Control mechanisms for intelligent transportation systems (ITS) cooperative safety applications

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PARIS INSTITUTE OF TECHNOLOGY

TELECOM ParisTech

2012-ENST-081

EDITE - ED 130

Doctorat ParisTech

T H È S E

pour obtenir le grade de docteur délivré par

TELECOM ParisTech

Spécialité « Informatique et Réseaux »

présentée et soutenue publiquement par

Fatma HRIZI

le 20 Décembre 2012

Mécanismes de Contrôle pour les Applications Coopératives de Sécurité Routière dans les STI

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THÈSE

Control Mechanisms for ITS Cooperative Safety Applications

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A doctoral dissertation submitted to:

TELECOM ParisTech

In Partial Fulfillment of the Requirements for the Degree of:

Doctor of Philosophy

Specialty : Computer Science and Networking

Jury :

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Acknowledgements

First of all, I would like to extend my sincere thanks to my advisors Prof. Christian Bonnet and Dr. Jérôme Härri for their invaluable support and brilliant ideas. Both are passionate researchers but above all true gentlemen. During these three years, they have always found the time for me to guide and encourage my research activities whenever it was needed. I very much appreciate their dynamism and their competences that made this thesis work a success.

I am grateful to the committee members of my jury, Prof. Javier Gozalvez-Sempre, Prof. André Luc Beylot, Prof. Marcelo Dias de Amorin and Prof. Carla-Fabiana Chiasserini for their valuable inputs and time spent reading this thesis.

I would like to thank my dear friends and colleagues at EURECOM, Sophia Antipolis, particularly, to my officemates for the good, friendly and professional, atmosphere they offered every day. The list is too long to be put here. But they made my stay very enjoyable during these three years of PhD.

My sincere thanks to the secretaries the IT support staff at EURECOM for all the efforts they are putting to offer a productive research environment.

Finally, last but no means least, I want to express my special gratitude to my parents for their unconditional support, love and trust. They, together with my brothers, sisters and their children, make my life full of kindness and happiness with their encouragement.
My thoughts go to all those who have been a real help for me..

Abstract

The effectiveness of ITS cooperative safety applications depends widely on the efficient exchange of two main types of information. The periodic "*awareness*" corresponding to the one-hop location information of surrounding environment and the multi-hop event-driven information generated at the detection of a safety situation. Due to the large scale characteristic of ITS, this information is expected to be subject to severe congestion which might impact its reliable reception.
The goal of this thesis is to focus on the reliable and robust control of safety-related information by controlling the channel congestion and at the same time taking into account the requirements of safety applications.
Due to its demanding constraints, we address first the event-driven safety information. We propose to adapt the multi-hop dissemination benchmark "*CBF*" (Contention-Based Forwarding) to the ITS challenging environment by first considering the non-uniform vehicular topology and the high fading channels. Second, we take into account the dissemination capabilities of the relays' antenna.
Even though that our multi-hop policy showed to improve the dissemination of the event-driven information and provide 40% reduction in overhead compared to *CBF*, it remains strongly sensitive to the channel load resulting from periodic awareness transmissions. On the other hand, the effective transmission of event-driven information depends primarily on the accurate detection of safety events and accordingly on the accuracy of awareness. Thus, we provide an efficient awareness control mechanism. Based on a bio-inspired prediction algorithm, our approach is to adapt the transmission of awareness messages and conceptually make it aperiodic in order to limit the channel congestion. Moreover, our aperiodic awareness system is capable of accurately detecting brutal awareness change. Simulations conducted with *iTETRIS* platform[1] show how our approach is capable of answering the trade-off between channel congestion and cooperative safety requirements.
Observing the fact that the transmissions related to safety events depend mainly on the global context perceived by the vehicles, we demonstrate the need for a global entity to handle efficiently the transmissions of safety-related information. We propose an information-centric dissemination framework that should be developed at higher layers in the protocol stack.

[1]iTETRIS simulation platform http://www.ict-itetris.eu/10-10-10-community/

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Glossary

Here are the main acronyms used in this document. The meaning of an acronym is usually indicated once, when it first occurs in the text.

ACC	Adaptive Cruise Control
ACK	ACKnowledgment
ADAS	Advanced Driver Assistance Systems
BSM	Basic Safety Message
BTP	Basic Transport Protocol
BZB	Bi-Zone Broadcast
CAM	Cooperative Awareness Message
CBF	Contention-based Forwarding
CCH	Control Channel
CDF	Cumulative Distribution Function
CDS	Connected Dominating Set
CL	Channel Load
CO2	Carbon Dioxide
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
C2C-CC	Car-to-Car Communication Consortium
DENM	Decentralized Environment Notification Messages
DSRC	Dedicated Short-Range Communication
ED	Error distance
EKF	Extended Kalman Filter
ER	Error Distance
ESP	Electronic Stability Program
ETSI	European Telecommunications Standards Institute
ETSI TC ITS	ETSI Technical Committee for Intelligent Transport Systems
FAR	False Alarm Rate
FPR	False Positive Rate
GPS	Global Positioning System
GSF	Glow-worm Swarm Filter
GSO	Glow-worm Swarm Optimization
I-BZB	Infrastructure BZB
iCS	iTETRIS Control System
ICT	Information and Communication Technology
IP	Internet Protocol
IPv6	Internet Protocol version 6

ITS	Intelligent Transportation System
KF	Kalman Filter
LOS	Line Of Sight
MAC	Media Access Control
MMSE	Minimum Mean Square Error
NLOS	Non Line Of Sight
NS-2	Network Simulator 2
NS-3	Network Simulator 3
OSI	Open Systems Interconnection
RFD	Relative Frequency Density
PF	Particle Filter
POI	Point Of Interest
RMSE	Root Mean Square Error
RSU	Road Side Unit
RTB/CTB	Request to Send/Clear to Broadcast
RTS/CTS	Request to Send/Clear to Send
SIR	Sequential Importance Resampling
SIS	Sequential Importance Sampling
SMC	Sequential Monte Carlo
SUMO	Simulation of Urban Mobility
TCP	Transmission Control Protocol
TraCI	Traffic Control Interface
TTL	Time To Live
UDP	User Datagram Protocol
UKF	Unscented Kalman Filter
VANET	Vehicular Ad-hoc Networks
V2V	Vehicle-to-Vehicle Communication
V2I	Vehicle-to-Infrastructure Communication
V2X	Vehicle-to-X Communication
WHO	World Health Organization

1
Introduction

1.1 Motivation and Objectives

Recently, new trends in wireless communications have been emerging enabling a wide variety of new applications. In particular, wireless vehicular communications (V2X) including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications, are currently being developed and implemented to support the integration of information and communication technology (ICT) within the transportation systems. This concept referred as Intelligent Transportation System (ITS) will provide innovative solutions to improve our lives and make transport safer, more efficient, comfortable and respecting the eco-system.
Accordingly, two primary branches of services targeted to ITS are created. First, *infotainment applications* designed to provide more comfort and assistance to the driver and passengers e.g. Internet access, useful information about weather forecast and nearby point-of-interests. Second, *safety applications*, being the most critical objective of ITS, aim at enhancing road traffic safety including collision avoidance services, accident notifications and, collection and distribution of information related to traffic road conditions. Safety information could be basically divided into two main types: The periodic one-hop location information referred as "*awareness*" corresponding to the knowledge of the surrounding environment and the event-driven safety information generated and sent in multi-hop mode at the detection of a safety situation.
For a successful operation of ITS safety, it is required that nodes *cooperate* and accordingly share together this information. Cars, trucks, trains, motorbikes and even pedestrians can contribute to safer roads if they efficiently disseminate and manage jointly the information.

Given their importance, ITS cooperative safety applications are particularly highly demanding in terms of accuracy and reliability of information reception. Moreover, they are drastically sensitive to delays. For instance, when an accident occurs, the safety information must be delivered accurately and on time respecting the delay constraint in order to prevent other road hazards from happening. Their effectiveness depends thus on the reliability of the shared communication medium.

The common communication strategy envisioned to be used is the *V2X broadcast* based on the *IEEE 802.11p MAC* [16] standard which is an amendment of the IEEE 802.11 adapted for vehicular environment. Although efficient in small scale environment, broadcast is constrained by the limited shared spectrum and cannot scale consequently with the huge number of nodes in the vehicular network. Other issues, that are worth considering, are on one hand the diverse and large amount of data conveyed over the network, and on the other hand, the high dynamic of the nodes. All of these challenging aspects will result naturally in a severe wireless congestion problem yielding to a degradation of the performance of the communication system. Additionally, the absence of feedback (no acknowledgement) in the 802.11p broadcast channel might further restrain the reliability of transmissions and more particularly, "safety-of-life" transmissions requiring higher reliability and lower latency.

The main objective of this work is to deal with the ITS challenging environment and ensure robust delivery and management of the safety-related information. We propose to design efficient *"control mechanisms"* devoted to control the channel load and thus, reduce the issue of channel *congestion*.
Reducing the channel congestion blindly might imply also reducing the precision of the vehicles' knowledge about the surrounding environment (or the awareness), as it impacts directly the transmissions. Besides, ITS safety applications depend greatly on the accuracy of the awareness information.
Clearly, this imposes a trade-off between two conflicting objectives leading to the question: how to limit the channel congestion without affecting the performance of safety applications?
We suggest therefore, to design *control policies* to *control* the awareness system ensuring adequate precision for ITS safety applications and at the same time effective congestion control.

1.2 Thesis Contributions and Outline

In the scope of this thesis, we address first the design of control mechanisms to efficiently disseminate the event-driven safety information. We propose a congestion control scheme to adapt the multi-hop dissemination benchmark "*CBF*" (Contention-Based Forwarding) to the vehicular challenging environment by first considering the non-uniform vehicular topology and the fading wireless channels. Second, we take into account the diversity in the communication capabilities of the nodes and the use of V2I communication paradigm to support the information dissemination.

We observe that most of the ITS safety applications rely strongly on the exchange of the *awareness*. The accuracy of this latter is crucial for an efficient and correct

detection of hazardous situation. A false detection of a dangerous situation might yield to the generation of unrequired messages saturating unnecessarily the channel. To the opposite, an over detection of awareness leads to channel saturation, which in turn significantly reduces the capability to warn about the danger. An efficient control of the awareness is thus required.
We propose in the next part of this work to manage the one-hop awareness information. We design a robust awareness control mechanism, namely Glow-worm swarm filter (GSF), capable of providing the required accuracy to cooperative safety applications. In order to tackle the unreliable characteristics of the wireless channel as well as the unexpected sudden changes in vehicular motion, the idea is to extrapolate the unreliable and/or missing awareness data using tracking. Our approach is a swarm-based particle filtering that models typical awareness update losses by several alternative hypotheses.
Then, we evaluate the capability of GSF to achieve efficient detection of safety situations. Being based on tracking, our awareness accuracy control is less dependent to regular awareness update, we might as well limit their transmission to only when required and reduce the channel load. Therefore, we suggest to apply our GSF to adapt the transmit rate of the awareness. The principal concept is to conceptually make the awareness transmission system aperiodic and to be capable of accurately detecting brutal changes and temporarily switching to periodic.
Observing the fact that the transmissions related to safety events depend mainly on the global context perceived by the vehicles, we demonstrate the need for a global entity to control both the network congestion and the awareness. Therefore, we propose to define a generic control framework to be located at the ETSI/ITS Facilities layer as it controls all the inputs and outputs of the nodes. This framework will gather all the control mechanisms needed for the efficient control and dissemination of event-driven and awareness information.

For an effective evaluation of our control mechanisms, we have contributed to the design of the *iTETRIS*[1] platform which is a large scale simulation platform tailored for the evaluation of cooperative ITS protocols and technologies in a close-to-real environment. It is designed to model the several peculiar characteristics of ITS environment and cover communication and mobility aspects as well as the diversity of ITS applications.

The rest of this manuscript is organized as follows. In addition to the introduction and final conclusion, we divide the content of this thesis in three main parts. We present a brief description of the related works to our thesis in the first part. Then, in each of part II and III, we go more into details with a detailed overview of existing efforts.

- In the first phase of this thesis, we provide a broad overview of ITS. In Chapter 2, we introduce the state of the art of the ITS environment and its challenges.

[1] *iTETRIS* simulation platform http://www.ict-itetris.eu/10-10-10-community/

Particularly, we analyze systematically the requirements of ITS safety applications. Then, we go through the standardization process around the globe. In chapter 3, we define the performance metrics that are essential to assess the effectiveness of ITS mechanisms, more precisely designed for safety applications, and that we will use throughout this thesis. Moreover, we give an overview about our contributions on the design and development of the realistic ITS simulation platform *iTETRIS*.

- The second part is dedicated for the study of the event-driven multi-hop congestion control. In Chapter 4, we survey, classify and compare the existing multi-hop dissemination strategy. Chapter 5 introduces our proposed schemes for reliable dissemination of event-driven information in ITS environment. We have suggested an enhancement of the ITS forwarding benchmark the Contention-Based Forwarding (CBF). Three primary assumptions that cannot comply with ITS environment have been considered by this approach: the uniform vehicular topology, the non-fading channels and the homogeneous communication capabilities. We propose to adapt CBF to such challenging environment by first employing two different policies as a function of the topology. Second, we consider additionally the dissemination capabilities of the relays, allowing for example road-side units or tall vehicles to act as relays when necessary. Then, we evaluate the performance of our dissemination approaches under realistic scenarios.

- In the last part, we address the one-hop awareness control. In Chapter 6, we design a management system capable of efficiently providing a high precision in awareness information. We propose to mitigate the limitations of ITS by developing an advanced particle filter, we provide thus a bio-inspired swarm-based filtering approach designed to extrapolate the missing and unreliable data. Then, in Chapter 7, we provide an efficient management of the awareness transmission intended to reduce the channel congestion. Our approach aims at satisfying the safety applications requirements and at the same time reducing the channel congestion. We propose a transmit rate control approach based on our proposal (Chapter 6).

  Finally, Chapter 8 summarizes the main findings of this thesis and the conclusion that can be drawn and provides direction for future works.

The contributions of this thesis have been published in [55], [54], [53], [75], [57], [56] and [116].

Part I

Background Analysis

Overview of Part I

In Part I, we provide a background analysis of the current situation of the development of ITS with a particular insight into vehicular communication challenges and requirements of cooperative safety applications.

In Chapter 2, we overview ITS environment in addition to the related applications expected to be deployed in the coming years. We first define the concept of ITS and present the various research efforts and standardization initiatives to propose novel communication architecture, application paradigms and advanced technologies. Then, we highlight the challenging characteristics of ITS environment, notably the properties of vehicular communications. We provide particularly an overview of ITS cooperative safety applications and their requirements. We present also a brief description of existing congestion control mechanisms related to the area of information dissemination in ITS cooperative safety applications and proposed to deal with the issues present in ITS environments.

In Chapter 3, we define the requirements of an efficient performance evaluation of the designed ITS applications and the associated communication protocols. We demonstrate the need for new evaluation tools and specific metrics that can cover the different characteristics of vehicular systems. We present first our contribution to the development of an integrated simulation platform designed to ITS studies. Then, we determine the appropriate performance metrics required for an efficient assessment of the ITS cooperative safety applications.

In summary, this part essentially describes the challenges that ITS and vehicular communications impose. Moreover, it introduces the suitable evaluation environment for ITS safety applications.

2
Intelligent Transportation Systems: Vision and Challenges

2.1 Introduction

In the last few decades, a rapid emergence of intelligent transportation systems has been perceived. An increasing interest from governments as well as private entities has led to an attractive diversity and richness of contributions in this wide research area. Including both in-vehicle and out-vehicle systems, ITS are expected to alleviate the problems related to transportation systems as such roads congestions and fatalities. In-vehicle applications have reached already a high degree of maturity and are typically deployed and used nowadays [2].
Vehicles equipped with various sensors such as cameras and radars, and computing devices on-board, offer already intelligent services for drivers. These applications include *Advanced Driver Assistance Systems* (ADAS) applications (e.g. Adaptive Cruise Control (ACC) and, autonomous driving and collision avoidance) and navigation applications (e.g. route guidance and POI access).

On the other hand, ITS out-vehicle systems still require advanced procedures and policies to enable the communication and distribution of information and data in real time among network entities including vehicles and infrastructures. Standardization bodies have been identifying the key concepts that should constitute the fundamental building blocks for ITS out-vehicle systems.
In particular, a new set of cooperative applications has been introduced with the aim of enhancing traffic safety and efficiency. Basically, it can be summarized in two main classes: safety and non-safety applications. Safety applications, which are devoted to traffic control and vehicle collision avoidance services, increase the safety of passengers by exchanging safety relevant information. However, non-safety applications concern the improvement of passenger comfort, road traffic efficiency and the optimization of drivers' routes.

Due to this wide diversity of applications, a large amount of data is expected to be exchanged among nodes. The key challenges for a successful deployment of such

applications is to manage efficiently the information dissemination and thus, to provide relevant information to the driver fitting specific requirements and constraints. Accordingly designed control mechanisms and communication strategies have to cope with:

- **The challenging ITS environment**
  ITS environment is characterized by several challenging aspects. They are mostly related to the unreliable and uncertain nature of the vehicular medium. Moreover, the large scale characteristic associated to the limited capacity of the shared spectrum are other crucial aspects that are worth consideration.

- **The requirements of ITS applications**
  ITS safety applications require very short delay and high reliability in the information reception which is not the case for non-safety applications where the data is less sensitive to delay, but also generate more load on the wireless channel. Passengers can tolerate to receive a video downloaded from Internet with delay. However, it is crucially important to be informed in time about an eventual accident before its occurrence. This could be even lethal since it may lead to other hazardous situations.

In the following section, we give more details about these challenging aspects. This chapter is organized as follows, In Section 2.2, we introduce the concept of ITS and the original motivation for its creation. We unveil also the different properties of vehicular communications, efforts for the design of new communication architecture targeted for ITS, and the challenges associated with such environment. Then, we provide an overview of ITS applications, more particularly safety applications, their requirements and their needs. In Section 2.3, we present existing control approaches related to ITS safety applications.

2.2 Intelligent Transportation Systems and its Applications

2.2.1 Intelligent Transportation Systems: Motivation and Concept

In 2010, the worldwide vehicle population has exceeded one billion for the first time in the history according to Ward's research [10]. The OECD's International Transport Forum states that it is expected to double further and reach 2.5 billion by 2050. The evolution of the number of cars from 1995 to 2010 in a set of countries around the globe is illustrated in Figure 2.1. This augmentation has a major impact on the world's population, energy, economy and environment. Vehicles' emissions, road traffic congestion and road fatalities are accordingly expected to increase.

According to the *World Health Organization (WHO)* [14], road accidents annually cause approximately 1.2 million of deaths and between 20 and 50 million of non-fatal

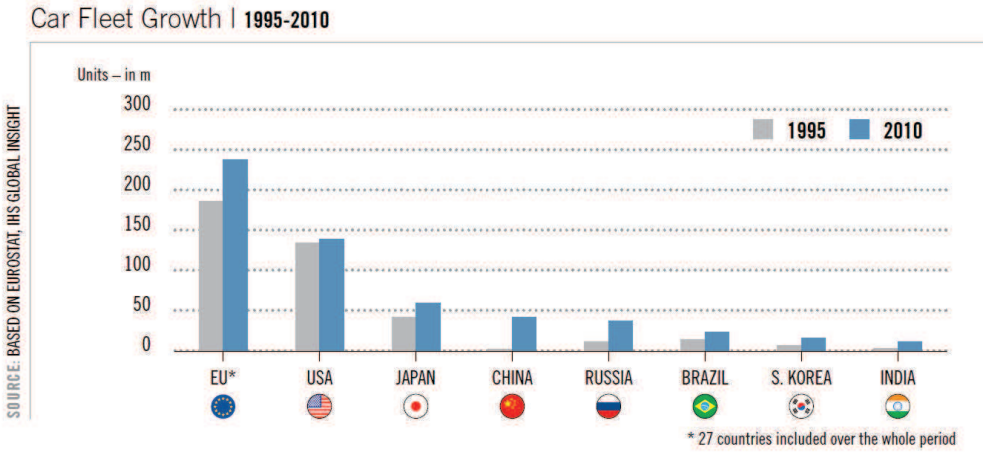


Figure 2.1: The evolution of the number of cars in 15 years from 1995 to 2010. For example, in the European Union, the number of cars has increased by 25% (around 100 millions of additional cars). The figure is taken from [1] and the statistics are based on Eurostat, Ihs Global Insight.

injuries in the world. If preventive measures are not taken road fatality is potentially becoming the third cause of death in 2020 from ninth place in 1990.
Traffic jams, on the other hand, affect drastically the environment. According to the *INRIX European National Traffic Scorecard* in 2010 [5], "drivers spend more than 50 hours a year in road traffic jams in London, Cologne, Amsterdam and Brussels. In Utrecht, Manchester and Paris, they spend more than 70 hours stuck on roads". Figure 2.2 reports statistics about the *CO2* emissions in five years from 2005 to 2010. The reduction illustrated in these curves is due to the efforts conducted by both private and public entities to find solutions to environment pollution.
Although governments and public authorities have already piloted several outstanding initiatives to improve the management of the transportation system, new policies and actions have to be deployed. Funding construction programs and/or improving road networks and infrastructures cannot solve all transport problems of congestion, emissions and accidents.
Intelligent Transportation Systems (ITS) suggest an alternative solution to make transport safer, more sustainable and especially, respecting the ecosystem. The term *"Intelligent Transportation Systems"* has gradually evolved to describe the application of information and communication technologies to the transportation systems. According to ERTICO (Europe)[2], ITS are *"New information and communications technologies are finding exciting applications in urban transport. Also called Transport Telematics"*. ITS America [6] defines them as *"A broad range of diverse technologies, which holds the answer to many of transportation problems. ITS is comprised of a number of technologies, including information processing, communications, control, and electronics. Joining these technologies to our transportation system will save lives, save time, and save money"*.

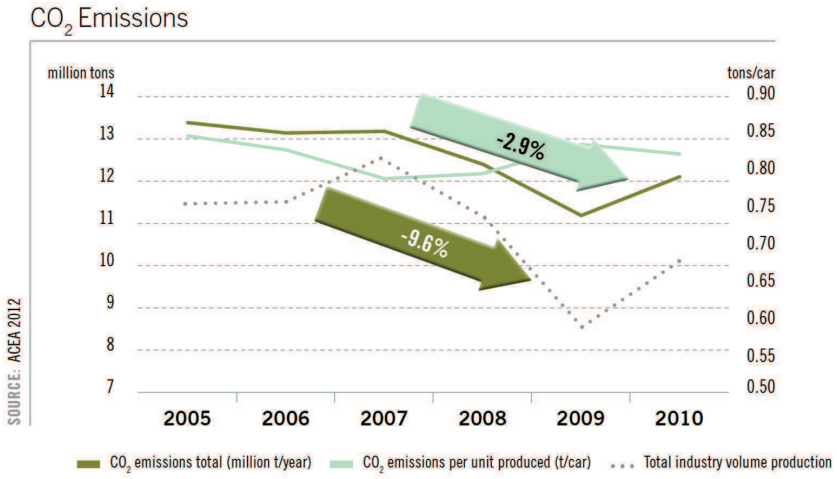


Figure 2.2: The evolution of the CO2 emissions of cars from 2005 to 2010. The overall CO2 emissions dropped by 9.6%. The figure is taken from [1] and the statistics are based on ACEA data.

The main innovation is to apply information and communication technologies to transportation domain. ITS as such reuse existing technologies to create innovative services that can be applied in every transport mode and used by both passenger and freight transport.

2.2.2 Enabling ITS with Vehicular Communications

The basic concept of ITS can be designated as the capabilities of sharing particular information among vehicles in order to support a large set of applications intended to enhance transportation systems and more particularly safety. Vehicular communications are the promising communication tools that can provide facilities for exchanging and sharing information in the vehicular wireless network. They are thus the keystone technologies to enable ITS applications and services.
In this context, vehicles such as cars, trucks, buses and motorcycles, and even pedestrians will be equipped with network interfaces, on-board computing capabilities and several sensing devices like positioning systems (e.g. Global Positioning System (GPS)), video cameras and radars. Infrastructures can also cooperate with vehicles and participate in the communication process in order to provide better coverage. Figure A.1 illustrates a scenario of vehicular communications including V2V and V2I.

- **V2V Communication**
  In such type of communication, vehicles can exchange information with neighboring vehicles that are within their transmission range without involving fixed infrastructures. A network based on V2V communications is a special kind of broadcast ad hoc networks based on IEEE 802.11p. Enabling safety applications is the key application of V2V. Vehicles can exchange vital data over

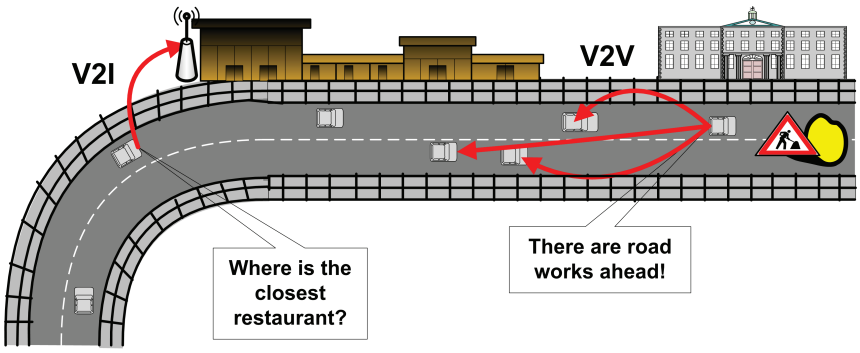


Figure 2.3: The communication paradigms in vehicular environment. V2V communications involve only vehicular nodes. For instance, information about the road works is exchanged among the approaching cars. On the other hand, V2I communications integrate sharing data among vehicles and infrastructures. The driver can accordingly get information about the closest restaurant in the city.

a wireless network including vehicle's latitude, longitude, time, speed, length, width, turn signal status, and maybe even the number of occupants in the vehicle. Sharing this latter data with other vehicles in the vicinity offer the possibility to significantly improve collision avoidance and detection systems. The benefit of V2V networks is their easy deployment in areas where it is not feasible to install the needed infrastructure. It would be unrealistic and very expensive to cover all the existing roads with infrastructures.

- **V2I Communication**
  It has been designed to allow the communication of moving vehicles with fixed road infrastructures, also defined as Road Side Units (RSUs). By deploying RSUs in vehicular networks, V2I communications open the way to the access to Internet backbone allowing passengers to browse the web while moving and benefit from various Internet services. V2I can support also traffic efficiency as well as safety-related applications. For instance, the drivers can receive from RSUs information relevant to a specific road segment in order to prevent from bad weather conditions e.g. fog, ice, snow and rain.

Various efforts around the globe from both public bodies and private entities have been conducted in order to design new communication architecture supporting the possibility to reuse existing protocols and technologies. Accordingly, a common agreement to consider an architecture inspired from the Open Systems Interconnection (OSI) model [63] has been reached among the European and worldwide standardization bodies. Figure 2.4 illustrates an outline of this reference architecture as specified by the ETSI [40]. On the top, ITS Applications have been introduced with the concept of cooperation to satisfy a large diversity of operational requirements. The Facilities layer represents the intelligence core of this architecture since it pro-

vides functions and services for upper and lower layers and manages the storage of information in several data elements. Below, Transport and Networking layers handle the communication with specific protocols such as the GeoNetworking [9] or more usual ones such as TCP [94] or UDP [95] associated to IPv6[38]. On the sides, Management and Security layers provide utilities and support to the data-plane layers for an enhanced operation.
Regarding lower layers (PHY and MAC), several access technologies are made available to applications. Particularly, new MAC amendment which is referred as IEEE 802.11p [16] associated to the 5.9 GHZ Dedicated Short-Range Communication (DSRC) [4] system has been proposed. In Europe, ITS services could be deployed and developed with a frequency designation of 30 MHz for road safety applications in the band $5875 - 5905$ Mhz, $5855 - 5875$ MHz for non-safety applications and the band $5905 - 5925$ MHz is reserved for eventual future ITS extension. Requirements of the 802.11p/DSRC are mostly derived from the constraints of ITS safety applications, where reliability and low latency are crucial.

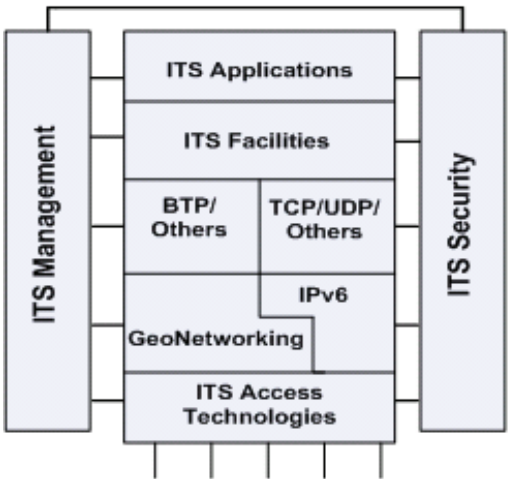


Figure 2.4: ITS communication architecture.

2.2.3 ITS Environment Challenges

For a favorable deployment, ITS applications have to be able to cope with the adverse conditions of the ITS environment. It is worth mentioning that, in vehicular networks most of the transmissions will be based on broadcast technique. In the following, we identify and outline the core challenges for vehicular communications. Some of them are more related to the nature of the wireless channel and the communication mode:

- The unreliable and uncertain nature of wireless communication that is due to multi-path propagation, fading and severe interference resulting from other transmissions. Phenomena such as path loss and/or fading can lead to unpredictable losses in the power of the received signal and thus, degradation of the

information reception ratio. These losses are more intensified by the multiple reflecting and shadowing objects present especially in urban environment where e.g. buildings and trees.

- The IEEE 802.11p MAC standard that lacks of reliable mechanisms for broadcast transfer. It is based on the *Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)* where the acknowledgments (ACKs) are only considered in the case of unicast communications. It is, indeed, not reasonable to receive acknowledgments from all neighboring nodes that receive the broadcast frame. Without receiving an acknowledgment, the sender cannot determine whether the message was successfully received or not.

- The channel congestion problem which is fundamentally due to the large amount of exchanged data in the vehicular network. When a high number of vehicles are concentrated in a small area the number of transmissions increases and thus, collisions become significantly important. Moreover, using broadcast communication mode may intensify this problem since no reservation mechanism (i.e. *Request to Send/Clear to Send (RTS/CTS)*) is used.

The other challenging properties concern the nature and characteristics of the nodes and road traffic environment:

- The high mobility of nodes in ITS environment which is the distinguishing factor of vehicular networks in comparison to traditional wireless ad hoc networks. This feature affects implicitly the vehicular topology and accordingly its spatio-temporal connectivity. The average length of time that two vehicles are in direct communication range is approximately one minute as shown by [25]. Indeed, vehicular environment presents unfavorable characteristics to develop ITS applications: frequent and sudden changes in vehicular mobility and topology will degrade primarily the performance of upper layer applications.

- The road and traffic pattern and conditions that can influence also the vehicles propagation and, consequently, the information dissemination. For instance, in typical urban environment (as mentioned above), communications are subject to Non Line Of Sight (NLOS) situations where obstacles (e.g. cities and buildings) between transmitter and receiver obstruct the radio signal, particularly penalizing considering high frequency ranges such as the ITS band.

2.2.4 ITS cooperative Safety Applications Requirements

Using vehicular networks in an automotive environment will enable large body of ITS services. Ranging from infotainment and driver comfort to vehicles safety [104], these applications are expected to be deployed in the upcoming years. A classification of ITS applications is presented in Figure 2.5. Non safety applications comprise traffic efficiency applications and infotainment. This category of applications aims at improving the road traffic flow and reducing congestion which will have beneficial

impacts on the environment. Also, providing services to drivers and passengers as well as improving their comfort are other objectives of these applications.

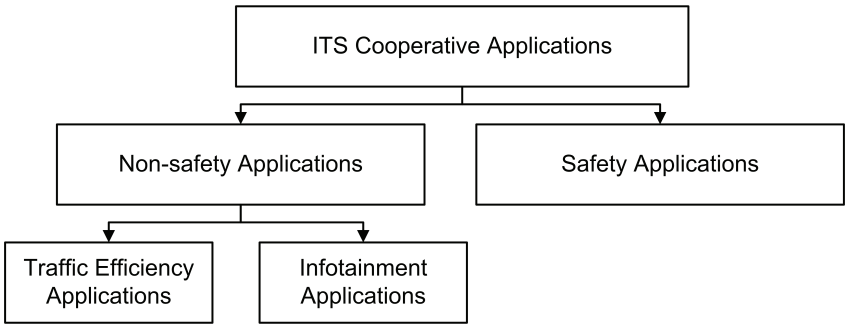


Figure 2.5: Classification of ITS cooperative applications.

In particular, safety applications have gained more attraction since they are considered as the original motivation behind ITS. They are mainly devoted to reduce accidents and injuries and thus, to save lives. Typical ITS cooperative safety applications include for example accident notification messages and, collection and distribution of information on traffic road conditions. In the scope of this thesis, we focus on ITS cooperative safety applications as we believe that they represent the most critical and vital ITS services that need further investigation.

Although their considerable diversity, ITS safety applications depend mainly on sharing two essential types of information:

1. **Local scope information**
   This information is mostly related to the knowledge of surrounding environment over a given range. Generally called *Awareness*, it is conveyed through specific messages designated as Cooperative Awareness Message (CAM) [46] in European standardization and Basic Safety Message (BSM) [18] in USA standardization or simply beacons. These messages are transmitted periodically in single hop broadcast mode including localization data i.e. the state of vehicles such as geographic position provided by GPS receiver, the speed and the direction.

2. **Global scope information**
   This second category of information reflects the occurrence of one or multiple hazardous situations on the road that could be accidents or bad weather conditions like glaze or fog. Upon detection of such typical emergency situation, specific messages are accordingly transferred in multi-hop broadcast enclosing information on the position of the hazard. Generally, this information concerns a specific area on the road. Thus, the dimension of the "dissemination area" where the information is supposed to be received is included in the message. These messages are called *Decentralized Environment Notification*

Messages (DENM) in Europe. In USA, they are defined in the *SAE 2735* message library [18].

Several cooperation efforts between European and US standardization bodies have yielded to a harmonization of the safety messages. For instance, even though CAM and BSM do not contain the exact set of data, they are compatible enough to be generated, received and handled by EU or US hardware.
In the sequel of this thesis, we use the European terminology (CAM and DENM). Beacons and safety messages are used as well to designate respectively CAMs and DENMS. A scenario showing the transmissions of CAMs and DENMs is depicted in Figure 2.6.

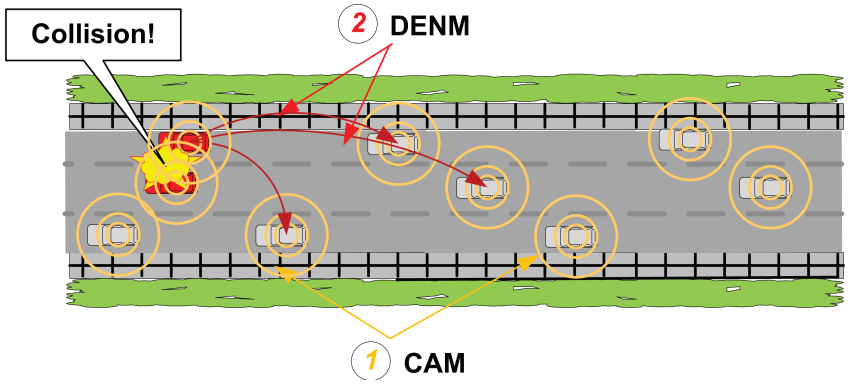


Figure 2.6: Illustration of the exchange of CAMs and DENMs. CAMs are transmitted periodically. Upon the detection of a collision between two cars, a DENM is generated and transmitted accordingly.

Given their promising and important role to ensure driver's safety, ITS cooperative safety applications are considered to be more effective in the range of milliseconds before the actual time of the emergency event's occurrence. Moreover, they are highly demanding in terms of reliability of reception. In fact, the safety-related information being the most critical must be delivered with highest priority and with lowest latency. Table 2.1 reveals the requirements from network perspective of a set of ITS cooperative safety applications. These requirements have been identified by the *European Car-to-Car Communication Consortium (C2C-CC)* [8] and the *European Telecommunications Standards Institute (ETSI)* [45].
Three use cases have been chosen [17]:

- **Cooperative Forward Collision Warning**
  In this use case, vehicles use the location knowledge about the vicinity to detect eventual rear-end collisions with neighboring nodes in order to prevent them from happening. the driver is warned at detection of potential collision. This use case requires a reasonable market penetration rate (at least 10%) and accurate positioning of the vehicles which is supposed to be ensured by

Application	Communication Mode	Transmission Mode	Frequency (Hz)	Latency (ms)
Cooperative Forward Collision Warning	V2V Broadcast GeoCast	Periodic	10	100
Pre-Crash Sensing	V2V Unicast	Periodic	10	100
Hazardous Location Notification	V2V Multi-hop Broadcast GeoCast	Time limited Periodic	10	–

Table 2.1: Requirements of cooperative safety applications as defined by ETSI/ITS. The latency denotes the time allowable between when information is available for transmission and when it is received by the receiver [45].

periodic transmissions at $10Hz$. Furthermore, reliable information reception and low latency (100 ms) are also required.

- **Pre-Crash Sensing/Warning**
  The second use case attempts to reduce the risk of collisions between vehicles instead of avoiding them. Accordingly, *"vehicles exchange more precise information to optimize the usage of actuators such as airbags and seat belt pre-tensors"*. The requirements of this use case are mostly similar to the previous one. Only unicast communication mode is used instead of broadcast.

- **Hazardous Location V2V Notification**
  This use case concerns the exchange of information related to a hazardous situation in multi-hop mode. "*On one hand, vehicles may detect the dangerous locations from sensors in the vehicle or from events such as the actuation of the Electronic Stability Program (ESP). On the other hand, recipients of this information may use it to properly configure active safety systems and/or warn the driver*". In addition to the aforementioned requirements, it requires a reliable data dissemination mechanism.

It is clear that when considering the imperfect and the unreliable characteristics of the ITS environment, it becomes quite difficult to respect the requirement on "latency". It is expected that safety applications can tolerate not more than 300 ms of latency corresponding to two successive lost packets [69]. However, as discussed in Section 2.2.3, the network congestion problem is expected to occur frequently. Thus,

it is required to efficiently manage and control information dissemination in order to regulate the channel access and to efficiently share safety information among a potentially large set of vehicles.
In the next section, we overview briefly some visions to design control mechanisms related to the area of information dissemination in ITS cooperative safety applications.

2.3 Related Works on Control Mechanisms for ITS Cooperative Safety Applications

Congestion control is an extremely crucial feature in ITS. Many efforts have been carried out aiming at designing several congestion control policies. From lower to higher layers of the communication architecture illustrated in Figure 2.4, we propose, in this section, to give a brief overview of the existing approaches in the literature for each layer of this architecture.

2.3.1 MAC/PHY layers

With regards to the MAC layer, two key fields that regard contention window and transmission data rate control have been studied. Transmission data rate control concerns the adaptation of channel rate regarding the channel statistics. On the other hand, contention window adjustment approach [26] is based essentially on using a network state estimation and an adaptive contention window. A node is able to dynamically adjust its contention window size according to the percentage of packets that was successfully received and using messages sequence number.

2.3.2 Transport and Network layer

Transport layer

Existing control mechanisms at the transport layer are more related to the TCP/IP [94, 59] stack. The current Basic Transport Protocol (BTP) does not provide a specific congestion control approach. TCP defines an end-to-end congestion control policy that could not differentiate between packet loss due to congestion and that caused by bad channel or interferences. Therefore, an approach suitable for vehicular networks and that could distinguish between both cases should be designed.

Network layer

Most of the research has been concentrated on this layer, many efforts have been carried out aiming at enhancing network dissemination. Most of these proposals focused on the use of one or a combination of the optimal selection of the relay node and the adjustment of the transmission power or the transmission rate according to the network conditions.

Relay selection A very large body of proposals focused on relay selection. The existing works in this field are regrouped into two basic classes: sender-based and receiver-based approaches. Examples of receiver-based scheme are [27][72][48] where the nodes participating in the forwarding process are selected according to the distance from the source and generally the farthest neighbor is selected. On the other hand, sender-based approaches are related to clustering and group management. For example, BROADCOMM [42] aims at a structural information dissemination. A virtual cell infrastructure is first built. The information is then transmitted in multicast between cells and in broadcast into the same cell.

Packet transmission power adjustment Another important area which has been considered in ITS environment is the adjustment of the transmission power according to vehicle environment and many other circumstances. There are protocols which are distributed and use beacons exchange to collect information from neighbors and use it in the transmission power control e.g. DFPAV[110] while other use only local information. For example, [24] and [78] focused on estimating the local density by the means of analytical models using local information and adjust the transmission power or range according to this estimate.

Packet transmission rate control Controlling the packet transmission rate consists in adapting the timing of message transmission taking into account several environmental constraints. For instance, in [98] and [81], an adaptive mechanism is proposed aiming at reducing the communication rate of periodic messages. Nodes estimate their own position and the positions of their neighbors using a tracking model. They are allowed to communicate only when there is an error between their estimate and the estimate of their neighbors.
Some works attempted to combine the advantages of both power and rate control approaches, for example, the work in [96] suggests assigning a fraction of resources to each node to ensure fairness. When a node increases its transmit power, it has to decrease its transmit rate and vice versa.

With the absolute aim to guarantee efficient safety information dissemination, the aforementioned approaches tried to tackle merely from network perspective the congestion control problem without:

1. Considering the challenging characteristics of ITS environments. In case of relay selection methods, the dynamic topology in vehicular network has been overlooked in addition to the unreliable wireless channel and high fading properties.

2. Focusing on the important question of *"how"* to ensure safety applications requirements. In case of transmission rate control, situations where higher rates are needed are not considered especially in case of sudden topology change.

Moreover, position prediction is critical especially in case of safety applications and the use of traditional models does not provide enough accuracy.

Recently, some approaches attempted to answer safety applications needs and requirements. For example, in [82] an application-oriented congestion control policy has been introduced. It consists in adapting each vehicle communication parameters i.e. the packet transmission range and power while satisfying the application requirements that depend basically on a minimum distance at which the transmission is required. Authors in [58] attempted also to jointly address safety requirements at a reduced transmit rate but limited their study to stable mobility. Unfortunately, most of the safety-related situations will be generated from unstable and uncertain traffic pattern.

In this thesis, we basically deal with these two issues. Mainly, we consider the challenging features of ITS in the design of a new dissemination control mechanism based on relay selection. Then, we address the consideration of the requirements of cooperative safety applications to propose transmit rate control mechanisms.

2.4 Conclusion

This chapter is aimed at providing a general overview of ITS and its applications. We have first gone through the concept of ITS. Furthermore, the various initiatives from standardization bodies to propose advanced automotive technologies and new communication architecture have been described. Then, we have discussed the different properties of vehicular communications and the challenges associated with such environment. An overview of ITS applications has been provided with a particular insight into ITS cooperative safety applications, their requirements and their needs. Existing control mechanisms have been described briefly. All these schemes will be discussed in details in next parts of this manuscript. In each part of the manuscript, a detailed study of the related works will be presented.
We concluded that it is required to design new control mechanisms for safety information dissemination that could take into account the requirements of safety applications and the dynamic of ITS environments. In the next chapter, we first focus on the requirements for an effective evaluation of control mechanisms designed for ITS.

