N° d'ordre : .../2016

REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
Université des Sciences et de la Technologie Houari Boumediene
Faculte d'Electronique et Informatique

THÈSE

Présentée pour l'obtention du diplôme de

DOCTORAT

En : INFORMATIQUE
Spécialité : Programmation et Systèmes

par

Zouina DOUKHA

Intitulée

VANETs: Les réseaux inter véhiculaires

Soutenue le 27/06/2016, devant le Jury composé de :

Prof. Nadjib BADACHE	USTHB	Président
Prof. Samira MOUSSAOUI	USTHB	Directrice de thèse
Prof. Mohamed AISSANI	EMP	Examinateur
Prof. Nasreddine LAGRAA	UATL	Examinateur
DR. Nadia NOUALI	CERIST	Examinatrice
Dr. Fayçal BOUYAKOUB	USTHB	Examinateur

Résumé

La sécurité routière est une préoccupation majeure des autorités à travers le monde. Elle requiert des mesures strictes en termes d´ infrastructures routières, de qualité des véhicules et du respect du code de la route. Malgré les efforts déployés en vue de diminuer les accidents de la route, ils continuent à cueillir des centaines de milliers de morts et de blessés au niveau mondial. Les réseaux véhiculaires possèdent un potentiel important pouvant réduire considérablement les dangers de la route voir les éliminer. Dans ce contexte, la dissémination est un outil indispensable pour propager en temps réel des informations utiles sur le trafic routier. Ce travail couvre deux types de dissémination: la dissémination d'alertes et le beaconing. L'objectif de la dissémination d'alertes est de propager des messages urgents, générés suite à un constat de danger potentiel, à travers un ensemble de véhicules roulant dans la direction du danger. Dans ce contexte, notre contribution consiste en une étude détaillée des techniques proposées dans la littérature dans laquelle nous avons mis l'accent sur les difficultés de réaliser un compromis entre les éxigences d'une telle application en termes d'efficacité et de délais réduits et l'environnement sévère tant du point de vue du site de déploiement que de la technologie de communication offerte. Ainsi, à l'issue de cette étude, une classification des différents protocoles de dissémination d'alerte est proposée ainsi que trois protocoles UUB, UB et DGcast.
Comme nous l'avons déjà mentionné, le beaconing constitue la seconde partie de notre travail. Le beaconing est une technique utilisée dans les systèmes sans fil pour collecter des informations sur le voisinage. C'est un service de couche liaison et consiste en un échange périodique de messages courts appelés beacons, contenant des informations d'état (position, vitesse, direction, etc.). L'information ainsi disséminée, permet à chaque nœud (véhicule) d'être avisé de l'éxistence de ses voisins et de leurs status, ce qui lui permet aussi de construire une carte de topologie de son environnement. Ces informations de position peuvent être exploitées par les couches supérieures, notamment par les applications de sécurité routière, dans le transfert des données. Parallèlement, le beaconing est largement proposé comme un outil pour la prévention contre les accidents en fournissant des informations temps réel sur l'état de la conduite des véhicules voisins. A travers notre étude, nous avons proposé une classification des solutions existantes et nous avons proposé une stratégie de découverte de voisinage où l'envoi des beacons dépend de la localisation géographique des nœuds. L'approche que nous proposons est basée sur la segmentation de la route en segments égaux et sur la synchronisation des transmissions des beacons. Le principe de base de ce protocole est que si deux nœuds transmettent leurs beacons simultanément, ils doivent être suffisamment loin l'un de l'autre. Ainsi, les collisions ne peuvent pas se produire puisque les émetteurs issus de segments différents sont suffisamment éloignés les uns des autres. Le protocole proposé améliore le standard en termes d'efficacité en consommation de la bande passante, de pourcentage de reconnaissance des noeuds voisins et de pertinence de l'information.

Acknowledgement

I am grateful to the Almighty Allah SWT for giving me the faith, the courage and the patience to achieve this work.

I feel very lucky to collaborate with many brilliant researchers and students and learn from them. These wonderful colleagues have contributed and continue to contribute to my research accomplishments and academic career. I am deeply grateful to all of them.

I would express my deep gratitude to the experts Professor Mohamed AISSANI and Dr. Fayçal BOUYAKOUB for their kind willingness to review and evaluate this work.

I am very much honored by Professor Nadjib BADACHE for agreeing to chair the thesis committee.

My thank you is owed to the committee members Professor Mohamed AISSANI, Dr. Fayçal BOUYAKOUB, Dr. Nadia NOUALI and Professor Nasreddine LAGRAA for their efforts in reviewing and criticizing this work to improve it.

A special thank you goes to my supervisor Professor Samira MOUSSAOUI for her confidence and her invaluable support, guidance, and encouragement throughout these years.

I am deeply grateful to my family: my mother for her priers, my brothers and sister for their faith in me and encouragement, my husband and daughters for their help and patience.

I am grateful to many of my friends for their constant support.

Contents

List of Figures

List of Algorithms

Chapter 1

Introduction

1.1 Introduction

Vehicular ad hoc networks (VANETs) constitute the basic infrastructure for Intelligent Transportation Systems (ITS), where safety applications are the core component. These applications are diverse; they vary according to the type of communication: vehicle to vehicle (V2V), vehicle to infrastructure (V2I) or hybrid, and the goal: Is it a simple information pulling, in order to regulate road traffic, or a danger warning? In the latter, is the warning sent to get cars out of the danger zone and keep conductors aware or is it requiring a particular action to avoid casualty? In this work, we deal with safety issue and, principally, with dissemination and beaconing in V2V environment. So, in this first chapter, we situate the context of our work through an overview given in section 1.2. We present the addressed problematic and highlight our motivation and contribution in section 1.3 and, in section 1.4, we give the thesis organization.

1.2 Overview

The beginning of the twenty first century witnessed an extraordinary revolution in computer networks. This is especially the case for emerging wireless technologies that aim to extend communication capabilities to environments where their presence can create new kinds of networks, such as cellular networks, Mobile ad hoc NETworks (MANETs), Wireless Sensor Networks (WSNs), Wireless Mesh Networks (WMN), etc. Vehicular Ad hoc NETworks (VANETs), one promising form of this extension, support road infrastructure that becomes a geographical space hosting moving vehicles that can exchange data in order to widen the drivers visibility of their environment for a safe, beneficial, and enjoyable travel experience. VANETs are considered to be a particular type of Mobile Ad hoc NETwork (MANET) in the sense that nodes self-configure themselves and do not need a fixed infrastructure or centralized administration to communicate; they share common radio frequencies (Industrial, Scientific and Medical (ISM) radio bands) over which a distributed medium access control (MAC) protocol manages access to the medium. However, VANETs have several distinguishing characteristics. Nodes, which are vehicles in VANETs, are highly mobile; this causes some physical phenomena, such as the Doppler effect and multipath fading, which increases the distortion of a radio frequency signal as the mobility and presence of buildings, trees, and pedestrians increases as well [4]. The high mobility is also likely to engender network partitions that cause connectivity losses. A VANET can extend to a very large scale. Let us consider a section of road with two lanes: assuming that vehicles move with the velocity of 90 km/h, the minimum inter-vehicular distance of 50 meters, and a communication range of 300 m, there are about 24 vehicles traveling in a given vehicle vicinity. In contrast, during a traffic jam, with a minimum safety distance of 3 m, there can be up to 400 vehicles in the same vehicle vicinity. The movement of vehicles is relatively predictable because it is constrained by roads, signposts, and obstacles like buildings, which leads to a linear distribution of vehicles within the road. Architecturally, each vehicle is equipped with a wireless device known as an On-Board Unit (OBU) that allows it to communicate with other vehicles as well as with roadside units (RSUs). RSUs are located in some critical sections of the road infrastructure, such as traffic lights or road signs, and can be used as access points to provide a connection to a backbone network that offers several services, such as traffic management and Internet access. Currently, vehicle manufacturers provide their vehicles with driving assistance features, such as positioning services and itinerary computation, which are enabled by embedded devices such as Global Positioning System (GPS) receivers and electronic road maps enable. Furthermore, they use sensor technology to enhance the options inside the vehicle, such as position measurement and Electronic Stability Control (ESC), which improves vehicles stability by detecting and reducing loss of traction. In fact, several technologies, such as cellular, Bluetooth, Ultra Wide Band (UWB) [5][6][7][8], can be envisioned for VANETs, and a useful comparison can be found in [9]. Dedicated Short Range Communications/Wireless Access in Vehicular Environments (DSRC/WAVE) [10], however, is the preferred technology for VANETs due to its suitability and low device costs [11]. Yet, there is no real deployment of VANETs in term of communication between vehicles, except for experimental projects. Given that, road accidents are major cause of death across the world [12], VANETS can play an important role in improving driving conditions by providing safety applications as shown in Table 1.1. The many commercial applications that are possible, namely traffic management, user infotainment services, local news delivery and advertisement, and Internet connectivity, are projected to be the most important sources of revenue for companies. Over the last several years, a number of research projects and consortia have been created to realize the vision of communicating vehicles. In past projects such as Demo [13], JARI [14], FleetNet [15], and CarTALK [16], researchers investigated the feasibility of wireless communication between vehicles. In more recent VANET projects, such as NetworkOnWheels [17], the European SafeSpot project[18], CVIS [19], and Coopers [20], the industrials and academia developed and integrated applications to enhance and consolidate previous projects. The latest projects, such as the Car-to-Car Communications Consortium (C2C-CC) [21] and Vehicle Infrastructure Integration (VII) (recently renamed IntelliDrive) [22], have started the process of standardizing systems and protocols. In the future, more efforts should be made to improve VANETs technology and deployment in real life to enhance road users safety, reduce fuel consumption and pollution, and continue to advance the economy of nations.

1.2.1 Standards and Technologies

VANETs are based on short-range wireless transmissions. In 1999, the United State Federal Communications Commission (FCC) allocated 75 MHz of spectrum between 5.580 and 5.925 GHz for Dedicated Short Range Communication (DSRC) for exclusive use of V2V and V2I communications for both safety and non-safety applications [23]. As shown in Figure 1.1, the DSRC spectrum is divided into seven 10MHz channels, and 5MHz are reserved as the guard band. The central channel (Channel 178) is the Control

Table 1.1: Overview of Safety applications [2]

Safety applications	**Application examples**
Collision Avoidance	Intersection collision warning, obstacle detection, lane change assistance, lane departure warning, rollover warning, road departure warning, forward collision warning, and rear impact warning.
Driver Assistance	Navigation/Route guidance, driver communication, vision enhancement, object detection, adaptive cruise control, intelligent speed control, lane management, roll stability control, drowsy driver warning system, precision docking, coupling-decoupling, and on-board monitoring.
Collision Notification	Mayday/ACN (Automatic Collision Notification).
Arterial/Freeway Management	Surveillance, traffic control, lane management, information dissemination, and enforcement.
Crash Prevention & Safety	Road geometry warning, highway-rail crossing warning systems, intersection collision warnings.
Road Weather Management	Surveillance, monitoring & prediction, information dissemination advisory strategies, traffic control strategies, and response & treatment strategies.
Roadway Operations & Maintenance	Information dissemination, asset management,and work zone management.
Transit Management	Operations & fleet management, information dissemination, transportation demand management, and safety & security.
Traffic Incident Management	Surveillance & detection, mobilization & response, information dissemination, and clearance & recovery.
Emergency Management	Hazardous materials management, emergency medical services, and response & recovery.
Traveler Information	Pre-trip information and in-route information.

CHannel (CCH) which is generally restricted to safety communications only. Channel 172 and Channel 184 are reserved for future advanced accident avoidance applications

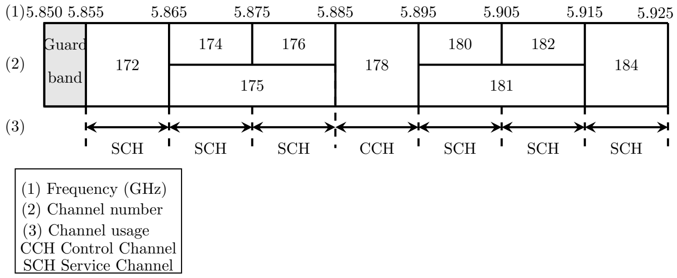
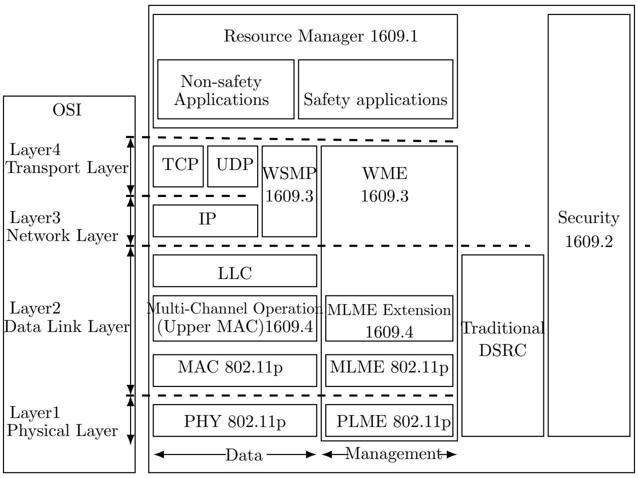


Figure 1.1: The DSRC frequency allocation in US [1]



OSI	Open System Interconnection	**WSMP**	Wave Short Message Protocol
TCP	Transmission Control Protocol	**WME**	Wave Management Entity
UDP	User Datagram Protocol	**MLME**	Mac Layer Management Entity
IP	Internet Protocol	**PLME**	Physical Layer Management Entity
LLC	Logical Link Control	**PHY**	PHYsical layer

Figure 1.2: IEEE VANET standards [1]

and high-power public safety communication. Other channels are service channels and are available for both safety and non-safety applications [23]. Using the 10 MHz channel allows for data communication rates of 3, 4, 5, 6, 9, 12, 18, 24, and 27 Mbps while the optional 20 MHz channels (Channel 175 and Channel 181) allow for up to 54 Mbps. The DSRC specifications [23] were intended to extend the IEEE 802.11 [24] technology into the outdoor high-speed vehicle (up to 200 kmh) and deal with rapid multipath fading and different environments (rural, highway, and urban). The physical layer (PHY) of DSRC is an adapted version of IEEE 802.11a PHY, which is based on orthogonal frequency division multiplex (OFDM) technology, and the MAC layer is similar to the IEEE 802.11 MAC, which is based on the carrier sense multiple access with collision avoidance (CSMA/CA) protocol with minor changes. The IEEE 802.11 working group adopted DSRC as 802.11P [10], and it is also kept the MAC and PHY layer of the IEEE P1609 standard family (the IEEE standard for wireless access in a vehicular environment (WAVE)). The stack structure of the IEEE P1609 (WAVE) is shown in Figure 1.2. This figure illustrates that 802.11p operates below several management protocols in charge of resource management, network services, channel selection, and security. The specifications IEEE802.11P and IEEE1609 define represent the most complete set of standards for DSRC/WAVE networks. As the Resource Manager for WAVE, IEEE P1609.1 [25] defines the services and interfaces of the WAVE resource manager application and describes the message data format. IEEE P1609.2 [26] defines security services for Applications and Management Messages, including formatting and processing secure messages. IEEE P1609.3 [27] defines Networking Services such as routing and transport services, and provides an alternative to IPv6. It also defines the management information base for the protocol stack. IEEE P1609.4 [28] deals mainly with Multi-Channel Operations.

1.2.2 Intelligent transportation Systems

Intelligent Transportation Systems (ITS) refer to advanced applications applied to road transportation. ITS provide innovative services to improve the safety, security, and efficiency of transport systems. The expected impact of ITS is traffic congestion alleviation, collision avoidance, and improvement of transport management in support of public safety requirements. As shown in Figure 1.3 [2], the US Department of Transportation proposed an architecture to realize the vision of a connected transportation environment. The main components of this architecture are travelers, control centers, intelligent vehicles, and field infrastructure; the whole architecture is composed of 22 subsystems. The communication level identifies four major types of communication: fixed-point to fixed-point, wide area wireless, field to vehicle (DSRC), and vehicle to vehicle communications. The ITS applications can be categorized based on interface classes as shown in Table 1.2 [2]. It is important to note that only applications based on an approved or published ITS standard are included in Table 1.1. According to this table, safety applications retain the most important ITS components.

1.2.3 VANETs safety applications

According to the International Traffic Safety Data and Analysis Group (known as the IRTAD Group) [29], traffic fatalities have decreased in the last decade across the world due to the safety measures many nations have adopted recently. In the US, traffic fatalities declined steadily since reaching a near-term peak in 2005, and the reduction accelerated between 2008 and 2010. However, the reported road fatalities and injury crashes remain very high since a single accident is too many. In the US, 32.885 road fatalities and 1.546.000 injury crashes were reported in 2010. In 2012, the US experienced the first increase in fatalities since 2005, and from 2011 to 2012 there was a 3.3 per cent increase [29]. We believe that improving road safety should not only focus on saving lives and reducing the burden road injuries place on public health services, but also on tackling problems such as time wasted in traffic jams, fuel consumption, and exhaust gas pollution while increasing nations´ economy. It is worth noting that human behavior (drunk-driving, speeding, and failure to wear seat belts) is one of the most significant causes of road casualties. Given the

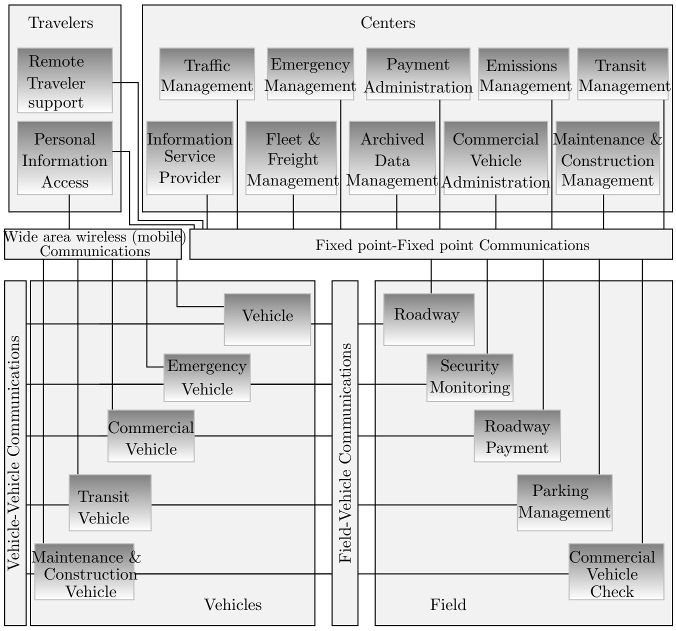


Figure 1.3: ITS architecture [2]

Table 1.2: ITS Applications [2]

ITS Architecture Interface Class	**Application Areas**
Center to Center - This class of application areas includes interfaces between transportation management centers.	Data Archiving Incident Management Rail Coordination Traffic Management Transit Management Traveler Information
Center to Field - This class of application areas includes interfaces between a management center and its field equipment (e.g., traffic monitoring, traffic control, environmental monitoring, driver information, security monitoring, and lighting control).	Data CollectionMonitoring Dynamic Message Signs Environmental Monitoring Lighting Management Traffic Metering Traffic Signals Vehicle Sensors Video Surveillance
Center to VehicleTraveler - This class of application areas includes interfaces between a center and the devices drivers or travelers use. It includes interfaces with travelers for exchanging traveler and emergency information as well as interfaces between management centers and fleet vehicles to support vehicle fleet management.	Mayday Transit Vehicle Communications Traveler Information
Field to Field - This class of application areas includes interfaces between field equipment, such as between wayside equipment and signal equipment at a highway rail intersection.	Highway Rail Intersection (HRI)
Field to Vehicle - This class of application areas includes wireless communication interfaces between field equipment and vehicles on the road.	Probe Surveillance Signal PriorityPreemption Toll/Fee Collection Vehicle Safety
Vehicle to Vehicle (On Board and Vehicle Coord) - This class of application areas includes communications links between devices on-board a vehicle as well as direct wireless communications links between vehicles.	Vehicle Safety

pervasiveness and low cost of wireless technologies, safety applications over VANETs have the potential to make roads safer by providing pertinent and timely information about road conditions, such as distant hazards or traffic congestion. The environments in which safety applications are the most beneficial are listed below.

- **Accidents** The high speed of vehicles does not allow drivers to react in a timely manner when approaching a dangerous area, which may cause a traffic jam. Receiving an alert early could help drivers to prevent or react to abnormal vehicle behavior to avoid an accident or experience it with minimal damage.

- **Intersections** Intersections, which merge traffic flows from multiple in/outgoing roads, can foster collisions. Safety applications can be used to warn drivers of an intersections status and to regulate the traffic flow.

- **Road Congestion** Traffic jams are sources of many problems: wasted time, unnecessary fuel consumption, pollution, etc. Thus, safety applications could be used to guide drivers by providing better routes to their destinations and a means for traffic regulation.

- **Drivers´ misbehavior** Humans are a common cause of road casualties due to their non-compliance with traffic rules. Intelligent vehicles can mitigate this potential safety hazard in several ways. Providing drivers with notifications of unfastened seat belts may ensure that they wear them more frequently. It is also possible for a safety application to alert other drivers and authorities rapidly of abnormal driving, as in the case of drunk driving.

- **Weather conditions** Weather data monitoring systems are designed to monitor current meteorological conditions. The information is then used to forecast inclement weather. The systems enable network managers to act promptly, informing drivers of possible bad weather and initiating appropriate winter maintenance or emergency procedures.

- **Natural disaster** When earthquakes, tsunamis, etc. occur, it is likely that the communication infrastructure will be damaged and out of service. Vehicles in good condition can form an ad hoc network to provide information about the risk zones and rescue operations. In this case, the concept of 'hovering information' can be useful to manage the rescue operations locally [30]. Hovering information is generally adequate for many applications in Vehicular Ad Hoc Networks, especially where information needs to be kept on hand within a specific geographical area for an interval of time.

In this context, the international community has put forth great efforts to lead innovative projects to reduce or eliminate crashes and to provide the best tools for road management [2]. Proposed applications in the area of safety, as shown in Table 1.1, can be deployed in V2V communication as well as V2I. To realize these ambitious applications, the key technique of dissemination is used to propagate pertinent information in real time: "Data dissemination is commonly defined as the spreading of information to multiple destinations through broadcasting. The main objective is to reach the maximum number of neighbors with every sent packet. In this communication scheme, no routing is required thus neither routing tables nor end-to-end paths are maintained" [31]. Since safety applications are delay sensitive, the broadcast paradigm is widely used to cover all the interested parties.

1.3 Motivation and contribution of this study

As aforementioned, road safety is the core component of ITS and dissemination is a key tool that keeps drivers aware of their environment in order to assist and allow them to take relevant decisions based on pertinent and timely fresh information. It can mean the difference between life and death. Indeed, a driver who is constantly aware of road dangers and the general state of traffic is more likely to be a conscientious and skilled driver. The main goal of safety dissemination is to distribute road-state information between vehicles, to notify them of conditions such as jams and blocked streets. The core technique relies on the design of a broadcast scheme that is mainly concerned with timely and reliable information delivery. Two scenarios can be applied according to the context: V2I/I2V or V2V communication. V2I/I2V safety dissemination can be useful for announcing general information about traffic, including bad weather, work zones, and hazards. The scenarios are mainly centralized [32][33]. According to the push model, vehicles pass their information to the RSU. The backbone network processes the collected information from the RSUs and periodically broadcasts it to passing vehicles. The strength of this scheme is the high availability of pertinent information. However, all vehicles are not necessarily interested in the information. One idea is to adopt a request-response model known as the pull model, but this may lead to cross traffic that may result in congestion. V2I communication can also be used for accident avoidance in intersections and road segments containing certain conditions that might lead to an accident. Examples of such conditions include speeding drivers, drivers who run red lights or stop signs, pedestrians, work zones, etc. Detailed analyses of pre-crash scenarios can be found in [34]. In these scenarios, V2I safety can be enhanced through connectivity that enables the exchange of information between vehicles and infrastructure and between infrastructure components. When receiving alerts, vehicles generate an alarm to signalize drivers that they need to take immediate action to avoid an imminent crash. On the basis of the available information, various operations, such as statistics and traffic regulation, may also help to enhance road conditions. In V2V schemes, the communication system is distributed. V2V can help both to prevent imminent accidents [35][36][37] and to notify vehicles traveling towards dangerous areas about the danger several kilometers sooner to give drivers enough time to take an alternative route. In one scheme, vehicles periodically broadcast their statuses to be aware about their surroundings [38]. This passive dissemination, commonly called beaconing, increases the load on the network. In contrast, only risky incidents are disseminated in the reactive scheme. The multi-hop broadcast technique is used to disseminate this time-sensitive safety information. The simplest strategy, known as flooding or blind forwarding [39], involves rebroadcasting a vehicle´ s message once it is received. This strategy is rarely beneficial since it causes congestion [40]. Two of the main issues many multi-hop broadcast protocols have investigated are: How to decrease the number of nodes responsible for re-broadcasting (relay nodes)? and how to select those nodes in such a way to ensure the timely propagation of the message to all vehicles in a given region called *zone of relevance*?. Hybrid dissemination [41][42] makes use of both V2V and V2I modes to increase reliability. With this vision, our study focuses on safety dissemination protocols in V2V environments. In fact, our contribution is twofold:

- **alert dissemination.** The goal of alert dissemination is to spread urgent information, generated in reaction to a sensed danger, within a set of vehicles that are running towards the danger. Accordingly, we studied dissemination techniques in the literature. Since multi-hop broadcast is the main technique used to disseminate the alert, we proposed a classification based on the way relay nodes are selected for multi-hop message forwarding. Consequently, we proposed two dissemination protocols. The first protocol aim is to enhance the reliability of multi-hop farwarding by joining two communication modes unicast and broadcast. The second protocol deals with redundancy. Thus, we propose to add a filter module as a sub-layer above the MAC layer to discard unnecessary messages which are in general redundant messages. This first part of our study gave rise to these papers: [43] [44] [45] [46] [47].

- **beaconing.** The second contribution of our study deals with beaconing which is a link layer neighborhood discovery service. In addition, beaconing can serve to safety applications in providing topology information to the nodes and piggybacking additional information to ensure its reception. Besides, since beacons are sent periodically, beaconing is widely proposed as a tool for accident avoidance by providing status information about vehicles such as abnormal driving. Through this thesis, we studied several papers in the literature and proposed a classification of beaconing strategies. Most of the proposed strategies propose adaptive solutions to decrease the channel load regarding the network parameters such as density and emergency of the situation. Based on our observation, we noticed that adaptive approach may decrease the channel load but, fails in message collision avoidance and lacks in providing accurate neighborhood information. We think that scheduling approach may improve these aspects and when joined to the adaptive approach the performances can be improved in term of channel load as well. So, based on Space Division Multiple Access technique (SDMA), we proposed a strategy for beaconing. Thus, the road is segmented into several portions (segments) of 2*R long, where R is the transmission range, and the beacon sending is organized so that in each segment beacons are sent sequentially, knowing that the parallel transmission occurs only between nodes located in different segments. This strategy not only avoids collisions but allows the netwok to rise to scale. This work gave rise to these papers: [48] [49].

Furthermore, since simulation is the main tool that researchers use to evaluate the performances of their protocols, making it realistic is a fundamental issue. Indeed, the more the simulation is realistic, the more research results are reliable and accurate. In this context, we studied the existing simulation tools and we discussed new perspectives in [50].

