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كلية العلوم

Faculté des Sciences

THÈSE PRÉSENTÉE ET SOUTENUE PAR:

Bousbaa Fatima Zohra

LE 09/02/2020

Pour l'obtention du diplôme de DOCTORAT en Sciences

Spécialité: Informatique

THÈME

Les protocoles de routage multicast/geocast pour les applications de sécurité et de confort dans les réseaux de véhicules

Multicast/geocast routing protocols for safety and comfort applications in VANET

Jury

Youcef Ouinten	Professeur	(Université de Laghouat)	Président
Abderrahmane Lakas	Professeur	(Université d'AL Ain UAE)	Examinateur
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بسم الله الرحمن الرحيم

Dedication

I would like to dedicate this thesis to my parents and most importantly to the memory of my father, who was my true inspiration and guiding light. He always encouraged me to pursue higher studies.

This is to you Papa!

Acknowledgments

First of all, I must thank Allah, for giving me the ability and perseverance necessary to complete this dissertation. All praise is due to Allah, the Lord of the Worlds.

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I am very grateful to all family members who gave me courage all these years to continue my efforts for the completion of this dissertation.

Fatima Zohra, February 2019

Abstract

Cooperative Vehicular Ad-hoc NETwork (VANET) has yielded remarkable research results to enable the Intelligent Transportation System (ITS) for a safe, reliable, convenient, and comfortable driving experience. However, the high vehicular mobility and frequent network fragmentation hinder the reliable and successful data communication in cooperative vehicular networks. In this dissertation, we are interested to data communication strategies in cooperative vehicular networks, their common aim is to deliver data to vehicles within a specific group. As the transmission bandwidth is restricted in wireless environments of VANET same as all mobile wireless networks, developing group communications is a very challenging problem due to the aforementioned challenges (i.e., high mobility of vehicles and frequent network fragmentation) together with the transmission range limitation of the Dedicated Short Range Communication (DSRC) devices. Thus, a multi-hop relaying system based on cooperation between vehicles is adopted for the communication of group messages. The multi-hop relaying strategy can extend the transmission range of DSRC devices. However, it also introduces a lot of challenges such as, power consumption and Quality of Service (QoS) requirements (delay, reliability, and scalability).

To address the aforementioned issues, we pay specific attention to geocasting and multicasting routing techniques which are the most adapted strategies to multi-hop group communications. In this dissertation, after elaborating an extensive study of group data communication protocols in connected vehicles, we propose two new robust geocast routing protocols: the first one, called Robust Geocast Routing Protocol for Safety Applications (RGRP-SA), is designed for delivering delay-critical short safety packets while taking into account the high mobility of vehicles and the frequent internal network fragmentation, while the second, namely, Robust Geocast Routing Protocol for Comfort Applications (RGRP-CA), is designed to maintain good network connectivity among vehicles along with comfort applications and solve the problem of frequent external network fragmentation.

Moreover, in order to reduce transmission interferences for multicast messages in VANET, we propose two new routing protocols. Hence, we develop a heuristic algorithm called Time-Limited Reliable Broadcast Incremental Power (TRBIP) to construct a safety message delivery tree. By reducing the total transmission energy and the number of hops, TRBIP is able to reduce the transmission interference and thus-forth it maximizes the reliability. In the second contribution, we propose a distributed hybrid version of TRBIP called DTRBIP. Our proposal is based on a road segmentation technique through hybrid scheme, DTRBIP is extended to handle both delay-sensitive and delay-tolerant applications respectively in urban and highway environments.

The results of the simulation conducted using NS-2 simulator demonstrate the effectiveness of our protocols proposed in this dissertation in terms of solving the internal and external network fragmentation problems, increasing the packet delivery ratio, reducing the total emission energy, the average delay, and the transmission overhead. The simulation validation confirms also the performance advantage of our solutions compared to the up to date protocols in the literature that tackle the same problems.

Keywords: VANET, group communications, geocast, multicast, hybrid, internal and external network fragmentation problems, RGRP-SA, RGRP-CA, TRBIP, DTRBIP, road segmentation, total transmission energy, QoS, safety and comfort applications.

Résumé

Au cours de ces dernières années, la communication de groupe entre les véhicules intelligents devient un sujet brûlant dans l'industrie automobile et la communauté scientifique. Cependant, il y a encore des défis à résoudre dans la communication coopérative de groupe inter-véhicules (Inter-Vehicle Communication (IVC)), tels que la robustesse, le passage à l'échelle, et la qualité de service (la fiabilité, le délai et throughput en particulier).

En plus, la mobilité des noeuds dans les réseaux véhiculaires (VANET) provoque des fragmentations fréquentes du réseau, liées à la vitesse et la variation de densité des véhicules qui sont très importantes dans les routes, par conséquent, le problème de routage est loin d'être évident dans les réseaux véhiculaires. Le degré de dificulté du problème augmente dans le cas où l'acheminement de données concerne un groupe de noeuds (routage geocast/multicast) et tous ces derniers peuvent se déplacer avec une variation de vitesse.

Cette thèse contribuera à développer des protocoles IVC pour les VANET, en particulier en mettant l'accent sur les protocoles de routage geocast et multicast qui sont les techniques les plus adaptées à la communication coopérative du groupe au sein de VANET, ce sont les types de communications un-à-plusieurs ou plusieurs-à-plusieurs sur lesquels de nombreux services véhiculaires sont basés.

Pour ce faire, cette thèse examine d'abord des méthodes existantes de communication de données dans un groupe, ensuite propose des techniques efficaces de dissémination d'informations utilisant des approches multi-métriques basées sur différentes mesures en temps-réel. Deux méthodes robustes de routage geocast sont proposées (RGRP-SA et RGRP-CA) qui permettent de diminuer les délais d'acheminement prenant en compte la forte mobilité des véhicules et les problèmes des fragmentations interne et externe du réseau.

Dans un troisième volet, cette thèse propose deux méthodes heuristiques (TRBIP et DTR-BIP) afin de palier au problème de routage multicast et hybride des messages de sécurité routière et de confort dans VANET. L'objectif principal est de minimiser la consommation d'énergie afin de réduire les interférences de communication inter-véhiculaires et de diminuer les émissions de gaz carbonique prenant en compte le délai, la fiabilité de transmission des messages et le passage à l'échelle par l'utilisation d'une nouvelle technique de segmentation de la route.

Nous analysons la performance des solutions proposées en utilisant le simulateur NS-2, nous présentons des séries d'expérimentations que nous avons conduites pour valider nos contributions. Les résultats de simulation montrent que nos approches permettent effectivement de surmonter les contraintes inhérentes aux réseaux de véhicules. Les validations de simulation montrent également l'avantage de performance de nos solutions par rapport aux protocoles qui traitent des mêmes problèmes.

Mots clés: VANET, communications de groupe, geocast, multicast, hybride, fragmentation interne et externe, RGRP-SA, RGRP-CA, TRBIP, DTRBIP, segmentation, consommation d'énergie, qualité de service, applications de sécurité et de confort.

ملخص

تعد صناعة المركبات أحد القطاعات الدائمة التجديد والتي تميزت بقدرتها على استيعاب التطور التكنولوجي في مجالات عدة ومن أهمها مجال الاتصالات الذي جعل الاتصال بين المركبات الذكية ممكنا مما أتاح مزيدا من الأمان والراحة والتقليل من المخاطر مع الحد من التلوث البيئي. ولتحقيق هذه الأهداف، اهتم الباحثون في مجال الاتصالات والشبكات خصوصا بتطوير بروتوكولات تستجيب لتحديات هذا النوع من الشبكات كديناميكية التحرك (mobility) وقابلية التوسع (scalability) وجودة الخدمة (QoS).

في إطار البحث في هذا المجال، تهدف هذه الأطروحة أساسا إلى اقتراح طرق جديدة لنشر المعلومات بين مجموعة من المركبات الذكية متعددة القفزات (Multi-hop)، من خلال التركيز على بروتوكولات البث الجغرافي (geocast) والبث الشبكي المتعدد (multicast) التي تعد أكثر التقنيات ملاءمة لهذا النوع من الاتصال داخل شبكات المركبات (VANET).

في هذا السياق، نقوم في هذه الأطروحة أولاً بفحص التقنيات المقترحة لنقل رزم المعلومات بين مجموعة من المركبات، قبل أن نقوم باقتراح بروتوكولين للبث الجغرافي واللذين اسميناهما RGRP-SA و RGRP-CA. كلاهما يهدف إلى انقاص وقت التوجيه ومراعاة خاصية التنقل العالية مع الحفاظ على التغطية الإذاعية الكاملة بين المركبات.

بالاضافة إلى ذلك، نقترح في هذه الأطروحة بروتوكولين آخرين (TRBIP وDTRBIP) للبث المتعدد. يهدف كلاهما إلى التقليل من استهلاك الطاقة وانقاص الرزم المتبادلة بين المركبات مع مراعاة محدودية الوقت وموثوقية نقل رزم المعلومات وقابلية التوسع، و ذلك باستخدام تقنية جديدة لتجزئة الطريق.

نتائج المحاكاة المحصل عليها باستعمال محاكي الشبكات NS-2 تظهر جليا الفعالية الجيدة للطرق المقترحة مقارنة ببقية بروتوكولات البث الجغرافي والبث المتعدد.

كلمات مفتاحية: شبكات المركبات VANET، الإتصال الجماعي، البث الجغرافي، البث المتعدد، تجزئة الطريق، تقليل استهلاك الطاقة، جودة الخدمة، تطبيقات الأمان و الرفاهية.