3
Requirements for Effective Performance Evaluation

3.1 Introduction

The deployment of ITS cooperative applications requires initially effective evaluation tools. Several aspects of ITS environment have to be considered including road traffic characteristics, mobility patterns and wireless channel properties. Moreover, the diversity of ITS applications is another important aspect to take into account. This chapter introduces our contribution in the design and the implementation of a new simulation platform targeted to ITS evaluation namely *iTETRIS* [11]. Then, we identify the suitable metrics to evaluate explicitly the effectiveness of the ITS cooperative safety applications and their related communication protocols.
The rest of this chapter is organized as follows: We first start with describing the actual design and implementation details of the *iTETRIS* platform in Section 3.2. Then, in Section 3.3, we identify the required evaluation metrics for safety applications. Also, we discuss some aspects of the existing evaluation methodologies.

3.2 Evaluation Tools for ITS

Studying ITS often requires an assessment of various applications, network architectures, proposed protocols and access technologies. These evaluations must take road traffic details and conditions, wireless communication properties and drivers' behavior into consideration. In particular, simulation and real word testbeds are possible methods for assessing the system performance. As large scale realistic experiments composed by hundreds of equipped vehicles are not feasible, the performance evaluation of research on ITS depends strongly on simulation analysis.
In this section, we discuss related works on simulation tools that have been designed for ITS evaluation. We provide a description of the large scale simulation platform tailored for the evaluation of cooperative ITS mechanisms in a close-to-real environment. *iTETRIS* couples traffic and network simulation methods providing an ETSI/ITS standard [40] compliant platform.

3.2.1 Related Works of ITS Simulation Tools

Several simulation mechanisms have been proposed to provide reliable and robust evaluation of ITS systems. In the following, we provide details about the tools found in the literature.

For example, *GrooveSim* [83] is an integrated traffic and network simulator including a variety of mobility models but it lacks of validated communication modules. One key disadvantage of this approach is its incapability to alter the traffic mobility data in real time. There is no possibility for an application to change the behaviors of the vehicles during runtime which reduces the level of realism of cooperative safety operation.

There have been some works that addressed this shortcoming and developed integrated simulators achieving dynamic interaction between traffic and network simulation environment. For example, *NCTUns* [114] integrates some traffic features and allows the control of vehicles' mobility. However, it does not implement any well known traffic mobility model. Moreover, traffic and network simulations are highly integrated, which makes the possibility of extension difficult. *TraNS* [93] is another platform that was developed to couple two open-source simulators the *Simulation of Urban Mobility (SUMO)* [13] simulator and the *Network Simulator 2 (ns-2)* [7] using an interface called Traffic Control Interface *TraCI* [115]. While still being popular, *TraNS* has the problem of being not longer actively supported since 2008 which disallows its usage with current versions of *SUMO*. Furthermore, it does not support the specifications of ETSI/ITS architecture.

Another proposal called *Veins* [15] is a simulation framework that employs the *OMNeT++* simulation kernel for discrete event simulation. All simulation control and data collection is performed by *OMNeT++*. Vehicles mobility is simulated by SUMO road traffic simulator, which is instantiated and controlled by the running simulation. Veins provides a suite of models that can serve as a modular framework for simulating applications. These can include custom and application-specific data generation and dissemination protocols, e.g. for traffic efficiency, safety, and comfort applications.

In the following, we give a detailed overview of *iTETRIS* and our contribution to the development of this platform.

3.2.2 *iTETRIS*

Following the same approach as *TraNS* and *Veins*, *iTETRIS* proposes a 3-Blocks simulation architecture, a real-time closed-loop coupling between the traffic simulator, *SUMO* [13] and the *Network Simulator 3 (ns-3)* [12]. The integrated system also proposes to provide a central control block to realize the coupling called *"iTETRIS Control System" (iCS)*.

iCS would also provide a platform for Application developers to develop and integrate their novel applications as well as a user interface to facilitate the usability of the platform by various section of users without any knowledge of the hidden kernel.

An overview of the *iTETRIS* 3-Blocks architecture are shown in Figure 3.1.

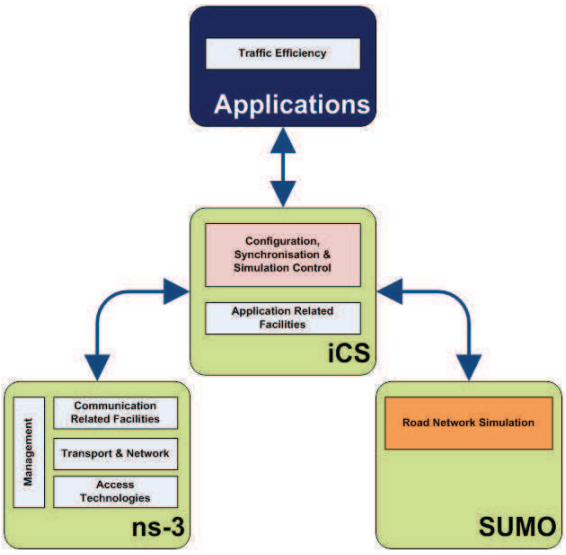


Figure 3.1: The *iTETRIS* platform architecture.

3.2.2.1 Simulating the Communication Using Ns-3

iTETRIS adheres to the objective of maintaining constant effort in order to be in compliance with reference communication architectures being developed at The ETSI Technical Committee for Intelligent Transport Systems (ETSI TC ITS) [3]. Based on the constraints involved with large scale integrated simulations, *iTETRIS* accordingly adapts to the reference architecture to suit its objectives.
As illustrated in Figure 3.1, the ITS Applications and Facilities are included in the *iTETRIS* Application and iCS respectively, whereas the ITS Transport and Network, Management and the Access technologies are present in the ns-3. For computational optimization (adhering to the large scale simulation requirements of the *iTETRIS* platform), the implementation approach of the ITS Facilities' message management will be shared between iCS and ns-3.

Adaptation of ITS Facilities for Large Scale Integrated Simulation: Communication and Application Related Facilities in *iTETRIS* Facility layer is a supporting layer defined by ETSI for ITS cooperative systems. It covers 5-7 OSI layers [63] and provides generic functions to cooperate with transport & network layers and to support ITS applications. ETSI defines three basic components in this layer: Application support facilities and information support facilities are responsible for data management and application support functions, while communication support facilities aim to achieve applications' requirements in terms of communication modes. *iTETRIS*' 3-Blocks architecture design complements the efforts to reduce computational time and resources by intelligent placement of mod-

ules to reduce inter-block message exchanges. Given this consideration, facilities layer as defined within ETSI is shared between iCS and ns-3. ns-3 will contain communication-related facilities. On the other hand, iCS implements Application-related facilities representing all the facilities closer to the application. Basically, it contains both application support and information support facilities. This aims to reduce as much as possible messages exchanges between these two blocks. The facility components are modified accordingly to function efficiently across the communication module spread across iCS and ns-3. Appropriate adaptation of the ITS facilities for an efficient large scale simulation (*iTETRIS*) can be demonstrated by referring to the methodology adapted for implementation of the communication-related Message Management Facility. *iTETRIS*' Message Management facility is responsible for handling exchange of V2X messages for cooperative communication. Examples of some of the safety and traffic efficiency cooperative messages proposed to be included within *iTETRIS* are CAM and DENM (ETSI). The Message Management block is divided between the iCS and ns-3. The idea is to maintain a record of transmitted message payload data in iCS but not to send the actual payload to the message management component in ns-3 and subsequently to the transport layer (in ns-3) and further down the stack to be transmitted. Here, *iTETRIS* exploits the capability of ns-3 to create packets with dummy payloads (without actual payload data) of specified size. In addition, iCS's Message Management also maintains a track of sent payloads and identifiers to locate on reception by the destination node. Subsequently on reception, the actual payload is obtained by the destination node by doing a simple look-up and delivered to the application. This method prevents excessive and large (in terms of size of data exchange) interactions between ns-3 and iCS, thus minimizing computation resources. This approach would limit the interaction between ns-3 and iCS, to only when it is necessary i.e when a facility message content (eg. DENM) has to be modified. Also the method abides to the classical notion of a layered network architecture, according to which a forwarding node is not suppose to be aware of the payload content, unless it is the intended destination, in which case it passes up to the application (or the Facilities located at iCS in *iTETRIS*).

VANET Protocols for *iTETRIS*: Adaptation for a Computationally Efficient Large Scale Simulation *iTETRIS* intends to propose geo-networking non-IP stack (*iTETRIS* C2C stack) along with the existing IPv4 and IPv6 stacks. *iTETRIS* C2C stack would embed within a combination of basic and advanced (with topology awareness, advanced routing capabilities, etc) geo-networking protocols. *iTETRIS* has built liaisons with other on-going EU projects and standardization bodies. For development of the *iTETRIS*' basic geo-networking, it follows the specifications proposed by the on-going EU project, GeoNet [16]. The basic geo-routing protocols' implementations, intended to be included within *iTETRIS* platform are geo-unicast, geo-anycast, geo-broadcast and topo-broadcast. In addition, *iTETRIS* also proposes innovative mechanisms to enhance the routing capability of classical

geo-routing protocols. Advanced geo-broadcast routing schemes focus basically on ensuring reliability in multi-hop message dissemination. For instance, BZB [53] uses a distance-based strategy to select the forwarder node in order to cover the entire area. Other geo-routing protocols, also planned to be implemented are eg. GPSR, MOPR etc. Another mechanism that will be adopted is Intelligent Geo-routing. This concept enables nodes to self-estimate the road topology and the neighbors' heading direction making use of network beaconing in the absence of digital maps. The neighbor data collected by this process is then statistically analyzed by each vehicle and subsequently, information like the number of neighbors, direction of traffic can be estimated by each node, this leads to intersection identification which helps efficient forwarding of packets. In addition, by Intelligent Geo-routing, vehicles can also be able to identify curves in the road topology. Furthermore, all above mentioned protocols will be studied and extended (if possible) to have a better V2V/V2I integration.

Geo-networking stack implementation in ns-3 For the development of the c2c stack in ns-3, the node structure is analyzed. An overview of ns-3 conceptual implementation architecture can be observed in Figure 3.2. Any communication stack in ns-3 needs to be attached on similar guidelines. Depending on the simulation scenario and application requirements, the appropriate stack will attach itself to an ns-3 node.

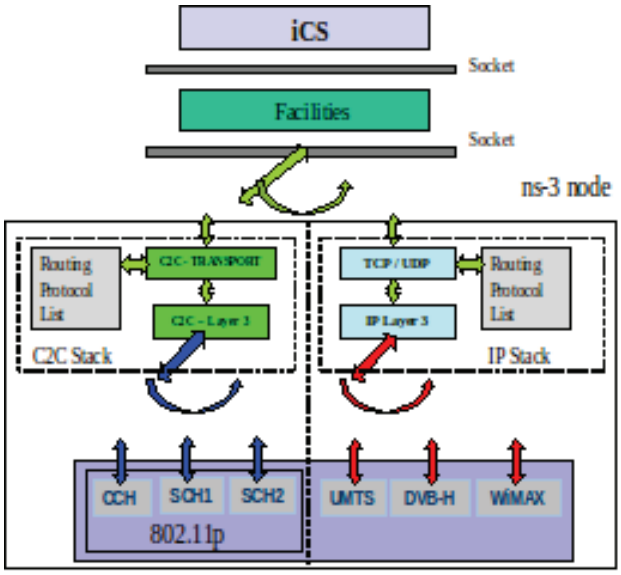


Figure 3.2: C2C stack implementation in ns-3: conceptual overview.

Apart from the c2c stack structure in ns-3, *iTETRIS* would incorporate in ns-3 a geographical based addressing scheme, relevant geonetworking headers/packets' structure and modification of the tracing mechanisms. Depending on the application requirements and network congestion status, a specific communication stack

and/or access technologies can be selected, and accordingly activated by facilities. This communication channel management is one of the most important functions being defined in ETSI TC ITS. This platform benefits from the modularity and extensibility in ns-3 and aims to serve as a de-facto platform for ITS research on network simulation. Last but not the least, a socket based interface needs to be implemented in order to couple ns-3 and iCS. *iTETRIS* Adaptation of a general ns-3 node structure is illustrated as in Figure 3.3. The implemented structure can be explained by considering the flow of information from iCS to the Message Management entity in an ns-3 node, which is the first component that receives information/commands from iCS based on application requirements. The Message Management passes the information to the StackHandler which queries Communication Channel Selector and receives back the communication channel identifier which symbolizes assignment of a specific path (Combination of Transport Protocol, Routing Protocol, Network Protocol and Access Technology) to the message. In order to maintain the extendibility of ns-3 platform for further medication when standards are finalized and incorporation of other advanced protocols, *iTETRIS* partners decides to externalize the networking and/or transportation protocols and other advanced functionalities from the basic implementation ns-3 architecture. The basic architecture implementation is recently achieved within the project. Advanced protocols and functionalities are planned in the next phase of implementation.

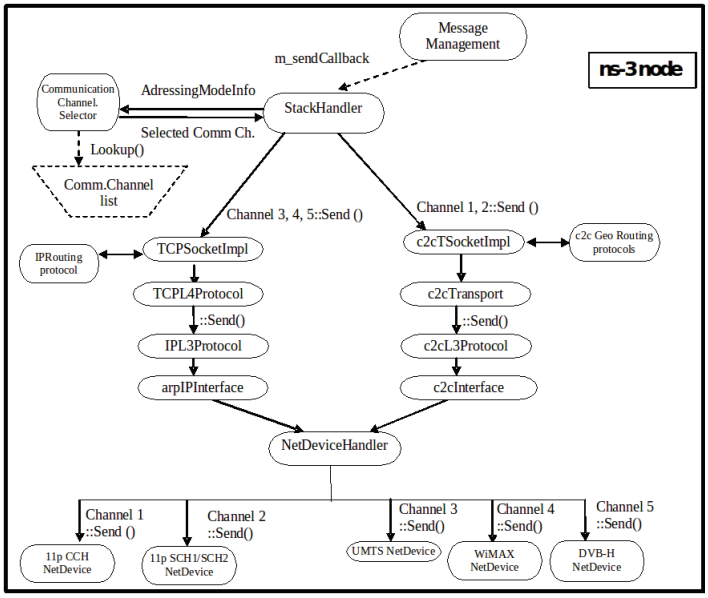


Figure 3.3: C2C stack implementation in ns-3: Implementation flow.

3.2.2.2 Simulating Road Traffic Using *SUMO*

Being highly demanding in terms of realism, a high level of precision is required when simulating ITS cooperative safety applications. Microscopic simulation meth-

ods is the most adapted to provide detailed models of individual drivers' behavioral decisions and, different car-following and lane changing models. Intersection management and traffic rules are considered as well.
Another issue is the pollutant emissions estimation which is an increasingly important matter when studying vehicular traffic. Also, the capability to influence the behavior or even the movement of cars during simulation is a crucial feature that has to be taken into account. This is ensured by the interactivity of the traffic simulator with the network simulation environment.
SUMO has been shown to answer most of the requirements stated above. It is an open source, microscopic road traffic simulator developed at the German Aerospace Center since 2001. SUMO has been successfully used within several projects for traffic management. Probably because of being available as open source, SUMO is often the first choice of institutions which are not originally involved in traffic science, but who need some basic characteristics of a real traffic's behavior. Due to this, SUMO is often used by wireless communication researchers, while traffic scientists still tend to use well-established commercial simulators such as Vissim [112], AIMSUN [19], or Paramics [90].
Because of being designed to simulate the behavior of a synthetic population in large scale, urban road networks, SUMO is able to simulate around 200.000 vehicle movements in real time on a modern desktop PC and no restrictions are put on the network size or on the number of simulated vehicles despite the used computer's memory. These qualities make SUMO a proper tool for evaluation of large-scale traffic management strategies. Within the *iTETRIS* project, SUMO was extended to meet the needs posed by the project. Because *iTETRIS* puts a strong emphasis on developing strategies which bring an ecological benefit, i.e. reduce pollutant emissions or fuel consumption, SUMO was extended by the possibility to compute and write the amount of CO, CO2, HC, PMx, and NOx emissions emitted by the simulated vehicles as well as their fuel consumption. The used model was derived using the "HBEFA" database [9] which includes data about vehicle emissions for 130 vehicle classes, divided by the size (passenger, light duty and heavy duty vehicles), by the fuel type they use, by engine displacement, and Euro-norm, for different modes of travel. The values from this database were fitted using a common emission function given below, first. The obtained curves' parameter were then clustered in order to obtain a lower number of (abstract) vehicle classes for simplifying the set-up of a vehicle population for a given scenario.

$$e(v,a) = (\frac{1}{h \times \gamma}) \times (P_0 + mav + mg\mu_0 v + mg\beta v + mg\mu_1 v^2) \tag{3.1}$$

with, c_w aerodynamic drag resistance m vehicle mass (μ_0, μ_1) (static and dynamic) friction coefficient P_0 idle power consumption γ efficiency of the engine A front area of the vehicle h energy content of the fuel ρ density of the air g gravitational constant β slope of the road
Furthermore, SUMO was extended by the Harmonized noise emission model [10]. A visualization example is given in Figure 3.4.

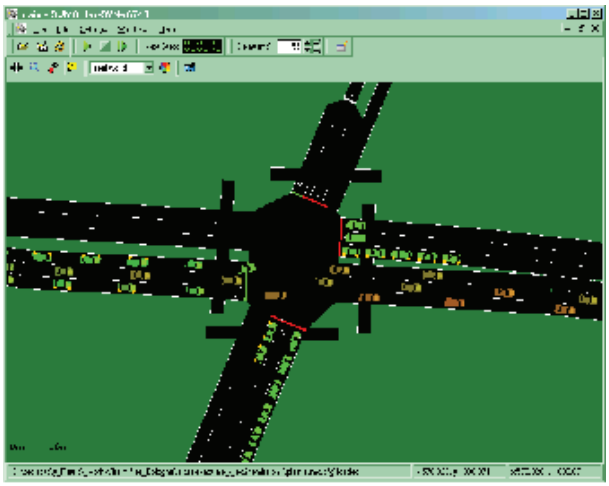


Figure 3.4: Visualization of CO2 emissions.

In subsequent *iTETRIS* tasks, further extensions were implemented, divided into the topics intelligent rerouting, intelligent traffic lights, and advanced driver assistance systems. Most of this work concerned extending SUMO's accessibility by an external application by implementing interfaces for reading values of simulated structures, such as induction loops, traffic lights, and vehicles as well as interfaces for changing these structures' behavior. As already stated, these interfaces allow implementing the logic of a method to evaluate in any programming language and use it to control the simulation's behavior. The interfaces were implemented by extending SUMO's already available communication sub-system named TraCI [11][12] which was originally implemented by staff member of the technical university of Lubeck. A further work package is concerned with allowing SUMO to simulate with steps <1s. Two reasons make this necessary. At first, wireless communication simulation is normally performed using very fine grained time steps and lowering the simulation time steps is here necessary for a better synchronization of both simulators. Additionally, modern traffic flow models are often using steps of 0.1s. Allowing SUMO to use lower time steps is assumed to improve the simulation quality by enabling the usage of such models and also allows their evaluation in the context of road traffic simulation research.

3.3 Performance Evaluation Metrics for ITS Cooperative Safety Applications

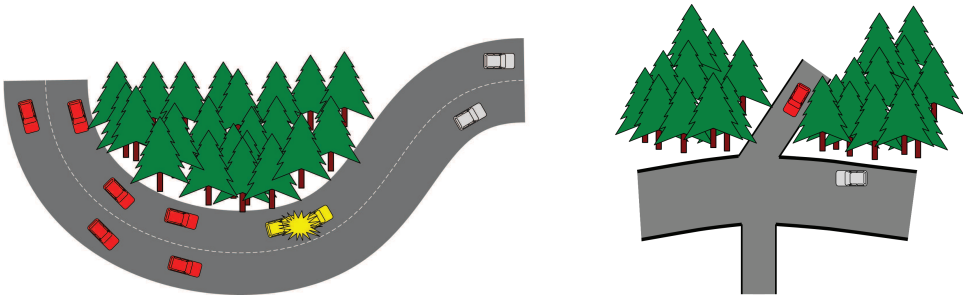
In this section, we define the performance metrics that are crucial to assess the effectiveness of the ITS cooperative applications and its related control mechanisms. As mentioned above, we focus more particularly on safety applications.

These metrics have been identified to accurately examine the capability of the designed control and dissemination mechanisms to answer the needs of cooperative

safety applications notably, in terms of latency and probability of reception.

3.3.1 Reliability

An ITS cooperative safety application is considered as reliable if the used control policy is capable of ensuring a reliable and efficient reception of the safety related information. The reliability of information reception is one of the most relevant metric for the evaluation of safety-related protocols.
As illustrated in Figure 3.5a, it is crucial for the driver's security to receive the information about the emergency situation with highest reliability especially if he/she is located in the danger area. Another example, is in case of awareness, is depicted in Figure 3.5b, vehicles in a given intersection have to receive CAMs in order to avoid collisions with other vehicles coming from the opposite road.



(a) (b)

Figure 3.5: Illustration of a traffic safety situation. In the first scenario (a), an accident occurs between two cars and to avoid other potential accidents, the safety information must be delivered to all red nodes located behind. In the second scenario (b), the information that the vehicle is approaching the junction has to be delivered to the red vehicle to reduce the risk of accident and to guarantee driver security.

This metric represents the probability that the information has been received by all the intended entities. In case of multi-hop dissemination, it corresponds to the ratio of the vehicles that receive properly the safety information to the total number of vehicles in the safety area. This metric is calculated as follows: If an emergency message is received correctly and for the first time by a given node, the number of receivers is incremented by one. At the end, the ratio is calculated between the obtained number of receivers and the total number of vehicles in the danger area.

$$Reliability_{DENM} = \frac{Receiving\_Vehicles}{Total\_Vehicles} \tag{3.2}$$

Regarding one-hop communication protocol, the reliability of information delivery corresponds to the ratio between the neighboring vehicles receiving correctly the message and the total number of neighbors:

$$Reliability_{CAM} = \frac{Receiving\_Neighbors}{Total\_Neighbors} \tag{3.3}$$

3.3.2 Reactivity

Obviously, it is not worthy to receive the information after the occurrence of the hazardous event. For instance, in Figure 3.5a, if the vehicles behind receive the safety message after reaching the position of the hazard, other accidents could happen. Therefore, to the reliability, we add the reactivity time as the second major metric for the performance evaluation of safety-related communication mechanisms.
The reactivity of a given communication protocol defines its capability to deliver information to the destined vehicle(s) in the appropriate time. For example, in multi-hop dissemination of DENMs, when an accident occurs the faster that other drivers receive the safety message, the greater the chance they will be able to avoid an accident.
In that case, the reactivity delay $\delta_r(DENM)$ for a given receiver 'A' located at a specific distance from the originator is defined as the interval from the time a DENM message is generated to the time this message is firstly received by 'A':

$$\delta_r(DENM) = t_r(DENM) - t_s(DENM) \tag{3.4}$$

where $\delta_r(DENM)$ denotes the reactivity delay is the time that the message, generated by s, takes to reach the node r.
$t_s(DENM)$ is the time at which the message has been generated at the application layer by the node s.
$t_r(DENM)$ is the time of the first reception of the message at the application layer by the node r.

To show the distribution of the reactivity delay over all the nodes in the geographic area, the Relative Frequency Density (RFD) could be measured.

$$RFD(x,y) = \sum_{r \in N} \frac{P((x \leq \delta_r(DENM) \leq y))}{N} \tag{3.5}$$

$$WhereP(a \leq x \leq b) = \begin{cases} 1, & \text{if } a \leq x \leq b \\ 0, & \text{else} \end{cases} \tag{3.6}$$

The reactivity for the whole danger area denotes the interval of time during which the message is received by the nodes in the zone. This latter allows the evaluation of the capability of a communication mechanism to efficiently guaranty the needs of a certain application. For example, assuming that an accident information has an expiry time of 15 s. The information needs to reach at least 90% of the nodes in the zone. The 10% represent the nodes that have not been covered and/or received the information after 15 s. The Cumulative Distribution Function (CDF) of the delay

could be used to model this metric. It is the ratio of delay values less or equal than a certain threshold delay x:

$$CDF(x) = \sum_{\delta_r(DENM) \leq x} (P(X = \delta_r(DENM))) = \sum_{r \in N} \frac{((\delta_r(DENM) \leq x))}{N} \quad (3.7)$$

In case of one-hop awareness dissemination, the reactivity corresponds to the level of sensitivity of the one-hop communication policy to detect a contextual change and accordingly, the safety issues that could result from that. Considering a scenario of a collision avoidance at an intersection as shown in Figure 3.5b, the reactivity $\delta_r(CAM)$ is designated as the time of the reception of a CAM by the red vehicle at a given distance from the intersection. This distance is defined as the limit distance of urgent braking considering the vehicle's speed.

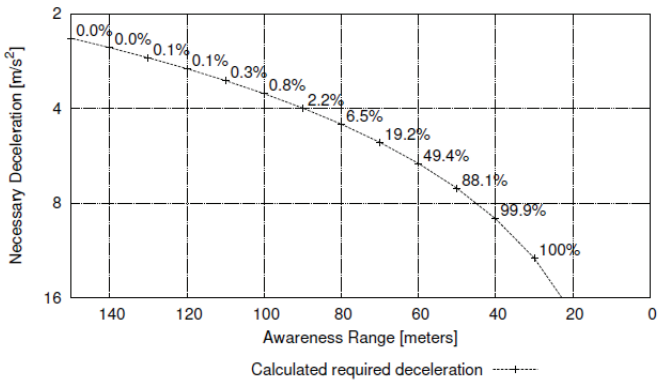


Figure 3.6: Needed deceleration as a function of the awareness range that is necessary to avoid an accident. We assume a vehicle speed of 96 km/h, no reaction time and constant braking behavior. The labels are representing the probability of a collision to occur, by simply comparing the calculated minimum needed deceleration value with the probability of drivers that were able to achieve this deceleration value in realistic measurements. Figure taken from [22].

For instance [22], as shown in Figure 3.6, if a vehicle A is approaching another vehicle B with a speed of 96 km/h, A has to receive the CAM of the vehicle B at a distance of $80m$ in order to decelerate ($4.5m/s2$) and to avoid an eventual accident. The sooner we receive the awareness, the less collision probability we have and therefore, the less deceleration needed. However, an awareness control mechanism fails to answer the application needs if the CAM is received beyond the urgent braking distance.

$$\delta_r(CAM) = \frac{BrakeDistance_r(CAM)}{Speed_r(CAM)} \quad (3.8)$$

where $\delta_r(CAM)$ is the time of reception of the CAM by the node r.
$BrakeDistance_r(CAM)$ is the limit distance of urgent braking considering the speed of the vehicle r.
$Speed_r(CAM)$ is the speed of the vehicle r.

3.3.3 Information Accuracy

Mainly, the information exchanged via CAMs and DENMs encloses position or "awareness" information. From the application perspective, the accuracy of this information is vital and more precisely for safety applications. Unfortunately, this information is frequently exposed to errors. GPS signals might be obstructed by high buildings in urban environment. Also, the loss of packets in the vehicular networks is expected to occur often due to fading channels. We define the accuracy as the distance of error between the actual and the estimated positions:

$$D_{accuracy} = |Position_{estimate} - Position_{actual}| \tag{3.9}$$

where
$D_{accuracy}$ is the metric of position information accuracy.
$Position_{estimate}$ is the estimate of the position information that could be acquired from GPS or from exchanged messages.
$Position_{actual}$ is the real position.

To model the impact of awareness accuracy on the applications, let's consider the use case "Cooperative Forward Collision Warning" [17], the vehicle is supposed to detect the "potential" collision which depends deeply on the level of precision of its awareness. Situations where false alarms are triggered, are envisioned to often occur if the position information is not accurate enough. Two metrics could be measured:

- False Positive Rate (FPR) or False Alarm Rate (FAR) which measures the probability to detect an alarm/alert when no actual event occurs.

  $$FAR = FP/(FP + TN) \tag{3.10}$$

  where FP, the false positive is defined as the times of detection of a safety event that did not occur. TN, the true negative denotes the times of the correct detection of an event which is identified as not safety (does not require action).

- False Negative Rate (FNR) that denotes the probability to ignore a safety event when it actually took place.

  $$FNR = FN/(FN + TP) \tag{3.11}$$

  where FN, the false negative is defined as the times where the vehicle ignore a safety event that did happen. TP, the true positive defining the times of the correct detection of the safety event.

3.3.4 Scalability

Scalability is a key issue for ITS applications in general. It defines the ability of the application and the communication scheme to adapt to growing demands without major changes in its design. Scalability and performance are often associated, if an ITS application is capable to perform the same in either low or high dense scenarios, it is scalable.
This metric could be modeled by the amount of the information generated by a given application (and its associated dissemination control mechanism). The less "redundant" information is exchanged in the network, the more efficient and more scalable the application is. The overall network traffic being created and received by all the nodes in the network are measured using the equations below:

$$TxOverhead = i * PS \tag{3.12}$$

$$RxOverhead = j * PS \tag{3.13}$$

Where PS is the packet size, i is the number of transmissions and retransmissions of the packet, j is the number of received packets.
The transmission redundancy factor is expressed by:

$$RedundancyFactor = \frac{RxOverhead}{TxOverhead} \tag{3.14}$$

It is worth noting that this issue becomes more crucial in case of non-safety applications such as infotainment which strongly relies on infrastructure and backbone support. Safety applications are fundamentally studied for small scale scenarios since it is more localized in specific geographic zones.

3.4 Conclusion

This chapter has given an insight about the requirements of an efficient evaluation of ITS cooperative safety applications. We provided first an overview of *iTETRIS* and its different components. We have described both the communication aspect and the traffic simulation component, and its compliance to the reference ETSI/ITS architecture. Then, we have defined the requirements in terms of performance metrics. Now we can transit to the next step which consists of the design of reliable control mechanisms for ITS cooperative safety applications. Next part will present our contribution to the reliable dissemination of multi-hop event-driven information.

Conclusion of Part I

In Part I of this thesis, we have focused on the definition and the identification of the challenges present in ITS environment and in particular the characteristics associated to vehicular communications. A description of the requirements of ITS safety applications have been also provided. Furthermore, we have been interested in providing appropriate evaluation environment for such applications.

In Chapter 2, we have discussed the current research and efforts in ITS. we concluded that the specific characteristics of ITS and the challenges associated with such environment require innovative control mechanisms that could cope with the requirements of ITS cooperative safety applications in addition to the dynamic properties of ITS environments.

In Chapter 3, we identified the need for new performance evaluation tools and metrics to efficiently assess the performance of ITS applications and control mechanisms. We have presented the simulation tool "iTETRIS" that will be used later in our simulation studies. Moreover, we identified the performance metrics which we will consider for the effective evaluation of ITS safety applications.

In Part II, we will present our contribution to the reliable control of multi-hop event-driven information.

Part II

Design of Event-driven Information Control Mechanism

Overview of Part II

In Part II, we focus on the dissemination control mechanisms for ITS safety applications intended to achieve optimal control of network congestion problem. We review first the related works in this area. Then, we provide our solution to efficiently control the dissemination of safety information. Last, we discuss the limitations of our proposal.

In Chapter 4, we provide an up-to-date and comprehensive survey and taxonomy of dissemination techniques which have been focused on channel congestion control and examine their pros and cons. We present also a classification and a qualitative comparison of these control mechanisms.

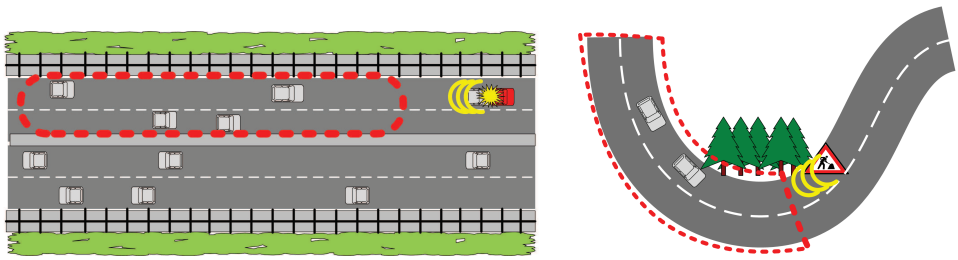
Chapter 5 is devoted to answer some limitations posed by the existing dissemination control approaches. We address the design of two efficient CBF contention mechanisms, called *BZB* and *I-BZB*, tailored to the requirements of ITS safety applications and adapted to the specificities of vehicular urban environments. Three main aspects are considered: the uniform vehicular topology, the non-fading channels and the homogeneous communication capabilities.

4
Multi-hop Information Forwarding Strategies to Control Network Congestion: a Survey and Taxonomy

4.1 Introduction

ITS have been considered as one of the most emerging research area due to their promising role in promoting traffic efficiency and particularly enhancing road safety. Traffic safety applications, being the most vital and critical ones, have gained a lot of attention. A particular aspect of such applications is their sensitivity to the delay. Let's consider a scenario where an emergency event occurs in a specific area, as depicted in Figure A.2a. Another scenario (shown in Figure A.2b) could be road works. In order to avoid potential accidents and to guarantee driver security, the emergency information must be conveyed in very brief delay and to all the vehicles located in a specific area in proximity of danger, short range multi-hop and periodic broadcasting should be used.

Explicit acknowledgement not being available, achieving reliable broadcast still remains a very challenging topic. It is also a crucial aspect that needs to be solved before any successful deployment of ITS traffic safety applications. As a given sender cannot know if its transmission has been successful, it relies on redundant transmissions either directly or via forwarding nodes. Flooding accordingly appears to be an appropriate method to address such problem. Although efficient in small scale scenarios, flooding does not scale and leads to the well known broadcast storm problem [87], as the number of retransmitters grows exponentially, and eventually saturates the wireless channel with unrequired communications leading to network congestion problems. The challenge is therefore to reach a similar dissemination rate as flooding but with significantly less transmissions. Several works have been carried out aiming at enhancing multi-hop dissemination in vehicular networks with the aim to reduce network congestion.



(a) (b)

Figure 4.1: Illustration of two safety situations. In the first scenario (a), an accident occurs between two cars and to avoid other potential accidents, the safety information must be delivered to all nodes located at the same road as the hazard (red zone). Vehicles on the other roads are not concerned with this information. In the second scenario (b), the information of the local roadwork should be conveyed in the red area to reduce the risk of accident and to guarantee driver security.

The focus of this chapter is to provide an up-to-date and comprehensive survey and taxonomy of dissemination techniques for vehicular communication systems. In particular, we address basically recent dissemination proposals which have been focused on reducing channel congestion. Section 4.2 overviews and classifies relevant proposals for message dissemination. Each protocol operation will be outlined and the performance evaluation of each analyzed. In Section 4.3, we provide a comprehensive and qualitative comparison of these broadcast protocols. Finally, we conclude this chapter in Section 4.4.

4.2 Dissemination Strategies to Control Channel Congestion

Many efforts have been conducted in prior research to address the multi-hop dissemination problem. As shown in Figure 4.2, they can be classified into two main categories: the *sender-based* and the *receiver-based* broadcasting.

The *blind flooding* appears to be the classic solution for information dissemination, but vehicular environment requires more innovative approaches. One popular solution is to build a priori forwarding structure, such as clusters [35, 32] or Connected Dominating Sets (CDS) [101, 102], or explicitly designate the nodes that will participate in the dissemination process. These specific nodes are referred as *"broadcast relays"*. This approach is known as *sender-based* as relays are explicitly selected or known by senders. Another solution is the *receiver-based* approach where receivers autonomously decide if they should broadcast the received message or not by the mean of a contention procedure.

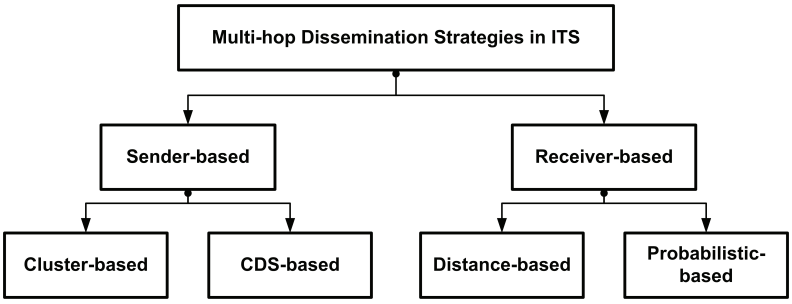


Figure 4.2: Classification of dissemination approaches proposed for ITS systems.

4.2.1 Blind Flooding: The broadcast Storm Problem

A straightforward solution for reliable delivery is the blind flooding. Traditionally used in peer to peer file sharing, the flooding mechanism consists in sending the broadcast message on reception. This approach ensures the fact that every node in the network receiving correctly the information participates in the broadcast event. This could considerably improve the delivery rate. However, at the same time it may lead to the *broadcast storm problem*. A study on this problem has been carried out in [87] which demonstrates that by increasing the number of nodes involved in the dissemination process information redundancies, contentions and collisions are intensified. Particularly, in large scale environments such as ITS, the number of network entities is expected to be huge as depicted in Figure 4.3 and, thus, is the number of retransmissions of packets in the network.

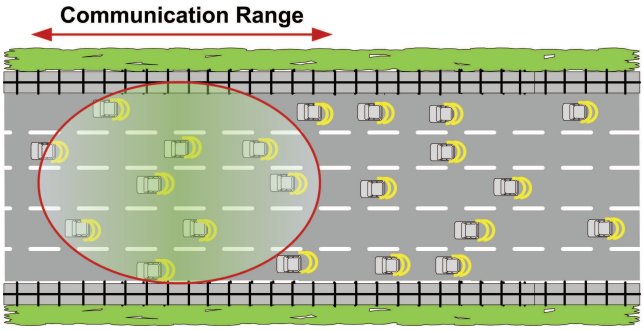


Figure 4.3: An illustration of a road scenario where all the vehicles are involved in the dissemination process. The broadcast storm problem is likely to occur in such a situation.

Various forwarding protocols have been inspired by the concept of flooding targeting the improvement of the dissemination for ITS cooperative safety applications. The idea is to alleviate broadcast storm problems while preserving the high delivery rate that flooding mechanism ensures. Most of these proposals focused on the minimization of the number of re-transmitters or relays. Only a given number of nodes is

allowed to be involved in relaying the message. In the following, we investigate the different categories of these approaches.

4.2.2 Sender-based Forwarding Schemes

As illustrated in Figure 4.2, *sender-based* dissemination concept includes cluster-based and CDS-based approaches. The basic idea is to establish a specific architecture before beginning the dissemination procedure. As shown in Figure 4.4, a given number of groups are formed and consequently, relays are selected according to their position with regards to the group. The node that is covering the whole group is selected to transmit.

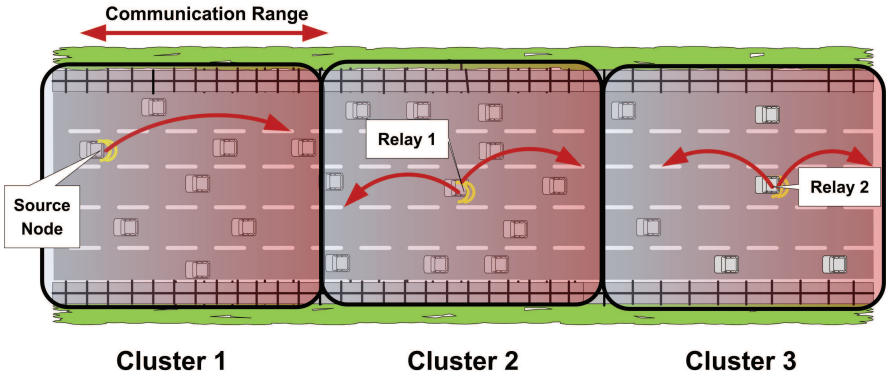


Figure 4.4: An illustration of a dissemination scenario where sender-based approach is applied. We can see that a topology structure is built before the dissemination process. Three non-overlapping clusters are formed to cover the area resulting in only two relays.

In this section, we present an overview of the existing approaches in the literature related to this class.

Ros *et al.* propose in [101, 102], the Acknowledged Broadcast from Static to highly Mobile (ABSM) protocol, a distributed CDS-based dissemination approach. Based on one-hop position information collected from beacons, each vehicle determines whether it belongs to the CDS or not. In graph theory, a CDS is a set of nodes D of a graph G where each node in D can reach any other node (belonging to D). Moreover, every node in the graph G belongs either to D or is adjacent to a node in D. Using a contention timer, only nodes belonging to the CDS are allowed to transmit the message if their neighborhood has not been already covered. Identifiers of recently received messages are included in the beacons in order to serve as acknowledgements for transmissions. Furthermore, the store and forward technique is also used to address the problem of network partitioning. Evaluated in highway and urban scenarios, ABSM showed good performance reducing considerably the number of retransmissions.

Examples of cluster-based approaches are [105, 80, 32, 35], in the following we go into details of each protocol.
In [105] the TRAck DEtection protocol (TRADE) protocol classifies the neighboring vehicles into three groups according to their position in the road: "same-road ahead", "same-road behind" and "different road". Then, the algorithm selects a few nodes from each group to forward safety messages; the farthest vehicles from "same-road ahead'" and "same-road behind" groups and all vehicles from "different road" group. A time to live is specified aiming at limiting message broadcast to a specific number of hops. A given vehicle calculates the angle between its vector of direction and its neighbor vector and compares the result to a threshold. In this way, it could determine the category to which belong its neighbors.
In [80], the authors present a cluster-based protocol, named BROADCOMM designed to achieve reliability in emergency data dissemination. They suggest an approach to construct the "cell" infrastructure, which consists of a partition of the road, and a protocol to broadcast safety information. To create the cell infrastructure, vehicles exchange their position information and speed. More precisely, this phase is achieved in two steps. In the first step, the cell creation, nodes exchange their position using "Hello" messages and determine their cell number with respect to the position of the first node which initiates this process. The second step is the cell relay selection, only nodes which belong to the cell are permitted to participate in this phase. The elected vehicle will then behave as a base station. A process of update and maintenance is performed periodically after the cell selection. If an emergency event occurs, the source node broadcasts the safety message to its cell member. A cell reflector, receiving the message, multicasts it to other neighbor reflectors. After that, each cell reflector broadcasts the safety message to all cell members. A comparison with DOLPHIN, a flooding-based approach, has been performed. The results prove that BROADCOMM outperforms DOLPHIN. The advantage of this scheme is reducing the number of broadcasting nodes which results in attenuating redundancy. However, the difficulty in updating and maintaining the formed cells remains a major problem that must be considered. Furthermore, the choice of the period of update is very critical.
Another study has been carried out in [32]. Both a backbone creation strategy and a forwarding scheme for the MAC layer are proposed. The former assumes that a vehicle can be in two possible states: normal or backbone vehicle. A normal vehicle initiates the backbone creation when it does not receive periodic beacons and elects itself as a backbone member. A contention phase, depending on the estimation of the distance from the backbone member, is then executed by neighboring vehicles and whose winner will be the next backbone member. A backbone creation process is then initiated. The latter, called Dynamic Backbone Assisted MAC (DBA-MAC), defines two priority classes: backbone member with the highest priority and normal vehicle. Additionally, two MAC schemes are proposed; a backbone member receiving a message sends immediately an acknowledgment to the sender, waits a SIFS, and then re-broadcasts it. This is called the Fast Multi-hop Forwarding (FMF) scheme. However, if the acknowledgment is not received, the node leaves this scheme and

enters the basic MAC scheme with a higher priority to backbone members. This scheme is used also by normal vehicles. If the vehicle is a backbone member the contention window is initialized to a low value. Conversely, if it is a normal vehicle the size of the contention window is invertially proportional to the distance from the sender. The performance of the proposal is evaluated by means of a comparison with three other schemes. In terms of end-to-end delay, the proposed approach outperforms other protocols even in high density scenarios as no mechanism of backoff is used.
We also found a study [35] that proposes a Local Peer Group (LPG) architecture whose main idea is to organize vehicles on the road into groups called "LPG". The authors suggest two LPG architecture alternatives: dynamic and stationary LPG. The stationary LPG approach uses location-based and well defined LPG area so LPG members dynamically change as vehicles move. On the other hand, the dynamic LPG approach is based on the radio coverage of the neighboring vehicles. They also further detailed two dynamic LPG organization schemes to form, update and maintain LPG groups: the group header based organization and the linked-ECH based organization. The former consists in partitioning the vehicles into groups and defining a group header for each group which is responsible for LPG maintenance while the latter is based on forming a broadcast tree with LPG groups where the relative ordering between vehicles groups is respected. May be the main advantage of the stationary LPG approach is the lack of messages' exchange. So, there is no need to perform LPG forming and updating. However, there is a difficulty in partitioning the road into LPG areas and in the choice of the size of each stationary LPG. In case of dynamic LPG, the high amount of exchanged messages to update LPG may be considered as a major problem. Also, the difficulty in setting the period of update remains an issue.

