shown due to space limitations. In the PIAR protocol, a source node $n_S \in V$ that is transmitting data packets to a destination $n_D \in V$ along $P_{opt}(n_S, n_D)$ periodically (each T_p seconds) sends a control packet called Probe-REQuest ($PREQ$) to its neighbor $n_{St} \in N(n_S)$ that belongs to $P_{opt}(n_S, n_D)$ in order to test the SIR value on the link toward the destination; node n_{St} will forward the $PREQ$ packet to its neighbor, and so on, until the $PREQ$ reaches the previous hop of n_D. At this point, each node on $P_{opt}(n_S, n_D)$ will answer to n_S with a Probe-REPly packet ($PREP$), containing the SIR value related to the active transmission channel, so node n_S can evaluate the average level of instantaneous SIR on $P_{opt}(n_S, n_D)$ at the $h-th$ step as follows:

$$SIR\_PROBES_h = \frac{1}{\|P_{opt}(n_S, n_D)\| - 1} \sum_{k=1}^{\|P_{opt}(n_S,n_D)\|-1} SIR\_PROBES_k \quad (4.13)$$

where SIR_PROBE_k is the value of SIR contained in the $k-th$ received $PREP$ packet. At this point node n_S will evaluate the following relation:

$$SIR\_PROBES_h(1-D) \leq SIR\_PROBES_{h-1} \tag{4.14}$$

where D is an input threshold (discussed in the next section) and SIR_PROBES_{h-1} is the value of the average SIR on $P_{opt}(n_S, n_D)$ evaluated at the $(h-1)-th$ step (the previous step). If the relation in 4.14 is verified, then the route from n_S to n_D has to be updated and node n_S starts the PD procedure as in IAR (exchange of RREQ and RREP packets), but the expression of the instantaneous $SIR_{nm,chc}$ of eq. 4.3, is substituted with the one of eq. 4.6 $SIR_{nm,chc}(n)$ that considers a predicted value of SIR.

4.1.6 Smoothed metric

In order to consider more stable interference values in the route selection procedure, a smoothed metric of interference is defined. This metric is included in PIAR protocol and this new protocol variant is called $SPIAR$ (Smoothed PIAR). This variant is not based on the RLS algorithm for the prediction but it considers a smoothed evaluation of the SIR, based on past and current values of SIR. In particular, given $(n-1)$ SIR samples, and the current one, then the $(n+1)-th$ predicted value of SIR will be:

$$SIR_{n_m,ch_c}(n+1) = \frac{\sum_{i=1}^{n-1} SIR_{n_m,ch_c}(i)}{(n-1)}(1-\alpha) + SIR_{n_m,ch_c}(n)(\alpha) \tag{4.15}$$

where $\alpha \in (0,1)$ is the smoothing factor and acts as weight between past and current values of SIR. In section 4.2, the performance evaluation of the IAR, PIAR and SPIAR is considered.

4.1.7 Interference aware On Demand Routing Scheme

The novelty of the proposal consists in the adopted metric for the choice of the optimal route from source to destination, and in the route maintenance procedure:

it is based on the interference concept, as explained before. The IAR is based on the following assumptions:

- data packets can be delivered on six Service CHannels (SCH - 172,174,176,180,182 and 184), while signaling ones are transmitted only on the Control CHannel (CCH - 178);
- each node can transmit/receive on one channel, so no simultaneous transmissions per node are allowed;
- each node is equipped with two interfaces radio (with multiple channels); one of theseis always tuned to the control channel (CCH) and the other one is tuned to any of the 6 service channels (SCH);
- channels are essentially time synchronized using Coordinated Universal Time (UTC), commonly provided by Global Positioning System (GPS) equipped on board the vehicles;
- the time needed for channel switching is negligible (in terms of the 802.11p MAC implementation, the channel router only has to forward data units to a different queue).

For the IAR, PIAR and SPIAR it is also supposed that a node knows exactly the SIR level on the available channels for each neighbour and packet transmission over the final optimum path from a source node n_S to a destination node n_D will be made using a set of channels that minimizes the inter-node interference, achieving better signal quality during the considered session.

4.2 Performance Evaluation

The idea proposed in previous sections has been implemented in the Network Simulator 3 (NS-3)[28]. Different classes were created or modified in the NS3 source code. The SUMO mobility generator [29] was introduced in order to obtain a more realistic scenario. Simulation parameters are listed below:

- Simulation Map dimension(see fig. 4.7): 1500 meters x 1500 meters;

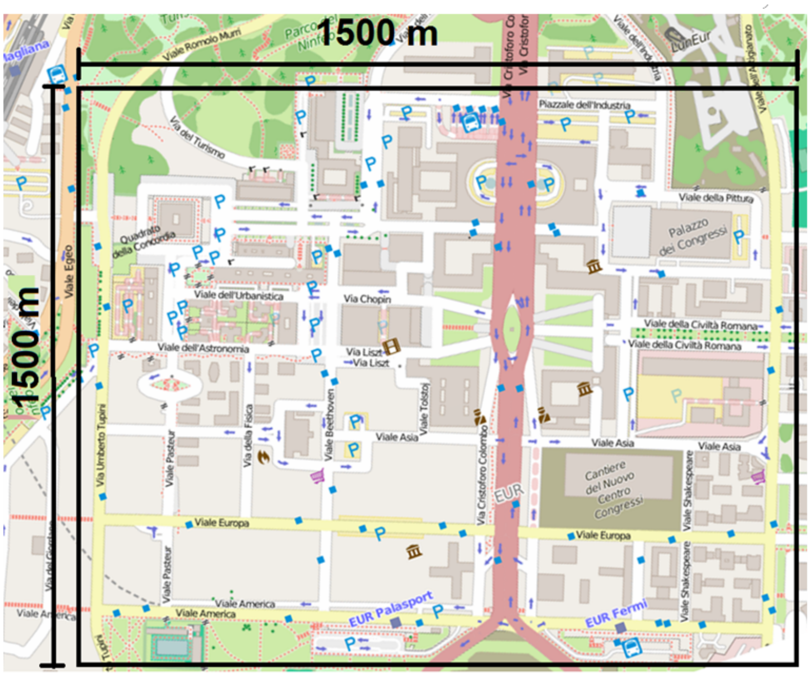

Figure 4.7: Map of the Rome City

- Transmitting coverage radius: 300 meters;
- Streets width: 10 meters;
- Simulation time for a single run: 1000 seconds.

The considered protocols are four: SPIAR, PIAR, IAR and CLWPR[30] protocol. The last one is a Cross-Layer protocol that utilizes the prediction of the node's position and the information about the link layer quality in term of SNIR (Signal to Noise Interference Ratio).

4.2.1 How to choose protocol parameters in PIAR protocol

PIAR protocol uses some critical parameters: N and M (for the prediction of SIR values associated to the different channels), the timer T_p (for the periodical sending of Probes packets), the threshold value D (used to consider a degradation of SIR, due to mobility of nodes).

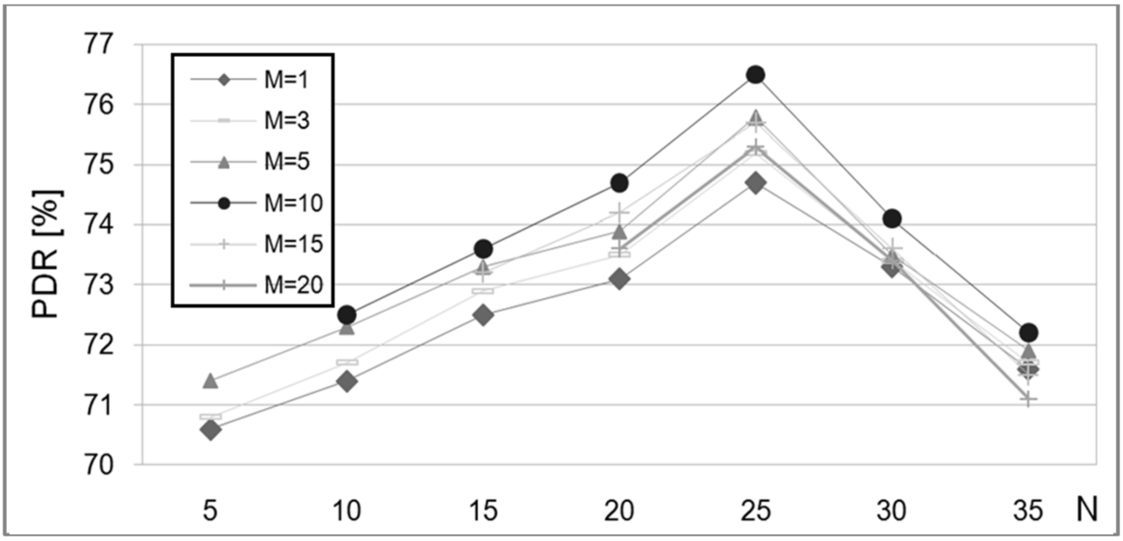

Figure 4.8: Packet Delivery Ratio for different values of N and M.

Simulation campaigns were carried out in order to set these parameters to the values that lead the protocol to obtain the best results, in terms of Packet Delivery Ratio (PDR), Throughput, Overhead, etc. Figure 4.8 shows that for $N = 25$ and $M = 10$ the best results are obtained in terms of PDR. The use of Probes packets for PIAR is of crucial importance for the monitoring of SIR values on different paths; the right choice of T_p can improve protocol performance; also in this case, due to space limitations, only the Throughput trend is illustrated in fig. 4.9.

It can be noticed that for $T_p = 75ms$ the network offers the best performance independently from the number of nodes. Another parameter that has to be tuned for PIAR is the SIR threshold D, used to decide if the transmission route has to be updated. The choice of the value of D influences the end-to-end ($e2e$) delay (every time a path is changed an additional amount of time is requested to establish the new route) and the overhead (the updating of a new path triggers new overhead in the network). Also in this case, only one figure is shown, but also for the other results the chosen value of D leads to the best performance.

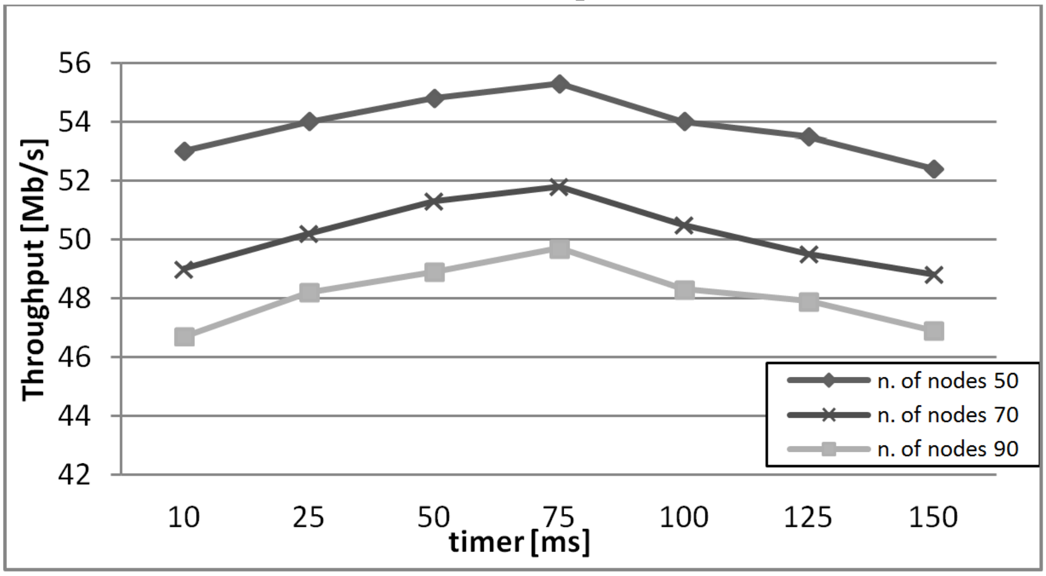

Figure 4.9: System throughput vs Probes-timer T_p.

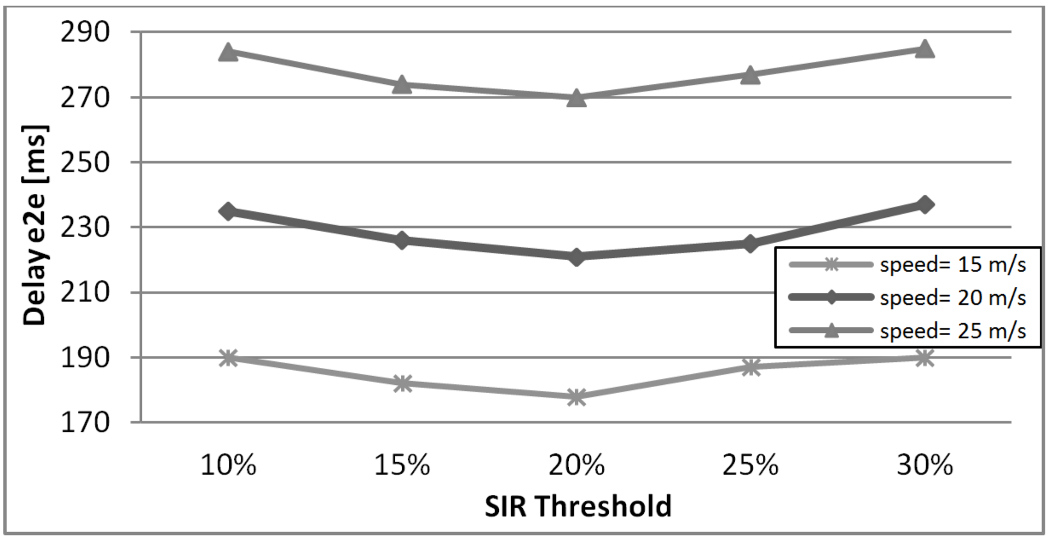

Figure 4.10: Delay end-2-end versus threshold D.

Observing figures 4.8, 4.9 and 4.10, it can be concluded that if D is set to 0.2 (20% of SIR degradation on the path), for different average node velocity, the system performs better in terms of end to end delay, PDR, Throughput and SIR on the link of the followed path. In the next section it will be shown that the additional overhead is acceptable.

4.2.2 Protocols performance evaluation

It is possible to note in fig. 4.11 that PDR is inversely proportional to the number of nodes of the considered network. The best performing protocol in terms of PDR is PIAR, because it is able to execute, under a SIR level degradation on the transmission channels used for data forwarding, a strategy to select a novel path with a higher SIR. IAR reaches values lower than PIAR, because it re-computes the overall path when a SIR degradation occurs on the transmission channels (it executes just one channel switching on the channel that maximizes the SIR value).

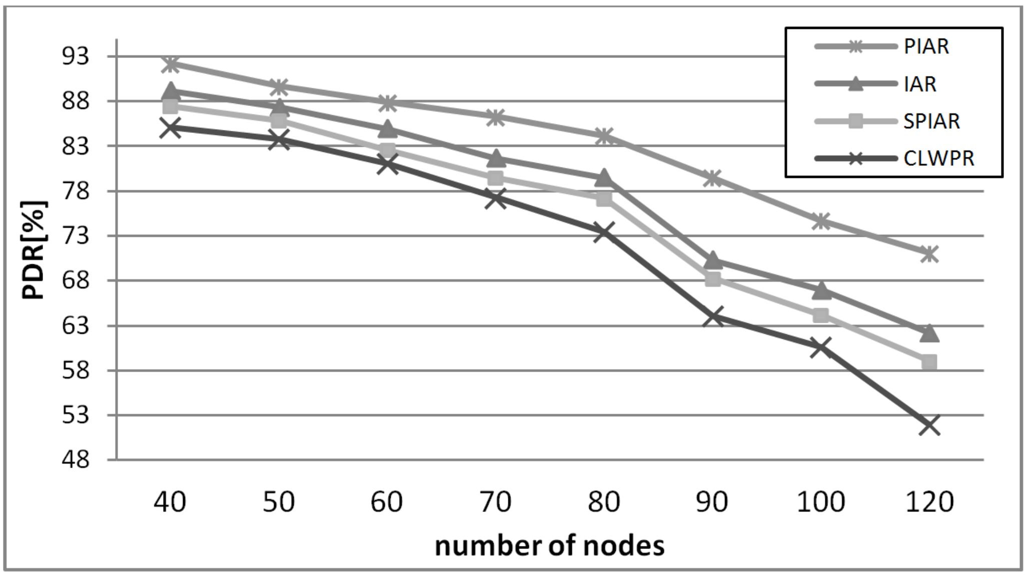

Figure 4.11: Network Packet Delivery Ratio for 20 active connections.

The SPIAR protocol, on the other hand, obtains PDR values lower than IAR because it does not use a dynamic prediction scheme and it bases its channel switching strategy only on the previous SIR values. This approach can lead to some prediction errors. Concerning the CLWPR, it obtains lower performance in comparison with the other protocols because it considers a metric without exploiting the potential of multi-channel MAC for vehicular networks. For different mobility speed of network nodes (these graphs are not shown for space limitations), the routing protocols obtain similar performance in comparison with the previous simulation scenario. PIAR protocol performs better than other routing schemes for higher speeds scenario because it is able to better adapt and switch to minimum interference paths. From fig. 4.12 it can be noticed that throughput values are higher for PIAR protocol, because it is able to recompute, in a more efficient way, the entire path with higher SIR after a SIR level degradation due to nodes mobility.

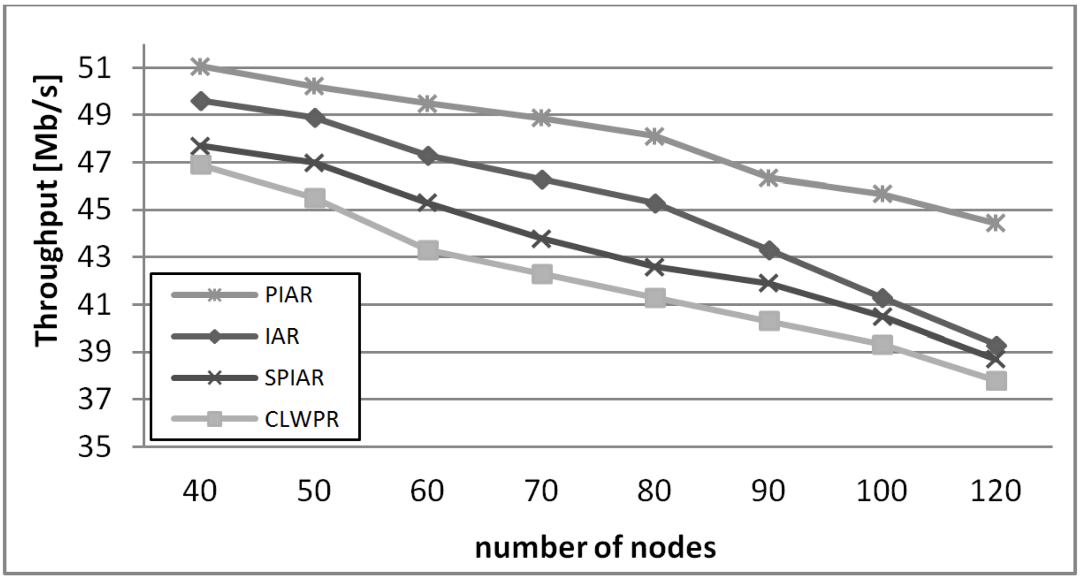

Figure 4.12: Network Throughput with 20 active connections.

IAR protocol presents lower Throughput values in comparison with PIAR, because it does not re-compute the overall path after a SIR level degradation but, instead, makes just a local channel switching to the best channel (in terms of SIR) on the nodes belonging to the already used path. The SPIAR protocol, instead, offers lower throughput values than IAR, because it uses a not dynamic prediction scheme based just on previously computed SIR values and, for this reason, it can commit errors in SIR prediction. With regards to the CLWPR protocol, it continues to present lower performance than other protocols due to the different metric. The throughput presents a decreasing trend for increasing number of nodes. For very high-density network, PIAR protocol presents higher throughout values due to its capacity to select lower interference paths.

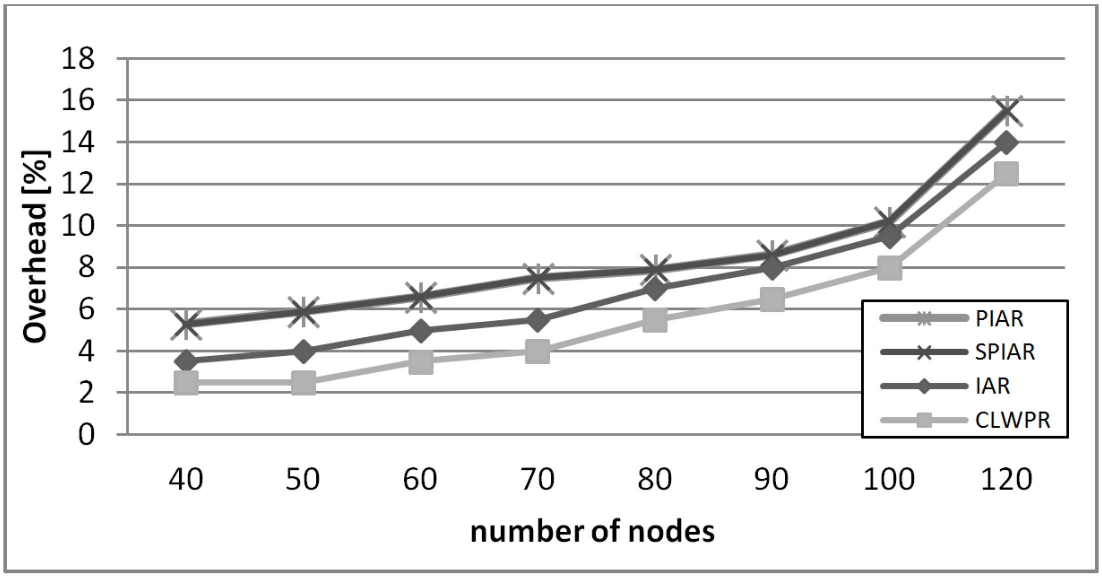

Figure 4.13: Network overhead with 20 active connections.