1.4 Thesis Organization

This work is split into two principle parts: The first part deals with alert dissemination as a safety application; the second part focuses on beaconing as challenging link layer service. Thus, the organization of this thesis is as follows: Chapter 2 covers the dissemination problematic and presents different solutions proposed in the literature. Our own observations and a thorough review of related literature leads us to identify a number of challenging aspect related to broadcast and multi-hop which are the key techniques used for information propagation. we also propose a classification based on the criterion of selection of relay nodes. In Chapter 3, we present our solutions regarding alert dissemination in VANETs. In our first contribution, we deal with congestion and reliability. Thus, congestion is decreased by avoiding broadcast transmissions at each hop and reliability is decreased by the use of unicast mode. In fact, this solution proposes to alternatively use unicast and broadcast modes. Consequently, two protocols are involved: UB and UUB protocols. In these protocols, we tried to get benefice from the reliability of unicast mode and the ability of broadcast to cover a large area. In our second contribution we principally deal with redundancy. In this work, we propose a filter module on top of MAC layer that permits to eliminate unnecessary redundant packets.

In the second part this work, we detail in chapter 4 a state of the art of beaconing in the literature. In this study, we conclude that adaptive beaconing is largely investigated and the proposed solutions in the literature outperform the standard beaconing proposed in [10]. However, collisions are not avoided due to the randomness of beacons transmission over the network. This leads us to focus more on scheduling solutions such as TDMA and SDMA which are widely investigated for Channel access control. Unfortunately, to the best of our knowledge, these approaches are not applied for beaconing. This observation leads us to propose a scheduling approach based on SDMA technique. So, in chapter 5, we present our first contribution regarding beaconing. In this work, we organize beacon sending so that all vehicles in the same transmission range send their packets sequencially, while nodes sufficiently far from each other can send simulataneously their packets. This is made possible thanks to segmentation and synchronization techniques that are proposed. An extension of this work is also proposed in this chapter as our second contribution. In the latter, we propose a load balancing technique to enhance the network performances. Finally, we conclude this work in chapter 6 by summarizing the main contributions of this thesis and give recommandations for potential future work directions.

Chapter 2

Study of alert dissemination in VANETs

2.1 Introduction

Road safety over VANETs is a promising field, that standard organizations, researchers in academia, industry and the government sector are expanding through their remarkable efforts. Dissemination is an important part of vehicular safety applications; it is used as a tool to keep conductors aware of traffic conditions and to allow them to make pertinent decisions for a safe and enjoyable route. We present a survey of alert message dissemination techniques for safety applications in Vehicular Ad Hoc NETworks (VANETs). We focus on forwarding and recovery techniques, and we introduce the hovering concept, which can be useful for safety applications. We review issues related to the disseminating safety messages in a VANET environment, and we classify proposed protocols that deal with such issues. We discuss each class of protocols with respect to its strengths and weaknesses.

2.2 Challenges of dissemination in VANETS

In VANETs, embedded devices provide vehicles with high calculating, memorizing, and sensing capabilities in addition to an unlimited energy source, which the vehicles´ batteries guarantee. This is a noteworthy advantage for VANETs compared to other wireless networks like MANETs and WSN. However, many challenges must be considered when designing a dissemination protocol. While the challenges relate to many facets of VANETs, we review the most critcal challenges in the following section.

- **Heterogeneous environment** Given that VANET environments can vary significantly in their characteristics, they can have a considerable influence on vehicles´ behavior and their geographic distribution [51][52]. A high density of vehicles, especially during rush hours, characterizes the urban environment. Some popular destinations, such as supermarkets, can also increase the density of vehicles. Like density, speed is also dependent on the travel environment. Since highways are built for rapid travel between towns, the high speed of vehicles most characterizes this environment. As the density is relatively low compared to urban area, network partitioning is likely to occur. In other vast spaces, like deserts, the main challenge is connectivity between vehicles. Intersections are challenging component of road infrastructures too; depending on the type of intersection, vehicles will behave in different, albeit predictable, ways. For example, vehicles will behave differently in an intersection with a traffic circle compared to a three-way intersection. Intersections can be seen as large spaces that dynamically regroup a large number of ingoing and outgoing vehicles with a specific distribution.

- **Mobility/connectivity** In comparison to MANETs, VANETs have a highly dynamic topology. Nevertheless, mobility is predictable due to road infrastructure and traffic rules. For example, given two vehicles, V1 and V2, that are traveling in the same direction with a constant speed, S1 and S2, respectively, the maximum communication duration between the two vehicles $TMax$ is given by the following formula:

  $$TMax = \frac{2R}{|S_2 - S_1|} \tag{2.1}$$

  Where R is the transmission range. So, with R=300 m, S1= 90 km/h, and S2 = 70 km/h, TMAx = 1.8mn. On the other hand, given two vehicles traveling in opposite directions with the same values of constant speed, the connectivity is available only for 13.5 s, according to the following formula.

  $$TMax = \frac{2R}{|S_1 + S_2|} \tag{2.2}$$

  This statement emphasizes the instability of the connectivity between vehicles. Even though the signal propagation is much faster than the vehicles´ movement, the impact of mobility on the communication efficiency is important in the microsecond range [53]. In reality, vehicles´ velocities are variable; their variation is a random parameter that depends on the maximum authorized speed, traffic density, drivers will. Outdoor experiments for VANETs are difficult and expensive to conduct; thus, researchers resort to simulation tools. The main problem with these tools is that achieving realism is difficult. Several mobility models for VANETs have been proposed [54] and have influenced protocol designs [53][55],

- **Network Partitioning** Partitioning can be fatal for a dissemination process that aims to cover a given region. Thus, recovery mechanisms should disseminate information to different partitions in a timely manner.

- **Scalability** Scalability can be defined as the ability to maintain an acceptable level of performance while adding nodes in a network [56]. This characteristic is crucial and difficult to achieve since the number of nodes impacts network connectivity and the occurrence of channel congestion. The actual Medium Access Control (MAC) Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is not suitable for wide scale vehicular networks and requires some modifications [57][58].

- **Signal distortion and packet loss** The wireless and mobile nature of VANETs may cause perturbation of the links´ physical properties, thereby resulting in packet loss [1],

- **Quality of service requirement** Safety dissemination protocols must ensure real-time coverage. For example, in the case of abnormal vehicle behavior, such as a sudden application of brakes, the surrounding vehicles should be made aware of the behavior immediately to help their drivers avoid a car crash [59].

2.3 Message dissemination techniques

Dissemination is one of the most important tools in ITS. It can mean the difference between life and death. Indeed, a driver who is constantly aware of road dangers and the general state of traffic is more likely to be a conscientious and skilled driver. The main goal of safety dissemination is to distribute road-state information between vehicles to notify them of conditions such as jams and blocked streets. The core technique relies on the design of a broadcast scheme that is mainly concerned with timely and reliable information delivery. Two scenarios can be applied according to the context: V2I or V2V communication. V2I safety dissemination can be useful for announcing general information about traffic, including bad weather, work zones, and hazards. The scenarios are mainly centralized [32][33]. According to the push model, vehicles pass their information to the RSU. The backbone network processes the collected information from the RSUs and periodically broadcasts it to passing vehicles. The strength of this scheme is the high availability of pertinent information. However, all vehicles are not necessarily interested in the information. One idea is to adopt a request-response model known as the pull model, but this may lead to cross traffic that may result in congestion. V2I communication can also be used for accident avoidance in intersections and road segments containing certain conditions that might lead to an accident. Examples of such conditions include speeding drivers, drivers who run red lights or stop signs, pedestrians, work zones, etc. Detailed analyses of pre-crash scenarios can be found in [34]. In these scenarios, V2I safety can be enhanced through connectivity that enables the exchange of information between vehicles and infrastructure and between infrastructure components. When receiving alerts, vehicles generate an alarm to signalize the drivers that they need to take immediate action to avoid an imminent crash. On the basis of the available information, various operations, such as statistics and traffic regulation, may also help to enhance road conditions. In V2V schemes, the communication system is distributed. V2V can help both to prevent imminent accidents [35][36][37] and to notify vehicles traveling towards dangerous areas about the danger several kilometers sooner to give drivers enough time to take an alternative route. In one scheme, vehicles periodically broadcast their statuses to be aware of their surroundings [38]. This passive dissemination increases the load on the network. In contrast, only risky incidents are disseminated in the reactive scheme. The multi-hop broadcast technique is used to disseminate this time-sensitive safety information. The simplest strategy, known as flooding or blind forwarding [39], involves rebroadcasting a vehicle´ s message once is received. This strategy is rarely beneficial since it causes congestion [40]. Two of the main issues that many multi-hop broadcast protocols have investigated are firstly, how to decrease the number of nodes responsible for re-broadcasting (relay nodes) and secondly, how to select those nodes in such a way to ensure the timely propagation of the message to all vehicles in a given region or *zone of relevance*. Hybrid dissemination [41][42] makes use of both V2V and V2I modes to increase reliability. In the following section, we focus on safety dissemination protocols in V2V environments, presenting the core techniques used in the protocols and providing a classification for them.

2.3.1 Parameters and Metrics

According to their importance for human life, safety applications can be grouped into two main classes: life-critical safety and announcement safety. The first class is related to a dangerous event, such as an accident or abnormal driving, that happened or may happen on the road. The goal of dissemination in this case is to prevent accidents or to avoid exacerbating them if they have already occurred. The second class is concerned with providing general information about traffic conditions, such as jams, work zones, and bad weather. The goal of dissemination in this class is to improve traffic flow. Both classes rely on dissemination, which is based on the broadcast paradigm, and have approximately the same requirements given their shared concern for safety[60]. The requirements are summarized in the following section.

- **Dissemination delay** Protocols must ensure relaying techniques that incur minimum delay dissemination. Furthermore, the high priority attributed to safety applications and media control access techniques may ensure no delayed channel access.
- **Packet-loss-tolerant dissemination** Packet loss can be fatal for the dissemination process. Protocols have to provide mechanisms to retrieve lost packets, such as acknowledgements.
- **Delay-sensitive dissemination** Due to the high speed of vehicles and resulting network partitioning, mechanisms should be in place to avoid information loss by sending message between the parts of the network, as in the carry and forward technique.
- **Effectiveness/reliability** Ideally, the dissemination message will reach all nodes in a given region.
- **Robustness** Given the unreliable wireless link, the dissemination process should recover lost packets and ensure the effectiveness of the relaying strategy.
- **Scalability** The dissemination protocol should cope with increasing traffic density, which is a source of performance degradation.
- **Efficiency** Multihop broadcasting with an omnidirectional antenna results in redundancy, which causes node saturation and increases the probability of collisions. There will be a trade-off between minimizing relaying nodes and achieving successful delivery to all nodes in the region.

According to the previously mentioned QoS requirements related to safety dissemination, we define the following metrics that show to what extent protocols´ performances meet these requirements.

- **Latency** Dissemination latency is the maximum time duration for delivering a message to intended receivers within a geographical area.
- **Delivery ratio** This metric defines the number of nodes that received the message out of the number of nodes in the network.
- **Speed** Speed is the number of informed nodes out of the number of nodes in the network depending on time. This metric measures the progression of the dissemination over time.
- **Overhead** Overhead indicates channel occupancy by determining the number of generated messages, including both the control and data packet overhead, during an interval of time.

- **Redundancy** A redundancy occurs when an informed node receives the same message again. This metric measures the number of redundant messages received.
- **Collision** Simulators generally provide information to measure the total number of collisions occurring during the dissemination process.

2.3.2 Broadcast problems

The main goal of safety dissemination is to cover a large area where vehicles are involved in the distribution of the information. Two important quality criteria for dissemination schemes are message delay and reliability. As we mentioned earlier, broadcast is mostly used in safety dissemination in both V2V and V2I scenarios. However, while broadcast may be the fastest way to send messages because it requires less access control, its reliability suffers for the same reason. Sending safety messages without using an access control mechanism may lead to the broadcast storm problem [40][61][3]. In spite of the WAVE standard efforts to meet the QoS requirements (high reliability, low latency) for safety applications, the use of broadcast, which suffers from unreliable wireless links, makes this goal difficult to achieve. The following points summarize the broadcast related problems especially when the number of vehicles grows.

- **No MAC-level recovery on broadcast frames.** In a broadcast situation, the sender has no way of knowing whether or not all nodes received the packet correctly because having each receiver send an acknowledgement (ACK) may lead to the implosion problem. Therefore, a sender never retransmits the packet in case of packet loss or errors.
- **Static Contention Window (CW) size.** The main technique used for congestion control relies on exponentially increasing the contention window (CW) size in case of transmission failure. Unlike unicast, which uses acknowledgements to ensure packet receipt, there is no failure detection in broadcast transmissions. Thus, the size of the CW never changes, which may result in severe collisions, especially in dense traffic. Furthermore, in IEEE802.11P, the initial value of the CW is 3 [62] for the highest priority application. When a node tries to access the medium and finds the channel busy, it chooses a random value in the interval [0,CW] and executes the backoff algorithm in which the value is decremented each time the channel is found idle until it reaches 0; then the node accesses the channel. If the random value is equal to CW and more than 3 nodes try to access the medium, more than one node will be accessing the channel simultaneously, which will result in collision.
- **Timeslot Boundary Synchronization Problem.** The authors in [3] describe one important issue called the Timeslot Boundary Synchronization Problem. This problem may occur when nodes rebroadcast the same message in the case of a multi-hop message or nodes reply to an announcement from the RSU; the near simultaneous message creation may lead to collision as shown in Figure 2.1.
- **No RTS/CTS/ACK (hidden node problem)** It is inconceivable to use Request to send/clear the (RTS/CTS) handshake and acknowledgement (ACK) mechanisms for broadcast because broadcast packets are meant to reach all nodes around the sender. Therefore, there is no channel reservation, which makes communication suffer from severe packet collisions in dense networks with congested channels. Also, there is no reception guarantee for broadcast. Currently, no mechanism dealing with unreliable links and hidden terminal problems in broadcast exists.

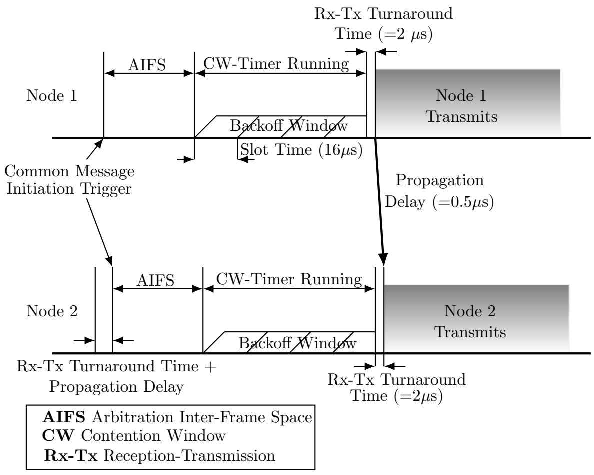


Figure 2.1: Timeslot Boundary Synchronization Problem due to near simultaneous message initiation [3]

2.4 Classification of V2V safety dissemination protocols

Most dissemination protocols rely on multi-hop broadcast forwarding. When a node holds information about a hazard that has occurred in some region, it is responsible for forwarding this information to all vehicles traveling towards the danger. Broadcast is used to cover the entire region in the sender´ s vicinity, and relaying allows the information to reach all the nodes outside of the vicinity within a geographical region known as *zone of relevance*. According to the method of selecting the relay nodes, we classify the dissemination protocols into 6 classes as shown in Figure 2.2. In the following section, we review the most popular protocols according to the class to which they belong.

2.4.1 Topology-based protocols

Topology-based protocols [63][45] rely on neighborhood knowledge. They use beacon messages to acquire information about the neighborhood, such as position, direction, and speed of neighboring vehicles. The main idea is that a sender will select the next relay in advance since it knows its neighbors´ positions. The sender selects its farthest neighbor as a relay node and sends a broadcast message that contains the identity of the relay. When receiving the message, the node that finds its identity enclosed in the message recognizes

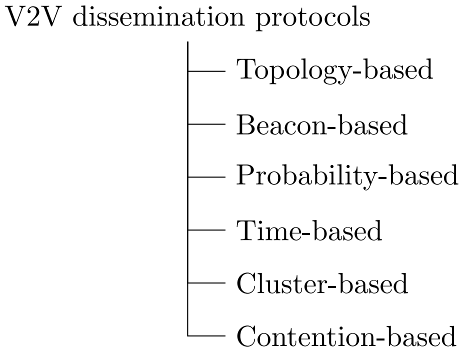


Figure 2.2: Classification of V2V safety dissemination protocols

itself as a relay node and repeats the process in order to forward the message. Nodes that receive the message but are not designated as the relay simply retain the message to stay informed. To the best of our knowledge, the first safety dissemination protocol [63] belongs to this class. The main goal of this protocol is to reduce the number of re-broadcasts to limit basic flooding, which causes congestion. In [45], the authors proposed a protocol that uses unicast and broadcast modes alternatively. The objective of this strategy is to enhance reliability and to ensure the message is forwarded throughout the zone of relevance. In [47], the authors deal with the redundancy problem. In their Directional Geocast warning dissemination protocol (DGcast), they propose a filter module that resides above the MAC layer that passes data to the application layer only when it is necessary. Thus, redundant messages are not processed but eliminated at the filter module. Topology based protocols generally suffer from two main disadvantages. The first one is the overhead that beacons cause; the second one is the lack of assurance that the farthest selected node can receive the message correctly and can re-broadcast it successfully since the medium is not reliable. One solution to this problem is the use of acknowledgements. In [45], when the current relay rebroadcasts the message, the previous relays receipt of this message is considered to be an implicit acknowledgement. If the acknowledgement does not arrive after a short time, the previous relay resends the message again. In [64], intermediate nodes that are not selected as relays keep an active role: they wait for a duration of time Tw given in Formula 2.3 and, while waiting, will discard the message if the message is received again from another forwarder farther than themselves. Otherwise, they consider themselves to be a relay and forward the message after the waiting time expires.

$$Tw = \left(1 - \frac{min(R_{RSS}, R_{max})}{R_{max}}\right)\left(\frac{\lambda_S}{\lambda_{Smax}}\right)\tau \tag{2.3}$$

The same idea is proposed in [65]. In this protocol, the portion of road in the sender´ s transmission range is divided into segments; vehicles located in the furthest non-empty segment contend for the duration of time depending on their contention window and check if the selected relay rebroadcasted the message. If not, they forward the message after executing the backoff algorithm to avoid congestion.

Discussion

Deterministic relay election does not consider the impact of mobility and signal distortion. Other techniques may recover after instances of packet loss, such as in [64][65]. However, techniques that rely on waiting times before forwarding may lead to increased latency and collisions. On the other hand, if the recovery technique fails, all the dissemination process stops, which is unacceptable in the case of an emergency.

2.4.2 Beacon-based protocols

Beacon-based protocols [66][67][68] take advantage of existing beacons by piggybacking the dissemination of packets on beacons frames. In [66], the authors investigated the feasibility of deploying safety applications based on beacon message dissemination through extensive simulations where vehicles were assumed to send beacons periodically to announce their current status to other vehicles and to use received messages to prevent possible unsafe situations. They defined a new metric known as effective range, which affects the reliability and thus the QoS of their approach. The authors concluded that there is a strong need to design an adaptive algorithm that controls the load of the channel by setting parameters dynamically. After running several simulations, the authors in [67] showed that performances, such as the forwarding delay and the packet reception probability, can differ under various conditions. For example, if the network load is less than the optimum, increasing the load will also increase the throughput; beyond this optimum, however, an increase of the load will result in a decrease of the throughput. In [68], the authors designed an experiment to measure the amount of stress on the medium when piggybacking application data onto scheduled beacons and compare it to the situation in which application data is forwarded independently of the beaconing process. In their approach, application data is piggybacked on top of the periodic beacon and sent with it without changing its timing. By having multiple nodes repeat the process, they can disseminate the data over the road. The authors argue that piggybacking application data onto beacons leads to a lower busy time on the medium in comparison to the separate dissemination of data where the nodes have to access the medium separately, which increases their chance of not accessing the channel. Consequently, nodes have to wait for an additional back-off period. According to the authors, this solution is expected to relieve the amount of stress on the medium.

Discussion

Using beacons to piggyback data merits additional investigation to determine its effectiveness and efficiency compared to other safety applications. It is likely that this technique will reduce the impact on the medium. However, from our point of view, piggybacking on beacons can cause the following problems.

- Delay of message receipt: delivery can be delayed because the message will wait to piggyback on the next scheduled beacon.
- Redundancy: a selective mechanism should cancel unnecessary piggybacking to avoid multiple nodes receiving the same information from several sources.
- Increased beacon frame size: beacon frame is specially designed as a Wireless Short Message (WSM) because short messages are likely to be successfully received and less exposed to collisions. Adding supplementary fields will extend the frame size.
- Collisions: this problem intrinsic to beacons can cause information loss.
- Increased network density: the density of the network can exacerbate all the previous problems.

Furthermore, we argue that even the concept of periodic beacons should be reconsidered because of the overhead that is generated [69].

2.4.3 Probabilistic protocols

In this section, we classify a protocol as probabilistic when probability is the basic criterion for electing a relay. In this class of protocols, every node rebroadcasts a message with a predetermined probability. When the probability is 100%, the technique is similar to simple flooding. In [70], the authors proposed the nth-powered p-persistent broadcast protocol (NPPB), which deals with collisions in dense VANETs. They try to decrease the number of rebroadcasting nodes on the border of the senders vicinity by using the probability given in Formula 2.4.

$$P_i = \left(\frac{L_{ij}}{R}\right)^n \times 100\% \tag{2.4}$$

Where, L_{ij} is the relative distance between the node i and the sender j of the message and the average transmission range is R, Pi denotes the probability of forwarding. In this scheme, Pi increases exponentially, making outer nodes concentrate toward the border of the sender´ s transmission range. The n value can be selected according to various densities. This can decrease the number of border rebroadcasting nodes, but uncontrolled multiple rebroadcasting can cause packet loss due to collisions. Some other protocols are also assumed to be probabilistic [71][72], but we classify them in the time-based protocols class because the criterion for selecting the relays is based on time rather than probability, which is used as a parameter in the waiting time formula.

Discussion

Probability-based protocols decrease the number of forwarding nodes, thereby decreasing contention and collision compared to simple flooding. However, multiple forwarding, which may increase the probability of forwarding, should be combined with a mechanism that avoids simultaneous forwarding.

2.4.4 Time-based protocols

Several protocols belonging to the time-base class have been proposed to alleviate the problem of simple flooding in broadcast. In this class, neighborhood knowledge is not required; the relay node is self-elected after receiving the safety message. All vehicles that have received the message start a waiting time phase before deciding whether or not to rebroadcast the message; the vehicle that waits the shortest duration considers itself to be a relay and decides to rebroadcast the message. The other nodes can hear the sent message while in their waiting time phase; they stop waiting when they conclude that some nodes are relaying the message. Since the goal is to reach all the nodes between the vehicle and the dangerous area, it seems reasonable to allow a node that can cover more new area to rebroadcast the message sooner than a node covering less new area; nevertheless, some protocols do not share this point of view. In this section, we present the most relevant techniques used for relaying transmissions. Table 2.1 lists the waiting time functions proposed in the related time-based protocols. In the Distance Defer Transmission (DDT) protocol [63], the waiting time is known as the defer time, and it is inversely proportional to the distance between the sender and the receiver so that border nodes retransmit earlier. During defer time, the receiver records the position of neighboring vehicles that retransmit the same message. This information is used to determine if its neighbors have covered most of its transmission area. If so, retransmission would be redundant so the receiver drops the message. If not, the receiver retransmits the message. Given the maximum n defer time slot and a uniform distribution of neighboring vehicles on the road, an average $\frac{1}{n}$ of the neighboring vehicles retransmit the message. The resulting multiple retransmissions may increase as the density increases and lead to overhead and congestion. The same idea with the main goal of making one relay node at each hop, which is considered sufficient, is discussed in [73][74][76][71][77][72]. While these protocols can be efficient in low density scenarios, they are at a disadvantage in terms of scalability because nodes waiting time values are highly correlated, retransmission can result in heavy contention known as the spatial broadcast storm problem [75]. In fact, the minimum difference between two calculated waiting times should be equal to the duration of one hop transmission, but this value will increase the dissemination delay. In [75], the authors experienced the spatial storm problem and proposed the Probabilistic Inter-Vehicle Geocast (P-IVG) protocol to address this problem as illustrated in Figure 2.3.

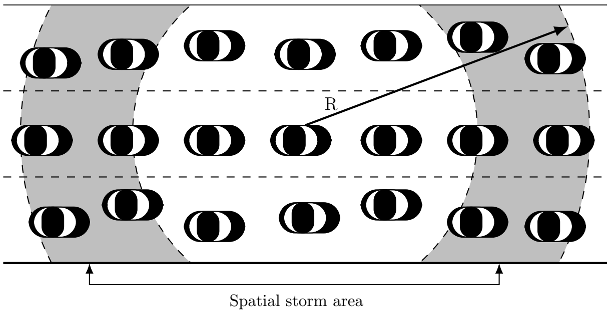


Figure 2.3: Multiple vehicles at the boundary can cause spatial broadcast storms

P-IVG proposes a probabilistic rebroadcasting technique based on the density of the surrounding vehicles. When receiving a frame, a vehicle first selects a random number in [0,1]. If the selected number is less than $\frac{1}{density}$, the timer is started with respect to the formula 2.5. If not, the vehicle will not re-broadcast the frame. As the density increases, the number of nodes that will start their timers decreases. Unfortunately, it is possible that no node will relay the transmission in this strategy. Furthermore, if the density surrounding the sender is low, the relay, which is likely to be in the region, will need to wait for a given time for no reason since waiting time depends on the relay´ s distance to the sender. Accordingly, a more suitable arrangement will use an appropriate transmission control set within nodes in the border. The protocol discussed in [78] addressed the signal attenuation problem at the border of the transmission range. The authors strategy is based on the fact that the farthest node from the sender is not necessarily the relay node. In [78], the dissemination message contains a stamp that gives a location 'Designated Position (DP)' on the road behind the sender where the signal is stable. A receiver calculates a waiting time commensurately with its distance to the DP point. Thus, the nearest node to the DP point is the next relay. In [79], the authors argue that relay nodes cannot be guaranteed to be at the border in the VANET in real scenarios unless the node density is very high. Calculating a waiting time inversely proportional to the distance between the sender and the receiver may result in too a large value if the relay is not at the border and leads to unnecessary increased waiting time. Thus, the overall dissemination delay is increased. Because a relay node can choose its waiting time in a given time window in the proposed Range-Based Relay node Selecting (RBRS) protocol, the relay will not necessarily be the furthest node. However, to equilibrate the distribution of time windows, near nodes have a wider range of waiting times than remote nodes. This lowers the possibility of near nodes selecting shorter waiting time. This strategy [78][79] can improve message reception, which can improve the dissemination reliability, but may also cause message redundancies. To alleviate the redundancy problem, some protocols [80] proposed the use of directional antennas. Directional antennas physically point in a certain direction with a small beam width that can achieve a longer transmission range and better Signal-to-Noise Ratio (SNR). Moreover, in warning applications, the message only needs to be sent backward to reach vehicles moving toward the danger. So, when a directional antenna is used for broadcasting, it can alleviate redundant transmissions by forwarding the message only in the direction of the dissemination. As shown in [81], in directional carrier sensing, there are more possible scenarios where a parallel signal transmission, which can cause collisions, may not be detected. Thus, the dissemination application needs to use explicit acknowledgment to notify the success of the transmission, which is unnecessary with omni-directional antennas. Since the acknowledgement requires the use of an additional transceiver to cover the opposite direction, coordination between antennas becomes necessary.