Sender-based mechanisms require an accurate and up-to-date knowledge of the topology to build the system architecture and to maintain it. This aspect turns out to be not compatible with vehicular environments, mostly due to the high mobility and dynamic topology requiring a constant update and maintenance of the relaying architecture. Also, conceptually speaking, the vehicular fading environment makes a sender not an appropriate decision-maker for relaying purposes. This led to the development of receiver based approaches that we investigate next section.
We believe that sender-based mechanisms are more adapted for non-safety applications mostly because they are non-sensitive to delay. For instance, when there is a traffic jam at a specific part of the road, usually a number of vehicles, in a given geographical area, share a common interest in receiving this information. This imply the need of group structuring and managing the information dissemination based on the formed architecture.

4.2.3 Receiver-based Forwarding Schemes

Receiver-based solutions are mainly designed to comply with the needs of ITS envi-

ronment. Each node decides locally of the message relaying. Accordingly, receivers contend to be potential relays, the node winning the contention relaying and all other nodes overhearing the relay stopping their contention. The efficiency of this approach, also known as *Contention-based Forwarding (CBF)* [48], has been investigated for several contention mechanisms.

For instance, *probabilistic-based CBF* makes relays draw a timer based on a given distribution. *Distance-based CBF*, on the other hand, makes relays derive a timer invertially proportional to their Euclidean progress from the sender. This approach can be found in most of the safety applications-related schemes.

In probabilistic-based dissemination, the decision of transmission depends on a given distribution that could be built on global and/or local knowledge. In [65], the authors propose *REAR*, a scheme where each node calculates an estimate reception probability for each of its neighbors based on their positions exchanged via beaconing. The reception probability is estimated using the relationship between the received signal strength and the packet loss rate. The node with the highest estimate is selected as a relay with the mean of a contention process. The propagation is limited to a specific direction included in the broadcast message with the node's list of neighbors. *REAR* has been compared to a location-based algorithm and simulation results reveal that it outperforms the location-based scheme in terms of reliability and information redundancy. Regarding latency, REAR has longer latency than location-based algorithm which is due to the contention time.

The authors in [21] propose *OAPD/DB*, an adaptive approach where nodes compute the relaying probability based on their local network density information within two hops. Nodes with the highest density are given the priority to forward the information.

There are two key drawbacks of the probabilistic concept. First, it is very probable that two nodes decide to relay the same information even if they are very close to each other. This might increase the channel load unnecessarily without providing additional coverage of the dissemination area. The second drawback is very critical especially when dealing with safety information. It might happen that all the nodes in a specific area choose to not transmit which will lead to a severe delay in the information delivery which cannot unfortunately be tolerated by such applications. Additionally, this approach requires a fresh knowledge of surroundings which might be highly variable in dynamic vehicular environment. In case of both protocols, the relay selection process is performed relying on the information received from neighbors that could be potentially uncertain and unreliable.

The second category of receiver-based dissemination is the distance-based scheme. Most of the research works in this field rely on a contention time invertially proportional to the distance from the sender. Thus, implicitly designating nodes with maximum progress in the dissemination area as relays, as illustrated in Figure 4.5.

Generally the contention time is expressed as follows:

$$Contention\_Time = T_{max} \times (1 - \frac{Distance}{Range}) \tag{4.1}$$

Where *Range* is the given transmission range of the node, *Distance* is the Euclidean distance from the last transmitter and T_{max} is the maximum time.

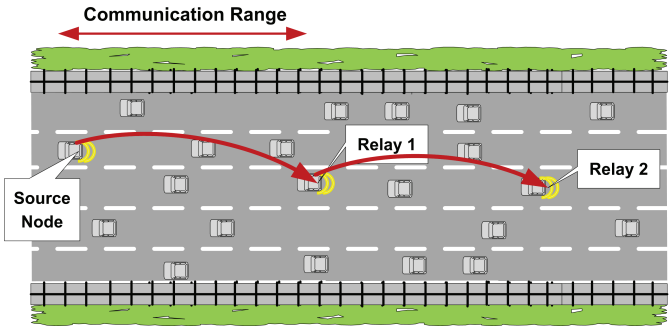


Figure 4.5: An illustration of a dissemination scenario where only three nodes are involved in the dissemination phase. Compared to blind flooding, in this particular scenario the distance based CBF scheme is able to reduce the number of retransmitters from more than twenty to only three.

In addition, the broadcast procedure is controlled by limiting the number of hops for example in [33] or by setting the geographic destination area and/or the direction of propagation where the safety information must be delivered like in [28, 47, 109]. In [28], Benslimane proposes *ODAM* protocol targeted to reduce network congestion and, consequently, increase reliability of the reception of safety messages. Based on the same concept of distance, the relays are chosen as the furthest neighbors away from the sender ensuring the coverage of the greatest zone not covered by the transmitter. The author reveals performance evaluation results comparing ODAM to other broadcast protocols. The results of the experiments show that ODAM is more reliable in all of the considered situations.
SBA [47] assumes that the road is partitioned in non-overlapping sectors. According to the sender position included in the broadcast message, a node tries to determine to which sector it belongs and enters the dissemination procedure. A contention time invertially proportional to the distance from the sender is enabled. Using OPNET, the authors present performance evaluation of SBA. The proposal has been compared to flooding approach and another broadcast protocol. The results of experiments prove a high reachability and minimum redundancy.
Also in [33], Briesemeister *et al.* propose an approach to distribute safety information by adopting the same idea of selecting a waiting time invertially proportional to the distance. Obviously, vehicles that are in the border of the transmission range are selected as relays. Furthermore, the authors suggest limiting the number of hops to a specific threshold. The simulation results show that the proposed protocol performs better when using homogeneous topology.

In [109], the authors describe Contention Based Dissemination *(CBD)* which suggests to use in addition to the contention aspect a transmission rate control algorithm for periodic awareness transmissions called *D-FPAV* to decrease channel load and to provide more bandwidth to safety messages. The network simulator ns-2 has been used where *IEEE802.11p* was implemented. The results of the experiments reveal that CBD is more reliable in terms of delay and reception probability when it is used with D-FPAV.
In Distance Defer Transmission protocol (DDT) [105], nodes have to determine according to the location information included in the received message if most of its transmission area has been covered by its neighbors. If not the vehicle should retransmit the packet. The message's time to live (TTL) is used also to reduce the number of hops. The bandwidth utilization and the reachability are the metrics which have been introduced to evaluate the performance of the proposal for both urban and rear areas. The results of the comparison of DDT with traditional broadcast approach reveal an improvement of bandwidth utilization. In terms of message reachability, DDT performs better than traditional broadcast. DDT uses implicit acknowledgment by receiving copies of the original message from receiving neighbors. Nevertheless, there is no specification of the propagation direction of the safety information.
Some optimization techniques have been proposed for instance in [72, 89, 70, 84, 20]. Authors in [84] introduce the backfire algorithm as a mechanism for suppressing redundant retransmissions. A dynamic scheduling is also proposed to prioritize received packets transmissions. Moreover, a congestion detection algorithm based on neighborhood density and vehicle velocity has been implemented to alleviate the problem of network congestion. The cut-through concept is used in [20] to allow packets forwarding before being entirely received. To do this, multiple channels are used to reduce interferences. In [30], Blaszczyszyn *et al.* propose another receiver based broadcasting mechanism. Active signaling is used, on one hand, as an acknowledgement technique and on the other hand, to select the best relay offering better progression.
In [72], the authors suggest Urban Multi-hop Broadcast (UMB) protocol, which is designed mainly to address the broadcast storm problem, and especially, hidden node problem. The main idea is to use Ready/Clear to Broadcast (RTB/CTB) mechanism to enhance messages reception. Upon receiving a successful CTB, the source node sends the packet acknowledged by the receiver. The proposed protocol has been compared to other flooding-based MAC protocols. In all scenarios, UMB shows the highest reliability in terms of percentage of success and channel occupancy. In high packets load scenarios, UMB presents a very low speed in packet dissemination due to the overhead added by the RTB/CTB approach.
In [77], the authors assume that each vehicle is equipped with two fixed directional antenna for both of road directions. Obviously, a vehicle can listen in two directions. Moreover, they propose a distance-based approach, namely Efficient Directional Broadcast (EDB). In fact, a node receiving a broadcast message waits a given time that is inversely proportional to the distance from the sender before transmitting the

same message to the front. Additionally, to prevent other nodes that already received the message from retransmitting, the selected relay sends an acknowledgment to the sender (in the opposite direction to one of dissemination) before re-broadcasting the safety message.

Kim *et al.* [106] raise the problem of selecting the relay in low density traffic scenario. They provide a distance-based protocol named Time Reservation-based Relay node Selecting (TRRS). The authors assume that a relay node cannot be guaranteed to be at the border of the sender's transmission range especially in case of low density traffic where there are no vehicles at the border. Accordingly, a potential relay node that is not at the border can wait the time which waits a border node. Then, it will not wait wastefully and re-broadcast the message. The results of simulation studies and comparisons of the proposal with other relay selection schemes demonstrate that the proposed approach has the lowest end-to-end delay and network overhead.

[89] suggests Fast Broadcast (FB) protocol, composed of two phases; on one hand, the estimation phase in which vehicles exchange their location information and their estimate of the transmission range. On the other hand, the broadcast phase in which a vehicle receiving a message computes a distance-based contention time depending on its estimated transmission range declared in the received message. The authors have compared their proposal with a distance-based protocol that does not make use of dynamically estimated transmission range. The simulation results show that the proposed algorithm achieves its main goal by having the minimum number of hops traversed and also in terms of number of collisions.

[70] considers the problem of network fragmentation and proposes a distance-based protocol with a technique to detect and alleviate this critical problem particularly for cooperative safety applications. In case of network partitioning, the last relay includes its position and identifier in a message and sends it periodically. If it receives the same message with additional entries corresponding to the position and the identifier of vehicles in the direction of dissemination, it re-broadcasts the message. The proposal has been compared to UMB with respect to the number of equipped vehicles. The results prove it has the highest percentage in dense or sparse network. However, overcoming fragmentation lead to a higher cost regarding the time to deliver message to all vehicles especially in sparse network where network fragmentation occurs often. The primary advantage of this proposal is that vehicles need to exchange additional messages (beacons) only when they detect a fragmentation problem which may provide lower overhead and may reduce congestion problem. However, this protocol performs well only in sparse networks in case of fragmentation.

Previous contributions, as shown earlier, are based on relay election according to the distance from the previous relay. And generally, the waiting time of a node is invertially proportional to this distance as such the farthest node is elected to be the next relay node. However, Taha *et al.* in [107] introduce a new approach. They assume that the road is divided into non-overlapping segments. The vehicle in the most dangerous situation corresponding to the closest segment to the sender has the highest priority to re-broadcast the safety message. Moreover, the proposed

protocol adopts RTB/CTB [72] mechanism to achieve reliable message dissemination and to avoid the hidden terminal problem. The authors conducted a performance evaluation of the proposal and a comparison of the proposed protocol with UMB and SBA has been performed. The latency for vehicles in the danger and closest zone is improved. However, the performance results prove that the good performances of this protocol are shown only in case of a large number of segments.
Eichler *et al.* in [44, 43] introduces the aspect of benefit-based dissemination which is a contention-based scheme that extends the idea of optimizing the information progress to the enhancement of the global network benefit. Each node computes the benefit provided by each packet to all the adjacent nodes which depends on various parameters such as the distance to the information source, the information type and quality, vehicle speed and message specific characteristics. The packet providing the highest benefit to all neighbors has the highest priority to be forwarded. Furthermore, a contention scheme is introduced and which depends on the estimated benefit of the message to broadcast. The simulation results show that the proposed scheme accomplishes its goal in improving the overall network benefit and reducing the overall data throughput. This new strategy may help to improve message dissemination reliability by increasing the global network benefit, at the same time it may decrease traffic congestion and heavy collisions.

Various proposals focused on adding techniques to enhance the reliability of messages' reception. For example, Jiang *et al.* [64] suggest two new proposals introducing acknowledgment in safety messages forwarding. The one is the Piggybacked ACKnowledgment protocol (PACK) [64] which consists in inserting some additional information in outgoing safety messages such as the identifier (ID) of most recently received messages. According to this list of IDs, a node A receiving a message from a node B can determine a feedback of negative or positive acknowledgment by verifying if A's message ID is present in B's message. Using all received feedback, a node can be informed of the performance of each broadcast message and make sure of the message delivery success. Therefore, the authors present a probabilistic model using logarithmic function in order to calculate the broadcast failure of each node. Furthermore, a re-broadcast process is enabled when the reception rate of a given node is below a particular threshold. To evaluate the validity of this scheme, a simulation analysis has been executed showing a correlation between the broadcast performance and the failure score of broadcast messages' reception.
The second proposal is the ECHO Protocol that can be used for both safety messages and beacons. This concept is mainly designed to increase the probability of messages' (beacons or safety messages) reception and to improve broadcasting quality and reliability. The main idea relies on piggybacking an additional message in the frame to transmit. In the case of beacons, a sender includes a recently received message in its own message. By comparing the message's identifier to the history of recent receptions, a receiver passes an unheard message to upper layer otherwise it discards it. However, in the case of safety message broadcasting, the sender includes only relevant messages in terms of time of reception and distance, only recent and

nearby safety messages are echoed. In this way, a safety message is echoed multiple times resulting in an improvement in its reception.
An additional technique has been proposed by Q.Xu *et al.* in [117]. It focused on the design of an extension of the MAC layer. The strategy adopted consists of a repetition of each message without acknowledgment. The MAC extension layer has the role to generate and to remove repetitions. Each node picks randomly a given number of time slots to repetitively transmit the safety message. This protocol is simple to implement since the repetition is easily added to *IEEE 802.11a*, and his main advantage is to increase the reliability of message reception without channel reservation (by using RTS/CTS mechanism) due to the broadcast nature of safety messages dissemination. Moreover, the authors design six different schemes for message repetition.
The common characteristic of the aforementioned receiver-based schemes is that they can be considered as a special case of CBF scheme. Although the method used in the contention phase differs from one scheme to another, the node wining the contention will be at the end the next to forward the message. In the next section, we provide a qualitative analysis and a comparison study of the different dissemination approaches.

4.3 Protocols Comparisons

In this section, we provide a brief comparison of the protocols discussed previously. In Table 4.1 summarizes the advantages and drawbacks of both sender-based and receiver-based approaches. Yet, sender-based mechanism remains suboptimal in highly dynamic ITS environment and cannot cope with the requirements of traffic safety applications as it requires a constant and periodic update and maintenance of the built structure. We deduce that receiver-based is the most adapted mechanism for ITS environment even though that it lacks of acknowledgment techniques.

Protocol	Advantages	Drawbacks
Receiver-based	Reducing congestion and redundancy by restricting a broadcast to given number of vehicles.	No Acknowledgment. Due to vehicular environment many nodes near to the sender may not receive the safety message.
Sender-based	Increasing reliability with the use of acknowledgment.	The difficulty in updating and maintaining the formed architecture (CDS or clusters).

Table 4.1: Advantages and Drawbacks of dissemination protocols.

Table 4.2 shows a comparison of the aforementioned mechanisms with regards the following criteria: the nature of the scheme, the technique used to limit the propagation of the broadcast message, the use of awareness information, the application

of acknowledgment techniques and the use of infrastructures. We can notice that most of the proposals use a specific technique to limit the propagation of broadcast messages which can be a geographic area or a counter (TTL) decremented when the number of hops traversed by the broadcast packet is incremented. Also, we can observe that most of the receiver-based protocols do not explicitly need beaconing or awareness information while all of the sender-based approaches are beaconed. In general, the receiver-based schemes do not need the knowledge of the neighborhood so the exchange of beacons is unnecessary. However, the sender-based approaches are based on the information collected from neighbors in order to form and maintain the clusters architecture. Therefore, beacons exchange is crucial.

Protocol	Sender Based	Receiver Based	Propagation Limitation	Beacon	ACK	Infrastructure
REAR		✓	Propagation Direction + Risk Zone	Beaconed		
DDT		✓	TTL	Beaconless	✓	
ODAM		✓	TTL	Beaconless		
SBA		✓	Propagation Direction	Beaconless		
CBD		✓	Rectangle (2Km)	Beaconed		
TRRS		✓	Specific Range	Beaconless		
UMB		✓	Propagation Direction	Beaconless		✓
EDB		✓	Propagation Direction	Beaconless	✓	✓
FB		✓	Area of Interest	Beaconed		
REAR		✓	Propagation Direction + Risk Zone	Beaconed		
ABSM	✓			Beaconed	✓	
TRADE	✓		TTL	Beaconed		
BROADCOMM	✓		Unspecified	Beaconed		

Table 4.2: A comparison of the existing dissemination protocols.

4.4 Conclusion

In this chapter, we provided an overview of the ongoing researches for vehicular networks and especially in the area of safety information dissemination. We, first, surveyed and classified the approaches proposed for reliable safety dissemination addressing the problem of congestion control. Then, we provided a qualitative comparison of these protocols. Mainly, a general observation which can be made from this survey leads us to the rather conclusion that dissemination for vehicular safety applications still a challenging topic. Innovative *control* approaches that can be able to manage efficiently the delivery of the safety information, tackle the problem of congestion and at the same time consider the challenging aspects of ITS environment, are required.

The results of this chapter are mainly utilized in the next chapter to rethink of existing communication systems and propose new control mechanisms adapted to the special needs of ITS environment. We deduced that receiver-based approaches are more adapted to ITS environment and more particularly, CBF scheme. In the following chapter, we propose to adapt CBF to such challenging environment.

5
Adapting Contention-Based Forwarding

5.1 Introduction

As introduced in the previous chapter, contention-based forwarding is a broadcasting technique used to control the dissemination of emergency messages. Even though it has been proposed to be adopted for ITS safety applications, its design hypotheses have however been based on three major assumptions: uniform vehicular topology, non-fading channels and homogeneous communication capabilities. Realistic ITS environment and more particularly, urban topologies do not comply with any of them, making CBF select relays, which may not exist, may not be reached or may not be optimal due to heterogeneous transmit capabilities.

In this chapter, we first study the different limitations that a distance-based CBF scheme presents. Then, we address the design of an efficient CBF contention mechanism tailored to the requirements of ITS safety applications and adapted to the specificities of vehicular urban environments. Also, none of the CBF mechanisms available today differentiates relays based on their dissemination capabilities. We therefore propose two approaches, called *Bi-Zone Broadcast (BZB)* and *Infrastructure Bi-Zone Broadcast (I-BZB)*, which regroup the asset of both random and distance-based CBF. I-BZB further adjusts the contention-timer to provide a higher chance for nodes with good dissemination properties (RSUs, buses, trams, trucks..) to be relays. We separate the forwarding area into two zones, one where a random CBF should be applied, and one where a distance-based CBF should be used. The two zones, depending on a distance threshold *"D_{th}"*, can be adjusted to the topology and connectivity. The contention-timer is then weighted by the neighbor degree of the relays. Using the iTETRIS platform and a calibrated realistic urban environment of a city of Bologna, we illustrate how this hybrid strategy showed to be significantly more adapted to vehicular urban environment providing around 46% improvement in dissemination delay and 40% reduction in overhead compared to plain CBF or flooding. We present then a study on the variation of the parameter D_{th} and its impact on the protocol performance. We finally shed light to other aspects of CBF

that remain unsolved and should be addressed to further improve the reliability of dissemination protocols for traffic safety protocols. Particularly, we focus on the cost of unrequired transmissions providing uncertain or wrong information, which are caused for instance by wrong detection of emergency events e.g. collisions.

The rest of this chapter is structured as follows. In Section 5.2, we identify the different challenging trade-offs of existing approaches. Section 5.3 introduces the proposed dissemination solutions. In Section 5.4, a simulation study is performed that evaluates the performance of the designed dissemination system. Finally, Section 5.5 reports the conclusions and provides directions for further research.

5.2 Identification of Challenges of Event-driven Multi-hop Information Dissemination

Particularly, the main concern of ITS safety applications is to warn drivers about imminent emergency situations so that they can manage to take appropriate actions to prevent any other dangerous event from happening. To this end, we assume that vehicles are equipped with a positioning system e.g. GPS to obtain their positioning information in real time. Moreover, they share periodically awareness information by the exchange of CAMs. Upon the detection of a emergency event, the transmission of safety or "event-driven" messages (DENMs) is triggered. As illustrated in Figure 5.1, this information should be conveyed to each vehicle located in a particular "destination" or "dissemination area" in the network with high reliability and with the lowest reachable delay.

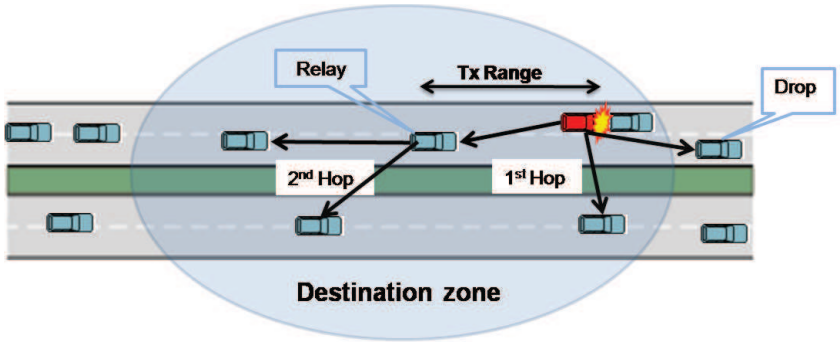


Figure 5.1: Illustration of an example of a road situation where a vehicle in a dangerous situation issues emergency messages. The distance-based CBF is used to propagate the information in the destination zone. The farthest node in the communication range is always selected to relay the message. Nodes outside the destination zone are not involved in the dissemination process.

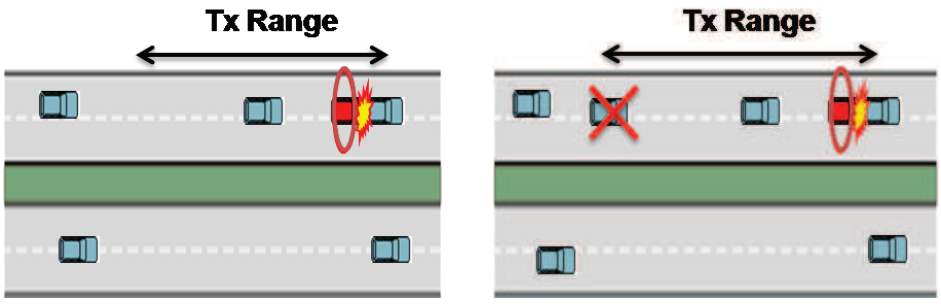
5.2.1 Non-homogeneous topology and connectivity

The major concept of CBF is that, initially, all receiving nodes are selected as forwarders, but postpone their relaying by a given timer and enter a contention phase. The first receiving node, which timer expires, immediately forwards its packet. Any node overhearing that transmission stops its timer and does not forward. As a consequence, only a specific number of nodes in the network are allowed to forward the message, and the global number of potential transmissions in the network is reduced.
The optimality of such CBF depends partially on the timer selection process. The standard approach of CBF lets receiving nodes randomly select a timer following a uniform distribution. In the following this approach is called "random" CBF. All nodes, receiving properly the message, have equal probability of relaying. A popular extension is known as distance-based CBF, where the timer depends on the geographic position of the nodes, farthest ones situated close to the limit of the communication range of the current transmitter are given more opportunity to forward the message. For each node, the length of the contention period is inversely proportional to its progressed distance from the sender. As a result, a significant reduction of the number of transmissions is expected. As shown in the Figure 5.1, contrary to the flooding approach where all vehicles receiving the emergency message broadcast, only one (the one with the highest coverage) out of four nodes, is selected to forward.

In spite of their advantages, these approaches are adapted only in some particular situations. Indeed, they have been developed for an environment fulfilling the following three conditions:

- The homogeneity of topology: all vehicles are uniformly distributed in space.
- The homogeneity of connectivity: the information reception probability is equal in space.
- The homogeneity of communication capabilities: all vehicles have equal transmission capabilities.

Unfortunately, the vehicular environment does not fulfill any of them. In an ideal scenario, as the one depicted in Figure 5.1, vehicles are uniformly distributed and the probability that a node is located at the transmission range of another is fairly high. Therefore, farthest nodes are always selected as relays which ensures the effectiveness of the distance-based scheme. However, due to the ITS environment dynamicity, network partitions become inevitable and vehicular distribution acquires a non uniform aspect. As illustrated in Figure 5.2a, the existence of distant nodes on the border of the communication range cannot be guaranteed in such environment. Furthermore, the attenuation that is due to buildings and other mobile obstacles as well as multi-path propagation and interferences can lead to severe fading, especially at far distances. As shown in Figure 5.2, the node selected by distance-based CBF providing the maximum progress may either not exist (Figure 5.2a) or not receive



(a) (b)

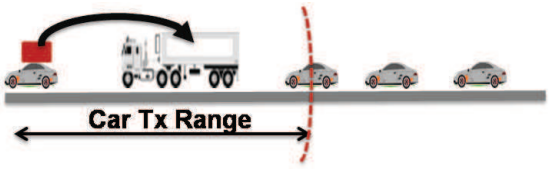
Figure 5.2: First limitation of the distance-based dissemination approach. (a) There are no distant nodes at the border of the radio range of the transmitter due to the non uniform distribution of vehicles. (b) Farthest nodes from the transmitter cannot receive correctly the message due to fading phenomena.

properly the message (Figure 5.2b).

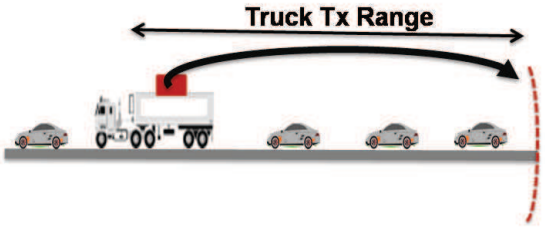
In both cases, existing nodes close to the previous transmitter and that can be reached will wait wastefully for opportunities to send with a time relatively high (inversely proportional to their distance). This may hinder the reliability of data delivery and introduce extra delay. So, in some circumstances, it is not worth considering the concept of distance-based CBF of giving the highest chance to nodes situated at the border of the communication range to become relay and postponing the transmission of others that would represent the most adequate relays in that situation. Also, the distance-based approach does not distinguish between nodes located at the same distance from the transmitter. They perform similar contention timers which may lead to a severe problem of network collisions especially in case of high density scenarios.

5.2.2 Non-homogeneous communication capabilities

Another issue is related to the high diversity of ITS entities that are expected to be deployed in the near future. This would be reflected in a significant non uniformity of their communication and forwarding capabilities. For instance, compared to standard cars, vehicles with important height e.g. trucks and buses are equipped with high antennas that may ensure more coverage than other network entities. Therefore, they can be considered as appropriate relays. As shown in Figures 5.3a and 5.3b, if the standard car is selected to forward, only the truck could be covered because it will hide the signal to the other car. However, if the truck is selected, all the cars will be able to receive briefly the safety data.
On the other hand, RSUs, if deployed effectively, may contribute to a significant improvement of the efficiency of the safety information dissemination. They can even be connected via wired networks between each other and can communicate



(a)



(b)

Figure 5.3: Impact of the participation of the vehicles with important antenna height in the dissemination process. (a) The first case where the farthest car cannot act as the next relay because the signal is hidden by the truck. (b) The second case where the truck is selected as the next relay.

directly. A representation of the capabilities of V2I communications with respect to V2V communications is illustrated in Figure 5.4. A considerable enhancement of the message reception probability can be perceived. A packet sent by a RSU can reach up to $820m$. However, when it is sent by a regular vehicle less than $400m$ are covered.
Figure 5.5a depicts a typical scenario where the information could not be propagated on particular roads in case of an urban environment where various static and dynamic obstacles exist and obstruct the Line-Of-Sight (LOS) between road segments and accordingly prevent direct communication among nodes. The forwarder, selected by distance-based CBF, is located far away from the intersection, vehicles situated in the secondary road will not receive the message. Nevertheless, in the second scenario in Figure 5.5b, if the RSU, placed in the intersection, participates in the dissemination process, all the vehicles in the other road will be reached.
In the following section, we will give more details on the solutions that we propose to the several limitations of distance-based forwarding presented in this section.

5.3 Proposed dissemination approaches

One of the major goals considered in this thesis is to design a new dissemination control system that supports and improves traffic safety. It should aim to optimize the network resources usage and fit safety applications requirements in terms of delay and reception reliability. Moreover, the scheme used to select the next forwarder has to face the shortage of the distance-based CBF. We first consider

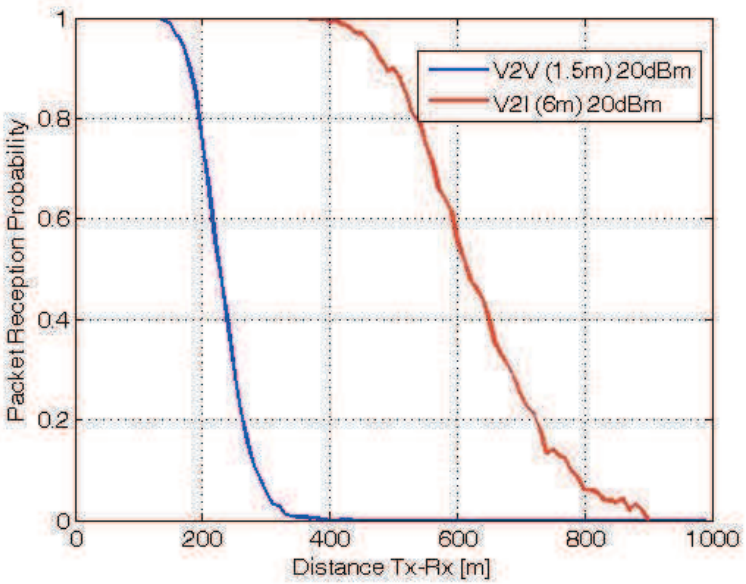
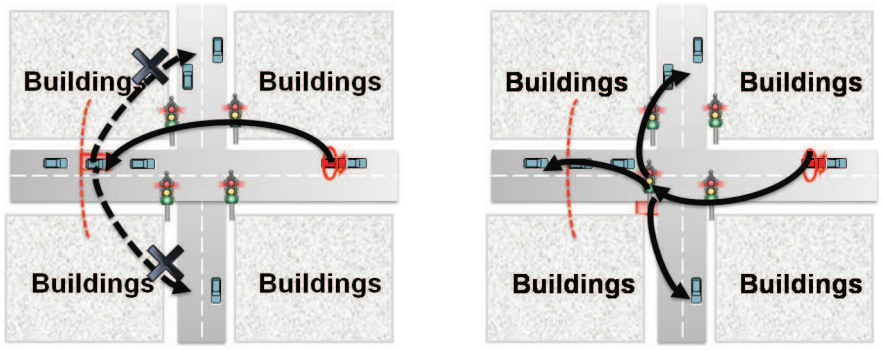


Figure 5.4: A representation of the capabilities of V2V communications (with an antenna height of $1.5m$) vs. V2I communications (with an antenna height of $6m$) [61, 60].



(a) (b)

Figure 5.5: Road Side Unit role in the dissemination process. (a) The first case where the vehicle is selected as the next relay. (b) The second case where the RSU is selected as the next relay.

the non-homogeneous topology and connectivity that characterizes the vehicular environment then the non-homogeneity in vehicular communication capabilities.

5.3.1 Bi-Zone Broadcast

Distance-based CBF yet remains sensitive to the vehicular urban topology and connectivity. If the geographic area providing a maximum progress does not contain any relay or the relay cannot be reached due to intense fading, alternate relays will be penalized and will have to wait longer than required. We propose a flexible and hybrid CBF that mix together, on one hand the randomness of the standard CBF and on the other hand the main concept of distance-based CBF i.e. taking into account the progressed distance in the contention scheme. The distance-based CBF showed to be sub-optimal at close range, especially in case where no potential relay at the transmission range exists. We consider relying on a random timer that can increase the chance of close vehicles to forward faster and avoid waiting wastefully for a non existing farther forwarder. At the same time, the concept of distance-based CBF is preserved after a specific distance threshold. In other words, it is ensured that farthest nodes (after the threshold), if they exist, will wait shorter time before transmitting. Moreover, our approach permits to consider unknown topology and to avoid that nodes in a similar distance get the same timer.

Our protocol namely, *Bi-zone Broadcast (BZB)* is based on the idea of dividing the potential receivers into two distinct groups i.e. close and far nodes according to their geographic positions and given a certain distance threshold. A random CBF approach is applied to the closest vehicles, regardless their relative distances from the sender. It is ensured that they get a waiting time higher than the farthest ones. However, given the random aspect of the applied contention procedure, it can occur that they wait less than they would do in case of standard distance-based CBF. The contention of distant nodes relies on a random distance-based scheme. In worst case, they are supposed to process the standard algorithm of the distance-based CBF. However, they have the possibility to wait less due to the random nature of the contention. Another important benefit of the randomized contention scheme is that it solves the problem of contention between nodes in the same positions. Even if there exist two nodes having identical distance from the last transmitter, they will pick out different waiting times with a high probability.

We assume that the transmission range is partitioned in two adjacent and non-overlapping areas, as depicted in Figure A.3. The former considered as the closest zone to the sender, it is defined by the distance threshold D_{th}. The latter is the remainder of the node's communication range.

As outlined in Figure A.3, where dashed line presents the evolution of the waiting time of a standard distance-based CBF with regards the distance from the sender. Plain lines present the different bounds of *BZB* contention scheme, the contention each node has to perform, depends mainly on these two zones.

In both areas, the waiting time is selected randomly between two bounds. For closer nodes where the distance is lower than the D_{th}, the interval of contention time selection is fixed to [T2, T_{max}], T2 is given in Eq. A.2 and T_{max} is the

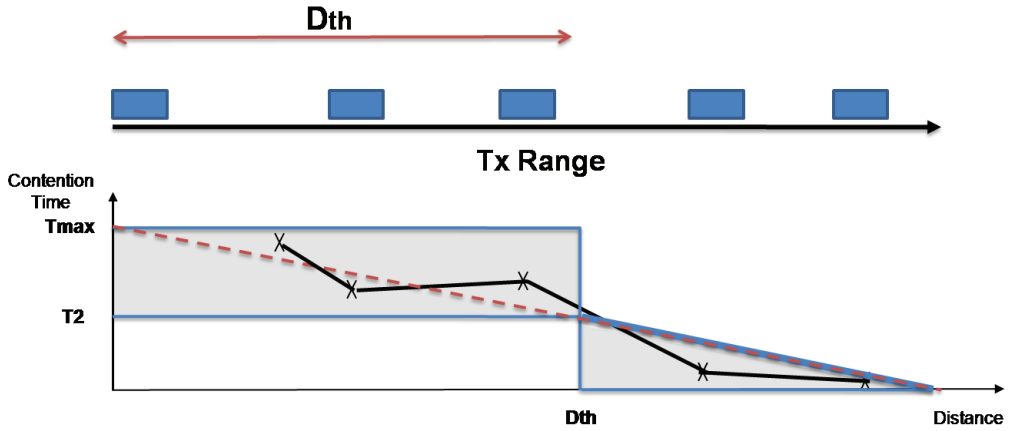


Figure 5.6: The *BZB* contention scheme where the dashed and the plane curves represent respectively the distance-based CBF waiting time and the bounds of *BZB*.

maximum waiting time. Due to the random fashion of *BZB*, an improvement of the contention scheme is perceived, as depicted in Figure A.3, closer vehicles i.e. third node after the transmitter acquired a contention time lower than the one obtained by a basic distance-based CBF.
The contention interval of vehicles with distance beyond D_{th} is [0, T1] where T1 is detailed in Eq. A.1. Having a lower bound of 0, farthest nodes are granted the possibility to forward immediately the message at reception without waiting a specific time. In worst cases, distance-based forwarding approach is applied.

$$T_1 = T_{max} \times (1 - \frac{d}{r}) \tag{5.1}$$

$$T_2 = T_{max} \times (1 - \frac{D_{th}}{r}) \tag{5.2}$$

Where r indicates the transmission range, T_{max} is the maximum waiting time, D_{th} is the bi-zone distance threshold and d is the distance from the sender.
In the following, we present detailed equations of our contention scheme. A node receiving the safety message computes its distance from the source. Then, it schedules a broadcast timer. The waiting time, as expressed by Eq. 5.5, is randomly calculated between two bounds. The upper bound of waiting time T_{upper} and the lower bound of waiting time T_{lower} defined as shown in Eq. 5.3 and Eq. 5.4 respectively.

$$T_{\text{upper}} = \begin{cases} T_1 & where\ d > D_{th} \\ T_{max} & where\ d \leq D_{th} \end{cases} \tag{5.3}$$

$$T_{\text{lower}} = \begin{cases} 0 & where\ d > D_{th} \\ T_2 & where\ d \leq D_{th} \end{cases} \tag{5.4}$$

$$WaitingTime = random(T_{lower},\ T_{upper}) \tag{5.5}$$

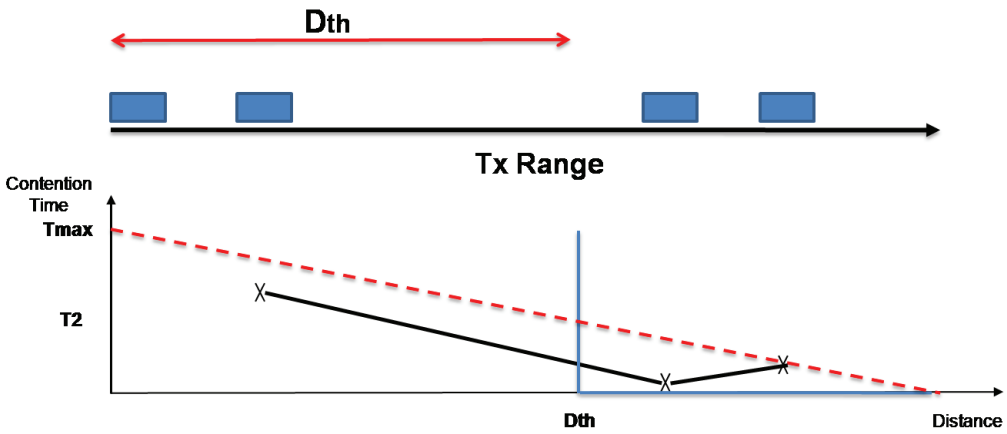


Figure 5.7: A scenario illustrating the limitation of *BZB*.

It is worth to mention that there might be some cases where standard distance-based CBF outperforms our approach. For instance, in Figure 5.7, even though distant node at the border of the radio range exists, we observe that *BZB* selects another node that does not guarantee the maximum progress. This is due to the arbitrary selection of the waiting time within the bounds which may cause in some cases a potential degradation of the performance of the dissemination process. The reduced progress due to our timer however remains minor with respect to the transmission range.

5.3.2 I-Bi-Zone Broadcast

Many approaches, especially for sensor networks, have been focusing on enhancing the contention-based mechanism when taking into account the capabilities and limitations of communicating entities. For instance, some of them proposed energy-aware or duty cycle-based protocols to limit the power consumption of the dissemination process. For ITS environment, the energy does not represent an issue. However, the dissemination capabilities created by transmit characteristics, i.e. antenna height and transmission power, of different entities building ITS systems could be considered. None of existing vehicular dissemination approaches can yet discriminate relays based on their relaying capabilities. Vehicles with important high antenna may ensure more coverage than other network entities. For instance, Road-Side Units (RSUs) have usually a higher transmit power, and with tall vehicles, they also have higher antenna heights, therefore improving their communication range compared to regular vehicles. Accordingly, it becomes clear that the dissemination characteristics of a relay should be considered in the CBF contention timer, as nodes with similar or even smaller progress could make better relays.

We believe that an advantageous usage of these capabilities can significantly improve the dissemination performance. Therefore, we propose an enhanced contention

scheme for *BZB* where we consider the combination of V2I and V2V communications. This dissemination protocol named, *I-BZB* (Infrastructure-BZB) has to benefit from available RSUs to improve data dissemination by weighting the selection process to let RSU or vehicles with high antenna height relay before other vehicles. Furthermore, we consider that entities having more nodes in the neighborhood should procure more opportunity to disseminate the emergency information quickly. This may further enhance data reception probability.
As expressed in Eq. 5.6 and Eq. 5.7, the contention time depends on the number of neighbors of the vehicle. It guarantees that the timer of vehicles with relevant antenna height will be shorter with high probability than that of ordinary vehicles.

$$WaitingTime = K \times random(T_{lower},\ T_{upper}) \tag{5.6}$$

$$K = \begin{cases} \frac{1}{N_{neigh}} & Antenna\,height\ > \alpha \\ 1 & Otherwise \end{cases} \tag{5.7}$$

where T_{lower} and T_{upper} are given by Eq. 5.3 and Eq. 5.4, and α is an arbitrary value bigger than the antenna height of regular vehicles. It is worthy to note that the distance threshold D_{th} in T_{lower} and T_{upper} depends on the nature of the vehicle and thus, its radio range.

5.3.3 Main algorithm

The main algorithm of our proposed dissemination approaches is illustrated in Algorithm 1, a DENM is generated when the originator detects an emergency event. The original message should contain the required information for other vehicles such as the limits of the dissemination area and the positioning data of the source. After a successful reception of a DENM, the vehicle checks whether the message has been received before and whether the transmitter follows the receiver along the message propagation direction. Then, it should determine the area it belongs to by comparing the geographical coordinates of the transmitter node with its own and then enter the re-broadcast phase. The node executes the contention scheme represented by the procedure *ContentionPhase*(). At this step, either the first contention scheme of *BZB* (Section 5.3.1) or the second one (Section 5.3.2) is used. At each time step, the waiting time is decremented. Forwarders that countdown until zero, rebroadcast the message after writing their own coordinates in the packet header in addition to the originator's information. Any time a node receives a valid copy of the DENM, it checks whether the message has been received before. In this case, the vehicle aborts the rebroadcast procedure.