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List of Algorithms

List of Acronyms

A | C | D | E | F | G | I | J | L | M | O | P | Q | R | S | T | V | W | Z

A

AG Abiding Geocast. 20

APAP Adaptive Probability Alert Protocol. 17

ARP-QD Adaptive Routing Protocol based on QoS and vehicular Density. 51

C

CA Comfort Applications. 7, 49, 53

CAFC Centralized Approach for setting Floating Content parameters. 22

CCD Coordination for Content Dissemination. 22

CCITT Consultative Committee for International Telephony and Telegraphy. 48

CCN Content Centric Networking. 22

CCWS Cooperative Collision Warning System. 48, 57, 58

CG Cached Geocast. 20

CGR Coverage-aware Geocast Routing. 20

D

D-CMST Delay-Constrained minimum Steiner Tree. 46

DDT Distance Deferred Time. 19

DRG Distributed Robust Geocast. 19

DS Delay-Sensitive-oriented. 9, 55

DSRC Dedicated Short Range Communication. iv, 2, 57, 58, 1

DT Delay-Tolerant-oriented. 47, 55

DTRBIP Distributed TRBIP. 55, 56, 57, 64, 67, 69, 72, 73, 76, 77, 79, 81, 82, 84, 85

DV-CAST Distributed Vehicular broadCAST. 17

DZ Destination Zone. 2, 9, 11, 19, 20, 22, 23, 24, 25, 27, 47, 52, 53, 55, 84

E

ENF External Network Fragmentation. 2, 19, 21, 23, 24, 25, 26, 27, 33, 41, 52, 53

ESME Efficient Safety message dissemination with Minimum Energy. 46

F

FNF Frequent Network Fragmentation. 2, 19, 21, 22, 46, 51

G

GeoMob Mobility-aware Geocast. 47

GeoSUZ Geocast SUb Zones. 23

GLF Green Light Forwarding. 21

GPS Global Positioning System. 17, 31, 57, 68

GPSR Greedy Perimeter Stateless Routing. 23, 64, 69

GRP Geographical Routing Protocol. 21

I

IA Infotainment Applications. 7, 53

INF Internal Network Fragmentation. 2, 19, 23, 24, 26, 27, 32, 38, 40, 41, 52, 53

ITS Intelligent Transportation System. iv, 1, 2, 1

IVC Inter-Vehicle Communication. vi, 9, 49

IVG Inter-Vehicle Geocast. 19, 26, 28, 35, 37, 38, 44

J

JSF Junction Store and Forward. 17

L

LCG Loosely Connected Group. 7

LTE Long Term Evolution. 22

M

MAC Medium Access Control. 10

MANET Mobile Ad-hoc NETwork. 1

MCF Mobicast with Carry-and-Forward. 23, 26, 30, 35, 40, 41, 42, 43, 44

MILP Mixed Integer Linear Programming model. 46

MRPV Mobicast Routing Protocol in VANETs. 22, 23, 26, 28, 29, 35, 37, 38, 44

MRS Multicast Routing Scheme for efficient safety message dissemination. 46

MURU MUlti-hop Routing protocol for Urban VANET. 51

MVSV Multi-source Video Streaming in VANETs. 46, 47

O

OMV Dynamic Overlay Multicast. 47

P

PDR Packed Delivery Ratio. 48, 49, 52, 53, 83

POI Point Of Interest. 1, 2

Q

QoS Quality of Service. iv, v, 3, 6, 13, 14, 21, 45, 46, 47, 48, 47, 48, 49, 50, 49, 50, 51, 52, 53, 54, 55, 83, 1

R

RBIP Reliable Broadcast Incremental Power. 58, 59, 62, 77, 81, 82

RGRP-CA Robust Geocast Routing Protocol for Comfort Applications. 25, 26, 30, 31, 35, 40, 41, 42, 43, 44, 84, 85

RGRP-SA Robust Geocast Routing Protocol for Safety Applications. 25, 26, 28, 29, 30, 31, 35, 37, 38, 40, 41, 44, 77, 81, 82, 84

RSU Roadside Unit. 22, 55, 64

RTBP Road-Topology based Broadcast Protocol. 51

S

SA Safety Applications. 7, 53

SDN Software Defined Networking. 22

SNIR Signal-to-Noise-and-Interference Ratio. 58, 65

SONs Self-Organized Networks. 1

STAR Shortest-Path-Based Traffic-Light-Aware Routing. 21

T

TRBIP Time-Limited Reliable Broadcast Incremental Power. 55, 56, 58, 62, 64, 72, 73, 77, 81, 82

T-TSG Traffic light based Time Stable Geocast. 21

TCG Tightly Connected Group. 7, 9

TLO The Last One broadcast method. 17

TR Transmission Range. 3, 23, 24, 52, 53

TRADE TRAck DEtection. 19

V

V2I Vehicle-to-Infrastructure. 1, 11, 13, 22, 24, 25, 47, 50, 53

V2V Vehicle-to-Vehicle. 1, 11, 13, 24, 25, 47, 50, 53, 58

VANET Vehicular Ad-hoc NETwork. iv, vi, 1, 2, 3, 4, 5, 6, 7, 11, 13, 17, 18, 19, 20, 21, 25, 26, 27, 28, 44, 45, 46, 47, 48, 50, 51, 56, 57, 58, 62, 64, 65, 67, 69, 77, 81, 83, 84, 1

VDL Vehicle Density and Load aware protocol. 21

VMaSC Vehicular Multi-hop algorithm for Stable Clustering. 18

W

WSN Wireless Sensor Network. 1

Z

ZOF Zone Of Forwarding. 19

Chapter 1

Introduction

Contents

1.1 Context

Recent advances in both automobile industry and computation and communication technologies resulted in the tremendous number of applications that either directly or indirectly contribute in making our lives easier. In addition, the growth in the Internet speed for lower costs have also contributed to the emergence of new Internet and wireless communication-based applications and services. These new services and applications are realized thanks to the development of new wireless technologies allowing the emergence of Self-Organized Networks (SONs) and all their breeds including Mobile Ad-hoc NETwork (MANET), Wireless Sensor Network (WSN), Internet of things, and VANET [1].

By providing efficient Vehicle-to-Vehicle (V2V) communication, Vehicle-to-Infrastructure (V2I) communication, or both, VANET is considered as the keystone of Cooperative ITS (C-ITS) [2, 3, 4, 5]. Currently, C-ITS provides a plethora of applications such as safety-related and comfort or information and entertainment (collectively referred to as *infotainment*) applications. Safety-related applications include emergency braking, ambulance approaching, black ice on the pavement, and accident alert services, whereas infotainment applications include traffic information, in-car entertainment services, platooning, Internet on the move, chatting, gaming between passengers in nearby cars, video download, streaming services, social network services, and location-based services (i.e, WEB surfing) [6, 7, 8, 9, 10, 11].

Unlike traditional applications, vehicular communications enable new emerging group applications including Point Of Interest (POI) distribution. POI distribution refers to inform drivers and passengers about specific location points (i.e., parking lots, restaurants, etc.), which can be interesting and useful for the nearby road users.

Most of the aforementioned applications are based on group communications. For instance, alerting drivers about an accident on the road requires transmitting the message to all endangered vehicles in the risk area. Also, platooning and chatting or gaming require group communication schemes. In addition to this, announcing nearby restaurants or empty parking lots in a specific area like in POI require group messages delivery from a source (vehicle or infrastructure) to a set of vehicles located in a specific Destination Zone (DZ) [1].

Group communications is of great importance in vehicular networks due to the potential use cases it targets. Whatever the communication type (one-to-many or many-to-many), group communication has many benefits:

- First, as the transmission bandwidth is restricted in wireless environments of VANET, group communication optimizes the use of the channel by reducing the number of sent messages compared to mechanisms that use broadcast or multiple unicast destinations.
- Second, organizing vehicles as a group reduces the complexity of managing several individual entities by setting up a unified mechanism for the group. Hence, the system is more flexible to leaving/joining members.

The pinnacle of ITS through VANET is the communication among different entities in the group such as vehicles, roadside infrastructure and management authorities. Communication among these entities can take place at different levels ranging from cooperative awareness messages to routing information. In fact, different applications exhibit different behaviors and thus-forth require different kinds of communications.

1.2 Problem statement and motivations

The high mobility of vehicles and the density variation features together with the transmission range limitation of the DSRC devices [12, 13] make a real challenge in the design of group data communications in VANET. In fact, the highly dynamic topology results in frequent changes in its connectivity. Thus, the communication between group vehicles can quickly disappear while transmitting information. The Frequent Network Fragmentation (FNF) is highly occurring due to the unpredictable mobility and variation density of vehicles. In highways, velocity of vehicles

[1] We use the terms ‘destination zone’ and ‘transmission zone’ interchangeably in the rest of the thesis.

may go up to 200 km/h, while density of nodes may be very low. Furthermore, in rural areas, speeds can reach up to 80 km/h and node density can be very low. In the previous two cases, the group is dispersed with low connectivity between the vehicles. This initiates the need to new protocols taking into consideration the FNF phenomenon. On the other hand, for urban environments, vehicles velocities can reach up to 80 km/h and vehicle density can be very high. Hence, different factors such as multi-path in intersections and obstacles face the inter-vehicle communication in these environments [14]. In addtion, vehicles can quickly leave/join the group in a very short period of time. This phenomenon can cause two different unwanted situations: (i) Internal Network Fragmentation (INF) and (ii) External Network Fragmentation (ENF).

- **Internal Network Fragmentation (INF):** It takes place when a vehicle v_i in the group cannot successfully receive a message from the source vehicle or is not covered by the Transmission Range (TR) of any relay vehicle v_j, i.e, some of vehicles are unreachable.
- **External Network Fragmentation (ENF):** It happens when a vehicle is disconnected from the group after a certain period of time.

By studying these features and challenges, we can say that mobility and frequent network fragmentation are widespread factors in the group communication. Hence, any practical communication must take them into consideration. Therefore, a multi-hop relaying system is adopted for the communication of group messages. However, it also introduces many challenges: First, delay is the main feature of delivered messages. For example, to avoid potential accidents, the emergency message should reach the endangered vehicles timely so that drivers are able to react to the emergency on time. Second, multi-hop communication degrades a lot the transmission reliability and scalability of the delivered message that can extremely degrade the network's QoS, throughput in particular. The more are the hop-counts in a wireless path, the less reliable is the wireless communication, since the overall reliability is computed considering all links in a wireless path [15]. Third, multi-hop communication also increases the vehicles' fuel consumption. For this reason, power efficiency is becoming a major issue in VANET, and green communications have attracted more attention by both academic and industry researchers [16, 17]. Besides the fuel consumption optimization, the design of new protocols minimizing the total power consumption for message communication in a group helps also to reduce the interference and to minimize the transmission collision, that is what motivated us to propose four protocols addressing the aforementioned issues and a survey. The following describes the research contributions of the dissertation.

1.3 Contributions of the thesis

(i) Group data communication in connected vehicles: A survey [18]

In this work, we hover the existing group data communication strategies in VANET, which can be classified in many ways, according to different aspects such as: type of communication used, type of application, and transmission strategies. To the best of our knowledge, none of the existing works highlight the importance of group routing strategy and QoS-awareness, that is what motivated us to present this study. Hence, the focus of this work is to provide detailed group classifications considering all the previously mentioned classes. Moreover, the performance of all protocols studied is analyzed by comparing their QoS requirements.

(ii) Robust geocast routing protocols for safety and comfort applications in VANET [19] [20]

In this work, we study the geocast routing problem in VANET, which aims at delivering data to a specific group of mobile vehicles identified by their geographical location. Although many geocast routing protocols have been proposed, only partial inherent constraints of VANET (such as mobility, internal network fragmentation problem, external network fragmentation problem, and overload) are taken into account. Therefore, we propose two novel and robust geocast routing protocols: the first one, called Robust Geocast Routing Protocol for Safety Applications (RGRP-SA), is designed for delivering delay-critical short safety packets while taking into account all the constraints in VANET, while the second, namely RGRP-CA, is dedicated to comfort applications it allows the dynamic adjustment of the transmission zone to maintain good network connectivity among vehicles along with the comfort applications.

Simulations conducted in NS-2 simulator demonstrate that our safety-oriented RGRP-SA protocol outperforms Inter-Vehicle Geocast protocol (IVG) and Mobicast Routing Protocol in VANETs (MRPV) by solving the internal network fragmentation problem. Besides, it is also shown that our comfort-oriented RGRP-CA protocol serves well comfort applications with only light overhead by solving internal and external network fragmentation problems, and providing more reliable data delivery and higher network throughput utilization in comparison to Mobicast with Carry-and-Forward (MCF) protocol.