Discussion

Time-based protocols do not need neighborhood knowledge, which is provided by periodically sending short wave messages to advertise vehicles´ presence and status. This characteristic cannot be considered an advantage of the protocols since the beacon mechanism is independently active. The main advantage of these protocols is that they ensure at least one forwarding node exists in the senders´ vicinity. However, these protocols are not scalable because of the spatial storm problem stated in [75]. In the case of a sparse network, the best forwarder, in the sense of the shortest waiting time, can be close to the sender because of the probable absence of vehicles in the border of the senders´ vicinity; this situation can lead to wasteful waiting time.

2.4.5 Cluster-based protocols

In [82], the authors proposed a mechanism, known as the Directional Propagation Protocol (DPP),to disseminate information over the clustered network. Special nodes have the role of header and trailer: the header node is located at the front of a cluster, and the trailer node is located at rear of a cluster. The header and trailer are entrusted with the task of communicating with other clusters. The remaining nodes in the cluster are intermediate nodes, and they have a passive role. Messages originating from intermediate nodes are routed to header or trailer nodes according to the direction of the information propagation. DPP is composed of three components: a Custody Transfer Protocol (CTP), an Inter-Cluster Routing Protocol, and an Intra-Cluster Routing Protocol. The custody transfer mechanism is applied in case of network partitioning; the message is buffered for retransmission from the originating cluster until an acknowledgement is received from the next hop cluster. Inter-cluster communication ensures the information exchange between nodes within a cluster. The Intra-Cluster Routing Protocol governs the communication between clusters to achieve global forwarding. In this protocol, the authors do not discuss the cluster formation mechanism, cluster head election, or cluster maintenance. In [83], each cluster is composed of a cluster head (CH) that receives information from the cluster members and propagates it inside the cluster and a gateway (GW) that is responsible for forwarding the message to the next cluster and inside the current cluster after receiving the message from the previous gateway.

Discussion

Clustering is an important technique for imposing hierarchy and organization in a mobile ad hoc network. By helping to reduce complexity in the management of information about the mobile nodes, it simplifies some essential processes, such as routing and bandwidth allocation. In VANETs, the concept of clusters had been investigated with respect to both infrastructure-based applications and V2V applications. The main difficulty with cluster-based solutions is cluster formation and its maintenance in a distributed manner [84][85][86][87], especially in rapidly changing topologies that result in high delay and overhead. In cluster-based dissemination protocols, the network is represented as successive clusters formed by vehicle nodes that are reachable at one or more hops in diameter; a cluster head, which is selected among nodes (known as members) within a cluster, is responsible for forwarding messages over the clusters. This strategy is suitable when the topology of the network does not change quickly.

2.4.6 Contention-based protocols

The protocols that belong to this class adjust the MAC layer parameters. Some protocols proposed entirely at the MAC layer define access methods to make dissemination strategies more reliable since the broadcast problems affect dissemination performance [88][89] [90][91]. The proposal in [88], aims to reduce the latency and overhead of message broadcasting. The key idea is to assign different access priorities by assigning a different contention window value to the vehicles that are currently in charge of forwarding the message. A larger distance from the sender correlates to a smaller contention window. A vehicle cancels its rebroadcast attempt if it receives the same message from a vehicle ahead of it. The problem with this solution is the static contention window that leads to multiple broadcasts and causes overhead and collisions. One of the most important papers in this scheme is [89], which had been extended in [90]. The aim of this protocol is to maximize message forwarding, alleviate the broadcast storm, and prevent the hidden terminal problem in order to increase reliability. This protocol proposes a handshake sequence, known as Request-To-Broadcast (RTB)/Clear-To-Broadcast (CTB), that is similar to the Request-To-Send (RTS)/Clear-To-Send (CTS) sequence defined in IEEE 802.11. The RTB packet contains the position of the source node and the dissemination direction. When receiving the RTB packet, all nodes in the direction of dissemination transmit a jamming signal known as a black-burst with a length proportional to their distance from the source. Therefore, the furthest node sends the longest black-burst. After sending the black-burst, each node listens to the channel. If it finds the channel idle, it concludes that it is the furthest node from the source and is responsible for replying by sending a CTB packet to the source, defining itself as a relay. The source sends the message to the relay, which acknowledges it afterwards. This process is repeated all along the road. The proposed protocol in [91] also uses the RTB/CTB handshake but eliminates the black-burst signal. Its aim is to minimize the time needed to perform a hop. As in [88], the strategy is based on a contention mechanism to elect the next relay. The source node transmits a RequesttoBroadcast (RTB) control message. The RTB is a MAC-broadcast packet that contains the geographical position of the sender node and other control information, such as the sector width, message propagation direction, and contention window size CW. When receiving the RTB, the nodes behind the sender that are in the direction of dissemination determine the sector to which they belong by comparing their coordinates with those of the source. Sectors are numbered from $S1$ to SNs, starting from the furthest sector and moving to the closest one in the transmission range of the source node, where Ns is the total number of sectors. Each sector is associated with a contention window Wr of size CW: Wr=$(r1)cw, (r1)cw + 1, ..., rcw1$, $r = 1, 2, ..., NS$ .Thus, nodes randomly choose a backoff time in the contention window associated with the sector to which they belong. According to the CSMA/CA policy, when receiving the RTB control packet, nodes start decrementing their backoff counters at each idle slot. When a node reaches a zero value, it sends a Clear-to-Broadcast (CTB) packet with its ID and coordinates. Upon receiving a valid CTB packet, nodes cancel the contention phase. The source node transmits a MAC-broadcast frame that contains the next relay ID and the message after a Short Inter Frame Spacing (SIFS). Then, the relay node becomes a source node for the next contention phase. The procedure is then repeated all along the road. These protocols suffer from high delays since each relay node has to initiate a

Request-to-Broadcast (RTB) and Clear-to-Broadcast (CTB) handshake to select the next source node before sending the message.

Discussion

Contention-based protocols propose solutions at the MAC layer to alleviate broadcast unreliability. In adaptive contention window protocols [88], considering distance as the lone parameter is not enough; it may lead to the spatial storm problem in case of high density, thereby limiting the scalability of the network. Solutions that rely on the handshake sequence register high delays in message delivery. All these solutions do not discuss how the proposed mechanisms can be integrated with the existing MAC protocols.

2.5 Intersection as a special environment

Intersections are special part of road infrastructure where vehicles behave differently according to the type of intersection, such as intersections with traffic circles, three-way intersections, and even access roads. The rules regulating traffic, such as road priority and traffic lights, may also be different at intersections. Intersections can be seen as large spaces that dynamically regroup a large number of ingoing and outgoing vehicles with a specific distribution and predictable behavior. Few protocols considered intersections as a particular case that needs dedicated solutions. In [89], the solution relies on repeaters installed at the intersections to initiate directional broadcasts to all intersecting roads. When a relay node is inside the transmission range of the repeater at the next intersection, the node sends the packet to the repeater using the unicast mode with channel reservation (RTS/CTS/DATA/ACK). Then, the repeater forwards the message to all road directions except the direction from which it received the packet. In [90], a distributed and infrastructureless solution is proposed: the vehicle closest to the center of the intersection is seen as a good candidate for broadcasting the message because it has the best coverage of other road segments.

2.6 Summary of dissemination protocols

In the following we summarize the set of protocols presented in this study according to our classification. Table 2.2 provides an overview on contribution and weakness of each protocol regarding its class and Table 2.3 provides qualitative analysis of these protocols based on different parameters.

Table 2.1: Waiting time formulation

Acrn.	**WT formula**	**Parameters**
DDT[63]	Not provided	/
IVG[73] ODAM[74] P-IVG[75]	$$WT\left(x\right) = max\_WT.\frac{\left(R^{\epsilon} - D^{\epsilon}_{SX}\right)}{R^{\epsilon}} \quad (2.5)$$	ϵ: is a positive integer; ϵ=2 permits the generation of a uniform timer value between [0, max_WT], Dsx: is the distance between the sender (s) and the receiver (x), max_WT: is equal to twice the average of communication delay.
[76]	$$WT\left(d\right) = -\frac{MaxWT}{Range}.\widehat{d} + MaxWT \quad (2.6)$$ $$\widehat{d} = \min(d, Range)$$	$MaxWT$:maximum waiting time is equal to twice the transmission duration, d: is the distance between the sender and the current node (the receiver).
[71]	$$\Delta\left(t\right) = \Delta\left(t\right)_{max} \times \left(1 - \overline{\phi}\right) + \delta \quad (2.7)$$	δ:random value of order ms, ϕ:rebroadcast probability.
PAB[72]	$$t_{delay} = \frac{k_1}{d^2_{i,j}} + \left(-1\right)^m .k_2. \left\vert\overline{v_i}\right\vert \left\vert\overline{v_j}\right\vert \cos\theta_{i,j} \quad (2.8)$$	$k1$,$k2$:constants, m: m is even if the delivery direction is the opposite of the driving direction but odd if the delivery direction is the same as the driving direction, vi,vj:the velocities of the sender j and the receiver i, $Teta_{i,j}$: cosine value of angle between i and j.
Hi-CAST[77]	$$SWT\left(i, j\right) = \left(1 - \frac{S(j)}{n}\right) \times maxSWT \quad (2.9)$$	Transmission range is divided into the equally sized blocks called segments, $SWT(i, j)$: is..... $S(j)$:segment number through which destination vehicle j is traveling, n: the number of segments, $maxSWT$: represents the maximum segment waiting time.
SNB[78]	Not provided	/
RBRS[79]	$$RWT_i = \{T : T_{min} \leq T \leq T_{max}\} \quad (2.10)$$ where, $$T_{min} = RWT_{max} \times \left(1 - \frac{d_b}{R}\right)$$ and $$T_{max} = RWT_{max} \times \left(1 - \frac{d_i}{R}\right)$$	d_b: the distance of a border node from the previous relay node, d_i: the distance of the node from the previous relay node. R: is the transmission range. $RWTmax$: is the maximum waiting time.
EDB[80]	$$WT = \left(1 - \frac{D}{TR}\right) * maxWT \quad (2.11)$$	D : distance of the node to the sender, TR:the transmission range. $maxWT$: parameter that can be adjusted according to the network density.

Table 2.2: Summary of dissemination protocols

Ref	**Acron.**	**Year**	**Contribution**	**Weakness**
Topology-based protocols: the sender selects the relay.				
[63]	TRADE	2000	As one of the first solutions in this context, it has the merit of innovation.	Selecting one relay node may lead to packet loss due to unreliable links.
[45]	UUB	2012	Uses both unicast and broadcast messages. Increases reliability and coverage.	Overhead.
[64]	NTPP	2010	Uses time-based techniques to enhance reliability. Increase the probability of rebroadcasting.	Collisions due to multiple rebroadcasting. May increase latency.
[65]	CBB	2011	Uses contention-based techniques to enhance reliability. Increase the probability of rebroadcasting.	Collision due to contention techniques. May increase latency.
[47]	DGcast	2014	Proposes a filter module to avoid processing unnecessary data. Decreases redundancy.	No recovery technique in case of failure in reception at the elected node.
[92] [93]	HADD SFBB	2013	Uses predictive technique for relay selection. Uses opposite direction as recovery technique. Data is customized to the driver's requirement degree according to the vehicle's position regarding the data source [92].	The rapidly change of topology is considered as the only cause of unreliable links: rebroadcast messages are not exploited as acknowledgements.
Beacon-based protocols: No relay election; all nodes participate in forwarding the message due to beacons.				
[66] [67] [68]	/	2007 2011 2012	Extensive simulation study to prove the feasibility of deploying safety applications based on beacon message dissemination and performance study under several traffic loads.	Extended beacon frame length. Redundancy due to all nodes sending beacons with the same information. Packet loss due to unreliable beacons. Latency.
Probability-based protocols: Nodes forward the received packet with a certain probability.				
[70]	NPPB	2010	Decreases the number of forwarders at each hop compared to simple flooding. Uses road traffic parameters to formulate the probability of forwarding.	High probability of multiple broadcasting leads to severe contention. Redundancy and overhead. Does not recover lost packets.

Ref	Acron.	Year	Contribution	Weakness
Time-based protocols: Each receiving node calculates a waiting time, which is the shortest for the next forwarder.				
[63] [76] [73] [74]	DDT / IVG ODAM	2000 2000 2003 2004	No need for neighborhood knowledge. One relay node is self-elected.	Spatial broadcast storm problem. Limited scalability.
[71] [72] [77]	/ PAB Hi-CAST	2005 2008 2011	No need for neighborhood knowledge. One relay node is self-elected. Probabilistic parameters to select the most suitable relay.	Spatial broadcast storm problem. Limited scalability.
[75]	P-IVG	2009	Reveals the spatial broadcast storm problem and deals with it.	Possible non-self-electing relay in dense traffic. Possible multiple broadcasting. Possible waste of time if the relay is too close to the sender.
[94]	VSPP	2014	Guarantees that the vehicles in the farthest group from the sender probabilistically forward the message first	Overhead du to beacons Possible non-self-electing relay in dense traffic. Possible multiple broadcasting. Possible waste of time if the relay is too close to the sender.
[78]	SNB	2006	Heightens message receipt, which can improve dissemination reliability.	Causes message redundancy.
[79]	RBRS	2008	Aims to gain time, especially in a sparse network when the probability of nodes on the border of the transmission range of the sender is low.	Redundancy.
[80]	EDB	2007	Exploits directional antennas to improve efficiency. Dissemination message only sent backward in the dissemination direction. No redundant transmissions.	Needs explicit acknowledgement using additional directional antennas. Needs coordination between antennas.
Cluster-based protocols: A cluster is a hierarchical structure is imposed on the network. A multi-hop broadcast between clusters is defined.				
[82]	DPP	2005	The structure of the cluster assigns forwarders in advance to the two directions. May improve the probability of reception.	Cluster head election and maintenance are not discussed Overhead and redundancy.
[83]	/	2009	The structure of the cluster assigns forwarders in advance to the two directions. May improve the probability of reception.	Overhead and redundancy due to both the dissemination strategy and cluster maintenance.

Ref	**Acron.**	**Year**	**Contribution**	**Weakness**
Contention-based protocols: MAC protocol are adapted to serve the forwarding strategy.				
[88]	/	2005	Prioritization mechanism for forwarding according to the geographical location of nodes.	Static contention window may lead to multiple broadcasting and cause overhead and collisions. Shortening the CW size to give separate intervals to the segments may result in increasing spatial broadcast storm problems and limiting the scalability of the network.
[89] [90]	UMB AMB	2004 2008	Innovative use of a handshake sequence (RTB/CTB) similar to RTS/CTS. Maximizes message forwarding and alleviate broadcast storm to prevent the hidden terminal problem and to enhance reliability.	The handshake phase repeated at each hop causes high delays. Overhead due to additional control messages that may be increased in case of packet loss.
[91]	SB	2006	Enhances UMB protocol by eliminating the black-burst step and making use of beacons. Proposes a contention mechanism similar to [88]	High delay. Overhead due to control messages that may be increased in case of packet loss. May not be scalable because of sectioning the size of contention window, which may also lead to congestion problems.

Table 2.3: Qualitative analysis of dissemination protocols

Protocol	**Simulator**	**Environment**	**Prop. Model**	**Ack.**	**Link loss**	**Inters.**	**Metrics**
Topology-based protocols.							
TRADE[63]	Own	Urban, rural	Not provided	No	No	Yes	Bandwidth utilization, reachability
UUB[45]	NS2.34	Highway, unidir.	Path loss	Yes	Carry& Forward	No	Redundancy, collision, overhead, delay
NTPP[64]	NS2.33	Highway, bidirectional	Not provided	No	No	No	Coverage %, Number of retransmission/hop, delay
CBB[65]	MATLAB	Highway, bidirectional	Nakagami-m (m=3)	No	No	No	Collision, delay
DGcast[47]	NS2.34	Highway, unidir.	Path loss	Yes	Carry& Forward	No	Redundancy, collision, overhead
HADD[92]	Matlab-based sim.	Urban, bidirectional	Not provided	No	Opposite direction	Yes	Data rate, delay
SFBB[93]	GloMoSim	Highway, bidirectional	Not provided	No	No	No	Delivery ratio, delay,
Beacon-based protocols.							
[66]	Glo-MoSim	Highway, unidir.	Two-ray ground	No	No	No	Delivery rate, delay
[67]	OMNET++, MiXiM	Manual	Log-normal Shadowing	No	No	No	Delay
[68]	OMNET++, MiXiM	Highway	Not provided	No	No	No	Channel busy Time, Number of hops, collisions, travel time
Probability-based protocols.							
NPPB[70]	OPNET	Highway, bidir.	Not provided	No	No	No	Coverage ratio, reachability,Delay, broadcast ratio, number of hops, load, throughput

Protocol	Simulator	Environment	Prop. Model	Ack.	Link loss	Intersec	Metric
Time-based protocols.							
DDT[63]	own	Urban, rural	Not provided	No	No	Yes	bandwidth utilization
[76]	SHIFT Lang.	Highway, bidirectional	Not provided	No	No	No	Delivery ratio
IVG[73]	Glomosim	Highway, unidirectional	Not provided	Yes	Periodic rebroadcast	No	Delivery success
ODAM[74]	NS2	Highway, unidirectional	Not provided	Yes	Periodic rebroadcast	No	Informed vehicles
[71]	NS2.26	Highway	Two-ray ground	No	No	No	Delivery ratio, overhead, Delay
PAB[72]	NS2	Highway, unidir./bidir.	Not provided	No	No	No	Time of message delivery,
Hi-CAST[77]	MATLAB	Not provided	Not provided	No	No	No	Delivery rate, collision, delay
P-IVG[75]	ASH	Highway, unidirectional	Not provided	No	No	No	Backoff Percentage, reception rate, delay
VSPP[94]	NS2	Highway unidirectional	Two-ray ground	No	No	No	Delay, collision ratio, overhead
SNB[78]	NS2	Highway, unidirectional	Not provided	No	No	No	Succesfull reception, overhead
RBRS[79]	Not provided	Highway, unidirectional	No	No	No	No	Delivery rate, Network traffic, delay
EDB[80]	Own tool	Urban, real map	Not provided	Yes	No	Yes	Delivery ratio, Forward ratio
Cluster-based protocols.							
DPP[82]	Formal analysis	Highway, bidirectional	Yes	Opposite Dir.	Carry& Forward	Yes	Infor. propagation speed
[83]	Formal analysis	Highway, unidirectional	Not modeled	No	No	No	Delay

Protocol	**Simulator**	**Environment**	**Prop. Model**	**Ack.**	**Link loss**	**Intersect**	**Metric**
Contention-based protocols.							
[88]	OPNET	Highway	Not provided	No	No	No	Channel load, maximum reached distance
UMB[89]	CSIM library, Matlab	Urban	Not provided	Yes	No	Yes	Success reception, dissemination speed, channel load,
AMB[90]	CSIM library	Urban	Not provided	Yes	No	Yes	Packet delivery, channel load, dissemination speed
SB[91]	Formal analysis + MATLAB	Highway	Not modeled	No	No	No	Latency, propagation speed

Dissemination protocols have been improved over the years. The first protocols dealed with the problematic of multihop broadcast in which researcher had to overcome collisions, redundancy and overhead. From the simple flooding to the more sophisticated solutions new issues emerged such as spatial storm problem and recovery. One important issue is simulation. Indeed, the more the simulation is realistic the more results are reliable and accurate. In the following, we list the major drawbacks in dissemination protocols simulation:

- Certain protocols were evaluated with simulators only known by the authors because they are developped in their laboratories [90][89][80]. Thus, it is impossible to estimate the accuracy of the simulation.
- Several Protocols were simulated with tools that are not suited for VANETs technology such as the initial versions of NS2 and GloMoSim [74][73][66].
- In certain protocols parameter were set in an inappropriate way such as setting WIFI as underlying radio access technology.
- In the major of the studied protocols, mobility scenarios were not realistic and do not denote the behavior of vehicles in real situation, because scenarios do not change during the simulation runtime due to the lack of realistic simulators.
- Most simulations do not take in consideration realistic propagation models[95].

Actually, realistic simulation with real maps and realistic mobility scenarios tackling different types of intersections and using VANET technology should be considered to garantee a successful simulation [50].

2.7 Techniques to enhance robustness to transmission failures

Some of the important challenges of safety dissemination are to ensure packet loss recovery and permanent service. Temporary disconnections induce delivery delays in any protocol. When disconnection lasts for a long period, it may be fatal for the progress of the dissemination. Several techniques are proposed in the literature to enhance the robustness of the proposed protocols. In Table 2.4, we review the most important techniques found in the literature.

Table 2.4: Techniques to enhance robustness to transmission failures

Technique	**Description**	**Ref**
Carry and forward	Nodes that sense the partition carry the packet and forward it to the first vehicle that enters the vicinity of a carrier node. This strategy requires the existence of a neighborhood service.	[96] [82]
Periodic broadcast	When the sender does not receive an acknowledgement, it concludes a partition case. Without neighborhood service, there is no way to know if some nodes enter the vicinity of the sender. Thus, the sender rebroadcasts the packet periodically until it receives an acknowledgement.	[73] [74]
Relying on road infrastructure	RSUs can be used temporarily as relays to connect different parts of the network.	[42]
Relying on vehicles in opposite direction	Vehicles traveling in the opposite direction can act as relays in case of partitioning.	[82]
multiple dissemination	Some nodes store the information in order to repeat the dissemination process periodically to ensure coverage of all incoming vehicles.	[97]
Piggybacking acks on beacons	Beacons are exploited to bring acknowledgements. To check whether or not all neighbors successfully received a broadcast message, the nodes include the recently received broadcast messages in their beacons to serve as acknowledgments of reception.	[96]

2.8 Conclusion

Multi-hop broadcast is the key technique used to disseminate time-sensitive safety information in VANETs. Researchers have invested significant efforts over the last decade to improve traffic safety information dissemination in vehicular networks. Due to unreliable links, it is difficult to design a highly reliable, scalable, and rapid dissemination protocol without high cost in term of network load. This survey has presented some innovative solutions. Combining many strategies may enhance the reliability of these protocols. Future works should address this issue as two distinct but related parts: a MAC protocol that enhances the broadcast communication mode and a safety dissemination application that focuses on how to ensure timely coverage.

Chapter 3

UUB, UB and DGcast, our alert dissemination protocols

3.1 Introduction

There is a growing need to make vehicular safety applications reliable and efficient. Several protocols were proposed in the literature. They provide innovative solutions principally relying in multi-hop broadcasting. By using broadcasting, a message sender can reach all the vehicles in its vicinity at once. With multi-hop technique and relay nodes, a sender can reach all other nodes outside of its communication range. However, this technique causes several problems essentially due to the unreliability of broadcast mode and the lack of MAC layer to provide techniques to reduce the medium access delay and packet loss. Consequently, the existing strategies [43] still suffer from the redundancy, contention and collision problems and their performance depends on the MAC level functionalities. Actually, the broadcast transmission is performed at every hop so that the nodes located in the common region covered by two relays, therefore, receive the message at least twice; multiple receipts of the same message can increase when there is a communication failure during which a retransmission of the message occurs. Based on our observation, the proposed solutions try to improve efficiency and avoid congestion. The addressed problem is how to cover a region of interest with respect to quality of service requirements (reliability, delay and efficiency). In this section, we propose our three protocols respectively, Unicast Unicast Broadcast (UUB)[45], Unicast Broadcast[46] and Directional Geocast (DGcast)[47] dissemination protocols.

3.2 Assumptions

We assume that vehicles use wireless communication through omni-directional radio antennas with a transmission range of R. Each vehicle is equipped with a device (such as a Global Positioning System (GPS) device) enabling it to obtain its geographical location at any time and a preloaded digital map, which provides general information about roads. The MAC layer provides information about the neighborhood by making use of periodic beacon transmissions. A beacon packet contains information such as physical location, velocity and direction of the vehicle. The neighborhood service allows vehicles to construct tables containing neighbors´ status. Emergency messages are transmitted in the opposite direction of vehicle´ motions. We consider only a section of road.

3.3 Using unicsast for alert dissemination

An emergency message can be generated by a vehicle (called initiator) in a dangerous situation. For example, in case of an accident, a vehicle can recognize it is in a dangerous situation through sensors that are able to detect internal events like airbag ignition. Omni antennas used in wireless transmission allow a mobile node to transmit its signal all around it within a transmission range R. To the best of our knowledge, existing protocols discarded the use of the unicast mode because it needs more time than the broadcast mode. However, it is more reliable [24]. Thus, the reliability of unicat mode can be beneficial for dissemination protocols. In our protocol, we propose to combine both unicast and broadcast modes to improve the reliability of dissemination. In view of that, we use the unicast mode between relay nodes to propagate the information as far as necessary while the broadcast mode is used every two hops to inform nodes that there is an emergency situation. So, the redundancy zone between two relays shown in Figure 3.1 can be eliminated.

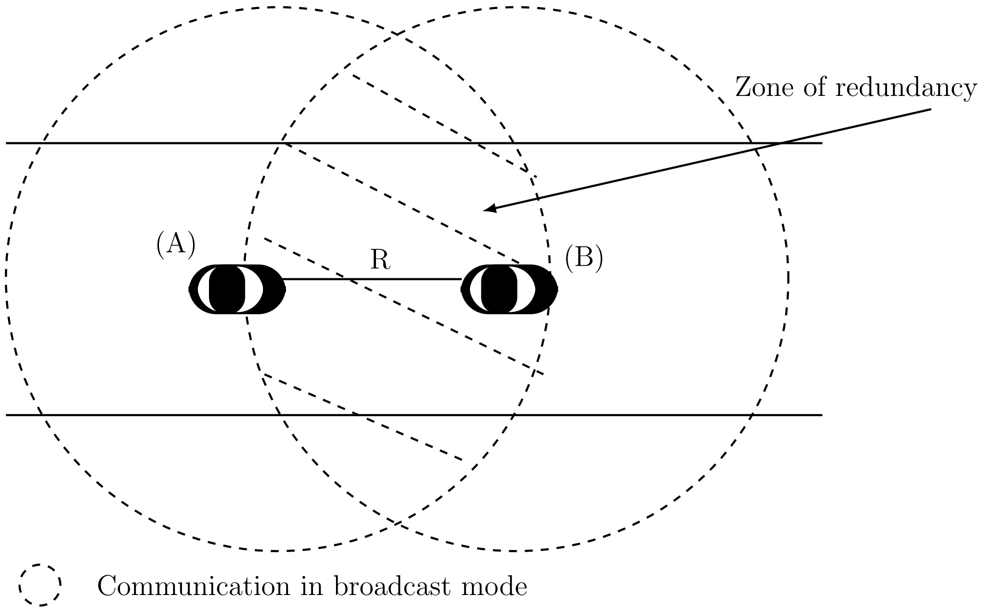


Figure 3.1: Broadcasting at every one hop causes redundancy

3.3.1 Contribution of UUB and UB protocols

In this work, we used a multi-hop unicast to propagate reliably the alert message as far as the limits of the region of interest. Each two hops, broadcast message is sent to avoid redundancy that existed in multi-hop broadcast. With the reliability of unicast, we insure the coverage; while with broadcast, we insure that all the nodes in the network are kept informed. Furthermore, if broadcast fails, it can be recovered locally without delaying the dissemination process.