It is worthy to mention that our algorithm does not consider the eventual change that can occur on the positioning information during the transmission decision process. We think that the contention time that a vehicle can wait could be considered as negligible. For example, considering a scenario where a car traveling in $120km/h$,

the maximum deviation that could occur on the position during a maximum waiting time of $10ms$ goes to $0.5m$. We believe that this deviation is not remarkably important and that the decision of relay selection could be done considering the outdated position information without any major impact on the relay selection.

Algorithm 1 pseudo-code of the proposed dissemination schemes

```
1: Procedure: DENMMsgTx ()
2: if (detectEmergency) then
3:    TransmitDENMMessage ()
4: end if
5: Procedure: DENMMsgRx ()
6: if (notReceivedBefore) then
7:    if (inPropagationDirection (myPostion, senderPosition)) then
8:       if (myPosition in senderForwardArea) then
9:          ContentionPhase (D_th)
10:      else
11:         abort
12:      end if
13:   else
14:      abort
15:   end if
16: else
17:   abort
18: end if
19: Procedure: ContentionPhase (D_th)
20: Time ← Random (T_upper , T_lower)
21: Contending ← true
22: Contend (Time)
23: Procedure: Contend (Time)
24: while (Time > 0) do
25:   Time← Time - slotTime
26:   if (Time = 0 AND notReceivMessage) then
27:      TransmitMessage()
28:   end if
29: end while
```

5.4 Performance Evaluation of the Proposed Multi-hop Event-driven Protocols

In this section, we evaluate the performance of our proposed dissemination control system: *BZB* and *I-BZB*. As a first step, we assess the impact of the consideration of the non-homogeneity in topology and connectivity in Section 5.4.2. We perform

a comparison of *BZB* with both the standard distance-based CBF and a basic geo-broadcast protocol that follows the specification of the GeoNet project [9]. Mainly, it is based on a simple flooding approach and does not implement an intelligence in its dissemination process.
Then, we evaluate the effect of considering the non-homogeneity of the communication capabilities in Section 5.4.3, by a comparison with the first scheme *BZB*. Section 5.4.4 is devoted to analyze some issues related to the proposed schemes. In particular, we discuss, the impact of the variation of the threshold D_{th} and the effect of wrongly detect an emergency event on the performance of *BZB*. In the following, we introduce the simulation setup (Section 5.4.1) and the configuration of mobility and network scenarios. We present then the set of performance metrics we have measured, and finally the results of our experiments.

5.4.1 Simulation setup

We have conducted a set of experiments to analyze the performance of our proposed contention-based communication protocols under various realistic conditions. We have used the simulation platform iTETRIS[11].

5.4.1.1 Mobility scenario

With the aim to realistically evaluate our proposed approaches, we considered an urban scenario modeling the non-homogeneity of the topology and connectivity of vehicular environment. The traffic scenario that we have used, illustrated in Figure 5.8, is a validated, calibrated and realistic urban scenario from the iTETRIS project [11] called *"Acosta Pasubio joined"*. This scenario models an urban environment and is composed of multiple intersections with different lengths of road sections connecting each other. The size of the road network is $2126mx2117m$. Five mobility traces are created by SUMO with each scenario the duration of $200s$ starting from the second $3000s$, respectively $3000s-3200s$, $3200s-3400s$, $3400s-3600s$, $3600s-3800s$, $3800s-4000s$. The reason to choose this time window is in order to obtain a fully loaded road network i.e. from 1500 to 2200 vehicles.
Regarding the performance evaluation of *I-BZB* and the integration of V2I communication, RSUs are placed at each intersection and added into the mobility model. Fifty five RSUs are manually positioned at all intersections. The positions of these RSUs are also fed to ns-3. Figure 5.8 gives a visual presentation of the "Acosta Pasubio joined" scenario taken from SUMO-GUI [13].
A summary of the configuration parameters of our mobility scenario can be found in Table 6.3.

5.4.1.2 Network scenario

In our communication scenario, we consider that vehicles communicate through periodic awareness and event-driven messages (DENM). The awareness is conveyed by beacons at network layer, which are sent with the frequency of $1Hz$ by all the nodes

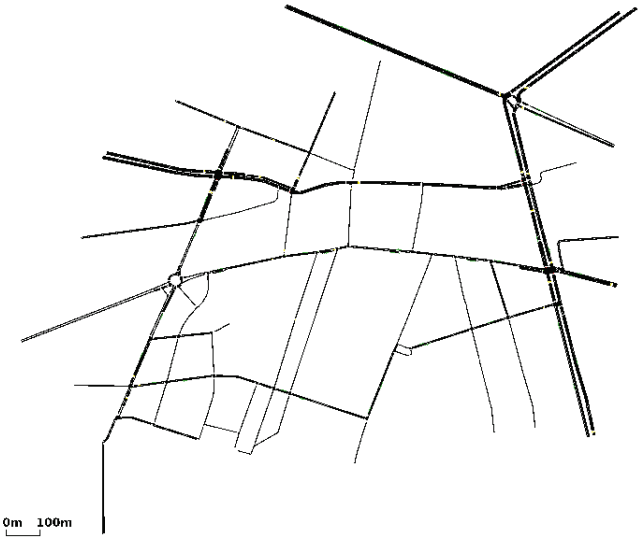


Figure 5.8: Acosta mobility scenario.

Parameter	**Value**
SUMO scenario	Urban-acosta pasubio joined
Scenario size	$2126mX2117m$
Average number of vehicles generated	1500 to 2000
Equipped vehicles rate	100%
Number of RSUs	55
Mobility traces	$3000s - 3200s$, $3200s - 3400s$, $3400s - 3600s$,$3600s - 3800s$, $3800s - 4000s$

Table 5.1: Configuration parameters of the mobility scenario.

existing in the network. For the event-driven data, an ITS application implemented in iTETRIS, has been used for the testing. It consists in triggering the transmission of DENM messages at the detection of an emergency event. They are sent at the maximum allowed transmission power.

Each simulation is executed for $200s$. In order to obtain reliable results, simulations have been carried out several times with five different values of the random number seed to vary the network topology and configuration. At the beginning of each simulation, the dissemination area, where the emergency information should be propagated, is selected randomly. The closest node to this area initiates the DENM transmission process. Only nodes located at this specific area will participate in the dissemination procedure. DENM are required to be transmitted to $1000m$ from

the originating node. The geographic coordinates of the center of the dissemination area are picked out from the map.

The variation of the network topology as well as the connectivity is ensured, on one hand, by the various mobility scenarios that we have used and, on the other hand, by the random selection of the source for each run. At this level, we vary the packet size to evaluate the impact of the overhead on the performance of the different schemes. Four packets size have been selected: 500 Bytes, 1500 Bytes, 2000 Bytes and 2200 Bytes. The propagation model that has been used is the *WINNER B1* model for urban environment, which takes into account correlated log normal shadowing and LOS/NLOS visibility between vehicles. Since we are targeting ITS traffic safety applications requiring brief dissemination delays, we have set the maximum waiting time (T_{max}) to $10ms$. Table 6.4 gives an overview of the configuration parameters for the communication scenario.

Parameter	**Value**
Awareness messages	Network beacon
Event-driven messages	DENM
Destination area size	$1000m$
Network beacon rate	$1Hz$
Packet sizes	500 Bytes, 1500 Bytes, 2000 Bytes, 2200 Bytes
Simulation Time	$200s$ for each run
Maximum waiting time (T_{max})	$10ms$
Number of simulation runs	100
Propagation model	WINNER II LOS/NLOS
Shadowing	Correlated log-normal
Fast Fading	Rician (LOS) / Rayleigh (NLOS)
Transmission power	$20dBm$
V2V maximum transmission range	$400m$
V2I maximum transmission range	$900m$

Table 5.2: Configuration parameters of the network scenario.

5.4.1.3 Performance metrics

To evaluate the issues associated with dissemination protocols in ITS environment, we have defined a set of performance metrics.

1. **Reactivity**
   This metric is the most relevant metric to analyze the performance of safety related communication protocols. When an accident occurs the faster that other drivers located in the given danger zone receive the safety message, the greater the chance they will be able to avoid an accident. As mentioned in Section 3.3 the reactivity delay is defined as the interval from the time an application generates a DENM message and handed over to the network layer to the time this message is firstly received by the corresponding network layer at another vehicle located at a specific distance from the originator:

   $$\delta_r(DENM) = t_r(DENM) - t_s(DENM) \tag{5.8}$$

   $\delta_r(denm)$ the reactivity delay is the time that the DENM, generated by s, takes to reach the node r.
   $t_s(denm)$ is the time at which the DENM has been generated by the node s.
   $t_r(denm)$ is the time of the first reception of the DENM at the network layer by the node r.

   To show the distribution of the reactivity delay over all the nodes in the simulation, we have measured the Relative Frequency Density (RFD). The Cumulative Distribution Function (CDF) of the delay has been used also to evaluate the success of our data dissemination algorithms to reach the whole dissemination zone in the required time.

2. **Scalability**
   To evaluate the ability of the dissemination scheme to adapt to growing demands, we have considered the transmission redundancy factor where the network load is measured. In case of flooding-based approaches e.g. basic geo-broadcast protocol, every vehicle that receives the DENM will rebroadcast it creating a high redundancy in packet transmissions and, thus, severe network overhead. Enhanced dissemination protocols are expected to alleviate this problem and ensure lower redundancy. This allows the support of large scale scenarios.

   As discussed in Section 3.3, the transmission redundancy factor is given by:

   $$RedundancyFactor = \frac{RxOverhead}{TxOverhead} \tag{5.9}$$

where the system overhead created and received by all the nodes in the network is expressed as:

$$TxOverhead = i * PS \tag{5.10}$$

$$RxOverhead = j * PS \tag{5.11}$$

Where PS is the packet size, i is the number of transmission and retransmission of the packet during the simulation, j is the number of packets received.

5.4.2 Evaluation of *BZB*: Impact of the non-homogeneity in topology and connectivity

In this section, we evaluate the performance of our proposed concept *BZB*. A comparison between *BZB* and both distance-based CBF and the basic geo-broadcast [9] protocols is performed. In the following, we analyze the results of the conducted simulations. As mentioned above, transmission redundancy and reactivity delay are considered as evaluation metrics. The bi-zone distance threshold D_{th} is fixed to the half of the transmission range $200m$.

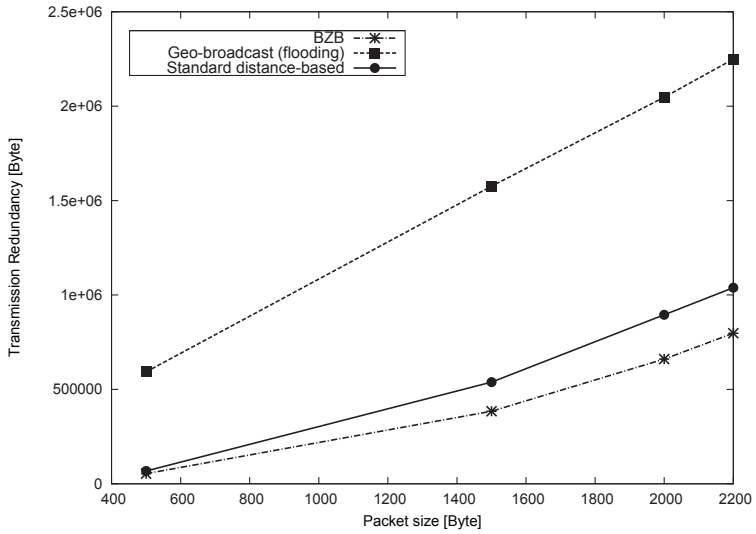


Figure 5.9: The variation of the transmission redundancy factor in case of *BZB*, flooding and standard distance-based approaches with regards to the payload.

Figure 5.9 plots the global redundancy factor or the overhead with respect to the packet size. Various payload sizes of 500, 1500, 2000 and 2200 bytes have been used. We can deduce, first, that by the increase of the packet size, overheads increase linearly for all protocols. Obviously, distance-based protocol performs better than flooding-based geo-broadcast approach in terms of transmission redundancy since it ensures a selective retransmission of the safety information. *BZB*, in his turn, outperforms both distance-based and geo-broadcast. In case of the first curve related to the basic geo-broadcast protocol, the redundancy factor increases from 500M till reaching up to 2G. However, for *BZB* it goes to only less than 800M for 2200 bytes of packet size. This could be explained by the fact that *BZB* is designed to reduce the number of forwarders and, accordingly, network congestion. *BZB* provides a forwarding scheme that ensures an accurate relay selection in order to

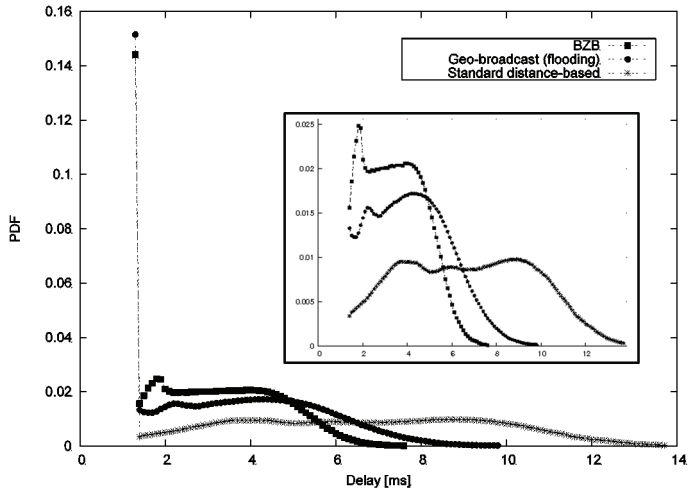


Figure 5.10: The RFD of the average reactivity delay in case of *BZB*, flooding and standard distance-based approaches for packet size 500 bytes.

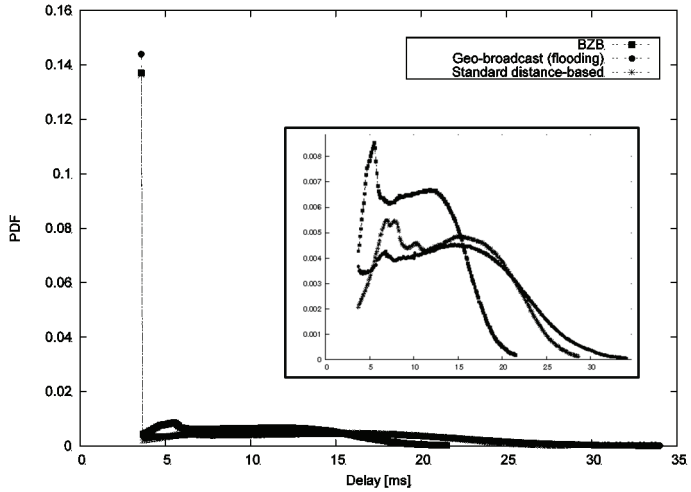
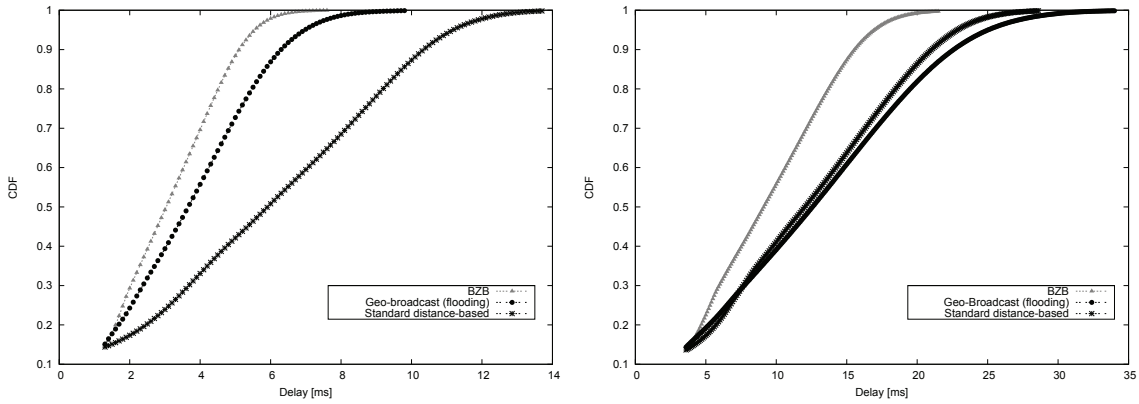


Figure 5.11: The RFD of the average reactivity delay in case of *BZB*, flooding and standard distance-based approaches for packet size 2200 bytes.

increase information dissemination reliability and reduce network overhead.
An aspect that is worth investigating is the behavior of the reactivity delay of *BZB* when varying the packet size. Figure 5.10 and Figure 5.11 illustrate the RFD regarding the average reactivity delay for packet sizes 500 bytes and 2200 bytes respectively. We can observe that, for all of the protocols, around 15% of nodes can receive the message in less than 1.8 ms in case of the first scenario (500 bytes) and around 14% are able to receive it in 4 ms for the second one (2200 bytes). This is explained by the fact that, all the nodes that are covered by one-hop communication can receive the information quickly. However, the performance of our proposal is more perceived for multi-hop communication where *BZB* achieves the lowest delays.



(a) (b)

Figure 5.12: The CDF of the average reactivity delay in case of *BZB*, flooding and standard distance-based approaches. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

Figure 5.12 shows the obtained simulation results in terms of CDF with respect to the average reactivity delay. We plot the most relevant results that better illustrate the performance of the different protocols. Only results for packet sizes 500 bytes and 2200 bytes are shown. From the first sight, we can deduce that for all the protocols when increasing the packet size, the average delay to reach the corresponding geographic destination area increases. For instance, in case of geo-broadcast, 90% of receivers receive the corresponding packet within less than 10 ms for a payload of 500 bytes. However, only 50% of transmissions reach within 10 ms time frame for payload 2200 bytes. We can observe that geo-broadcast outperforms the standard distance-based scheme in the first scenario i.e. 500 bytes. They perform approximately the same way for the other scenario. This is because of the trade-off that a distance-based approach presents: reducing redundancy by performing contention and at the same time introducing extra delay due to that contention. Indeed, flooding-based geo-broadcast may succeed to propagate the information with admissible delays especially in the case where the network load is not very important (500 bytes).

Regarding *BZB*, up to 90% of intended receivers get the packet for each payload within less than 22 ms. However, the average delay is about 35 ms in case of distance-based CBF and geo-broadcast protocols. So, we conclude that *BZB* outperforms both protocols in terms of average delay. Furthermore, we can deduce that, in contrast to distance-based dissemination scheme, the performance of *BZB* remains almost stable when varying the packet size. This is due to the intelligence in our dissemination strategy and its reliability to provide the lowest latency to reach all neighbors with lowest overhead.

The obtained simulation results reveal that *BZB* achieves its design goal of delivering information within a geographical area in a rapid and efficient manner as compared

to the flooding-based geo-broadcast and the standard distance-based CBF schemes. *BZB* performs better in terms of reactivity delay and overhead factor.

5.4.3 Considering the heterogeneity in communication capabilities: Evaluation of *I-BZB*

In this section, we analyze the results obtained in the simulation of the impact of the non-homogeneity in communication capabilities. A comparison with the first contention scheme of *BZB* is performed. Without loss of generality, we have considered only RSUs in the dissemination phase to represent the ITS entities with high antennas height. We fixed α to $6m$. The distance threshold D_{th} used here is fixed to 200m for vehicles and 450m for RSUs.
Figure 5.13 illustrates the CDF with regards to the data reception delay. All the scenarios with the several packet sizes are presented in the figure. We deduce that, when considering the non-homogeneity in communication capabilities, the second contention scheme proposed for *BZB* shows better results. In all the cases, as expected, from payload 500 bytes to payload 2200 bytes, the reception delay does not exceed around 16 ms however it goes to 22 ms in case of the first approach of *BZB*. This is due to the beneficial impact of the use of RSUs in the dissemination procedure.

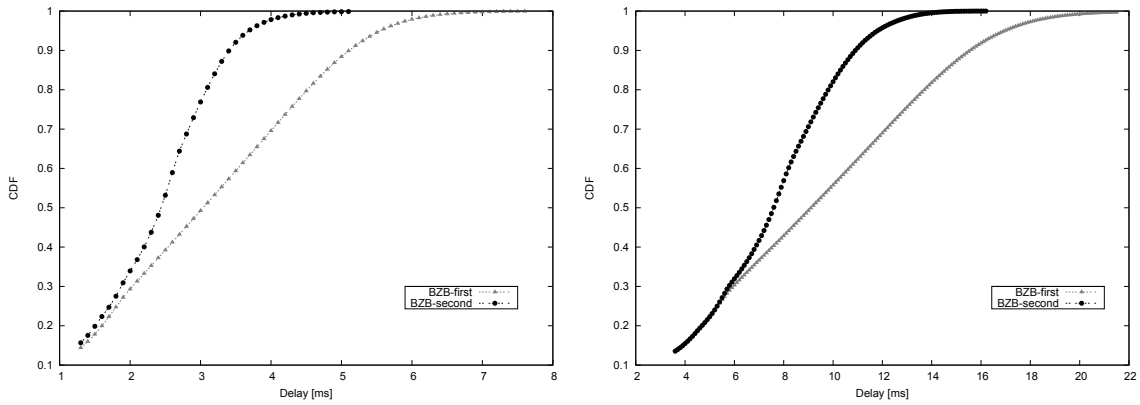


Figure 5.13: The CDF of the average reactivity delay. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

Figure 5.14 plots the global redundancy factor with respect to the packet size. Various payload sizes of 500, 1500, 2000 and 2200 bytes have been drawn. We can notice, that both approaches perform slightly in a similar way. Indeed, our main concern is to further improve the propagation delay of the safety data. The transmission redundancy has been already enhanced by the *BZB* concept.
So, by considering infrastructure nodes as potential relays, dissemination delay can be reduced noticeably. This aspect can be explained first by a better communication

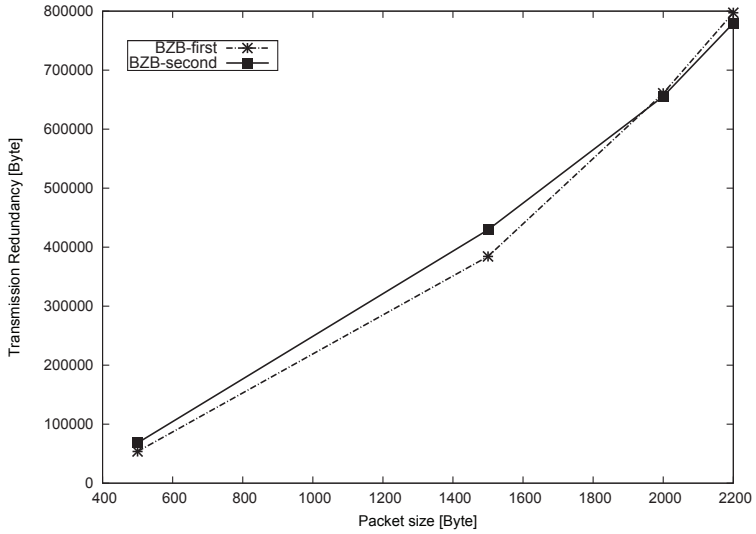


Figure 5.14: The variation of the redundancy factor with regards to the payload.

range due to higher antenna and increased transmit power, but also due to optimized distributions of the infrastructure nodes.

5.4.4 Discussions

We discuss in this section the behavior of *BZB* when varying the bi-zone distance threshold parameter D_{th}. Moreover, we evaluate the effects of awareness inaccuracy on the network performance of the dissemination protocol and its repercussions on the transmission redundancy and the delivery delay.

5.4.4.1 Impact of the variation of the threshold D_{th} on the performance of *BZB*

For the effectiveness of *BZB*, the parameter D_{th} is of key importance. Particularly, adapting its value according to a set of environmental constraints influences strongly the performance of our approach. Figures 5.15 and 5.16 show the variation of the contention timer in both zones when varying D_{th} value.
We can see that for very low values of D_{th} (Figure 5.15), nodes that are in the second zone (after the distance D_{th}) and are relatively close to the sender are given the opportunity to forward before potential distant nodes. In the other case (Figure 5.16), for very high D_{th}, only distant nodes (located after D_{th}) have the highest probability to be selected as relays.
In the simulation analysis that we have conducted, we have considered four different values of the threshold D_{th}: 200m (half of the communication range), and three other close and far distances 50m, 100m and 300m. Figure 5.17 shows the obtained simulation results in terms of transmission redundancy in various packet size scenarios. We can deduce that D_{th} 200m corresponding to about half of the

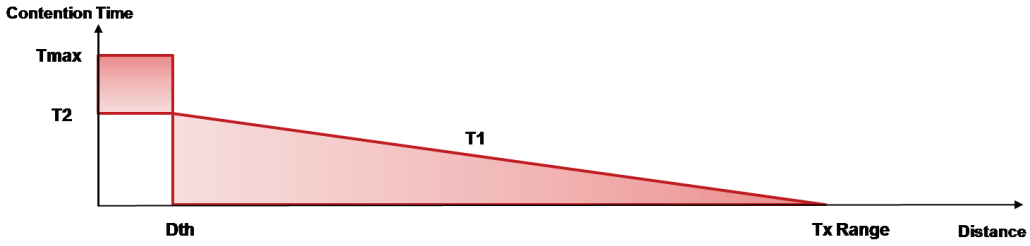


Figure 5.15: The variation of the contention timer for low values of the D_{th}.

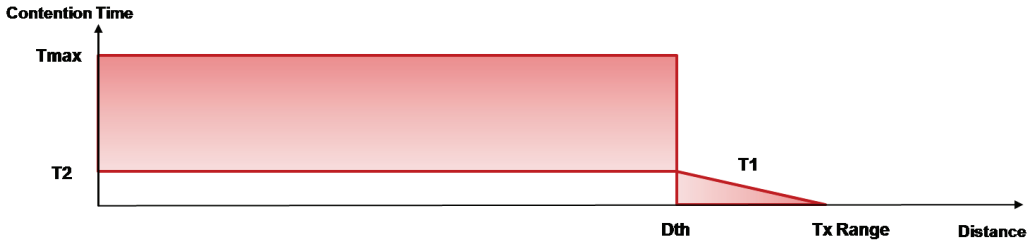


Figure 5.16: The variation of the contention timer for high values of the D_{th}.

maximum communication range performs the best comparing to other D_{th} values: 50m, 100m and 300m. However, when setting the distance threshold too close to the transmitter (50m and 100m), the probability that close nodes (located just after the D_{th}) transmit become important, as demonstrated in Figure 5.15. Therefore, the network overhead becomes important due to the increase in the number of hops.

For high values of D_{th} i.e. 300m, the network overhead is not that important as compared to D_{th} 50m and 100m, since it ensures the maximum progress. But, it is still higher than D_{th} 200m. This can be explained by the fact that when we maximize the chances of the selection of distant nodes as relays, and due to the fading effect, the probability that close nodes to the transmitter (with distance lower than D_{th}) receive correctly that transmission (of the selected relays) and cancel accordingly their transmissions is reduced. Therefore, the transmission redundancy is increased. Another case that can occur is when potential nodes situated after D_{th} i.e. 300m are not present, close nodes will be selected and again the number of hops is increased.

Figure 5.18 plots the CDF of the reactivity delay for the different values of D_{th}. We can observe that for the different network loads, D_{th} 300m performs poorly with regards to the data reception delay. Again, D_{th} 200m outperforms all the other values, particularly, for high network load. This is due to the fact that when there is not any node situated after 300m, an extra delay is introduced because close nodes with higher waiting time will be selected as relays.

So, the system performance is optimized in case of D_{th} 200m i.e. the average of the transmission range. This could be explained by the fact of running many scenarios that have different vehicle distribution and 200m have ensured a fair relay selection procedure between these different scenarios.

Therefore, the optimal value of D_{th} could not be deduced because it depends on

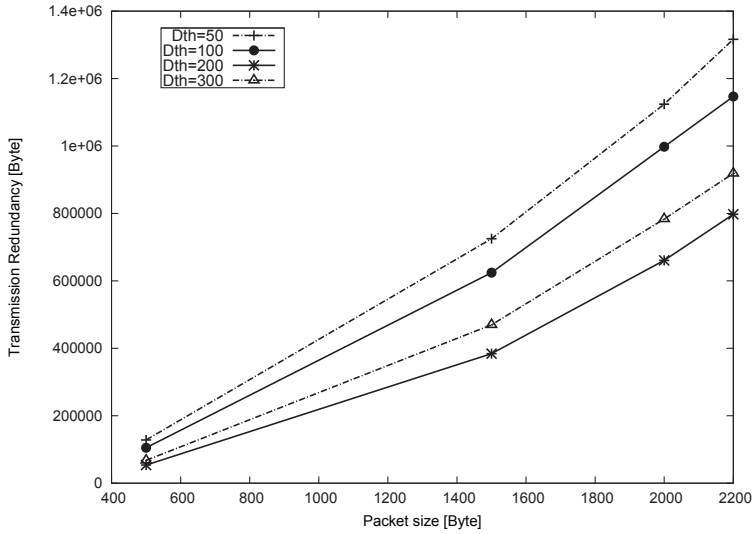


Figure 5.17: The *BZB* transmission redundancy factor when varying the D_{th} value with regards the payload

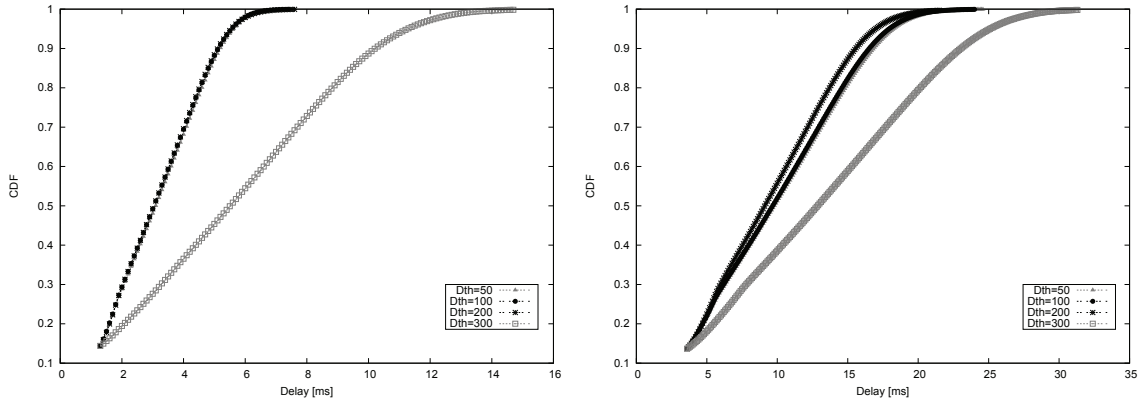


Figure 5.18: The CDF of *BZB* delay when varying the D_{th} value. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

multiple criteria i.e. the traffic density, the vehicular inter-space and/or the vehicle coverage range, but could be adapted as a function of the topology.

For instance, it can be tuned according to the network density state: sparse or dense. In case of very dense network, where the probability of the existence of nodes with the maximum progress is high enough, the bi-zone distance threshold D_{th} must be set as close as possible to the transmission range so that existing vehicles that are far away from the source obtain the highest priority. However, in case of sparse network, it is not guaranteed that nodes do exist at the border of the transmission range, D_{th} should be lower than the transmission coverage, in order to give other close distances

the opportunity to relay. As a result, *BZB* acquires a contextual adaptive aspect taking into account the global perception of the surrounding context built on the basis of awareness information.

5.4.4.2 Impact of awareness inaccuracy on the performance of *BZB*

Dissemination control mechanisms, and more particularly receiver-based approaches, operate on the basis of the position information or "awareness". For instance, the decision of the relay selection depends mainly on the location of the originator and the receiver nodes. This location data is collected from several sources, notably, GPS, DENMs, CAMs or beacons. Unfortunately, such sources are often exposed to *inaccuracy* and uncertainty resulting basically from high rate of losses in ITS environment. GPS signals are attenuated by tall buildings blocking the satellites LOS which might generate errors in the order of tens of meters. In addition to that, reflections, high fading and interferences influence drastically the CAMs and DENMs transmissions and can produce consequently high rate of missing positioning data. Furthermore, dynamic and sudden changes in vehicular mobility is an additional issue for awareness precision.
The main objective of this section is to provide an understanding of the relation between the awareness information and the effectiveness of dissemination mechanisms to deliver reliably and accurately the emergency information. In particular, we focus on the effects of awareness inaccuracy on the behavior and the performance of *BZB*. Imprecision and inaccuracy of awareness data could yield to several issues related to either the dissemination operation or the detection of the safety event itself from the application perspective:

Effect on the coverage of the dissemination area: Particularly, the operation of the distance-based CBF can be altered by the positioning uncertainty. As discussed earlier, the efficiency of this approach lies mainly in the proper selection of the farthest node from the source to forward the data. However, when there are errors on the positioning information, a vehicle which is close to the source (but wrongly estimating his position as the furthest) can be chosen as relay instead of the actual furthest node. In [71], a study have been conducted to evaluate the impact of GPS errors on the performance of UMB [72]. Mainly, it has been proved that GPS errors influence the protocol's latency and the network overhead as closer nodes have more chance to be selected as relays and thus more number of hops.

Generation of *"false alarms"* of emergency events: Another important issue is associated to the application level and especially to the detection of the emergency events. For instance, an inaccurate positioning data of the other vehicle in front leads to a wrong detection of an eventual collision between the two vehicles and accordingly issuing false alarms, as depicted in Figure A.7. Relays at reception cannot distinguish that and re-transmit the wrong information.

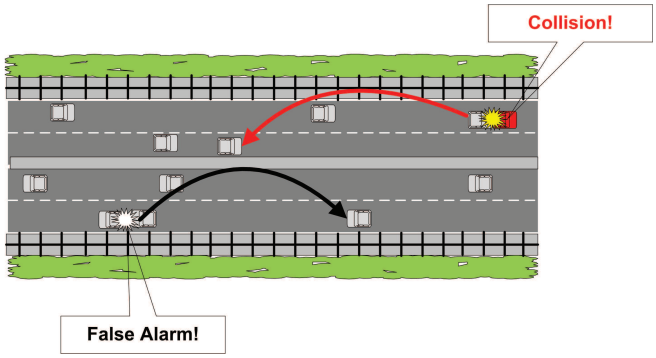


Figure 5.19: An illustration of a scenario where a false alarm is triggered upon wrong estimation of positioning information. Another actual collision occurred and accordingly a transmission is triggered.

Multiple detection of the same event: A scenario that might happen as well is when several nodes (distinct applications) detect the same emergency situation and thus, trigger several alerts. As illustrated in Figure A.8, node (A) and (B) trigger two different messages that contains information about the same perceived event. The relay node upon receiving the two messages, will send two distinct but redundant messages.

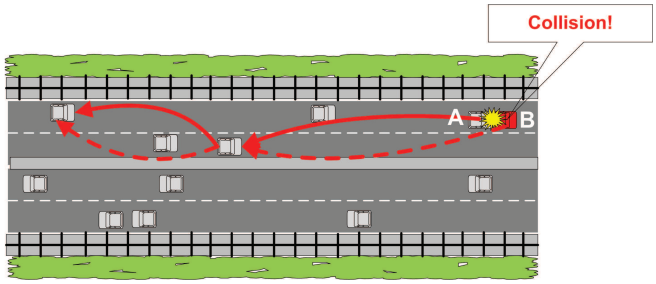


Figure 5.20: An illustration of a scenario where two nodes (A and B) detect the same emergency event and send different packets to the network.

We have conducted a simulation study to investigate specifically the effects of inaccurate detection of safety events on the performance of *BZB*. Two scenarios have been considered, mono detection and multiple detections. In the second scenario, four different sources (or nodes) have been used to trigger the safety information transmission one is considered as actual and three as redundant or false alarms. Figure A.9 depicts the measured transmission redundancy. The network overhead of multiple detections scenario is highly important as compared to mono detection. It corresponds almost to more than the double in case of packet size 2200 bytes which is nothing but an extra and useless overhead. Analogously, in Figure A.10, it is clear to observe that when increasing the number of redundant transmissions or false alarms, *BZB* fails to respect ITS safety applications requirements in terms

of reactivity delay. At best case, up to 90% of the receivers get the packet within more than 50 ms.

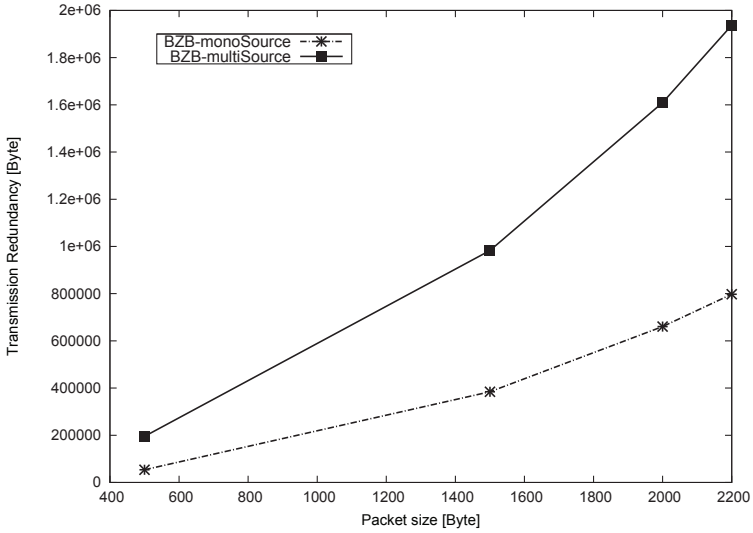
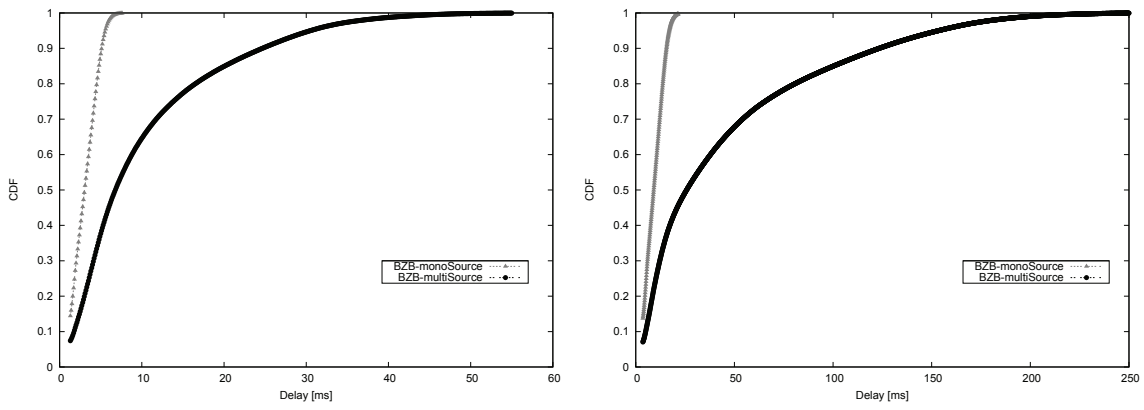


Figure 5.21: The variation of *BZB* transmission redundancy factor with regards the payload in case of multiple sources scenario.



(a) (b)

Figure 5.22: The CDF of *BZB* delay in multiple sources scenario. (a) Packet size 500 bytes. (b) Packet size 2200 bytes.

The obtained results reveal the strong impact of awareness inaccuracy on the effectiveness of the event-driven dissemination procedure. An accurate detection and dissemination of an emergency situation depends on an accurate perception of the global context. The cancellation of a triggered transmission of DENM is highly costly [41] as extra "cancellation" DENMs have to be sent to inform other nodes that the event is obsolete. Therefore it is worthy to avoid from the beginning wrong

or redundant transmissions. We believe that it is required to further investigate the accuracy and certainty of the global perception (or "awareness") of the vehicles.

5.5 Conclusion

In this chapter, we have proposed two dissemination schemes *BZB* and *I-BZB*, new hybrid Contention-Based Forwarding (CBF) approaches developed for ITS safety applications. We have identified limitations of the benchmark distance-based CBF considering the challenging ITS urban topology. We then described first *BZB*, a randomized distance-based scheme considering the non homogeneous topology and connectivity characterizing urban vehicular environment, and second *I-BZB* taking into account the non-homogeneity in communication capabilities of the various ITS actors such as road-side units, buses, trams, or vehicles.
The obtained simulation results showed that *BZB* achieves its design goal by delivering traffic safety information in a geographic area in a fast and efficient way compared to the benchmark distance-based CBF or flooding schemes. Also, with *I-BZB*, involving vehicles with considerable communication capabilities in the dissemination process further improves the performance of the system, in particular in terms of reception delay. Finally, using the bi-zone distance threshold of *BZB*, we can adapt its characteristics to the environment constraints e.g. the traffic density and the vehicular inter-space, in order to cope with the non-homogeneity of urban vehicular systems.

We demonstrated that there are still many other issues that need to be addressed in data dissemination. Particularly, an aspect that we further investigated is the behavior of *BZB* in case of awareness inaccuracy. We considered the case of false alarms or multiple redundant sources (transmitting the same safety information). BZB remains sub-optimal as it is unable to detect false alarms or redundant information.
We conclude that focusing only on controlling the dissemination of safety information might be not sufficient. Yet, it is required to study the precision of the global perception of nodes as it is a key element for the effectiveness of the event-driven information dissemination and thus, the efficacy of ITS of safety applications.

Another issue that has to be taken into account is the impact of periodic awareness transmissions (CAMs) on the channel load and thus the performance of the safety -related dissemination. Controlling the channel load resulting from periodic transmissions is also crucial.

Conclusion of Part II

In this part, we reviewed and compared existing dissemination control techniques. Then, we propose new mechanisms designed to deal with the challenging characteristics of the ITS environment.

In Chapter 4, we surveyed and classified the existing approaches proposed for reliable safety dissemination control addressing the problem of congestion control. The results of this chapter are used in Chapter 5 to propose new dissemination control mechanisms adapted and tailored to the special needs of the challenging ITS environment. We have noticed that receiver-based approaches are more adapted to fit ITS environment and more especially, the CBF scheme. There are, however, still several issues have not been addressed in existing schemes based on CBF. The dynamic topology of the vehicular networks in addition to the high fading environment are crucial properties that need further investigation.

In Chapter 5, we proposed *BZB* and *I-BZB*, new hybrid CBF approaches. The main idea is to adapt CBF to ITS challenging environment by first employing two different mechanisms as a function of the vehicular topology, and second by considering the dissemination capabilities of the relays. Using iTETRIS, we have conducted simulation study under large scale urban scenarios. The obtained simulation results showed that both *BZB* and *I-BZB* outperform the benchmark CBF.

In addition, we have investigated the behavior of BZB in case of awareness inaccuracy. First, we demonstrated the need to study further the awareness system and propose control mechanisms that could provide on one hand the suitable precision of the global perception required by ITS of safety applications, and on the other hand, control the network congestion that could result from periodic awareness transmissions. In Part III, we will address the management and control of the awareness system.