(iii) Reducing transmission interferences for multicast safety messages in VANET [21]

In this work, we study the problem of efficient multicast safety message dissemination in VANET. The objective is to reduce vehicular communication interferences for safety message delivery while guaranteeing the low delay and the reliability of messages to avoid accidents. Therefore, we propose a heuristic algorithm called Time-Limited Reliable Broadcast Incremental Power (TRBIP) to construct a safety message delivery tree. Extensive simulation results show that the proposed algorithm outperforms its counterparts in terms of delay, reliability and interference reduction.

(iv) A distributed time-limited multicast algorithm for VANET using incremental power strategy [22]

Efficient information dissemination is the pinnacle of VANET. In case of delay-sensitive information such as safety-related messages, it is imperative to minimize the transmission delay and increase the message reliability in VANET. TRBIP algorithm is able to reduce the transmission interference and thus-forth maximizes the reliability. Furthermore, in TRBIP, VANET' features such as vehicle mobility and frequent network fragmentation are also taken into account through store-carry-and-forward and the periodic multicast tree reconstruction strategies. However, multicast tree management is hard to maintain in urban environments due to the high density of nodes in VANET (large trees), and also change in multiple directions at the intersections. To address the aforementioned issues, we propose in this work a Distributed version of Time-Limited Reliable Broadcast Incremental Power (DTRBIP) based on a road segmentation technique. Our proposal is extended to handle both delay-sensitive and delay-tolerant applications, and also both low and high dynamic VANET scenarios respectively urban and highway environments.

The results of the simulation conducted using NS-2 simulator advocate for the efficiency of our proposed method in term of reducing the total emission energy, reducing the average delay, increasing the packet delivery ratio, and reducing the protocol overhead. Obtained results show a clear enhancement compared to the previous solutions (i.e, RGRP-SA, RBIP, and TRBIP).

1.4 Organization of the dissertation

This thesis is organized as follows:

- **Chapter two (2)** concerns the state-of-the art and the systematic review of group data communication in VANET and presents an overview of applications and techniques for group communication systems. The chapter also illustrates some of the existing surveys that are related to group communication and briefly summarizes the different group data communications in connected vehicles with a detailed synthesizing and comparison of all discussed protocols.

- **Chapter three (3)** presents two new robust geocast routing protocols, designed for safety and comfort applications in VANET.
- **Chapter four (4)** focuses on the problem of multicast and hybrid routing strategies in VANET. It briefly summarizes the different multicast and hybrid routing protocols with a detailed comparisons and synthesizing, and illustrates also the classification of QoS requirement in group routing strategies.
- **Chapter five (5)** presents two new multicast and hybrid routing protocols: the first solution illustrates the problem of reducing transmission interferences for multicast safety messages in VANET. The second solution describes the distributed version of our designed multicast routing protocol. This routing protocol handles both delay-sensitive and delay-tolerant applications through geo-multicast scheme in urban and highway environments.
- **Chapter six (6)** concludes this dissertation by summarizing our contributions and giving the perspectives of our work.

Chapter 2

Group data communication in VANET: A systematic review

Contents

2.1 Introduction

Due to the importance of communications over multi-hop VANET, many strategies have been proposed, their common aim is to deliver data to vehicles within a specific group. As the transmission bandwidth is restricted in wireless environments of VANET, group data communication is critical for an efficient usage of network resources. Along with this chapter, we start with the presentation of group-based applications and techniques. We also illustrate some of the existing surveys related to this work. Then, we hover the existing group data communication strategies with a detailed synthesizing and comparison of all discussed protocols.

2.2 Group-based applications in VANET

We can classify group-based applications into three main categories including (c.f. Fig. 2.1): (i) Infotainment Applications (IA) , (ii) Safety Applications (SA), and (iii) Comfort Applications (CA).

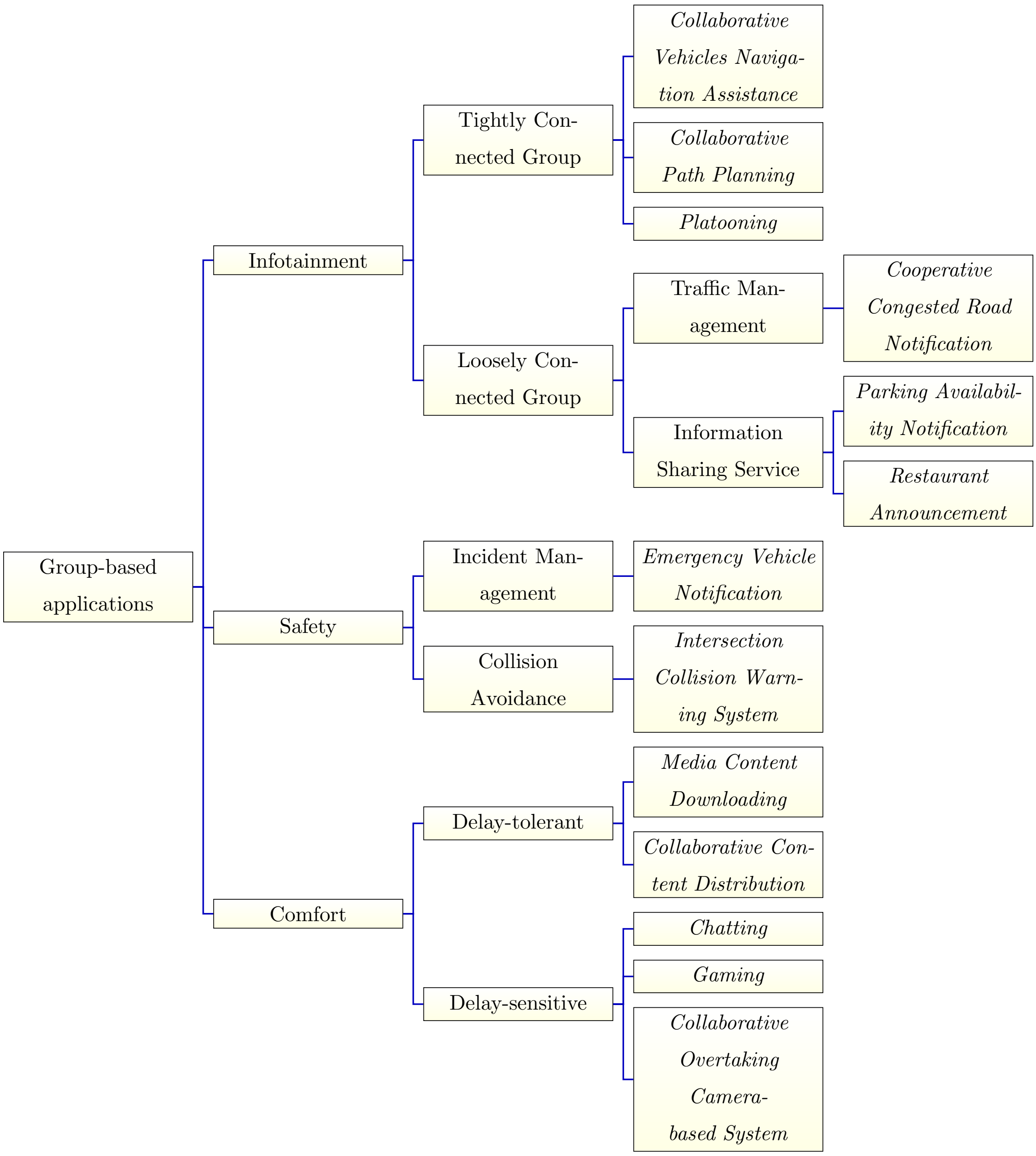


Figure 2.1: Classifications of group-based applications

1. **Infotainment Applications (IA):** Infotainment applications are divided into two sub-categories: (i) Tightly Connected Group (TCG) and (i) Loosely Connected Group (LCG).

    - **Tightly Connected Group (TCG):** In this category, the group of vehicles receives a service depending on their identity, which is usually pre-configured or set dynamically. The group of vehicles can be managed centrally by the infrastructure or by collaborative vehicles. *Collaborative vehicles navigation assistance* and *collaborative path planning* [23, 24] are examples of TCG applications.

      Another notable application in this category is the *platooning* [25]. Vehicles in a platoon are connected to each other by IVC and driven automatically. A platoon leader vehicle in the front of this platoon is conducted by human, which is responsible for managing the following vehicles. In this way, the group of vehicles can move efficiently, safely, and environment friendly, since a smooth travel of platoon can increase traffic flow and decrease the fuel consumption. Meantime, the safety of passengers is guaranteed because the possibility of mechanical or electronic fault is much less than the one of human fault [26].

    - **Loosely Connected Group (LCG):** In this category, data is transmitted in a specific area (DZ) to a group of vehicles, which can operate relatively independently of each other and they are usually autonomous. This type of data provides the location of new restaurant, parking, or hotel and their prices through *information sharing service* [27, 28]. In many cases, the communication will happen between vehicles and infrastructure, with no need for a large bandwidth. However, the typical requirements of these applications are providing the reliable and available information in the right moment that the drivers and passengers need.

      Infotainment applications can be also used for *traffic management service* [29] by suggesting the uncrowded paths to decrease congestion on the involved roads. This can potentially increase the road capacity and prevent traffic jams.

2. **Safety Applications (SA):** Also known as Delay-Sensitive-oriented (DS) applications which are used to avoid and decrease the number of road accidents and traffic collisions [30], that eventually enhance the safety of vehicular environments. Normally, the typical requirements of these applications are delay and reliability and the groups can be qualified as *loosely connected groups.*

   Due to the high speed of vehicles on the roads, drivers may not react promptly and correctly in the hazard situations. *Incident Management Applications (IMA)* can be used to warn the drivers about the hazardous situations (For example, an accident notification). When the *IMA* sends emergency messages to the vehicles in the risk area (DZ), the drivers can reduce their speeds before approaching to the zone of the accident, thus, another accident can be prevented.

Moreover, the likelihood of accident occurring and traffic jams at the intersection is high. The drivers can use *IMA* to inform each other about an emergency situation occurred at the intersection.

According to the study in [31], if the driver gets a warning half a second before the collision, more than half of the accidents can be avoided through sharing *collision avoidance*-related information (such as, current position, real-time speed, and direction). This type of information is not only important to assist the drivers in passing, but it is a necessary condition to warn drivers that are approaching the same intersection if there is a possibility of an accident occurrence. In such cases, a specific application is used, namely Intersection Collision Warning System (ICWS) [32]. ICWS aims at avoiding collisions for the vehicles approaching an intersection. Sensors on the vehicles, e.g., ultrasonic, radar and video camera, can be used to assist drivers in detecting potential collision with other vehicles.