As explained previously, simulation campaigns proved that performance evaluation of the considered protocols under increasing mobility speeds presented similar trends in comparison to the shown curves. From fig. 4.13, it is possible to note how the control overhead (evaluated as the ratio between signaling transmitted packets and all the packets) is directly proportional to number of network nodes and number of connections (source-destination pairs). PIAR and SPIAR obtain higher control overhead due to the additional signaling packets (such as periodical probes). In this specific case, the two protocols present the same overhead because the same timer for probes forwarding is applied. However, for the same control overhead, PIAR presents a higher PDR and throughput in comparison with SPIAR. On the contrary, CLWPR protocol presents lower overhead values in comparison with PIAR and IAR, because they do not need to update the state information about interference between neighbor nodes. Moreover, the overhead increases in a constant way for higher network density or higher mobility condition. Also in this case, due to space limitations, the curves are not shown. Observing fig. 4.14, it is possible to see how the SIR value related to the transmission channels is inversely proportional to the number of network nodes.

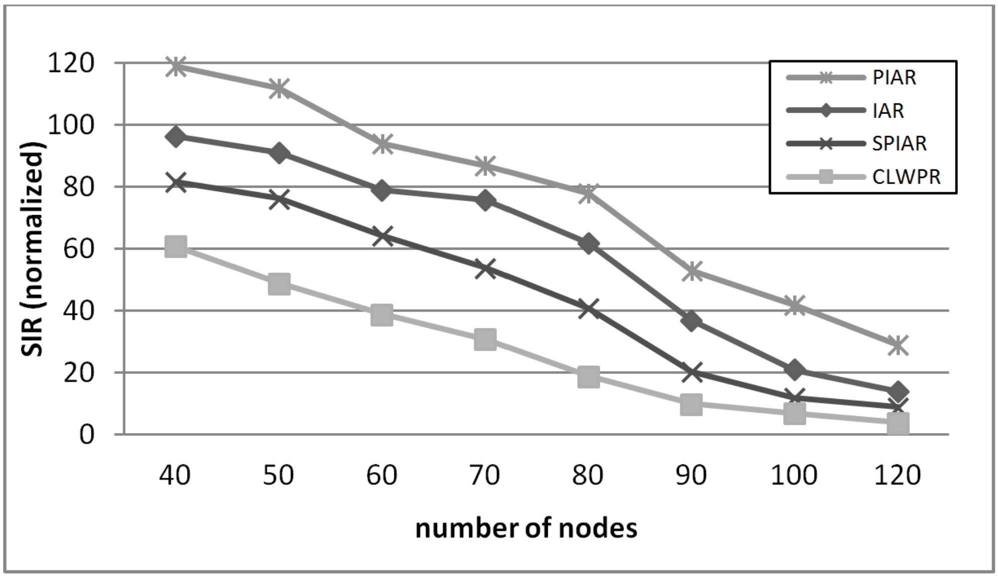

Figure 4.14: Average Normalized SIR value for 20 active connections.

The protocol that presents the best performance is PIAR, which has as its primary purpose the selection of the maximum-SIR path on the available channels for data transmission. The IAR protocol has lower values in comparison with PIAR because, when SIR values of the transmission channels degrades due to mobility, it tries to maximize the SIR value, changing the channel (differently, PIAR re-builds the overall path). SIR values obtained by the SPIAR protocol are slightly lower than PIAR and IAR values, because the smoothed metric is based only on historical and current SIR values, differently from the PIAR scheme, that is based on RLS algorithm. It is also possible to observe how low dense network interference-aware routing schemes present more visible improvements in terms of SIR on the different channels. This is due to the possibility to better distribute the data traffic on the different channels and on the lower length paths that can be discovered. The CLWPR protocol presents lower SIR values in comparison with other protocols, because it is mainly based on the construction of paths using the position of the nodes and the problem of interference is not crucial in it.

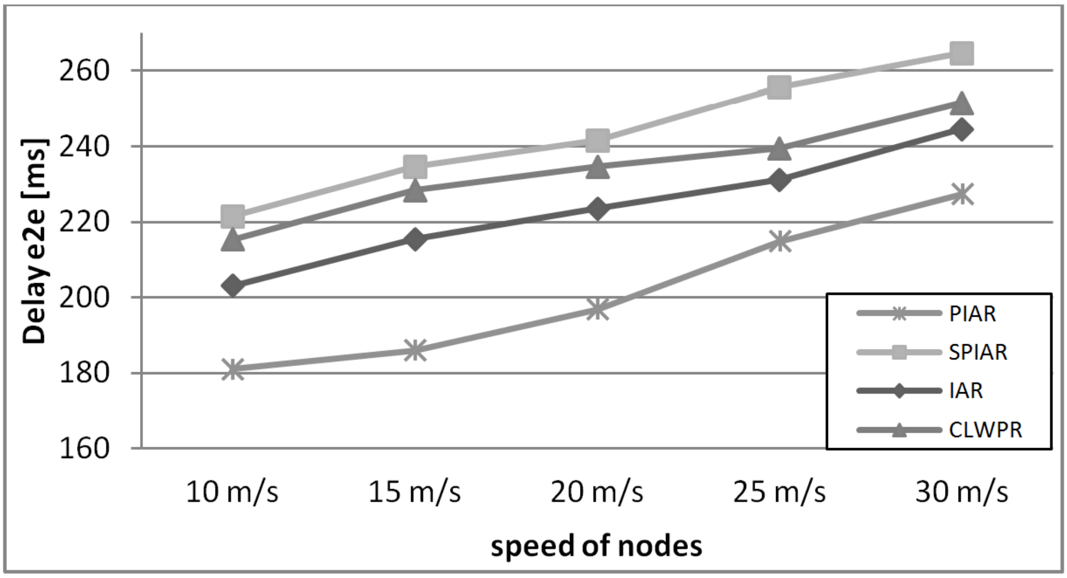

Figure 4.15: End-2-end delay for 20 active connections and 60 mobile nodes.

In fig. 4.15 it is possible to observe how the end-to-end delay is directly proportional to the speed of nodes. Protocols that obtain better results in terms of end-to-end delay are respectively PIAR, IAR and SPIAR because they use a robust metric that minimizes the number of retransmissions that take into account the values of interference due to transmission data. Some reasons for the slightly higher delays of IAR routing schemes are listed below:

- SPIAR protocol presents higher delay because, after a SIR degradation, it applies a procedure to re-compute the overall path from source to destination. This means that he packet forwarding needs longer times;
- PIAR obtains delays slightly lower than SPIAR, because it makes use of a more accurate prediction algorithm;

- IAR obtains delays which are lower than PIAR and SPIAR because it does not use a procedure to re-compute the path, but it makes use of a local channel switching on the nodes where the SIR is degraded.

CLWPR obtains a value that is slightly lower than SPIAR in terms of end-to-end delay because it employs a procedure to build paths considering the location of vehicles. Regarding fig. 4.16, have been setted the number of nodes to 30 and the transmitting coverage radius to 100 meters, in order to considerate a low density scenario.

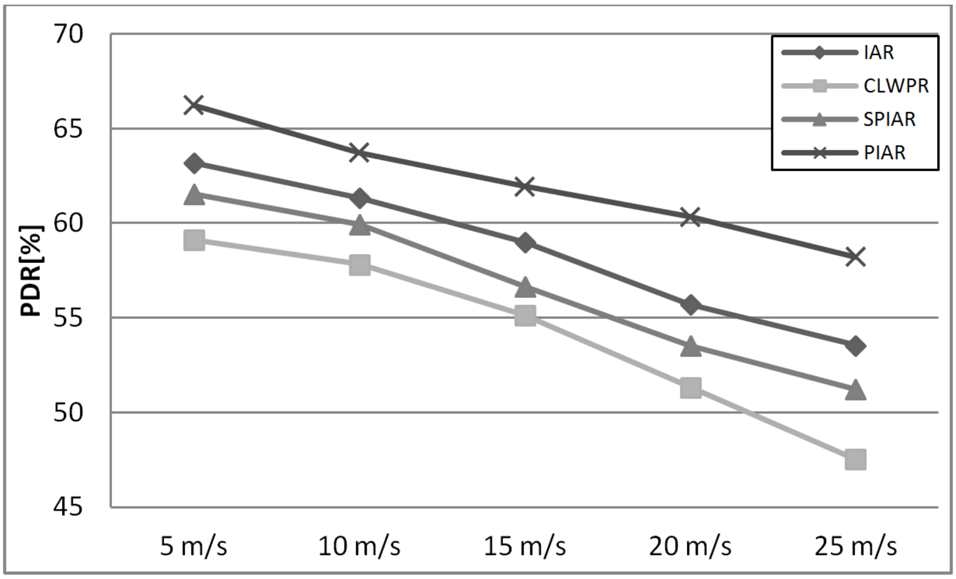

Figure 4.16: Network Packet Delivery Ratio versus speed of nodes.

In this case, it is possible to see how the PDR decreases compared to the previous scenarios (see fig. 4.11). By reducing the coverage radius, it is easy to obtain many network disconnections and, consequently, the PDR decreases. Therefore, the PIAR protocol outperforms others routing protocols, reacting better to the rapid changes of the network topology, due to the nature of the VANETs.

Chapter 5

Routing Optimization in Vehicular Networks: A New Approach Based on Multiobjective Metrics and Minimum Spanning Tree

In this chapter, a new routing protocol for VANETs, dedicated to the optimization of path length, interference level, and link duration has been proposed. It is based on a dynamic allocation mechanism of the DSRC spectrum, aimed at the reduction of the co-channel interference and the maximization of link duration (two key issues in vehicular environments). A new multi-objective metric, based on the evaluation of co-channel interference levels, end-to-end delay, and link duration along the different links from sources towards destinations, has been proposed and modeled through an optimization problem. Through an NS2 implementation of the IEEE802.11p standard, with the simulation of vehicles mobility in an urban environment, it has been shown that the proposed idea overcomes classical protocols performance in terms of throughput, packet delivery ratio, and end-to-end delay, despite a slight increase in protocol overhead.

5.1 State of the Art and Related Work

There are many efforts in the literature for VANETs and many authors have proposed some routing schemes, but most of them lack the employment of the multichannel availability of the mobile devices.

5.1.1 QoS Routing Protocols

In [31] authors propose a new geographic routing protocol that does not require proactive transmission of beacon messages. Data packets are broadcast to all direct neighbors, which decide if they should forward the packet. Receivers of the broadcast data would compare their distance to the destination to the last hops distance to the destination: in that scheme, the bigger is the difference, the larger is the progress and the shorter is the timer. The ad hoc QoS on-demand routing protocol [32] also maintains some information about neighbor nodes, incorporating interference and broadcast route requests. In this way, feasible paths are detected and the final choice is made at the destination. More recently, Zhu and Corson [33] proposed other algorithms to determine the exact schedule of slots for a flow through the network, guaranteeing the bandwidth by taking interference into account. In [34][35], the problem to find the best multicast tree to distribute data along the source and multicast destinations has been presented. In these works, the authors look for the best solution facing an NP-complete problem considering several constraints on QoS parameters. In order to find the best solution the authors propose an evolutionary genetic algorithm, which does not guarantee finding the optimum due to the nature of the algorithm. However, they demonstrated finding a local optimum closer to the optimum in the available solution space configuring the possible algorithm parameters driving the evolution and avoiding the evolutionary divergence.

5.1.2 Location-Based Routing Protocols

The grid location service (GLS) [36] divides the network area in a hierarchical structure known as a quadtree, which is a square area divided recursively into squares of equal size. Squares of the same size are said to belong to the same order. Each network node maintains a list of all the positions of the nodes belonging to its first-order square (smallest possible), broadcasting periodically this information. A node periodically sends updates of its position to a node in each adjacent first-order square. The Anchor-based Street and Traffic Aware Routing (A-STAR) [37] is a position-based routing protocol; the words anchor-based refer to the fact that a source node includes in each packet an array containing a list of geographical points (anchors), through which the packet must pass to reach the destination. A-STAR is based on the assumption that each vehicle knows its position via GPS, the location of the destination through a location service, and is equipped with a digital map of the city that includes statistical information on road traffic. This last aspect has been faced in a recent contribution [38] where authors proposed interference-aware metrics in the context of UWB channel model. However, the different context of VANET environment suggests applying other strategies based on the specific MAC, later associated with vehicular communications. The intersection-based geographical routing protocol is proposed in [39]; it is based on a smart selection process, during which some road intersections are considered as positions where packets have to flow to reach the gateway. The idea is very suitable because it guarantees, through the formulation of an optimization problem solved by genetic algorithms, network connectivity among the road intersections, satisfying QoS constraints, considering a geographical place where to forward packets, instead of single nodes. But if all nodes in the network focus their behavior on this routing strategy, there will eventually be a great amount of data traffic on particular higher rated roads. In [40], the authors propose an RFID-assisted localization system. The proposed system employs the DGPS concept to improve GPS accuracy. A vehicle obtains two different position data: GPS coordinates from its own GPS receiver and accurate physical position via RFID communication. Then, it computes GPS error and shares it with neighbors to help them correct inaccurate GPS coordinates. In [41], the authors considered the effects of mobility, which causes frequent and rapid topology variations, with a consequent increase in routing overhead. The proposed idea mitigates these undesired effects, considering a reactive location-based approach each time the location information degrades. In [42], the authors present a fault tolerant location based service discovery protocol for Vehicular Networks. The main advantages of this protocol are its ability to tolerate service providers failure, communication links failure, and roadside routers failure. The authors of [43] introduced a new greedy routing protocol named Greedy Routing with Abstract Neighbor Table, based on the knowledge of the n-hop neighborhood. This protocol operates a smart network subdivision, in the sense that it separates the geographical area into several regions, considering only one representative neighbor for each region.

5.1.3 MAC Layer Protocols

In [24] a novel multichannel TDMA MAC protocol (VeMAC) has been proposed for a VANET scenario. The VeMAC supports efficient one-hop and multi-hop broadcast services on the control channel by using implicit acknowledgments and eliminating the hidden terminal problem. The protocol reduces transmission collisions due to node mobility on the control channel by assigning disjoint sets of time slots to vehicles moving in opposite directions and to road side units. In [44] an adaptive medium access control (MAC) retransmission limit selection scheme is proposed to improve the performance of IEEE 802.11p standard MAC protocol for video streaming applications over vehicular ad hoc networks (VANETs). A multiobjective optimization framework, which jointly minimizes the probability of playback freezes and startup delay of the streamed video at the destination vehicle by tuning the MAC retransmission limit with respect to channel statistics as well as packet transmission rate, is applied at road side unit (RSU).

5.1.4 Multiobjective Routing Protocols

In [45] a contextual cooperative congestion control policy that exploits the traffic context information of each vehicle to reduce the channel load has been proposed to reduce the load on the communications channel while satisfying the strict applications reliability requirements. In [46], the authors present the profile-driven adaptive warning dissemination scheme (PAWDS) designed to improve the warning message dissemination process. Regarding traffic safety applications for VANETs, warning messages have to be quickly and smartly disseminated in order to reduce the required dissemination time and to increase the number of vehicles receiving the traffic warning information. In [47], the authors propose a novel approach for the sanitary resources allocation in traffic accidents. This approach is based on the use of multi-objective genetic algorithms, and it is able to generate a list of optimal solutions accounting for the most representative factors. In [48], the authors propose a QoS routing protocol for MANET with specialized encoding, initialization, crossovers, mutations, fitness selections, and route search using genetic algorithm with multiple objectives. In [49] the authors present a new modelling framework for routing in ad hoc networks which, used in conjunction with metaheuristic multi-objective search algorithms, will result in a better understanding of network behaviour and performance when multiple criteria are relevant. In [50], the authors introduced the notion of multi-objective route selection in mobile ad hoc networks (MANET) using an evolutionary fuzzy cost function (it is a continuous function of the metrics describing the state of a route) to deliberately calculate cost adaptively.

5.1.5 Interference-Aware Protocols

Another important issue in VANETs is the choice of an appropriate transmission channel, not only considering the type of traffic (emergency, security, platooning, etc.) but, mainly, focusing on the reduction of the inter-node interference. In our previous works [51][52][53][54] an enhancement of the Ad hoc On-demand Distance Vector has been proposed, in terms of metric optimization. In particular, it has been modified in order to take consideration of the availability of different transmission channels with an integrated metric, which takes into account the interference level over the different channels. In particular, it allows the management of the multichannel capability of the WAVE standard at the routing layer through a higher-level channel selection, which is based on an interference-aware algorithm. The proposed protocol periodically estimates the Signal to Interference Ratio (SIR) on the available channels, reducing the interference level among nearby mobile nodes. In this way, the new considered metric gives the opportunity to choose the next hop in routing operations depending on the best perceived SIR value on the link. It has been shown how, despite a negligible increase in terms of protocol overhead, there are good enhancements in terms of throughput and packet delivery ratio.

5.1.6 Other Protocols

The effects of mobility are considered in [55], in which a new metric is introduced in order to proactively adapt to a constantly changing topology. The scheme proposed by Sofra et al. considers the lifetime of a link and the forwarding operation is carried out on the basis of how much a link can be considered stable during routing operations. A precise mobility model evaluates link duration; moreover, the model is able to capture the trend of link degradation and fluctuations. In [56] the authors propose a predictive technique based on sequential patterns and two mechanisms used to prepare data for this technique, as well as some performance evaluation for these mechanisms to determine the most feasible choice in terms of communication overhead. VANETs have been also considered for new applications [57], like security and smart operations in vehicular environments or optimized data delivery [58]. In [59] the Delay-Tolerant concept has been investigated for vehicular networks, considering the opportunity of carrying opportunistic and asynchronous communications, based on the store-and-forward paradigm. The authors have shown how by introducing some fragmentation approaches network performance can be improved, also in terms of delivery ratio.

5.2 Problem Statement, Contribution, and Proposed Protocol Scheme

This paper focuses its attention on the enhancement of routing operations in VANETs, taking into consideration both neighbour's interference level and link duration, in addition to classical end-to-end delay term. The proposed idea, called Multi-Objective Routing Protocol (MO-RP), is general and does not depend on the considered routing protocol. It can be integrated with the majority part of existing routing protocols and it is based on the following:

- analysis of interference dynamics for choosing an appropriate transmission channel in order to minimize Co-Channel Interference (CCI);

- periodical refresh, in order to evaluate the updated interference value available on each channel;
- definition of Link Duration Probability (LDP), in order to choose more stable paths;
- periodical calculation of end-to-end (e2e) delay on each couple of mobile nodes that build a path;
- transmission of synchronization packets in order to advise the receiving node of a new channel selection.

As introduced and explained in previous chapter, also in this proposed protocol, each VANET node has two interfaces (transceivers): the first (transceiver1), which is always tuned to the control channel (CCH), and the second one (transceiver2), which can be tuned to any of the 6 service channels (SCH). Using the information carried out in the messages sent and received on CCH, in each time slot a node can switch on selected service channels. As illustrated in the next subsections, the novel idea is proposed in the form of optimization problem, based on the discovery of the appropriate spanning tree. The proposed protocol is based on a multi-objective metric related to LDP, e2e-delay and CCI; these three factors, dimensioned through an objective function, are aimed at building paths more robust to CCI and more stable in time (considering vehicular mobility) and, finally, selecting the paths which minimize the e2e delay, (due to the multihop scheme). First of all, the node which wants to transmit data sends a hello packet for the activation of the neighbor discovery process. In this packet, information about weights and metric is inserted and exchanged. Once the node which wants to transmit data has collected the information about all the possible paths, the best one is chosen.

5.2.1 Scenario Description

Let us consider the VANET topology illustrated in Fig. 5.1. A path discovery phase is initiated each time a source node $v_S \in V$ needs to transmit to a destination node $v_D \in V$, where$V$ is the set that composes the vehicular network.

The terms ρ, χ and θ are, respectively, the evaluation of the metric parameters (end-to-end delay, co-channel interference, and link duration probability).

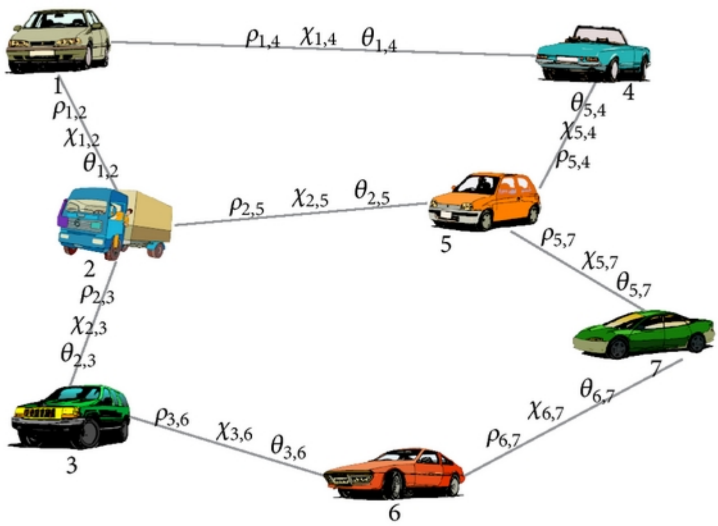

Figure 5.1: An example of a VANET scenario.