Part III

Design of a Cooperative Awareness Control Methodology

Overview of Part III

In Part II, we demonstrated the need for the efficient control of awareness system. In this part, we address this issue in an appropriate manner. We first focus on reliable control of awareness accuracy and precision. Then, we study the awareness congestion control designing a transmit rate control.

In Chapter 6, we propose Glow-worm Swarm Filter (GSF), an awareness accuracy control mechanism designed to deal with the issues present in unreliable ITS environments. GSF is based on multiple hypotheses concept that allows to consider various potential positions modeling the eventual loss of GPS signals or packets in addition to the unpredictable motion changes.

In Chapter 7, we highlight the effectiveness of our tracking algorithm GSF applied to an awareness transmit rate control approach to efficiently detect not only safety events but also false alarms.

6
Control Cooperative Awareness Accuracy with Swarm-based Particle Filters

6.1 Introduction

In ITS, GPS data, CAMs and DENMs messages represent the major sources to build the *"global perception"* or the "cooperative awareness" system of each node in the vehicular network. GPS provides local geographic data of the ego vehicle, while information of the surrounding environment is collected from the broadcast messages among nodes.
A high precision in the global perception is strongly required by event-driven dissemination protocols as well as many ITS cooperative safety applications. For instance, in case of collision avoidance application, accurate geographic information of each vehicle and its neighborhood has to be provided in order to efficiently evaluate the risk of collision with potential vehicles. Yet, GPS signals and wireless communication are known to be unreliable and uncertain. Packets losses due to high fading and interferences may occur frequently, and GPS signals may be missed or received with large errors. In such cases, extrapolation using position tracking represents a possible solution to recover from unreliable or missing positioning data.

Tracking has been studied extensively in the last decades and several tracking approaches have been proposed. Bayesian filters i.e. Kalman filters (KF) [68] and particle filters [99] are the most well-known ones. The limitation of these approaches is the fact that they rely on reliable and constant position updates either from GPS, or from CAMs and DENMs. In addition, they depend on the assumptions that future motions not varying much from the previous ones as well as that positioning errors are uncorrelated and Gaussian. Yet, the unreliable characteristics of the wireless channel, as well as unexpected sudden motion changes typically found in vehicular motions, make those filters lose the actual location of the vehicles. Observing that vehicular mobility is jointly governed by physical and social laws, e.g. clusters are

formed on the road as a result of social needs and behaviors, and depicts comparable patterns to swarm behaviors, we suggest to rely on artificial swarm intelligence to enhance tracking algorithms which in their turn, are expected to improve the awareness accuracy.

In this chapter, we propose a control mechanism for cooperative awareness accuracy. We focus mainly on the one-hop awareness provided by CAMs. Our approach called Glow-worm Swarm Filter (GSF) is a swarm-based Sequential Importance Resampling (SIR) particle filtering based on multiple hypotheses tracking. The proposed solution is to consider not only a single potential future location but also to consider various other potential locations modeling the eventual loss of GPS signals or packets in addition to the unpredictable motion changes. A Glow-worm Swarm Optimization (GSO) algorithm has been used because of its capabilities to find multiple local optima and to cluster the search space into various multiple hypotheses. This might implicitly improve the functionality of particle filter by augmenting the diversity of particles and avoiding the degeneracy problem.
Basically, we evaluate the performance of GSF with a SIR particle filter scheme (later referred as SIR-PF) in terms of information accuracy and convergence speed. A brief comparison study with Kalman filter is also provided. We consider also assessing the effect of messages loss and GPS positioning error on the performance of the tracking algorithms. Using the iTETRIS [11] simulation platform and calibrated realistic vehicular scenarios, we demonstrate that GSF is adapted to adverse channel conditions and to unexpected change in mobility patterns, providing better tracking accuracy with a lower number of particles compared to the standard SIR-PF. Moreover, GSF showed to achieve its design goal to ensure a trade-off between high tracking precision and fast convergence.
The rest of this chapter is structured as follows. In Section 6.2, we provide related works of position tracking. Section 6.3 analyses the tracking problem in ITS environment: the standard particle filter is discussed with its challenging problems then we introduce our tracking approach GSF. Afterwards, in Section 6.4, a simulation study is performed evaluating the performance of GSF compared to the basic PF. Finally, Section 6.5 reports the conclusions derived from this chapter.

6.2 Related Works on Tracking

Tracking has been extensively studied in many research domains. Several mechanisms have been proposed to enhance the accuracy of the state estimation. The most relevant techniques of microscopic mobility prediction that we found in the literature can be classified in two categories:

- Kinematic schemes based on kinematic equations.
- Heuristic approaches based on neural networks [34][92] and genetic algorithms [103].

- Bayesian filters [36] such as Kalman [68] and particle filter [99][52].

The first class depends on simplistic kinematic equations which cannot model well the dynamics of ITS. Generally, the issue with heuristic schemes is the memory usage. Genetic algorithms are characterized by a long processing time and there is no guarantee for convergence. On the other hand, the performance of neural networks depends on the learning phase which is inappropriate for dynamic environments.

Kalman filter is optimal Bayesian filtering approach that has been widely used for tracking in several research fields including GPS signals and other triangulation navigation systems. The main advantage of KF is the simplicity in implementation and computation. However, the key drawback comes from the implicit assumptions that vehicular motions follow a linear model, and that collected measurements is subject to Gaussian noise. Extended Kalman Filters (EKF) [23, 49] represent a possible alternative for the estimation of non-linear systems. The main concept of EKF is the linearization of the possibly non-linear motion and observation models using a first-order Taylor series expansion. However, the posterior distribution remains approximated by a Gaussian distribution. Moreover, the linear approximation of the system may introduce errors in the state estimation which could make the state diverge. Accordingly, the EKF could be only reliable for systems that are almost linear.

Studies in [88, 37, 29, 100] have proved that the performance of the Unscented Kalman Filter (UKF) [113] is superior to the EKF especially for high non-linear systems. The "unscented transformation" [66] is employed instead of the simplistic linearization concept that EKF uses. Using a deterministic sampling mechanism, the posterior density is represented by a number of carefully chosen points known as "sigma points" [67], but still is approximated by a Gaussian distribution.

"The EKF and the UKF operate in the framework of Gaussian approximation for the posterior density. While this makes them simple to implement and fast to execute, they suffer from inherent inability to model higher-order moments of truly non Gaussian posterior densities" [99]. When dealing with the challenging environment of ITS, both Gaussian approximations and motion linearizations are not accurate assumptions and might yield to low tracking performance. In such situations, alternative discrete Bayes' filter approximations are required.

Particle filters instead do not make any assumptions in the motion or the posterior distributions, and have been shown to fit well in position tracking. In [76], authors show that PF outperforms UKF when applied to Received Signal Strength Indication (RSSI) based tracking.

PF approximates the posterior distribution by a set of *"weighted particles"* corresponding to potential estimates of the unknown state. Also they do not require very complex computation resources. In spite of these advantages, particle filters have the drawback of particles degeneracy.

Even with a high number of particles, it may happen that the set of particles loses its diversity and deviates from the real state. While increasing the number of particles degrades the computation performance, maintaining a small set of particles is required for the effectiveness of the tracking algorithm.
Many optimization algorithms have been proposed to tackle this limitation. For instance, several schemes tried to combine Bayesian approaches such as Un-scented Particle Filters or Extended Kalman Particle Filter [111]. Other works, like in [91], propose to introduce genetic algorithm in the basic particle filter approach. As mentioned above, this may reduce the convergence rate due to the heavy computation time that genetic algorithms require.

In the following, we focus essentially on enhancing particle filters operation and propose a new mechanism capable to find a trade-off between an effective tracking accuracy and robust convergence rate.

6.3 Tracking in ITS

In ITS and related cooperative safety applications, a precise and up-to-date knowledge of the local and the surrounding contextual awareness is becoming increasingly important and required. GPS provides in real time local positioning information consisting in 3-dimensional position information $[x,\ y,\ z]$, velocity vector $[Vx,\ Vy]$ and time information (referred as local awareness). Neighborhood awareness is acquired from the vehicular network, periodic CAMs include location and mobility data e.g. geographic position, speed and direction. This latter is designated as global awareness. Both local and global awareness compose the *"cooperative awareness"* system.

6.3.1 Cooperative Awareness

The "cooperative awareness" can be schematically defined (as depicted in Figure 6.1) as a circular area of range R in which the location of the ego and all neighboring cars are known with probability p to the ego vehicle, with error e in range R. Both R and p are strongly dependent to a specific application. To this, we should add the *"awareness accuracy"* or *"freshness"* corresponding to the availability of the last update of the actual location information of either the ego or the neighbors. This last aspect is also depending on the application. As we mentioned before, cooperative safety applications for example require much more accuracy than infotainment applications.

The sources of the cooperative awareness system (either GPS, CAMs messages) are unfortunately exposed to frequent loss of precision. In some specific zones in the road, the GPS reception might be obstructed especially by tall buildings leading to a wrong estimation of the self state. Additionally, due to the high fading of wireless channel in the vehicular environment: CAMs transmissions sent from neighboring

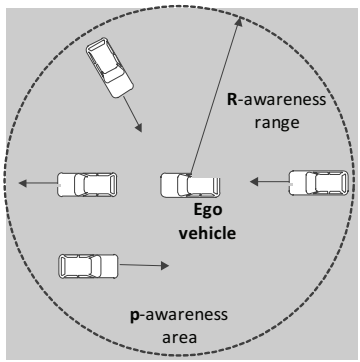


Figure 6.1: A representation of the awareness from the perspective of the ego vehicle. A range R is defined in which the location of all neighboring cars are known with probability p.

nodes are highly influenced by channel losses. Aperiodic transmit rate control mechanisms might also increase the awareness error. This concept makes the periodic transmissions aperiodic which reduces the number of updates.
Figure 6.2 shows a representation of the awareness systems for the ego car and its neighborhood. Each node maintains a local data base containing its location information (local awareness from GPS) and global awareness (collected from exchanged messages in the vehicular network). As wireless channel is expected to further degrade the precision of the position information, we can see in the figure the accumulation of the errors from GPS receivers and the errors that may come from channel losses.

These unreliable characteristics of ITS environment suggest position tracking to support and to enhance the precision of the awareness system. Tracking could be applied for both local and global awareness. Various estimators have been proposed over the past years. Bayesian particle filters [99] have been distinctly designed to fit dynamic and non-linear environments.

6.3.2 Bayesian Filtering

6.3.2.1 State Space Model

A general non-linear filtering system can be modeled by a state vector x_t corresponding to the location information at time t of a given vehicle, e.g. 3-dimensional position and velocity information. The state space model including the state transition and the observation models, is expressed as:

$$x_t = f(x_{t-1}, v_{t-1}) \tag{6.1}$$

$$z_t = h(x_t, r_t) \tag{6.2}$$

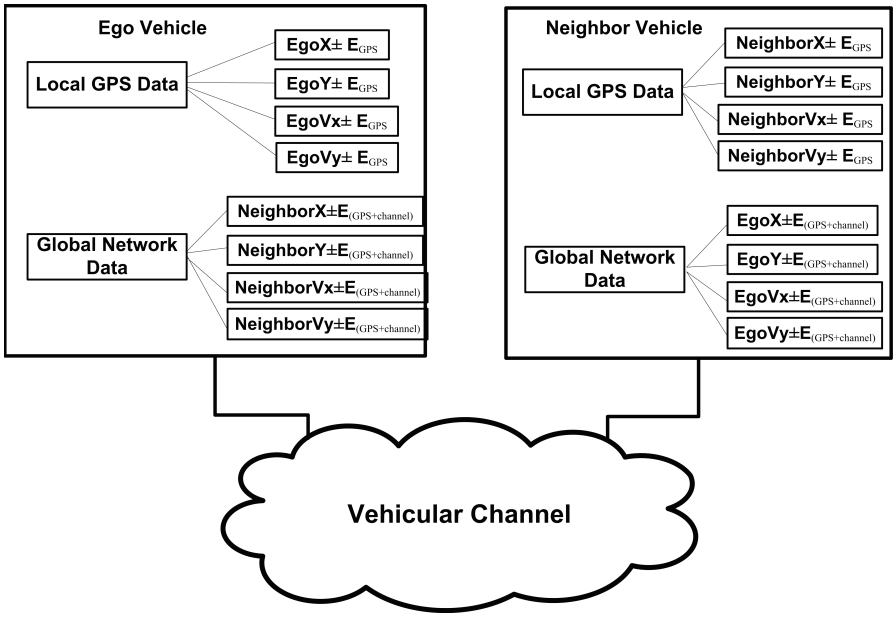


Figure 6.2: Cooperative awareness system for both the ego and the neighbor's vehicle.

where x_t is the state vector, z_t is the observation vector and f, corresponding to the internal motion model that controls the evolution of the state over time. The observation model h is used to ensure the mapping between the state vector x_t and the corresponding observation z_t. It is assumed to be independent given the states. v and r denote the noise terms.

When tracking in ITS, the motion model represented by f is expected to be non-linear. In the scope of this work, car following model is considered. The acceleration of the following car depends on the speed of the leading car ensuring a collision free mobility model. The Krauss car-following [73] equations of motion providing the future speed and position are expressed by:

$$x_f(t+\Delta t) = x_f(t) + v_f(t) \times \Delta t \tag{6.3}$$

$$v_f(t+\Delta t) = max[0, v_i^{des}(t+\Delta t) - \mu] \tag{6.4}$$

$$v_f^{safe}(t+\Delta t) = v_l(t) + \frac{\Delta x_f(t) - (v_l(t) \times T)}{\Delta v_f(t)/(2 \times b + T)} \tag{6.5}$$

$$v_f^{des}(t+\Delta t) = min[v^{max}, v_i(t) + a \times \Delta t, v_i^{safe}(t+\Delta t)] \tag{6.6}$$

$$\tag{6.7}$$

Where
a, b are the acceleration and the decceleration respectively.
μ is a stochastic parameter modeling the human reaction, v^{max} is the maximum speed and T is the reaction time.

Observations in their turns, cannot be modeled by a Gaussian error. As illustrated in Figure 6.2, the error on position is accumulated over time. The GPS positioning error, being Gaussian, when coupled to the missing awareness updates due either to channel losses or to aperiodic transmit rate control, becomes non-Gaussian.

6.3.2.2 Bayesian Tracking Approach

The key idea of Bayesian non-linear tracking is to recursively estimate the state x_t each time step t from received observations z_t creating a posterior distribution $p(x_t|y_{0:t})$ of the inner state considering on one hand previous states and on the other hand all collected "observations" $z_{0:t-1}$ (e.g. from GPS or received messages). This is done in two phases: prediction and update.

- Prediction Phase:
  Taking into account only the state motion, the internal motion model (expressed in equation 6.1) is used to predict the current state of the vehicle. The prior distribution is expressed using the Chapman-Kolmogorov [39] equation as:

$$p(x_t|z_{0:t-1}) = \int p(x_t|x_{t-1})p(x_{t-1}|z_{0:t-1})dx_{t-1} \tag{6.8}$$

- Update Phase:
  At the reception of new observations, Bayes' rule is then applied to estimate the posterior probability:

$$p(x_t|z_{0:t}) = \frac{p(z_t|x_t)p(x_t|z_{0:t-1})}{p(z_t|z_{0:t-1})} \tag{6.9}$$

  where

$$p(z_t|z_{0:t-1}) = \int p(z_t|x_t)p(x_t|z_{0:t-1})dx_t \tag{6.10}$$

The solution to the position tracking is obtained by recursively solving the two equations 6.8 and 6.9.

Summarizing, in a Bayesian framework, the tracking problem is conceptually composed of three main blocks as illustrated in Figure 6.3:

1. *Internal Motion Model*
   The internal representation of the evolution of the position modeled by f in equation 6.1. It is described by a mobility model, which is supposed to match closely the movement of the vehicle and provide its current position x_t given its current position x_{t-1}. Mathematically, it is represented as $p(x_t|x_{t-1})$. An example is the car following model [73] where the movement of each vehicle depends on the preceding vehicle.

2. *Estimation Model*
   The estimation of the internal state from a noisy collection of measurements or observations z_t (gathered from GPS or received messages). For instance, particle filters or Kalman filters could be employed to solve the likelihood function $p(z_t|x_t)$ in equation 6.10 which is defined by the observation model 6.2.

3. *Decision Making Model*
   The output of the tracking. The posterior probability equation 6.9 conditioned to the observations obtained by the decision model. Mathematically, it is represented as $p(x_t|z_{0:t})$, and solved by functions such as Minimum Mean Square Error (MMSE) or Root Mean Square Error (RMSE).

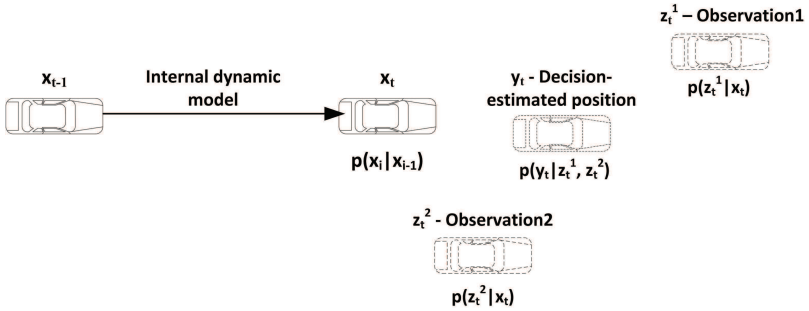


Figure 6.3: Tracking system blocks.

The effectiveness of Bayesian tracking depends extremely on two basic elements.

First, the accessibility of the external observation (coming from received messages) is required for the good performance of the tracking system. When a GPS signal is missing or when packet exchanged between nodes are lost due to bad channel conditions, a sudden large deviation is expected to occur. Mathematically, if z_t are missed for several t values, then the likelihood function and the posterior function cannot be evaluated properly.

Second, the reliability of the internal motion model. If it is known, predefined and well controlled (as the case of the assumptions of most of the Bayesian tracking approaches), the tracking problem is not complex as it depends only on observations (e.g. missile tracking systems). Unfortunately, highly dynamic environments, such as vehicular environment are characterized by frequent and sudden changes in dynamic patterns. Accordingly, the evolution of the estimated position $p(z_t|x_t)$ deviates significantly from the real state.

Both aspects are regularly experienced in ITS environments. In this work, our main focus is to improve the accuracy of the awareness and provide an efficient estimation of the state of the ego vehicle and other moving neighboring nodes un-

der such circumstances. We address in details the first major problem consisting of missing or erroneous GPS signals, or losing packets exchanged between nodes due to a bad channel conditions. We discuss as well the second issue where motion model is subject to sudden and unforeseeable movement changes. In the next subsections, we propose to mitigate these limitations by developing an advanced particle filter. We provide a bio-inspired swarm-based filtering approach designed to extrapolate the missing and unreliable data and to improve cooperative awareness accuracy.

6.3.3 Particle Filtering

Particle filter, also known as Sequential Monte Carlo method (SMC), applies recursive Monte Carlo [85, 86] sampling guided by a dynamic motion model. In the following, we introduce the basic concepts of Monte Carlo sampling methods.

6.3.3.1 SIS Algorithm

Sequential Importance Sampling (SIS) [79] is the basis of the sequential Monte Carlo sampling filters. It approximates the posterior distribution $\mathrm{p}(\mathrm{x}_{0:t}|\mathrm{z}_{0:t})$, describing the state of the system, by a finite set of weighted samples (or *particles*) $\{(\mathrm{x}_t^{(i)}, \mathrm{w}_t^{(i)})$; i=1,..,N$\}$ and recursively update these particles to obtain an approximation to the future posterior distribution in the next time step.
In analogy with the formal filtering problem outlined in Section 6.3, the algorithm proceeds in two phases:

- Prediction Phase:
  A set of particles are drawn from the importance density function.
  $$x_t^{(i)} \sim q(x_t^{(i)}|x_{t-1}^{(i)}, z_{1:t}) \tag{6.11}$$
- Update Phase:
  Taking into account the received observations z_t, the algorithm assigns a weight for each of the samples $\mathrm{x}_t^{(i)}$ by computing the likelihood $\mathrm{p}(\mathrm{z}_t|\mathrm{x}_t)$.
  $$\sum_{i=1}^{N} w_t^{(i)} = 1 \tag{6.12}$$
  The posterior probability density function at time t is approximated by the importance weights $\mathrm{w}_t^{(i)}$ as follows:
  $$p(x_t|z_t) \approx \sum_{i=1}^{N} w_t^{(i)} \delta(x_t - x_t^{(i)}) \tag{6.13}$$
  where δ is the discrete Dirac function. The importance weights are assigned using the concept of Importance Sampling [50]:
  $$w_t^{(i)} = w_{t-1}^{(i)} \times \left(\frac{p(z_t|x_t^{(i)})p(x_t^{(i)}|x_{t-1}^{(i)})}{q(x_t^{(i)}|x_{t-1}^{(i)}, z_{1:t})}\right) \tag{6.14}$$
  where q is the importance density and all the weights sum to unity:

A pseudo code of SIS is illustrated in Algorithm 2. A common issue with the SIS

Algorithm 2 Pseudo-code of the SIS particle filter

1: **Initialization**: Draw N particles with equal weights

$$x_t^{(i)} \sim p(x_t|x_{t-1}, z_{1:t}) \tag{6.15}$$

2: **for** $t = 0$ to T **do**
3: {t is the time-step, T is the duration of the tracking operation}
4: **for** $i = 1$ to N **do**
5: {i is the particle number, N is the total number of particles}
6: **Prediction**: Draw particle i from the importance distribution

$$x_t^{(i)} \sim q(x_t^{(i)}|x_{t-1}^{(i)}, z_{1:t}) \tag{6.16}$$

7: **Update**: Assign an importance weight

$$w_t^{(i)} = w_{t-1}^{(i)} \times \left(\frac{p(z_t|x_t^{(i)})p(x_t^{(i)}|x_{t-1}^{(i)})}{q(x_t^{(i)}|x_{t-1}^{(i)}, z_{1:t})}\right) \tag{6.17}$$

8: **end for**
9: Calculate total weight: t = $\sum_{i=1}^{N}(w_t^{(i)})$
10: **for** $i = 1$ to N **do**
11: **Normalization**: Calculate $\tilde{w}_t^{(i)} = \frac{w_t^{(i)}}{t}$
12: **end for**
13: **end for**

particle filter is the degeneracy problem. After a few iterations, particles will acquire negligible weights. Resampling is an option to avoid this problem. It consists in keeping the particles with important weights and eliminating the ones with low weights. In the next subsection, we introduce the SIR [51] algorithm, a particle filter that uses the resampling procedure.

6.3.3.2 SIR Algorithm

Several implementations have been proposed for Particle Filtering. They can be regarded as special cases of the general SIS [79] algorithm. Their main differences lie in the used resampling method and/or importance sampling distribution. SIR PF [51] is the most used implementation in tracking systems. In order to avoid the problem of degeneracy of the SIS-PF algorithm where all but one of the importance weights are close to zero, resampling is used in SIR at each time step. Moreover, SIR has the advantage that the importance weights are easily evaluated and the importance density $q(x_t|x_{t-1}^i, y_{1:t})$ is easily sampled. It is approximated as $p(x_t|x_{t-1}^i)$.
This means that the particles x_t^i are drawn from the motion model defined by the

equation 6.1. The weights are expressed as follows, deduced from equation 6.17:

$$w_t^{(i)} = w_{t-1}^{(i)} \times p(z_t|x_t^{(i)}) \tag{6.18}$$

However, as resampling is applied each time step t:

$$w_t^{(i)} = p(z_t|x_t^{(i)}) \tag{6.19}$$

Algorithm 3 gives an overview of the SIR particle filter operation. Mainly, SIR consists in three steps, the state prediction where the posterior probability is given based on the probabilistic system transition model $\mathrm{p}(\mathrm{x}_t|\mathrm{x}_{t-1})$. The second step is the update which is performed based on the likelihood $\mathrm{p}(\mathrm{z}_t|\mathrm{z}_{t-1}^{(i)})$. The particles are then resampled to generate an unweighted particle set. Resampling is performed by drawing N particles from the current set with probabilities proportional to their weights and then assigning to them equal weights $1/N$.

Algorithm 3 Pseudo-code of the SIR particle filter

1: **Initialization**: Draw N particles with equal weights

$$x_t^{(i)} \sim p(x_t|x_{t-1}) \tag{6.20}$$

2: **for** $t = 0$ to T **do**
3: {t is the time-step, T is the duration of the tracking operation}
4: **for** $i = 1$ to N **do**
5: {i is the particle number, N is the total number of particles}
6: **Prediction**: Draw particle i from the importance distribution

$$x_t^{(i)} \sim p(x_t|x_{t-1}) \tag{6.21}$$

7: **Update**:
Calculate the importance weight

$$w_t^{(i)} = p(z_t|x_t^{(i)}) \tag{6.22}$$

8: **end for**
9: Calculate total weight: $\mathrm{t} = \sum_{i=1}^{N}(w_t^{(i)})$
10: **for** $i = 1$ to N **do**
11: **Normalization**:
calculate $\tilde{w}_t^{(i)} = \frac{w_t^{(i)}}{t}$
12: **end for**
13: **Resampling**: Generate a new set of particles $\mathrm{x}_t^{(i_*)}$ by resampling with replacement from $\mathrm{x}_t^{(i)}$ where the probability of replacement $\Pr(\mathrm{x}_t^{(i_*)} = \mathrm{x}_t^{(i)}) \sim \tilde{w}_t^{(i)}$
14: **end for**

Figure 6.4 depicts a detailed graphical representation of the evolution of particles when the SIR algorithm is applied with only $n = 9$ samples. First, particles are

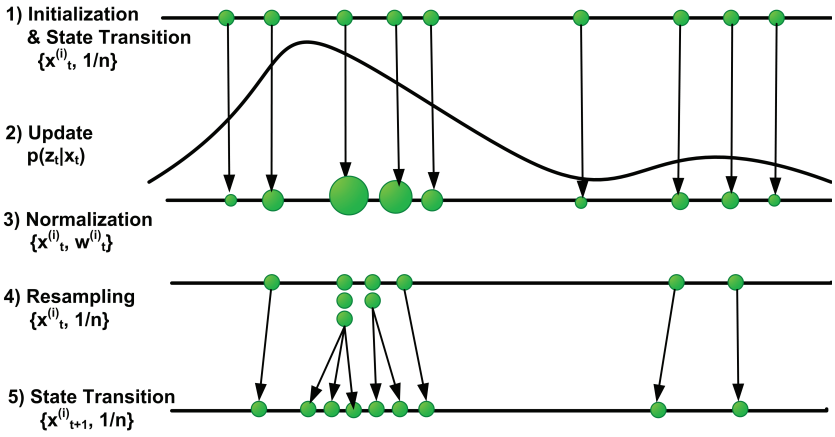


Figure 6.4: A representation of the evolution of the particles following the SIR algorithm.

initialized or distributed according to the probability distribution $p(x_t|x_{t-1})$. At the reception of a new observation, weights are computed for the different samples according to the likelihood of the observation given the current state $p(z_t|x_t^{(i)})$. Normalization and resampling are then performed to generate new particles according to their weights with more particles in areas with high weights and fewer particles in areas with low weights. The state transition generates new particles states given the current states and the algorithm is restarted.

The degeneracy problem remains a weak point of SIR particle filters although applying the resampling process. Even with a high number of particles, it may happen that the set of particles loses its diversity and deviates from the real state. This is emphasized by the lack of external observations due to GPS signals or packets losses and/or to the unexpected and sudden change in motion patterns. As depicted in Figure 6.4, in such situations, the regions of likelihood are far away from the prior distribution. Thus, most of the particles are generated with low weights. The reason behind this degeneracy problem is that PF maintains one single hypothesis which is strongly connected to the motion model's assumptions. An example of a vehicular scenario is illustrated in Figure A.11, based on this unique hypothesis, PF fails to track accurately the neighboring vehicle after an update loss. The particles lose the diversity yielding to severe divergence from the real position.

The proposed solution we describe next section is not only to consider a single potential future location (illustrated as *Major Hypothesis*) but also to consider various other eventual locations due to the loss of GPS signals or observations (illustrated as *Minor Hypothesis*), and/or to unpredictable motion changes.

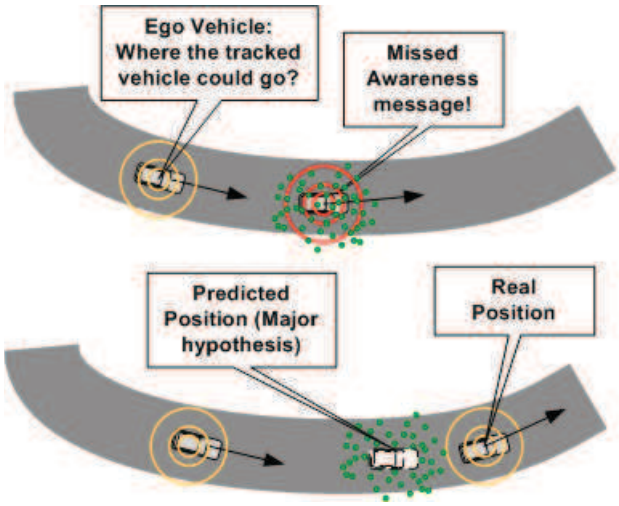


Figure 6.5: An illustration of a tracking scenario where the dots illustrate the generated PF particles. The tracked vehicle is estimated by the PF of the ego vehicle to be in the major hypothesis. After missing the beacon, PF fails to predict properly the real position.

6.3.4 Glow-worm Swarm Filter (GSF)

Following observed human behaviors, when we lack clues on where something disappeared, we look in various *"potential"* locations as function of the context. Our filtering proposal follows the same approach. Consequently, typical situations resulting from GPS signals or messages losses, or sudden change in mobility are modeled as alternative hypotheses apart from the expected single major hypothesis. Maintaining multiple hypotheses allows the filter to handle sudden changes and recover from temporary diversions. The idea is to cluster the set of particles into sub-groups representing each a potential hypothesis. Therefore, we extend the SIR PF with the bio-inspired pattern, namely the Glow-worm Swarm Optimization algorithm [74]. Before the resampling phase, the GSO algorithm is applied. Accordingly, the PF particles are mapped onto the glow-worms of the GSO. The algorithm is able to divide the particles into clusters that can converge simultaneously to multiple optima during the mobility phase. The set of particles is enriched with not only high but also low probable hypotheses. The glow-worms behavior applies well to the idea of having multiple tracking hypotheses.

Figure A.12 reproduces the same scenario of Figure A.11 but this time GSF is applied, particles are sub-divided into three groups, one major hypothesis and two minor hypotheses. Considering these different hypotheses, the filter, consequently, is able to manage the loss of the beacon and maintain efficiently the tracking process stable.

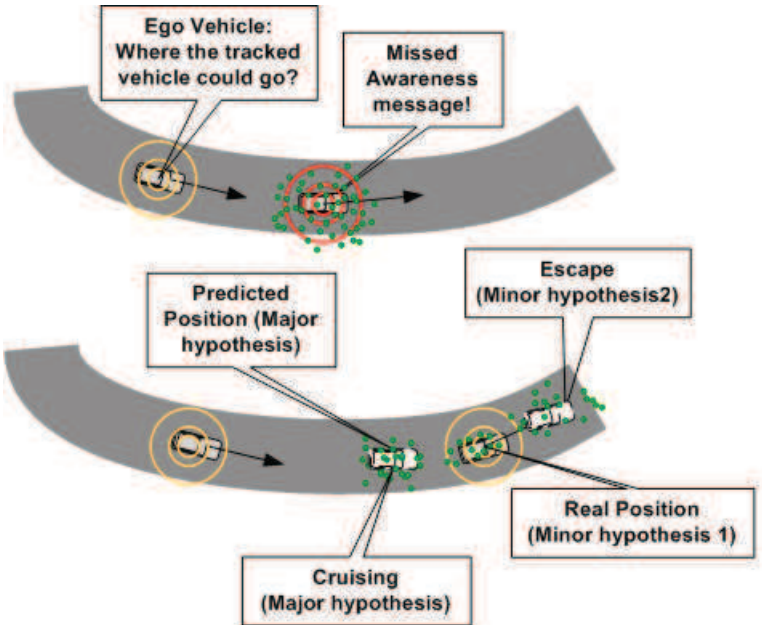


Figure 6.6: An illustration of a tracking scenario. The dots in the figure represent the particles corresponding to the position estimate of the vehicle. The tracked vehicle is estimated by GSF to be in the minor hypothesis. Considering unexpected beacons losses, GSF is able to ensure good tracking performance.

6.3.4.1 Glow-worm Swarm Optimization Algorithm

In this section, we give more details about the GSO algorithm. Basically, Glow-worm swarm optimization (GSO) [74] is a swarm intelligence [31] based algorithm inspired by the behavior of the glow-worms in nature where the female glows to attract a male for mating.

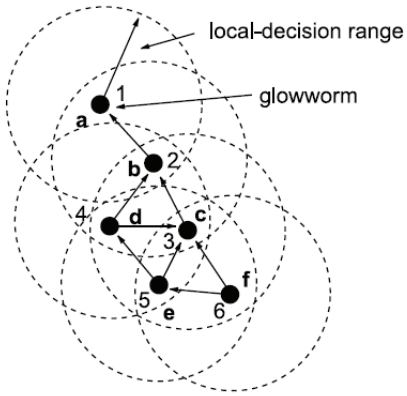


Figure 6.7: This Figure is taken from [74]. Glow-worms "are ranked according to the increasing order of their luciferin values"[74]. For instance, glow-worm b moves toward glow-worm a, whose luciferin value is highest, and thus, is ranked 1.

Parameter	Definition
N	Number of glow-worms
l_0	Initial value of the luciferin
r_0	Initial neighborhood range
r_s	Maximum sensor range
N_t^i	Number of neighbors of the glow-worm i
γ	Luciferin enhancement constant
ρ	Luciferin decay parameters
β	Luciferin decay parameters

Table 6.1: The definition of the parameters of the GSO algorithm.

In the algorithm, a probabilistic approach is used to select neighbors with brighter glow. A luciferin value proportional to the intensity of the glow is associated with each glow-worm. Moreover, a neighborhood decision range r_d^i defines the "local-decision domain" of each glow-worm. A glow-worm i considers another glow-worm j as its neighbor if j is within r_d^i and the luciferin level of j is higher than that of i. Each glow-worm is attracted by the brighter glow (corresponding to the higher luciferin) of other glow-worms in the neighborhood. As depicted in Figure 6.7, glow-worm "b" selects only one neighbor "a" with higher luciferin and moves then towards it using a probabilistic mechanism. We can notice from this figure the construction of sub-groups that will converge into multiple optima.

The algorithm of GSO is further explained in Algorithm 4. GSO starts with a random deployment of an initial population of N glow-worms in the search space with equal quantity of luciferin l_0 and with the same neighborhood decision range r_0. Each iteration consists of a luciferin *update phase* followed by a *movement phase* based on a transition rule.

For each time step t, the luciferin value l_t^i is updated, following the equation 6.23, based on previous luciferin value and the objective function $J(x)$ that evaluates the fitness of the previous position of the glow-worms. γ and ρ are respectively the luciferin enhancement constant and the luciferin decay parameters. The former scales the fitness function $J(x)$ and the latter, if is equal to 0, the luciferin depends only on $J(x)$. The particularity of GSO is its decentralized decision making aspect. In the movement phase, the decision to move toward a given neighbor is based on the local information. Using a probabilistic scheme defined in equation 6.25, glow-worms select the neighbors with high luciferin. The transition rule, expressed in equation 6.26, is then applied for each glow-worm. An update (equation 6.27) of the neighborhood range is performed at the end of the algorithm. The definition of all the GSO parameters are listed in the Table 6.1.

Algorithm 4 Pseudo-code of the GSO

Parameters: N, l_0, r_0, γ, ρ, β, s, r_s, N_t
Deploy N glow-worms randomly with equal luciferin l_i (0) = l_0
while t<itermax **do**
  Update Phase
  for $i = 1 \rightarrow N$ **do**

$$l_t^i = (1-\rho)l_{t-1}^i + \gamma J(x_t^i) \tag{6.23}$$

  end for
  Movement Phase
  for $i = 1 \rightarrow N$ **do**
    Determine the list of neighbors for glow-worm i:

$$N_t^i = \{j : d_t^{ij} < r_d^i(t) < r_s; l_t^i < l_t^j\} \tag{6.24}$$

    for $j = 1 \rightarrow N_t^i$ **do**
      Calculate moving probability to neighbor j:

$$P_t^{ij} = \frac{(l_t^j - l_t^i)}{(\sum_{k=1}^{N_t^i}(l_t^k - l_t^i))} \tag{6.25}$$

    end for
    Select Glow-worm j according to the probability calculated in 6.25
    Move Glow-worm i toward j:

$$x_t^i = x_{t-1}^i + s * (\frac{(x_{t-1}^j - x_{t-1}^i)}{(||x_{t-1}^j - x_{t-1}^i||)}) \tag{6.26}$$

    Update neighborhood range:

$$r_d^i(t) = min(rs, max(0, r_d^i(t-1) + \beta(n_{t-1} - |N_{t-1}^i|))) \tag{6.27}$$

  end for
end while

6.3.4.2 GSF Algorithm

GSF, as shown in Algorithm 5, is based on the SIR-PF. GSO is applied to particles before the resampling phase. Particles are mapped to glow-worms considering their weights as luciferin values. After the normalization phase of the SIR, particles, considered as glow-worms, move towards neighbors with high weights.
This results in a creation of several sub-groups with varied weights in the solution space. The particles resampling is then performed for each sub-group. Only particles with highest weights in each sub-group will survive.
Figure 6.8 depicts a representation of an example of the evolution of particles according to GSF algorithm. The GSO algorithm is performed before resampling phase. Particles move towards neighbors with high weights. Accordingly, different groups are built corresponding to multiple hypotheses. The resampling process is then applied to each group with more particles in areas with high weights and less particles in areas with low weights. The state transition predicts new particle states given the current particle states and the algorithm is restarted.

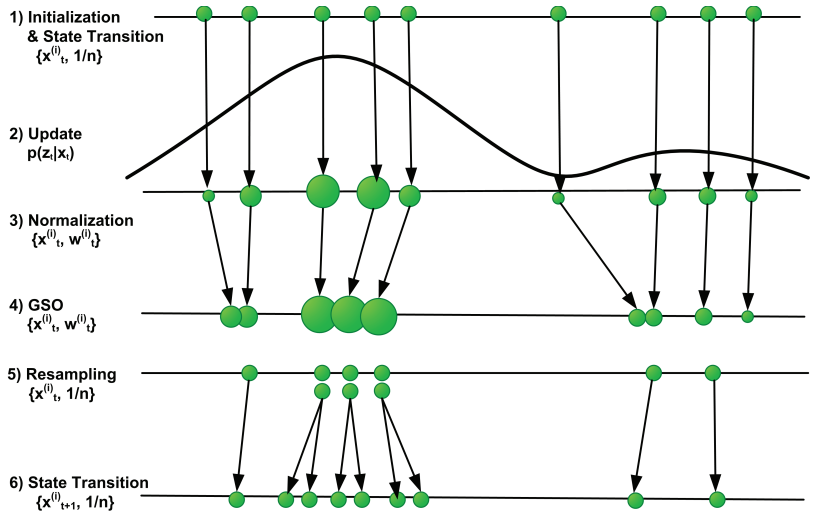


Figure 6.8: A representation of the evolution of particles according to GSF algorithm.

6.4 Evaluations

In this section, we evaluate the performance of our new tracking system GSF aiming at enhancing the cooperative awareness accuracy. We attempt to examine the effectiveness of our GSF algorithm to track efficiently the state of both the ego vehicle and the moving neighboring nodes considering the two cases with and without GPS (or packets) losses and under dynamic constraints. Moreover, GPS positioning errors resulting from the precision of the navigation system are considered. We conduct first a brief comparative simulation study with Kalman Filter. Then, in the

Algorithm 5 Pseudo-code of the GSF

Initialization: Draw N particles with equal weights

$$x_t^{(i)} \sim p(x_t|x_{t-1}) \tag{6.28}$$

for $t = 0$ to T **do**
  {t is the time-step, T is the duration of the tracking operation}
  for $i = 1$ to N **do**
    {i is the particle number, N is the total number of particles}
    Prediction: Draw particle i from the importance distribution

$$x_t^{(i)} \sim p(x_t|x_{t-1}) \tag{6.29}$$

    Update:
    Calculate the importance weight

$$w_t^{(i)} = p(z_t|x_t^{(i)}) \tag{6.30}$$

  end for
  Calculate total weight: t = $\sum_{i=1}^{N}(w_t^{(i)})$
  for $i = 1$ to N **do**
    Normalization:
    calculate $\tilde{w}_t^{(i)} = \frac{w_t^{(i)}}{t}$
    Move particle according to GSO algorithm:
    Determine the list of neighbors for glow-worm i:

$$N_t^i = \{j : d_t^{ij} < r_d^i(t); w_t^i < w_t^j\} \tag{6.31}$$

    for $j = 1 \rightarrow N_t^i$ **do**
      Calculate moving probability to neighbor j:

$$P_{ij} = \frac{(\tilde{w}_t^j - \tilde{w}_t^i)}{(\sum_{k=1}^{N_t^i}(\tilde{w}_t^k - \tilde{w}_t^i))} \tag{6.32}$$

    end for
    Select particle j according to the probability calculated in 6.32
    Move particle i toward j:

$$x_t^i = x_{t-1}^i + s * (\frac{(x_{t-1}^j - x_{t-1}^i)}{(||x_{t-1}^j - x_{t-1}^i||)}) \tag{6.33}$$

    Update neighborhood range as in equation 6.27
  end for
  Construct sub-groups corresponding to the multiple hypotheses
  Resampling taking into account the sub-groups created by GSO: For each sub-group apply the resampling process defined in Algorithm 3
end for

following we consider to compare GSF to the standard particle filter scheme SIR-PF. We consider vehicular environment as a case study to model dynamic systems. In the following, we introduce the simulation setup and the configuration of mobility and network scenarios. We present then the set of performance metrics we have measured, and finally the results of our experiments.

6.4.1 Simulation Setup

We have carried out a set of simulations to examine the performance of our proposed system under various realistic conditions. We have used iTETRIS [11], the integrated ITS simulation platform. iTETRIS enables the simulation of V2X communications and the modeling of vehicular mobility patterns and traffic conditions. Simulations have been carried out on the basis of one ego vehicle that runs GSF and the SIR-PF to compare both filters performances. Accordingly, simulations of GPS signals and beacons losses are performed using the same scenario. In the first case, by considering the scenario as self tracking of the ego vehicle. In the second case, by running the same algorithm of the neighboring node on the ego node. To simulate the loss, we proceed by suppressing the beacons transmissions in some given time steps. We apply three different schemes of beacon update loss (or GPS signal loss): one loss out of ten updates per second, two successive losses and three successive losses. We have simulated also the error on GPS positioning by using a normal distribution *N(0,5)*.
The tracking filters estimate has been evaluated based on MMSE. Regarding the configuration of the GSO algorithm, the parameters' values resulting from [74] have been used. They are illustrated in Table 6.2.