3.3.2 UUB Protocol design

The initiator vehicle selects among its neighbors behind it, the farthest one, and, sends it a unicast packet data that contains the emergency message. The farthest node is considered as a relay. It first transmits a unicast message to the farthest neighbor behind it within

its transmission range to ask it to act like an initiator and then broadcasts the message. So, there are two unicast messages followed by one broadcast message to reach two hops. In Figure 3.2, when vehicle B receives the vehicle A packet, it first sends a packet which contains the emergency message to vehicle C in a unicast mode, and then broadcasts it. Vehicle C sends immediately its unicast message to the farthest vehicle from it in its vicinity (vehicle D) which acts like vehicle B. Considering the same figure, when the node A receives the same message from B, it considers it as an acknoledgement. But supposing that the broadcast performed by vehicle B failed. In this case, vehicle A resends its packet to vehicle B which is asked to perform only the broadcast. At the same time, vehicle C has already sent its packet to vehicle D which acts like vehicle B. Consequently, the propagation time of emergency message is not delayed.
The proposed protocol has two characteristics:

- On one hand, we can see that there are two processes in progress at the same time: the unicast and the broadcast transmissions,
- On the other hand, the fail of a broadcast performed by one relay node does not affect the following ones. So, the dissemination process continues its track while the problem can be processed locally by resending the message.

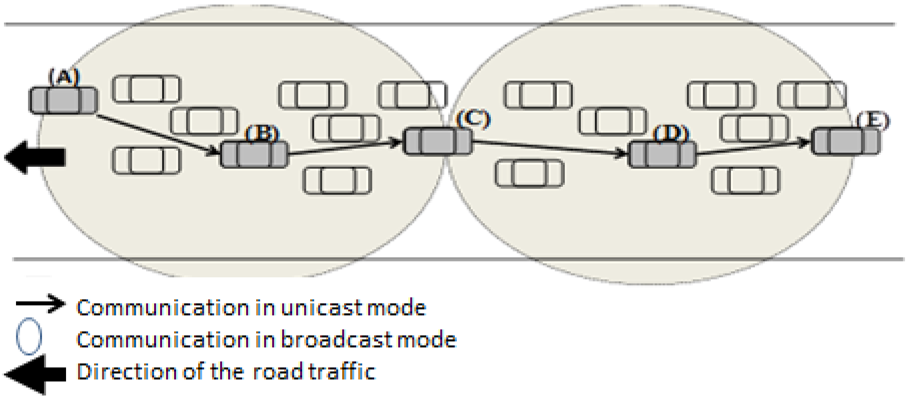


Figure 3.2: The dissemination scheme of UUB protocol

3.3.3 UB protocol: A variant of UUB

UB protocol is a variant of UUB protocol. It uses less messages. Thus is less reliable. In the following, we describe UB approach:
The initiator vehicle selects among its neighbors behind it, the furthest one, and, sends it a unicast packet data that contains the emergency message and an order to broadcast it. The receiver selects among its neighbors behind it the furthest one and elects it as a relay; it adds the identity of the relay to the message and broadcasts it. When a vehicle receives the broadcast message, it compares its identity to the identity added to the message, if the two identities are different the receiver only considers itself informed, otherwise, it recognizes itself as a relay and acts as an initiator vehicle (it sends a unicast message to the furthest vehicle behind it). So, this process will be repeated all along the road. As we can notice, the protocol is made of successive toggling between unicast and broadcast messages as it is shown in Figure 3.3.

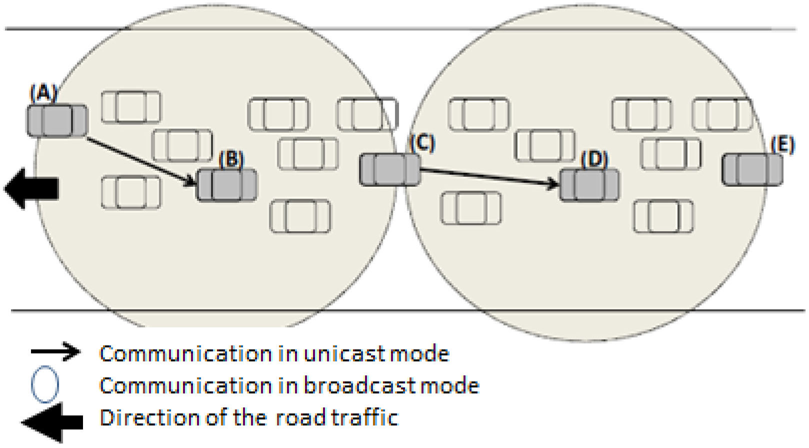


Figure 3.3: The dissemination scheme of UB protocol

3.3.4 Message form and algorithms

In UB and UUB protocols, we define two types of data messages: A unicast message U and a broadcast message B where,
U=[messageId,content,relayId,sourceId]
B=[messageId,content,relayId,sourceId,fromId]
The algorithms at the reception are given in Algorithm 1 and Algorithm 2 respectively for UUB and UB protocols:

1 UUB Algorithm for the vehicle receiving message

```
procedure UUB
    if $mode == broadcast$ then
        if $myId == sourceId$ then $ackReceived()$
        end if
    else                                                    ▷ mode=unicast
        if $order = broadcast$ then
            $nextRelay \leftarrow fetchNode(neighbors)$
            $message \leftarrow (messageId, content, location, unicast, beInitiator, myId)$
            $sendMessageToNextRelay()$
            $message \leftarrow (messageId, content, location, broadcast, noOrder, sourceId)$
            $sendMessage()$
        else
            if $order = beInitiator$ then
                $nextRelay \leftarrow fetchFurthestNode(neighbors)$
                $Message \leftarrow (messageId, content, location, unicast, broadcast, myId)$
                $SendMessageToNextRelay$
            end if
        end if
    end if
end procedure
```

2 UB Algorithm for the vehicle receiving message

```
procedure UUB
    if $mode == broadcast$ then
        if $myId == sourceId$ then $ackReceived()$
        end if
        if $myId = relayId$ then
            $nextRelay \leftarrow fetchNode(neighbors)$
            $message \leftarrow messageId, content, location, unicast, nextRelay, myId)$
            $sendMessageToNextRelay()$
        end if
    else                                                    ▷ mode==unicast
        $nextRelay \leftarrow fetchNode(neighbors)$
        $message \leftarrow (messageId, content, location, broadcast, nextRelay, sourceId)$
        $sendMessage()$
    end if
end procedure
```

3.4 DGcast protocol

3.4.1 Contribution of this work

Displayed Emergency dissemination protocol requirements are very strict. Indeed, such protocols have to ensure a high delivery ratio of warning messages with low latency which is difficult to obtain because of the congestion problem caused by broadcast. Many past efforts have previously explored how to avoid unnecessary forwarding at the application layer. However, since the MAC layer approach has a direct impact on upper layers, we need to take MAC layer factors also into consideration to achieve fast, reliable warning message delivery. In this context, we propose a cross layer solution that can disseminate warning messages and avoid congestion by filtering unnecessary data using a filter module residing above the MAC layer. This filter module discards unnecessary messages (redundant messages) from being processed by the application layer. So, the region where a vehicle is located can be considered as a dynamic multicast address that allows the vehicle to know early at the MAC level whether it is a destination of a message.

3.4.2 Protocol design

When a node holding a warning message has to forward it as an initiator or a relay node, it considers its surrounding area as two geographical regions: the region it is moving toward (region 0) and the region behind it (region 1) as shown in Figure 3.4. It selects among its neighbors located in region 1 the furthest one and elects it as the next relay, and then the packet is broadcasted. When receiving the warning message, each node determines whether it is located in region 1 or not based on the locations of vehicles and the digital map. The major benefit in determining the nodes region is to avoid processing the message if the node is located in region 0. So, we use a common reference point such as the next intersection which is considered as a specific point on the road. The receiver of the message calculates *ds* and *dr* values, where *ds* is the Euclidean distance between the sender and the next intersection and *dr* is the Euclidean distance between the receiver and the next intersection. In Figure 3.4, *dr* belongs to the current relay; all the nodes that are in the sender´ s vicinity calculate their local *dr*. If *dr* is greater than *ds*, a node concludes that it is located in the addressed region (region 1) otherwise it is not. In the first case, it compares its identifier with the identifier of the next relay vehicle enclosed in the packet and if it is the same, the node recognizes itself as the relay. It then, updates the packet with information such as next relay, previous relay, etc. and rebroadcasts the message. If the receiver node is not designated as the relay by the sender, it keeps itself informed. In the second case, the receiver is located in region 0 (*dr* less than *ds*). The receiver checks whether it is the previous relay; it then considers the packet as an acknowledgment, otherwise it simply ignores the packet. If the previous relay does not receive the packet after a short time it considers the packet as lost and repeats its transmission until it receives the acknowledgement. If a relay node senses no neighbors, it first broadcasts the message that serves as an acknowledgement to the previous relay and keeps it until a vehicle enters its vicinity. It then executes the same algorithm as a relay node. Our proposed DGcast dissemination protocol makes use of two modules: a filter module above the MAC layer and an application module as shown in Figure 3.5. The filter module determines whether the node is located in the addressed region by comparing the two values *ds* and *dr*. If it is in the region, it passes the message to the application module which processes it. The application module has to determine one of the two cases:

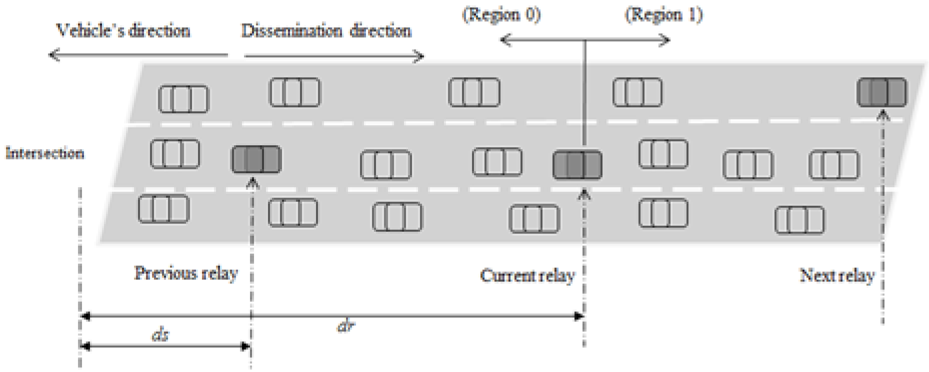


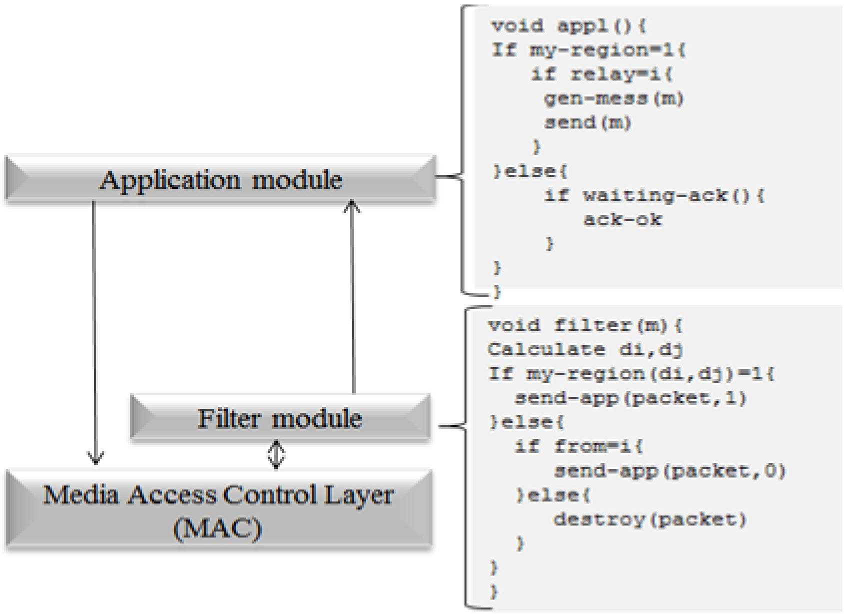
Figure 3.4: The DGcast scheme

- If the current node is a relay node,
- If the message is a warning or an acknowledgment: the only case where the message reaches the application layer in (region 0) is when the receiver is the previous relay vehicular node.

The DGcast protocol has four characteristics which can be summarized as follows:

- There is no need to incur the waiting time because the application makes use of the neighborhood table which stores information such as the identifiers of the neighbors, their positions, speed etc.,
- There is no need to have multiple antenna systems which need be properly oriented (positioned) and synchronized between the sender and the receiver and do not need explicit acknowledgement,
- The filter module does not process the message in the sense of making decisions such as forwarding or selecting the next relay. The module only decides if a vehicle is a relevant target for the warning message according to its location,

- Since the filter module resides above the MAC layer, only relevant packets are processed by the application, so the receipt of multiple copies of the same message by the nodes does not affect the application.



```
void appl(){
If my-region=1{
   if relay=i{
     gen-mess(m)
     send(m)
    }
}else{
     if waiting-ack(){
        ack-ok
     }
}
}
```

```
void filter(m){
Calculate di,dj
If my-region(di,dj)=1{
  send-app(packet,1)
}else{
  if from=i{
     send-app(packet,0)
  }else{
     destroy(packet)
  }
}
}
```

Figure 3.5: Proposed Architecture

Message Format

The format of an emergency message is described in table 3.1. When a warning message m is received by a node i from a node j, the filter module is executed to decide whether the message has to be passed to the application layer. To achieve this, the filter uses local information that gives the vehicle location, the field *Origin* that is used to get the location of the sender and the location of the next intersection to determine if the vehicle is located in region 0 or region 1. There are three cases: in the first case, the node can be in region 0 but its identifier matches the *from* field of the packet, thus the message is an acknowledgment and it is passed to the application module. In the second case, the node is located in region 1 and is therefore one of the multiple destinations of the message. The node´ s application module has to determine if it is selected as a relay; if so, it rebroadcasts the message otherwise, it just keeps it. In the third case, the node is located in region 0 and its identifier does not match the *from* field of the packet; the packet is discarded (ignored).

3.4.3 Simulation study

In this simulation study, we compare our UUB and UB protocols with the ODAM [74] protocol. At the MAC layer we use the IEEE 802.11p standard and a transmission range of 250 m. The radio propagation model is set to the Path loss model. To evaluate the performance of DGcast protocol, we compare it to three of previously proposed approaches namely, the topology-based, time-based and cluster-based approaches. For the topology-based approach, the one that is closest to our approach for comparison is

Table 3.1: Messsage format.

Fields	**Description**
Id_mess	Sequence number
Type_mess	Emergency
R	The region; 0=before the vehicle, 1=behind the vehicle
Data	Message content
From	The identifier of the previous relay
Origin	The identifier of the sender
Nxt_relay	The identifier of the next relay

Table 3.2: Messsage format.

Parameter	**Value**
Vehicle beacon interval	1sec
Road length	10 km
Number of lanes	4
Traffic density	2, 4, 6 and 8 veh/km/lane
Maximum vehicle velocity	30m/s

[63]. For the time-based approach, we used the formula in [74] to calculate the waiting time. For the cluster-based strategy we used the approach in [82] with one hop forwarding to make it close to our proposed DGcast approach and to enable the communication between clusters, two successive clusters are considered as a non-disjoint sets of nodes. At the MAC layer we use the IEEE 802.11p standard and a transmission range of 250 m. The radio propagation model is set to the Two Ray Ground model. The parameters of our simulations are listed in table 3.2. We have implemented the protocols and carried out simulations with NS-2 [98] using various mobility scenarios generated with the MOVE generator [99] by varying the vehicles densities (respectively 2, 4, 6 and 8 vehicles per lane per kilometer). We simulated a road of 4 lanes and 10 km. Vehicles move with a mean velocity of 30 m/s. We used the following performance metrics in our performance evaluation tests:

- Dissemination delivery ratio: The number of the informed nodes out of the number of the nodes in the network,

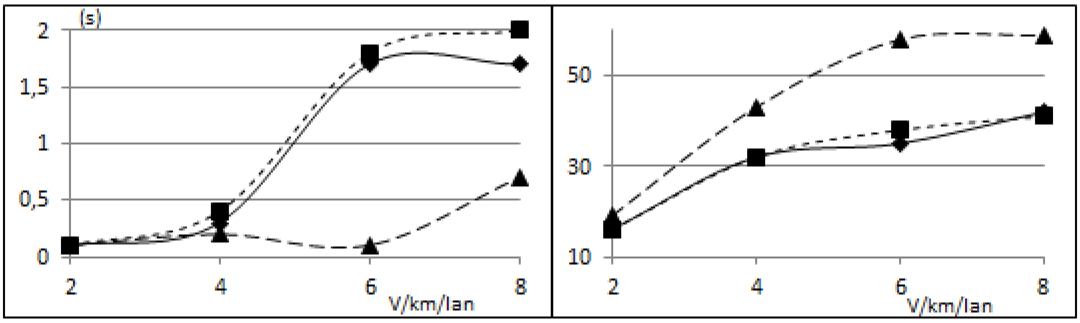
- Number of generated messages: the number of dissemination messages transmitted by relays along the road,

- Number of redundant messages: where a redundancy occurs when an informed node receives the same message again,

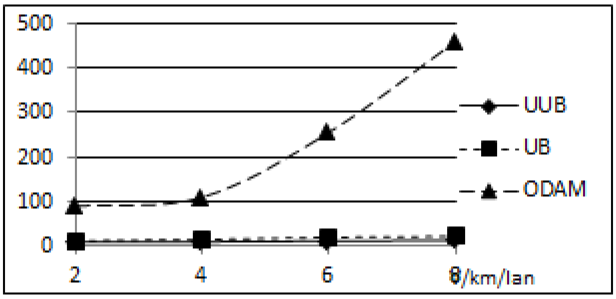
- Number of redundant messages eliminated: The number of redundant messages that have been discarded at the filter module,
- Dissemination delay: The dissemination delay is the time interval between the first generated message and the first message received by the last informed vehicle in the network.

The simulation results show that the delivery ratio of our protocols is 100% for all mobility scenarios with none or partial fragmentation. This result confirms our assumption. Indeed, all vehicles generated in the simulation have received the emergency message. So, the simulation shows that our protocols are reliable.

UUB and UB simulation results



(a) Dissemination delay (b) Generated messages



(c) Redundant messages

Figure 3.6: UUB and UB simulation results

It is shown in figure 3.6.a, that ODAM gives best delays. This is due to some collisions that have occurred between the information and the beacon messages during the simulation of UB and UUB protocols. These collisions can be seen in trace files generated by the simulator NS2. If a fragmentation occurs, the delay depends on the fragmentation duration. The mean number of generated messages is approximately similar in both ODAM and UB protocols (figure3.6.b). UUB protocol generates more messages. This result can be explained by the fact that UUB generates three messages (two messages in a unicast mode and one message in a broadcast mode) to reach two hops, while it takes only two messages to ODAM and UB (two broadcast messages for ODAM and one unicast and one broadcast message for UB) for the same number of hops. Figure3.6.c shows mean number of redundant messages. A message is redundant when it is received more than once. ODAM gives the highest values because all vehicles between a sender and a relay node receive the same message at least twice. This is due to the fact that the broadcast is performed each hop. In our protocols, few redundant messages are generated. They are due to the acknowledgment reception which is functional. Figure 3.7 shows a comparison between UB and UUB protocols. We chose some mobility scenarios where several collisions messages have occurred. The simulation of the UUB protocol shows that when a communication fails because of a collision, two processes get in progress. The first makes progress the dissemination process toward the rest of the vehicles while the second treats locally the failure as it is explained previously. The experimentation confirmed that really, the dissemination continues its track in spite of some transmission failure. So, in the simulation of UUB protocol we calculated two values of delay for each density. The first is the delay of the dissemination process represented, in figure 3.7, by the curve of UUB protocol and the second is the necessary time to treat collisions which is explicitly registered on the same curve. We can see that the selected scenarios do not affect UUB performances in term of dissemination delay contrary to UB protocol where the delay increased significantly.

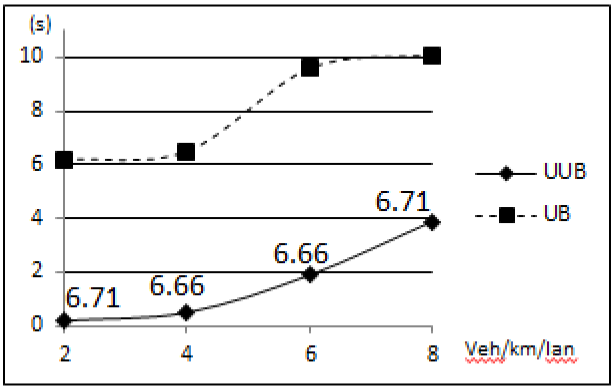


Figure 3.7: UUB and UB Dissemination delay in case of collisions

DGcast simulation results

The simulation results show that the delivery ratio reaches 100% for all mobility scenarios. Indeed, all vehicles used in the simulation tests received the emergency message. Our simulation results demonstrate that DGcast is reliable. This result will be a requirement for future dissemination protocols because several protocols reached the same delivery ratio [100][101][74] as we obtained for those we simulated. Figure 3.8 shows the simulation results. In terms of the number of generated messages, we note from the results in figure 3.8.a, that the cluster approach generates the highest number of messages. This is because the cluster heads have the responsibility of forwarding even there is a further node from the previous cluster head in the common area between clusters. Other solutions yield fairly similar results regardless of the vehicle density. In terms of the number of redundant messages, our proposed protocol (DGcast) does not generate redundant messages because the filter module eliminates all unnecessary messages. In contrast, other (topology-based, time-based and cluster-based) protocols suffer from a large number of redundant messages especially when the vehicle density increases (as shown in figure 3.8.b). Figure 3.8.c confirms this result by giving the number of redundant messages that have been eliminated by the filter module. In terms of the dissemination delay, small delays are obtained with all

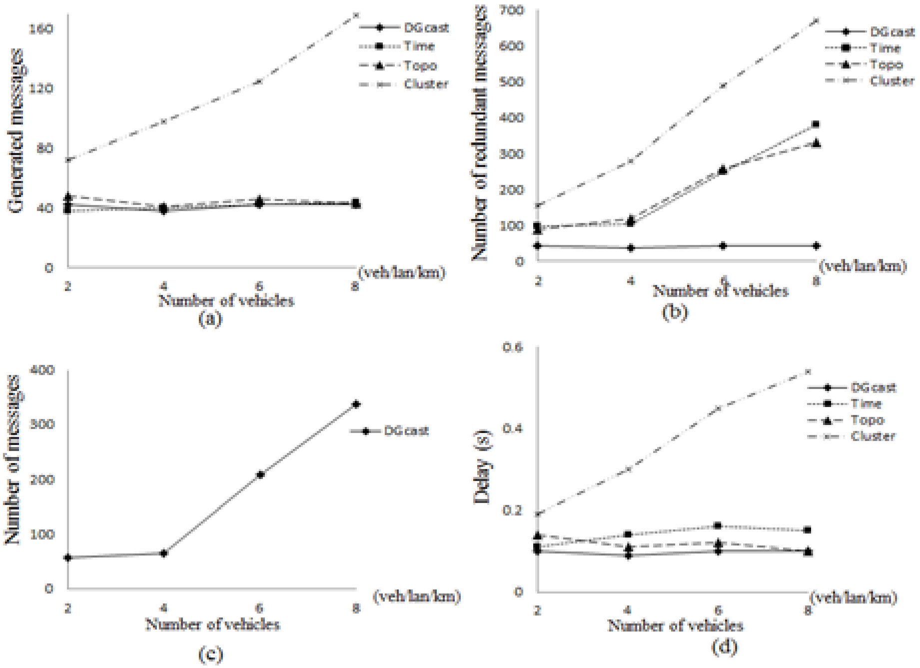


Figure 3.8: Simulation results obtained with DGcast compared with other approaches

protocols except the cluster-based protocol due to the high number of hops. Figure 3.8.d shows that DGcast gives lower dissemination delay compared to the time-based protocol. This is due to the fact that a relay node is chosen by the sender in the case of DGcast while with the time-based protocol a relay node has to wait for duration of time before retransmitting the message.

3.5 Analysis, conclusion and future work

In this work, we showed that the use of the unicast mode in emergency dissemination can give good performances in term of delay and efficiency. In UUB protocol, two processes get in progress at the same time. The first makes progress the dissemination process toward the rest of the vehicles while the second treats the broadcasting at each two hops. The unicat mode is used as a means of improving the broadcast mode, so that the broadcasted message can reach two hops simultaneously without redundancy. We can say firstly, that the unicast mode can be suitable for the dissemination service. Secondly, discarding the use of beacons for the reason that they cause collisions is not a good choice because on one hand most of the existing protocols especially routing protocols are beacon-based, on the other hand beacon messages provide crucial information about the topology which can be used in several applications. Simulation study shows that our protocols are reliable and efficient in traffic condition without fragmentation or with limited fragmentation. Our protocols reduced the number of redundancies in comparison with ODAM. On the other hand, we showed that our proposed protocol DGcast gives better performances in terms of delivery ratio, redundancies and dissemination delay over other approaches. Moreover, the use of a filter as a sublayer above the MAC layer helps to avoid the handling of unnecessary (redundant) messages by the application layer. Our study can provide a

guideline for improving the design of protocols that suffer from redundant messages at the application level.
The main drawbacks of these protocols are: First, they are not flexible. Indeed, assuming that communication is faster than nodes movement does not eliminate the impact of mobility. For example: the message can be received by the relay node, but the acknowledgment (ie, the forwarded message) may not be received by the previous relay because it may move out of the current relay transmission range. Second, the selection of the relay node is deterministic and does not take in consideration the signal attenuation due to distance, buildings and so on. So, the solutions do not recover timely in case the relay does not receive the message. Finally, this work deserves to be studied again with more recent simulators that integrate VANETs functionalities to study it with more realistic parameters and considering the two previous points. In fact, the protocol that deals with these observations is currently under study.

Chapter 4

Study of beaconing in VANETs

4.1 Introduction

The need for deployment of VANETs in real life motivates the expansion of a wide range of new applications for Intelligent Transportation Systems (ITS), precisely those related to road safety. Nowadays, safety applications can be seen as two main tracks namely event-driven and proactive. Event-driven applications react to events (hazard) that occur on roads and disseminate alerts in a limited zone around the danger called Zone Of Relevance (ZOR) [102]. Proactive applications systematically spread-out information across the network. One challenging technique to provide information about traffic status and surroundings is by beaconing which denotes the continual exchange of Wireless Short Messages (WSMs) between vehicles that contain positional information about vehicles. This way, vehicles can construct real time knowledge on neighboring [103], maneuver more easily for example in case of lane changing, and avoid likely sudden danger [104]. In addition, many safety applications resort to beaconing as support for forwarding safety messages [105] or acknowledgments [96]. Beaconing is challenging in three levels namely vehicular environment, communication and technique. First, the vehicular environment is severe; it can rapidly vary from sparse to dense leading to a highly dynamic topology. Furthermore, it is susceptible to large-scale/small-scale effects on radio wave propagation and signal attenuation especially in urban sites [1]. Second, beaconing service relies entirely on broadcast for the exchange of status messages. However, broadcast communication is known to be unreliable because it does not provide collision detection and avoidance; consequently, a high probability of packet loss is ensued, mainly in saturation cases [106][107]. Furthermore, periodical transmission of beacon messages, with a high rate but with no synchronization mechanism, explosively increases the network load engendering a degradation of global performances of the communication system. In addition, beacons and several classes of safety messages share the same channel (CCH); even with prioritization mechanism, safety messages may be delayed due to congestion and channel access conflict. Third, it is difficult to find a good compromise between beacon rate and accuracy. Indeed, while increasing the beacon rate generation leads to overhead and contention, reducing it, increases the gap between the last reported information and reality. In the literature, most papers focus on adaptive approaches namely beacon rate control, transmit power control, dynamic contention window, and hybrid [108]. The purpose of adaptive approaches is to adjust dynamically the beacon rate, the transmit power, the contention window or a combination of them with respect to the instant network parameters settings such as density and channel load that can be used as inputs. Scheduling approach can be promising. It includes Time Division Multiple Access (TDMA), Space Division Multiple

Access (SDMA) and clustering. These strategies have been widely used for channel access control [109][110], but unfortunately, they are not well investigated for beaconing. In this chapter, we review the most relevant approaches in this field and we provide a classification of the existing solutions.