When dealing with wireless communications (especially in vehicular environments), classical metrics become inadequate, since they do not consider all the negative effects that are present when paths from sources to destinations are built. If only the hop count is considered, the obtained paths may suffer huge interference levels and/or short duration and, on the contrary, minimizing the interference may bring the considered protocol to obtain longer paths with scarce duration.

5.2.2 The Main Terms of the MO-RP

This work focuses the attention on the proposal of a new multi-objective metric, which combines co-channel interference, link duration probability, and End-to-End delay. The number of signaling packets should be changed in order to take into account the new concepts; the main attention, instead, is focused on the definition of the key elements of a new metric. The proposed solution works in a distributed manner and exploits protocol messages to perform routing decisions and update routing table entries. This approach needs more time than a centralized approach to reach a stable routing path (converged network), but it is possible to initiate session faster. In fact, some paths could be changed during sessions for several reasons. In the transitory period, some paths can change because routing tables are not completely converged, so they lack information about complete network configuration. MO-RP is a distributed protocol and it works like the (DVMRP) distance vector multipath routing protocol. In particular, a mobile node sends a neighbour discovery message to know its neighbours. The neighbour responds to this message sending its identification number (ID) and its routing table information. The node that sends neighbour discovery receives several messages from its neighbours for building its own routing table. Once a node changes its routing table, then it propagates changes to its neighbours. In order to maintain the presence of the node as neighbour, it has to receive periodically (each 500 ms) an alive message from its neighbours. If a node does not receive an alive message until that amount of time, then it erases the entry related to the neighbour from its routing table and propagates this information to its neighbour nodes. When a new path information is coming from a neighbour, the node checks in its routing table if it has the entry related to the destination. If it is not present, then a new entry will be inserted into the routing table; otherwise the node performs the execution of a routing decision algorithm, taking into account three different terms in a metric, which will be faced in the next subsections, performing the update of the routing table. The flow chart in Figure 5.2 resumes the main phases of the protocol. In order to maintain an updated VANET topology, periodically, nodes exchange also information about links information, such as e2e delay, LDP, and CCI.

Therefore, each node keeps a snapshot of the topology into its memory. This knowledge is used to perform the routing decision algorithm when multiple paths are available to reach a destination. The routing algorithm can be viewed as a linear optimization problem and its formulation is presented in the following section.

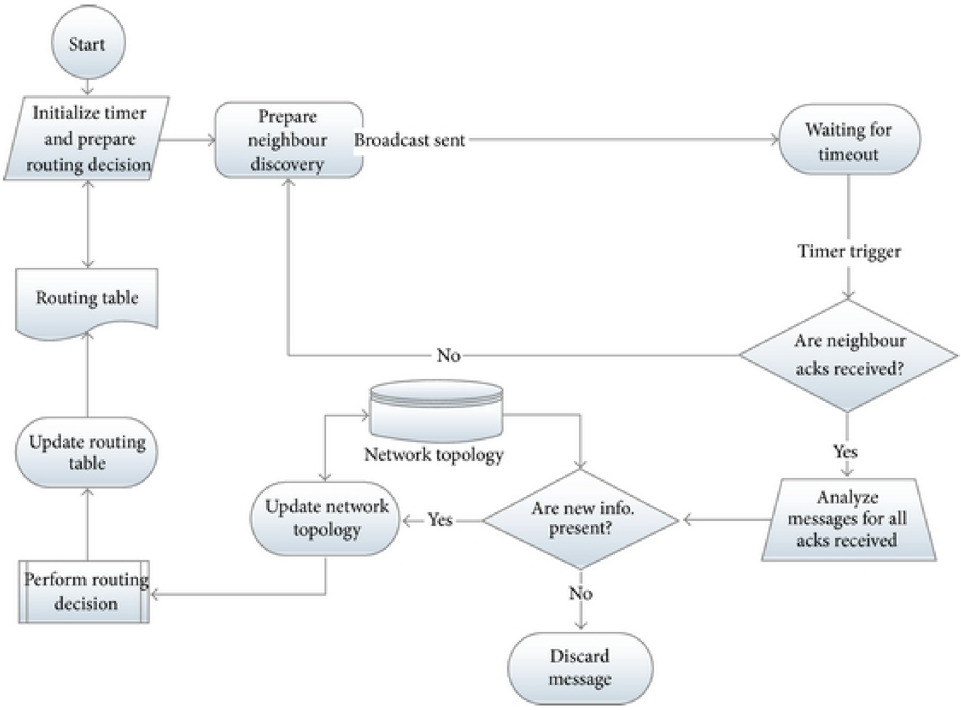

Figure 5.2: Flow chart of neighbor discovery process.

5.2.3 Linear Optimization Problem

In order to present the linear optimization problem, used in the construction of the best path from a source to a destination, some key concepts about the Graph Theory need to be recalled, with some analytic representations. A generic graph can be presented as $G(V, E)$, where V is the set of nodes that composes the graph (including OBU and RSU) and E is the set of edges.

Each edge has three associated terms, as shown in Figure 5.3:

- $\rho_{i,j}$ is the term related to the delay along the link that connects a node (i) with a neighbor (j);
- $\chi_{i,j}$ is the term related to the CCI among the node (i) and a neighbor node (j);

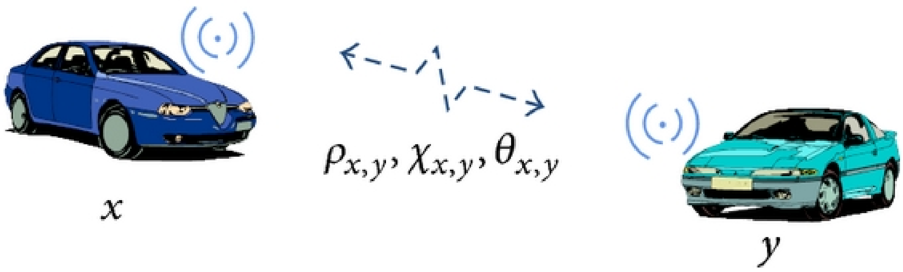

Figure 5.3: An example of a generic link and its related weights between two generic nodes (x, y).

- $\theta_{i,j}$ is the term related to the Link Duration Probability (LDP) among the node (i) and a neighbor node (j).

Once a source node $s \in V$ is chosen it is possible to define a set S defined as $S = \{s\}$. Moreover, a set of nodes D is composed of all the remaining nodes (vehicles). It is defined as shown in what follows:

$$D = V - S = \bigcup_{x=1}^{n} V_x \mid x \neq s. \tag{5.1}$$

Therefore we define n and z as $n =\mid V \mid$ and $z =\mid D \mid$, that is to say, the cardinalities of nodes, and destination nodes sets. Given a source node s, the related tree (T_s) is defined as $T_s = G(V_T, E_T) \subset G(V, E)$ in particular

$$V_T = V = S \cup D \mid S \cap D = \varnothing, E_T \subset E. \tag{5.2}$$

Given a tree (T) it is possible to define a unique path between the node s and all remaining nodes, so $z =\mid D_T \mid$ it is possible to say for all $j = 1 \ldots z$ where:

$$d_j \in D_T \exists Path(s, d_j)_T \subset V_T \tag{5.3}$$

Hence, is possible to define the number of hops(m_j) as follow: $mj =\mid Path(s, d_j)_T \mid$ that a generic packet has to pass through to go from source node s to node d_j. Additionally, z is the size of the set D related to a generic tree T.

5.2.3.1 Constraints Definition

Now, define the CCI contributing as derived from the expression of the received power, for all the available channels. It strictly depends on the transmission power and radio propagation phenomena. Using the theory of [60][61] for DSRC channels, it can be calculated as the signal attenuation of the received power, using the Rayleigh channel model that does not take under consideration the transmission channel but only the distance between transmitter and receiver:

$$P_{loss}(v_i, v_j) = 40lg(d_{i,j}) - [10lg(G_t \cdot G_r) + 20lg(h_t \cdot h_r)] \tag{5.4}$$

which indicates the loss in signal strength (in dB) among the couple of nodes $(v_i, v_j) \in V$. The terms G_t and G_r are the antenna gains, in transmission and in receive respectively, while h_t and h_t are the TX and RX antenna heights and lg indicates the logarithm with base 10. From eq.4.4, the expression of the received signal strength (in dB) by node v_i, for the signal transmitted by node v_i, on channel $c \in Chan$, where $Chan$ is the set of available transmission channels. The cardinality of the set $Chan$ is fixed to 6, because the $DSRC$ channels are 7 in total, but in the proposed schema is not considering the channel CCH). Therefore, can be easily written as follows:

$$P_r(v_i, v_j, c) = P_t - P_{loss}(v_i, v_j) \tag{5.5}$$

where P_t is the transmission power (the same for each node on each channel). In real environments, the value of P_r can be easily evaluated via hardware, but for our simulation purposes, the expression of (4.5) is very suitable. It can be used for accounting path loss effects, which are dominant in VANET environments, because channel coding and frequency interleaving make the bit error performance of an OFDM link in a frequency selective channel depend more on the average received power than on the power of the weakest sub-carrier. From the value of (4.6), the expression of the CCI term for node v_i on channel c is obtained as follows:

$$\chi(v_i, c) = \sum_{j}^{\|neigh.nodes(v_i)\|} P_r(v_i, v_j, c) \tag{5.6}$$

where $neigh.nodes(v_i)$ is the set of neighbour nodes of v_i. At this point, each node v_i can evaluate the best value of CCI associated with a particular channel:

$$c_{min}(v_i) = index\{\min_{c} \chi(v_i, c)\},\ \chi_{min}(v_i) = \min_{c \in Chan} \{\chi(v_i, c)\} \tag{5.7}$$

The End-to-End delay between two nodes is given in (4.8). Here the source node is the radix of the tree; instead, the destination node is one of the nodes that belong to the set D. However, the cumulative delay is carried out considering each edge that belongs to the path between the source (s) and the considered destination (d_j):

$$\Delta_{s,d_j} = \sum_{k=1}^{m_j-1} \rho_{k,k+1} \mid s \in S, d_j \in D, k \in Path(s, d_j)_T \tag{5.8}$$

In order to present the LDP term (θ_{s,d_j}), some additional terms have to be introduced, as shown in [62]. First of all we present the β^e , which indicates the signal attenuation on the edge e that it is composed of two factors:

$$\beta^e = \beta_1^e + \beta_2^e \tag{5.9}$$

The first term β_1^e is related to the distance between nodes:

$$\beta_1^e = \alpha 10lg(d_{xy}) = \alpha 10lg(\frac{avg_s \cdot \tau}{L}) \tag{5.10}$$

where α is the evanescence exponent, which depends on the environment (generally $\alpha = 4$), d_{xy} is the distance among the considered couple of nodes x and y, avg_s is the average node speed, τ is the average time lag between two vehicles, L is the number of considered lanes. The second term β_2^e, is related to the fading contribution and can be considered as a random variable, normally distributed, with zero mean and σ^2 variance, whose pdf is:

$$f(\beta_2^e) = \frac{1}{\sqrt{2\pi}\sigma} exp(-\frac{\beta_2^{e2}}{2\sigma^2}) \tag{5.11}$$

At this point, the sensitivity of the receiver can be defined through a threshold of the attenuation level β_{th}; that is to say, a link among a couple of VANET nodes on the edge e is still valid if $\beta_2^e \leq \beta_{th}$ and the probability on a generic path between tree source node (s) and a generic destination (d) is presented in the following:

$$\theta_{s,d_j} = \frac{1}{2} \cdot [1 + erf((\beta_{th}(k, k+1) - \alpha 10lg(\frac{v_{k,k+1} \cdot \tau_{k,k+1}}{L}))\sqrt{2} \cdot \sigma)^{-1}] \tag{5.12}$$

5.2.3.2 What about Mobility

The nodes mobility is considered in several terms that are involved into path discovery process. The first important concept to recall is that the neighbour discovery process is performed continuously and some dedicated messages of keep alive are sent as WSMP to know if a neighbour is still present or not. Moreover, new nodes are discovered by the neighbors discovery process and a new edge is built on the graph, allowing us to consider a new connection. In addition, since the link-duration concept is inserted in the metric, more stable paths are chosen as preferred links. This allows the system to consider mobility in terms of speed and direction updating, in a real-time manner, the weight of the edges, and adding or removing connection on the graph. So the resultant path is reliable and can distribute packets.

5.2.3.3 Minimum Spanning Tree (MST)

Considering QoS constraints, it is possible to define the Minimum Spanning Tree (MST) finding problem like an optimization problem as follows:
$\min_{x \in X} f(x)$

$$\max_{j=1}^{z}\{\sum_{k=1}^{m_j-1} \delta_{k,k+1} \mid k \in Path(s, d_j)\} \leq \Theta \tag{5.13}$$

$$\max_{j=1}^{z}\{\forall_{k=1}^{m_j-1} \chi_{k,k+1} \mid k \in Path(s, d_j)\} > Z \tag{5.14}$$

$$\max_{j=1}^{z}\{\forall_{k=1}^{m_j-1} \theta_{k,k+1} \mid k \in Path(s, d_j)\} > H \tag{5.15}$$

where the Θ , Z, and H are the End-to-End delay, CCI, and LDP bounds, respectively. $x \in X$ are the paths between the source node and destination set along the tree T_x, while X is the set of all available trees. Moreover, $f(x)$ is the objective function which has to be minimized and it is given by the following:

$$f(x) = \gamma_{\Delta} a(x) + \gamma_{\chi} b(x) + \gamma_{\theta} c(x) \tag{5.16}$$

In eq. 5.16 the $a(x)$ is the evaluation of the delay along the path in Tx, $b(x)$ is the evaluation of the Co-Channel Interference along the path in Tx, and at last the $c(x)$ is the evaluation of the LDP along the path in Tx. The proposed protocol, now, has three degrees of freedom (γ_{Δ} called End-to-End delay weight, γ_{χ} called CCI weight, and γ_{θ} called LDP weight), which have to be set adequately. We know that X is the set of the found solutions (Trees); therefore, let us declare$p = \mid X \mid$ as the size of the set X. At this point, it is possible to define the $a(x)$, $b(x)$ and $c(x)$ as:

$$a(x_j) = \frac{\overline{Delay(x_j)}}{\sum_{i=1}^{p} \overline{Delay(x_i)}} \cdot \sigma^2(Delay(x_j)) \cdot \frac{\sum_{i=1}^{p} [D_{max}(x_i) - D_{min}(x_i)]}{D_{max}(x_j) - D_{min}(x_j)}. \tag{5.17}$$

In eq. 5.17 the delay evaluation function is presented. It is possible to note that the solution feasibility is related to the mean value, variance, and bound values about min and max delay. In order to understand how $a(x)$ works it needed to explain some utilized terms. The mean values of the solutions give us the possibility to achieve an overall evaluation, while the variance term permits to consider those solutions where the end-to-end delay is commonly closer between destinations. Last term, instead, permits to consider those solutions where the distance between the max-Delay and the min-Delay is close enough that all destinations receive information into a narrowed time window.This permits to receive information avoiding that "old information" travelling through the network.

In eq. 5.18 the CCI function also called $b(x)$ is presented. In this function, it is considered the mean value about the CCI along all paths between the source node and the destinations. Moreover, the difference between the minimum available CCI and the imposed bound is also considered. In the presented function, the higher is the difference, the lesser is the $b(x)$ value:

$$b(x_j) = \frac{\overline{CCI(x_j)}}{\sum_{i=1}^{p} \overline{CCI(x_j)} \cdot (Z - \overline{CCI(x_j)})}. \tag{5.18}$$

In eq. 5.19 the LDP function is shown. It is related to the mean value of the LDP, considering all paths between source and destinations nodes. Moreover, also the constraint bound is considered, in order to evaluate the solution:

$$c(x_j) = \frac{\sum_{i=1}^{p} \overline{LDP(x_i)}}{[\overline{LDP(x_j)} - H]}. \tag{5.19}$$

The$[\gamma_\Delta, \gamma_\chi, \gamma_\theta]$ is the array of the weight costs related to delay, Co-Channel Interference, and LDP function, respectively; moreover they are also a normalizing factor and therefore they follow the following laws:

$$\gamma_\Delta = \alpha_\Delta \cdot \frac{1}{\sum_{i=1}^{p} a(x_i)}, \tag{5.20}$$

$$\gamma_\chi = \alpha_\chi \cdot \frac{1}{\sum_{i=1}^{p} b(x_i)}, \tag{5.21}$$

$$\gamma_\theta = \alpha_\theta \cdot \frac{1}{\sum_{i=1}^{p} c(x_i)}. \tag{5.22}$$

These weight costs have to be greater than zero and they permit to normalize the objective function components. Next section shows some considerations about them. Before observing performance evaluation, it must be said that due to the presence of mobility and wireless phenomena, some degradations are dynamically introduced into the system, so once the optimal channels have been chosen for data transmission, they have to be checked and refreshed each δ amount of time, verifying if some better conditions (in terms of channels and paths) exist.

5.3 Performance Evaluation

Network Simulator-2 (NS-2)[63] has been used to integrate the proposed idea with different existing protocols. First of all, the QoS MAC of IEEE802.11e has been introduced and then it has been extended in order to include all the functionalities

Table 5.1: Simulation Parameter

Sim Number	Delay bound (s)	LDP Bound (s)	CCI Bound (dB)	α_Δ	α_χ	α_θ	T_x Rate (Mbps)	Vehicles Number
1	0,3	40	300	1	1	1	4	40
2	0,3	40	300	0,6; 0,3	[0,1; ...; 0,9]	[0,1; ...; 0,9]	4	40
3	1,1	40	300	0,6; 0,3; 0,9	[0,1; ...; 0,9]	[0,1; ...; 0,9]	4	[40; ...; 100]

of the multi-channel IEEE802.11p standard. The SUMO [64] mobility generator with a user friendly GUI has been used to create mobility log files, with the following parameters: map dimensions 2000m 2000m, maximum vehicle speed 15 m/s. Transmission rate has been fixed to 4Mbps and the transmission range has been fixed to 300 meters.The number of concurrent connections has been fixed to 15. An example on how the signalling packets are changed in order to take into account the additional fields can be found in [51].The optimal values of some simulation parameters have been determined through different campaigns of simulation. The first campaigns have been carried out in order to find the right parameters for the route finding problem. In particular, once a scenario is defined, it is important to well design the related bounds, otherwise it will be not possible to find admissible solutions. This step is made at simulation beginning and in future works it will be studied as an automatic procedure to self-configure the bounds of the networks. In order to evaluate the linear optimization proposal some dedicated campaigns have been carried out. In particular, we test the capabilities of algorithm to find the best solution that satisfies QoS constraints and spreads information among source and destinations. To make these campaigns we have utilized the parameters presented in Table 5.1 at Simulation no.1 related row. In Figures 5.4 and 5.5, the results of the simulation campaigns are shown: it is possible to observe that the more feasible solution is x_4, because it represents the better combination of QoS matching requirements. In fact, the chosen solution shows a lower delay, the second higher LDP value and a CCI value that is good enough to make the solution with the higher fitness value. However, all solutions that have been carried out respect the constraints over the delay, LDP, and CCI.

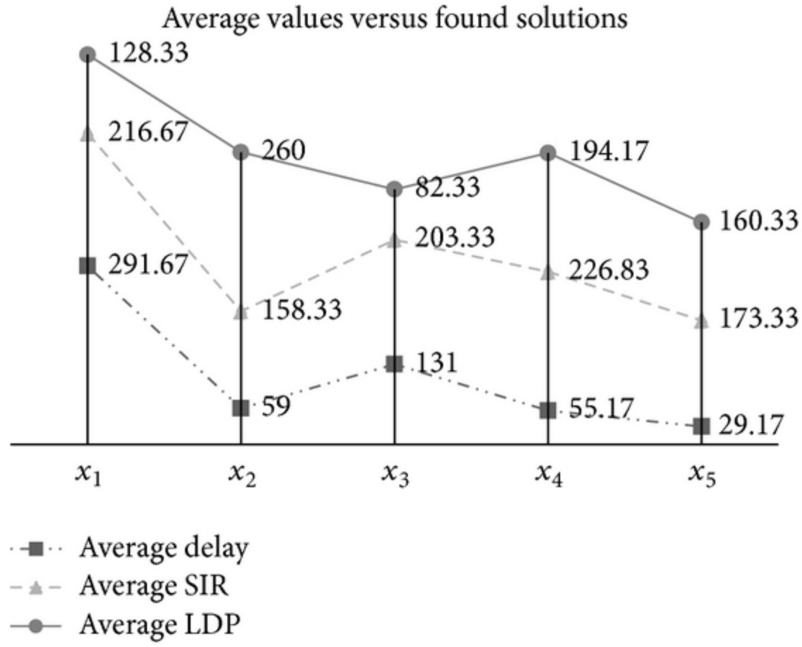

Figure 5.4: Delay, SIR, and LDP average values versus available solutions.

First addicted campaign of simulations has been carried out, considering a transmission rate of 4 Mbps, in order to evaluate protocol performance (in terms of Packet Delivery Ratio PDR and Aggregate Throughput) and different weights values { α_Δ, α_χ, α_θ } belonging to the set of values [0,1;...;0,9] (see Table 5.1 at Simulation no.2 related row.).