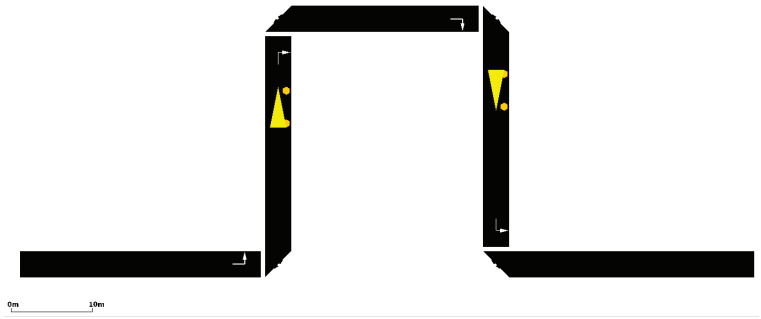
ρ	γ	β	n_t	s	l_0
0.4	0.6	0.08	5	0.03	5

Table 6.2: Configuration parameters of the GSO algorithm.

6.4.1.1 Mobility Scenarios

We have considered both urban and highway traffic environments. The former models the unpredictable and the uncertain mobility due to the brutal change that can occur in the vehicle trajectory in such environment. The latter represents the high dynamic aspect of vehicular environment. The simulation experiments are based on four scenarios. We have used two calibrated realistic scenarios from the city of "Bologna". The Figures 6.16 and 6.11 illustrate the "Acosta Pasubio joined" modeling an urban environment composed of multiple intersections, and the highway iTETRIS scenarios representing the high speed and the large scale feature of the ITS environment. Furthermore, two artificial scenarios: urban and highway represented in Figure 6.9 have been designed to model respectively sudden turns and higher

speed. All of the scenarios are based on the Krauss car-following mobility model [73]. The configuration parameters of our simulations are shown in Table 6.3.



(a)

(b)

Figure 6.9: Artificial scenarios. (a) The urban artificial scenario modeling slow speed and sudden turns. (b) The 1D highway artificial scenario modeling higher speed.

Scenario	**Size**	**Mean Speed** [m/s]	**Max Speed** [m/s]	**Max Accel** [m/s2]	**Max Deccel** [m/s2]
Artificial-Urban	x:2000m y:100m	12.2	13.5	1	4.5
Artificial-Highway	x:10000m y:0m	18.47	36	1	4.5
iTETRIS-Urban	x:2126m y:2117m	8.01	13.89	3	4.5
iTETRIS-Highway	x:69000m y:53000m	11.31	36.11	3	4.5

Table 6.3: Configuration parameters of the mobility scenarios.

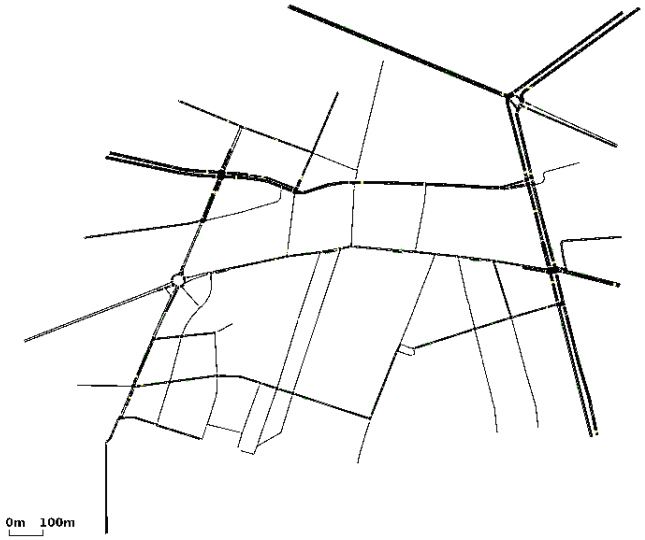


Figure 6.10: iTETRIS Acosta Pasubio joined mobility scenarios.

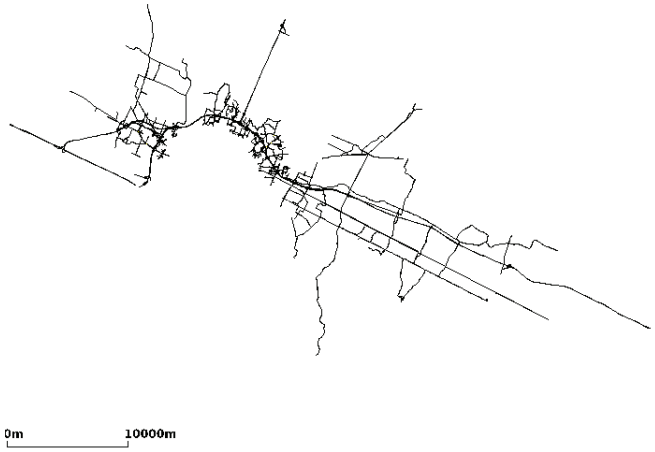


Figure 6.11: iTETRIS Highway mobility scenarios.

6.4.1.2 Network Scenario

In our communication scenario, we consider that vehicles send periodic awareness through network beacons. A maximum period of transmission is respected until which a network beacon must be sent. We have set this period to $1s$. Table 6.4 gives an overview of the configuration parameters for the communication scenario.

6.4.1.3 Performance Metrics

Performances of GSF and the basic SIR particle filter have been examined in terms of:

Parameter	Value
802.11p Channel	CCH 5.9GHz
Simulation time	100s for each run
Number of simulation runs	5 times for each scenario
Propagation model	Logarithmic Distance
Transmission power	20 dBm
V2V transmission range	400m
Awareness transmission frequency	1Hz

Table 6.4: Configuration parameters of the network scenario.

1. Information Accuracy
   This metric is the most relevant for the estimation of the precision of the awareness control algorithm. It is defined as the *Error distance (ED)* which is the Cartesian distance between the estimate obtained from filtering algorithms (SIR-PF or GSF) and the real position: ED = $\sqrt{(D_x^2) + (D_y^2)}$ where D_x^2 and D_y^2 denote respectively the error on X and Y position. This metric represents a measure of the level of accuracy of the filters.

2. Scalability
   To evaluate the ability of the awareness accuracy control mechanism to adapt to large scale needs, we have considered the convergence time which denotes the filter run-time reflecting its real-time capability and its convergence speed.

6.4.2 GSF Performance Evaluation

In this section, we aim first to validate our assumption that Kalman filter is not adapted to ITS non-linear systems. Then we evaluate the performance of our GSF algorithm and compare it with the generic particle filter scheme considering several traffic environments. Mainly, we examine in this section the level of accuracy of the filters in urban and highway scenarios. As a first step, we assess the performance of both filters in loss free channel. Then, we consider beacon messages or GPS signals losses with various ratios. Finally, the impact of positioning errors on both tracking schemes is studied. Moreover, the results of the convergence time for both schemes are represented. Error distance and convergence time are considered as the evaluation metrics.

6.4.2.1 Comparison with Kalman Filter

We have discussed in Section 6.2, the non adaptability of Kalman Filter to non linear systems. In this section , we demonstrate that and we show how it cannot cope

with the abrupt and dynamic movement changes. Figure 6.12 shows the evolution of the X and Y position of a vehicle in the artificial urban scenario. We observe that at a given point in the network (the first turn on the road), Kalman Filter deviates rapidly from the actual position. This is due to the sudden modification in the trajectory of the node. The tracking error reaches more than 40 m in case of Kalman filter, however, GSF succeeds to track the vehicle till the end of the simulation.

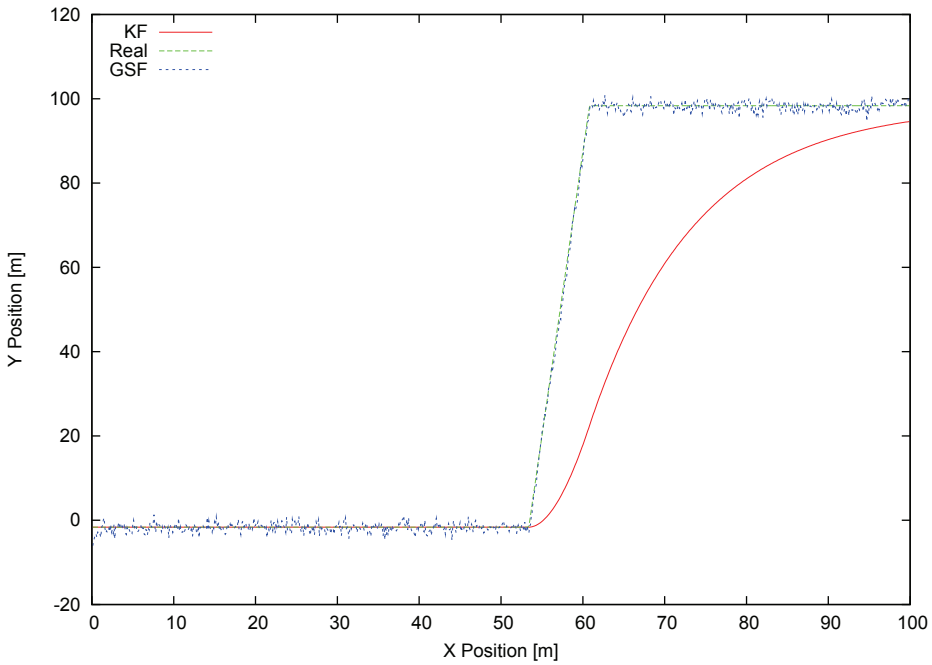


Figure 6.12: Tracking error on X and Y position in comparison with KF.

Given these results, our comparison study will be based only on SIR-PF in the rest of this work.

6.4.2.2 Tracking Precision

Urban Scenario Table A.1 shows the average error distance obtained for both GSF and the SIR-PF in case of artificial urban scenario. Table A.2 lists the results in case of iTETRIS urban scenario. We notice that the performance of SIR-PF is enhanced with the increase of the number of particles while the performance of GSF does not vary very much. This is due to the multiple hypotheses concept of our algorithm. Even with low number of particles, GSF is able to construct sub-groups and thus multiple hypotheses that can converge to the optimal solution. The operation of the algorithm is then insensitive to the dimension of the set of particles. On the other hand, in case of SIR-PF, by providing more particles, more possible positions are added which give more chance to the algorithm to converge. This is reflected in Figure 6.13 where the tracking benefit provided by GSF is decreased by

Artificial Urban	**10**	**100**	**500**
Error GSF [m]	1.53	1.49	1.55
Error SIR-PF [m]	2.73	2.44	2.24
Absolute Error [m]	1.2	0.95	0.69
Benefit %	44%	39%	31%

Table 6.5: Error distance of GSF and the basic PF in case of artificial urban scenario when considering 10, 100 and 500 particles.

iTETRIS Urban	**10**	**100**	**500**
Error GSF [m]	1.36	1.31	1.27
Error SIR-PF [m]	2.42	1.79	1.69
Absolute Benefit [m]	1.06	0.48	0.32
Benefit %	44%	27%	25%

Table 6.6: Error distance of GSF and the basic PF in case of iTETRIS urban scenario in case of 10, 100 and 500 particles.

the increase of the number of particles.

GSF gives better estimation results, the error distance goes below 1.3 m in case of iTETRIS urban scenario. However, the best performance of the basic SIR-PF exceeds 1.65 m of position error. An improvement on the tracking error: 44% comparing to the SIR-PF is provided by GSF in case of 10 particles for both artificial and iTETRIS scenarios. A slight decrease in the distance error is observed for realistic iTETRIS scenario which can be explained by the fact that the average speed is more important for artificial scenario. The speed is indeed an influencing factor on the tracking model which will be more shown in next section for highway scenarios.

Highway Scenario The first observation that can be taken from Tables 6.7 and 6.8 is that the distance error increases when the velocity of the vehicle becomes important. Again, we see that the number of particles does not affect the results of GSF. GSF outperforms the standard particle filter scheme which even with 500 particles cannot perform the same way as GSF with 10 particles. GSF is capable of enhancing the tracking error of 21% only with 10 particles compared to 500 particles for PF.

Artificial Highway	10	100	500
Error GSF [m]	2.10	2.11	2.10
Error SIR-PF [m]	2.68	2.52	2.19
Absolute Benefit [m]	0.58	0.41	0.09
Benefit %	21%	16%	4%

Table 6.7: Error distance of GSF and the basic PF in case of the artificial highway scenario for 10, 100 and 500 particles.

iTETRIS Highway	10	100	500
Error GSF [m]	1.41	1.39	1.35
Error SIR-PF [m]	2.14	1.58	1.60
Absolute Error [m]	0.73	0.19	0.25
Benefit %	34%	12%	15%

Table 6.8: Error distance of GSF and the basic PF in case of iTETRIS highway scenario in case of 10, 100 and 500 particles.

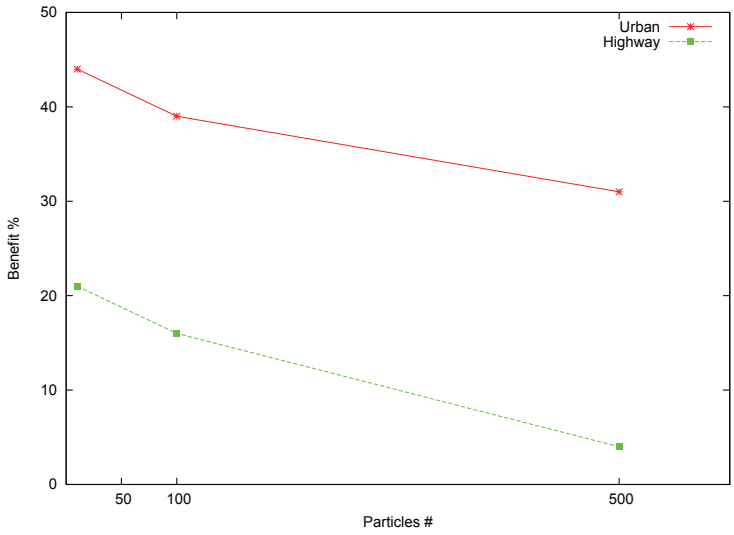


Figure 6.13: Illustration of the tracking benefit resulting from the use of GSF compared to SIR-PF when varying the number of particles.

6.4.2.3 Impact of Awareness Messages/GPS Loss

ITS environment is constrained to high fading channels and congested network which lead to a serious problem of packet loss. Moreover, it may be common in ITS environment to miss GPS signals. The impact of this aspect on tracking algorithms

Urban Scenario	No Loss	1 Loss	2 Loss	3 Loss
GSF	1.53	1.69	1.88	2.50
SIR-PF	2.73	3.23	4.26	4.72
Absolute Error [m] (GSF/SIR-PF)	-/-	0.16/0.5	0.35/1.53	0.97/1.99
Error % (GSF/SIR-PF)	-/-	10%/18%	22%/56%	63%/72%

Table 6.9: Impact of packet loss on the error distance of GSF and the basic PF in case of urban scenario for 10 particles.

Highway Scenario	No Loss	1 Loss	2 Loss	3 Loss
GSF	2.10	2.82	3.68	4.64
SIR-PF	2.68	3.99	4.94	5.78
Absolute Error [m] (GSF/SIR-PF)	-/-	0.72/1.13	1.58/2.26	2.54/3.1
Error % (GSF/SIR-PF)	-/-	34%/49%	75%/84%	121%/116%

Table 6.10: Impact of packet loss on the error distance of GSF and the basic PF for highway traffic scenario for 10 particles.

is worthy to investigate. In the following, we study this aspect in both urban and highway traffic environments.

Urban Scenario From Table A.4, we observe that in all the cases the distance error from real position grows when the packet loss ratio increases. The distance error does not exceed around 2.5 m for GSF scheme however it goes up to 4.7 m in case of the SIR-PF. The particles in the basic PF lose their importance. However, in GSF they are spread in all possible directions to augment the space search. The table shows how the error increases by more than 70% for SIR-PF (1.99 m). However, in case of GSF the increase does not exceed 63% (0.97 m). For one and 2 losses of awareness, SIR-PF error increases by 18% and 56% respectively which is more or less the double compared to the error % of GSF (10% and 22%).

Highway Scenario Table 6.10 shows the behavior of both tracking algorithms in high speed environments. From the first sight, we can deduce that for both filters the distance error increases compared to urban scenario. In fact, the impact of missing an awareness update is more pronounced in case where the average speed and acceleration are higher. When a vehicle misses an update, the prediction of the next position will be based on the outdated data, in particular, the speed will lead to wrong estimation because it is far different from the actual value. Moreover, when increasing the update loss ratio the error becomes more and more important.

Figure 6.14 depicts the evolution of the distance error in urban scenario during simulation time. Both results with and without updates loss (one loss) are plotted. We can observe that the distance error increases in case of update loss for both the SIR-PF and the GSF over time which is due to the accumulation of error in vehicle position. Moreover, we distinguish two zones in the curve, the former where both filters perform approximately the same way. The latter is the zone where the basic particle filter deviates from the real position and gives more than 2m of position error which is due to the augmentation of vehicle speed. In contrast to SIR-PF, the performance of GSF remains almost stable when varying the vehicle velocity. This is due to the intelligence in our tracking scheme and its reliability to provide the highest position accuracy. Regarding highway scenario illustrated in Figure 6.15, three zones can be defined. The first corresponds to an equivalent performance for both filters. It is worthy to note that the performance of our tracking model can be shown in the second zone where GSF outperforms PF and the last one, corresponding to higher velocity, where both filters deviate from the real position and exceed 2 m of error.

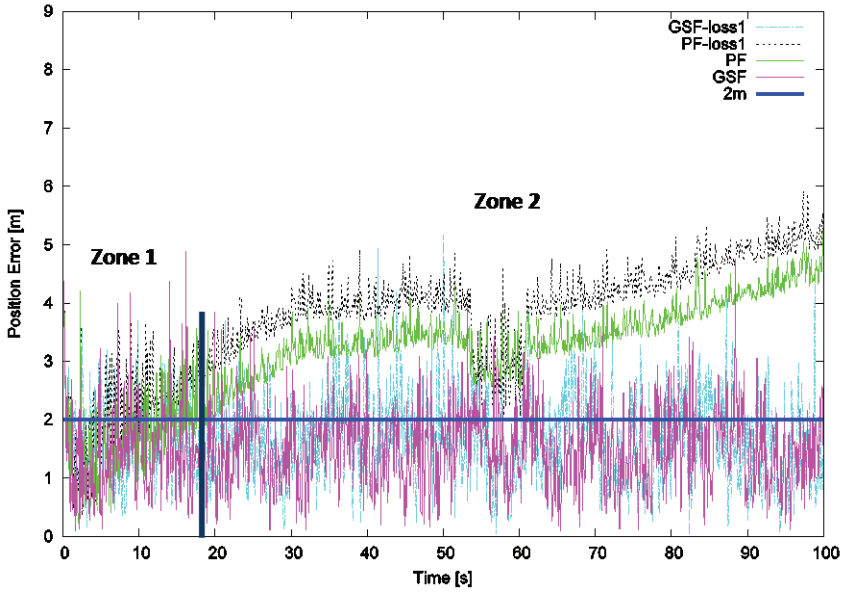


Figure 6.14: The evolution of the Error distance of GSF and PF with packet loss ratio (1/1) in case of urban scenario.

6.4.2.4 Impact of Sudden Changes in Motion Model

Sudden and unexpected movement changes influence dramatically the performance of the tracking scheme. It is the subject of investigation of this section. Figure 6.16 depicts a tracking case taken from iTETRIS Acosta scenario where the vehicle starts moving from second 32. At seconds 40 and 42 the position of the vehicle deviates abruptly due to two successive lane changes. This leads to a severe deviation of the

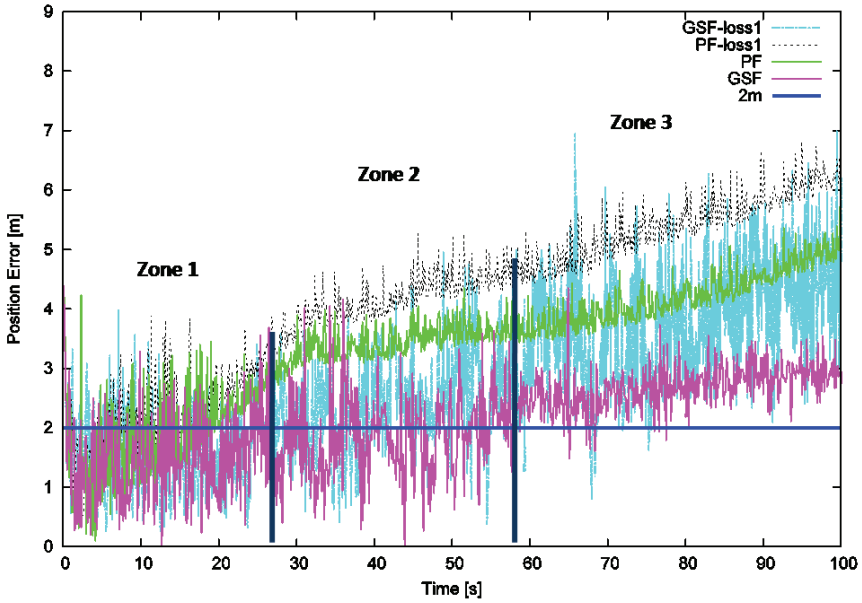


Figure 6.15: The evolution of the Error distance of GSF and PF with packet loss ratio (1/1) in case of highway scenario.

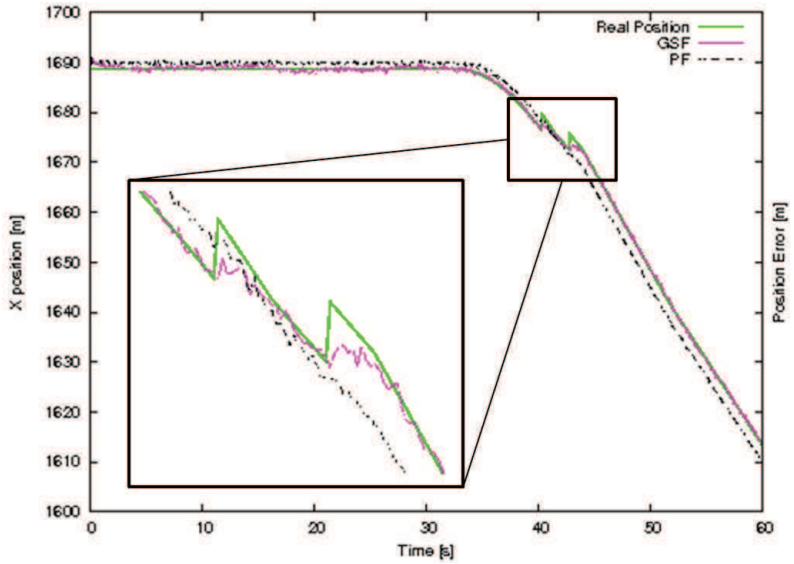


Figure 6.16: Tracking error over simulation time of GSF and PF in case of lane change.

particle filter where the position error reaches 4m that might be seriously dangerous for cooperative safety applications. However, GSF succeeds to track well the vehicle giving an average position error of around 1.3 m.

6.4.2.5 Effect of Positioning Errors on Tracking Performance

A part from GPS signal loss, another source of error more related to the precision of the navigation system can be introduced to the positioning information. In this section, we examine this aspect and we evaluate the behavior of GSF and the SIR-PF when we consider the error of positioning devices that can be introduced to the real position. As mentioned above, we have considered a Gaussian distribution *N(0,5)* to simulate the error.

Urban Scenarios Tables 6.11 and 6.12 summarize the obtained results for urban traffic scenarios. We can conclude that the performance of GSF remains stable however a degradation of SIR-PF performance can be observed. Based on the multiple hypotheses approach, our algorithm achieved good performance to ensure a rapid recovery from adverse conditions such as GPS errors even with low number of particles. Compared to Table A.2, in case of iTETRIS urban scenario, when using 10 particles, the error distance of the SIR-PF goes from 2,42 m to 3.26 m. For higher number of particles the SIR-PF is capable to recover from the GPS error leading to the similar performance as in the scenario without error (Table A.2).

Artificial Urban	**10**	**100**	**500**
Error GSF [m]	1.58	1.51	1.53
Error SIR-PF [m]	3.08	2.85	2.62
Absolute Benefit [m]	1.5	1.34	1.09
Benefit %	49%	47%	41%

Table 6.11: Impact of GPS error on SIR-PF and GSF in case of artificial urban scenario in case of 10, 100 and 500 particles.

iTETRIS Urban	**10**	**100**	**500**
Error GSF [m]	1.38	1.30	1.24
Error SIR-PF [m]	3.26	1.84	1.70
Absolute Benefit [m]	1.88	0.54	0.46
Benefit %	57%	29%	27%

Table 6.12: Impact of GPS error on SIR-PF and GSF performance in case of iTETRIS urban scenario considering 10, 100 and 500 particles.

Highway Scenarios The results in case of highway scenarios are given in Tables 6.13 and 6.14. We notice that the tracking error is more important compared to

urban scenarios. Again, the results of GSF are invariable to the samples size. However, the position error goes from 2.68 m (without error in Table 6.7) to 3.18 m when applying the SIR-PF in realistic iTETRIS acosta scenario.

Artificial Highway	**10**	**100**	**500**
Error GSF [m]	2.09	2.08	2.08
Error SIR-PF [m]	3.18	3.06	2.67
Absolute Benefit [m]	1.09	0.98	0.59
Benefit %	34%	32%	22%

Table 6.13: Impact of GPS error on the SIR-PF and GSF performance in case of artificial highway scenario taking into account 10, 100 and 500 particles.

iTETRIS Highway	**10**	**100**	**500**
Error GSF [m]	1.44	1.36	1.32
Error SIR-PF [m]	2.31	1.76	1.77
Absolute Benefit [m]	0.87	0.4	0.57
Benefit %	38%	23%	25%

Table 6.14: Impact of GPS error on SIR-PF and GSF in case of iTETRIS highway scenario for 10, 100 and 500 particles.

The obtained simulation results reveal that GSF achieves its design goal of providing a good and sufficient level of accuracy for position as compared to the basic particle filter scheme. GPS signals and awareness updates losses as well as errors on positioning have shown to be important and influencing factors for the precision of filters. In the next section, we study the performance of the filters in terms of convergence time.

6.4.2.6 Convergence Time

In order to evaluate the real-time performance of the tracking algorithms, the execution time has been measured for different numbers of particles. Tables A.3 and 6.16 illustrate the real execution time in seconds of 100s of simulation in ns-3 for some scenarios. The basic SIR-PF ensures the lowest run time compared to GSF for the different scenarios which is due to the extra computation that GSF algorithm introduces. However, in order to respect real-time requirements of ITS safety applications and at the same time preserve a high level of accuracy, a trade-off between fast convergence and high precision must be taken into account.

In Figure 6.13, it has been proved that the maximum benefit of GSF in enhancing the tracking performance is gained in case of 10 particles. On the other hand, 10 particles provide the lowest execution time, and thus, it allows to ensure this trade-off.

Urban	**10**	**100**	**500**
GSF [s]	1.3	33.7	934.6
SIR-PF [s]	0.6	8.2	158.2
Benefit [s]	0.7	25.5	776.4

Table 6.15: Convergence time of GSF compared to the basic SIR-PF in case of artificial urban scenario for 10, 100 and 500 particles.

Highway	**10**	**100**	**500**
GSF [s]	1.6	40.7	1715.4
SIR-PF [s]	0.6	8.2	158.7
Benefit [s]	1	32.5	1556.7

Table 6.16: Convergence time of GSF compared to the basic PF for artificial highway scenario considering 10, 100 and 500 particles.

6.5 Conclusion

In this chapter, we proposed to control the cooperative awareness accuracy by a swarm-inspired tracking mechanism. Our approach has been designed to improve the accuracy of awareness system for uncertain and unreliable ITS environment. We have presented GSF (Glow-worm Swarm Filter), an improved particle filter designed to deal with unreliable wireless channel resulting in the loss of CAMs messages and in missing (or receiving with errors) GPS signals. The unpredictable internal dynamic model has been considered as well.
The main feature of GSF is the abilities of the glow-worms to track multiple hypotheses (i.e. potential location estimates), typically required when a large uncertainty on the location estimates is present. Simulation results show that GSF outperforms the SIR particle filter and ensures a good trade-off between high precision in position estimate and fast convergence.

We have demonstrated in section 5.4.4 of chapter 5 that the efficiency of ITS safety applications depends on the accuracy of the cooperative awareness system. In the next chapter, we investigate the capability of our tracking algorithm to ensure better performance for such applications by accurately detecting safety events and

efficiently disseminating periodic information in CAMs that might affect the event-driven dissemination.

7
Efficient Transmit Rate Control Methodology

7.1 Introduction

Novel and innovative ITS applications are being under development to provide advanced and effective transport and traffic road management. Yet, there is no doubt that improving safety on roads remains the most vital application sphere in ITS. As discussed in Chapter 5, the effectiveness of such applications depends widely on the accuracy of the location information and thus, the availability of a precise "global perception" of the surrounding context. For instance, in case of collision avoidance application, vehicles must acquire accurate cooperative awareness of neighborhood to avoid potential accidents with other approaching nodes.

In this chapter, we examine the application of our tracking algorithm GSF presented in Chapter 6 in typical safety scenarios and its capability to enhance the performance of ITS safety applications to efficiently detect not only safety events but also false alarms.
Furthermore, to limit network congestion that could result from periodic transmissions of awareness, based on GSF, we propose an approach to control the awareness transmit rate. This approach benefits from the fact that GSF can adapt to aperiodic transmissions.
So basically, we intend to handle, on one hand, the channel load and, on the other hand meet the safety applications requirements. The challenge of this system is to understand how to conveniently:

1. *Control channel congestion and reduce unnecessary awareness transmissions.*
2. *Control critical events and being able to detect unexpected safety situations.*
3. *Control false alarms and limit the unrequired transmissions resulting from incorrect detections of a hazardous situations.*

The rest of this chapter is organized as follows. In section 7.2, we start by an overview of related efforts that attempted to review the concept of cooperative

awareness control. Section 7.3 formulates our research problem and describe our transmit rate control approach designed to deal with safety requirements. We then provide performance evaluations in Section 7.4 before providing the conclusion in Section 7.5.

7.2 Related Works on Cooperative Awareness Control

Various protocols have been proposed in the context of one-hop cooperative awareness control. Most of them addressed the congestion control problem by adapting the transmission parameters e.g. tuning the transmit power and/or rate to reduce the network congestion.

7.2.1 Transmit Power Control

An important area which has been considered by many researchers is the adjusting of transmission power according to vehicle environment and many other circumstances in order to reduce messages redundancy. In this section, we briefly look at some of power adjustment proposals found in the literature. There are protocols which are distributed and use beacons exchange to collect information from neighbors while others use only local information to adjust the power of transmission, we deal in the following with the distributed ones.
In [108], Torent-Morreno proposes a distributed adaptive algorithm, D-FPAV. The protocol requires that every node collects the status information of all its neighbors to compute the appropriate transmission power level. Using this information, a vehicle sets the transmit power level of the awareness messages (or beacons) to the minimum value under a specific threshold to achieve fairness. Additionally, a prioritization of safety message over beacons is observed since the probability of correctly receiving safety message with using D-FPAV is higher than the reception probability in case of no power control. D-FPAV is used typically to reduce the beaconing load on the channel in case of saturation. The adjustment of the transmission power of beacons reduce the collisions and provide to safety messages more bandwidth.
Mittag et al. present in [62] a Distributed Vehicle Density Estimation scheme (DVDE) and a Segment-based Power Adjustment for Vehicular environment (SPAV). The DVDE provides an approximation of the surrounding traffic density for each vehicle according to the information included in the received beacons. This approximation is used then by SPAV to adjust dynamically the transmission power of vehicles.
In [97], Reumerman et al. suggest a distributed communication protocol based on restrictive flooding mechanism where each node receiving, within a period of time, a number of copies of a given message higher than a threshold does not re-broadcast it. The threshold depends on the number of surrounding nodes detected. Besides flooding-based mechanism, the authors propose another approach to increase the performance of the protocol which is the power control mechanism. The transmission power is dynamically calculated on the basis of feedback information gathered

from the channel (Hello messages) and using the average path-loss information per neighbor. The simulation results show that with the progressive reduction of the transmission power the message redundancy and the reachability are improved.
Other suggestions focused on estimating the local density of vehicles by the means of analytical models using local information.
Artimy suggests in [24] a scheme that allows vehicles to estimate their local density using the average vehicle speed and the fraction of vehicles that are stopped due to traffic congestion. According to this density estimate, each vehicle can control its communication range by adjusting its transmission power using Dynamic Transmission Range Assignment (DTRA) algorithm. This later uses two analytical models to compute the transmission power for each vehicle.
We found also in the literature another proposal [78] introducing an approach to estimate the local density using an analytical model and to adjust the transmission range of the node according to this estimate. To estimate the local density, a node calculates the number of its neighbors by listening to the radio channel and evaluating the distance from each neighbor which can be derived from the signal strength or a timing-differential signal approach.

7.2.2 Contention Window Control

Another adaptive approach has been proposed by Balon and Guo in [26], originally designed for event-driven information control but could be applied for cooperative awareness control. This scheme aims also to improve the reception rate of safety messages and to reduce channel congestion. This approach is based essentially on using a network state estimation and an adaptive contention window adjustment. According to the percentage of packets that was successfully received and using messages sequence number, a node is able to dynamically adjust its contention window size which is decreased if there is network congestion and increased otherwise.

7.2.3 Transmit Rate Control

In this section, we give an overview of the proposed policies in the context of awareness transmit rate control. The idea behind is to adapt the timing of message transmission. This aspect impacts straightforwardly the awareness transmission decision. Unnecessary transmissions are avoided and thus, unnecessary adjustment of eventual transmit parameters (e.g. power or data rate) is prevented. Therefore, we consider transmit rate control as the primitive step to build an effective network congestion control. Thus, in the scope of this work, we focus mainly on this concept.
Some studies, such as [98, 81], considered the observed regularities behind vehicular mobility to predict future vehicular positions and reduce the number of unnecessary transmissions which makes the system switch from being periodic to aperiodic. For instance, in [98], nodes track their own position based on a Kalman Filter and the positions of their neighbors using a kinematic model. Furthermore, the decision to transmit is made by comparing the deviation of the tracking model (from

the real position) to a threshold. The work in [81] is based on the same aperiodic transmission concept as in [98] but propose an advanced tracking model based on SIR Particle Filter which models better the conditions of ITS environment. Moreover, transmission decision making task is performed using an information-centric evaluation that is based on an entropy model.
It is worth to mention that some efforts combined the advantages of both power and rate control approaches. The authors in [96] suggested assigning a fraction of resources to each node to ensure fairness. When a node increases its transmit power, it has to decrease its transmit rate and vice versa.

All of the aforementioned approaches have been focusing on reducing the network congestion either by adapting the transmit rate of awareness transmissions or adjusting their transmit power. Although showing a significant capability to lower the wireless channel congestion, these mechanisms have not been optimized with traffic safety requirements in mind. Situations where higher precision of the cooperative awareness is needed are not considered.
To the best of our knowledge, only one study in [58] considered to jointly address safety requirements at a reduced CAM transmit rate but has been limited to stable mobility. However, most of the safety-related situations will be generated from unstable traffic, which in turn is hardly predictable.

7.3 Cooperative Awareness Control under Safety Constraints

Cooperative safety applications require each vehicle in the network to be aware of its surrounding vehicles. The update of this information is commonly handled by periodic transmissions. Taking into account the unreliable characteristics of vehicular channel (as discussed in Chapter 2) in addition to the large scale nature of ITS and its mobility dynamics, periodically exchange awareness among all the equipped vehicles in the vehicular network may engender congestion and accordingly the degradation of the shared channel performance, as shown in Figure 7.1.
As mentioned previously, in the scope of this thesis, we consider transmit rate control as we believe that it is a crucial step for efficiently controlling the network congestion. Obviously, other techniques such as power control could be used in association with awareness transmission rate control like in [96].

The transmit rate control implies the reduction of the number of awareness transmissions, and consequently the increase of the time interval between the consecutive updates. In absence of updates, errors on the position information are cumulated over time and the position precision degrades. This does not cope with cooperative safety applications. As discussed in Section 5.4.4, such applications have a special need for cooperative awareness accuracy.
The main goal of this work is to ensure the sufficient accuracy to enable efficient

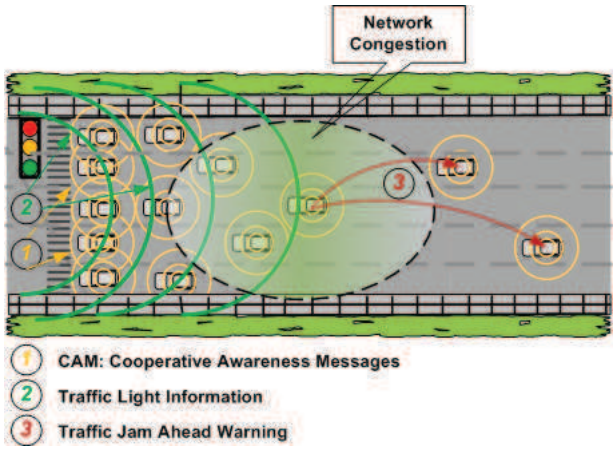


Figure 7.1: Traffic scenario illustrating the transmission of several types of messages leading to the problem of channel congestion. The transmission of traffic jam ahead warning message might be affected by the high channel load.

operation of safety applications under these constraints. In the next section, we present our transmit rate control approach where the awareness system is managed by the means of a tracking model.

Cooperative Transmit Rate Control Approach

The basic concept of our tracking-based approach is to let all nodes predict the awareness of their surroundings. Moreover, each vehicle should predict its own position as well in order to evaluate the precision of the prediction of others. Vehicles are allowed to communicate and send their local awareness only when they perceive a critical deviation from the actual position and detect the need of others to the fresh information. A flowchart of this scheme is presented in Figure A.14.

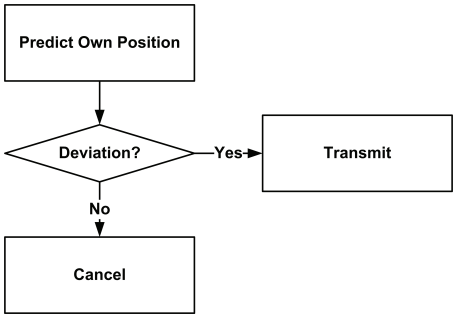


Figure 7.2: Flowchart of the tracking-based cooperative awareness rate control.

As illustrated in Figure 7.3, tracking-based awareness transmit control system consists of two main components:

1. The tracking model which provides the estimate of the cooperative awareness. For instance, Bayesian filters could be applied. The more accurate this block

is, the more efficient will be the control of the transmit rate. If nodes are able to track precisely their neighbors, the frequency of transmissions will reduce.

2. The transmission decision making block that controls the awareness transmissions based on the results of the tracking model. This system evaluates the degree of the deviation of the tracking system from actual awareness which may depend strongly on the requirements of upper applications. Considering the multiple hypotheses aspect, the decision of this block depends on the deviation of each of the hypotheses from the real data.

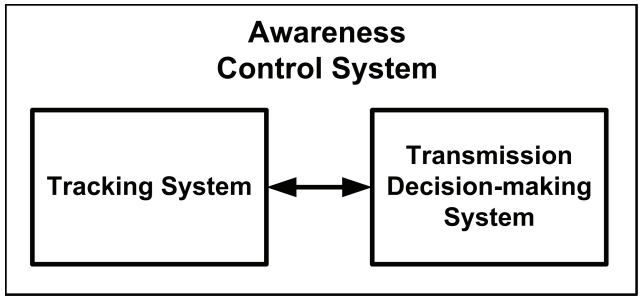


Figure 7.3: Cooperative awareness control system.

It is worth to note that the output of each block is dependent on the output of the other. The decision of transmission is made on the basis of the output of the tracking model. On the other hand, the decision making system in its turn, impacts implicitly the tracking model since it acts on the frequency of updates. Algorithm 6 summarizes the operation of our awareness transmission control. The tracking model is based on GSF and the transmission decision making system is based on a threshold *"AppTh"* depending on the nature of application.
This aspect makes conceptually **periodic** awareness transmissions become **aperiodic**. Yet, this may reduce the quality of awareness and as such does not cope with the constraints from safety applications. For instance, in the scenario illustrated in Figure 7.4, the vehicle behind being not aware of the sudden brake of the car in the front, collides with this latter.
Typical traffic situation might occur due to sudden deviations on mobility patterns, e.g. sudden brake or acceleration, leading to potential safety issues. Accordingly, *aperiodic* awareness schemes will have a high chance of failing to detect a potential danger.
Switching to periodic transmissions when detecting such scenarios, could be a solution. The issue here is that, in dynamic ITS environments, these situations are expected to be present often but with varied degrees of criticalness. For example, considering the case of traffic jams, vehicles are assumed to accelerate and decelerate frequently. However, transmissions are not needed each time. This could lead to unnecessary channel load. An efficient detection of the context is therefore needed in order to distinguish between actual safety situations and false alarms (false positives)

Algorithm 6 pseudo-code of the awareness rate control algorithm

```
1: T_min = minimum period of transmission (100ms)
2: T_max = Maximum transmission period (1s)
3: T_ls: last time the node sent
4: Input: lastData(X_l, Y_l), actualData (X_a, Y_a)
5: Output: Decision (bool)
6: predictedData = GSF (lastData)
7: if (predictedData) > AppTh then
8:    Decision = true
9: else
10:   Decision = false
11: end if
12: if t = T_ls + T_max then
13:   Decision = true
14: end if
15: Return Decision
```

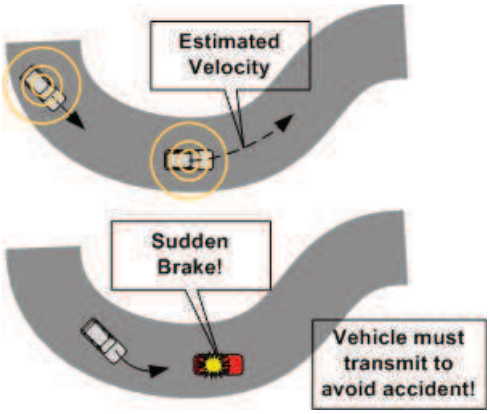


Figure 7.4: Traffic scenario illustrating the need of periodic transmission of CAM to detect the urgent braking of the vehicle in front and to avoid the accident.

(as discussed in Section 5.4.4). Typical events have not been addressed carefully in existing approaches. For instance, in the work [58], the authors have not considered the evaluation of false alarms, they focused only on the performance of their system to detect safety situations.
It is thus required to design new system to control the transmission of awareness. The new approach has to be able to accurately detect safety events and trigger accordingly awareness transmissions and at the same time, it has to reduce false alarms. So we propose to apply the concept of multiple hypotheses (GSF) to this problem. We use the results of Chapter 6 that demonstrated the effectiveness of GSF in tracking. The idea is to provide alternative hypotheses and transmit the awareness only when the future mobility does not exist in neither of these hypotheses. Additionally, the transmission is triggered only when one of the hypothesis

detects a safety event which is defined according to the application.
We evaluate the effectiveness of our transmit rate control based on GSF to reduce false positives maintaining the same performance in detecting safety situations (and reducing false negatives). We demonstrate how well this aspect fits safety constraints.