3. **Comfort Applications (CA):** In this category, most of the applications mainly resort to carry-and-forward mechanism, in which data is stored when there is no neighboring vehicle in the transmission range of the relay vehicle, meanwhile, the data is carried until it reaches a new neighboring vehicle. Services or applications using this mechanism are generally *delay-tolerant*. Media content downloading and collaborative content distribution [33, 34] are an examples of *delay-tolerant* applications. In this category, we have also some *delay-sensitive* applications such as chatting, gaming between passengers in nearby cars, online video streaming diffusion (soccer games for instance), and collaborative overtaking camera-based systems [35]. In these types of applications we can qualify the groups as *tightly coupled groups*.

2.3 Group-based communication techniques in VANET

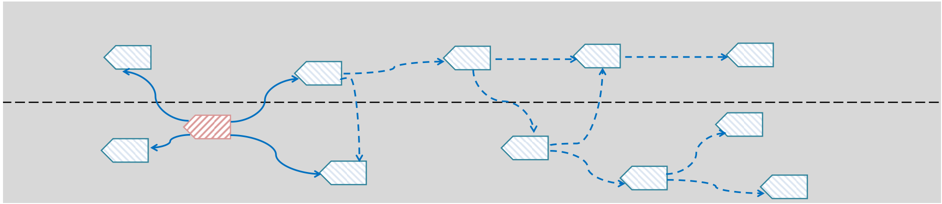
Communication in a group-based techniques comprises the following schemes:

- **Broadcast-based Group (BG):** In this scheme, messages are distributed by flooding where vehicles rebroadcast the packets if they are located in the group (as shown in Fig. 2.2a). This simple flooding scheme is enhanced with techniques based on packet numbering to alleviate the effects of so-called broadcast storms. Broadcast storms (a typical problem in wireless ad-hoc networks) occur when multiple nodes simultaneously rebroadcast a message that they have just received, causing packet collision and extra delay at Medium Access Control (MAC) layer. To avoid message duplication, a broadcast message is sent only once by using a time to live parameter. But the performance of this routing scheme degrades with the increase in network size [36].

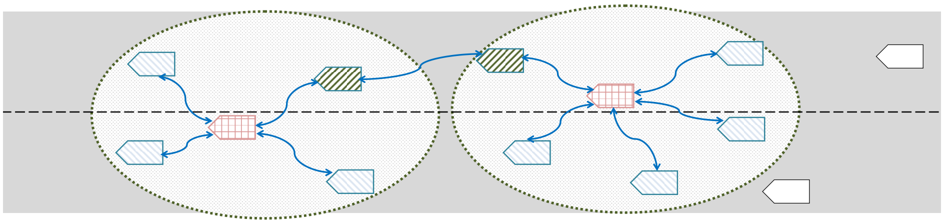
- **Cluster-based Group (CG):** This approach can be defined as the virtual partitioning of the dynamic nodes into various groups [37]. A group of nodes identify themselves to be part of a cluster (c.f. Fig. 2.2b). A special node, designated as cluster-head is responsible for managing inter and intra-cluster communication. The remaining nodes are served by the cluster head. Moreover, clustering structure acts like a virtual network infrastructure whose scalability favours routing and media access protocols. However, an overhead cost is paid when clusters are formed in highly mobile network environments thus resulting in network delays in large VANET [38].
- **Multicast-based Group (MG):** This scheme is developed to deliver packets from a source to only a subset of vehicles (called group members) as illustrated in Fig. 2.2c by creating and maintaining a data communication structure (tree).
- **Geocast-based Group (GG):** This approach is designed to transmit messages to vehicles belonging to a specific geographic region (called DZ) (c.f. Fig. 2.2d) whose data is determined by the mobility pattern of vehicles.
- **Geo-Multicast-based Group (GMG):** In this hybrid scheme, message delivery from the source to the multicast vehicles in a specific DZ (c.f. Fig. 2.2e) follows a specific path that can rely on a tree or a mesh structure.

2.4 Group data communication in VANET: Related works

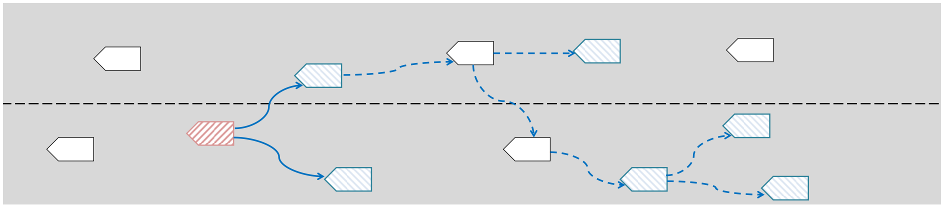
Traffic data communication has been the target of several research works [39, 40, 14, 41], mainly because the transmitted data mostly concerns with the traffic situation and accident alerting services (i.e., the state of the road, traffic signal violation warning, lane change warning, and so forth.). An efficient data dissemination has several advantages such as: facilitating the movement of drivers and passengers on roads and enabling them to take appropriate decisions depending on real-life traffic estimations. In addition, data communication is also important for interactive games between passengers of nearby vehicles, chat services, files download, streaming services, and Internet-based services. Data concerning the latter applications is usually sent to a group of vehicles.



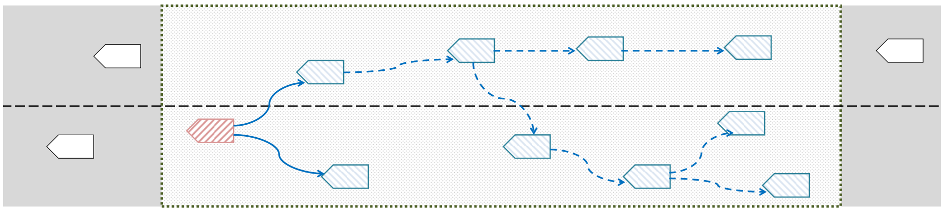
(a) *Broadcast-based group: flood a message to vehicles in the n-hop neighborhood*



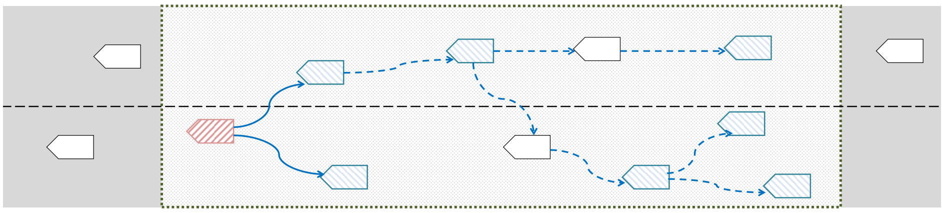
(b) *Cluster-based group: virtual partitioning of the dynamic nodes into various groups*



(c) *Multicast-based group: send a message to a specific group of vehicles using specific structure*



(d) *Geocast-based group: transmit a message to all vehicles in a specific DZ*



(e) *Geo-muticast-based group: transmit a message to specific members vehicles in DZ*

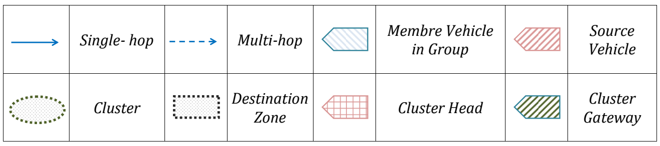


Figure 2.2: Group-based communication techniques in VANET

Data communication approaches in VANET are broadly classified in two main categories [42, 43, 44] : (i) V2I communication, which allows a vehicle to communicate with infrastructures and (ii) V2V communication, which allows the direct vehicular communication without relying on a fixed infrastructure. According to the type of application, other papers classified VANET communication protocols, into two classes: (i) safety-oriented applications and (ii) non-safety-oriented applications [39, 45, 46, 19, 20]. Safety-oriented applications contain protocols transmitting emergency warning and road safety information. while non-safety-oriented applications exploit protocols suitable for both infotainment and comfort applications. Furthermore, based on routing strategies classification, there are three types of protocols: (i) unicast, (ii) broadcast, and (iii) multicast/geocast [47, 48]. The main goal of unicast routing protocols is to transmit data from a single source to a single destination by either using multi-hop or carry-and-forward techniques. The objective of broadcasting protocols is to deliver data to all the vehicles in the network. On the other hand, the objective of geocasting and multicasting protocols is to distribute data to vehicles within a specific group/zone.

One of the main data delivery challenges is how to develop an efficient multicast/geocast protocol over VANET with the mobility and the frequent network fragmentation problems. According to the property of geographic region, existing solutions are classified into simple multicast/geocast protocols and spatiotemporal multicast/geocast routing protocols [48, 20]. On the other hand, other papers classified them into five categories: (i) topology-based routing protocols, (ii) position-based routing protocols, (iii) cluster-based routing protocols, (iv) geocast-based routing protocols, and (v) broadcast-based routing protocols [49, 50, 51, 52].

In addition, several authors have published surveys focusing on different routing-related strategies in group-based communication such as, broadcast warning message dissemination schemes. Sanguesa et al. [53] classified broadcast protocols into (i) one-hop and (ii) multi-hop schemes depending on whether or not warning message forwarding is allowed. Authors of [54, 55] presented a classification of geocast routing protocols into two groups namely: (i) urban and (ii) highway based on the traffic environment.

Farooq et al. [56], presented a comprehensive overview of multicast routing protocols. In particular, their review was divided into three categories: (i) multicast routing methods, (ii) multicast routing approaches, and (iii) multicast routing types.

However, all previous classifications did not target the group-based communication classification. To the best of our knowledge there are no specific VANET oriented works offering a classification of group-based communication. In addition, none of the existing works highlights the impact of QoS on group-based communication, that is what motivated us to elaborate such a classification work.

Table 2.1: Comparison of group-based routing surveys

	Criteria													
	Communication			Challenge				Application		Routing strategy				
Group Routing Surveys	V2V	V2I	hybrid	Frequent network fragmentation	Reliability	Scalability	Power consumption	Safety-oriented	Non-safety-oriented	Broadcast-oriented	Cluster-oriented	Multicast-oriented	Geocast-oriented	Hybrid
[42][43][44]	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
[39][45][46]	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗
[19][20]	✗	✗	✗	✓	✗	✗	✗	✓	✓	✓	✗	✓	✓	✗
[47][48]	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	✓	✗
[49][50][51][52]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗
[53]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗
[54][55]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
[56]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Our classifications	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

In Table 2.1, we compare the existing group data communication surveys based on the following criteria: communication type consideration, challenges-awareness, application-oriented, and routing/transmission strategy. By studying these surveys, we can say that: (i) communication type consideration, (ii) routing strategy-awareness, and (iii) QoS-awareness are essential classifications in group-based communication. Hence, any comprehensive overview taking into consideration these classifications is preferable. We will present in the rest of this chapter and in the following chapters a detailed group-based classification considering all previously mentioned features.