Figure 5.6 shows the trend of PDR: it is shown that, fixing the values of α_i, there are some values that lead to maximum point on the surfaces.Therefore, it can be concluded that if a higher weight is given to the interference term and to the link duration probability ($\alpha_\Delta = 0,6$, $\alpha_\chi = 0,6$, $\alpha_\theta = 0,7$), then the system will observe a higher percentage of correctly delivered packets.

Figure 5.7 shows a similar trend for the average system throughput as the one shown in the previous figure. Also in this case, an optimal value can be obtained

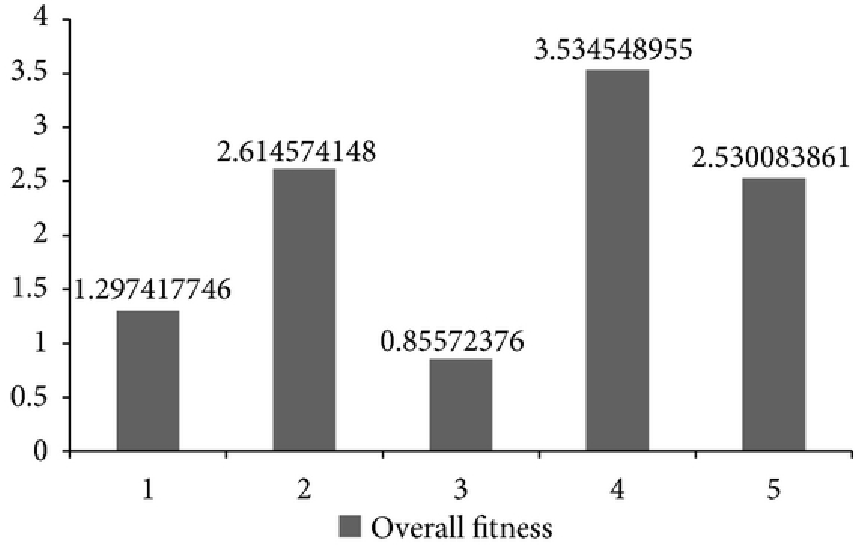

Figure 5.5: Feasibility of the found solutions.

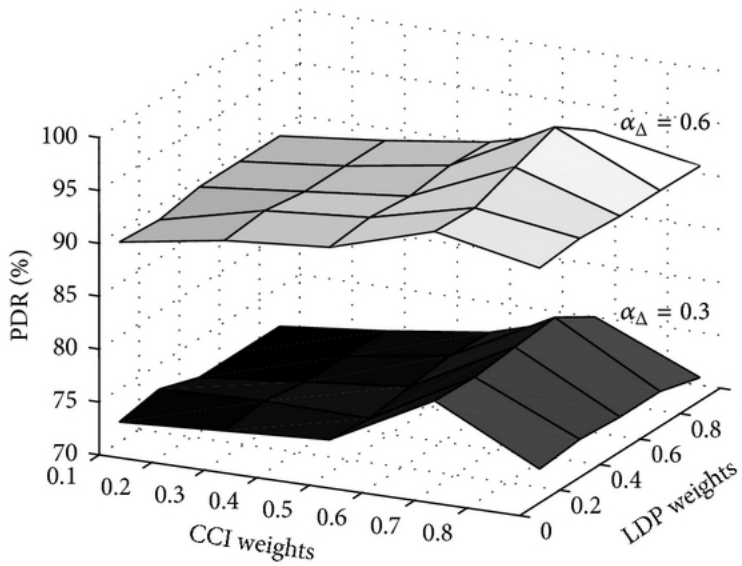

Figure 5.6: PDR trend for different values of α_i.

for the configuration ($\alpha_\Delta = 0,6$, $\alpha_\chi = 0,6$, $\alpha_\theta = 0,7$), for which the maximum performance is obtained.

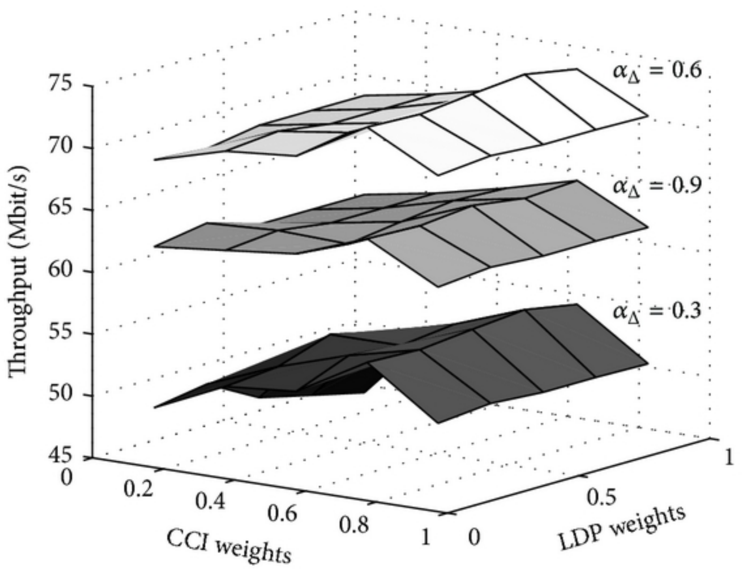

Figure 5.7: Average throughput trend for different values of α_i.

At this point, the metric of MO-RP protocol is completely defined and it can be used to evaluate the performance of the proposed protocol scheme.We compared the MO-RP scheme to classical AODV protocol, A-STAR, and DSR. Simulation parameters are the same of the previous campaign, but in this case the number of mobile vehicles change from 40 to 100.

In Figures 5.8 and 5.9, how the MO-RP outperforms the other protocols in terms of PDR and System Throughput are shown. Some considerations can be made about the aggregated throughput (the sum of the throughputs of all connections): introducing a composite metric, interference level and link duration are taken into account, so more stable paths are chosen, reducing the probability of packet loss and retransmissions.Therefore, this is evident when considering the percentage of correctly delivered packets and system throughput.

Referring to the overhead performance, as illustrated in Figure 5.10, the MO-RP protocol performs slightly worse than the other ones, due to the new signaling packets that are introduced into the network. These packets are utilized for the construction of alternative paths. The introduction of new protocol messages makes the overhead (evaluated as the ratio between the number of signaling

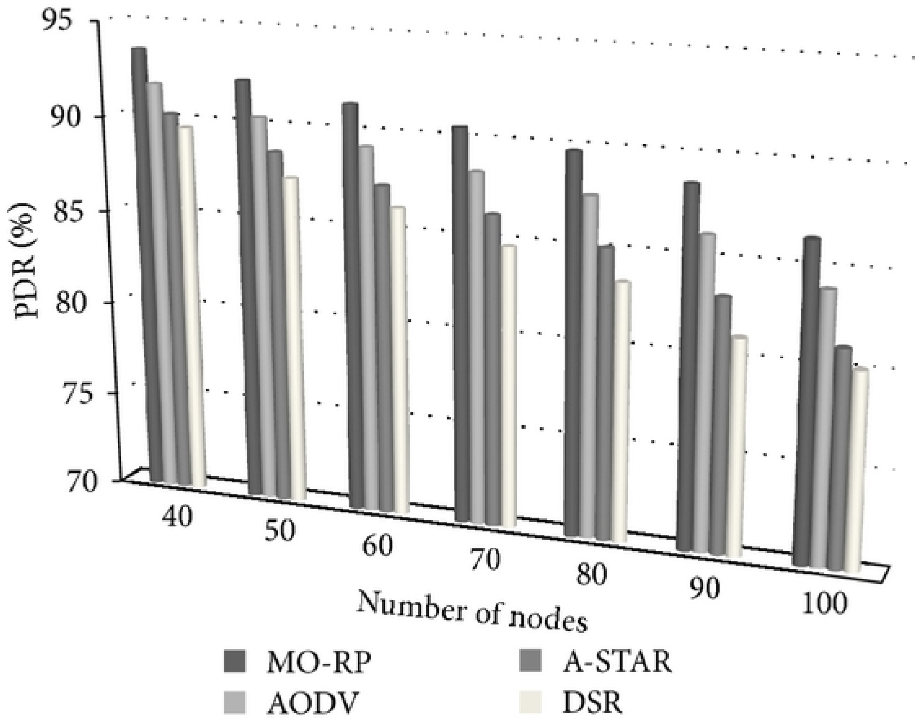

Figure 5.8: Average PDR versus the number of mobile nodes.

packets and the number of total packets) of MO-RP higher than classical AODV schemes.

Figure 5.11 shows the trend of the average End-to-End (e2e) delay observed by mobile nodes. In this case, the proposed protocol obtains the best results compared to other protocols.

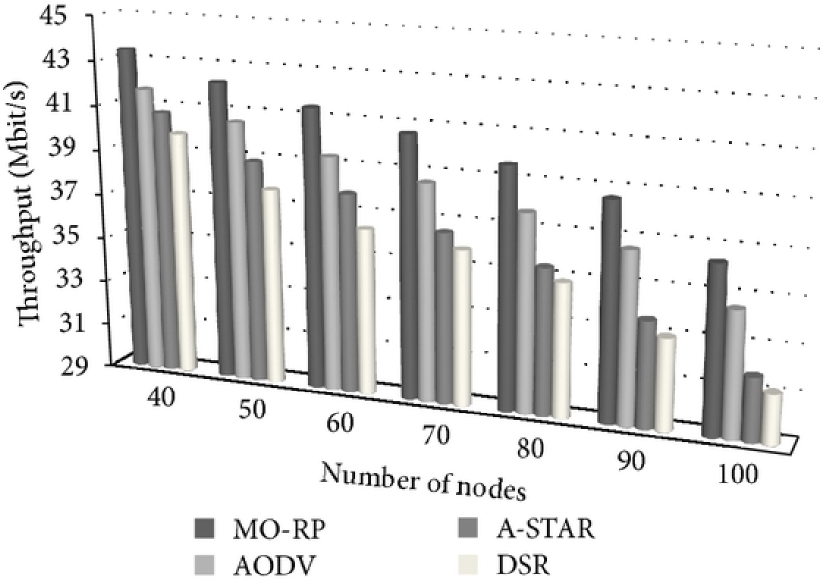

Figure 5.9: Average aggregated throughput versus the number of mobile nodes.

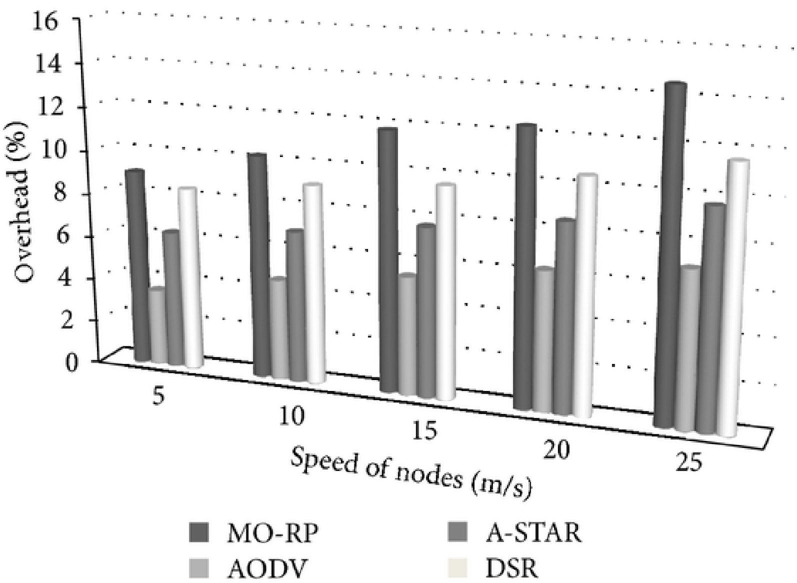

Figure 5.10: System overhead for 40 mobile nodes.

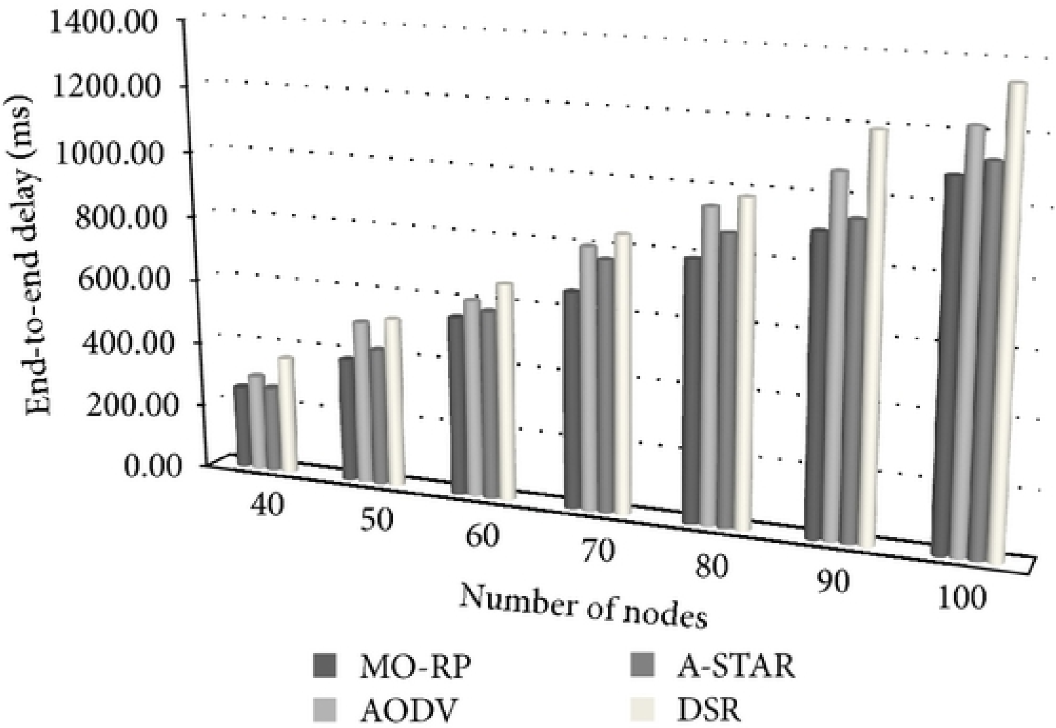

Figure 5.11: The average e2e for the proposed protocol.

Chapter 6

Safety enhancement and CO_2 reduction in VANETs

In this Chapter, a novel cooperative architecture that allows vehicles to communicate between them exploiting Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) connections is presented . In order to spread information we propose a network protocol called SeAWave that takes advantages of IEEE802.11p standard and tries to enhance it adding useful messages increasing vehicles' passive and active safety systems. In this work we propose a novel protocol in order to gather important data about environment such as collisions, block, emission levels and so on. These data are collected by the CTM exploiting dedicated messages sent by the vehicle and infrastructure devices. They are used by the system to activate alerting mechanism using protocol messages in a controlled broadcasting. In addiction, CTM knowing the whole status of the road network can avoid traffic blocks making some high level decisions. Also a smart traffic management system is addressed in the proposed framework in order to reduce vehicles' CO_2 emissions in the urban area increasing, where possible, air quality. In order to validate proposed framework and protocol we use a well know Discrete-Event Simulator (DES) simulator with a dynamic mobility generator that allow us to change and control reference areas, area size, and loads rate.

6.1 Architecture

In this work, a heterogeneous architecture composed of a CTM, RSUs and vehicles has been proposed. The CTM communicates with RSU layer and it picks up information about the real time traffic conditions. The RSUs communicate with the CTM in a periodic manner in order to guarantee an efficient message exchange avoiding worst effects of an uncontrolled flooding. These messages are sent exploiting the wired communications used also to connect RSUs with external domains such as internet and son on. CTM supplies distributed services and it is designed following the Cloud Computing architecture. CTM has the main task to inform systems about roads condition and traffic management making a distributed analysis of the acquired data, the V2I communications are used to spread those information and to acquire from the network needed data. Thus, vehicles can require information about lanes that belong to the chosen path sending a message towards local RSU to the CTM. The RSU can communicate with the CTM every T_{update} seconds asking for network updates. In this message, some important parameters related to covered lanes and roads are also supplied by the RSU exploiting the CTMD. CTM can exploit these information to evaluate congestion levels updating lanes costs reducing traffic loads. Messages exchanged allows vehicles to keep road information updated making possible a re-computation of the paths if the involved roads as well as their closer roads weight changes. The reference architecture is shown in Fig.6.1.

6.1.1 System

In this section we describe the main systems used in our work, such as OBU, RSU and CTM which are already defined in the previous sections. Deeper details about each system are given in the following subsections.

6.1.1.1 On Board Unit (OBU)

In our work we design a more complex vehicle unit. This device is composed of a core unit that can communicate exploiting inner interfaces with the vehicles sensors, Global Positioning System (GPS) unit and environmental sensors such

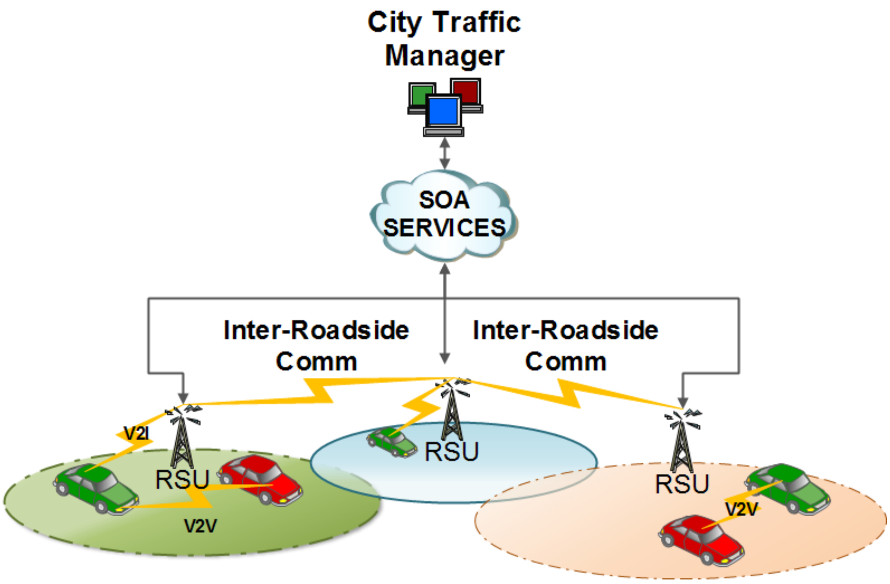

Figure 6.1: Reference Layered Architecture

as proximity sensors, distance sensors and so on. All data are briefly elaborated and filtered by the internal core and summarized to be sent towards external interface as a WSM. We will explain SeAWave messages in next sessions. The vehicles are equipped with this OBU and they can receive messages from the network layer exploiting multihop (V2V) and from the V2I communications that are established between RSU and OBU. Related to the proposal protocol the OBU can receive and send several messages, for more details refer to table 1.

6.1.1.2 Road Side Unit (RSU)

In this section we are going to briefly explain main tasks of the RSU. The RSU is used to work as connector between vehicles and CTM having also the task of spreading messages along the network. It also monitors the covered roads with its own services. When the OBUs reach a covered area they send messages regarding their location and become information suppliers for the RSU and the whole system, helping them to increase the real-time knowledge of traffic, road and environment conditions. An overall scheme of the RSU core capabilities is shown in fig.6.2. As it is possible to note the RSU is equipped with an internal SeAWave-Data Base (SW-DB) used to collect protocol messages avoiding multiple

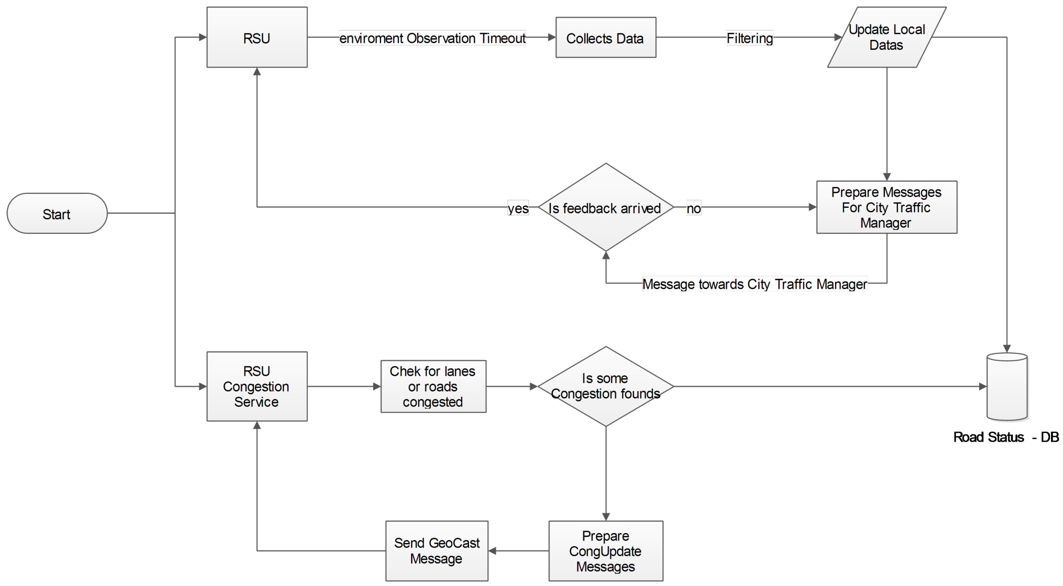

Figure 6.2: RSU - High Level Block Diagram for the core thread of the RSU

sending of the same information.