7.4 Evaluations

In this section, we evaluate the performance of our cooperative awareness control system based on GSF and compare it with a control system based on the SIR-PF scheme. First, under safety constraints, we examine the performance of our approach to reduce both false negatives and false positives considering a car braking scenario. Second, we study the effectiveness of our approach in reducing the channel congestion taking into account large scale dense scenarios (urban and highway).

7.4.1 Simulation setup

A set of experiments has been carried out using the ITS simulation platform iTETRIS [11]. In the following we present the configuration parameters of mobility and network scenarios. It is worth noting that the number of particles used in these simulations is 10.

7.4.1.1 Mobility scenarios

To evaluate the capabilities of our transmit rate control approach to accurately detect emergency events and limit accordingly false negatives and false positives, we consider an urgent braking scenario as shown in Figure 7.5 where two vehicles are driving in the same lane and the vehicle in front brakes down. The vehicle in front is referred later as the ego vehicle the vehicle behind is called target vehicle. For the evaluation of the detection of safety events, both vehicles run the given awareness control algorithms (transmit rate based on GSF and PF-based). We examine the capability of the ego vehicle to reduce the false negatives. The target vehicle is used for the assessment of the false positives.
On the other hand, for the evaluation of the impact on channel load and the reduction of congestion, we have considered calibrated and realistic scenarios modeled from the city of "Bologna". The first is called "Acosta Pasubio joined", modeling an urban environment composed of multiple intersections. Figure 6.16 illustrates the map of this scenario. Figure 6.11 illustrates the highway iTETRIS scenarios representing the high speed and the large scale feature of the ITS environment.
The mobility configuration parameters of our simulations are shown in Table 7.1.

7.4.1.2 Network scenario

In our communication scenario, we consider that the awareness is conveyed among vehicles in beacons which are sent at the network layer. The propagation model that

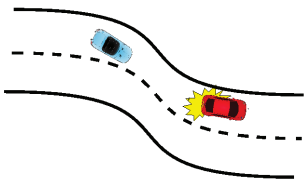


Figure 7.5: An urgent braking scenario. Two vehicles are driving on the same lane when the ego vehicle brakes down urgently. The target vehicle is the blue, the ego is the red vehicle.

Scenario	Size	Mean Speed [m/s]	Max speed [m/s]	Max accel [m/s2]	Max deccel [m/s2]
Braking Scenario	1 km	7.04	36	1	8
iTETRIS Acosta Scenario	x:2126 m y:2117 m	8.01	13.89	3	4.5
iTETRIS-Highway	x:69000m y:53000m	11.31	36.11	3	4.5

Table 7.1: Configuration parameters of the mobility scenarios.

has been used is the WINNER B1 model for urban environment, which takes into account correlated log normal shadowing and LOS/NLOS visibility between vehicles. Table 7.2 gives an overview of the configuration parameters for the communication scenario.

7.4.1.3 Performance metrics

A comparison between our transmit rate approach based on GSF and the system based on the generic PF has been carried out using the following metrics:

- Information Accuracy
  In order to evaluate the impact of awareness accuracy on the safety applications, False Alarm Rate (FAR) or False Positive Rate (FPR) has been used.

Parameter	value
802.11p Channel	CCH Control channel CCH 5.9GHz
Simulation Time	100 s for each run
Number of simulation runs	5 times for each scenario
Propagation model	WINNER II LOS/NLOS
Transmission power	20 dBm
V2V maximum transmission range	400 m

Table 7.2: Configuration parameters of the network scenario.

This metric measures the probability that the given approach detects an alarm/alert when no actual hard braking occurs.

$$FAR = FP/(FP + TN) \tag{7.1}$$

where FP, the false positive is defined as the times of the incorrect detection of safety event. TN the true negative denotes the times of the correct detection of non safety event. This metric is used to determine how robust is the transmit rate approach to conveniently detect safety events.

- Scalability
  To assess the performance of the awareness transmit control mechanism under large scale constraints, Channel Load (CL) is used to measure the success of the given transmit rate control to reduce the channel congestion. It is approximated as:

$$CL = P_s \times TX_{rate} \times D \times P \times TX_{range} \tag{7.2}$$

  Where P_s is the awareness message size which is equal to 500 bytes.
  TX_{rate} is the awareness message transmission rate.
  D is the vehicular density and P is the penetration rate.
  TX_{range} is the vehicular transmission range which is approximated to maximum 1000 m.

7.4.2 Satisfying Safety Requirements: Collision Avoidance Use Case

We evaluate in this section the performance of our transmit rate control scheme based on multi-hypotheses tracking and compare it to the control mechanism based on PF. We consider the ITS collision avoidance application. The effectiveness of this application depends on the efficient transmission of the awareness to approaching vehicles at a given distance. For instance when a vehicle stops, the awareness should be received by approaching vehicles immediately to prevent accidents from happening. We discuss the capability of our system to correctly detect emergency event on the ego vehicle and reduce false alarms on the target vehicle.

7.4.2.1 Detecting Safety Events: Reducing False Negatives

Figure A.15 plots the evolution of the speed of a braking scenario. The number of transmissions of both GSF-based and PF-based transmit rate control is also illustrated. We can deduce from this figure that PF based awareness transmission is mostly periodic in the whole scenario which is due to the increasing accumulated error on the position estimate of PF. However, GSF before deceleration showed to be aperiodic due to its ability to track the awareness. Then, when the vehicle starts to decelerate GSF detects this context change and remains aperiodic even after the detection.

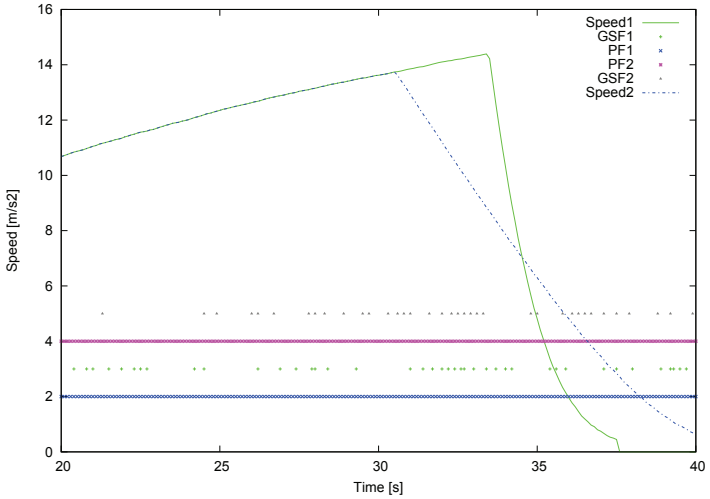


Figure 7.6: Speed vs. simulation time. Impact of deceleration on tracking performance and on ITS collision warning application in case of medium speed.

Figure 7.7 illustrates another braking scenario with high speed. In this scenario both transmit rate control models are periodic before deceleration phase. PF remains periodic even after deceleration however GSF can detect the context change and reduce the periodicity of transmissions when it becomes unnecessary to send. We can notice here that the effectiveness of tracking for active safety applications is ensured by GSF since it is able to detect an abrupt context change. Furthermore, it is capable to reduce the number of transmissions when it is not needed, and as such also contribute to the reduction of the channel load.
We conclude, here, that SIR-PF-based scheme even being almost the time periodic cannot ensure good prediction performance. However, apart from ensuring precise awareness prediction, GSF can remain aperiodic and at the same time detect the context change.

7.4.2.2 Detecting False Alarms: Reducing False Positives

In this section, we examine the performance of the transmit rate approaches to detect correctly the urgent event of braking and limit false alarms. The FAR is

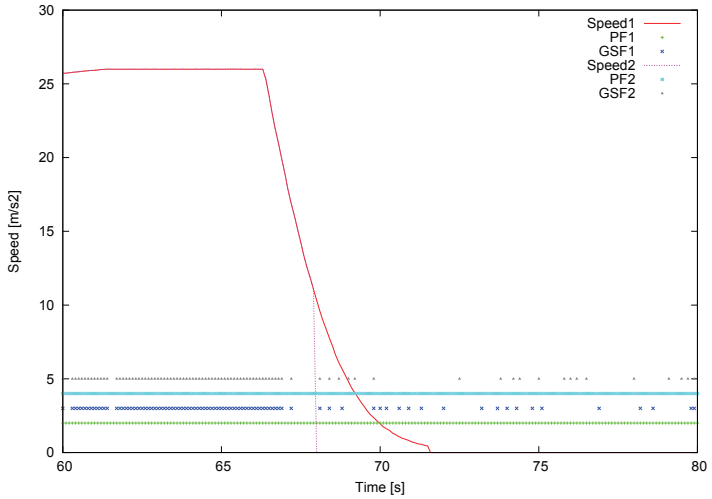


Figure 7.7: Speed vs. simulation time. Impact of deceleration on tracking performance and on ITS collision warning application in case of high speed.

considered as the performance metric. The distance between the ego vehicle and the target vehicle has been measured in order to evaluate the detection of the safety alert. A threshold distance of 8 m has been used, under this value a safety situation should be triggered.
Figure A.13 shows the evolution of the distance between both vehicles with regards to the simulation time. The real distance, GSF-based and PF-based distances are plotted. In this scenario, the ego vehicle performs multiple sudden deceleration. From the curves illustrated in Figure A.13 we can deduce that our transmit rate approach shows to give higher precisions. PF-based approach fails to detect accurately the braking event. We can notice that PF approach gives sometimes false alarms (two examples are depicted in the Figure). The average FAR for SIR-PF based approach reached easily the 54%. However, it is only 2% in case of our transmit rate control approach.
We conclude that our GSF based transmit rate control approach ensure good performance as it is capable not only to reduce false negatives and consequently detect emergency event but also to reduce false positive alerts.

7.4.3 Reducing channel congestion

In this section, we intend to study the performance of the transmit rate control schemes in terms of channel congestion reduction.
Simulation results in Table A.5, prove that GSF helps to reduce the rate of awareness transmissions, only 4.68 transmissions out of 10 (in case of periodic transmission) are performed in 1 s. More than 50% of periodic transmission has been suppressed by our GSF algorithm, only 16% for PF. We can notice also the improvement provided by GSF-based awareness control compared to PF-based algorithm, 45% for urban scenario and 30% in case of highway. We observe also that GSF-based mechanism

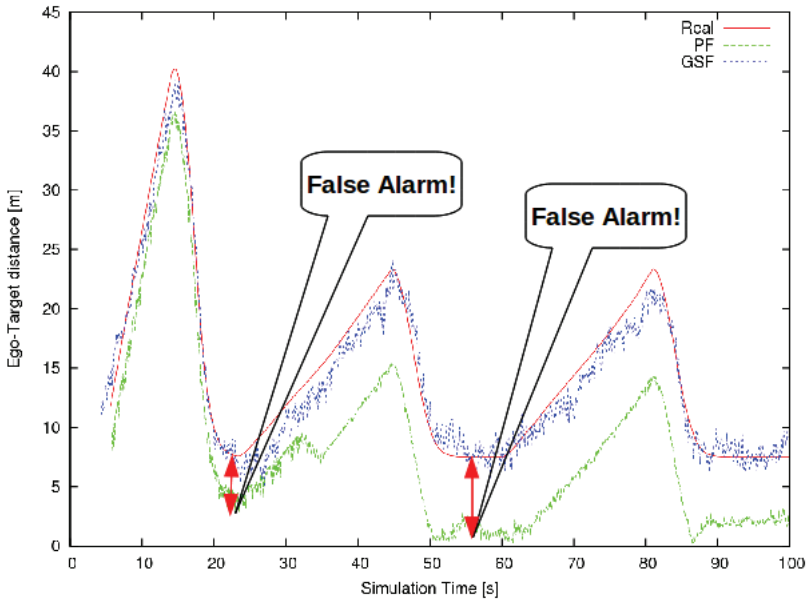


Figure 7.8: Distance between the ego vehicles and the target vs. simulation time.

Transmit Rate	Urban Scenario	Highway Scenario
GSF-based	4.68	5.92
SIR-PF-based	8.44	8.40
Benefit %	45%	30%

Table 7.3: Transmit rate for iTETRIS urban and highway scenario. The transmit rate is computed compared to periodic transmission (1 Hz).

gives lower performance for highway scenario which is due to the higher speed (see Section 6.4 for more details about the performance of GSF).

Figure A.16 plots the channel load of the different schemes, based on particle filter, GSF and periodic transmission. Periodic transmission shows the worst results in terms of channel load, more than 80% of channel usage may lead to a severe problem of network congestion. We can see that GSF ensures the best performance by maintaining the channel load to less than 15% which corresponds to the inactive status (0%-15%). On the other hand, PF exceeds 15% of channel load.

We conclude that our transmit rate control scheme based on GSF, apart from satisfying the safety applications' constraints, ensures on the other hand an efficient channel congestion management and control.

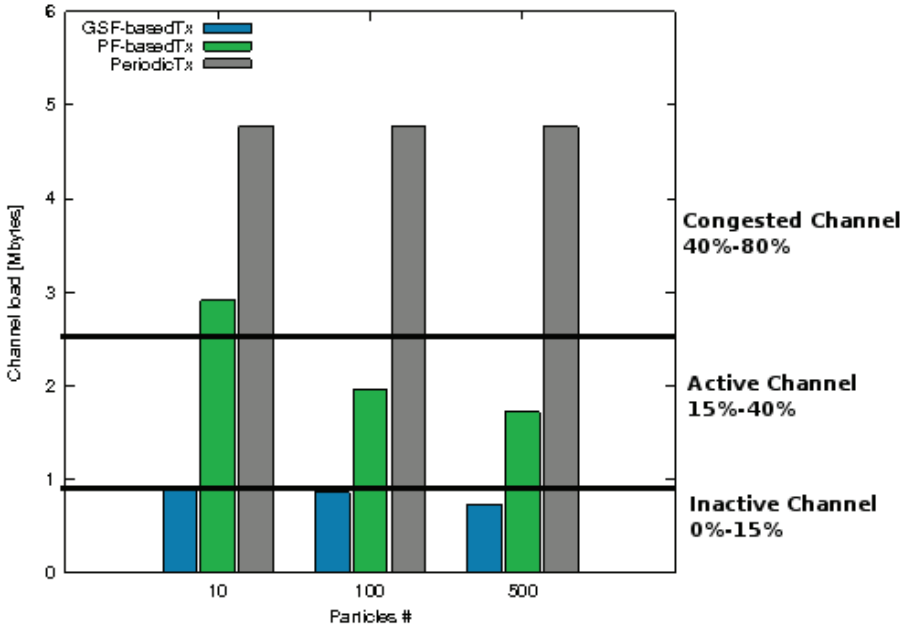


Figure 7.9: Channel load vs. particles number.

7.5 Conclusion

In this chapter, we developed an efficient transmit rate control scheme combined with a bio-inspired tracking model based on multiple hypotheses. The strong feature of our approach is its ability of detecting sudden and unexpected traffic changes typically found in traffic safety contexts and at the same time reducing false alarms rate. In addition, the aspect of aperiodicity in awareness transmissions is preserved in order to reduce the channel congestion.
Simulation results show that our transmit rate approach outperforms the basic scheme based on particle filter and ensures a good trade-off between high precise detection of safety events, decreasing false positive alerts and reducing channel congestion. Not only we could reduce the channel load in heavy traffic scenarios under a level where the channel is not considered as congested (less than 10% channel load instead of 80% channel load), but we could also illustrate that our system is able to efficiently detect context changes and to decrease the false positive rate (only 2% of FAR instead of 54% for PF-based approach). We believe that this is an important outcome of this work, as traditional tracking-based transmit rate control systems have never evaluated this issue.

Conclusion of Part III

In this Part, we have provided an effective awareness control system. Our control mechanisms ensure the required accuracy and precision of the awareness information. Moreover, an efficient control of awareness transmissions is also proposed.

In Chapter 6, we proposed to control the awareness accuracy by a swarm-inspired tracking mechanism. Performance evaluation results show that GSF outperforms the SIR particle filter and ensures a good trade-off between high precision in position estimate and fast convergence.

In Chapter 7, we suggested a transmit rate control mechanism coupled to GSF, developed with safety constraints in mind. Simulation results show the effectiveness of our transmit rate approach compared the control scheme based on SIR-PF. The trade-off between high precise detection of safety events, decreasing false positive alerts and reducing channel congestion, often overlooked, has been ensured.

In summary, we have attempted to cover the different aspects of awareness information in this part. We have proposed solutions to enhance its accuracy and reduce the network congestion. Furthermore, we have evaluated the impact of controlling the transmit rate on the performance of safety applications.

8
Summary, Conclusions and Outlook

In this chapter, we summarize our contributions and major findings. Furthermore, we present the conclusions drawn from the results of this thesis. Finally, we give an outlook on possible future work.

8.1 Summary

Intelligent Transportation Systems have emerged in the last decades with the main aim to improve the safety of drivers and passengers on the roads. Research efforts have been concentrated on investigating the design of the appropriate communication architecture and the development of robust mechanisms for these systems. This thesis suggested to rethink the existing control mechanisms. New approaches have to be designed in order to cope with the adverse conditions of ITS environments and guaranty the requirements of ITS cooperative safety applications.

Through this dissertation, the following objectives are achieved:

- **Identify of the challenges of ITS environment, the requirements of ITS applications and the related evaluation metrics**
  We examined in Chapter 2 the unique characteristics and challenges of the ITS environment. Moreover, we focus on the requirements of ITS safety applications has been provided. In Chapter 3, we have defined the performance metrics that are crucial to assess the effectiveness of the ITS cooperative applications.

- **Adapt existing dissemination control policies to ITS environments**
  We have overviewed in Chapter 4 current proposals for event-driven information dissemination for vehicular environment providing a comprehensive comparison. Based on this study, we conclude that existing dissemination control mechanisms are not compatible with the properties of ITS systems which could not ensure the required reliability and reactivity for safety applications. Thus, we propose in Chapter 5 an enhancement of the ITS dissemination benchmark

"CBF" overcoming these challenges and supporting safety in the road. The dynamic topology and high fading vehicular channel have been considered. Simulations using iTETRIS have proved to provide significant improvement in dissemination delay and network overhead compared to *CBF*. Furthermore, the results of this chapter showed that the effectiveness of safety dissemination control policies depends strongly on the awareness accuracy.

- **Control the accuracy of the cooperative awareness system**
  We address in Chapter 6 the one-hop cooperative awareness information. We designed an efficient control methodology of the awareness system capable of providing high accuracy and precision to cooperative safety information taking into account the challenging ITS environment. Our tracking approach, namely GSF, is based on multiple hypotheses concept considering not only one single potential future position but also other alternative locations modeling the eventual loss of GPS signals or packets in addition to the unpredictable motion changes. Performance evaluation have been conducted and proved that our accuracy control scheme outperforms existing algorithms.

- **Control the transmission of the cooperative awareness system**
  In Chapter 6, we apply GSF to adapt the transmit rate of the awareness. The idea is to conceptually make the awareness transmission system aperiodic and to be capable of accurately detecting brutal changes and limit false alarms. Simulations conducted with *iTETRIS* platform showed how our approach is capable of answering the trade-off between channel congestion and cooperative safety requirements.

- **Develop realistic ITS evaluation tool**
  We have contributed also in the scope of this thesis to the design and implementation of the generic realistic platform iTETRIS which is dedicated for the simulation of ITS applications, protocols and technologies in a high level of realism. iTETRIS platform can be exploited by researchers to validate and evaluate the performances of new designed communication protocols for vehicular communications.

The results accomplished in this thesis pave the way for the design of a generic framework for safety-related information control. The designed control mechanisms compose the basis of such framework. The main concept is to bring together all relevant control mechanisms in one block guaranteeing the needs and requirements of different ITS applications. We think that the most convenient layer to place control mechanisms is the Facilities layer (from the ETSI/ITS architecture [40]) since it controls all the input and output of the nodes.
Moreover, the modeling approach that we suppose is comprised of three building blocks: the awareness management block, the context management and the data aggregation blocks. The awareness management block is split into two blocks: the awareness accuracy control and the awareness transmit control. The former provides

the vehicles with high precision in its global perception using a specific mobility prediction model. The latter is designed to control the transmission rate of periodic awareness information in order to control the network congestion. The context management block provides functions for the management of the relevance of the transmission of event-driven safety data. The data aggregation model handles the potential aggregation of redundant information and takes the decision of the fusion of information.
The design of such generic framework has to be further investigated as it has to take into account all the challenging issues associated with the diversity of the ITS applications.

8.2 Conclusions

In this thesis, we have focused on the robust "control" mechanisms of the safety-related information. We identified the various control levers available and feedbacks metrics required by control mechanisms for safety applications.
Given its importance, we addressed first the *control of the dissemination* of safety event-driven information in order to limit the number of retransmitters and thus, the "channel congestion".
We observed that an efficient control safety-related message dissemination depends on parameters, feedback and levers that cannot be controlled at this level, i.e detection of event, channel load, which are all linked to the local cooperative awareness. Accordingly, we investigated efficient control mechanisms for local cooperative awareness precision and accuracy. A more precise awareness is capable of a better detection of safety events, but still does not impact the channel congestion. We finally applied the awareness control mechanisms to regulate the load on the channel, by reducing the transmission rate of awareness messages.
To conclude, we first identified the various influencing factors impacting efficient control mechanisms for traffic safety applications. We then provided a set of control mechanisms capable of regulating the detection and dissemination of traffic safety events at various level and at the same time optimizing channel resources.

8.3 Outlook

With the wish to support ITS cooperative safety applications, this thesis dealt with the design of robust and effective control mechanisms. Yet, it opens the door to new methodology and design innovations.
The concept of distance threshold of BZB that has been introduced in Chapter 5, requires further and detailed studies to investigate and determine its optimal selection. It could be adjusted according to specific parameters (e.g. the network density, the vehicular inter-space and/or the vehicle coverage range).
The integration of the swarm based algorithm GSO into our tracking system GSF, presented in Chapter 6, did not consider all the features of the GSO algorithm. For

instance, the use of the fitness function *"J"* that gives the possibility to GSF to use the previous information (history) of the filter, has not been considered. Furthermore, an improvement of the decision making model of our tracking system using for instance macroscopic tracking in order to differentiate between multi-hypotheses has to be performed. We believe we can manage to further reduce the awareness error to be below that of the GPS (1.5m). Also, some efforts should be devoted to evaluate our GSF based transmit rate control system under specific safety-critical road situations. Thus, we plan to conduct a larger evaluation.

Appendix A
Résumé de la thése en Français

A.1 Introduction

Récemment, de nouvelles technologies de communications sans fil ont été conçues ouvrant la voie à une grande variété d'applications et services innovants. En particulier, les technologies de communication sans fil véhiculaire (V2X) y compris les communications de véhicule à véhicule (V2V) et de véhicule à infrastructure (V2I), sont actuellement mises en oeuvre pour soutenir l'intégration des technologies de l'information et de la communication (TIC) dans les systèmes de transport traditionnels. Ce concept dénommé Systèmes de Transport Intelligents (STI) propose des solutions innovantes pour améliorer nos vies et rendre le transport plus sûr, plus efficace, plus confortable et respectant l'éco-système.
En conséquence, deux branches principales de services destinés aux STI sont créées. Tout d'abord, les *applications de divertissement* qui sont destinées à fournir plus de confort et d'assistance au conducteur et aux passagers, par exemple l'accès à Internet, la diffusion des informations météorologiques et des points d'intérêts à proximité. Deuxièmement, les *applications de sécurité* qui visent à améliorer la sécurité routière, y compris les services d'évitement des collisions, les notifications d'accidents et, la collecte et la distribution des informations relatives aux conditions de la circulation routière. Dans le cadre de cette thèse, nous nous intéressons aux applications coopératives de sécurité puisqu'elles représentent les services les plus vitaux des STI.
Compte tenu de leur importance, les applications de sécurité sont particulièrement très exigeantes en matière de précision et de fiabilité de la réception de l'information. De plus, ils sont considérablement sensibles au délai. Par exemple, quand un accident se produit, les informations les plus pertinentes doivent être livrées correctement tout en respectant les contraintes de délai afin d'éviter que d'autres accidents aient lieu. Les informations de sécurité pourraient être soit des informations de localisation envoyées périodiquement en un seul saut dénommé "*awareness*" correspondant à l'information relative au voisinage et qui constituent la perception globale du véhicule, ou bien des informations de sécurité événementielles générées et envoyées en mode multi-sauts lors de la détection d'une situation de sécurité.
L'efficacité des applications de sécurité routière dépend donc de la fiabilité du support de communication partagé. La stratégie de communication envisagée d'être

utilisée est la *diffusion V2X* basée essentiellement sur le standard *IEEE 802.11p MAC* [16] qui est un amendement de la norme IEEE 802.11 adapté pour l'environnement véhiculaire. Bien qu'elle soit considérée comme efficace dans un environnement à faible échelle, la diffusion est contrainte par la capacité limitée du canal partagé et par conséquent ne peut pas faire face au très grand nombre de nœuds dans le réseau véhiculaire. Autres aspects qui méritent d'être examinés, sont d'une part la quantité diverse et importante de données transmises sur le réseau, et d'autre part, la forte dynamicité des nœuds. Ce qui entraine un problème de congestion de réseau et, donc une dégradation de la performance du système de communication. En outre, l'absence de "feedback" dans le canal de diffusion pourrait encore freiner la fiabilité des transmissions et plus particulièrement, les transmissions de "sécurité" nécessitant une plus grande fiabilité et une latence plus faible.
L'objectif principal de ce travail est d'assurer une gestion efficace ainsi qu'une diffusion robuste des informations de sécurité routière tout en considérant l'environnement contraignant des STI. Nous proposons de concevoir des *mécanismes de contrôle* efficaces pour contrôler la charge de canal et réduire le problème de la congestion réseau et respecter les besoins des applications de sécurité routière.
Dans la section A.2, nous introduisons l'état de l'art de l'environnement STI. En particulier, nous analysons systématiquement les besoins des applications de sécurité routière. Dans la section A.3, nous abordons la conception de mécanismes de contrôle pour diffuser l'information événementielle de sécurité de manière efficace et optimisée. Nous proposons une approche de contrôle de congestion adaptant le protocole de diffusion multi-hop de référence " *CBF*" (Contention-Based Forwarding) à l'environnement véhiculaire. Après, nous proposons dans la section A.4 un mécanisme de contrôle robuste d'awareness, à savoir Glow-worm essaim filtre (GSF), capable de fournir la précision requise pour une détection efficace et exacte d'une situation de sécurité. Puis, dans la section A.5, nous suggérons d'appliquer notre GSF pour adapter la fréquence de transmission de l'awareness. En outre, nous évaluons la capacité de GSF pour obtenir une détection efficace des situations de sécurité.
Observant que les transmissions liées à des événements de sécurité dépendent essentiellement du contexte global perçu par les véhicules, nous démontrons dans la section A.6 la nécessité d'une entité globale pour contrôler à la fois la congestion du réseau et l'awareness. Enfin, la section A.7 présente la conclusion qui peut être tirée de la thèse et fournit des directives pour les travaux futurs.

A.2 Les applications de sécurité routière pour les STI

A.2.1 Aperçu sur les STI

Le concept des *"Systèmes de Transport Intelligents"* a progressivement évolué dans le but de décrire l'application des technologies de l'information et de la communication dans les systèmes de transport standards. Selon ERTICO (Europe) [2], les STI sont des *"nouvelles technologies d'information et de communication trouvant des applications intéressantes dans le domaine des transports urbains, aussi appelées, les*

télématiques des transports". ITS America [6] les définit comme *"une large gamme de technologies, qui répond à beaucoup de besoins de transport. Les STI sont composés d'un certain nombre de technologies, y compris le traitement de l'information, les communications, le contrôle et de l'électronique. Associant ces technologies à notre système de transport permettra de sauver des vies, gagner du temps et économiser de l'argent"*.

La principale innovation consiste à appliquer les technologies de l'information et de la communication au domaine des transports. Les STI réutilisent des technologies existant pour créer des services innovants qui peuvent être appliqués dans les différents modes de transport et utilisés par les passagers et aussi dans le secteur de transport de marchandises.

Le concept de base des STI est principalement le partage de l'information entre les véhicules ce qui permettra d'assurer le bon fonctionnement des diverses applications qui visent à améliorer les systèmes de transport. Les communications véhiculaires sont les outils de communication utilisés pour l'échange et le partage de l'information dans le réseau sans fil véhiculaire. Ce sont, donc, les technologies essentiels promettant un déploiement des applications et services des STI.

Dans ce contexte, des véhicules tels que les voitures, les camions, les bus et les motos, et même les piétons seront équipés d'une interface réseau, des capacités de calculs embarqués et plusieurs dispositifs de détection tels que les systèmes de localisation (comme par exemple le GPS), des caméras vidéo et des radars. Les infrastructures peuvent également coopérer avec les véhicules et participer au processus de communication afin d'assurer une meilleure couverture. Figure A.1 illustre un scénario de communications entre véhicules, y compris V2V et V2I.

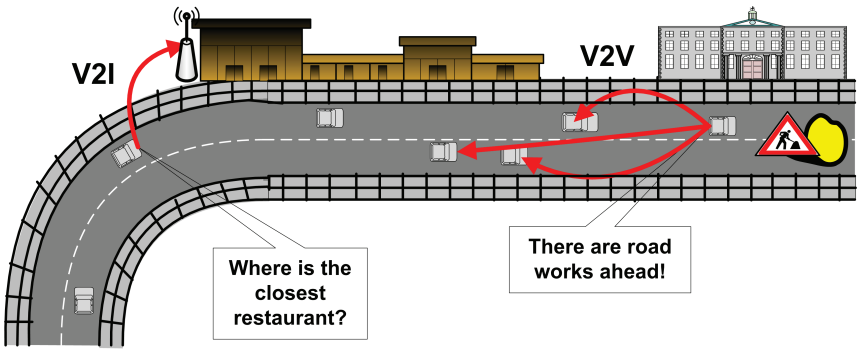


Figure A.1: Les différents paradigmes de communication en environnement véhiculaire.Seuls les véhicules sont concernés par les communications V2V. Par exemple, les informations sur les travaux routiers sont échangées entre les voitures qui approchent la zone. D'autre part, les communications V2I partagent les données entre les véhicules et les infrastructures. Le conducteur peut par exemple obtenir des informations à propos des restaurants les plus proches.

A.2.2 Les applications de sécurité routière

Étant considérées comme la motivation originale derrière la création des STI, les applications de sécurité routière ont acquis beaucoup d'intérêt de la part des entités publiques ainsi que des organismes de recherche. Elles ont principalement l'objectif de réduire le taux d'accidents et de décès sur les routes et, ainsi de garantir une bonne gestion du trafic routier. Donc, vu la grande diversité de ces applications, plusieurs types de données devraient être échangées entre les nœuds. En effet, il existe deux types principaux: Les informations de localisation périodique ou " *awareness*" qui sont transmises en diffusion en un seul-saut via des messages spécifiques dénommés CAM (Cooperative Awareness Message). Elles représentent la perception globale du véhicule, à savoir l'état des véhicules dans le voisinage tels que leurs positions géographiques (fournies par le récepteur GPS), leurs vitesses ainsi que leurs directions, etc.
Le second type concerne les informations de sécurité événementielles générées et envoyées en diffusion multi-hop lors de la détection d'une situation de sécurité. Ainsi, des messages spécifiques (DENM (Decentralized Environment Notification Messages)) sont donc transférés contenants des informations sur la location du danger. En général, ces informations portent sur une zone spécifique de la route. Ainsi, la dimension de la zone de diffusion où l'information est censée être reçue est incluse dans le message.
Pour assurer un bon fonctionnement des applications de sécurité routière, il est nécessaire que les nœuds *coopèrent* entre eux et, en conséquence partagent ensemble l'information de sécurité. Voitures, camions, trains, motos et même les piétons peuvent contribuer à des routes plus efficaces et sûres si la diffusion et le partage de l'information sont gérés efficacement fournissant les données pertinentes pour les conducteurs tout en respectant les exigences et contraintes spécifiques de ces applications. Par conséquent, plusieurs aspects doivent être considérés:

- **Le défi caractérisant l'environnement véhiculaire** Cet environnement est caractérisé par plusieurs aspects particuliers comme la nature non fiable et incertaine du support de communication ce qui n'est pas adapté aux besoins des applications de sécurité en matière de fiabilité de réception. En outre, l'aspect grande échelle du contexte véhiculaire ainsi que la capacité limitée du canal partagé sont d'autres aspects cruciaux qui doivent être prise en considération.

- **Les exigences des applications de sécurité des STI** Ces applications nécessitent des délais très courts et une grande fiabilité de réception de l'information ce qui n'est pas nécessairement le cas pour les applications de divertissement par exemple où les données sont moins sensibles aux délais. Les passagers peuvent tolérer de recevoir avec retard une vidéo téléchargée sur Internet, cependant, il est extrêmement important d'être informé à temps d'un éventuel accident. Cela pourrait être même mortel, car il peut conduire à d'autres situations dangereuses.

A.2.3 Métriques d'évaluation pour les applications de sécurité routière

Dans cette section, nous définissons les indicateurs de performance primordiaux pour évaluer l'efficacité des applications coopératives de sécurité des STI et des mécanismes de contrôle. Ces paramètres ont été identifiés afin d'examiner avec précision la capacité des mécanismes de contrôle conçus à répondre aux besoins des applications de sécurité coopératives en particulier, en termes de latence et de probabilité de réception.

A.2.3.1 Fiabilité

Une application de sécurité coopérative est considérée comme fiable si la politique de contrôle utilisé est capable d'assurer une réception fiable et efficace de l'information de sécurité. La fiabilité de la réception des informations est l'une des métriques les plus pertinentes pour l'évaluation des protocoles de communication utilisés.

A.2.3.2 Réactivité

À la fiabilité s'ajoute la réactivité qui est considérée comme la deuxième métrique importante pour l'évaluation des performances des mécanismes de communication de sécurité. La réactivité d'un protocole de communication donné définit sa capacité à fournir les informations nécessaires au véhicule dans les délais requis.

A.2.3.3 Précision de l'information

Du point de vue de l'application, la précision des informations échangées dans le réseau est vitale et plus précisément pour les applications de sécurité. Néanmoins, cette information est souvent exposée à des erreurs. Par conséquent, l'évaluation du degré de la précision de cette information demeure importante.

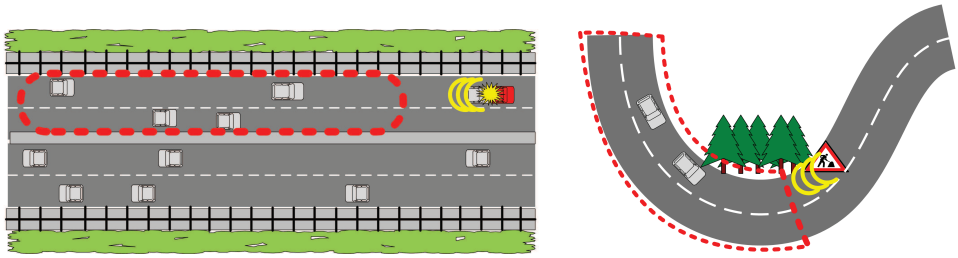
A.2.3.4 Extensibilité

L'extensibilité est un enjeu important pour les applications des STI en général. Il définit la capacité de l'application et le système de communication à s'adapter aux différents besoins et exigences sans changements majeurs dans sa conception. l'extensibilité et la performance sont souvent associées, une application STI est extensible si et seulement si elle est capable de garantir la même performance dans deux contextes différents par exemple basse et haute densité routière.

A.3 Mécanisme de contrôle des informations événementielles de sécurité routiére

Dans cette section, nous présenterons notre contribution au contrôle de la diffusion à multi-sauts des informations événementielles de sécurité. Un aspect particulier des applications de sécurité est qu'elles sont intolérantes aux délais de réception.

L'information de sécurité doit être transmise à tous les véhicules situés dans une zone spécifique à proximité du danger comme l'illustre Figure A.2, la diffusion périodique à multi-sauts et à courte portée devrait être utilisée.



(a) (b)

Figure A.2: Illustration de deux situations de sécurité. Dans le premier scénario (a), un accident se produit entre deux voitures et afin d'éviter d'autres accidents potentiels, les données de sécurité doivent être transmises à tous les nœuds situés sur la même route que le danger (zone rouge). Les véhicules sur les autres routes ne sont pas concernés par cette information. Dans le second scénario (b), l'information des travaux routiers doit être délivrée dans la zone rouge pour réduire le risque d'accident et de garantir la sécurité des passagers.

Vu la nature de communication utilisée dans les réseaux véhiculaires, les acquittements explicites ne sont pas employées. Par conséquent, assurer une diffusion fiable de l'information s'avère un objectif très difficile à réaliser. Toutefois, c'est un aspect crucial qui doit être résolu avant tout déploiement des applications de sécurité routière. Un moyen pour savoir si une transmission donnée est bien réussie est de s'appuyer sur les transmissions redondantes soit directement ou bien via des noeuds intermédiaires. Bien que cette idée, appelée "flooding", semble être efficace appliquée dans des réseaux à petite échelle, elle ne s'adapte pas au contexte à grandee échelle et peut engendrer le problème de "broadcast storm" [87]. En effet, le nombre de réémetteurs augmente de façon exponentielle et sature par conséquent, le canal sans fil avec les communications inutiles conduisant à des problèmes de congestion du réseau. Le défi içi est donc de parvenir à assurer le taux de réception le plus élevé possible, mais en réduisant le nombre de transmissions. Plusieurs travaux ont été effectués visant à optimiser la diffusion multi-sauts dans les réseaux véhiculaires dans le but de réduire la congestion du réseau.
La diffusion basée au niveau du récepteur, également connue sous le nom de *Contention based Forwarding (CBF)* [48] ou transmission fondée sur la contention, est l'une des solutions proposées. Chaque nœud décide localement du relai du message lors de sa réception. Tous les récepteurs entrent en contention afin d'aboutir à un mécanisme de sélection des potentiels relais, le noeud remportant la contention transmet et tous les autres nœuds entendant cette dernière transmission arrêtent leur contention. Cette approche est basée sur trois hypothèses de conception principales: l'uniformité de la topologie du réseau véhiculaire, la fiabilité des canaux

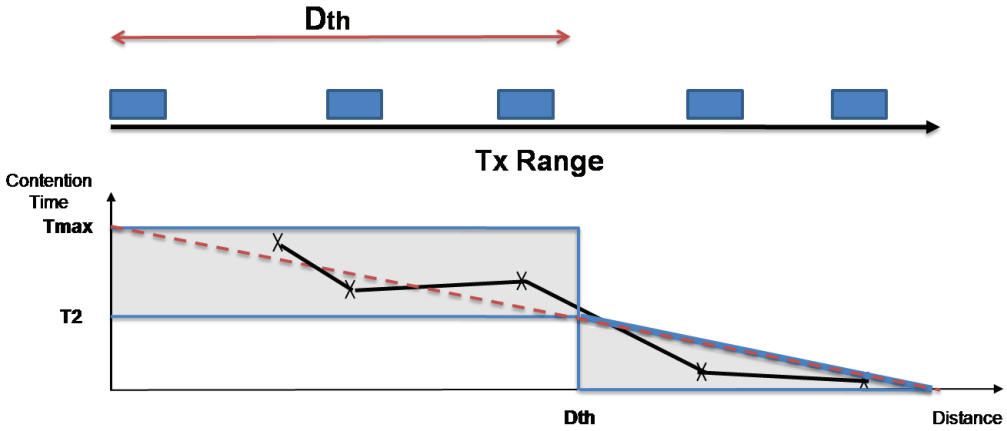


Figure A.3: Le système de contention de *BZB* où les courbes pointillées et continues représentent respectivement le temps d'attente du CBF basé sur la distance et les limites du temps de contention de *BZB*.

de communication (non-fading) et enfin l'homogénéité des moyens et capacités de communications. En revanche, l'environnement des STI, et plus particulièrement, le contexte urbain n'est pas conforme à ces aspects divers. Par conséquent, les relais sélectionnés par CBF peuvent être non-existants, non accessibles et/ou non optimaux en raison des capacités de transmission hétérogènes.

A.3.1 Bi-Zone Broadcast: BZB

Dans cette section, nous aborderons la conception d'un mécanisme efficace basé sur CBF adapté aux besoins des applications de sécurité ainsi qu'aux spécificités de l'environnement urbain véhiculaire. En effet, aucun des mécanismes CBF disponibles aujourd'hui différencie entre les relais en fonction de leurs capacités de transmission. Nous proposons donc deux approches, appelées *Bi-Zone Broadcast (BZB)* et *Infrastructure Bi-Zone Broadcast (I-BZB)*, qui regroupent l'aspect aléatoire ainsi que le principe de la distance dans CBF. I-BZB à son tout, ajuste le temps de contention pour fournir plus de chances aux nœuds ayant des propriétés de communication plus importantes (des RSUs, des autobus, des tramways, des camions, etc.) pour être élus comme relais. Nous séparons la zone de diffusion en deux zones, l'une où un "random" CBF est appliqué, et la deuxième où un CBF basé sur la distance doit être utilisé. Les deux zones peuvent être adaptées à la topologie et à la connectivité, en fonction d'un seuil de distance *"D_{th}"*.
Comme il est indiqué dans la Figure A.3, où la ligne pointillée montre l'évolution du temps d'attente du mécanisme standard CBF basé sur la distance en fonction de la distance par rapport à l'expéditeur. Les lignes continues représentent les différentes limites du temps de la contention de notre approche *BZB*. La contention que chaque nœud doit effectuer, dépend principalement de ces deux zones.
Dans ces deux distinctes zones, le temps d'attente est choisi au hasard entre deux

bornes. Pour les nœuds les plus proches où la distance est inférieure à D_{th}, l'intervalle de sélection du temps de contention est fixé entre [T2, T_{max}], où T2 est donnée dans l'équation Eq.A.2 et T $_{max}$ est le temps maximum d'attente. En raison de l'utilisation de l'aspect aléatoire dans *BZB*, une amélioration du système de contention est perçue, comme le montre Figure A.3, le troisième noeud après l'émetteur a acquis un temps de contention inférieur à celui obtenu par le standard CBF basé sur la distance.
L'intervalle de contention des véhicules dont la distance est au-delà de D_{th} est [0, T1], où T1 est détaillée dans l'équation Eq. A.1. Ayant une limite inférieure de 0, les noeuds les plus éloignés sont accordés la priorité de transmettre immédiatement le message, sans attendre un temps donné. Dans le pire des cas, l'approche CBF basée sur la distance est appliquée.

$$T_1 = T_{max} \times (1 - \frac{d}{r}) \tag{A.1}$$

$$T_2 = T_{max} \times (1 - \frac{D_{th}}{r}) \tag{A.2}$$

où r indique la portée de transmission, T_{max} est le temps d'attente maximum, D_{th} est le seuil distance et d est la distance par rapport à l'émetteur.