4.2 Beaconing approaches in the literature

One of the key factors for success in promoting safety applications in order to enhance road safety is to keep updated information exchanged between vehicles including speed, position and direction of the vehicles in the vicinity. The exchanged information helps in providing cooperative awareness in vehicular networks.The periodic exchange of packets called beaconing is already included in the IEEE802.11p/WAVE [111]. However, it has been shown in many papers the unsuitability of such technique [103][105], because the wireless channel rapidly becomes saturated with beacon messages especially under high traffic densities. As a result, the performance of the global system deteriorates. In Recent studies, there are many research works that deal with this issue. They could be classified into two main classes, besides the standard, namely adaptive and scheduling approaches as it is illustrated in figure 4.1. In the following sections, we detail each approach and give its strenght and weakness.

4.2.1 Adaptive beaconing

Adaptive approaches use the network parameters such as channel load and density as inputs to adjust dynamically the beacon transmission power and the beacon generation rate. Following the trend of research on beaconing, the authors in [112] proposed a channel load control approach that adjusts the beacon rate according to velocity and density of vehicles. In another attempt to improve network performance due to beacon load, the authors in [113] proposed a beaconing approach that dynamically adjusts beacon generation rate according to the level of danger severity and an estimated channel load. In [114] the authors proposed an Adaptive Beacon Rate (ABR) scheme based on fuzzy logic to adjust beacon generation rate by considering the density of vehicles and their status (emergency, non-emergency).
In [115], the authors stand that network traffic can be optimized by dynamically adjusting

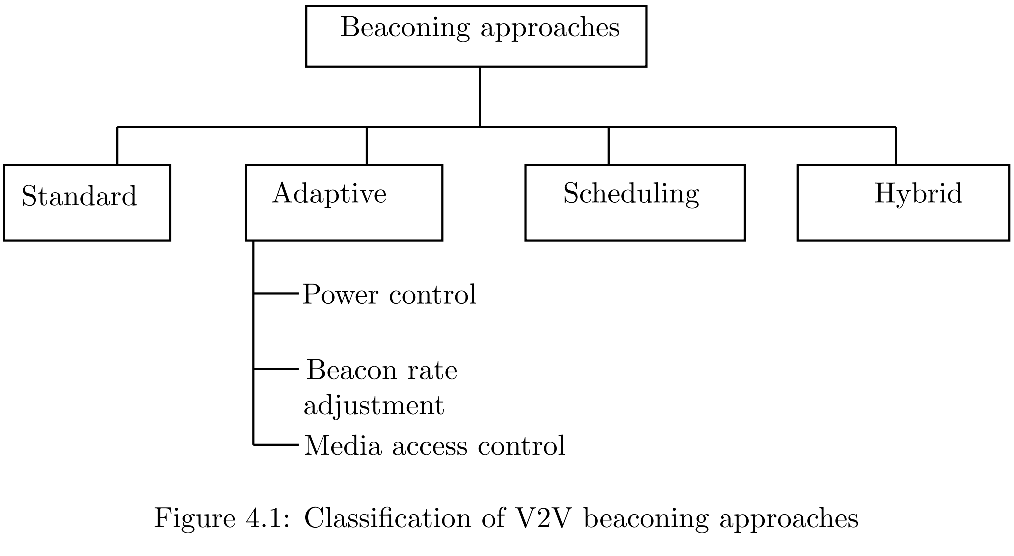


Figure 4.1: Classification of V2V beaconing approaches

the transmit power based on the channel load. Thus, Each node can estimate the network traffic conditions by including a sequence number to the transmitted packets, which is used to determine the missing packets. Consequently, nodes make their own decisions independently regarding the appropriate transmit power to use, according to the number of estimated neighboring nodes and the resulting reception ratio. In [103], the power adjustment is based on beacon load that is measured in terms of number of neighbors. The authors in [103] used the EDCA classification to assign different priorities to data packets and beacons so that data packets are assigned the highest priority and maximum transmit power. The simulation study shows a reduction in channel load, if transmit power is maintained to optimum, and an increase of message reception probability due to prioritization. The authors in [116] have proposed a hybrid adaptive protocol that adjusts joint transmission power and contention window in order to alleviate the network congestion. Adjusting transmission power is based on the network density wherein the adjustment of contention window collisions are constantly estimated. Obviously, the main technical difficulty with this solution would be how to achieve an accurate estimation of density and collisions. Keeping the same approach of power adjustment, the authors in [117] have simulated beaconing in single hop and multi-hop approach for VANETs. The study aimed to address whether the beaconing load can be reduced once periodic beaconing messages are disseminated using multiple hops with the reduction of transmission power instead of being disseminated using single hop with high transmission power. According to their study, they observed that the multi-hop beaconing is needed once there is no line-of-sight which may obstruct the radio coverage when using single hop beaconing. However, in order to reach a desired transmission range, multi-hop beaconing delays the packet delivery and increases the network load.

Contention Window (CW) is an important factor for channel access control. In IEEE DSRC/WAVE, it is used to attribute access priority to different applications. Following the same idea, in [118], the authors proposed an architecture that modifies the Contention Window (CW) according to the network parameters such as channel load. For example, the contention window is increased in response to high channel load. With the adaptive approaches, the channel load is considerably improved. Indeed, beacon rate is adjusted so that the negative influence of the periodic beacon transmission on the communication system performances is decreased. In addition, adaptive adjustment of the transmit power increases the reception rate at closer distances and decreases collisions at further distances. However, it is difficult to find an adequate adjustment dealing perfectly with the network parameters so that collision could be eliminated. Furthermore, decreasing the beacon rate due to channel load to promote data reception may lead to imperfect awareness of the surrounding resulting in delayed reaction in case of emergent situation.

4.2.2 Scheduling approaches

Scheduling approaches tend to give an organization into the communication system or into the network topology structure. Self-organizing Time Division Multiple Access (STDMA) is one of these promising approaches. It is used in several papers [109][110]. In STDMA technique the time is structured into infinite repeating frames where each frame is itself divided into time slots; each of which is affected dynamically to one vehicle to serve in sending a message. STDMA technique can help in collision avoidance since parallel transmissions cannot occur with unique assignation of time slots. Furthermore, it ensures fairness in channel access and predictable communication delay. Though, strict synchronization and adaptive slot assignation are required to avoid time loss, ensure adequate bandwidth

exploitation and bear the growth in scale of vehicles in the network.
In Space Division Multiple Access (SDMA) approach, the geographical space is divided into sub-spaces. Accessing to the communication channel is based on spatial locations of vehicles. In [119], the authors proposed a geographical cluster structure based on SDMA approach in which road is split into a number of segments. A cluster is established in each segment which combines two levels to be performed. In the first level, to reduce collisions, non-adjacent clusters can simultaneously perform the transmission. In the second level, a TDMA-like approach is internally scheduled for each cluster. In fact, each segment of the road is further split into several sub segments so that only one vehicle can occupy the sub-segment. Thus, only one sub-segment in a given time is involved in transmitting a beacon. The algorithm proposed in [119] does not discuss the dynamic aspects of vehicular networks such as nodes´ mobility and, cluster formation and maintenance. Furthermore, the proposed approach used for segmentation is not realistic since it is difficult to ensure the occupancy of each segment by only one vehicle, because on one hand it assumes that all vehicles have the same dimension, on the other hand vehicles move, so, it is difficult to have them all in separate segments. However, to the best of our knowledge this work is the only one in the literature that used the SDMA technique besides [48]. In [48] the authors proposed a SDMA-based approach. By the same way of [119], the road is equally split into segments where each vehicle locally decides whether it should send its beacon frame according to its position in the belonging segment. A linear equation is defined, in the interval of the control channel, that permits to nodes to obtain the time when they should send their beacon frame knowing their position. Thus, all the nodes in the network can send their beacons in the same CCHI. The proposed solution performs coordination of the transmissions among vehicles with no additional messages. However, this technique may create severe contention in beacon sessions which may delay emergent packets. In the folowing chapter, we will study this solution in details.

4.2.3 Hybrid approaches

Hybrid approaches join multiple strategies to improve the performance of the beacon service. In [120], The authors propose a hybrid protocol that join cluster approach with TDMA approach. In this solution, the cluster head plays the role of the centralized system that assigns the time slots to the requesting vehicles. The slot assignation is dynamic but requires additional messages to coordinate the system.

4.3 Summary of beaconing approaches

In the following we summarize the beaconing approaches presented in this study according to our classification. Table 4.1 provides an overview on strenght and weakness of each approach.

Table 4.1: Summary of the Related approaches

Approach		Strategy	Weakness	References
Constant period		Initial approach of blind and periodic beacon transmission.	- Contention. - Network load. - Collision.	[111]
Adaptive		Adjustment targets the beacon rate, the power rate, contention window or a combination of them. Network parameters such as density and channel load can be used as inputs for adaptive beaconing.	- Difficulty to find an adequate compromise between the network parameters and the perfect adjustment which may lead to inaccurate results.	[112][113][114][115] [117][103][116][118]
Scheduling	STDMA	Scheduling method that makes one transmitting node at a given time slot, so that no collisions are expected, fair channel access.	- Scalabity.	[109][110]
	SDMA	Scheduling method that divides the geographical space into smaller spaces and provides nodes access to the wireless channel depending on spatial locations.	- Should be improved for the neighborhood discovery service.	[119]
Hybrid		Join previous approaches in order to maximize the advantages of each of them	- Protocol complexity.	[120]

4.4 Conclusion

As we could see in this chapter, researchers focus on adaptive beaconing because they are promising in reducing overhead. However, collisions and packet loss remain as challenging issues, since they are intimately related to the broadcast problem. with scheduling solutions, the latter problems can be alleviated. The main issue in this context is how to find the best choice of the period and the transmission power that comply with the requirements such as real time, reduced load and eliminating collisions.

Chapter 5

Contribution: A SDMA-Based protocol

5.1 Introduction

There is an urgent need to improve the current transportation system with regard to traffic safety and system efficiency to accommodate the growth of vehicles in near future. To accomplish this, Intelligent Transportation System (ITS) has been employed to provide support for various traffic applications, specifically safety applications. Thus, one of the key factors for the success in promoting safety applications in order to enhance road safety is to keep updated information exchanged between vehicles including speed, position and direction of the vehicles in the vicinity. The exchanged information helps in providing cooperative awareness in vehicular networks. Based on that fact, beaconing is a crucial service to provide safety applications with pertinent information to perform properly. Based on IEEE WAVE/802.11p standards [10], safety communication including beacons share the same wireless medium (CCH:Control CHannel), periodic beaconing with high rate may consume the existent bandwidth and lead to a significant degradation in network performance resulting in a saturated channel due to the lack of any synchronization mechanism. In this work, we propose a new solution that permits synchronization in beacon sending so that collisions are avoided because the sending is not random but serialized in a distributed way. our strategy relies on road segmentation and the vehicles position to determine the right instant to send a beacon packet during a beacon interval. In this chapter, we present our solutions [48] and [49]: In [48], we investigate the feasibility of a beacon session that occurs within one $CCHI$. This way keeps the control channel free to be exploited by other safety applications outside a beacon session. For example, with periodicity of 1 second, we have 10 $CCHIs$; where only one $CCHI$ is exploited for beacons within the whole network and the 9 remaining $CCHI$ are free of beacons. We call this strategy: 'time theft'. In [49], we try to organize beacon sending in the whole period and adding data, we evaluate the impact on such strategy on both beacon reception and data reception ratios.

5.2 Motivation and Contribution of this work

Currently, as they are described in the standard [10], beacons are sent randomly across the network. Periodically, nodes blindly send their beacons, ignoring the presence of the other nodes. They rely on MAC layer access control (CSMA/CA) and back-off algorithm.

However, many studies showed the ineffectiveness of this strategy which leads to severe contention, packet loss and overhead [112][113][119]. In this chapter, we focus on a very important issue that deserves great interest: the neighborhood discovery Link Layer service. Actually, this service is provided by beaconing; with beaconing, we denote the process of periodically broadcasting status information, composed of a vehicle identifier, its geographical position, speed, direction and other important information, enclosed in the beacon frame. This information allows a vehicle to maintain locally a table of neighbors status and be aware of its surrounding. The major part of ITS applications relies on the availability of neighborhood knowledge to guarantee accurate estimation of safety-related situations and to make strategic decisions based on assumed fresh information. Yet, providing such service in VANETs introduces new challenges that motivate our work:

- Considering that all vehicles must transmit their beacons periodically, with a high rate but with no synchronization mechanism, explosively increases the network load resulting in degradation of the communication system global performances;

- Applications in VANETs (Safety and non-safety) principally, rely on broadcasting for the exchange of data and status messages. Yet, broadcast has no delivery insurance because of its weakness in providing collision detection and avoidance. As a result, it causes a high probability of packet loss, mainly in saturation conditions [106][107];

- Sharing the same channel, by several classes of safety packets including beacons, may delay the safety packets transmission due to the channel access conflict;

- Visibly, the frequency of beacons has a direct influence on cooperative awareness and safety traffic as well. Indeed, there is a trade-off between frequency and accuracy: increasing the frequency of beacon generation leads to overhead; while reducing it increases the gap between the last reported location and the real location.

In this work, we propose a new strategy to synchronize beacon sending in a distributed manner so that if two or more nodes need to send their beacons simultaneously, they would be far enough from each other. Our solution is based on road segmentation. Nodes make local decisions according to their positions since the position cannot be the same for different vehicles. In the same segment, which is $2R$ long, where R is the transmission range, nodes sequentially send their beacons with a minimum delay gap of Δt which is an experimental value, expressing the maximum transmission delay, commonly called latency. This way can enhance many issues of the current neighborhood link layer service:

- **Hidden node problem:** Theoretically, parallel beacon sending cannot occur between nodes within $2R$ meters from each other;

- **Collision avoidance:** All nodes within the same transmission range send their beacons with a delay gap of Δt seconds. Thus, no simultaneous sending occurs;

- **Scalability:** Since roads are segmented and the same distributed algorithm is executed, at the same time in each segment, the algorithm should bear existing vehicles with respect to the road rules that define minimum distance gap between vehicles [121].

In our solution, we introduce the concept of beacon session which is an interval of time where all nodes should have sent their beacons. Our distributed algorithm is composed of an infinite number of repeating sessions. In this chapter, we first investigate the feasibility of a beacon session that occurs within one $CCHI$. This way keeps the control channel free to be exploited by other safety applications outside a beacon session. For example, with periodicity of 1 second, we have 10 $CCHIs$; where only one $CCHI$ is exploited for beacons within the whole network and the 9 remaining $CCHI$ are free of beacons. We call this strategy: 'time theft'. In a second investigation, we try to organize beacon sending in the whole period and, adding data, we evaluate the impact on such strategy on both beacon reception and data reception.

5.3 The proposed neighborhood discovery service

The whole protocol provides a technique of organizing the beacon sending across the vehicular network. table 5.1 is created to enlist all abbreviations used for the design. In this section, we present our protocol design.

Table 5.1: List of abreviations

Abrev.	**Description**
SD	Safety Distance
DCCH	Control CHannel interval (Duration) equals 50 ms
P	Periodicity in seconds
CCHI session	Interval of time in which beacons are sent
SS_i	Sub-segment i
R	Sub-segment length
L	Road length
rd	Remaining distance, part of road after segmentation
M	Median line
numlane	Vehicle lane number
d	Direct distance to the median line
D	Distance to the median line after serialization
WT	Waiting Time
l	Number of lanes in a segment
Δt	Maximum transmission delay between two nodes
GT	Guard Time (necessary time to switch from CCH to SCH and vice versa)
minGap	Minimum distance between successive vehicles

5.3.1 Assumptions

We assume that vehicles use wireless communication through omni-directional radio antennas with a transmission range R. Each vehicle is equipped with a Global Navigation Satellite System (GNSS) receiver enabling it to obtain its geographical location and giving it a common time reference. A digital map is preloaded on each vehicle. Combining information from both GNSS and the preloaded map, vehicles can generate information about the road they are moving on such as coordinates of the intersections and the occupied lane number. Vehicles are running in the same direction. Safety distance between vehicles is supposed to be upheld with value SD, according to the applied road rules. The proposed scheme is applied in highway scenarios.

5.3.2 Description of the proposed strategy

When entering a road, each vehicle executes first the segmentation algorithm before participating in the beacon sessions. The goal of our approach is to synchronize beacon sending in such a way that nodes (that are in vicinity) send their beacons sequentially within an interval of time called session. Since beacons are sent in the $CCHIs$, we investigate, in this paper, the feasibility of using one $CCHI$ duration ($DCCH$) to make all nodes within a segment send their beacons. A beacon session will be repeated periodically with a period P. The same strategy is applied in all segments in parallel. The main challenge with this strategy is to make a distributed consensus between nodes to select the same $CCHIs$ called ` $CCHI$ sessions´ to be considered as beacon sessions. In this paper, we propose a solution to meet this task.

Road segmentation

Figure 5.1 shows how the road is segmented by each incoming vehicle. In figure 5.1, the road is divided into m segments of $2R$ long and each segment is itself divided into two sub-segments of R long. Sub-segments are numbered from SS_1 to SS_n. To achieve this segmentation, the following formula can be used:

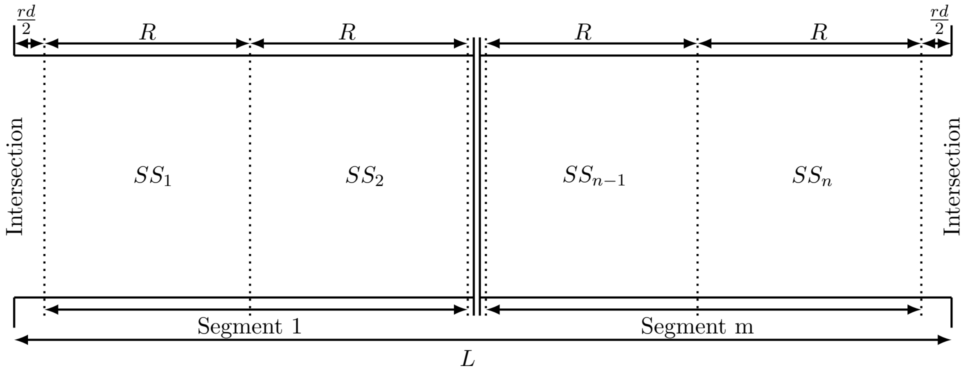


Figure 5.1: Road segmentation

$$L = n.R + rd \qquad (rd < R) \tag{5.1}$$

Where L denotes the road length, n denotes the number of sub-segments which can be odd or even, and rd denotes a remaining distance so that $\frac{rd}{2}$ is added to intersections in each road extremity as shown in figure 5.1.

5.3.3 Description of the environment

As previously mentioned, the strategy is applied simultaneously in all the segments. To simplify, let us describe the system using one segment as it is shown in figure 5.2. We note, in figure 5.2, that lanes are numbered from right to left and from bottom to top in the odd sub-segment and from top to bottom in the even sub-segment. The line (M) denotes the median line of the segment, that separates it into two sub-segments. We assume that each vehicle is able to calculate its lane number, in its subsection *numlane*, by using three parameters, namely: its location, its current lane and the number of lanes in the road. For example, according to figure 5.2 and considering vehicle 2, the corresponding *numlane* is 2. Now, considering vehicle 7, the *numlane* is 6. The process starts when the channel

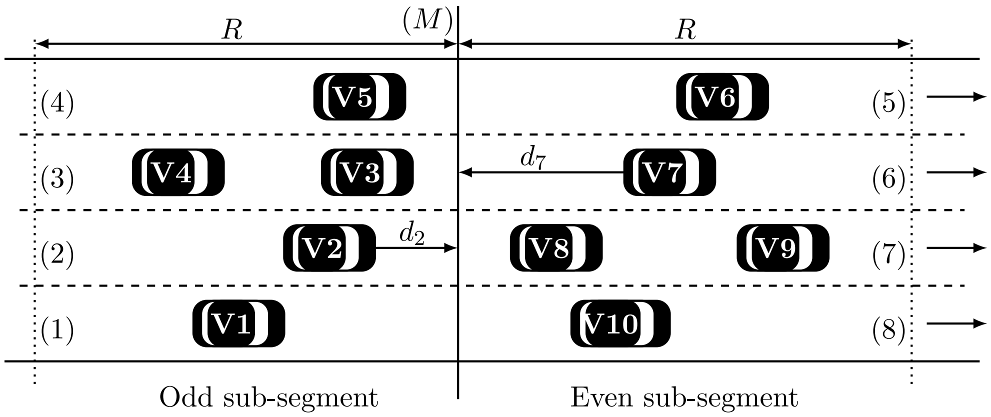


Figure 5.2: Organization of vehicles in a segment

switches to the $CCHI$ session. Each vehicle, within the segment, waits a duration called ` Waiting Time: WT´ before sending its beacon. The WT is proportional to the distance (D), calculated with formula 5.2.

$$D = d + (numlane - 1).R \tag{5.2}$$

Where d denotes the distance of the node to the median line (M) and *numlane* denotes the current lane number of the node in its subsection. For instance, considering vehicles 2 and 7: $D_2 = d_2 + R$ and $D_7 = d_7 + 5.R$. We can say that the value D is unique for each vehicle since vehicles cannot be simultaneously at the same place. To ensure the uniqueness of WT, we define a linear application, defined as a function f.

$f \quad : \quad x \quad \mapsto \quad f(x) = ax + b$

where x expresses the distance D and $f(x)$ expresses the WT. We can give the formula 5.3 as follows:

$$WT = aD + b \tag{5.3}$$

where value a and b can be easily obtained, considering two reference points A and B, belonging to the linear equation 5.3. Table 5.2 gives the two reference points coordinates. Using data in table 5.2, the formula 5.3 can be expressed as follows:

Table 5.2: Reference points

	$x = D$	$y = WT$
A	0	GT
B	$2.R.l$	$DCCH - \Delta t$

$$WT = \frac{DCCH - \Delta t - GT}{2.R.l}.D + GT \tag{5.4}$$

we note that WT is an increasing function of D. So, according to figure 5.2, the sequence of beacons sending is: $V1, V2, ..., V10$; where V_i denotes the vehicle i, $i = 1, ..., 10$.

Necessary condition and Analysis

Let us consider two vehicle $V1$ and $V2$, located in the same segment. According to the formula 5.4, $V1$ and $V2$ sequentially send their beacons, respectively after waiting during

Table 5.3: Numerical application: Minimum distance Gaps between vehicles

$DCCH = 50ms$ $\Delta t = 0,09ms$ $GT = 4ms$								
$R = 300m$								
	1 lane	2 lanes	3 lanes	4 lanes	5 lanes	6 lanes	7 lanes	8 lanes
$minGap(m)$	1,18	2,35	3,53	4,70	5,88	7,06	8,23	9,41
$R = 500m$								
$minGap(m)$	1,96	3,92	5,88	7,84	9,80	11,76	13,72	15,68

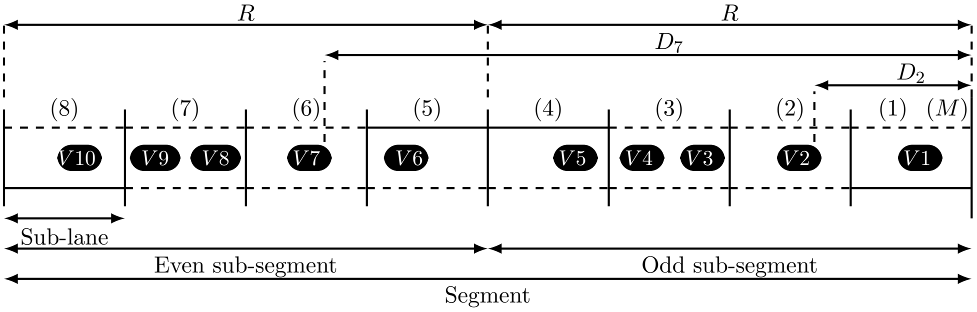


Figure 5.3: Serialization of lanes

$WT1$ and $WT2$. The required condition is given by inequality 5.5:

$$|WT2 - WT1| > \Delta t \tag{5.5}$$

This inequality expresses that the minimum time delay between two successive transmissions, in the same segment, should exceed the maximum transmission delay in order to avoid overlapping of successive beacons. Substituting $WT1$ and $WT2$ with their expressions, we obtain the next inequality:

$$|D2 - D1| > \frac{2.R.l.\Delta t}{DCCH - \Delta t - GT} \tag{5.6}$$

Where $|D2 - D1|$ is the effective distance between vehicles V1 and V2.
This inequality gives the expression of the minimum required distance between successive vehicles called *minGap*. Table 5.3 gives some obtained values after numerical application. In view of some traffic rules over the world for example in [121], the minimum safe distance exceeds the values in table 5.3. This would encourage the adoption of our strategy.
In practice, our organization looks as if the lanes in sub-segments (called sub-lanes) of the same segment are serialized as shown in the figure 5.3. In this latter, we reorganized the road represented in figure 5.2. The multi-lane road looks like a 1-lane road, where sub-lanes are put consecutively as shown in figure 5.3. However, since minimum distance gap *minGap* between vehicles should be respected, according to formula 5.6, we add a fictive distance gap between sub-lanes as shown in figure 5.4. In figure 5.4, we can see that D_2 and D_7 are respectively extended to $D_2^{'}$ and $D_7^{'}$. Therefore the formula 5.2 can be expressed with formula 5.7.

$$D = d + (numlane - 1) * (R + minGap) \tag{5.7}$$

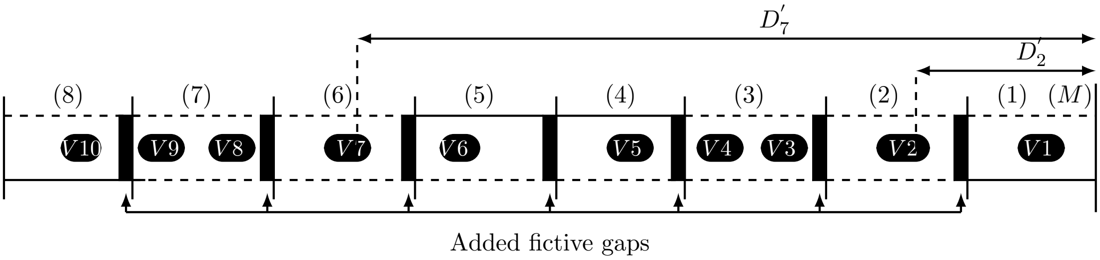


Figure 5.4: Serialization of lanes with added gaps

where *minGap* can be set to the minimum value according to table 5.3. Accordingly, we obtain formula 5.8 which will be used in our protocol implementation.

$$WT = \frac{DCCH - \Delta t - GT}{2.R.l + (2.l - 1) * minGap}.D + GT \tag{5.8}$$

Proposition

Let A and B be two nodes in the network, and let WTA and WTB be their respective waiting times in a given beacon session, we have:

$$WT_A = WT_B \quad \Rightarrow \quad dist(A, B) \geq 2.R \tag{5.9}$$

In other words, given two or more nodes in the network, if they have an equal waiting time, they should be located sufficiently far from each other to avoid collision, when sending their beacon at the same time.