6.1.1.3 City Traffic Monitoring Device (CTMD)

These devices are installed on the roads junctions and can communicate with RSUs sending information about lanes that composed the roads where they are installed on. These information regard ingoing and outgoing rates, number of vehicles, average speeds and *Lane Leave Time* (*llt*). These data are periodically sent and collected by the related RSU. RSU sends collected data to the CTM when it requests them exploiting the *CongestionCheck*(congCheck) message. They are sent back to the CTM on the congAck message, which it is better explained in the next sections.

6.1.1.4 City Traffic Manager (CTM)

In this section we describe the behaviour of the CTM that represents the entity that has the main task of managing the whole city traffic also in case of traffic blocks or congestions. The CTM takes information about roads and traffic level exploiting the VANET layer, these information are gathered by the exchange of messages among vehicles (V2V) and among vehicles to infrastructures (V2I) segments. In particular, the RSUs have the main task to collect information about vehicles, roads and sensors, sending important data to CTM. One of the most important challenge that the CTM has to face is the balancing of the traffic loads in order to avoid traffic blocks and road overloads. Of course, this auto load balancing is often stopped by some dynamic events that happen on the roads such as collisions and obstacles. These events can be recognized by vehicles and road units exploiting networking. Once the CTM recognizes them it changes the weights of the related roads and sends messages towards the RSU to communicate weights changes. After that the weight computation is made these messages are sent to the vehicles following dissemination rules in order to avoid congestion and further blocks. Collected information are used by vehicles in order to update their local map and a routing routine is forced to be executed.

6.1.2 On Board Device Cooperation

Taking advantages of IEEE802.11p based architecture and enhancing on-board device cooperation. A huge amount of data can be used to better understand drivers behaviours. Considering smart devices at the higher level of the architecture and triggering elaboration process on-demand, emergency or critical situations can be identified observing drivers actions on the vehicles, distances between them and considering external factors such as obstacles, road borders and blocks. It is possible to have information about vehicle position exploiting GPS. Data about driver style and current vehicle condition are gathered exploiting connections with On Board Diagnostic System - II (OBD-II) interface. In this way we can have the possibility to access several information in a real-time manner. Therefore, OBU that we are using is smarter and a little bit more complex than a standard OBU, which is commonly used in a IEEE802.11p environment.

6.2 Protocol proposal based on IEEE802.11p standard

In this section we introduce some details about this proposal and, in particular, about messages that we implemented on the basis of the WSM, which is composed as shown in fig.6.3. As stated in [65], WSM frame is data structure used to send WAVE short messages frames. WSMP Version field shows the version of the WAVE protocol, PSID Provider Service Identifier field, Channel Number field which defines the channel that is used for communication, Data Rate field specifies the data rate used in transmission, WAVE element ID field which represents WSMP header, WAVE Length field which determines length of the data field, and WSM Data field contains the payload data e.g. Hello World.

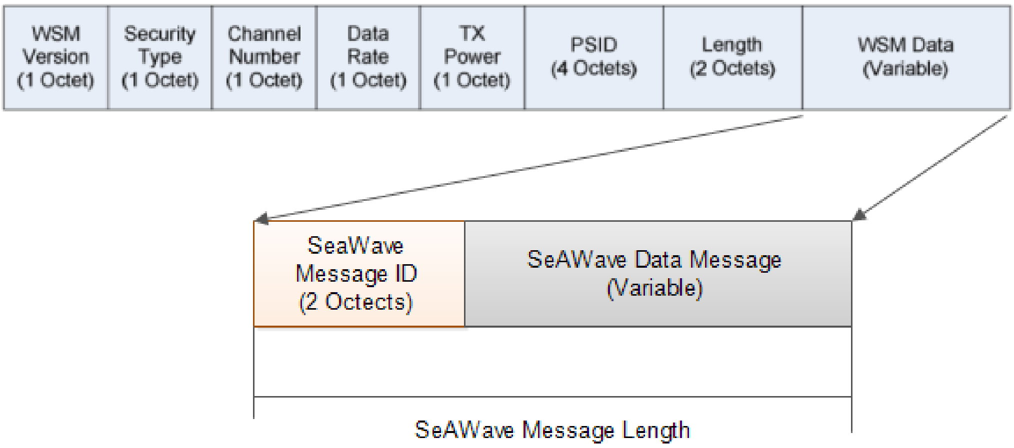

Figure 6.3: WSM - Packet format

Table 6.1: SeAWave messages specification

Message Name	ID	Sender	Receiver
collision msg	*0x1*	*OBU*	*OBU,RSU*
collision end msg	*0x2*	*OBU*	*OBU,RSU*
PosUpdate msg	*0x3*	*OBU*	*OBU,RSU*
beacon msg	*0x4*	*OBU, RSU*	*OBU,RSU*
warning msg	*0x5*	*OBU*	*OBU*
warning end msg	*0x6*	*OBU*	*OBU*
congestion check msg	*0xA*	*CTM*	*RSU*
congestion ack	*0xC*	*RSU*	*CTM*
congestion update msg	*0xB*	*CTM*	*OBU,RSU*
Topology Update msg	*0x20*	*OBU*	*RSU*

- **SeAWave Message ID**: this field is used to identify a message, the reference table is shown in Table 1. It is a 16-bit field size and it is used by the systems (CTM, RSU, OBU) to recognize information.

- **Message Data**: this field changes its meaning in function of the type of message, in fact its length is based on the type of information that are carried out.

6.2.1 Position Update

Position Update is an inner function that give us the possibility to bring up information about the neighbour vehicles. These data are picked up exploiting protocol messages called *Position Update* (*PosUpdate*). In order to reduce protocol overhead, the total amount of protocol messages that will flood in the network is limited. This is achieved by sending some info-messages, which are related to local issues, only to neighbours. In the *PosUpdate* messages all information related to the position of a vehicle taken from GPS are collected. Once these information are received, they are also elaborated and if and only if the distance among vehicles is lesser than a certain threshold both nodes become neighbours. If distance is greater than the threshold the vehicle is erased from the neighbour list and no more messages are sent towards it. Process of the inner function *PosUpdate* is shown in fig.6.4

6.2.2 Warning Message

Warning message is another kind of message that is sent by the vehicle in the network when something happens during a car journey. We can identify some common events during driving experience. We considered the following:

- **unexpected_vehicle_stop**: this event is generated when something happens and the drivers usually respond to the event with an instinctive action stopping the car. This road events are very common in the city environment and several collision accidents can happen. An example is shown in fig.6.5;

- **vehicle_control_lost**: in this event, the on-board system reveals that something goes wrong with the car or driver behaviours; this is managed by the

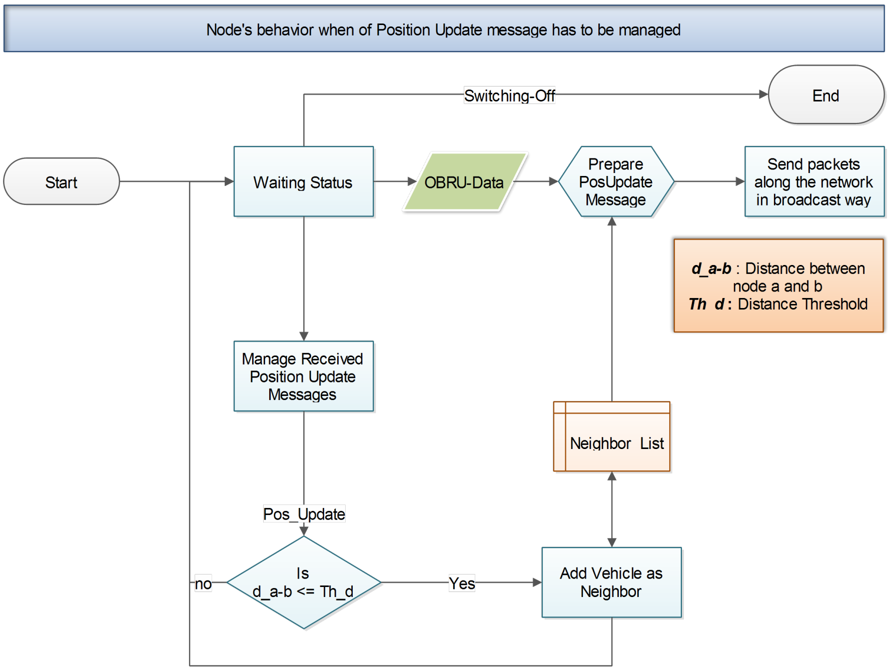

Figure 6.4: Position Update inner function flow chart

safety car system sending a warning message to other cars to avoid collision. Actually, message is sent towards the neighbour vehicles and a speed reduction is requested to avoid collisions or dangerous situations.

6.2.3 Collision avoiding messages

When an accident happens on a road, the vehicles that are involved on send a message to advice others about what happened. Of course, it is important to advice when this event is going out, therefore an explicit message, which has the main goal to inform other vehicles that the accident is ended, has to be sent as well. For this reason we introduced two messages that are presented below.

6.2.3.1 Collision Start Message

The accident message is sent along the network in a broadcast way exploiting the V2V and V2I connections. In this way we can reach all vehicles under coverage areas. The coverage areas are given by union of all cluster areas created by OBU

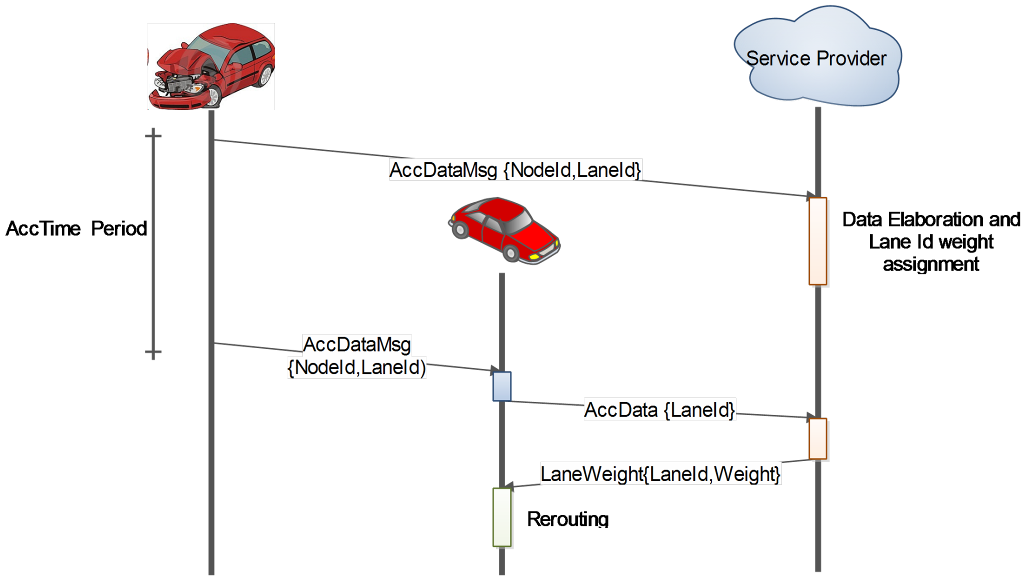

Figure 6.5: Car Accident Messages Diagram Timing

and RSU coverage areas. This is made in order to avoid congestion, in fact, a new paths discovery procedure is performed by the vehicles that are involved in those areas. This helps to solve in a shorter time collisions giving the possibility to find in a easy way exit gates. In order to avoid high level of flooding these messages are stored in nodes using a SW-DB helping us to avoid unneeded data along the exit interfaces of a node. Since collision can have a long duration several vehicles may arrive in a dynamic manner in the involved area. Vehicles involved send, in a periodic manner, Accident Data Message (AccDataMsg) that contain collision data and the identifier of the involved lane. Once a node receives these information it asks for the weights associated to the lane around the accident area to the service provider. Once these data are received it performs a re-routing in order to find a new path. A Timing Diagram of a collision message propagation is shown in fig.6.5

6.2.3.2 Collision End Message

This message is sent when a collision event is solved, therefore, all vehicles involved are free to move. When vehicles ends all activities, the authority can send messages that inform other systems that the collision is solved and road is free.

This allows other vehicles to use once again this lane so to optimize their paths.

6.2.4 Topology Update

Topology Update (*topUpdate*) message is generated by vehicles and it is sent towards the local RSU. When a connection link changes in terms of quality, the related weights are updated and these information have to be sent to the RSU that keeps the knowledge of the low-layer network. RSU has the main goal to collect information to better spread data along the network. One of the most important term is the interference that is noticed by both OBU and RSU when they are going to send beacon messages. This is continuously made each time a message is received or sent on an interface. In order to evaluate the interference metric, nodes have to perform a computation, monitoring the transmission and received power on the available channels. In order to better understand this process the pseudo-code of the computational module is herein reported. In Algorithm-**??**, TXGAIN represents the transmission gain of the antenna T_x, ANTENNAHEIGHT is the height of both antennas (T_x,R_x), TXPOWER represents the transmission power, *pLoss* is the path-loss and the term THERMALNOISE is the thermal noise.

Another typical change may be the loss of connection or new available connections. Therefore, these messages can help RSU to spread information along the available branches choosing the best path in terms of network routing.

6.2.5 CTM related messages

Now we present a set of messages used by the CTM to acquire and send information on the traffic level reached in the urban area. It is possible to find critical points in terms of traffic blocks through a continuous monitoring of the road status.

6.2.5.1 Congestion Check

This message is generated in a periodically by the CTM in order to bring up information about status of the roads that compose the city traffic network. These queries are sent to the RSU following the timing rules that are shown in Fig.6.6

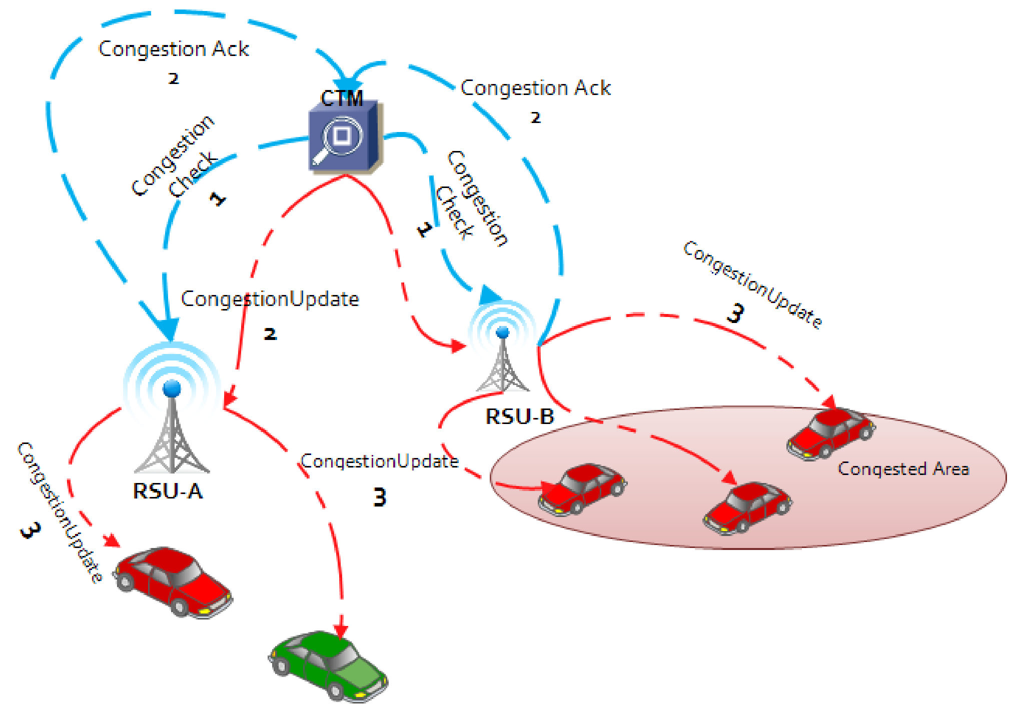

Figure 6.6: Road Congestion Identification process

(See message number 1). Once the RSU receives this message it encapsulates all information about traffic, which are gathered from the CTMD, sending data towards CTM exploiting the congAck message.

6.2.5.2 Congestion Ack

As shown in Table 1 and in Fig.6.6, this message is sent by the RSU towards the CTM, exploiting the internet connection (see message number 2) and a RESTful service. Moreover, this message contains information about roads status that belongs to the coverage area of the RSU. For each road that changes its status RSU sends an information packet that will reach the CTM. The packet format is shown in Fig.6.7, this message is composed of a fixed and variable section. In the first section there is a field called "*lanenumber*", that allows CTM to evaluate the total amount of data.

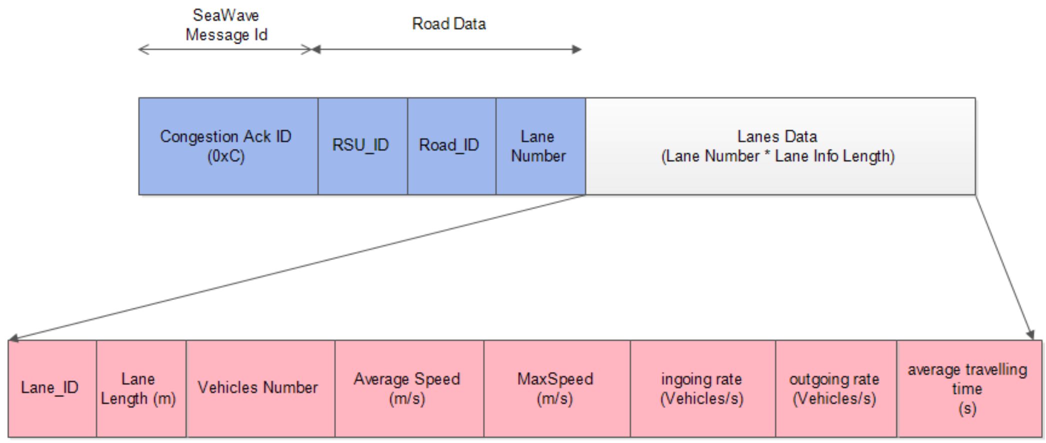

Figure 6.7: congAck message format

6.2.5.3 Congestion Update

In order to realize our proposal, we need to monitor roads condition in a real time way. This can be made exploiting several sensors around the city and RSU devices. The working schema is shown in Fig.6.6. The RSU collects messages coming from the OBU and CTMD sending these data when the CTM, in a periodic manner, asks for them (see message 1,2 and 3 in Fig.6.6). The CTM collects all data and sends back data through the *Congestion Updated* (*CongUpdate*) message in order to notice to the other systems if some traffic issues have been found. The RSU broadcasts the messages into the network covering roads areas.

6.3 Problem Description

One of the main issues that this work tries to face is the better management of traffic and roads congestion in urban and sub-urban areas. Usually, these blocks generate several disadvantages for those vehicles that have to move towards and outwards cities area in order to reach their destinations. Commonly due to these blocks, traffic level increases exponentially, because drivers cannot find feasible exit gates and they may be involved into congestion as well as other vehicles that reach the congested areas before them. This represents a big issue for traffic management; in fact, as several surveys have already demonstrated, the higher is the traffic level the higher is the CO_2 level into air. Using a protocol that allows communication among vehicles it is possible to implement an efficient CTM. It can control congestion in a faster way, avoiding high levels of traffic. This can be made acting a continuous traffic monitoring, exploiting vehicles communications and fixed devices (CTMD) along the roads. The whole system can be viewed as a hybrid network infrastructure composed of several devices able to collect, store, send and elaborate information from the environment. The main goal of our proposal is to face the problem dividing it in two sub-problems: the first one is the routing optimization in terms of packets delivery, the second one is the management of the traffic exploiting all information that can be picked up from the environment.

6.3.1 Road and Lane definitions

We refer to a generic Road (R) of the traffic network infrastructure. It may be composed of one or more lanes (each one indexed), so if we want to refer the $2-nd$ lane of the $i-th$ road (R_i) we can recall it using the notation $L_{2,i}$. Moreover, it is important to know the length of the $j-th$ lane to perform further computations; it will be called $l_{j,i}$. In order to avoid congestion we have to define some critical constraints to model the queues, so we assume that each lane related to a road R_i admits a certain maximum speed $MaxSpeed_{j,i}$, where j is the lane index of the road i. It is also important to define an average vehicle length that we assume to be $v_{length} = 2.5m$.