A.3.2 Évaluation des performances de BZB

L'étude d'évaluation a été réalisée en utilisant la plateforme iTETRIS qui est un environnement de simulation intégré qui est conçu pour les études d'évaluation des STI. Cette plateforme assure, d'une part, la simulation de l'échange de données V2X sans fil et les caractéristiques de communications, et d'autre part la modélisation de la mobilité des véhicules et des différentes conditions de trafic. Comme illustré dans Figure A.4, le simulateur de réseau ns-3 [12] et le simulateur de trafic SUMO [13] sont regroupés. Un module indépendant pour les applications est conçu ainsi qu'une entité intermédiaire pour gérer l'interconnexion entre les différents blocs.
Un environnement réaliste calibré et urbain de la ville de Bologne représentant la non-homogénéité de la topologie et la connectivité dans l'environnement véhiculaire a été également employé. À partir des résultats obtenus, notre stratégie hybride BZB a montré significativement qu'elle est plus adaptée à l'environnement urbain véhiculaire fournissant environ 46% d'amélioration de délai de réactivité comme le montre Figure A.5 et aussi une réduction de 40% de la charge réseau (Figure A.6) par rapport au flooding.

A.3.3 Impact de l'imprécision de l'awareness sur la performance de *BZB*

Les mécanismes de contrôle de diffusion, et plus particulièrement les approches basées au niveau du récepteur, dépendent principalement des informations de position ou de l'"awareness". En effet, la décision de la sélection des relais est basée

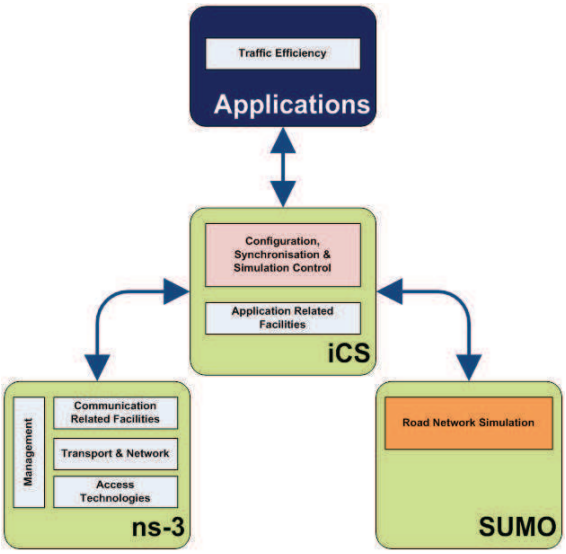
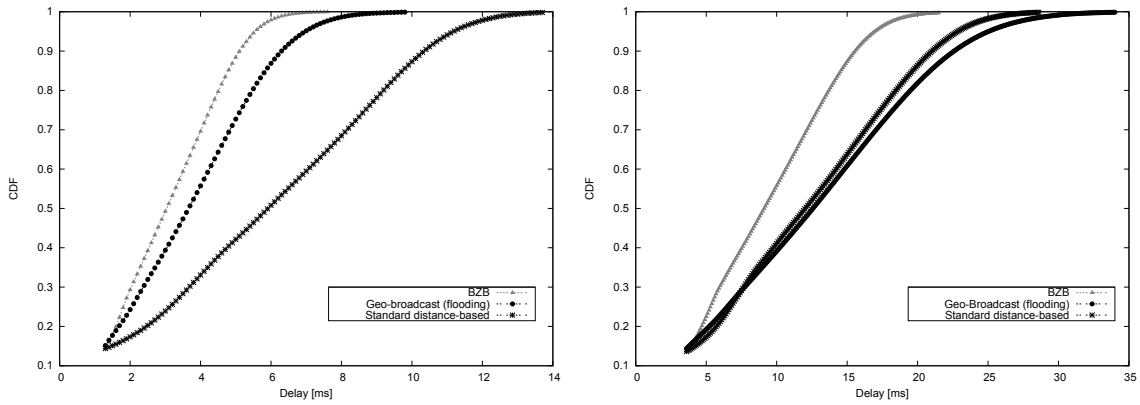


Figure A.4: L'architecture de la plateforme de simulation iTETRIS.



(a) (b)

Figure A.5: Le CDF du délai de réactivité moyenne dans le cas de *BZB*, du flooding et du standard CBF basé sur la distance. (a) taille de paquet 500 octets. (b) taille de paquet 2200 octets.

sur l'évaluation de l'emplacement du récepteur par rapport à l'émetteur. Ces données de localisation sont collectées auprès de plusieurs sources, notamment, le GPS et/ou les différents messages échangés. En outre, ces sources sont souvent exposées à l'imprécision résultant essentiellement du taux élevé de pertes. Le signal GPS est souvent atténué par des obstacles (par exemple les grands immeubles) qui bloquent le LOS (Line of Sight) des satellites ce qui pourrait générer des erreurs de l'ordre de plusieurs dizaines de mètres. En plus de cela, les réflexions, le fading et les interférences influencent considérablement les transmissions des CAMs et DENMs et par conséquent peuvent produire des taux très importants de perte des données de

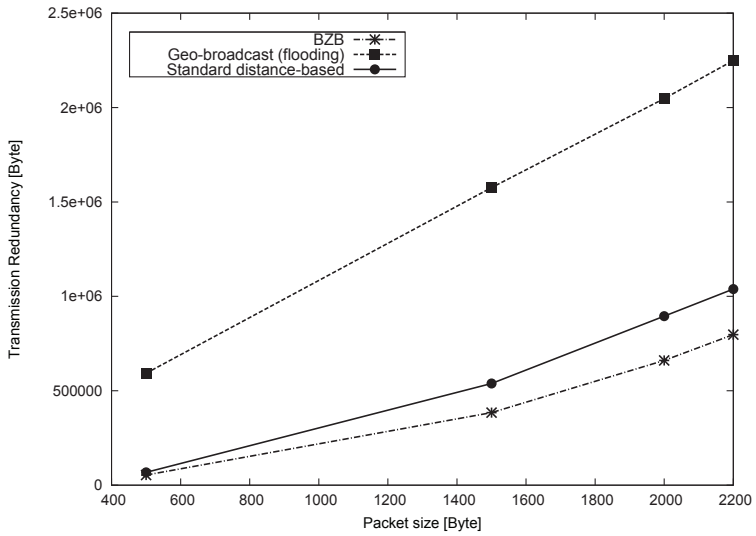


Figure A.6: La variation du facteur de la redondance de transmission dans le cas de *BZB*, du flooding et du standard CBF basé sur la distance en fonction de la taille de paquet.

localisation. D'autre part, les changements dynamiques de la mobilité des véhicules sont un problème supplémentaire à prendre en compte.
L'objectif principal de cette section est d'analyser la relation entre d'un côté l'information d'awareness et d'un autre côté l'aptitude des mécanismes de diffusion d'assurer une transmission fiable et précise des informations de sécurité routière. En particulier, on s'intèresse à l'impact de cette imprécision sur le comportement et la performance de *BZB*. En particulier, l'imprécision des données d'awareness pourrait entrainer des problèmes liés à la diffusion ou à la détection de l'événement de sécurité de la part de l'application:

Génération de *" fausses alarmes"*: Le premier aspect important est associé particulièrement à la détection des situations d'urgence au niveau applicatif. Des données de positionnement imprécises pourraient conduire potentiellement à une fausse détection d'une collision entre deux véhicules et en conséquence l'émission d'une fausse alarme, comme illustré dans la figure A.7. Les relais à la réception ne peuvent pas distinguer cela et vont retransmettre à leur tours des informations erronées.

Détection multiple du même événement de sécurité: Un scénario qui pourrait se produire aussi bien, c'est quand plusieurs nœuds détectent la même situation d'urgence et, par conséquent, déclenchent plusieurs alertes redondantes. Comme décrit dans Figure A.8, noeud (A) et (B) déclenchent deux messages différents qui contiennent des informations du même événement perçu. Le nœud relais à la réception les deux messages et enverra deux messages séparément mais redondants.

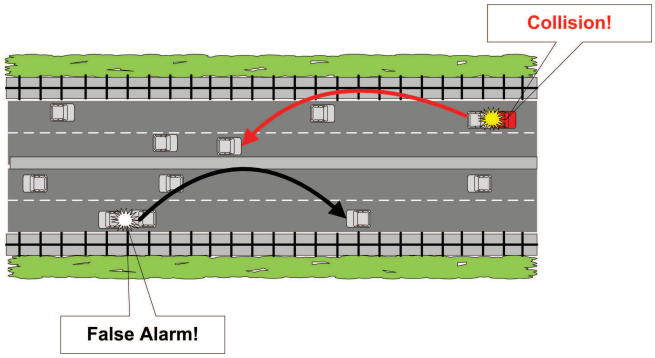


Figure A.7: Une illustration d'un scénario où une fausse alarme est déclenchée lors d'une estimation erronée des informations de positionnement. Une autre collision réelle s'est produite et en conséquence une transmission est déclenchée.

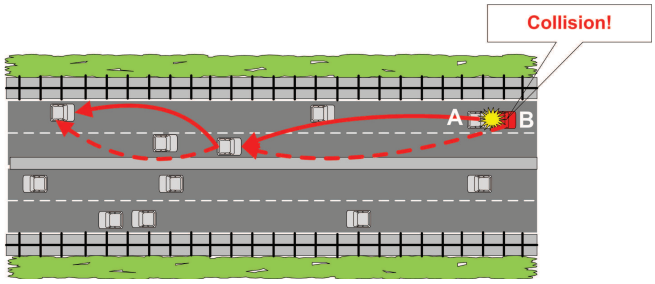


Figure A.8: Une illustration d'un scénario où deux noeuds (A et B) détectent le même événement d'urgence et envoient des paquets différents.

Nous avons mené une étude de simulation pour étudier spécifiquement les effets de la détection inexacte d'événements de sécurité sur la performance de *BZB*. Deux scénarios ont été envisagés, la mono-détection et les détections multiples. Dans le deuxième scénario, quatre sources différentes (ou nœuds) ont été utilisés pour déclencher la transmission d'informations de sécurité, un est considérée comme réelle et trois comme fausses alarmes (ou alertes redondantes).

Figure A.9 représente la redondance de transmission qu'on a mesurée. La surcharge du réseau dans le cas du scénario de multiples détections est très importante par rapport à la mono-détection. Elle correspond à quasiment plus du double en cas de paquet de 2200 octets, ce qui représente une charge supplémentaire et inutile générée dans le réseau. De manière analogue, dans Figure A.10, on peut constater que lorsque l'on augmente le nombre de transmissions redondantes ou de fausses alertes, *BZB* ne respecte pas les exigences des applications STI de sécurité en matière de délai de réactivité. Dans le meilleur des cas, jusqu'à 90% des récepteurs reçoivent correctement le paquet dans plus de 50 ms.

Les résultats obtenus révèlent l'impact important de l'imprécision de l'information d'awareness sur l'efficacité de la procédure de diffusion des informations événementielles. Une détection précise d'une situation d'urgence dépend d'une perception

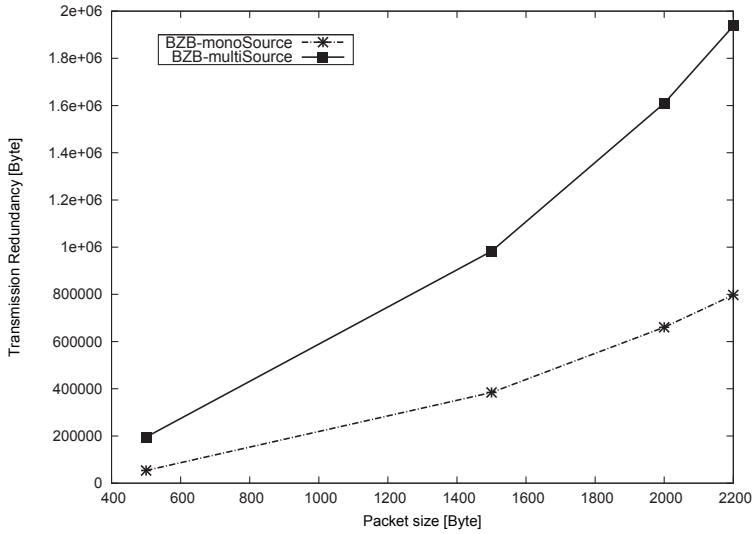


Figure A.9: La variation du facteur de la redondance de transmission de *BZB* en fonction de la taille de paquets dans le cas du scénario de multiples détections.

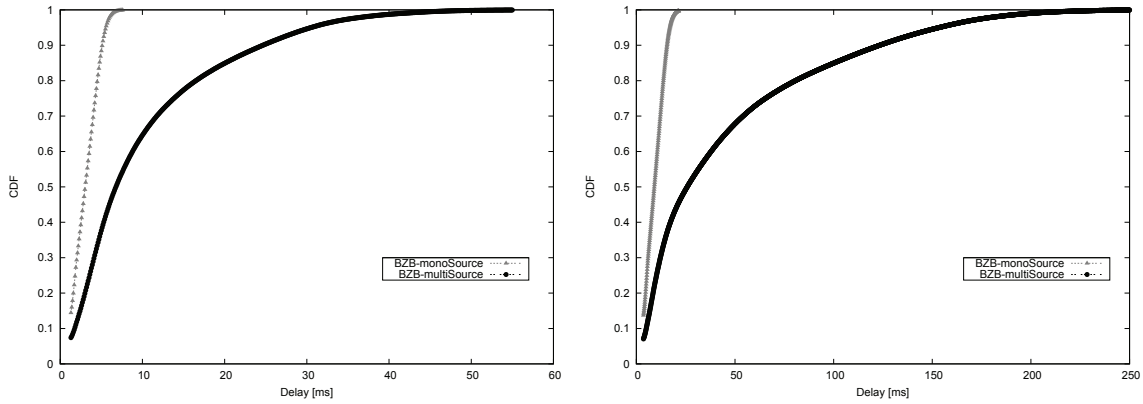


Figure A.10: Le CDF de *BZB* dans le cas du scénario de multiples détections. (a) Taille de paquet 500 octets. (b) Taille de paquet 2200 octets.

exacte du contexte global. Nous pensons qu'il est nécessaire d'étudier davantage ce sujet afin d'assurer la précision de la perception globale (ou " awareness") des véhicules requise par les applications de sécurité routière.

A.4 Contrôler la précision de l'awareness

Comme démontré dans la section précédente, les protocoles de diffusion d'événements de sécurité ainsi que les applications coopératives de sécurité exigent fortement une haute précision de la perception globale. Par exemple, en cas d'application de

l'évitement des collisions, les données géographiques exactes de chaque véhicule et de son voisinage doivent être fournies afin d'évaluer efficacement le risque de collision avec des véhicules potentiels. Cependant, les signaux GPS et les communications sans fil sont connus pour être peu fiables et incertains. En effet, les pertes de paquets dues au fading et aux interférences peuvent se produire fréquemment, et les signaux GPS peuvent être reçus avec des erreurs importantes.
Dans de tels cas, l'extrapolation en utilisant la prédiction de mobilité représente une solution possible afin de récupérer les données de localisation perdues ou bien non fiables.
La prédiction de mobilité a été largement étudiée dans les dernières décennies et plusieurs approches de prédiction ont été proposées. Les filtres Bayésiens notamment les filtres de Kalman (KF) [68] et les filtres particulaires (PF) [99] sont les plus connus. La limitation de ces approches est le fait qu'elles sont basées sur une mise à jour fiable et constante des données de localisation, soit en provenance du GPS, soit à partir des CAMs et DENMs. En outre, ils sont basés sur les hypothèses que la future mobilité ne varie pas trop par rapport aux positions précédentes ainsi que les erreurs de positionnement sont Gaussien et non corrélées. Toutefois, les caractéristiques non fiables du canal sans fil, ainsi que les changements brusques du mouvement qu'on trouve habituellement dans la mobilité véhiculaire, entraîne une déviation importante des filtres de la position réelle. En observant que la mobilité véhiculaire est régie conjointement par les lois physiques et sociales, par exemple la formation des groupes (ou clusters) sur la route en raison des besoins et des comportements sociaux, et présente des comportements comparables aux comportements des essaims, on propose de considérer l'intelligence artificielle des essaims pour améliorer les algorithmes de prédiction afin d'optimiser la précision d'awareness.

A.4.1 Glow-worm Swarm Filter: GSF

Nous proposons dans cette section un mécanisme nouveau de contrôle pour optimiser la précision de l'awareness. Nous nous intéressons principalement à l'awareness fourni par les CAMs. Notre approche appelée Glow-worm Swarm Filter (GSF) est un filtre particulaire (PF) à base d'essaims qui est basé sur de multiples hypothèses de prédiction. La solution proposée est de considérer non seulement un seul emplacement futur potentiel, mais aussi d'envisager divers autres emplacements potentiels ce qui permettra une modélisation de la perte éventuelle de signaux GPS ou des paquets ainsi que les changements imprévisibles du mouvement. L'algorithme Glow-worm Swarm Optimisation (GSO)S a été utilisé afin de trouver des multiples optimums locaux et à grouper l'espace de recherche en différentes hypothèses multiples. Cela pourrait implicitement améliorer la fonctionnalité du filtre particulaire en augmentant la diversité de particules et d'éviter le problème de la dégénérescence (voir Figure A.11). Figure A.12 représente un scénario de prédiction appliquant GSF, les particules sont divisés en trois groupes, une hypothèse majeure et deux hypothèses mineures. Compte tenu de ces différentes hypothèses, le filtre, par conséquent, est capable de gérer la perte de l'awareness et de maintenir efficacement le

processus de prédiction.

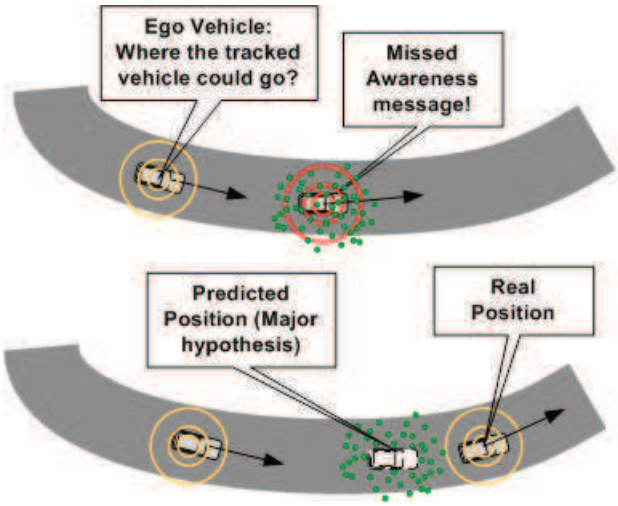


Figure A.11: Une illustration d'un scénario de prédiction où les points illustrent les particules générées par le standard PF. Après avoir perdu l'information d'awareness ce qui engendre une dégénérescence des particules, PF ne peut plus prédire correctement la mobilité réelle.

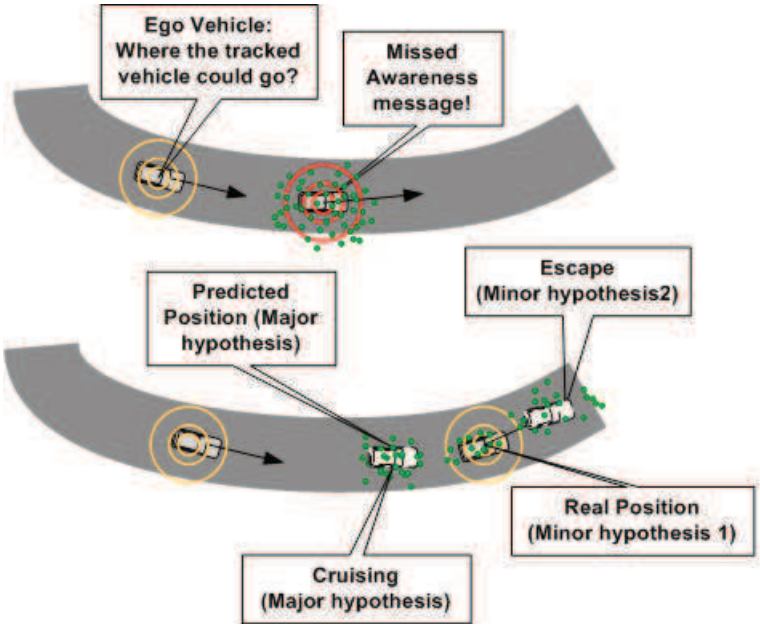


Figure A.12: Une illustration d'un scénario de prédiction. Les points de la figure représentent les particules correspondant à l'estimation de la position du véhicule. La position du véhicule poursuivi est estimée par GSF à être dans l'hypothèse mineure. Compte tenu des pertes inattendues des messages, GSF est en mesure d'assurer des bonnes performances de prédiction.

Artificial Urban	**10**	**100**	**500**
Erreur GSF [m]	1.53	1.49	1.55
Erreur PF [m]	2.73	2.44	2.24
Erreur Absolue [m]	1.2	0.95	0.69
Gain %	44%	39%	31%

Table A.1: L'erreur de prédiction de GSF et du standard PF dans le cas du scénario urbain artificiel considérant 10, 100 and 500 particules.

iTETRIS Urban	**10**	**100**	**500**
Erreur GSF [m]	1.36	1.31	1.27
Erreur PF [m]	2.42	1.79	1.69
Erreur Absolue [m]	1.06	0.48	0.32
Gain %	44%	27%	25%

Table A.2: L'erreur de prédiction de GSF et du standard PF dans le cas du scénario urbain iTETRIS considérant 10, 100 and 500 particules.

A.4.2 Évaluation des performances de GSF

En utilisant iTetris [11] et des scénarios réalistes et calibrés, nous démontrons que GSF est adapté aux conditions du canal sans fil ainsi qu'aux changements imprévus de la mobilité véhiculaire, offrant des meilleurs résultats de prédiction avec un faible nombre de particules par rapport au standard filtre particulaire. Ainsi, GSF assure un compromis entre la précision de la prédiction et la convergence rapide de l'exécution. Notre algorithme donne de meilleurs résultats d'estimation de position avec une erreur en dessous de 1,3 m dans le cas du scénario urbain iTetris. Cependant, dans le cas du standard filtre particulaire PF, la meilleure performance dépasse le 1,65 m d'erreur de position. Une amélioration de l'erreur de prédiction de 44% est assurée par GSF comparant à PF en cas de nombre de particules de 10 dans les deux scénarios artificiel et iTETRIS.

Afin d'évaluer la performance en temps réel des algorithmes de prédiction, le temps d'exécution a été mesuré pour différents nombres de particules. Tableau A.3 illustre le temps d'exécution réel en secondes de 100s de simulation en utilisant ns-3. L'algorithme standard PF assure le plus faible temps d'exécution par rapport à GSF pour les différents scénarios ce qui est dû au calcul supplémentaire que notre algorithme introduit. Toutefois, afin de respecter les exigences en temps réel des applications de sécurité des STI et en même temps préserver un haut niveau de précision, un compromis entre la convergence rapide et la précision doit être pris en compte ce qui est assuré par notre approche GSF pour 10 particules comme le

montre le Tableau A.3.

Urban	**10**	**100**	**500**
GSF [s]	1.3	33.7	934.6
PF [s]	0.6	8.2	158.2
Gain [s]	0.7	25.5	776.4

Table A.3: Temps de convergence de GSF comparé au standard PF dans le cas du scénario urbain artificiel pour 10, 100 and 500 particules.

Nous considérons également l'évaluation de l'effet de la perte de messages sur les performances des algorithmes de prédiction. D'après le tableau A.4, on constate que dans tous les cas l'erreur de la position devient de plus en plus importante lorsque le nombre de perte des paquets augmente. L'erreur ne dépasse pas environ 2,5 m en appliquant GSF mais elle va jusqu'à 4,7 m dans le cas du PF standard. En effet, les particules du PF perdent leur pertinence. Cependant, dans le cas de GSF ils sont dispersés dans toutes les directions possibles afin d'optimiser l'espace de recherche. Le tableau montre comment l'erreur augmente de plus de 70% pour PF (1,99 m). Toutefois, en cas de GSF l'augmentation ne dépasse pas 63 % (0,97 m). Pour un et 2 pertes d'awareness, l'erreur de PF standard augmente de 18% et 56% respectivement, ce qui est plus ou moins le double par rapport à l'erreur de GSF (10% et 22% respectivement).
Afin d'évaluer l'impact de l'amélioration de la précision de l'awareness sur la détection des événements de sécurité, nous proposons d'appliquer notre concept à multiples hypothèses (GSF) et évaluer son efficacité à éviter les fausses alertes.

A.4.3 Détection des fausses alarmes

Dans cette section, nous examinons la performance de notre approche GSF à détecter correctement l'événement d'urgence entre deux véhicules et de limiter les fausses alarmes. Nous considérons un scénario d'urgence de freinage où deux véhicules se suivent sur la même voie d'une route. Le véhicule en avant décélère brusquement

Urban Scenario	**No Loss**	**1 Loss**	**2 Loss**	**3 Loss**
GSF	1.53	1.69	1.88	2.50
PF	2.73	3.23	4.26	4.72
Erreur absolue [m] (GSF/SIR-PF)	-/-	0.16/0.5	0.35/1.53	0.97/1.99
Gain % (GSF/SIR-PF)	-/-	10%/18%	22%/56%	63%/72%

Table A.4: Impact des pertes de paquets sur l'erreur de prédiction de GSF et du standard PF dans le cas du scénario urbain pour 10 particules.

plusieurs fois. Le véhicule en avant est appelé le véhicule ego le véhicule derrière est appelé véhicule cible. Le taux de fausses alarmes (False Alarm Rate (FAR)) est utilisé comme la métrique de performance. La distance entre les deux véhicules a été mesurée pour évaluer la détection de l'alerte de sécurité. Une distance seuil de 8 m a été employée, au-dessous de cette valeur une alerte de sécurité doit être déclenchée.
Figure A.13 montre l'évolution de la distance entre les deux véhicules en fonction du temps de simulation. La distance réelle, les distances estimées par GSF et le standard PF sont tracées. Dans ce scénario, le véhicule ego effectue plusieurs décélérations brusques. À partir des courbes illustrées dans Figure A.13 nous pouvons en déduire que notre approche donne plus de précisions. L' approche standard PF ne parvient pas à détecter avec précision l'événement de freinage. On peut remarquer que PF donne parfois de fausses alarmes (deux exemples sont représentés sur la figure). Le moyen FAR pour le standard PF atteint facilement les 54%. Néanmoins, il est seulement de 2% dans le cas de notre approche GSF.

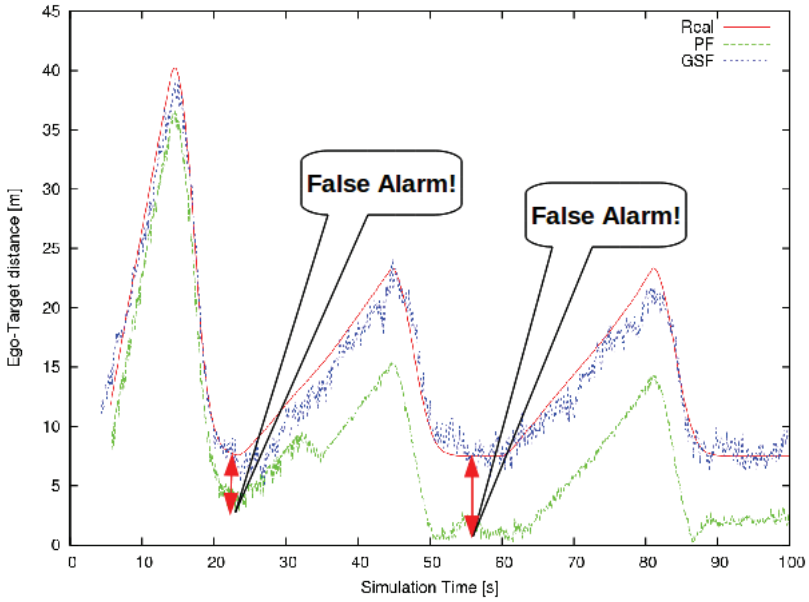


Figure A.13: La distance entre les deux vehicles en fonction du temps de simulation.

A.5 Contrôler le taux de transmission de l'awareness

Afin de limiter la congestion du réseau qui pourrait résulter des transmissions périodiques d'awareness, nous proposons une approche pour contrôler le taux de transmission d'awareness basée sur les multiples hypothèses. Cette approche bénéficie du fait que GSF peut s'adapter aux transmissions apériodiques. En effet, on propose de considérer, d'une part, la charge du canal, d'autre part de répondre aux

exigences des applications de sécurité routière. Le défi de ce système est d'assurer efficacement:

1. *Un contrôle de la congestion du canal sans fil et une réduction des émissions inutiles d'awareness.*

2. *Un contrôle des événements critiques et d'être capable de détecter les situations de sécurité routière imprévus.*

A.5.1 Contrôle du taux de transmission basé sur les multiples hypothèses

Le concept de base de notre approche est de permettre à tous les nœuds de prédire l'awareness de leur environnement. De plus, chaque véhicule doit prévoir sa propre position aussi afin d'évaluer la précision de la prédiction des autres. Les véhicules sont autorisés à communiquer et à envoyer leur awareness si et seulement s'ils perçoivent un écart critique par rapport à la position réelle et détectent le besoin des autres véhicules de l'information actuelle. Un flowchart de ce mécanisme est présenté dans Figure A.14.

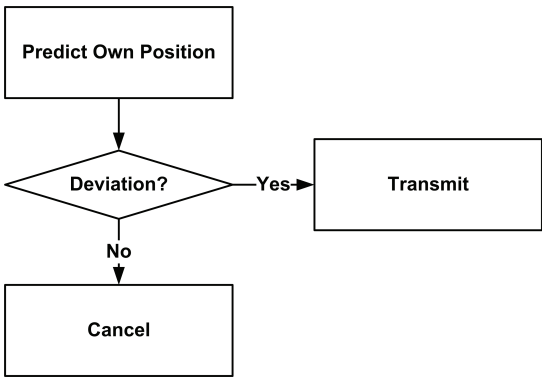


Figure A.14: Flowchart du contrôle du taux de transmission d'awareness basée sur la prédiction.

Cet aspect rend conceptuellement les transmissions périodiques d'awareness apériodiques. Toutefois, cela peut réduire la qualité et la précision de l'awareness ce qui n'est pas compatible avec les contraintes des applications de sécurité.
Le passage aux transmissions périodiques lors de la détection de scénarios critiques, pourrait être une solution. Le problème ici est que, dans des environnements dynamiques comme les STI, ces situations devraient être présentes souvent. Par exemple, en considérant le cas d'embouteillages, les véhicules accélèrent et décélèrent fréquemment, cependant, il n'est pas nécessaire de transmettre l'information d'awareness à chaque accélération ou décélération. Cela pourrait conduire à une surcharge inutile du canal de communication. Une détection efficace du contexte est donc nécessaire afin de distinguer entre les situations de sécurité réellement critiques et les fausses alarmes.

L'idée est de fournir des hypothèses alternatives et de transmettre l'awareness que lorsque la position future n'existe pas dans aucune des différentes hypothèses de notre système. En outre, la transmission est déclenchée uniquement lorsque l'une des hypothèses détecte un événement de sécurité qui dépend de l'application. Nous évaluons l'efficacité de notre mécanisme de contrôle de détecter des situations de sécurité.

A.5.2 Évaluation des performances de notre mécanisme

Dans cette section, nous évaluons la performance de notre système de contrôle de l'awareness basé sur GSF et le comparons avec un système de contrôle basé sur le standard PF. Tout d'abord, sous des contraintes de sécurité, nous examinons la performance de notre approche pour détecter les événements critiques de sécurité dans le contexte d'un scénario de freinage. Ensuite, nous étudions l'efficacité de notre approche dans la réduction de la congestion du canal tenant compte des scénarios denses (zones urbaines et autoroutes).

A.5.2.1 Détection des situations de sécurité

Figure A.15 trace l'évolution de la vitesse d'un scénario de freinage. Le nombre de transmissions de GSF et du standard PF sont illustrés. On peut déduire de ce résultat que l'approche de transmission basée sur le standard PF est essentiellement périodique dans l'ensemble du scénario ce qui est dû à l'augmentation de l'erreur accumulée sur l'estimation de la position. Toutefois, avant la décélération GSF est apériodique en raison de sa capacité à suivre et bien prédire l'awareness. Puis, lorsque le véhicule commence à ralentir GSF détecte ce changement de contexte et reste apériodique même après la détection. On peut remarquer ici que GSF est capable de détecter un changement de contexte brutal. En outre, il est capable de réduire le nombre de transmissions lorsque cela n'est pas nécessaire, et également contribue à la réduction de la charge du canal.
Nous concluons, ici, que l'approche standard de PF, ne peut pas garantir une bonne prédiction et par conséquent une detection robuste des événements critiques. Cependant, GSF est capable de maintenir son apériodicité et en même temps de détecter le changement de contexte, mis à part le fait d'assurer une précision considérable de l'awareness.

A.5.2.2 Réduire la congestion du canal

Dans cette section, nous avons l'intention d'étudier la performance de notre approche de contrôle de taux de transmission d'awareness en termes de réduction de congestion de canal.
Les résultats de simulation dans le tableau A.5, prouvent que GSF contribue à réduire le taux de transmission d'awareness, seulement 4,68 transmissions sur 10 (en cas de transmission périodique) effectuées en 1 s. Plus de 50% de transmissions périodiques ont été supprimées par notre algorithme GSF, seulement 16 % dans le

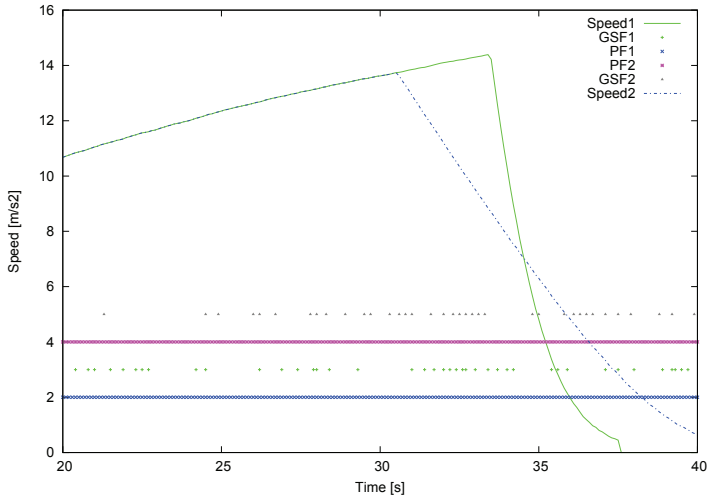


Figure A.15: La vitesse vs. le temps de simulation. L'impact de la décélération sur la performance du système de transmission d'awareness.

Transmit Rate	Scenario Urbain	Scenario Autoroute
GSF	4.68	5.92
PF	8.44	8.40
Gain %	45%	30%

Table A.5: Le taux de transmission dans le cas des scénarios urbain et autoroute.

cas du PF standard. On peut noter également l'amélioration apportée par notre mécanisme de contrôle basé sur GSF par rapport à celui basé sur PF, 45 % pour le scénario urbain et 30 % dans le cas de l'autoroute.

Figure A.16 trace la charge de canal des différents mécanismes, celui basé sur GSF, basé sur PF et la transmission périodique. La transmission périodique présente le taux le plus élevé de surcharge canal, plus de 80% de l'utilisation du canal peut conduire à un problème de congestion du réseau. Nous pouvons voir que GSF assure les meilleures performances en maintenant la charge de canal à moins de 15% ce qui correspond à l'état inactif (0% -15%). D'autre part, la charge de PF est supérieure à 15%.

Nous concluons que notre système de contrôle de transmission assure une gestion efficace de la congestion canal, en plus il permet de satisfaire les contraintes des applications de sécurité en matière de la détection efficace des événements critiques de sécurité.

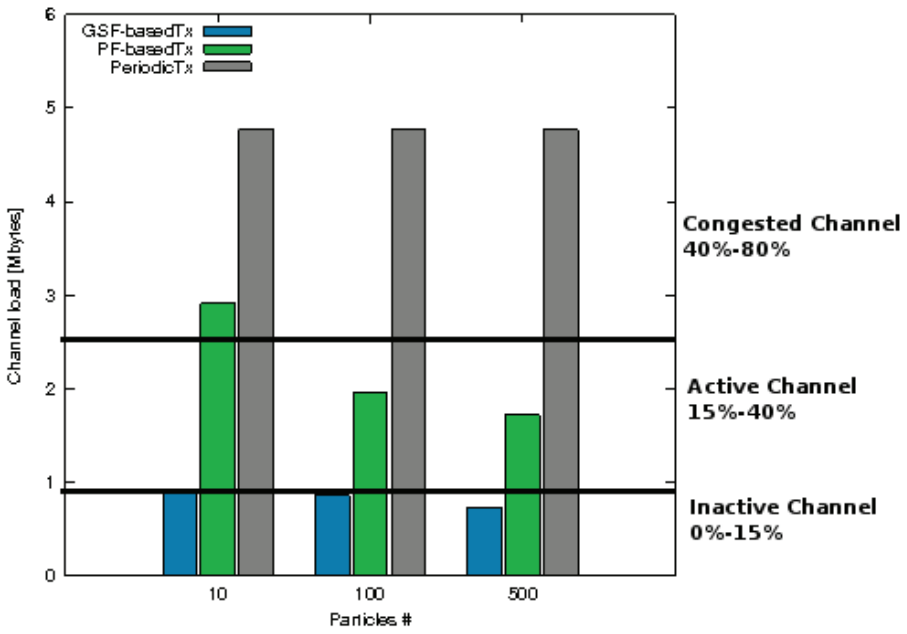


Figure A.16: Charge du canal vs. nombre de particules.

A.6 Design d'un framework générique pour les STI

Les résultats obtenus dans cette thèse ouvrent la voie à la conception d'un framework générique pour la gestion des informations de sécurité routière. Les mécanismes de contrôle conçus constituent la base de ce framework. Le concept principal est de rassembler tous les mécanismes de contrôle pertinents en un seul bloc garantissant les besoins et les exigences des différentes applications STI. Nous pensons que la couche (de l'architecture ETSI/ITS [40]) la plus adaptée pour regrouper ces mécanismes de contrôle est la couche Facilities car elle contrôle tous les données entrantes et sortantes des nœuds.

Par ailleurs, le système que nous proposons se compose de trois éléments constitutifs: un bloc dédié à la gestion d'awareness, un bloc de gestion du contexte global des véhicules et un bloc d'agrégation de données. Le bloc de gestion d'awareness est divisé en deux blocs: le contrôle de la précision de l'awareness et le contrôle du taux de son émission. Le premier fournit aux véhicules une grande précision de leur perception globale en utilisant un modèle de prédiction de mobilité spécifique. Le deuxième bloc est conçu pour contrôler la fréquence de transmission de l'information périodique d'awareness afin de contrôler la congestion du réseau. Le bloc de gestion du contexte globale permet la gestion de la pertinence de la transmission de données événementielles de sécurité. Le modèle de l'agrégation de données gère l'agrégation de l'information redondante et décide de la fusion potentielle d'informations.

A.7 Conclusion

Dans le cadre de ce travail, nous nous sommes intéressés au développement des mécanismes de contrôle de l'information de sécurité capables de réguler la détection et la diffusion d'événements de sécurité routière à différents niveaux ainsi qu'à optimiser les ressources de canal. Compte tenu de leur importance, nous avons abordé en premier lieu le contrôle de la diffusion des informations de sécurité événementielles afin de limiter le nombre de réémetteurs et donc, de réduire la "congestion" du canal.
Nous avons observé qu'un contrôle efficace de la diffusion des messages de sécurité dépend de différents aspects qui ne peuvent pas être contrôlés à ce niveau, à savoir la détection des événements de sécurité, la charge de canal, qui sont tous liés à l'awareness. En conséquence, nous avons proposé un mécanisme efficace de contrôle de précision de l'awareness. Une awareness plus précise est capable de fournir une meilleure détection des événements de sécurité. Nous avons enfin appliqué notre approche de contrôle d'awarenes pour réguler la charge sur le canal, en réduisant le taux de transmission de ces messages périodiques.
Les résultats obtenus dans cette thèse ouvrent la voie à davantage innovations et à la conception de nouvelles méthodes. Une amélioration de notre système de prédiction en utilisant par exemple la prédiction macroscopique afin de différencier les multiples hypothèses pourrait être envisagée afin de réduire davantage l'erreur de 'information d'awareness et obtenir des résultats inférieurs à ceux du GPS (1.5m). Par ailleurs, des efforts devraient être consacrés à l'évaluation de notre système de contrôle de transmission basé sur GSF. En outre, la conception du framework générique pour les applications de sécurité doit être étudiée davantage car il doit tenir en compte tous les aspects liés à la diversité des applications STI.

Appendix B
List of Publications

B.1 Journals

- Hrizi, Fatma; Härri, Jérôme; Bonnet, Christian "Adapting contention-based forwarding to urban vehicular topologies for traffic safety applications", Annals of Telecommunications, 2012.

B.2 Conferences and Workshops

- Hrizi, Fatma; Härri, Jérôme; Bonnet, Christian "Improving unreliable mobile GIS with swarm-based particle filters", MOBIGIS 2012, ACM SIGSPATIAL Workshop on Mobile Geographic Information Systems, November 6th 2012, Redondo Beach, CA, USA.

- Hrizi, Fatma; Härri, Jérôme; Bonnet, Christian "Can mobility predictions be compatible with cooperative active safety for VANET?", VANET 2012, 9th ACM International Workshop on VehiculAr Inter-NETworking, Systems, and Applications, in conjunction with ACM MobiSys 2012, June 25, 2012, Low Wood Bay, Lake District, United Kingdom.

- Wetterwald, Michelle; Hrizi, Fatma; Cataldi, Pasquale "Cross-layer identities management in ITS stations", ITST 2010, 10th IEEE International Conference on ITS Telecommunications, November 9-11, Kyoto, Japan.

- Hrizi, Fatma; Filali, Fethi "SimITS : An integrated and realistic simulation platform for vehicular networks", IWCMC 2010, 6th ACM International Wireless Communications and Mobile Computing Conference - Vehicular Communication Technology Symposium, June 28-July 2, 2010, Caen, France.

- Kumar, Vineet ; Lin, Lan; Krajzewicz, Daniel; Hrizi, Fatma; Martinez, Oscar; Sempere, Gozalvez; Manuel, Javier; Bauza, Ramon "iTETRIS : adaptation of ITS technologies for large scale integrated simulation", WIVEC 2010, 3rd IEEE International Symposium on Wireless Vehicular Communications, 16-17 May 2010, Taipei, Taiwan.

- Hrizi, Fatma; Filali, Fethi "An integrated and realistic simulation platform for vehicular networks", SIMUTools 2010, 3rd International ICST Conference on Simulation Tools and Techniques, March 15-19, 2010, Torremolinos, Malaga, Spain.

- Rondinone, M; Lazaro, O;Michelacci, C;Krajzewicz, D; Blokpoel, R; Maneros, J;Lin, L; Hrizi, Fatma; Leguay, L. "Investigating the efficiency of ITS cooperative systems for a better use of urban transport infrastructures : The iTETRIS simulation platform", POLIS Conference 2009, December 10-11, 2009, Brussels, Belgium.

- Hrizi, Fatma;Filali, Fethi "Achieving broadcasting efficiency in V2X networks with a simple distance-based protocol", COMNET 2009, 1st International Conference on Communications and Networking, November, 3-6, 2009, Hammamet, Tunisia.

- Hrizi, Fatma;Filali, Fethi "On congestion-aware broadcasting in V2X networks", Nets4Cars 2009 : International Workshop on Communication Technologies for Vehicles, October, 13-14, 2009, Saint-Petersburg, Russia.

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