Proof

For the sake of simplicity, let us consider a one-lane road and X-axis parallel to the road. Substituting WTA and WTB with their expressions in the formula 5.4, we obtain:

$\frac{DCCH-\Delta t-GT}{2.R.l}(D_B - D_A) = 0 \quad \Rightarrow D_B = D_A$

This means that the two nodes are located at the same relative position to their medians, which denotes that the two nodes are in separate segments and are located in the same side of their medians. According to this, and supposing that the two nodes are located in the odd sub-segment, we can say that: $D_B = D_A \quad \Rightarrow \quad d_B = d_A \quad \Rightarrow \quad xMB - posB = xMA - posA \Rightarrow \quad posB - posA = xMB - xMA$, where $x = xMA$ and $x = xMB$ are respectively the equations of the two medians of the segments related to the node A and B.
According to the segmentation method, $xMB - xMA \geq 2.R \quad \Rightarrow \quad dist(A, B) \geq 2.R$

Effect of the nodes' mobility

We assume that mobility will have an impact on our protocol design. For example, a vehicle running with a speed of $30m/s$ crosses a distance of $1.5m$ in $50ms$, that is the duration of a beacon session. With the simulation study, we can estimate this impact.

5.4 Packet format and Algorithms

5.4.1 Packet format

We added one field (*synchDate*:2 bytes), that is used to synchronize the nodes in the network to the original beacon packet. Synchronization will be presented in the following section. This field first represents the date of accessing the road by a vehicle. It will be updated on receipt of beacons from neighbors so that it contains the oldest date received. All the nodes that have the same value of *synchDate* are considered as synchronized in terms of sending their beacon within the same session ($CCHI$).

5.4.2 Algorithms

For the sake of simplicity, we assume that x-axis is parallel to the road direction. The protocol is composed of three main procedures presented in the following.

Procedure INIT

3 Initialization

```
procedure INIT
    $GetParameters(CoordIL, IR, R, curDate, l, nl, P, direction)$    ▷ //IL,IR:Intersection coordinates resp. left and right sides
    $switch \leftarrow false$    ▷ //to allow a random waiting before starting the beaconing process
    $syncgDate \leftarrow curentDate$
    $nMaxSwitch \leftarrow Pdiv100$    ▷ //$P$ in ms
    $countSwitch \leftarrow 1$
                                        ▷ //ex: $nMaxSwitch$=10 to get $P$=1 sec
    $list \leftarrow SEGMENTATION(IL, IR, R)$
    $wait(random\,[0,1])$
    $switch \leftarrow true$
end procedure
```

When entering a road, each vehicle executes the initialization procedure. This procedure serves to initialize variables and to segment the road, in order to set the beginning of each segment, sub-segment and the related fictive median line (M). A list of segments and their descriptions is generated consequently. In initialization, each node considers itself a leader and takes the responsibility to synchronize the other nodes in the network, by setting the variable *synchDate* to the current date. By convention, the node that has the lowest value of *synchDate* will be the leader as it is the most ancient in the system. Before starting their beacon process, nodes wait for a random time, in the interval [0,1] seconds, to avoid congestion in case of high vehicle flow arrival.

Procedure ONRECEIPT

This procedure has two goals: the first is synchronization: The nodes are synchronized when they all have the same local variable *synchDate*. The second goal is the neighborhood table update. Synchronization consists of a distributed consensus of making all nodes send their beacon within the same beacon session (the same $CCHI$). As we can notice, the synchronization does not generate additional messages. It takes place on receipt of a

4 On receipt of beacon Packet Algorithm

```
 1: procedure OnReceipt(packet WSM)
 2:     if ($nMaxSwitch = 1$ or $countSwitch = nMaxSwitch$) then
    ▷ //no synchronization needed
 3:         goto step 10
 4:     end if
 5:     if $WSM.synchDat < synchDate$ then
 6:         $synchDate \leftarrow WSM.synch_{d}at$
 7:         $switch \leftarrow true$
 8:         $countSwitch \leftarrow nMaxSwitch$
 9:     end if
10:     $updateNeighborTable(WSM)$
11: end procedure
```

beacon packet from a neighbor which means that this neighbor is executing its beacon session. The receiver synchronizes itself with the sender if the received *synchDate* is lower than the local *synchDate*. There are many cases on receipt of a beacon listed below:

- **The period is fixed to 0.1 seconds:** $nMaxSwitch = 1$. This means that all $CCHIs$ are beacon sessions; so no need for synchronization;
- **The sender and the receiver are already synchronized** (they have locally the same values of *synchDate*). In this case also, no action is needed;
- **The sender** *synchDate* **is lower than the local** *synchDate*. This means that the two nodes are not synchronized with each other and the receiver will be synchronized with the sender by setting its local variable *synchDate* to the received value of *synchDate* (L6); and, by setting *countSwitch* to $nMaxSwitch$, the receiver ensures that it will have the same beacon session as the sender's since the last has executed the same instruction before sending its beacon ($ONSWITCH : L5$).
- **The received** *synchDate* **is greater than the local** *synchDate*. This means that the two nodes are not synchronized with each other. But in this case no synchronization is ensued.

Procedure ONSWITCH

5 Periodic sending beacons Algorithm

```
 1: procedure OnSwitch
 2:     if $switch$ then
 3:         $countSwitch \leftarrow countSwitch - 1$
 4:         if $countSwitch = 0$ then
 5:             $countSwitch \leftarrow nMaxSwitch$
 6:             $WT \leftarrow CalcWT()$
 7:             $schedule(Send(WSM), WT)$
 8:         end if
 9:     end if
10: end procedure
```

OnSwitch procedure is invoked when the channel turns to CCH frequency. It is used to launch a beacon session and to maintain periodicity of the beacon process. In this procedure, when the beacon session starts, all nodes calculate their waiting time WT according to the formula 5.8 and schedule their sending accordingly.

5.5 Extension of the proposed strategy: Load balancing SDMA-Based protocol

In this section, we propose a neighborhood knowledge link layer service that operates in two steps: first, when a beacon session starts, the vehicles self organize into groups depending on their positions. Each group is then affected one respective CCHI along the period P. Inside each CCHI, the beacons are sent successively. A beacon session is defined as an interval of time where all beacons should have been sent. In the previous work a beacon session takes an amount of time of one CCHI which may create a stress in this period of time and may result in congestion. The load balancing method, proposed in this section, permits to distribute all beacons sending along all the period, where transmissions occur sequentially. This means that all the CCHIs in the same period are involved. Thus, the algorithm is made of an infinite number of repeating sessions. The whole protocol provides a technique of organizing the beacons sending across the vehicular network. The aim of this work is to study the impact of this strategy on data reception ratio and the impact of data overhead on beacon reception ratio. In this work, the same technique of segmentation, lanes coding and serialization are kept. In addition, the environment and all assumptions are the same. Table 5.4 enlists additional abbreviations used in the design. In the followings, we present the protocol in details.

Table 5.4: List of additional abreviations

Abrev.	**Description**
DCCH	Control Channel interval (duration) equals 50 ms
CCHI	Control Channel Interval
effCCHI	The effective time when beacon can be sent along a CCHI
effSession	The total effective time when beacon can be sent regarding the number of CCHIs in the interval
nG	Total number of groups regarding the period. Ex: if P=0.3s ⇒ there will be 3 CCHIs in this interval ⇒ nG=3
numGroup	Group number of a vehicle
EWT	Expected Waiting Time

5.5.1 Overview

As well as the previous work, the proposed strategy aims to provide a technique to organize beacons sending along a CCHI so that if more than one beacon is sent at a given time t, the senders would be enough far from each other to avoid collisions. Indeed, beacons are synchronized. Furthermore, the proposed solution provides an auto-organization of vehicles into dynamic groups in order to spread beacon load all along the period. The beaconing strategy steps are shown in figure 5.5. First, when a vehicle enters a new road it has to virtually divide the road into segments, according to the previous strategy, and define its corresponding one according to its current position. After this operation, the vehicle tends to synchronize with the existing vehicles. Synchronization is the process with which all vehicles agree on the same time beginning of periods. All the system is made of infinite repetition of periods. Thus, before participating to the beacon process, a vehicle waits a random delay while it listens to the other vehicles' beacons, from what it concludes the beginning of the next period. Once it synchronizes itself, the beacon process is on. The proposed strategy is built on two pillars. The first, is organizing vehicles into groups to ensure a load balancing of the beacons sending; the number of groups is given by the number of CCHIs during a period P. For example, a period of P=0.5s includes five CCHIs, so there will be five groups. All the vehicles in the same group send their beacon in the same CCHI. In that way, there will be a distribution of vehicles sending along the period, so that in each CCHI in the same period a limited number of vehicles belonging to the corresponding group will be involved in sending beacons. A period is considered as a beacon session where all vehicles in the system have sent their beacons. One challenging task with this strategy is to make a distributed agreement on the beginning of a beacon session. The second pillar is organizing beacon sending so that only one beacon is sent in a segment at the same time. The same behavior is in vigor in all segments, only one vehicle auto-elects itself to transmit its beacon that does not interfere with the other beacons in the other segments. Figure 5.5 shows UML State Machine that describes vehicle behavior in the proposed beaconing process.

5.5.2 The load balancing technique

The load balancing technique is based on organizing vehicles into groups. Thus, each vehicle uses its local value D to auto-determine its belonging group. Thus, it calculates the effective duration of a beacon session. For instance, the effective sending duration in one CCHI is given by: $effCCHI = DCCHI - GT - \Delta_t$. Where $DCCHI = 50ms$, $GT = 4ms$ of guard time and Δ_t is the maximum transmission delay. So, the effective session is given by, $effSession = nG * effCCHI$. Where nG is the number of groups in a session which corresponds to the number of CCHI in a session. This duration $(effSession)$ is used to create a linear function f defined as follows: $f \ : \ x \ \mapsto \ f(x) = ax + b$ where x expresses the distance D and $f(x)$ expresses the expected waiting time EWT for the corresponding vehicle. We can give the equivalent formula as follows: $EWT = aD + b$. Where value a and b can be easily obtained, considering two reference points A and B, belonging to the the same linear equation. We obtain the formula 5.10 expressed as follows:

$$EWT = \frac{nG(DCCH - \Delta t - GT)}{2.R.l}.D \tag{5.10}$$

we note that EWT is an increasing function of D. With the value of EWT, a vehicle can obtain its group number by using the next formula:

$$numGroup = RoundUp(\frac{EWT}{effCCHI}) \tag{5.11}$$

simplifying with $effCCHI$, we obtain:

$$numGroup = RoundUp(\frac{nG}{2.R.l}.D) \tag{5.12}$$

Where, $RoundUp$ gives the smallest integer value greater than $\frac{EWT}{effCCHI}$. As an example, let us consider the vehicle $V7$ of figure 5.3. Let us give an arbitrary value of $60m$ for $d7$ (the distance of $V7$ to the median line M). At the beginning of the beacon session,

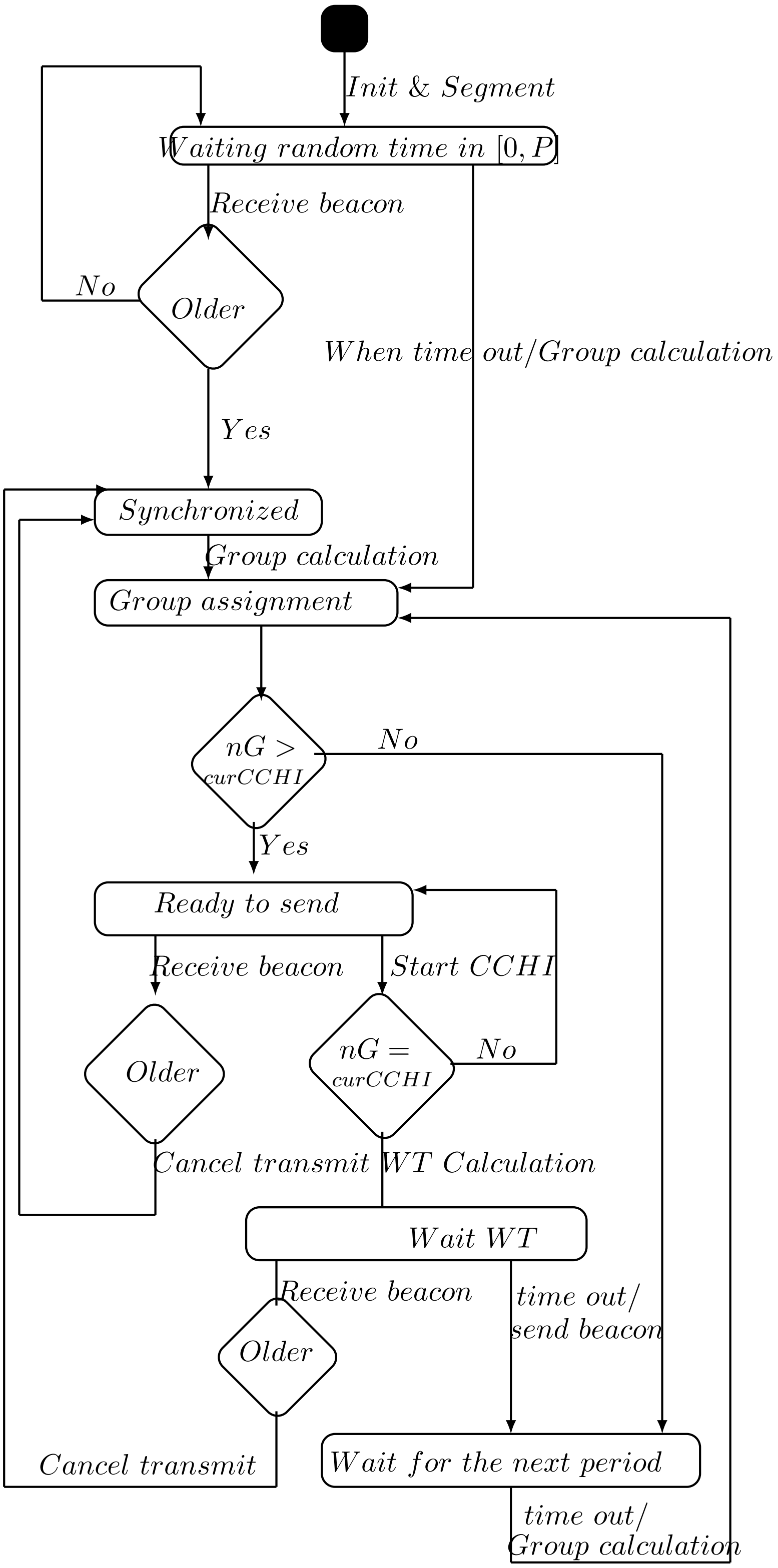


Figure 5.5: UML state machine

vehicle $V7$, first, calculates $D7$ by the formula 5.2. $D7 = d7 + (6 - 1)R = 1060m$ (with $R = 200m$). Then, it calculates its proper group with the formula 5.11 (In this example nG=3 because we take p=0.3s that signifies that there would be 3 CCHI in this interval). So, $numGroup = roundUp(1.9875) = 2$. The vehicle V7 will wait until the beginning of the next CCHI from the current one to calculate its WT by using the formula 5.13 according to its new position on the road. After calculating its WT, it has now to schedule its beacon creation and sending after a timeout of WT. Figure 5.6 illustrates an example on how vehicles within a segment are organized into groups. We kept the same environment of figure 5.3 and we gave approximate values for D to obtain their ordinate EWT. As we can see in this figure, Vehicle V1,V2,V3 and V4 belong to the first group: G1; vehicle V5,V6 and V7 belong to the second group: G2 and vehicle V8, V9 and V10 belong to the third group: G3.

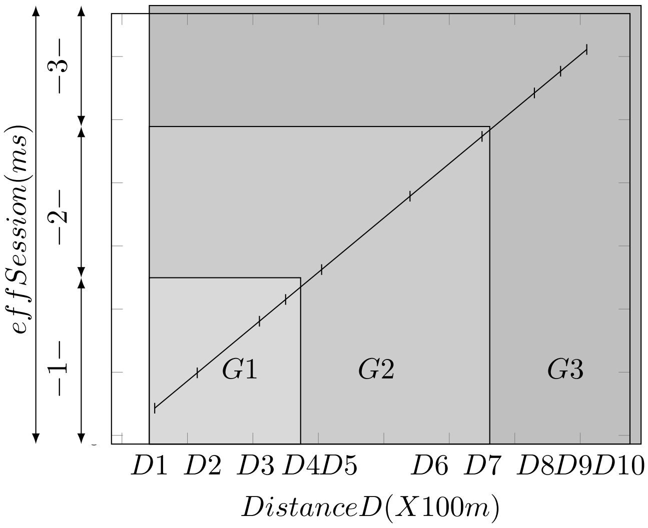


Figure 5.6: Groups assignment, P=0.3s

5.5.3 Organizing vehicles sending along the corresponding CCHI

The beacon sending of all vehicles, in a segment with the same group number, follows a linear equation g of (D, WT) where D is given as the distance to the median according to the serializing mechanism and WT is the Waitng Time before sending, starting at the beginning of the corresponding $CCHI$. Each vehicle in the corresponding group calculates its waiting time (WT) according to the formula: $WT = g(D)$. Where, g is a linear function given by:

$$g : WT = \frac{DCCH - \Delta t - GT}{2.R.l}.D + GT \tag{5.13}$$

The vehicle waits duration of time WT before sending its beacon. As we can see in formula 5.13, WT is proportional to the distance D. So, all beacon sending will be sequential in the same segment. Furthermore, since only vehicles belonging to the group are involved with transmitting their beacons, the beacon load will be spread over the period which leads to load balancing.

5.5.4 Synchronization

Synchronization is crucial because the beaconing process depends upon it. If nodes fail to synchronize, beacons may be sent randomly across the network because each vehicle or separate groups of vehicles may have their own knowledge of the session beginning which may be different from the other nodes. Synchronization is the process by which all nodes in the system agree in the same starting time of a beacon session. This process is in the background of beaconing process. It does not require additional messages but uses information included in the beacon packet. All vehicles set a local date when entering a road. On receiving a beacon message, if the date included in the message is older than the local date, this latter will be updated to the received date. This is because the sender is considered older in the system and sending its beacon currently, signifies it is in its beacon session. So, the receiver updates its beacon session to the senders and cancels its sending. Then it calculates its group number taking into account the remaining time until the end of the session and decides whether it can participate to the current session. If it cannot participate because its group number is left, it waits until the next session.

5.6 Simulation study

In this simulation, we use veins-2.1 tool [122]. Veins is an open source Inter-Vehicular Communication (IVC) simulation framework, composed of two distinct simulators; an event-based network simulator OMNeT++ [123] and SUMO [124] for road traffic simulation. During a simulation, OMNET++ and SUMO run in parallel and communicate via a TCP socket. The Veins framework relies on fully-detailed models of IEEE 802.11p and IEEE 1609.4 DSRC/WAVE network layers, including multi-channel operation, QoS channel access, noise and interference effects to make vehicular network simulation as realistic as possible [122]. The simulation is held in two steps; in the first step we demonstrate the feasibility of our approach. For this, we need to characterize our protocol and show how much it fits the design. In the second step, we evaluate the performances; we study our protocol behavior under different situations such as varying the density and the periodicity, and comparing our service with simple beaconing, as described in the standard [10].

5.6.1 Simulation scenario and configuration

Table 5.5 summarizes the parameters considered in our simulation. We assume that vehicles use wireless communication and all transmissions are omnidirectional with communication range R. Vehicles are equipped with devices (such as a Global Positioning System (GPS) device) enabling them to obtain their geographical location at any time, and a preloaded digital map which provides information about roads such as intersections coordinates, the number of lanes in a given road, and so on. We assume that vehicles move on a straight road of 3 km with multiple lanes as shown in figure 5.2. Vehicles move with respect to a minimum distance gap which is considered as a safety distance. Moving direction of vehicles is towards east with average speed S. We assume that only the distance between vehicles determines successful beacon reception, this means that we do not consider channel fading due to obstacles.

5.6.2 Preliminary simulations

This section shows our protocol characteristics and validates our approach by means of simulation throughout the following metrics:

- **Beacon distribution:** For each beacon sending, we record the position of the sender and the time of the sending. The measure lasts for 5 seconds. Each point represents a couple of data (t, p), where t is the time of sending and p is the position of the

Table 5.5: Simulation parameters

Parameter	**Value**
Propagation model	Simple Pathloss Model
Parameter alpha	2.4
CarrierFrequency	5.890e+9
txPower	20mW
Bitrate	18Mbps
Receiver sensitivity	-94dBm
maxTXPower	20mW
thermalNoise	-110dBm
Channel bandwidth	10MHz
thermalNoise	-110dBm
Periodicity of Beacon generation	0.1s, 0.5s, and 1s
Packet length	Standard DSRC: 512 bits Our protocol: 512+16 = 528 bits
Priority	3
Road length	3 Km
Sub-segment length R	300 m
Number of lanes	4
Vehicles densities	21, 45, 66, 90, 110, 125, and 135 Vehicle/Km/lane
Maximum vehicle velocity	30 m/s
Minimum distance gap between vehicles 'minGap'	5 m (according to table 5.3)
Vehicle length	2 m

related node. We can clearly see with figure 5.7 that in the standard, the beacons are randomly sent across the network whereas in our protocol they are organized in sessions as shown in figure 5.8.

- **Experimental relation between node position on the road and its waiting time:** This is an experimental representation of the equation 5.8. At the beginning of a beacon session (randomly selected during the simulation), we record the waiting time, calculated by each vehicle, in a given segment of 600 m of road selected randomly; and its distance D, calculated with the formula 5.2, by using its real position on the road, given by the simulator. Figure 5.9 shows that the waiting time really follows a linear equation, as it has been designed and, consequently, the beacon sending is synchronized since vehicles wait a distinct delay, depending on their positions before sending.

- **Delay between successive transmissions in the network:** With this metric, we aim to validate the necessary condition of formula 5. As we mentioned previously, the mobility scenarios were generated with respect to minimum following distance which is 5 m in our simulation (table 5.3). Figure 5.11 gives the delays between successive transmissions in one segment, selected randomly during one beacon period of 1 s.

We can see no value obtained under the line $\Delta t = 0.09ms$. This means that beacons are sent successively with a delay gap greater than $0.09ms$. However, in figure 5.10, the minimum delay gap tends to 0 which explains the existence of contention and collisions in the network.

- **time of synchronization:** At simulation launch, the beacon process is not stable because it takes some time for vehicles to be synchronized after the random exchange of the first beacons. This time is evaluated under different scenarios and represented in figure 5.12. This latter shows that the more the density increases and the more the periodicity decreases, the vehicles synchronize faster. We also noticed that once the system is stable the incoming vehicles are synchronized immediately after the first beacon received.

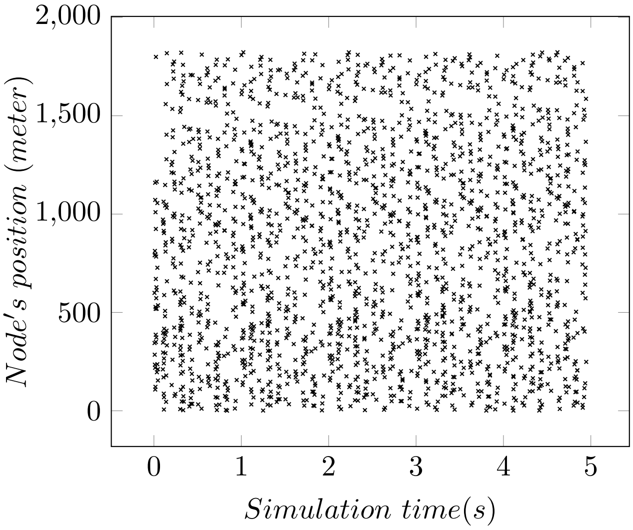


Figure 5.7: Sending distribution with DSRC periodic beacon.
P=1s, Density=66 Veh/km/Lan

5.6.3 Measurement and interpretation

We evaluate the two beaconing protocols, using the following metrics well and clearly defined in [125]. The measures are taken within 10 seconds of the system activity. Each measure is repeated 5 times with different scenarios and the final result is the mean of the different measures.

- **Channel Load:** *The channel load is the amount of data traffic, in bits/sec, a node u is exposed to during a time period t*[125]. More precisely, in our simulation, channel load is measured in *bits/s*, by summing all transmissions issued from a node, chosen randomly from the network and all received packets by the same node from its neighbors. This metric expresses the bandwidth consumption by the process of periodically transmitting the beacon messages.

- **Neighborhood Awareness:** *The neighborhood awareness is a metric which describes the probability that a node u is aware of its neighboring nodes*[125]. We calculate this metric as a ratio between the number of beacons received by a node u, randomly

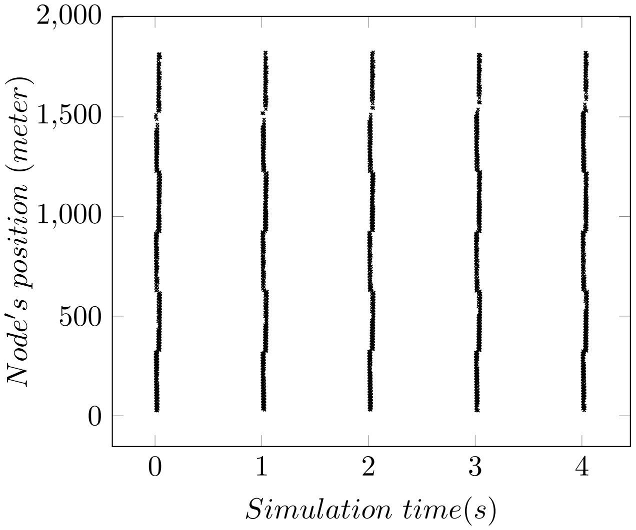


Figure 5.8: Sending distribution in our SDMA service. P=1s, Density=66 Veh/km/Lan

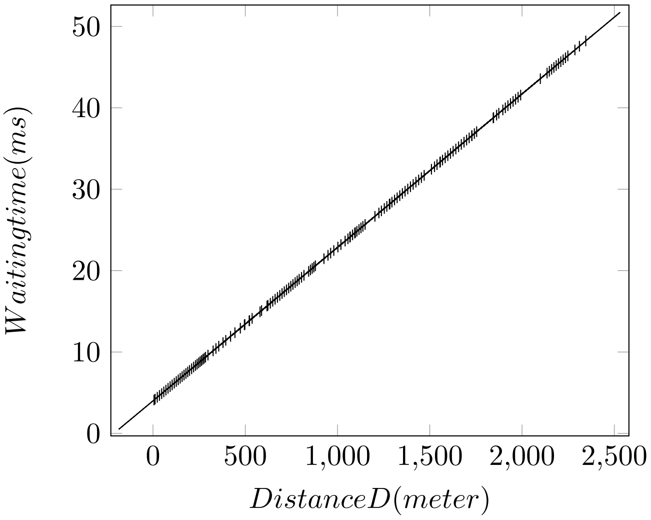


Figure 5.9: Empirical relation between position and waiting time.
Density=66 Veh/Km/Lan, P=1s, section of road = 1 segment of 600 m length

chosen from the network, out of the number of nodes present in u's vicinity, during one period P. This metric can also inform about the successful reception/Packet loss ratios since the successful reception ratio expresses the percentage of neighbors' beacons received by the node u [126].

- **Beacon Information Age:** The beacon information age is interpreted *as the average inter-reception time between two beacons of the same originator*[125]. This metric denotes the freshness of the information.