6.3.2 Neighbours discovery

In this section we are going to introduce how the nodes can discover a neighbour vehicle and how it can start to interact with it. A near node is classified as neighbour if and only if the air distance among nodes is lesser than a certain threshold (N_{TH}); all information about node position is carried by *PosUpdate* message, which is sent periodically by the vehicles. Therefore, a node is a neighbour of another one if the following constraints are satisfied:

$$rdistance = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{6.1}$$

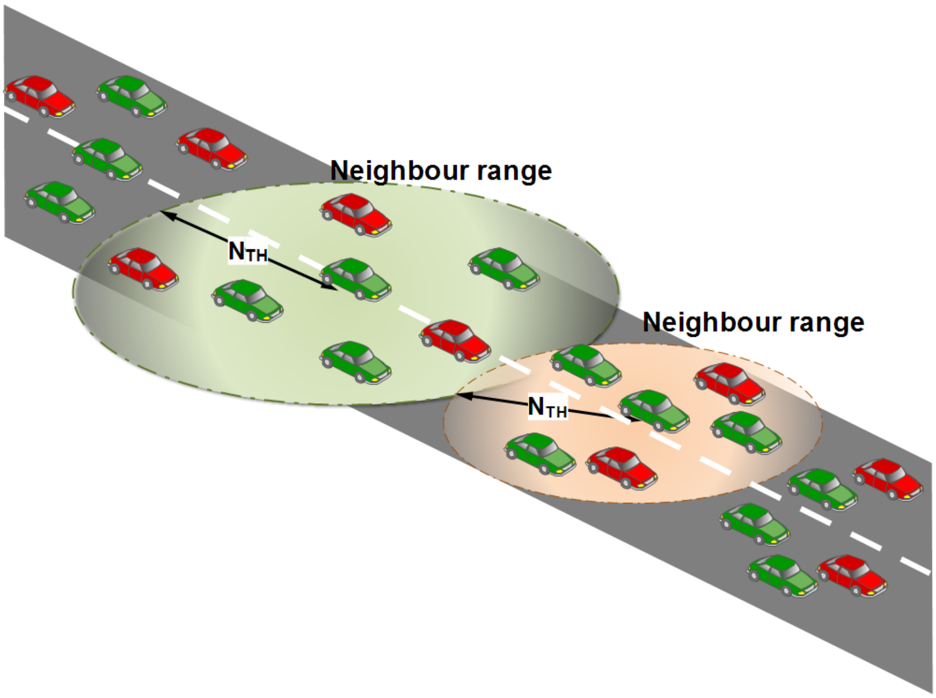

Figure 6.8: Neighbours Discovery using different N_{TH}, as is shown changing this value it is possible to consider a wider or a narrower space.

$$rdistance < N_{TH} \tag{6.2}$$

The effect of N_{TH} in the neighbours choice routine is shown in Fig.6.8. In this picture, it is possible to note that the wider is the value of N_{TH} the higher is the probability to have a higher number of neighbours. Of course, the higher is the number of the neighbours the higher is the number of messages that may flood in the network, due to the flooding of the *PosUpdate* messages. In order to find the right value of N_{TH}, several simulation campaigns have been carried out such as presented in the simulation results section. In equation (6.1) the position into the Cartesian plane of node 1 is given by $p_1 = (x_1, y_1)$, while the position of the second node is $p_2 = (x_2, y_2)$. Considering two adjacent nodes, n_k, n_h that belong to the Vertex set (V) of the network topology graph $G(V, E)$, node n_j can be able to receive messages sent by the node n_i if and only if the equation 6.2 is respected. The neighbour lists are managed exploiting *PosUpdate* protocol that spread along the network in a broadcast way, the position of each vehicles. This message is sent in a periodic manner and it contains information about current position (achieved by GPS on board device). Of course, the Latitude and Longitude coordinates are converted into a Cartesian reference system, which has the origin in the upper left corner of the city map area. The propagation of the *PosUpdate* message is made towards neighbours only limiting the dissemination on the basis of the vehicles position. This permits to avoid a drastic protocol overhead increase and message flooding that can influence the overall performances of the network.

6.3.3 Packet delivery routing problem

In this section the packet delivery is treated. In particular, we present considered metrics and the routing algorithm that are used to perform the distribution of the path computation.

6.3.3.1 Graph and networking

In order to better understand the further nomenclature used in this work, an introduction about graph theory is briefly presented in this section. A network topology can be viewed as an oriented and weighted graph where the network nodes represent the vertexes and the connections between nodes are the graph edges. Therefore, the network is represented by a Graph $G(V, E)$ where:

- V is the set of the vertex and it is composed of all active vehicles that are involved in the network;
- E is the set of the edges that connects nodes in the network;

Moreover, each edge belonging to (E) is related with a weight vector called $W_{E_{(i,j)}}$ that contains the edges' characteristics that will be used by the router algorithm to find the best routing paths as shown in figure (6.9).

6.3.3.2 Metrics definition

Metrics definition is important due to the path finding problem formulation. Considering two neighbours (vehicle) k and h, the term $\rho_{k,h}$ is related to the interference of the wireless channel between them. It can be viewed as a calculation

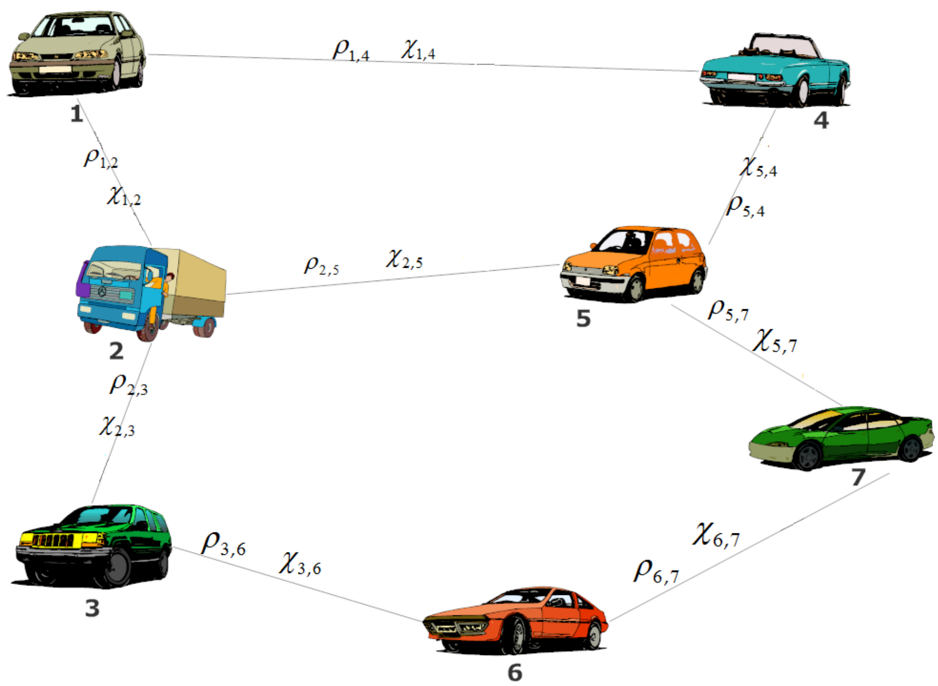

Figure 6.9: Links' weight definition

of Signal to Noise Interference Ratio (SNIR) considering the following parameters related to the wireless link, the transmission power P_{tx}, the received power P_{rx}:

$$SNIR(ch_j) = \frac{P_{tx}}{\sum_{i=1}^{N} P_{rx,i}(ch_j)} \tag{6.3}$$

where N is the number of the neighbour node, ch_j represent the available transmission channels. The term $\chi_{k,h}$ represents the delay on a wireless link between vehicles k and h, which is obtained considering the following contributions: processing delay ϕ, queuing delay φ, transmission delay ψ and propagation delay ϱ (see the following equation 6.4).

$$Delay = \phi + \varphi + \psi + \varrho \tag{6.4}$$

6.3.3.3 Routing Algorithm

In order to keep information updated about links' status and connection among nodes, it is important to exchange protocol messages. In particular, two messages

PosUpdate and *topUpdate* have been designed to address this issue. In particular, the first one is important to discover the neighbours and to build low-layer network connections. The second one is used to update the link cost (they are used also as a keep-alive message to maintain connections). Since the signalling messages are generated by the OBU systems, these messages are distributed in an easy way following broadcast or unicast distribution. In case of unicast dissemination the shortest path is evaluated on the known topology in order to reach the local RSU. Once the RSU is reached, the packets are sent on the rest of the networks making a routing computation in the RSU nodes in order to reach all involved nodes in the communications. For more details about messages please see the related sections.

Table 6.2: Symbol Table

Symbols	**Description**
N_{TH}	Neighbour Threshold
$n_{j,i}$	the number of vehicles on the lane (j) of the road (i)
$C_{j,i}$	the set of vehicles on the lane (j) of the road (i)
$att_{j,i}$	average travelling time along the lane (j)
$sd_{k,j,i}$	safety distance of vehicle k on the $j-th$ lane of the $i-th$ road
$S_{k,j,i}$	current speed of the $k-th$ vehicle on the $j-th$ lane of the $i-th$ road
$O_{k,j,i}$	total spatial occupancy of a vehicle (k) on the $j-th$ lane of the $i-th$ road
$lv_{k,j,i}$	the length of the $k-th$ vehicle on the $j-th$ lane of the $i-th$ road
$I_{j,i}$	the lower-bound in terms of travelling time
$llt_{j,i}$	the lane leave time of the $j-th$ lane on the $i-th$ road
$lw_{j,i}$	the average lane width
$llSp_{j,i}$	the average lane leave Speed
$VN_{j,i}$	the maximum vehicles number that determines a road without congestion

6.3.4 Congestion management

Sometimes, roads present several blocks that can influence the normal flow of the vehicles in the city areas. These blocks, commonly, are the main cause of congestion as well as accidents. They cannot be predicted due to the dynamics events directly connected with external factors. One of the goal is to spread information about rising congestion events, this can be made sending info messages along the network. Once these messages are received, other vehicles can change or rearrange their paths allowing network system to avoid critical traffic levels in the involved areas and closer areas as well. Of course the higher is the traffic loads the higher is the probability to generate a certain level of congestion. To minimize traffic loads around the involved areas we have to use a smart routines in updating road cost in order to spread traffic along several exit gates avoiding to use the same exit gates for all vehicles. Moreover, if we concentrate several vehicles in the same areas, the probability to generate another critical point in terms of congestion is higher. This is a big issue to correctly address, a smarter weighting cost function has to be found in order to estimate the real impact of the accident on the urban mobility area. Therefore, it is important to establish when a generic lane is going to face congestion. To do this we used the following assumptions:
in order to reveal congested roads we use a model based on the probability density function of the Poisson distribution [66]. Since the arrival of the vehicles in a generic lane (j) of a generic road (i) are random, during a generic observing time period, we can assume a poisson flow. Therefore, the probability density function is herein shown:

$$p(x)_{j,i} = \frac{{\mu_{j,i}}^{x} e^{-\mu_{j,i}}}{x!} \tag{6.5}$$

In equation (6.5), the $p(x)$ is the probability that x vehicles are present in a generic period on the lane j of the road i. The $\mu_{j,i}$ term is the arrival rate of the vehicles and it is given in $\left[\frac{vehicle}{minutes}\right]$. Thus, If we want to know the probability that in certain time interval the number of vehicles are lesser than a certain value we easy obtain, starting from the equation (6.5) the following relations:

$$p(n)_{j,i} = \frac{\mu_{j,i}}{n_{j,i}} \cdot p(n-1) \tag{6.6}$$

Therefore, the probability to have a number of vehicles lesser than a value n on the $j-th$ lane of the $i-th$ road (R) is given by the following equation:

$$p(x \leq n)_{j,i} = \sum_{h=0}^{n} p(h) \tag{6.7}$$

In equation (6.6) the term $n_{j,i}$ is the number of the vehicles that are recognized on the $j-th$ lane of the $i-th$ road, where $C_{j,i}$ is the set of vehicles that are currently present on the lane (j) of the road (i). Therefore $n_{j,i}$ is defined as

$$n_{j,i} = |C_{j,i}| \tag{6.8}$$

Since we have a model that the CTM can use to establish if a lane (j) is going towards congestion we can try to find a relation among several parameters such as travelling time and number of vehicles that are present on the lane to identify which is the upper-bound, in vehicles number, that the considered lane can serve avoiding congestion. Let us to define the *Average Travelling Time (att)* along the lane (j) as :

$$att_{j,i} = \frac{n_{j,i} \cdot l_j}{\sum_{k=1}^{k=|n_j|} S_{k,j,i}} \; : \; j \in R_i \tag{6.9}$$

where $S_{k,j}$ is the current speed of the $k-th$ vehicle on the $j-th$ lane of the $i-th$ road; how it is commonly known the $safetydistance$ is directly related with the speed of the vehicle, therefore safety distance for a generic vehicle is given by:

$$sd_{k,j,i} = \frac{S_{k,j,i}}{k_{speed}}, \forall k \in C_{j,i} \tag{6.10}$$

In order to know the total spatial occupancy of a vehicle (k) with a certain speed $(S_{k,j,i})$ we can use the following equation:

$$O_{j,i} = E[lv_{k,j,i}] + E[sd_{k,j,i}] \, : \, k \in C_{j,i} \tag{6.11}$$

where in (6.11) the term $lv_{k,j,i}$ is the length of the $k-th$ vehicle on the $j-th$ lane of the $i-th$ road. In order to find the upper-bound we have to know which is the outgoing rate $\eta_{j,i}$ of the lane (j) of the road (i). Moreover, another important parameter is the $MaxSpeed_{j,i}$ that is the maximum speed that a vehicle ($k \in C_{j,i}$) can reach on the given lane (j).

$$I_{j,i} = \frac{l_{j,i}}{MaxSpeed_{j,i}} \tag{6.12}$$

the $I_{j,i}$ represents the lower-bound in terms of travelling time that a vehicle can spend passing through the lane (j) of the $i-th$ road. As first step, we consider a lane without any kind of blocks on the end of the lane; this means, for example, that no traffic control devices are installed on it. In this case, the complete time to spend on the line is composed of travelling time plus the time spent by the car to leave the lane when it reaches a junction point (this time is called *Lane Leave Time* (llt)). This time is given by the following equation:

$$llt_{j,i} = \frac{2 * lw_{j,i}}{llSp} \tag{6.13}$$

Therefore, the Total Time Spent on Lane (TTSL) is given by

$$TTSL_{j,i} = att_{j,i} + llt_{j,i} \tag{6.14}$$

6.3.4.1 Departure model

Since the average spatial car occupancy and the average lane length are known, it is possible to find an upper-bound $VN_{j,i}$ that represents the maximum number of vehicles that a lane can manage avoiding traffic blocks. The basic idea is to consider that when a lane is congested several vehicles take place in an Indian row. This queue length can be used as an index in order to reveal if the congested lane can cause traffic blocks involving closer roads that are located around it. Taking into consideration a factor k_{cong} we can model the queue length as shown in equation (6.15). In order to reach this length also the ingoing rate and the residual outgoing rate play an important role, in fact the higher is the difference among outgoing and ingoing rate the faster will be the queue saturation. The

k_{cong} has been chosen to be $\frac{2}{3}$ of lane length. We are currently investigating on a variable value of k_{cong} because if several congestion events can be found on the same lanes this could mean that reducing the ingoing rate it will possible to reduce the impact of the congestion on the closer areas. This can be made reducing the queue length and therefore the value of $VN_{j,i}$. In this case the ingoing rate is reduced by the CTM that can change the associated weight on traffic map on the vehicles sending a *CongUpdate* message before the limit value is reached.

$$VN_{j,i} < \frac{k_{cong} \cdot l_{j,i}}{O_{j,i}} \tag{6.15}$$

As above stated considering the Vehicle Number upper-bound (VN), which is evaluated by CTM, it is possible to reduce the ingoing rate in order to break down congestion levels along the city. Exploiting equation (6.6) it is possible to know the probability to have VN value on a particular lane. This can be used to make a forecast on the congestion levels, our attempt to face this issue is to minimize this probability acting on the best path finding process in a real-time way. This can be done triggering a routine for cost computation (as shown in sub-section 5.4.2), made by the vehicles to reach their destinations as addressed in [67]:

$$p(x \leq VN_{j,i})_{j,i} = \sum_{h=0}^{VN_{j,i}} p(h) \tag{6.16}$$

In order to reduce the probability that a lane block can happen, we can act on the ingoing rate of the lane sending a *CongUpdate* message to the RSU and OBU systems changing the weight of the related lane. In this way the vehicles can change their path because a higher cost is found on the interested lane.

6.3.4.2 Cost computation

In order to better recognize when a lane is congested, it is possible to refer to the time spent along the lane monitoring the average travelling time, that we have already defined in equation (6.14). In this work we consider the lower bound represented by equation (6.13) to associate a weight on the lane:

$$w_{j,i} = I_{j,i} + (n_{j,i} - VN_{j,i}) * TTSL_{j,i} \tag{6.17}$$

6.4 Simulation Results

In this section we present the results achieved using the protocol SeAWave that we have already introduced in previous sections. First of all we have to introduce the simulation environment and used constraints in order to better understand the achieved results.

Table 6.3: Simulation Table

Parameter Name	**Values**
Map Size	1.6 $[Km^2]$
Average road length	27 $[Km]$
Average vehicle length	2.5 $[m]$
Vehicle In-Rate	$100, 200, 250, 300, 450 \left[\frac{vehicles}{hour}\right]$
K_{speed}	[1/3]
K_{cong}	[2/3]
$lw_{j,j}$	$[4m]$
$llSp_{j,i}$	2 $[m/s]$

6.4.1 Network Simulator

The simulator that we have used is OMNet++ [68]. It is a network simulator based on a modular implementation written in C++. This is a framework that gives the possibility to extend all modules in a easy way. To manage vehicles' mobility, the network simulator is connected with SUMO [69]. In order to implement the protocol and the system architecture that we used, the base of framework is Veins [70] framework. SeAWave has been written on the veins framework introducing protocol rules and some important components of the system such as RSU and CTM. In the following simulations, we compared our proposal protocol with Wave Short Message Protocol (WSMP) [71] and CAM based protocol proposed in [67]. WSM short messages can be delivered to multiple destinations. Higher layer entities take responsibility for message signalling providing channel information

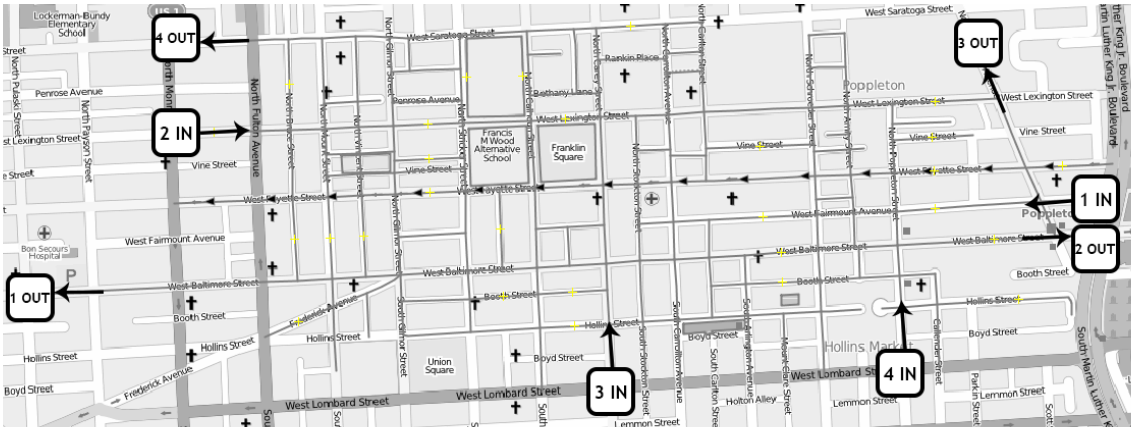

Figure 6.10: City map used for testing environment

about transmissions. WSMP ie. 1609.3 published by the IEEE Vehicular Society), is a part of the Dedicated Short Range Communications (DSRC) standards suite which include 802.11p and 1609.x series, which are used for "intervehicular communication" V2V and also for "vehicle to infrastructure communication" V2I. The aims of this section is to show the goodness of the proposal in terms of traffic management and safety goals reached. In the last scenarios we would like to show the goodness of the proposed solution in terms of CO_2 emissions. In [72] the CO_2 emission computation model that we use in our work is presented. Using the whole framework composed of on-board device collaboration and SeAWave it is possible to better spread traffic load along the city. It is also possible to view that the protocol help vehicles to reduce their traveling time around the city. Regarding protocol evaluation results (SeAWave) we carried out several simulations in order to bring up benefits of the proposed protocol also in terms of safety indexes such as number of accidents. The real map used in the simulation campaigns is shown in figure 6.10 as well as the ingoing and outgoing gates used for generating traffic flows inside the considered city blocks. The ingoing rates adopted for each flow are shown in table 3.