2.5 Group-based routing strategies in VANET

We classify group-based data communication into: (i) routing strategy-based and (ii) QoS-awareness as shown in Fig. 2.3. In the research literature, many strategies of routing are presented, which can be classified according to the already presented classification of group-based communication techniques (Section 2.3) into: (i) broadcast-oriented protocols, (ii) cluster-oriented protocols, (iii) geocast-oriented protocols, (iv) multicast-oriented protocols, and (v)

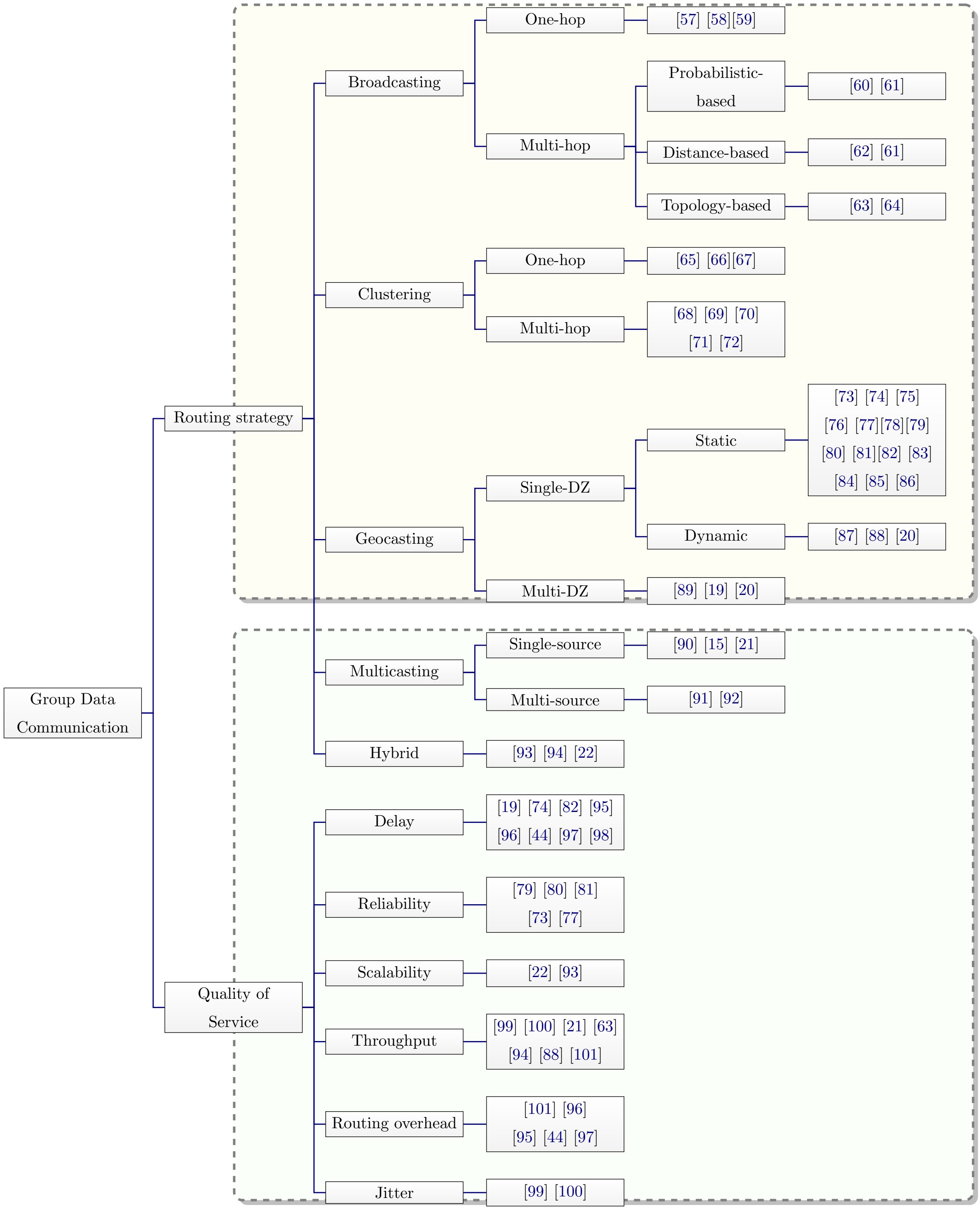


Figure 2.3: Classification of group data communication in VANET

hybrid protocols. In order to well organize the dissertation's chapters, the first three routing strategies will be discussed in the following Sub-sections and compared in Table 2.2. The rest of routing strategies and QoS class will be explained along with the used routing protocols in Chapter 4.

2.5.1 Broadcast-oriented protocols

Broadcast routing is generally utilized for information dissemination such as weather informations and road conditions. In this routing method, the packet is sent to all other vehicles in the network using flooding. When message needs to be disseminated beyond the radio transmission range, a multi-hop mechanism is utilized. Thus, in a pure broadcast implementation, all receiving vehicles simply rebroadcast the received messages. Broadcasting solutions can be divided into: (i) one-hop broadcasting and (ii) multi-hop broadcasting [53].

One-hop broadcasting messages are those periodically exchanged by neighbor vehicles and that are not forwarded to other vehicles [57, 58, 59]. For instance,

(i) Torrent-Moreno et al. [57] addressed how to manage power control in scenarios with high vehicular density when broadcasting single-hop safety messages, in particular, they limited the channel load by means of a fairness criterion. However, only simple straight road scenarios are used to evaluate the proposed solution, achieving optimistic performance results [53].

(ii) Hassanabadi and Valaee [58] presented a method specially designed to support safety applications using single-hop safety messages. However, it is necessary to rebroadcast the same messages several times to improve the overall reliability, making it necessary to include additional mechanisms to address well-known problems such as synchronized collisions and network congestion.

(iii) Park and Kim [59] studied collision control for safety services requiring message rates above 10Hz. An algorithm was designed to modify the transmission time of single-hop messages to increase the message reception probability. Since frequency adaptations are not allowed due to the application requirements, the transmission phase was modified to increase the performance of the system.

According to Sanguesa et al. [53], dissemination schemes based on single-hop provide only local information, hence requiring additional algorithms to be feasible in applications covering a wide area, which limits their functionality in such scenarios.

In addition, many multi-hop broadcasting protocols have been proposed. For instance,

(i) Wisitpongphan et al. [60] proposed three probabilistic and timer-based broadcast suppression techniques: weighted p-persistence, slotted 1-persistence, and slotted p-persistence schemes, where vehicles with a higher priority are allowed to use the channel in the least possible time. These techniques are among the few rebroadcast techniques conceived specifically for broadcast storm alleviation in VANET, although their particular design makes them mostly suitable for highway scenarios since performance problems emerge in urban scenarios.

(ii) The Last One broadcast method (TLO) is proposed in [62], where whenever a vehicle sends a warning message, there is a search process to locate the farthest reachable vehicle, which will be the only one granted to forward the packet. The distances between the sender and the rest of receiving vehicles are computed by means of positioning information gathered by Global Positioning System (GPS) devices. This method is simple and enhances performance when compared to simple rebroadcasting, but since it does not account for urban obstacles like buildings in wireless communications, it is only effective in highway environments. In addition, it is unclear how vehicles are able to estimate the position of neighbor nodes when this information is needed [53].

(iii) Kanitsorn et al. [61] presented Adaptive Probability Alert Protocol (APAP), it is an extension to the TLO scheme using adaptive probability to transmit road safety alert messages. This scheme outperforms the previous method, but it still presents the same limitations regarding the situations where it is applicable, being only assessed in simple highways.

(iv) In [63], Distributed Vehicular broadCAST (DV-CAST) is presented for a multi-hop topology-based routing protocol. It takes into account three traffic scenarios for a vehicular broadcasting: dense traffic scenario, sparse traffic scenario, and regular traffic scenario. In dense regime, the protocol reduces the number of hops. In sparse traffic regime, the message is stored until there is a neighboring node into the transmission range within a timeout period. If the timeout expires before establishing any connection, packets are discarded. This protocol causes high control overhead and delay in end-to-end data transfer [102].

(v) Sanguesa et al. proposed Junction Store and Forward (JSF) protocol [64], was specially designed to make use of the topology characteristics and the effect of obstacles in wireless communications, since it considers that vehicles should wait to be near the crossings to rebroadcast alert messages. Unlike other proposals that immediately allow vehicles to forward received warning messages, according to the JSF protocol vehicles can store warning messages until a better communicating situation arises. This scheme requires each vehicle to maintain a neighbor list, which is updated taking advantage of the beacons exchanged by the cars, as well as the information provided by the GPS to decide if a vehicle is near an intersection.

2.5.2 Cluster-oriented protocols

In cluster-oriented routing protocols the nodes of a wireless network are divided into several disjoint or overlapping clusters. Each cluster elects one node as the head which is called the cluster-head. The cluster-heads are responsible for the routing process and are able to communicate with each other using cluster-gateway. In terms of cluster formation, clustering schemes can be classified into: (i) one-hop clustering and (ii) multi-hop clustering, indicating the maximum number of hops from a cluster-head to its farthest cluster-member [103].

Many clustering algorithms are based on one-hop communication in which the cluster-member is one-hop away from its cluster-head [65, 66, 67]. Small coverage of one-hop clusters leads to an increase in the number of cluster-heads. This can decrease routing efficiency and raise communication cost when communication beyond the cluster small range is necessary.

Multi-hop clustering protocols extend the communication coverage in the same cluster and reduce the number of cluster-heads and subsequently the number of clusters. Most of recent researches are focus on multi-hop communication [68, 69, 70, 71, 72]. For instance,

(i) Zhang et al. [68] firstly proposed a multi-hop clustering algorithm for VANET, based on vehicle's relative mobility. The cluster size is limited by the number of hops between cluster-head and its farthest cluster-member.

(ii) The algorithm proposed in [70], known as Vehicular Multi-hop algorithm for Stable Clustering (VMaSC), is addressed as the first multi-hop clustering scheme to simulate under realistic traffic scenarios. The scheme aims to provide more stable clusters and to reduce the number of cluster-heads in the network. The cluster-head election is based on the calculated relative mobility with respect to its neighbors.

(iii) Chen et al. [72] proposed a neighborhood following strategy for multi-hop clustering, in which, each vehicle finds a stable target to follow. The vehicle only needs to know the information of its local one-hop neighbors, thus, it reduces the packet loss problem.

Compared to one-hop clustering schemes: On the one hand, a multi-hop clustering scheme can deliver good scalability for large networks but network delays and overhead are experienced when forming clusters in highly mobile VANET. On the other hand, a multi-hop clustering scheme requires more beacon exchanges within the maximum number of hops, which may cause the increase in the number of connections lost and longer cluster formation time [103].

2.5.3 Geocast-oriented protocols

In geocast routing protocols, the source vehicle sends a packet to vehicles in a specific geographic region (DZ). Existing geocast routing protocols assume that the transmission range is fixed for member's group. These solutions can be divided into: (i) single-DZ-based and (ii) multi-DZ-based.

2.5.3.1 Single-DZ-based

The protocols belonging to this category can be divided into: (i) static geocast-oriented protocols and (ii) dynamic geocast-oriented protocols. These two categories differ in several aspects from the point of view of DZ. DZ in the first category is static, while in the second category, DZ is changed dynamically along with the type of application. On the other hand, the first category requires to overcoming INF problem, while the second category has stringent requirements on handling both INF and ENF problems.