Figure 5.13 shows that our protocol does not improve the channel load since the same amount of packets is transmitted periodically in a deterministic manner in both protocols. Indeed, with the variation of density, the periodicity is kept with the same value and no adjustment mechanism is used. Furthermore, with the periodicity of $0.1s$, we can notice

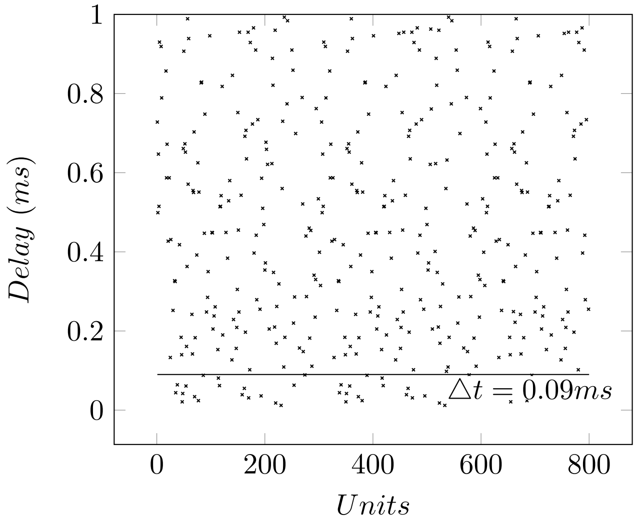


Figure 5.10: Delay between successive sending in DSRC service.
P=1s, Density=135 Veh/km/Lan

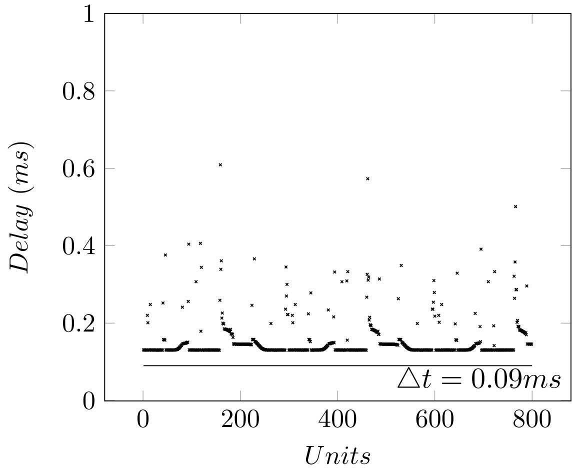


Figure 5.11: Delay between successive sending in our service.P=1s, Density=135 Veh/km/Lan

that our protocol records the highest values of channel load. This is due to the high transmitted packets on one hand and to the high ratio of packet loss in the standard, as it is confirmed in figure 5.15, on the other hand. In Figure 5.14, we can see the particularity of our protocol in terms of distribution of the channel load. We can see that the bandwidth is highly consumed in beacon sessions while it is free outside. This distinctive characteristic can allow other safety applications to exploit the entire bandwidth in the free time. In figure 5.15, we can note that, with our protocol, the awareness is close to 100% while the density variation has no important effect on our protocol. Figure 5.16 shows that the information age is close to the periodicity for both the standard and our protocol in low density. Our protocol keeps almost the same performance while the density increases and the standard degrades, especially with high beacon rate (P=0.1 sec).

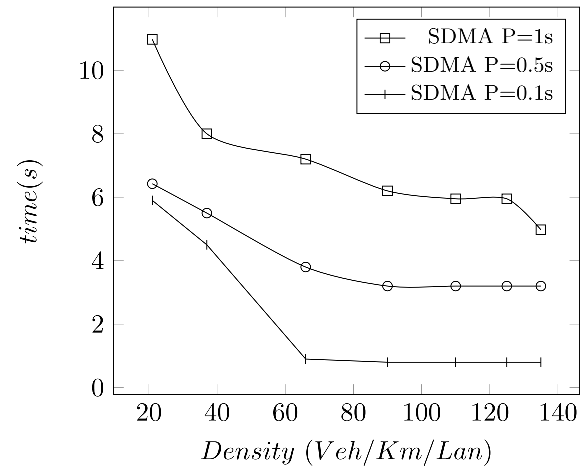


Figure 5.12: Synchronization time

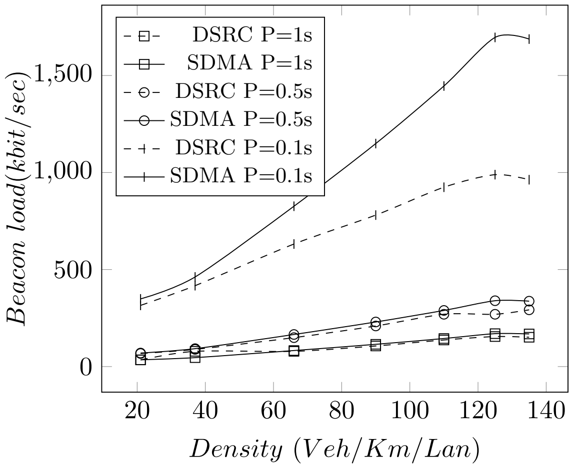


Figure 5.13: Beacon load

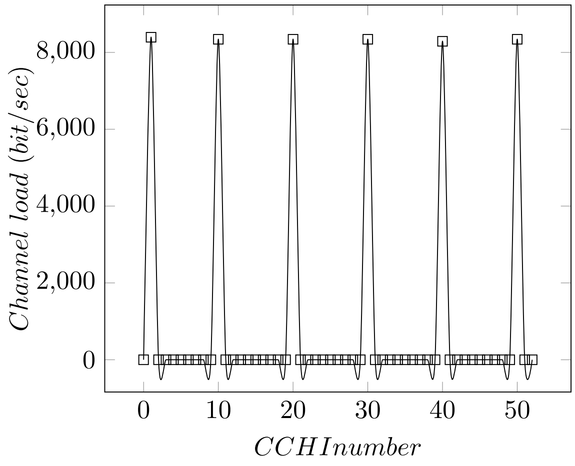


Figure 5.14: SDMA beacon load distribution.Density=80 Veh/Km/Lan and P=1s

5.6.4 Measurement and interpretation: Extended work

In the following, we present the performance metrics considered in this work and how measures are taken. We give the measurements realized during the simulation study and

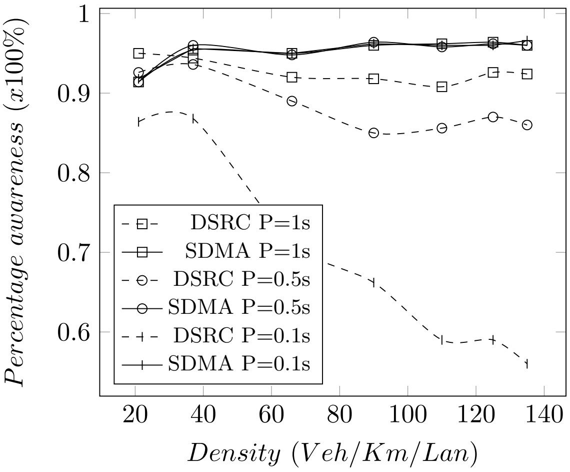


Figure 5.15: Neighborhood awareness

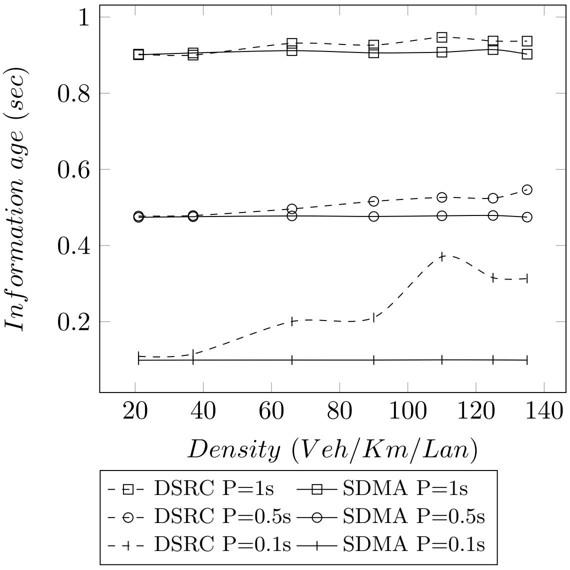


Figure 5.16: Information age

results interpretation:

- **Beacon distribution:** For each beacon sending, we record the value D for every vehicle within a segment from 0 m to 400 m, which gives values for D from 0 m to 1600 m because the four lanes are serialized, and the related time of beacon sending t is taken during one beacon session chosen randomly in the simulation run-time. We obtain a list of data couples (D, t). This measure is intimately related to our strategy and shows how beacons are distributed during a beacon session $P = 0.5s$. As it is illustrated in figure 5.17, beacons are distributed into 5 groups and in each group they follow a linear equation as it has been designed.

- **Synchronization delay:** When the simulation is launched, vehicles that are entering the road are not synchronized. First, as stipulated in the protocol design, after a random time of waiting, if vehicles do not receive a beacon, they consider the next $CCHI$ as the beginning of a beacon session. thus, it takes some time for vehicles to

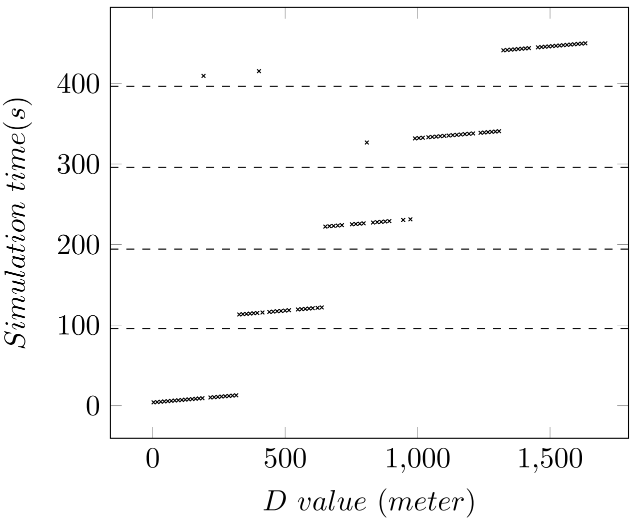


Figure 5.17: Sending distribution with SDMA approach.
P=0.5s, Density=66 Veh/km/Lan

be synchronized after the random exchange of the first beacons. This time is called *Synchronization delay* and is evaluated under different scenarios. Figure 5.18 shows that in the worst case it takes 9.8s with periodicity P=0.8s to all the nodes in the network to be synchronized. This delay decreases with the increase of the density and the decrease of the periodicity. We also notice in the simulation that once the system is stable, the incoming vehicles are synchronized immediately after the first received beacon.

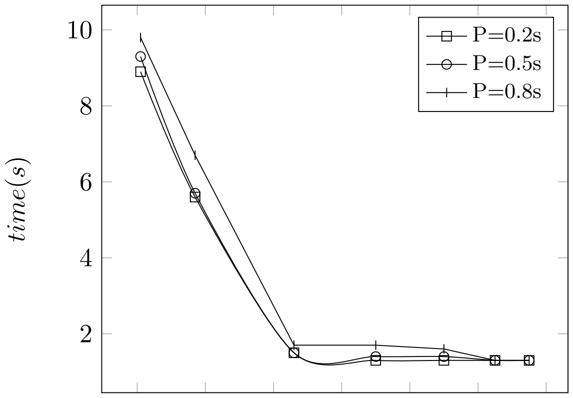


Figure 5.18: Synchronization time

- **Neighborhood Awareness:** It is expressed as a ratio between the number of beacons received by a node u, randomly chosen from the network, out of the number of nodes present in u's vicinity, during one period P. This metric informs also about the percentage of successful reception [126]. At the same time we can use it to estimate packet loss ratio with the next formula: $PLR = 1 - SRR$, where PLR is the packet loss ratio and SRR is the successful reception ratio. In figure 5.19,

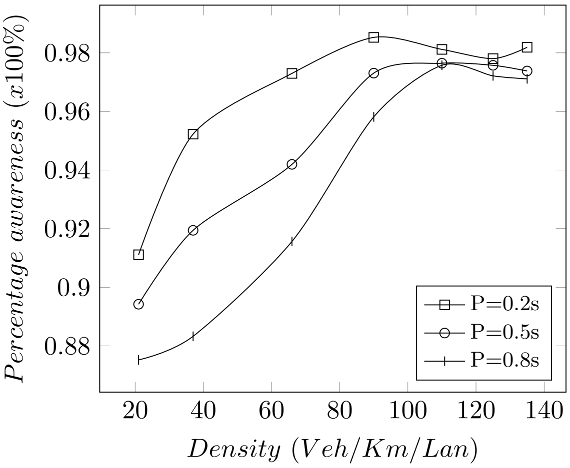


Figure 5.19: Neighborhood awareness

we notice that the awareness is higher than 80% for all situations. The awareness increases with the density increase and it is higher with higher beacon rate. With presence of data, the awareness is still high as it is illustrated in figure 5.20. Figure 5.20 illustrates the awareness as it is obtained by the DSRC to get a reference on how much our protocol is stable. The awareness is almost the same while varying the periodicity of the beacons and increasing the data flow. We notice a slight packet loss with the increase of data flow which is due to collisions because data flow is generated randomly in the network. In the DSRC service, the awareness increases with the decrease of both beacon rate and data flow.

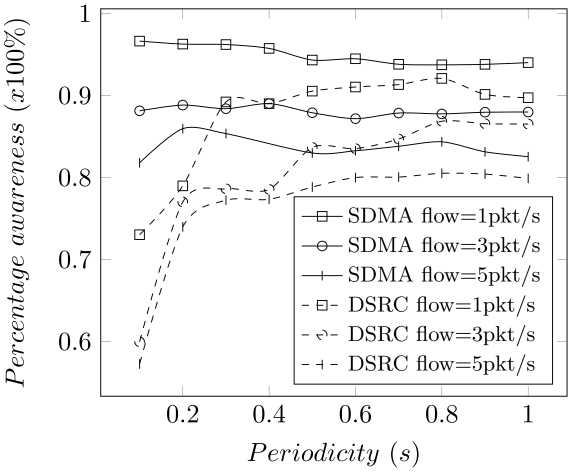


Figure 5.20: Neighborhood awareness in presence of data flow.Density=135veh/km/lan

- **Successful data reception:** The successful data reception is measured along a beacon session and it is given by $DRR = \frac{DR}{N}$, where DRR is the data reception ratio, DR is the received data and N is the number of neighbors present in vicinity. This metric is measured at an arbitrary node and its neighbors are known, thanks to the network simulator which is able to take this information from the mobility scenario. For this metric, we considered a density of 135 vehicles/Km/lane. Figure

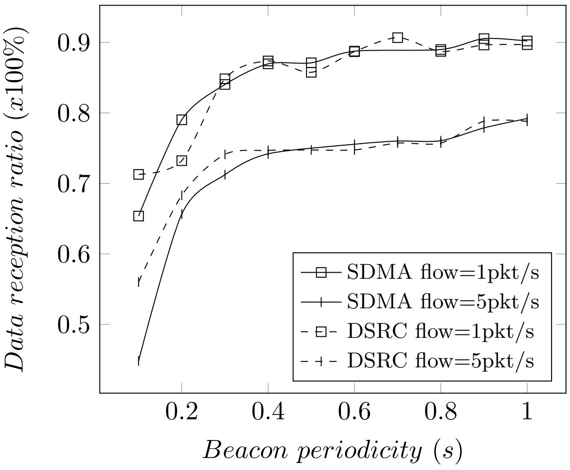


Figure 5.21: Data reception ratio. Density=135veh/km/lane

5.21 shows the influence of beacons on data reception with both the standard DSRC and our SDMA service. We can see that the data reception ratio increases with the decrease of beacon rate (increase of periodicity) with both services; and, with high beacon rate and high data flow, the standard DSRC performs better. The graphs have a logarithmic shape; They increase until p=0.5s and then they become horizontal which means that the variation of beacon rate does not highly affect the data reception. The increase signifies that with high beacon rate (low periodicity), there are collisions that decrease the data reception ratio. In this case we suggest to apply adaptive beaconing to adjust the beacon rate with traffic and communication status. Indeed, there is no point to keep a high beacon rate in case of high density unless for emergency situations. The variation of data rate DR is also responsible for packet loss; as we can see in figure 5.21, the higher data reception ratio is obtained with data flow of 1 packet per second.

- **Neighborhood information age:** As we mentioned previously, This metric denotes the freshness of the information. Figure 5.22 shows that, without data flow, the information age is stable and close to the periodicity even varying the density. this means that there is no contention between beacon packets, thanks to the proposed organization. Contention is sensed when data flow is added to the communication system. With a data flow of 1 packet/s there is a slight contention. With the increase of data flow the contention becomes more visible, especially with the increase of the density, but does not degrade the performance since information age does not exceed the periodicity.

5.7 Conclusion and future work

In this work, we showed, via simulation, that our approach is feasible. The challenge was to realize a beacon session in one $CCHI$ so that all nodes in the network can make a consensus on the same CCHI, in a distributed manner, and without the use of any additional messages. This way, other safety applications can use the remaining $CCHIs$ in the period separately; that is what we call 'time theft'. The simulation results are satisfactory and show that our approach can efficiently provide accurate and fresh information about neighbors. In addition, load balancing approach tries to equilibrate the

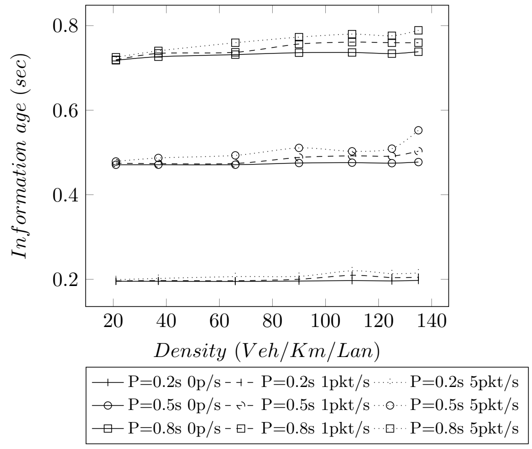


Figure 5.22: Information age (Data in packet/second)

beacons transmission during the period to avoid the stress that accurs when all beacons are sent in one $CCHI$. In this extension we show the effectiveness of our strategy. Indeed, by introducing data packets in the system for more realism, we showed by simulation that the awareness is not degraded in spite of the high priority assigned to data packets. On the contrary, the results were relatively stable notably for the percentage awareness. Information age denotes reception delays. In presence of data packets, we noticed a certain delay in beacon reception, especially with high density which denotes contention. But delays are close to the period values.
Furthermore, imperfect positioning, low time synchronization accuracy and maps error margins can degrade SDMA performance. So, in future work, we will investigate our approach with a real map with two circulation directions. We will combine our solution with the adaptive approach to create a dynamic beacon rate that will be sensitive to the traffic conditions in order to improve the channel load: We argue that adaptive beacon generation rate can improve the performances if it is joined to our strategy since there is no need of high beacon rate in dense traffic unless in emergent situation.

Chapter 6

Conclusion

Vehicular networks have the potential to improve significantly safety on roads. They constitute the basic infrastructure for Intelligent Transportation Systems (ITS) where safety applications are the core component. These applications are diverse, according to the environment (V2V, V2I or hybrid) and the goal such as information pulling in order to regulate road traffic, danger warning, etc. these applications are differenciated by the fact they are time sensitive or not. In this context, dissemination is a key tool to forward useful information in timely manner. Our work covers two aspects of dissemination: alert dissemination and beaconing. The goal of alert dissemination is to spread urgent information, generated in reaction to a sensed danger, within a set of vehicles that are running towards the danger. Accordingly, we studied dissemination techniques in the literature where we highlighted the challenging compromise between such application's requirements in terms of efficiency and delay and the severe environment from the point of view of deployment sites and existent technology. Thus, a classification of alert dissemination protocols is issued from this study, based on the way relay nodes are selected for multi-hop message forwarding [43]. Consequently, we proposed two dissemination protocols [44] [127] [45] [128] [46] [47].

The second part of our study deals with beaconing which is a link layer neighborhood discovery service in wireless networks. It consists in periodic exchange of short messages containing status information (position, speed, direction etc.). In addition, beaconing in VANETs can serve to safety applications in providing topology information to the nodes and piggybacking additional information to ensure its reception. Besides, since beacons are sent periodically, beaconing is widely proposed as a tool for accident avoidance by providing status information about vehicles such as abnormal driving. Through this thesis, we studied several papers in the literature and proposed a classification of beaconing strategies. Most of the existing strategies propose adaptive solutions to decrease the channel load regarding the network parameters such as density and emergency of the situation. Besides, we proposed an organizing strategy based on Space Division Multiple Access technique (SDMA) where beacon sending depends on vehicles location [48] [49]. During our study, we were interested in many secondary but related works such as channel access control [129] and simulation tools since we had to try the best available simulators [50]. We conclude our thesis work by giving constructive critics, recommendations and the direction for future work.

6.1 Summary of our contributions

We have first examined the related literature. The main result was a classification of dissemination protocols according to the way the relay node is selected for forwarding the dissemination message and a classification of beaconing solutions according to the applied techniques. The literature study allowed us to understand the related issues and the challenges. Based on this comprehension, we proposed three warning dissemination protocols: UB, UUB and DGcast and two beaconing protocols: A SDMA-based and a load balancing SDMA-based. As a part of that, we had to use NS2 and Veins as simulation tools, which gave us a better understanding of simulation tools requirements and how to choose a simulator. Furthermore, on behalf of this project, we had to study many Channel access control protocols and we participated in designing a MAC protocol that proposes an adaptative Backoff mechanism based on fuzzy logic.

6.2 Extensions of the work

Possible extensions of this work are as follows:

- The proposed warning dissemination protocols need to be simulated with more realistic simulators such as Veins and more quantitative metrics should be considered such as message dissemination propagation speed. Furthermore, real maps, realistic mobility models and realistic propagation models should be used for the proposed simulation varying environments from highway to urban to obtain more accurate results. A simulation study comparing these solutions with some related works is underway.

- A new solution for the feasibility of DGcast in severe environment where smart auto election is required in case of forwarding failure caused by unreliable links. An extension of DGcast is being designed followed by a thorough simulation study in severe environment.

- Extending the proposed beaconing protocols to support urban environment with intersections. Simulation should be as realistic as possible. A protocol design for intersection purpose is desirable to extend both proposed protocols.

- An extension of our beaconing protocols is required to overcome the problems of imperfect positioning, low time synchronization and maps error margins.

- Investigate our SDMA approach with a real map with two circulation directions and combine our solutions with the adaptive approach to create a dynamic beacon rate and power control that will be sensitive to the traffic conditions in order to improve the channel load.

6.3 Future challenges

Researchers have invested significant efforts over the last decade to improve traffic safety information dissemination in vehicular networks. In this section, we discuss some of the safety dissemination challenges that need additional investigation and innovative solutions to meet the two main QoS requirements: reliability and low latency. Future research should address the following issues.

- Create an efficient MAC protocol to provide reliable broadcasting techniques with adaptive contention mechanisms.
- Develop efficient and accurate neighborhood service at the MAC layer, which does not affect safety applications.
- Explore heterogeneous VANET systems to make use of applications with multiple sources of information.
- Propose safety dissemination techniques that use both V2V and V2I communications and provide such a flexibility that takes the best advantages from each mode. For example, in case of network partition, infrastructure may relay communications.
- Develop realistic mobility generators that take into account different environments related to real road infrastructure and vehicles behavior.
- Develop more realistic and efficient simulators that model the influence of the communication on the traffic scenarios by allowing vehicles, according to specific models, to react in response to particular events on road. For example, vehicle may slow or change itinerary in reaction to a received information that announce an accident in a certain location of road.
- Investigate intelligent flooding schemes to provide reliable broadcasts with maximal coverage and minimal overhead, latency, collision, and redundancy. The new solutions should also address partition problems and scalability.
- Explore other promising research areas, such as mobile agent techniques, that have been neglected until now in the context of safety dissemination.

6.4 Future work

As future work, we project to investigate the following issues.

- Propose an access control protocol which join both SDMA and adaptive techniques to improve the channel use. In this context, ideas are being discussed.
- Propose an access control protocol to alliviate the reliability problem of broadcasting. This work is underway.
- Explore heterogeneous networks in the context of both the vehicular sensors networks and the emerging 5G which is considered as promising for vehicular communication.
- Explore how vehicular technologies can be deployed for health care.
- Mathematical modeling can be promising in protocols communication design. Its rigour, reliability and formal representation may give excellent results when simulating VANETs. A comparative study is desirable to explore how formal design can affect VANETs performances.

Contribution in terms of papers

Table 6.1: List of papers

Ref.	**Title**	**Type**	**Year**
[44]	Message dissemination techniques for safety applications in vehicular ad hoc networks (vanets)	Under submission	2015
[45]	Dissemination of an emergency message in a vehicular ad hoc network	CCCA (Conference)	2011
[46]	An efficient emergency message dissemination protocol in a vehicular ad hoc network	NDT (Conference)	2012
[128]	An efficient emergency message dissemination in a vehicular ad hoc network	Journal of E-Technology	2012
[47]	An efficient alert dissemination protocol in a vehicular ad hoc network	ICDIM (Conference)	2012
[129]	An efficient alert forwarding in vanets	Journal of Networking Technology	2012
[130]	An adaptative backoff mechanism for vanets	CEIT (Conference)	2013
[48]	A directional geocast warning dissemination protocol for vehicular ad hoc networks (vanets)	WWIC (Conference)	2014
[49]	A sdma-based mechanism for accurate and efficient neighborhood discovery link layer service	IEEE Transactions on Vehicular Technology	2015
[50]	Load balancing aware sdma-based beaconing approach in vehicular ad hoc networks	Under submission	2015
[51]	Simulation tools for vehicular ad hoc networks: A comparison study and future perspectives	WINCOM (Conference)	2015

Bibliography

[1] M. Booysen, S. Zeadally, and G. J. van Rooyen, “Survey of media access control protocols for vehicular ad hoc networks,” *The Institution of Engineering and Technology (IET)*, vol. 5, no. 11, p. 16191631, 2011.

[2] [Online]. Available: http://www.standards.its.dot.gov

[3] J. J. Blum and A. Eskandarian, “Avoiding timeslot boundary synchronization for multihop message broadcast in vehicular networks,” in *Proc. of the 69th IEEE Vehicular Technology Conference (VTC)*, Barcelona, April 2009, pp. 1–5.

[4] B. Blaszczyszyn and P. Muhlethaler, “Performance of mac protocols in linear vanets under different attenuation and fading conditions,” in *proc. of the 12th IEEE Conference on Intelligent Transportation Systems.* St. Louis, USA: Springer, 2009, pp. 715–720.

[5] J. Santa, A. Moragon, and A. F. Gomez-Skarmet, “Experimental evaluation of a novel vehicular communication paradigm based on cellular networks,” in *proc. of the IEEE Intelligent Vehicles Symposium*, Eindhoven University of Technology Eindhoven, The Netherlands, June 2008, pp. 0–1.

[6] V. Gonzalez, A. L. Santos, C. Pinart, and F. Milagro, “Experimental demonstration of the viability of ieee 802.11b based inter-vehicle communications,” in *Proc. of the 4th International Conference on Testbeds and research infrastructures for the development of networks & communities (TridentCom’08)*, March 2008, pp. 0–1.

[7] C. M. Chou, C. Y. Li, W. M. Chien, and K. C. Lan, “A feasibility study on vehicle-to-infrastructure communication: Wi-fi vs. wimax,” in *proc. of the 10th International Conference on Mobile Data Management: Systems, Services and Middleware (MDM’09)*, May 2009, pp. 397–398.

[8] T. Okabe, T. Shizuno, and T. Kitamura, “Wireless lan access network system for moving vehicles,” in *proc. of the 10th IEEE Symposium on Computers and Communications (ISCC’05)*, La Manga del Mar Menor, 2005, pp. 0–1.