6.4.1.1 Neighbour Threshold evaluation

In order to find the right value for the *Neighbour Threshold* also called N_{TH}, several simulation campaigns have been carried out. In particular, as shown in

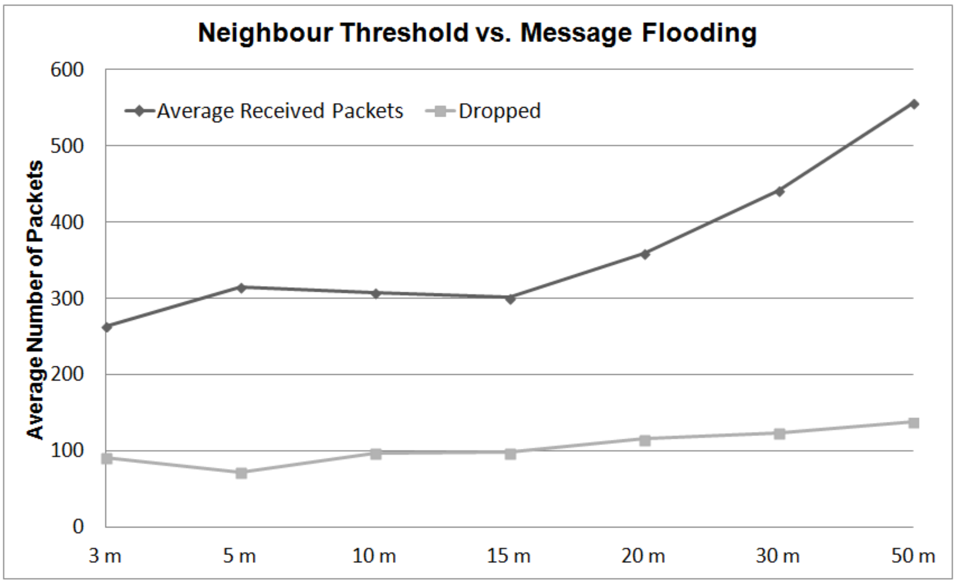

Figure 6.11: Neighbour Threshold impact on the flooding of the signalling messages

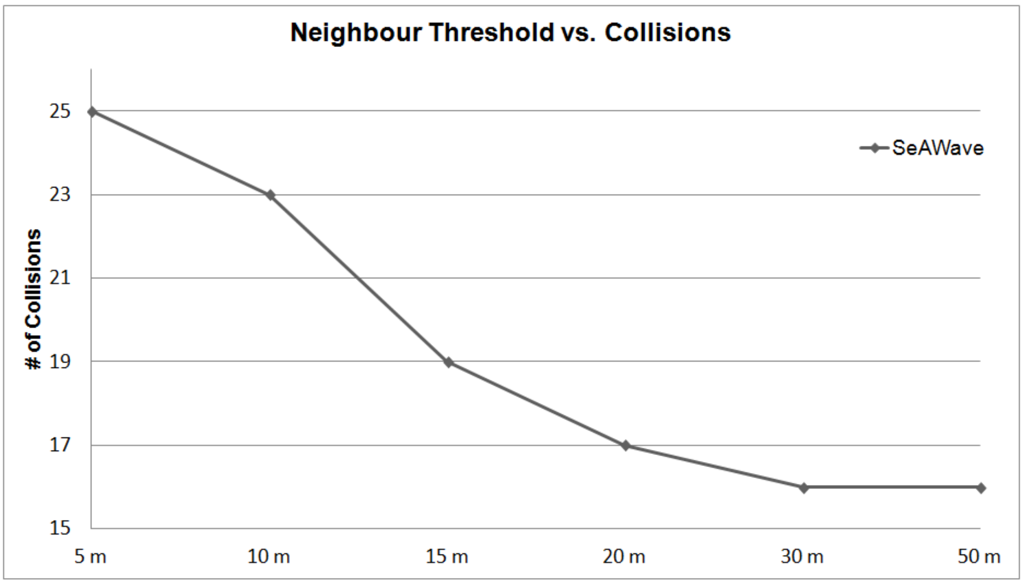

Figure 6.12: Neighbour Threshold relationship with the number of collisions

Fig.6.11 it is possible to highlight that using a N_{TH} value too low the messages used to enhance the protocol do not help us to improve safety levels. In particular, the signalling messages used for collisions reduction do not work as well as they should. This is depicted also in Fig.6.12 where the number of the accident is higher for low N_{TH} values. However, considering the impact of the N_{TH} on the message flooding it is not possible to use wider area because the number of the messages grow in an exponential way. In fact, the higher is the neighbour coverage area the higher is the number of the vehicles that could be classified as neighbour. In this campaign we used as vehicle input rate the value of 250[vehicles/hour]. A good trade-off has been found for a N_{TH} value in the range of [20m, 30m]. In this range the number of the collisions, as shown in fig.6.12, reaches an asymptote. This means that the higher are the values of N_{TH} the lower are the advantages to use a wider neighbour coverage area.

6.4.1.2 Protocol Overhead

In this simulation campaign we show the performance of the proposal in terms of protocol overhead reduction. In particular, we depict the effects of the protocol on the message flooding regarding the *PosUpdate* messages and warning message that will give us the possibility to save a lot of resources reserving them for data transmission. In this scenario, we planned to use several vehicles that travel along the map roads. In order to demonstrate the goodness of the proposal we use the protocol based on the CAM standard [67] and the SeAWave version equipped with neighbour management with a neighbour threshold set to 30m. In fig.6.13 the total amount of packets in the network is shown and it is also depicted how the SeAWave outperforms other protocols in terms of protocol overhead, in fact a lesser number of signalling packets are sent along the network in order to spread information obtaining good performances as well as demonstrated in other depicted figures.

6.4.1.3 Effects on Air Pollution

This simulation campaigns has the main goal to show that using communication and making an efficient cooperation among the entities, which are able to share

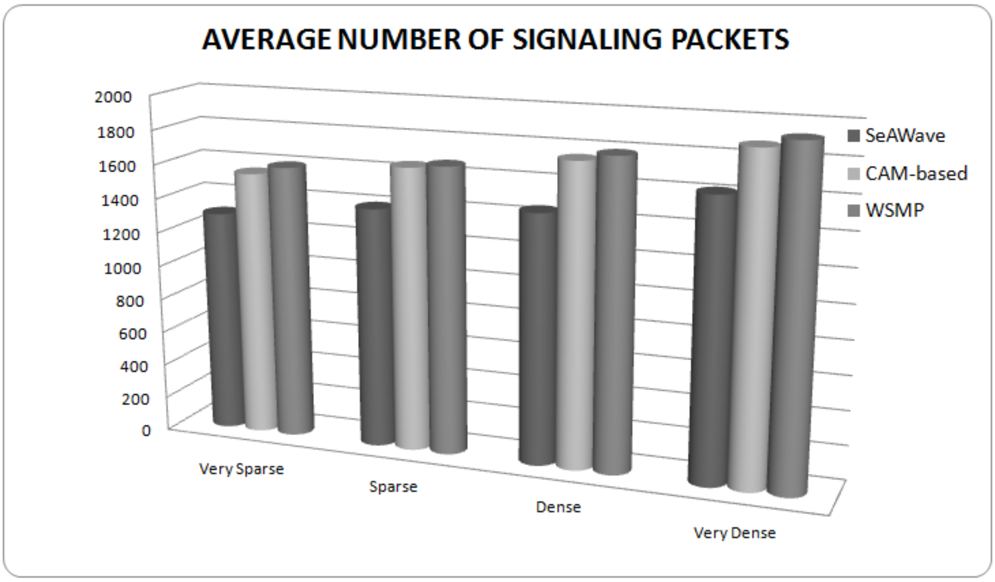

Figure 6.13: Average Signalling Packet

the same applicative context it is possible to reach important results for the communities. In this work, we propose a cooperative approach that tries to exploit proposed heterogeneous architecture to reach the main goal. Considering a cooperative work, it has been possible to reduce the total amount of CO_2 emissions and the average travelling time increasing the vertrage speed of the vehicles into the urban area. As it is already shown in [73], from the traffic lights point of view, avoiding accelerations and decelerations not needed it is also possible to demonstrate a CO_2 emissions reduction as shown in fig.6.14. In this scenario, three kinds of approaches have been tested, the first one is the proposal SeAWave, the second one is an approach already presented in [67] and last one is presented in [71]. How it is possible to view the SeAWave outperforms others protocols, exploiting protocol messages and traffic monitoring that avoid to generate blocks which may reduce the average speed of the vehicles.

6.4.1.4 City traffic block and congestion management

In this simulation campaign we show the benefits of the proposal in terms of traffic management especially in case of accidents. In the first approach to evaluate the goodness of the proposal we trigger some accidents that may involve several

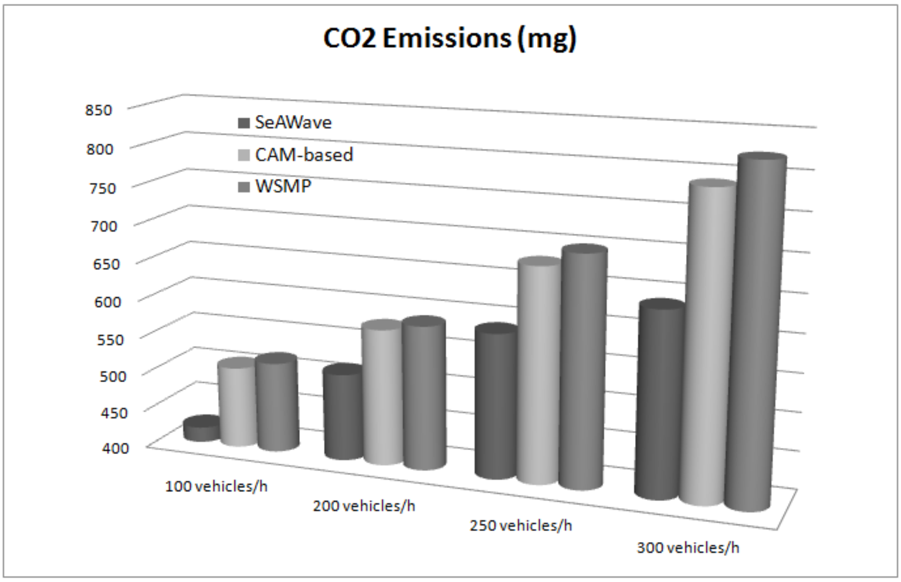

Figure 6.14: Average CO_2 Emission per vehicle

vehicles along the roads, the accidents we added within the scenario, are spread along the urban area in order to distribute blocks on several districts of the city observing how the traffic moves around the city rearranging loads on the neighbour roads.

How it is possible to note when the accident message is sent by the involved cars to other vehicles then they react in a shorter time and other collisions can be avoided. This is pointed out in fig.6.15 where the total number of accidents are depicted.

The protocols trends demonstrate that SeAWave protocol helps drivers to reduce the possibility to have an accident. It is interesting to note that if the distraction coefficient is not too high the number of the accidents remain constant and the communication among vehicles avoid collisions giving the possibility to the system to react. Instead, in case of only passive system enabled, the number of the collisions are higher even with a lower distraction coefficient as shown in fig.6.15 where DDC is shown on x-axes.

When drivers assume dangerous behaviour, the number of the accidents increase but the total number of collisions are lesser than protocols based on WSMP.

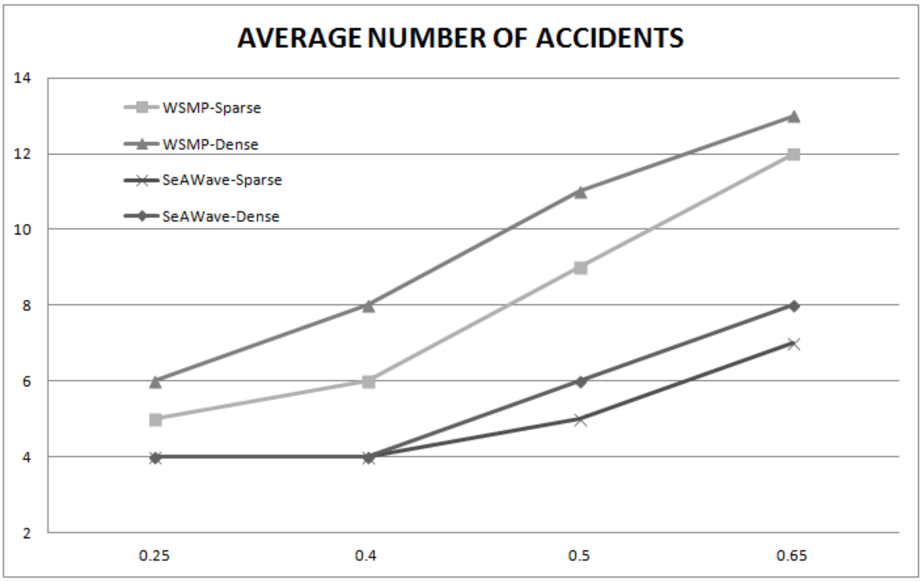

Figure 6.15: SeAWave Average Number of Accidents vs. Driver Distraction Coefficient (DDC) increasing.

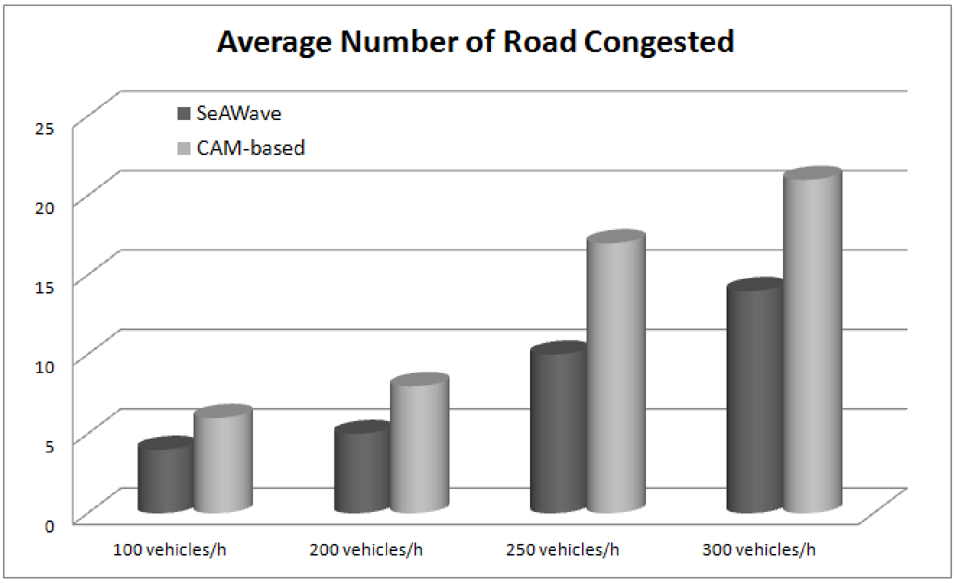

Figure 6.16: SeAWave congestion avoidance behaviors

Finally we can state that the Active system started up by the protocol incoming message having a deep impact on the safety level giving the possibility to reduce the number of the collisions and reducing the accident intensity that can direct influences health condition of the people involved in the accidents. We also considered the impact of the traffic load balancing when SeAWave protocol is used.

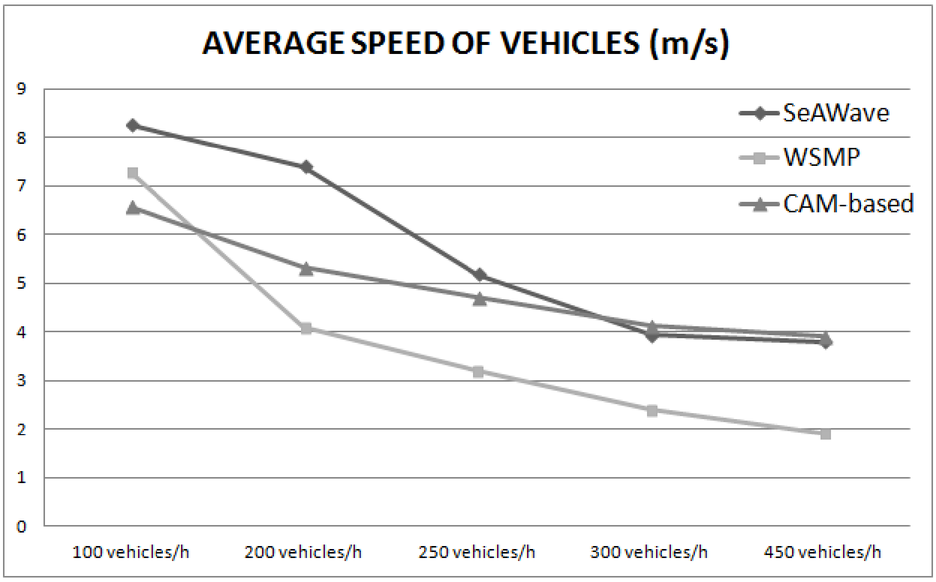

Figure 6.17: Average speed of the vehicles vs. the ingoing rate increasing, the ingoing rate is given by the sum of each ingoing rate measured at the gates of the city block which has been considered, (see Fig.6.10)
.

Observing fig.6.16 it is possible to carry out some considerations. First of all we can state that the SeAWave protocol solve congestion issues finding several exit gates allowing vehicle to recalculate paths also when the first signals of congestion are triggered by the monitoring functions included in the overall system.

It can be noted in fig.6.17 that the average speed of the vehicles increases as well as the number of congested roads decreases. This also justify the reduction of the time spent by the vehicles in the city area as shown in fig.6.18.

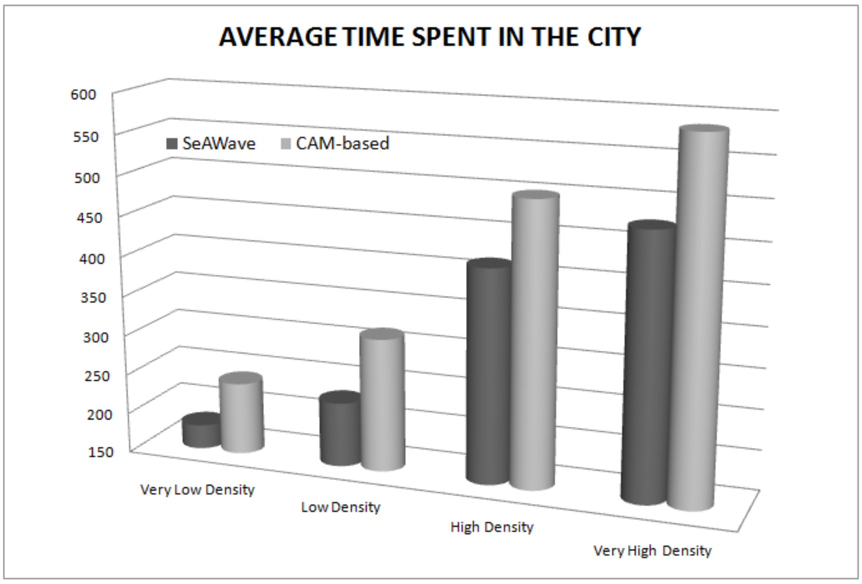

Figure 6.18: Average Time Spent in the City per vehicle vs. increasing of vehicle input rate at the input gates

6.5 Advanced Simulations using Real Traffic Data of the Bologna's City

In this section will be shown other simulation campaign, in order to test in a better way the previous proposed protocol, using the real traffic data relating to the city of Bologna [74]. This traffic data are collected and elaborated during the development of the European Project called "I-Tetris", an integrated wireless and traffic platform for real-time road traffic management solutions. This project was co-funded by the European Commission between 2008 and 2011 and was concerned in developing a simulation system for evaluations of large-scale traffic management solutions that work via vehicular communications. The considered scenario included the demand for Bolognas peak hour (8:00am 9:00am). It is a peak hour because during this part of the day, all schools, offices and commercial centres are opening. Additional data sets supported by the municipality of Bologna included positions of traffic lights, traffic light plans, inductive loop positions and measures. In order to realize the real traffic data, the passenger vehicles in the network are described in an aggregated manner: the numbers of vehicles to insert are given for certain roads located at the networks border. Following their initial route, the vehicles pass certain routing decision points at which they get a new route assigned randomly, according to a given distribution. This method is used for reproducing the turn percentages at intersections measured in reality using by 636 detection sites distributed in the map area. Unfortunately, the detectors are measuring only the amount of vehicles which are passing the detectors within five Minutes there are no other values like speed or vehicle type available. The provided network, traffic demand and additional infrastructure data is broad and a lot of work was done on improve the simulation quality.

6.5.1 Enviromental Setting of the Considered Scenario

In the first step of this Simulation, we have deployed four RSU in order to cover all area of the map (see figure 6.19). The aims of the RSU as wrote previously, are to receive road information from the vehicles and processing its and after send these information to the CTM. In this way, the CTM Server has the global status update of all streets, in order to make soundness the costs calculation.

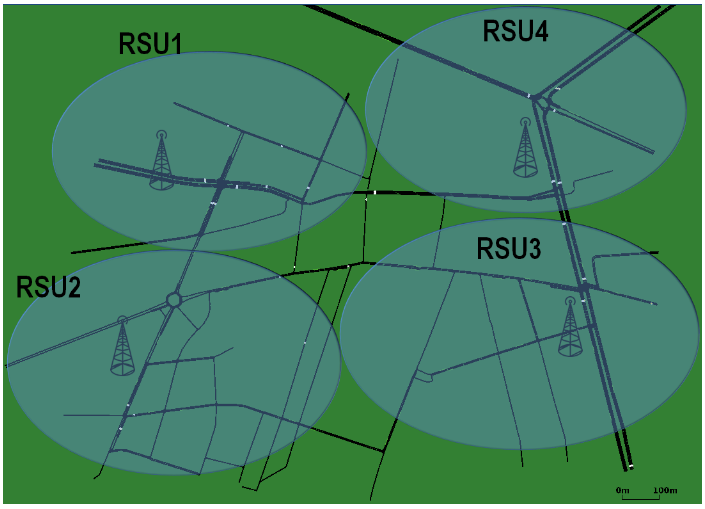

Figure 6.19: The Map of Bologna's City

After this, the second step was to reduce the protocol overhead due to high vehicles number that are travelling in the map. In order to avoid this issue, the vehicles that periodically send information (*PosUpdate* messages) to RSU, it was reduced by 50% avoiding the flooding mechanism, because the neighbour node of a specific vehicle, sends redundant information and its can be deleted and discarded. Another motivation is linked to the duration and the fluidity of the simulation in Omnet++ environment. In figure 6.20 is shown an example as the vehicles send *PosUpdate* messages to the RSU, by reducing the number of signalling packet.