- **Static geocast-oriented protocols:** Several static geocast solutions have been presented in highway and urban environments. In this category, authors assume that the DZ is a static rectangle.

  (i) Briesemeister et al. [73], proposed two geocast protocols TRAck DEtection (TRADE) and Distance Deferred Time (DDT) to reduce the number of messages retransmission in highway environments. In TRADE, a vehicle designates among its neighbors one relay for retransmitting messages based on their movements. In the DDT protocol, a vehicle v uses a deferred time before rebroadcasting a received message. During this time, if the vehicle v receives the same message, it cancels the rebroadcast. Although DDT protocol is used in many solutions, it does not address the FNF problems in VANET.

  (ii) In [74], Inter-Vehicle Geocast (IVG) is proposed. This protocol takes advantage of both TRADE and DDT protocols such that it overcomes the INF and utilizes dynamic relays for rebroadcasting warning messages periodically. The periodical retransmission of alerting messages generates a large number of messages, thus, it results in a high overload.

  (iii) Distributed Robust Geocast (DRG) protocol is presented in [75], which adopts the same principle as IVG. However, DRG uses relays in the opposite direction in the

Zone Of Forwarding (ZOF) to relay messages to other vehicles in DZ. The network overhead and delay rise by increasing the packet delivery ratio because more geocast messages are kept alive for long durations at DZ [56].

(iv) Maihöfer et al. [76], proposed Cached Geocast (CG) protocol. In this protocol, cache is introduced to forward geocast messages. The cache is added at the routing layer for storing geocast messages. If a suitable neighbor is not found, then the geocast messages are saved into the cache. The cached message is forwarded to newly discovered vehicles. It always chooses greedy distance approach to forward packet towards DZ. The cache is updated in case of any neighboring vehicle joining, leaving, or changing in its position. Similarly, it requires additional time in storing, retrieving, and maintaining the messages in cache [55, 56].

In addition, many static geocast routing protocols have been proposed in urban environments including:

(v) In [77], authors proposed a Coverage-aware Geocast Routing (CGR) protocol to measure vehicles' coverage capability. Afterward, to carry the packets, it selects the best relay vehicles having high successful delivery probability. In addition, a novel coverage graph is developed to maintain collected trajectories of all the encountered vehicles together with their check timing. Hence, the extended coverage capability of each vehicle can be estimated. The coverage graph is constructed in a distributed way based on locally shared information, and the packet forwarding decision can be adaptively made to meet different routing objectives. However, the analysis and arguments of this solution are not presented by the authors.

(vi) Maihöfer et al. [78], proposed an approach of Abiding Geocast (AG) that is a time stable geocast delivered to all nodes that are inside DZ during the geocast lifetime (a certain period of time). It uses three approaches for forwarding messages: (i) server approach, (ii) election approach, and (iii) neighbor approach. The first one is a server solution to store the messages. The second approach stores the messages at an elected vehicle inside the DZ that temporarily acts as a server. The last one complements the exchange of neighbor information necessary for many unicast routing protocols with abiding geocast information.

For VANET, the use of AG is suitable for some applications as following: advertising or informing drivers about the state of the road e.g., slippery surface, ice storm,...etc. Elected node approach and neighbor approach are more adapted to safety applications to inform drivers about an accident on their direction. In this protocol, periodic beaconing system is not mandatory since the geocast message is periodically broadcasted [104]. The packet loss and latency is high in abiding upon comparison with other approaches because saving and retrieving from the server take extra processing time [40].

(vii) A Traffic light based Time Stable Geocast (T-TSG) protocol is proposed in [79], for the purpose of informing vehicles after an accident in urban VANET. T-TSG is based on four concepts namely identification of Geocast Region (GR) from Region Of Interest (RoI) based on incident point, selection of forwarding vehicles are based on traffic situation, Geocast Message Stable Region (GMSR) and Stable Vehicle Region (SVR). T-TSG has three phases of geocast routing: Forwarding, Disseminating and Re-Live (FDRL). However, in this solution, the mobility and the density are not considered [54].

(viii) A Vehicle Density and Load aware protocol (VDL) is proposed in [80], the authors gather vehicles density and traffic load using Network Information Collection Packet (NICP) in distributed manner. Using NICP junction vehicles calculate a weight for each adjacent road section. VDL improves the accuracy of routing table information by real-time distance calculation between current forwarder and next forwarder. It also presents two algorithms one for enhancing beacon exchange mechanism and another for packet forwarding process.

(ix) In [81], a Shortest-Path-Based Traffic-Light-Aware Routing (STAR) and Green Light Forwarding (GLF) are proposed to reduce the effect of FNF in routing. For STAR it always tries to forward a packet through a road segment having the red light ON and connected links up to the next junction. Whereas, GLF always forwards packets through a road segment having the green light ON. Data delivery ratio of STAR and GLF has been studied using statistical methods and it has been proved that delivery ratio of STAR is better than GLF. The probability of having a path of connected links between two junctions with the red light ON is also derived. However, neither the mobility nor the ENF are taken into account in these works same as in the case of VDL and T-TSG.

(x) Authors of [82] developed an intersection-based Geographical Routing Protocol (GRP). The proposal is based on an effective selection of road intersections through which a packet must pass in order to reach the gateway having Internet access. The selection is made in a way that guarantees network connectivity among the road intersections while satisfying the desired QoS constraints in terms of end-to-end delay, hop count, and BER (Bit Error Rate). The geographical forwarding is used to transfer packets between any two intersections belonging to the path. The connectivity of GRP is calculated under the assumption that all vehicles on the road follow a Poisson distribution. Unfortunately, this assumption is unrealistic in urban VANET especially when FNF problems occur.

Also, many V2I geocasting protocols have been proposed [83, 84, 85, 86], to operate opportunistic content sharing over a given geographic area. The aim of these approaches is to control the probabilistic nature of the dissemination by providing models that ensure a desired level of content diffusion. The envisaged network architecture includes a Software Defined Networking (SDN) [105, 106] controller co-located within an advanced LoRA gateway [107], which is a Roadside Unit (RSU) equipped with multiple interfaces that allow communication via different V2I technologies (eg, IEEE 802.11p, or Long Term Evolution (LTE) [108, 109]). For instance,

(xi) Soua et al. [83] proposed an SDN Coordination for Content Dissemination (CCD) (SDN-CCD) approach using the RSU Controller (RSUC) and taking advantage of its global view of the network to identify the most popular content, according to a threshold, and the influential vehicles in which to cache such content. Moreover, they described how a network architecture based on SDN can support both Content Centric Networking (CCN) and floating content by coordinating distributed caching strategies and by optimizing the packet forwarding process and the availability of floating data items.

(xii) Maio et al. [84] proposed a Centralized Approach for setting Floating Content parameters (CAFC), it is a method to improve floating content performance by optimizing the destination zone size with the support of an SDN controller, which collects mobility information, such as speed and position, of the vehicles in its transmission range. However, same as SDN-CCD, the validation of the preliminary hypotheses and the derivation of an overall resource consumption model are not presented in this work.

- **Dynamic geocast-oriented protocols:** This category allows the dynamic adjustment of the DZ and adopts the strategy of enlarging the zone range in order to cope with the FNF problems.

  (i) Chen et al. [87], proposed a Mobicast Routing Protocol in VANETs (MRPV). Unlike ordinary routing protocols, it takes into account the time factor. The main idea of this method is to transmit information to all vehicles that are located in a geographical relevance zone at time t. Vehicles must maintain connectivity to support the real-time communication. The connectivity in DZ is lost when a vehicle suddenly accelerates or decelerates and goes out of the transmission range. To solve this problem, they define a forwarding zone at time t to forward the message to all vehicles in DZ, which generates a large number of messages. On the other hand, it may not perform well in a large network with a dynamic and dense environment [47].

(ii) A Mobicast with Carry-and-Forward (MCF) is presented in [88]. This algorithm is an improved version of MRPV to support comfort applications, which predefines a delay λ. If a source vehicle broadcasts a message at time t, vehicles located at DZ are required to receive this message before $t + \lambda$. Then, the message is carried by some possible vehicles and forwarded to another zone of relevance. This protocol allows to overcome the INF problems and maintain a low degree of channel utilization at the same time. But, this method cannot overcome the ENF and could cause a highly overhead and increase the end-to-end delay in the transmission.

2.5.3.2 Multi-DZ-based

In this category, the DZ is constructed by a union of multi-sub-zones. For instance, Allal et al. [89] presented the DZ as many shapes like circle, triangle, or quadrilateral. Authors of this protocol (called Geocast SUb Zones (GeoSUZ)) proposed to divide the DZ into sub-zones and to choose simple geometrical forms of each of them (i.e, circle, triangle, or quadrilateral). The authors provided a geometrical vision angles based technique that allows to know if two sub-zones are in the same direction in order to send them a single message and hence, reduce the messages overhead and they used greedy forwarding techniques to dissemination messages in each sub-zone to enhance reliability. Compared to a well known geocast routing protocol Greedy Perimeter Stateless Routing (GPSR) [110], the performances evaluation of GeoSUZ shows a significant gain in terms of number of messages sent over the network [89]. Still, end-to-end transfer may not be satisfied [111].

2.6 Comparison and summary

Table 2.2 summarizes the main characteristics of the discussed categories, where group-based protocols are classified according to their communications type, transmission strategies, and others criteria: (i) modified beacon packet, (ii) DZ, (iii) TR, (iv) intersections awareness, (v) segmentation awareness, (vi) centralized or distributed method, (vii) INF, (viii) ENF, (ix) communication environments, and (x) application.

Table 2.2: Taxonomy of broadcast-based, cluster-based, and geocast-based information delivery

	Communication Type			Routing Strategy[1]						Other Criteria[2]										
	V2I	V2V	Hybrid	Broadcasting		Clustering		Geocasting		MBP	DZ	TR	Intersections	Segmentation	C/Dd	INF	ENF	Environment	Application	
Protocols				S-Hop	M-Hop	S-Hop	M-Hop	S-DZ	M-DZ										Safety	Comfort
[57], [58], [59]	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	S	S	✗	✗	C	✓	/	H	✓	✗
[60], [61], [62]	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	S	S	✗	✗	Dd	✗	/	U & H	✓	✗
[63], [64]	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	S	S	✓	✗	Dd	✗	✗	U	✗	✓
[65], [66], [67]	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	S	S	✗	✗	C	✓	/	H	✓	✗
[68], [70], [72]	✗	✓	✗	✗	✗	✗	✓	✗	✗	✓	S	S	✗	✗	Dd	✗	/	H	✓	✗
[73], [75], [76]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✗	✗	Dd	✗	/	H	✓	✗
[74]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✗	✗	Dd	✓	/	H	✓	✗
[77], [78], [80]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✗	✗	Dd	✗	/	U	✓	✗
[79], [81]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✓	✗	Dd	✗	/	U	✓	✗
[82]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✓	✓	Dd	✗	/	U	✓	✗
[83]	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✗	✓	Dd	✗	✗	U	✗	✓
[84]	✓	✗	✗	✗	✗	✗	✗	✓	✗	✗	S	S	✗	✓	C	✗	✗	U	✗	✓
[87]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	S	S	✗	✗	Dd	✓	/	H	✓	✗
[88]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	D	S	✗	✗	Dd	✓	✗	H	✗	✓
[89]	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓	S	S	✓	✓	Dd	✗	/	H	✓	✗
RGRP-SA: [19] [20]	✗	✓	✗	✗	✗	✗	✗	✗	✓	✗	S	S	✓	✓	Dd	✓	/	U & H	✓	✗
RGRP-CA: [20]	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	D	S	✓	✓	Dd	✓	✓	H	✗	✓

[1] Routing Strategy (S: Single, M: Multi, DZ: Destination Zone).