[9] A. Rasheed, H. Zia, F. Hashmi, U. Hadi, W. Naim, and S. Ajmal, “Fleet & convoy management using vanet,” *Journal of Computer Networks*, no. 1, pp. 1–9, 2013. [Online]. Available: http://pubs.sciepub.com/jcn/1/1/1

[10] “IEEE 802.11p d3.0, draft amendment for wireless access in vehicular environments WAVE,” IEEE, Task Group p, July 2007.

[11] G. Chandrasekaran, “Vanets: The networking platform for future vehicular applications,” Department of Computer Science, Rutgers University, Tech. Rep., 2008.

[12] NHTSA National Highway Traffic Safety Application US. [Online]. Available: http://nhtsa.gov

[13] S. Tsugawa, S. Kato, K. Tokuda, T. Matsui, and H. Fuji, “A cooperative driving system with automated vehicles and intervehicle communications in demo 2000,” in *proc of the IEEE International Conference on intelligent transportation systems*, Oakland, CA, August 2001, pp. 918–923.

[14] K. Yasuto, “DSRC standards for multiple applications,” in *proc. of the 11th world congress on intelligent transportation systems (ITS’04)*, Nagoya, Japan, 2004.

[15] A. Festag, H. Fubler, H. Hartenstein, A. Sarma, and R. Schmitz, “Fleetnet: bringing car-to-car communication into real world,” in *proc. of the 11th world congress on intelligent transportation systems (ITS’04)*, Nagoya, Japan, October 2004.

[16] D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, and W. Schulz, “Cartalk 2000 safe and comfortable driving based upon inter-vehicle-communication,” in *IEEE Intelligent Vehicles Symposium*, no. 2, June 2002, pp. 545–550.

[17] (2008) Now (network on wheels). [Online]. Available: www.network-on-wheels.de

[18] (2006) Safespot integrated project. [Online]. Available: http://www.safespot-eu.org

[19] (2006) Cvis project for intelligent co-operative system. [Online]. Available: http://www.cvisproject.org

[20] (2006) Cooperative systems for intelligent road safety. [Online]. Available: http://www.coopers-ip.eu

[21] C2c car2car communication consortium. [Online]. Available: http://www.car-to-car.org/

[22] J. Santa, A. Moragon, and A. F. Gomez-Skarmet, “VII (vehicle infrastructure integration). proof of concept,” Eindhoven University of Technology Eindhoven, The Netherlands, Tech. Rep. FHWA-JPO-09-003, 2009. [Online]. Available: www.intellidriveusa.org/documents/052009-POC-vehicle-final-report.pdf

[23] Dsrc: The dsrc project. [Online]. Available: http://www.leearmstrong.com/DSRC/DSRCHomeset

[24] “IEEE 802.11, part 11: wireless lan medium access control (mac) and physical layer (phy) specifications,” IEEE, Task Group, IEEE Computer Society, 2007.

[25] IEEE, “IEEE trial-use standard for wireless access in vehicular environments (wave) - resource manager,” IEEE IEEE1609.1, 2006.

[26] IEEE, “IEEE trial-use standard for wireless access in vehicular environments - security services for applications and management messages,” IEEE IEEE 1609.2, 2006.

[27] IEEE, “IEEE standard for wireless access in vehicular environments (wave) - networking services,” IEEE IEEE 1609.3, 2010.

[28] IEEE, “IEEE standard for wireless access in vehicular environments (wave)–multichannel operation,” IEEE IEEE1609.4, 2011.

[29] Irtad group, road safety annual report. [Online]. Available: http://www.internationaltransportforum.org/Irtadpublic/index.html

[30] A. Villalba and D. Konstantas, "Towards hovering information," in *proc. of the 1st European Conference on Smart Sensing and Context (EuroSSC)*, vol. 4272, Amsterdam, 2006, pp. 250–254.

[31] M. H. Rehmani, A. C. Viana, H. Khalife, and S. Fdida, "Surf: A distributed channel selection strategy for data dissemination in multi-hop cognitive radio networks," *Computer Communications*, vol. 36, no. 10, p. 11721185, April 2013.

[32] K. Rezwana, "Vanet: Superior system for content distribution in vehicular network applications," in *Rutgers University conference*, March 2010, pp. 1–8.

[33] A. Bhm and M. Jonsson, "Real-time communication support for cooperative, infrastructure-based traffic safety applications," *International Journal of Vehicular Technology*, vol. 2011, pp. 1–17, 2011.

[34] F. H. A. U.S. Department of Transportation, "Crash data analyses for vehicle-to-infrastructure communication for safety applications," Report FHWA-HRT-11-040, November 2012. [Online]. Available: http://www.fhwa.dot.gov/publications/research/connectedvehicles/11040/11040.pdf

[35] X. Yang, J. Liu, F. Zhao, and N. H. Vaidya, "A vehicle-to-vehicle communication protocol for cooperative collision warning," in *proc. of the 1st Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services*, Cambridge, MA, USA, August 2004, pp. 114–123.

[36] F. Ye, M. Adams, and S. Roy, "V2v wireless communication protocol for rear-end collision avoidance on highways," in *Communication Workshops (ICC)*, Beijing, May 2008, pp. 375–375.

[37] W. Wolterink, G. Heijenk, and G. Karagiannis, "Dissemination protocols to support cooperative adaptive cruise control (cacc) merging," in *proc. of the 11th International Conference on ITS Telecommunications (ITST)*. St. Petersburg: Springer, August 2011, pp. 15–20.

[38] T. Nadeem, P. Shankar, and L. Iftode, "A comparative study of data dissemination models for vanets," in *Proc. of the 3rd Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services (MobiQuitous)*. San Jose, CA: Springer, July 2006, pp. 1–10.

[39] F. Martinez, J. C. Cano, C. Calafate, and P. Manzoni, "A vanet solution to prevent car accidents," in *XIX Jornadas de Paralelismo*, St. Louis, USA, September 2008.

[40] S. Y. Ni, Y. C. Tseng, Y. Chen, and J. P. Sheu, "The broadcast storm problem in a mobile ad hoc network," *Wireless Networks*, vol. 8, no. 2-3, p. 153167, 2002.

[41] Z. Jing, Z. Yang, and C. Guohong, "Data pouring and buffering on the road: A new data dissemination paradigm for vehicular ad hoc networks," *IEEE Transactions on vehicular technology*, vol. 56, no. 6, p. 32663277, 2007.

[42] V. Palma and A. M. Vegni, “On the optimal design of a broadcast data dissemination system over vanet providing v2v and v2i communications the vision of rome as a smart city,” *Journal of telecommunications and information technology (JTIT)*, vol. 2013, no. 1, pp. 41–48, 2013.

[43] Z. Doukha, S. Zeadally, and S. Moussaoui, “Message dissemination techniques for safety applications in vehicular ad hoc networks (vanets),” *under submission*, 2015.

[44] Z. Doukha and S. Moussaoui, “Dissemination of an emergency message in a vehicular ad hoc network,” in *proc. of the International Conference on Communications, Computing and Control Applications (CCCA'11).* Hammamet: IEEE, March 2011, pp. 1–6.

[45] Z. Doukha, S. Moussaoui, N. Haouari, and M. Delhoum, “An efficient emergency message dissemination protocol in a vehicular ad hoc network,” in *Proc. of the 4th Internationa Conference on Networked Digital Technologies, Communications in Computer and Information Science (NDT)*, no. 293. Dubai: Springer, April 2012, pp. 459–469.

[46] Z. Doukha, S. Moussaoui, and N. Haouari, “An efficient alert dissemination protocol in a vehicular ad hoc network,” in *Proc. of the Seventh International Conference on Digital Information Management (ICDIM2012)*, Macau, August 2012, pp. 22–24.

[47] Z. Doukha, S. Zeadally, and S. Moussaoui, “A directional geocast warning dissemination protocol for vehicular ad hoc networks (vanets),” in *proc. of the 12th International Conference on Wired and Wireless Internet Communications (WWIC)*, vol. 8458, Paris, 2014, pp. 55–67.

[48] Z. Doukha and S. Moussaoui, “A sdma-based mechanism for accurate and efficient neighborhood discovery link layer service,” *IEEE Transactions on Vehicular Technology*, no. 99, p. 1, February 2015.

[49] Z. Doukha, K. Ghafoor, S. B. Mussa, S. Moussaoui, and I. Loumachi, “Load balancing aware sdma-based beaconing approach in vehicular ad hoc networks,” *Under submission*, 2015.

[50] S. Mussa, M. Manaf, K. Ghafoor, and Z. Doukha, “Simulation tools for vehicular ad hoc networks: A comparison study and future perspectives,” in *proc. of the International Conference on Wireless Networks and Mobile Communications (WINCOM15)*, Marakesh, October 2015.

[51] S. Busanelli, G. Ferrari, and V. A. Giorgio, “I2v highway and urban vehicular networks: A comparative analysis of the impact of mobility on broadcast data dissemination,” *Journal of Communications*, vol. 6, no. 1, pp. 87–100, February 2011.

[52] A. Amirshahi, M. Fathi, M. Romoozi, and M. Assarian, “A fuzzy realistic mobility model for vanet,” *International Journal of Computer Science (IJCSI)*, vol. 8, no. 3, pp. 1694–0814, September 2011.

[53] K. A. Hafeez, . Zhao, Z. Liao, and B. N. W. Ma, “Impact of mobility on vanets safety applications,” in *IEEE Global Telecommunications Conference (GLOBECOM)*, Miami, December 2010, pp. 1–5.

[54] J. Harri, F. Filali, and C. Bonnet, “Mobility models for vehicular ad hoc networks: a survey and taxonomy,” *Communications Surveys & Tutorials, IEEE*, vol. 11, no. 4, pp. 211–213, 2009.

[55] M. Fogue, P. Garrido, F. J. Martinez, J. C. Cano, C. T. Calafate, and P. Manzoni, “Analysis of the most representative factors affecting warning message dissemination in vanets under real roadmaps,” in *proc. of the 19th Annual IEEE International Symposium on Modelling, Analysis, and Simulation of Computer and Telecommunication Systems*, Singapore, July 2011, pp. 197 – 204.

[56] T. Kosch, C. J. Adler, S. Eichler, C. Schroth, and M. Strassberger, “The scalability problem of vehicular ad hoc networks and how to solve it,” *IEEE Wireless Communications*, vol. 13, no. 5, pp. 22–28, 2006.

[57] K. Sjberg, E. Uhlemann, and E. G. Strm, “Scalability issues of the mac methods stdma and csma of ieee 802.11p when used in vanets,” in *Workshop on Vehicular Connectivity (ICC)*, CapeTown, South Africa, May 2010, pp. 1–5.

[58] K. R. Kumar, “Vanet parameters and applications: A review,” *Global Journal of Computer Science and Technology*, vol. 10, no. 7, pp. 72–77, September 2010.

[59] Y. Toor, P. Mhlethaler, A. Laouinti, and A. D. L. Fortelle, “Vehicle ad hoc networks: Application and related technical issues,” *IEEE communications SURVEYS & tutorials*, vol. 10, no. 3, pp. 74 – 88, 2008.

[60] B. Bako and M. Weber, “Efficient information dissemination in vanets,” *Advances in Vehicular Networking Technologies*, vol. 1, no. 1, pp. 45–64, 2011.

[61] N. Balon and J. Guo, “Increasing broadcast reliability in vehicular ad hoc networks,” in *3rd international workshop on Vehicular ad hoc networks (VANET’06).* NY, USA: ACM, 2006, pp. 104–105.

[62] Y. i Wang, A. Ahmed, B. Krishnamachari, and K. Psounis, “Ieee 802.11p performance evaluation and protocol enhancement,” in *proc. of IEEE International Conference on Vehicular Electronics and Safety Columbus*, OH, USA, September 2008, pp. 22–24.

[63] M. T. Sun, W. C. Feng, T. H. Lai, K. Yamada, and H. Okada, “Gps-based message broadcast for adaptive inter-vehicle communications,” in *proc. of the 52nd IEEE Vehicular Technology Conference (VTC)*, no. 6, Boston, MA, USA, September 2000, pp. 2685–2692.

[64] K. Hafeez, L. Zhao, Z. Liao, and B. Ma, “A new broadcast protocol for vehicular ad hoc networks safety applications,” in *proc of IEEE Global Telecommunications Conference (GLOBECOM).* Miami: Springer, December 2010, pp. 1–5.

[65] S. R. G.Samara, W.A.H.A.. Alsalihy, “Increase emergency message reception in vanet,” *Journal of applied sciences*, vol. 11, no. 14, pp. 2606–2612, 2011.

[66] S. Yousefi, M. Fathy, and A. Benslimane, “Performance of beacon safety message dissemination in vehicular ad hoc networks (vanets),” *Journal of Zhejiang University Science A*, vol. 8, no. 12, pp. 1990–2004, 2007. [Online]. Available: www.zju.edu.cn/jzus

[67] K. Wolterink, G. J. Heijenk, and G. Karagiannis, “Information dissemination in vanets by piggybacking on beacons an analysis of the impact of network parameters,” in *proc. of IEEE Vehicular Networking Conference (VNC)*, Amsterdam, 2011, p. 94101.

[68] C. Blommendaal, “A proposal to analyse the advantage of disseminating data on beacons in vanets,” in *proc. of the 16th Twente Student Conference on IT*, Enschede, The Netherlands, January 2012, pp. 715–720.

[69] R. K. Schmidt, T. Leinmller, E. Schoch, F. Kargl, and G. Schfer, “Exploration of adaptive beaconing for efficient intervehicle safety communication,” *IEEE Network*, vol. 24, no. 1, pp. 14–19, January-February 2010.

[70] L. Zhou, G. Cui, H. Liu, D. Luo, and Z. Wu, “Nppb: A broadcast scheme in dense vanets,” *Information Technology Journal*, vol. 9, no. 2, pp. 247–256, 2010.

[71] H.ALshaer and E.Horlait, “An optimized adaptive broadcast scheme for inter-vehicle communication,” in *proc. of the 61st IEEE Vehicular Technology Conference (VTC)*, vol. 5, Stockholm, Sweden, May 2005, pp. 2840–2844.

[72] Y. T. Yang and L. D. Chou, “Position-based adaptive broadcast for inter-vehicle communications,” in *proc. of IEEE International Conference (ICC), Communications Workshops*, Beijing, May 2008, pp. 410–414.

[73] A. Bachir and A. Benslimane, “A multicast protocol in ad hoc networks: Inter-vehicle geocast,” in *proc. of the 57th IEEE Semiannual Vehicular Technology Conference, VTC-Spring*, vol. 4, Jeju Island, Korea, April 2003, p. 24562460.

[74] A. Benslimane, “Optimized dissemination of alarm messages in vehicular ad hoc networks,” in *proc. of the 7th IEEE International conference, High Speed Networks and Multimedia Communications (HSNMC)*, vol. 3079, France, 2004, p. 655666.

[75] K. Ibrahim, M. Weigle, and M. Abuelela, “p-ivg: Probabilistic inter-vehicle geocast for dense vehicular networks,” in *proc. of the 69th IEEE Vehicular Technology Conference (VTC)*. Barcelona: Springer, April 2009, pp. 1–5.

[76] L.Briesemeister, L.Schafers, and G.Hommel, “Dissemination messages among highly mobile hosts bsed on inter-vehicle communication,” in *proc. of IEEE Intelligent Vehicles Symposium*, USA, 2000, pp. 522–527.

[77] I. H. Bae, “Design and evaluation of a hybrid intelligent broadcast algorithm for alert message dissemination in vanets,” *International Journal of Grid and Distributed Computing*, vol. 4, no. 4, pp. 1–10, December 2011.

[78] S. YU and G. Cho, “An effective message flooding method for vehicle safety communication,” in *proc. of the 3rd international conference on Ubiquitous Intelligence and Computing (UIC’06)*, vol. 4159. Heidelberg: Springer, September 2006, p. 219228.

[79] T. H. Kim, W. K. Hong, H. C. Kim, and Y. D. Lee, “An effective data dissemination in vehicular ad-hoc network,” *Information Networking. Towards Ubiquitous Networking and Services. Lecture Notes in Computer Science*, vol. 5200, pp. 295–304, January 2008.

[80] L. Da, H. Hongyu, L. Xu, L. Minglu, and T. Feilong, "A distance-based directional broadcast protocol for urban vehicular ad hoc network," in *proc. of International Conference on Wireless Communications, Networking and Mobile Computing (WiCom)*, Shanghai, September 2007, p. 15201523.

[81] R. Vilzmann and C. Bettstetter, "A survey on mac protocols for ad hoc networks with directional antennas," in *Open European Summer School (EUNICE)*, Colmenarejo, Spain, July 2005, p. 268274.

[82] T. Little and A. Agarwal, "An information propagation scheme for vanets," in *proc. of the 8th IEEE Conference on Intelligent Transportation Systems*, Austria, September 2005, p. 155160.

[83] K. H. Abboud and W. Zhuang, "Modeling and analysis for emergency messaging delay in vehicular ad hoc networks," in *proc. of IEEE Global Telecommunications Conference (GLOBECOM)*, Honolulu, HI, November 2009, pp. 1–6.

[84] Z. Y. Rawashdeh and S. M. Mahmud, "Toward strongly connected clustering structure in vehicular ad hoc networks," in *proc. of the 70th IEEE Vehicular Technology Conference (VTC)*, Alaska,USA, September 2009.

[85] B. Ramakrishnan, R. S. Rajesh, and R. S. Shaji, "Cbvanet: A cluster based vehicular adhoc network model for simple highway communication," *International Journal of Advanced Networking and Applications*, vol. 2, no. 4, pp. 755–761, 2011.

[86] P. Fan, P. Sistla, and P. Nelson, "Theoretical analysis of a directional stability-based clustering algorithm for vanets," in *proc. of the 5th ACM International Workshop on Vehicular Ad Hoc Networks (VANET)*. San Francisco: ACM, 2008, pp. 80–81.

[87] Y. Zaydoun and M. SyedMasud, "A novel algorithm to form stable clusters in vehicular ad hoc networks on highways," *EURASIP Journal on Wireless Communications and Networking*, January 2012.

[88] E. Fasolo, R. Furiato, and A. Zanella, "Smart broadcast algorithm for intervehicular communications," in *pWireless Personal Multimedia Communications Symposium (WPMC)*, Denmark, September 2005, pp. 1583–1587.

[89] G. Korkmaz, E. Ekici, and F. O. zgner, "Urban multi-hop broadcast protocols for inter-vehicle communication systems," in *proc. of the 1st ACM Workshop on Vehicular Ad-hoc Networks (VANET)*. ACM, October 2004, p. 7685.

[90] G. Korkmaz, E. Ekici, and F. Ozguner, "An efficient fully ad-hoc multihop broadcast protocol for inter-vehicular communication systems," in *proc. of IEEE International Conference on Communications (ICC06)*, vol. 1, Istanbul, June 2006, pp. 423–428.

[91] E. Fasolo, A. Zanella, and M. Zorzi, "An effective broadcast scheme for alert message propagation in vehicular ad hoc networks," in *proc. of IEEE International Conference on Communications (ICC'06)*, vol. 9, Istanbul, June 2006, pp. 3960–3965.

[92] X.Bai, Y. Hong, Y. Du, and Z. Gao, "Efficient data dissemination scheme for the urbain vehicular networks a survey of broadcast protocols for vehicular ad-hoc networks," *Information Technology Journal*, vol. 12, no. 9, pp. 1696–1706, 2013.

[93] J. Yang and Z. Fei, “Broadcasting with prediction and selective forwarding in vehicular networks,” *International Journal of Distributed Sensor Networks*, vol. 2013, no. 9, pp. 1–9, October 2013.

[94] J. Choi, J. Nam, and Y. Cho, “Robust broadcast scheme regardless of vehicle distribution in vehicular ad hoc networks,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2014, no. 133, pp. 1–8, October 2014.

[95] W. Viriyasitavat, M. Boban, H. Tsai, and A. Vasilakos, “Vehicular communications: Survey and challenges of channel and propagation models,” *IEEE Vehicular Technology Magazine*, vol. 10, no. 2, pp. 55–66, June 2015.

[96] F. Ros, P. Ruiz, and I. Stojmenovic, “Acknowledgment-based broadcast protocol for reliable and efficient data dissemination in vehicular ad-hoc networks,” in *IEEE Transaction Mobile Computing*, vol. 11, no. 1, 2012, p. 3346.

[97] S. Qixiang and H. Garcia-Molina, “Using ad-hoc inter-vehicle networks for regional alerts,” Stanford InfoLab, Technical Report, October 2004. [Online]. Available: http://ilpubs.stanford.edu:8090/669/

[98] The network simulator ns2. [Online]. Available: www.isi.edu/nsnam/ns/

[99] F. Karnadi, Z. Mo, and K.Lan, “Rapid generation of realistic mobility models for vanet,” in *proc. of the International IEEE Wireless Communication and Networking Conference (WCNC)*, Hong Kong, 2007, pp. 2506–2511.

[100] G. H. Q. Yu, “Abiding geocast for warning message dissemination in vehicular ad hoc networks,” in *proc. of the International IEEE Vehicular Networks and Applications Workshop*, Beijing, May 2008, pp. 400–404.

[101] P. Kheawchaoom, S. Kittipiyakul, and K. Ayutaya, “idtsg time-stable geocast for post crash notification in vehicular highway networks,” in *proc. of the International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Phetchaburi, May 2012, pp. 1–4.

[102] R. Kumar and M. Dave, “A review of various vanet data dissemination protocols,” *International Journal of u- and e-Service, Science and Technology*, vol. 5, no. 3, pp. 27–44, September 2012.

[103] M. Torrent-Moreno, J. Mittag, P. Santi, and H. Hartenstein, “Vehicle-to-vehicle communication: fair transmit power control for safety-critical information,” *IEEE Transactions on Vehicular Technology*, vol. 58, no. 7, pp. 3684–3703, 2009.

[104] F. Ye, M. Adams, and S. Roy, “V2v wireless communication protocol for rear-end collision avoidance on highways,” in *Communication Workshops ICC Workshops, IEEE International Conference.* Beijing: IEEE, May 2008, pp. 375–379.

[105] E. van Eenennaam, W. Wolterink, G. Karagiannis, and G. Heijenk, “Exploring the solution space of beaconing in vanets,” in *Proc. of the 1st Internationa IEEE Vehicular Networking Conference(VNC)*, Japan, October 2009, pp. 28–30.

[106] N. Wisitpongphan, O. Tonguz, J. Parikh, and P. Mudalige, “Broadcast storm mitigation techniques in vehicular ad hoc networks,” *Wireless Communications, IEEE*, vol. 14, no. 6, pp. 84–94, 2007.

[107] M. Torrent-Monero, D. Jiang, and H. Hartenstein, “Broadcast reception rates and effects of priority access in 802.11-based vehicular ad-hoc,” in *proc. of the first ACM International workshop on Vehicular ad hoc networks VANET*, Philadelphia, October 2004, pp. 10–18.

[108] K. Ghafoor, J. Lloret, K. Bakar, A. Sadiq, and S. Mussa, “Beaconing approaches in vehicular ad hoc networks: A survey,” *Journal of Wireless Personal Communications*, vol. 73, no. 3, pp. 885–912, 2013.

[109] K. Bilstrup, E. Uhlemann, and E. Strm, “Scalability issues of the mac methods stdma and csma of ieee 802.11p when used in vanets,” in *IEEE International Conference on Communications Workshops (ICC)*, Capetown, May 2010, pp. 1–5.

[110] K. Sjoberg, E. Uhlemann, and E. Strom, “Delay and interference comparison of csma and self-organizing tdma when used in vanets,” in *Proc. of the 7th International Wireless Communications and Mobile Computing Conference (IWCMC)*, Istambul, July 2011, pp. 1488–1493.

[111] “Ieee standard for information technology–telecommunications and information exchange between systems–local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications,” IEEE, Task Group, IEEE Computer Society, 2010.

[112] R. Schmidt, T. Leinmuller, E. Schoch, and F. Kargl, “Exploration of adaptive beaconing for efficient intervehicle safety communication,” *Network, IEEE*, vol. 24, no. 1, pp. 14–19, 2010.

[113] S. Alvin, T. Maolin, F. Yanming, and M. Looi, “Context aware rate adaptive beaconing for efficient and scalable vehicular safety communication,” *Int. J. Communications, Network and System Sciences*, vol. 5, no. 9, pp. 534–547, 2012.

[114] K. Ghafoor, K. Bakar, E. van Eenennaam, R. Khokhar, and A. Gonzalez, “A fuzzy logic approach to beaconing for vehicular ad hoc networks,” *Telecommunication Systems*, vol. 52, no. 1, pp. 139–149, August 2013.

[115] L. Yang, J. Guo, and Y. Wu, “Broadcast reception rates and effects of priority access in 802.11-based vehicular ad-hoc,” in *proc. of 11th International IEEE Conference on Intelligent Transportation Systems (ITSC).* Beijing: IEEE, October 2008, pp. 369–374.

[116] D. Rawat, D. Popescu, G. Yan, and S. Olariu, “Enhancing vanet performance by joint adaptation of transmission power and contention window size,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 9, pp. 1528–1535, 2011.

[117] J. Mittag, F. Thomas, J. Hrri, and H. Hartenstein, “A comparison of single- and multi-hop beaconing in vanets,” in *Proc. of the 6th ACM international workshop on VehiculAr InterNETworking*, USA, 2009, pp. 69–78.

[118] E. M. V. Eenennaam, G. Karagiannis, and G. Heijenk, “Towards scalable beaconing in vanets,” in *In. Proceedings of the 2010 ERCIM workshop on eMobility*, Lulea, 2010, pp. 103–108.

[119] V. Sadatpour, M. Fathy, S. Yousefi, A. Rahmani, E. Cho, and M. Choi, "Scheduling algorithm for beacon safety message dissemination in vehicular ad-hoc networks," *Communications in Computer and Information Science*, vol. 56, pp. 133–140, 2009.

[120] M. Hadded, R. Zagrouba, A. Laouiti, P. Muhlethaler, and L. Sadane, "An adaptive tdma slot assignment strategy in vehicular ad hoc networks," *Journal of Machine to Machine Communications*, vol. 1, pp. 175–194, 2014.

[121] French traffic legistation, article r412-12. [Online]. Available: http://legifrance.gouv.fr/

[122] Veins. [Online]. Available: http://veins.car2x.org/

[123] Omnet++. [Online]. Available: http://www.omnetpp.org/

[124] D. Krajzewicz, J. Erdmann, M. Behrisch, and L. Bieker, "Recent development and applications of sumo simulation of urban mobility," *International Journal On Advances in Systems and Measurements*, vol. 5, no. 3&4, pp. 128–138, December 2012.

[125] J. Mittag, F. Thomas, J. Hrri, and H. Hartenstein, "A comparison of single- and multi-hop beaconing in vanets," in *Proc. of the 6th ACM international workshop on VehiculAr InterNETworking*, USA, 2009, pp. 69–78.

[126] G. Samara, S. Ramadas, and W. Al-Salihy, "Safety message power transmission control for vehicular ad hoc networks," *Journal of Computer Science*, vol. 6, no. 10, pp. 1027–1032, 2010.

[127] Z. Doukha, S. Moussaoui, N. Haouari, and M. Delhoum, "An efficient emergency message dissemination in a vehicular ad hoc network," *Dline Journals, Journal of E-Technology*, vol. 3, no. 2, pp. 104–111, May 2012.

[128] Z. Doukha, S. Moussaoui, and N. Haouari, "An efficient alert forwarding in vanets," *DLINE journals, Journal of Networking Technology*, vol. 3, no. 2, pp. 177–184, June 2012.

[129] H. Zerrouki, S. Moussaoui, and Z. Doukha, "An adaptative backoff mechanism for vanets," in *International Conference on Control, Engineering & Information Technology (CEIT13)*, Tunisia, 2013.