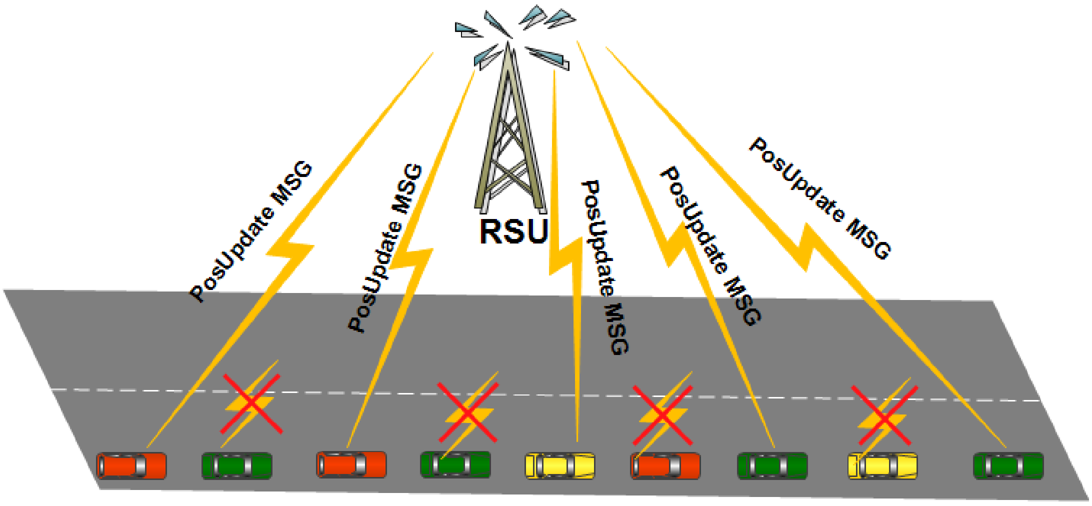

Figure 6.20: Overhead and redundant reduction

The goal of this Simulation Campaign is to verify if the protocol for smart traffic management described previously is still working or not, by using Real-traffic Data. The next step is to import the Real traffic data of the city of Bologna into SUMO simulator.

6.5.1.1 Traffic Information

As written previously, we employed 4 RSU to cover all map area. In this sub-section we describe in details how the vehicular traffic is distributed during the simulation.

The table 6.4 is used to better understand the performance evaluation that are shown in the next session. For example, it is normal to consider that the value of average CO_2 emission, or the average time spent of vehicles in the city, is higher in RSUs where pass-through an high number of vehicles. At the end of the simu-

Table 6.4: Vehicular Traffic Data in the Simulation

Fixed Infrastructure	**Total Vehicles Number**
RSU 1	5406
RSU 2	6003
RSU 3	5324
RSU 4	5970

lation, the four RSUs detect 22703 vehicles. During the one hour of observation, all vehicles are monitored in the real scenario trough the detectors fixed in the city of Bologna. For each vehicle, a complete route or journey is setted in SUMO, in order to simulate the real traffic scenario. In the following simulations, we compared the real traffic condition monitored by Vanet Infrastructure, with the SeaWave Protocol in order to verify if by using a policy for traffic management, the road conditions are improved or not. During the SeaWave performance, the routes of the vehicles may be changed, if it is detected a congestion state for a considered road, by acting the re-route mechanism.

6.5.2 CO_2 Emissions Evaluation

The first investigated parameter is CO_2 emissions of the vehicles. It is calculated in Veins framework following the assumptions described in [72] by Cappiello et al. Figure 6.21 shown that the SeaWave protocol by using a re-routing mechanism achieves better result then the real traffic situation detected by i-Tetris project, because the vehicles take roads less congested. Another possible reason is due to the reduction of the total number of accelerations and decelerations, because the vehicles pass-trough less traffic blocks.

6.5.3 Monitoring the Number of Congested Roads

In this subsection is shown how by using the SeaWave protocol, the number of congested roads detected by the RSUs is reduced then the real traffic situation monitored by i-Tetris project without the re-routing mechanism. This considered parameter represents the sum of the Congested Roads detected by the 4 RSU, every interval of 20 seconds. In the following figure is represented the total number

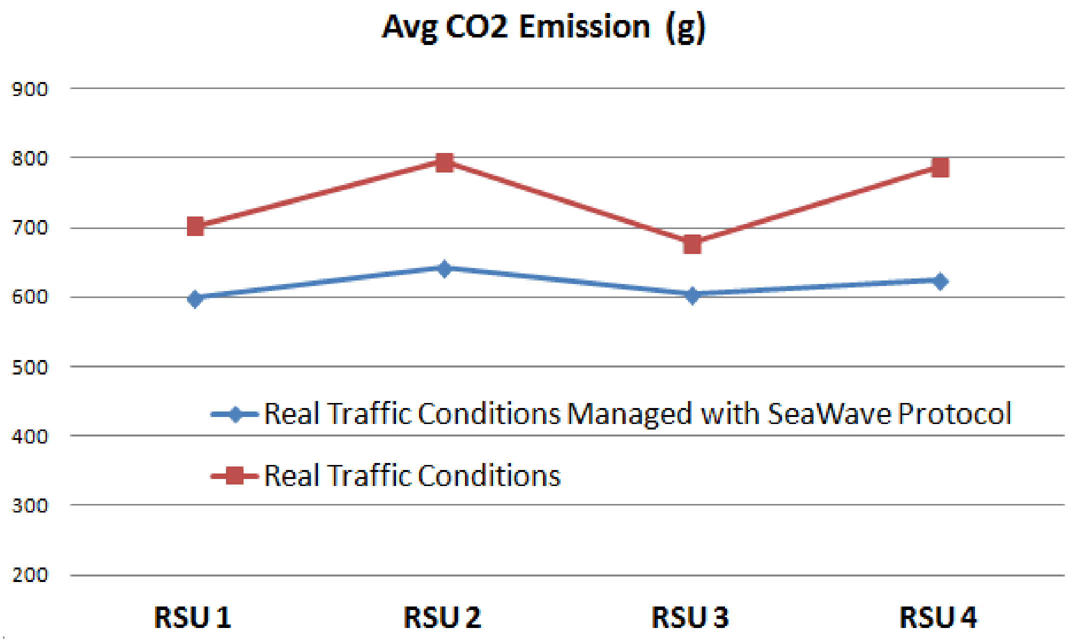

Figure 6.21: The comparison between real traffic scenario and the Seawave protocol in term of CO2 Emissions

of detected congested roads during the peak hour of observation in Bologna's City. The advantage to have a lower number of congested roads, as demonstrated by the figure 6.22, it can be translated in advantages in term of reduction of CO_2 emissions and time spent in the city by the vehicles, because the traffic is more fluent by using the SeaWave Protocol and the re-routing mechanism for the vehicles toward road less congested.

6.5.4 Total Average Time spent in the City by the Vehicles

When is active the congestion check with re-routing mechanism through SeaWave protocol, is possible to observe that the vehicles could find the roads status less congested then the case without the use of the re-routing mechanism. Thus, they can save the time to arrive at destination. Even if they take other path that is maybe little longer, as demonstrated in figure 6.23, the time spent by vehicles is still lower then the real world traffic condition, because the vehicular traffic is

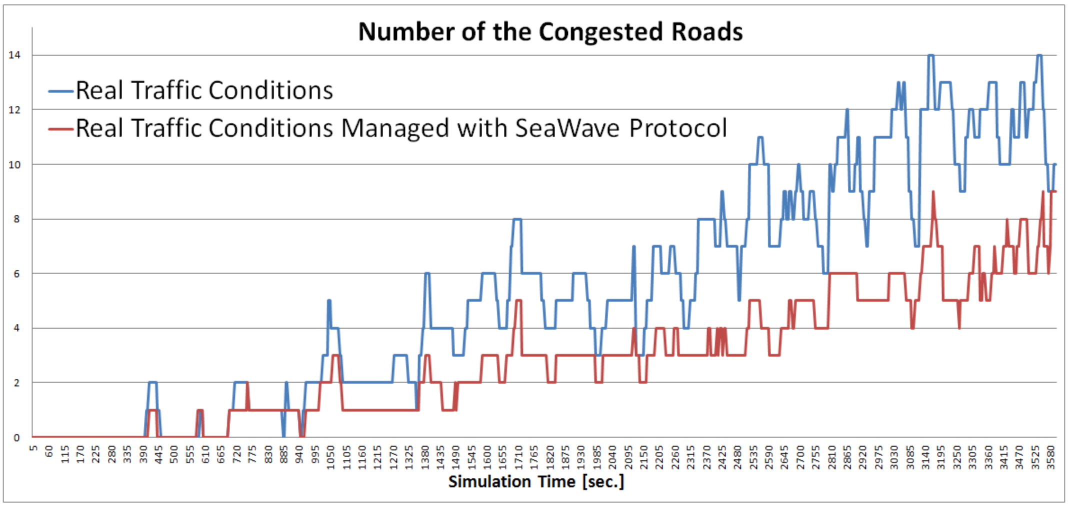

Figure 6.22: The comparison of the number of congested roads between the real traffic scenario and the SeaWave Protocol

more fluent.

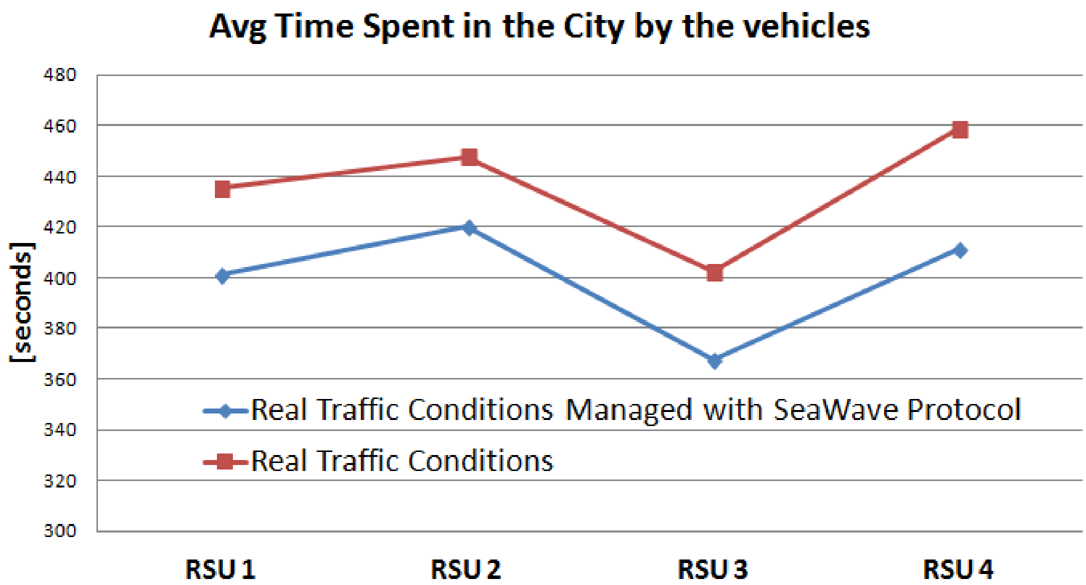

Figure 6.23: The comparison of the avg time spent of the vehicles in the city between the real traffic scenario and the SeaWave Protocol

6.5.5 The Trend of the Cumulative Vehicles' Number on a congested road

Another parameter that is important to show is the Cumulative Vehicles Number in a congested road during the entire simulation. In the case relating of the SeaWave Protocol, it is important to notice that this parameter when it reaches the congestion threshold it tends to remain constant for a few seconds, and after it tend to increase again but less rapidly, how it is possible to see in figure 6.24.

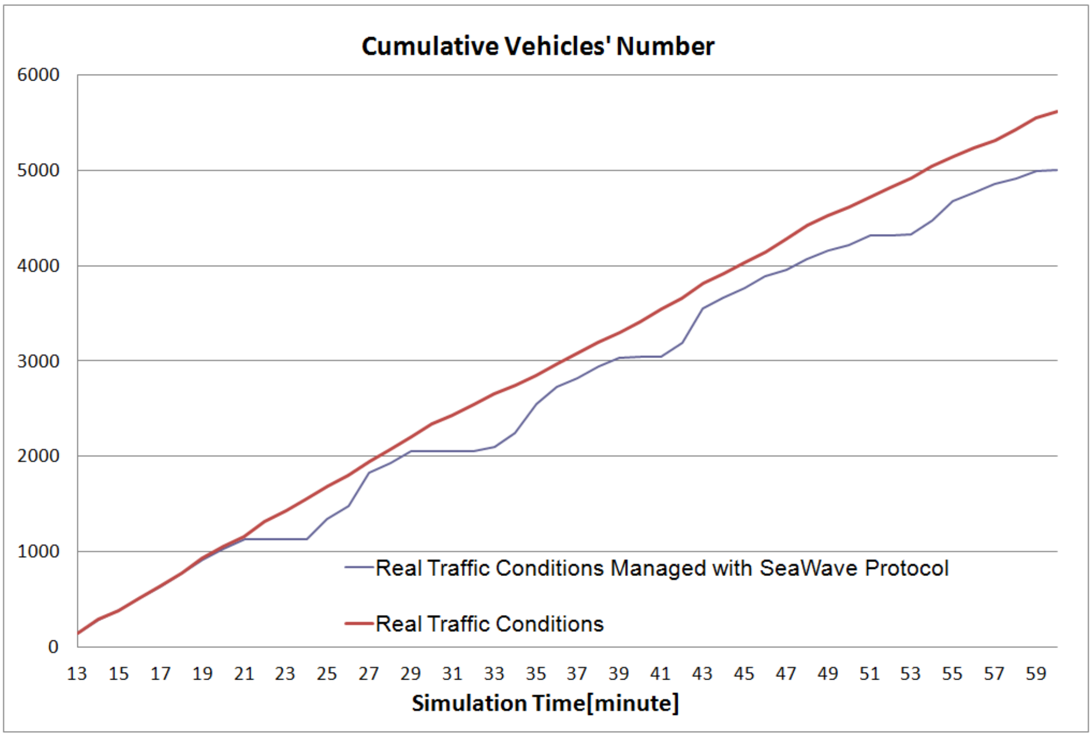

Figure 6.24: The Cumulative Vehicles Number trend for the real traffic scenario and the SeaWave Protocol

Chapter 7

Conclusions, Publications and Future Work

Throughout this Thesis several contributions have been made to the areas of Efficient Routing Protocol for Vehicular ad-hoc Networks and Intelligent Transportation Systems. In the first area, we designed two main approach. One of these is made on a novel metrics to account the interference levels of nodes in a condition of multi-channel MAC and reactive routing protocols for MANET. In particular, the PIAR protocol builds minimum interference paths on a hop-by-hop basis through the prediction by a time-series of the SIR on the available data channels of each single node. The protocols proposed, presented better results in terms of PDR, throughput of the network, interference level and end-to-end delay in comparison with the CLWPR protocol. However, interference-aware routing strategies present slightly lower performance in terms of control overhead. This is due to the computation and maintenance of state info associated to the channel interference levels among nodes. Instead, the protocol designed in the second main approach for the first area, is based on a new metric that takes into account the best values of Co-Channel Interference (CCI), Link Duration Probability (LDP) and the term of end-to-end Delay (e2eD). Regarding the data dissemination in vehicular networks, our protocol does this purpose through the mechanism of construction of the Minimum Spanning Tree (MST), in order to diffuse the messages to a large number of vehicles. The protocols proposed, presented better results in terms of Percentage of the Delivery Packets, Network's Throughput and end-to-end Delay in comparison with the well-knows AODV, DSR, A-STAR protocols. Also in this case, in term of protocol overhead our proposed protocol obtain lower performance then other protocols, because are used more signalling packets to build the paths of the composite metric. In the Intelligent Transportation Systems area we designed the SeAWave protocol to increase safety, to improve the management of the roads traffic, and reduce the total number of the packets sent on the network by using a more efficient dissemination technique based on geocasting and helps to reduce the gas emissions of the vehicles. The integration of the on-board devices with the OBU, allows us to enhance safety systems that may reduce the total number of accidents on the roads. Moreover, spreading traffic information on the network help finding new routes reducing travelling time and CO_2 emissions increasing average speed as well. In fact, as demonstrated in the simulation results section, these advantages for the drivers bring up an indirect advantage for the air quality of the city. Moreover, spreading data collected by a single vehicle on the network exploiting V2V and V2I communication has the effect of reducing the amount of accidents due to collisions.

7.1 Publications

The research work related to this Thesis and to other Telecommunication topics, has resulted in XX publications; among them, we have 6 journal articles (all of them indexed by the Journal Citation Reports (JCR) database or the SCImago Journal & Country Rank (SJR)), 1 book chapter paper (indexed by the Journal Citation Reports (JCR) database or the SCImago Journal & Country Rank (SJR)) and 8 conference papers (also indexed by the Computer Science Conference Ranking or the Computing Research and Education (CORE) lists).

7.1.1 Journals

J1 P Fazio, F De Rango, **C Sottile**,*A Predictive Cross-layered Interference Management in a Multichannel MAC with Reactive Routing in VANET*, IEEE Transactions on Mobile Computing, 2015

J2 AF Santamaria, **C Sottile**, P Fazio, *PAMTree: Partitioned Multicast Tree Protocol for Efficient Data Dissemination in a VANET Environment*, International Journal of Distributed Sensor Networks, Hindawi 2015

J3 AF Santamaria, **C Sottile**, F De Rango, S Marano, *Safety Enhancement and Carbon Dioxide (CO_2) reduction in VANETs*, Mobile Networks and Applications, Springer 2015

J4 AF Santamaria, **C Sottile**, *Smart Traffic Management Protocol Based on VANET architecture*, Advances in Electrical and Electronic Engineering, Vol. 12, N. 4, pp. 279-288, 2014

J5 P Fazio, F De Rango, **C Sottile**, AF Santamaria, *Routing optimization in vehicular networks: A new approach based on multiobjective metrics and minimum spanning tree*, International Journal of Distributed Sensor Networks, Hindawi 2013

J6 P Fazio, **C Sottile**, AF Santamaria, M Tropea, *Vehicular Networking Enhancement And Multi-Channel Routing Optimization, Based on Multi-Objective Metric and Minimum Spanning Tree*, Advances in Electrical and Electronic Engineering, Vol. 11, N.5, pp. 349-356, 2013

7.1.2 Book Chapters

B1 P Fazio, **C Sottile**, M Tropea, F De Rango, M Voznak, *Multi-Channel Multi-Objective Routing Metric for Vehicular Ad-hoc Networks*, Nostradamus 2014: Prediction, Modeling and Analysis of Complex Systems, Advances in Intelligent Systems and Computing, pp. 401-410, Springer 2014

7.1.3 International Conference

C1 P Fazio, M Tropea, **C Sottile**, A Lupia, *Vehicular Networking and Channel Modeling: A New Markovian Approach*, IEEE Consumer Communications and Networking Conference (CCNC), Las Vegas (USA), 2015

C2 AF Santamaria, **C Sottile**, S Marano, *Synchronized WSNs architecture for efficient remote tasks scheduling*, 20th IMEKO TC4 International Symposium and 18th International Workshop on ADC Modelling and Testing, Benevento (ITA), 2014

C3 **C Sottile**, AF Santamaria, S Marano, *A reactive routing protocol for VANETs based on composite metric concept*, International Symposium on Performance Evaluation of Computer and Telecommunication Systems (IEEE - SPECTS 2014), Monterey (USA), 2014

C4 AF Santamaria, **C Sottile**, A Lupia, P Raimondo, *An efficient traffic management protocol based on IEEE802. 11p standard*, International Symposium on Performance Evaluation of Computer and Telecommunication Systems (IEEE - SPECTS 2014), Monterey (USA), 2014

C5 **C Sottile**, AF Santamaria, V Curia, M Voznak, *Wireless sensors in complex networks: study and performance evaluation of a new hybrid model*, International conference of SPIE Sensing Technology+ Applications, Baltimore (USA), 2014

C6 AF Santamaria, **C Sottile**, F De Rango, M Voznak, *Road safety alerting system with radar and GPS cooperation in a VANET environment*, International conference of SPIE Sensing Technology+ Applications, Baltimore (USA), 2014

C7 P Fazio, M Tropea, **C Sottile**, S Marano, M Voznak, F Strangis, *Mobility prediction in wireless cellular networks for the optimization of call admission control schemes*, IEEE 27th Canadian Conference on Electrical and Computer Engineering (CCECE), Toronto(CAN), 2014

C8 P Fazio, M Tropea, S Marano, **C Sottile**, *Pattern prediction in infrastructured wireless networks: Directional vs temporal statistical approach*, IEEE IFIP Wireless Days (WD 2013), Valencia (SPA), 2013

7.1.4 Future Work

In the development of this Thesis several issues emerged which deserve further scrutiny in a future. The ones we consider most relevant are the following:

- In large and highly populated downtown areas, traffic congestion is becoming a challenging problem. The aim of the new protocol is to detect road segments that are suffering high traffic congestion using cooperative vehicular communication. I would try to design a new mechanism based on a genetic algorithm or objective function, in order to adapt in dynamic manner the values of the parameters of the SeaWave proposed protocol.

- Considering the potential of the VANETS fixed infrastructure, I would like to face with the design of an efficient protocol for RSU placement in urban environment, to solve resource-constrained coverage problem, which take into consideration budget constraints and quality constraints, using genetic algorithm and optimization algorithms resources. Also to reduce the interference issue and minimize the total number of the RSUs.

- To develop a system composed of Intelligent Traffic Lights (ITLs) fixed on board of the vehicles, which provides information to drivers about traffic density and weather conditions in the streets of a city. The main goal is to better manage the traffic using the ITLs, reducing also the CO2 Emissions and the time of the journey of the vehicles in urban area.

- Many data dissemination protocols have been proposed in the literature. However, most of these protocols were designed to operate exclusively in urban or highway scenarios and under dense or sparse networks. In addition, the existing solutions for data dissemination do not effectively address broadcast storm and network partition problems simultaneously. Considering the particular nature of the VANETs, I would try to maximizes the data dissemination capabilities across network partitions with short delays and low overhead, in this particular case.

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