[2] Other Criteria (MBP: Modified Beacon Packet, S: Static, D: Dynamic, DZ: Destination Zone, TR: Transmission Range, C: Centralized, Dd: Distributed, INF: Internal Network Fragmentation, ENF: External Network Fragmentation, H: Highway, U: Urban).

By studying these protocols and as presented before, we can say that group-based routing protocols are supported by V2I and V2V communications to disseminate data to all group members using different transmission strategies:

First, broadcast-oriented protocols are simple to implement which deliver messages reliably. However the broadcasting consumes a lot of bandwidth and power due to redundant messages which increase the network load and traffic congestion. The message redundancy causes collision in a network which results in packet loss.

Second, clustering is very effective and efficient for reducing power consumption, scalability and life time for a network with a greater number of nodes and high mobility of network nodes. However, clustering routing protocols also have drawbacks because constructing and maintaining clusters is a difficult task and the extra communication cost may add an important overhead.

Third, geocasting is mostly related to safety applications. Therefore, it requires a low delay and reliable delivery to all vehicles in the DZ on the one hand. The majority of geocast-oriented protocols can reduce end-to-end delay and maximize the reliability. On the other hand, we can say that high mobility of vehicles and network fragmentation are widespread phenomena in VANET. So, any practical geocast routing protocol must solve these problems. Existing safety message routing protocols have partially considered these problems. That is why we propose a novel and Robust Geocast Routing Protocol for Safety Applications (RGRP-SA), which takes advantage of the benefits of the proposed techniques and uses new techniques to adapt to VANETs' constraints. Regarding comfort applications, their routing protocols are poorly studied. The existing proposed comfort routing protocols do not handle ENF problems. Thus, we propose a novel and Robust Geocast Routing Protocol for Comfort Applications (RGRP-CA). Our protocol allows enlarging the transmission zone to cope with external network fragmentation. The following chapter describes the details of our contributions.

Chapter 3

Robust geocast routing protocols: Our contributions

Contents

3.1 Introduction

In this chapter, we address the geocast routing problems in highway and urban environments in VANET. We propose two novel and robust geocast routing protocols aiming at satisfying both road safety applications and comfort applications. Both of them take into account the vehicle mobility and network fragmentation problems.

- The first algorithm, namely Robust Geocast Routing Protocol for Safety Applications (RGRP-SA), is designed for delivering delay-critical short safety packets while taking into account all the constraints in VANET. Compared with IVG [74] and MRPV [87], RGRP-SA protocol is able to reduce the number of hops, cut the end-to-end delay in half, and solve the Internal Network Fragmentation (INF) problem (a major constraint for safety applications). It also utilizes better the network throughput by avoiding unnecessary and unsuccessful information exchanges between vehicles.

- The second proposed algorithm is called Robust Geocast Routing Protocol for Comfort Applications (RGRP-CA) such as, chatting between passengers in nearby cars. This solution allows the dynamic adjustment of the transmission zone and adopts the strategy of enlarging transmission range in order to cope with the External Network Fragmentation (ENF) problem (the key character for comfort applications). With very lightweight overhead, this protocol is able to provide more reliable data delivery (with a 25% higher packet delivery ratio) and higher network throughput utilization as compared to MCF [88]. It is able to maintain good network connectivity among vehicles along with the comfort application.

The rest of this chapter is organized as follows: We present the two novel geocast routing protocols in Section 3.2 for safety application and comfort application respectively. The performance of the proposed algorithms are evaluated in Section 3.3. Finally, the chapter is concluded in Section 3.4.

3.2 Robust Geocast Routing Protocols (RGRP)

In this section, we first describe the geocast routing problem, and then present the details of our proposed approaches.

3.2.1 System model

We consider two different applications in VANET: road safety applications in highway environments or in urban environments, and comfort applications. The first one contains emergency warning and road safety information, while the latter one includes interactive games between passengers of nearby cars, or chat services. Timeliness is the key character for safety applications. For example, vehicles are expected to be warned as quickly as possible in case of accidents. The transmission zone is static for safety applications. The constraints for comfort applications are much more strict. Besides the constraint of time, we must ensure the delivery of information to all vehicles in the transmission zone along with the comfort applications. The Transmission Zone (TZ or DZ) for road safety applications (risk zone) is generally static. INF takes place in case of isolation of a vehicle. While the transmission zone is dynamic for comfort applications, which is difficult to solve in presence of high vehicle mobility (dynamic zone and mobile vehicles). Also we have to solve the problem of ENF when a vehicle moves out of the transmission zone. However, the comfort application is only suitable for a highway environment rather than an urban environment for several reasons. On one hand, it is required to manage the vehicle mobility and direction in intersections [112], and to solve the problem of isolation of a vehicle for routing comfort messages in urban environments. Network connectivity among the participants of a comfort application is hard to maintain due to the possibility of changing directions in intersections. On the other hand, comfort applications like chatting, gaming or video streaming need the delivery of large amounts of data and have stringent requirements in terms of delivery ratio and delay [113]. Thus, it is reasonable to conclude that ENF is too difficult to solve in urban environments with intersections for comfort applications.

3.2.2 Phases of RGRP-SA and RGRP-CA algorithms

Considering those aforementioned constraints in VANET, we propose two robust geocast routing protocols for two different applications, which aim at routing messages to vehicles located in the same geographical zone $TZ(t)$ at time t.

1. Our first algorithm, namely RGRP-SA, is designed for road safety applications, for which the transmission zone is static. RGRP-SA algorithm can disseminate packets with the same method to all vehicles in $TZ(t)$ for highway (Fig. 3.1) or urban environments (Fig. 3.2). Fig. 3.1.A gives an example to illustrate the dissemination of geocast packet to all vehicles in a risk zone through the relays closest to the left axis A_L and the right axis A_R. Vehicles $V_A \sim V_I$ are located in $TZ(t)$, and must receive the packet from the vehicle V_s. In the beginning, V_s broadcasts the geocast packet to V_A, V_B, V_C and V_D within its transmission range. Vehicles V_A and V_B are respectively the closest to A_R and A_L, so they retransmit the packet to $V_E \sim V_I$. Instead, the IVG [74] algorithm selects the farthest vehicle as the relay, i.e., V_B and V_D. Then, V_B relays messages to $V_G \sim V_I$, and V_D will relay the message to V_A. Finally, V_A retransmits the message to V_E and V_F. We find that our RGRP-SA algorithm saves one hop compared with IVG algorithm. Furthermore, RGRP-SA verifies the presence of nearby vehicles periodically before the retransmission of geocast messages. Internal network fragmentation takes place when a node in transmission zone cannot successfully receive the message from the source node (isolation of vehicles), e.g., it is the case of V_G, V_I, and V_H at time $t + \lambda$ in Fig. 3.1.B. To solve this problem, RGRP-SA uses one relay in the opposite direction (case of V_K in Fig. 3.1.B) to relay the message to other vehicles in $TZ(t)$ after guaranteeing the presence of nearby vehicles in $TZ(t)$ (after Δt time). However, in order to solve the internal network fragmentation, MRPV [87] retransmits the packets by enlarging the transmission zone. Consequently, some packets will be rebroadcasted and relayed several times in $TZ(t)$.

   The novelties of the proposed RGRP-SA protocol lie at

   - **Reducing the number of hops and utilizing the prevision of presence of nearby vehicles before the retransmission of geocast messages**. This strategy permits to cut the end-to-end delay in half and improve the successful packet delivery ratio. Thus, it enables to avoid periodic exchange of packets and reduce the network

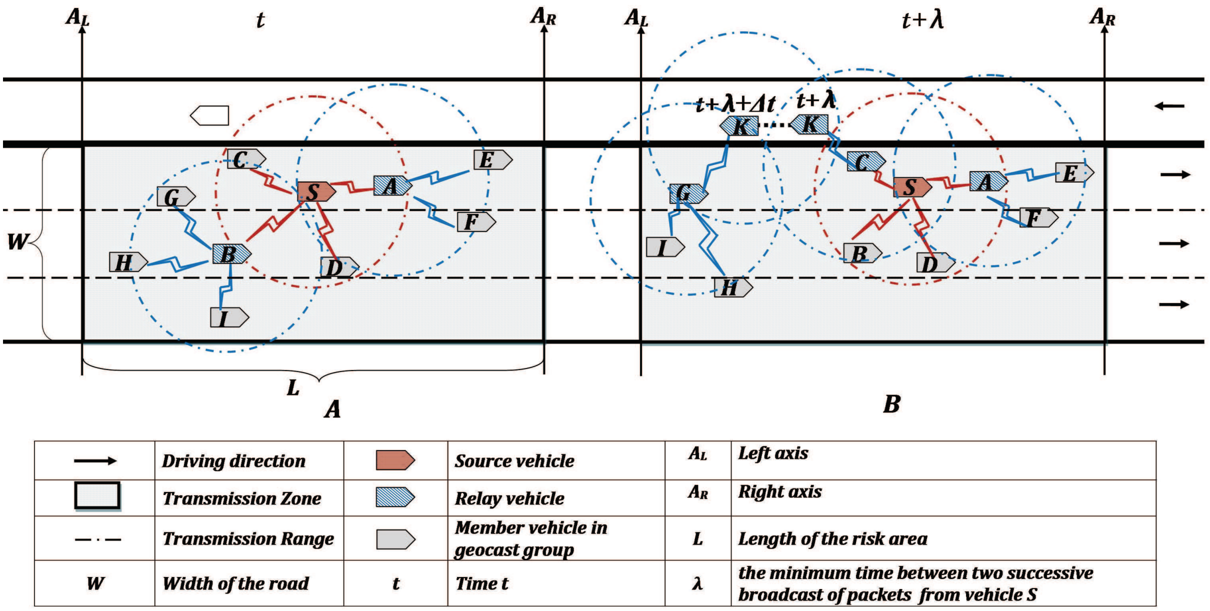


Figure 3.1: A: Packet Dissemination in $TZ(t)$ in highway for safety applications, B: Packet Dissemination to solve the internal network fragmentation (case of isolation of vehicles V_G, V_I, and V_H) in highway for safety applications

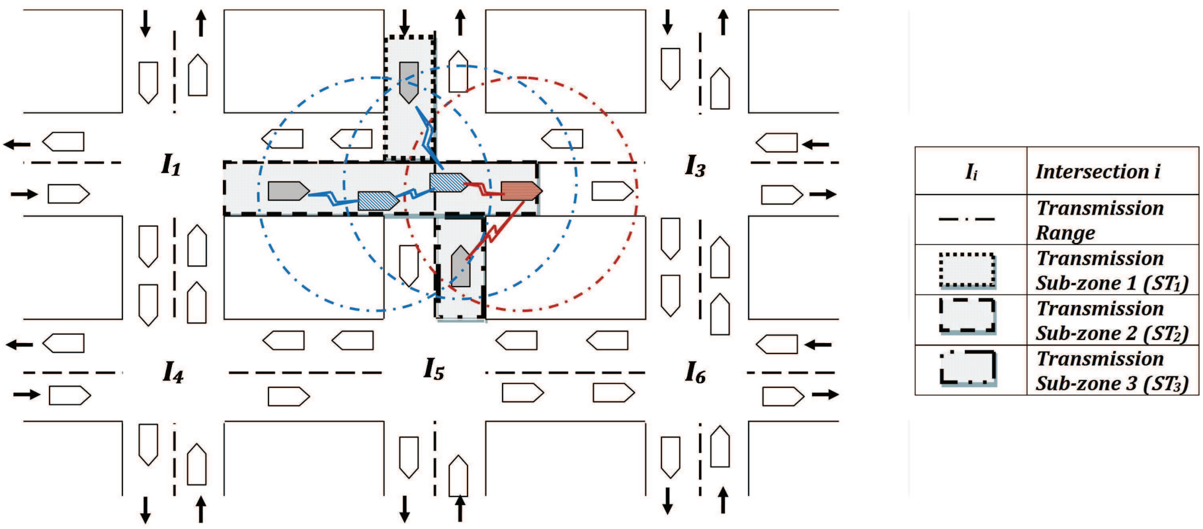


Figure 3.2: Packet dissemination in $TZ(t)$ in urban environment for safety applications

overhead. However in IVG, the packets are periodically retransmitted without any guarantee of good connectivity along the road.

- **Solving the internal network fragmentation problem (a major constraint for safety applications) without expansion of transmission zone**. However in MRPV, the enlarging of transmission zone increases the overload of the network.

The proposed RGRP-SA protocol consists of two phases: creation of transmission zone

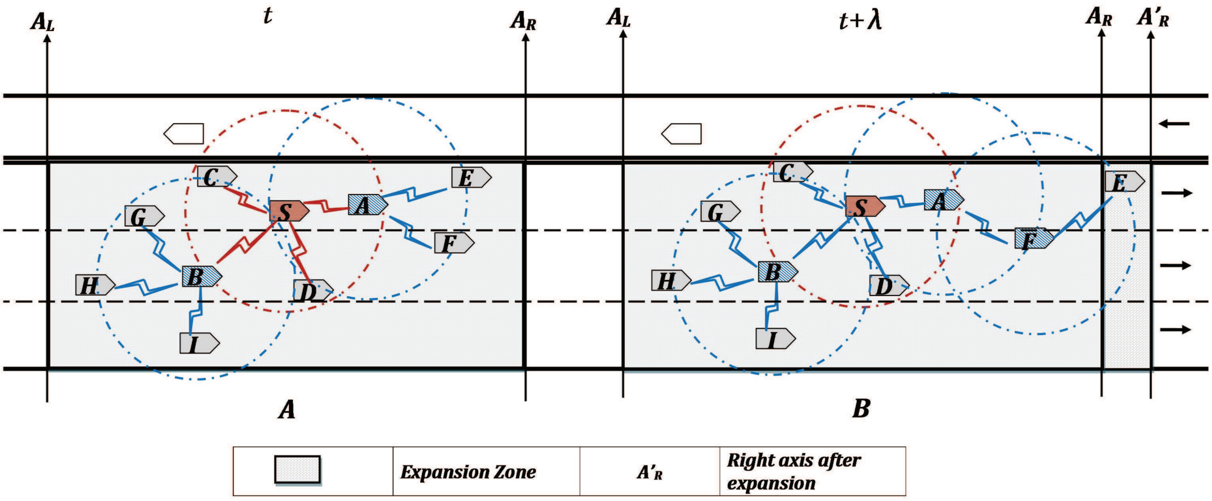


Figure 3.3: A: Packet dissemination in $TZ(t)$ in highway for comfort applications, B: Expansion of $TZ(t)$ to solve the external network fragmentation in highway for comfort applications

$TZ(t)$, and packet dissemination in static zone $TZ(t)$. The geocast zone for safety message depends on the position of the source vehicle from where warning message originates. It is also dependent on the direction of vehicles in a risk zone. As shown in Fig. 3.1 for an illustrative example in highway environments, and in Fig. 3.2 for an example in urban environments, an incident happens at the intersection I_2. The transmission zone is constructed by a union of three risk Sub-zones $TS_1(t)$, $TS_2(t)$, and $TS_3(t)$.

2. Our second algorithm is dedicated for comfort applications, which is called RGRP-CA. This algorithm not only adopts a dynamic transmission zone and a mobile source vehicle, but also takes the strategy of expanding transmission zone in the event of disconnection of a vehicle in the group. Fig. 3.3.B gives an example to illustrate the expansion of $TZ(t)$. The main idea of this method is as follows. Vehicles located in $TZ(t)$ form a geocast group (c.f. Fig. 3.3.A). These vehicles must maintain connectivity for communication along with the comfort applications. Connectivity is lost once a vehicle leaves $TZ(t)$ after an acceleration (case of V_E in Fig. 3.3.B) or deceleration. To solve this problem (external network fragmentation), $TZ(t)$ is expanded by estimating the new position of A_R after a time λ, where λ is the minimum time between two successive broadcasts of packets P_g from source V_s. However, the MCF algorithm [88] does not handle the problem of external network fragmentation.

The novelty of RGRP-CA is the strategy to overcome the problem of external network fragmentation (the key character for comfort applications). RGRP-CA uses the strategy of enlarging transmission zone in order to cope with the external network fragmentation problem. Instead, the MCF uses the expansion of $TZ(t)$ to overcome the internal network fragmentation, but it does not use a mechanism to handle the problem of the key character for comfort applications. Our method RGRP-CA uses the same strategy as RGRP-SA to solve the internal network fragmentation, and introduces a new strategy of geocast routing for solving the problem that a vehicle goes out of the transmission zone. It is able to maintain good network connectivity among vehicles along with the applications. The proposed RGRP-CA protocol can be divided into three phases: creation of transmission zone $TZ(t)$, package dissemination in a dynamic zone $TZ(t)$ (Fig. 3.3.A), and the expansion of zone $TZ(t)$ if necessary (Fig. 3.3.B). We can see that the latter two phases (dynamic zone and expansion of zone) make our RGRP-CA protocol suitable for comfort applications in highway environments.

In the following, we explain in detail these different phases for RGRP-SA and RGRP-CA algorithms.

3.2.2.1 Creation of zone $TZ(t)$ [RGRP-SA and RGRP-CA]

The shape of transmission zone $TZ(t)$ for a vehicle V_s is a rectangle in a highway environment. The transmission zone in a urban environment is a union of sub-zones. For instance, $TZ(t)$ in Fig. 3.2 is constructed by a union of three Transmitting Sub-zones $TS_1(t)$, $TS_2(t)$, and $TS_3(t)$, where $TZ(t) = \cup_{i \in \{1,2,3\}} TS_i(t)$. The length L of the zone must be no smaller than $2 \times R$, where R is the transmission range. The width W is defined as the width of the road. Each vehicle V_i can get its position $(x_i(t), y_i(t))$ at time t from the GPS. All the vehicles send the hello packet to its neighbors at an interval of one second. The information obtained from GPS including time, current position and speed of the vehicles are embedded in the hello message [37]. The format for the hello packet is shown in Table 3.1. Initially, the source vehicle V_s is the center of $TZ(t)$. Therefore, $TZ(t)$ moves at the same speed and in the same direction as V_s. We denote the left axis as A_L and the right axis as A_R for the transmission zone $TZ(t)$. The zone creation process ensures the delivery of a geocast packet to a virtual vehicle located at either A_L or A_R, as shown in Fig. 3.1.

The Zone creation process is done in three steps:

- Step 1: the source vehicle gets its position $(x_s(t), y_s(t))$ from its GPS.
- Step 2: $TZ(t)$ is determined by the road width W and the initial value of L.
- Step 3: V_s sends the first geocast packet P_g. The format for P_g is shown in Table 3.2.

Table 3.1: Format of hello packet

V_i	$(x_i(t), y_i(t))$	t	v_i	SN

V_i : unique identification of the vehicle i;
$(x_i(t), y_i(t))$: position of V_i at time t;
t: current local time;
v_i: velocity of the vehicle V_i;
SN: sequence number of a hello message;

Table 3.2: Format of geocast packet P_g

V_s	$TZ_s(t)$	m

V_s : identity of source vehicle;
$TZ_s(t)$: Transmission Zone coordinate for source vehicle V_s at time t;
m: content of geocast message;

3.2.2.2 Packet dissemination in $TZ(t)$ [RGRP-SA and RGRP-CA]

When a vehicle V_j receives a packet P_g from V_i, V_j will verify the relevance of P_g. A packet P_g is considered 'relevant' if and only if two conditions are satisfied:

$$\begin{cases} V_j \text{ in } TZ(t) \\ V_j \text{ receives } P_g \text{ for the first time} \end{cases}$$

If P_g is not relevant, it will be rejected, otherwise, V_j should not retransmit it immediately but has to wait a time T_w to take a decision about the retransmission of P_g. Vehicle V_j first calculates the closest axis A_x ($x \in \{L, R\}$) for the oriented broadcast packet in order to reduce overload. Before retransmission, V_j then must check whether there is a vehicle closer to A_x in its transmission range. When the wait time T_w has passed and if P_g is still relevant (received only once), V_j deduces that there is no relay vehicle closer to A_x. Then, V_j has to designate itself as a relay and retransmit the packet to the other vehicles closer to A_x. This verification avoids redundant multiple retransmissions, and thus permits to reduce the number of sent packets. We note $D(V, A_x)$ as the distance between vehicle V and A_x. The wait time of V_j receiving a packet P_g from node V_i is proportional to $\frac{D(V_j, A_x)}{D(V_i, A_x)}$. This is to favorite the vehicle closest to A_x to wait less time and to retransmit faster.

To solve the problem of INF in the event of isolation of a vehicle, we use one relay V_j outside of $TZ(t)$ (in the opposite direction) to relay P_g to other vehicles in $TZ(t)$. V_j should not retransmit P_g immediately but has to wait time Δt until it finds nearby vehicles in $TZ(t)$ closer to A_x. This strategy guarantees the oriented packet transmission to A_x. The packet dissemination is repeated until it reaches a vehicle V_z which is situated in the transmission zone $\mid D(V_z, A_x) < R$. The formal description of this dissemination process is presented in Algorithm 1.

Algorithm 1: Packet dissemination in $TZ(t)$

while *vehicle V_j receives packet P_g from V_i* **do**
    if *(P_g is not relevant)* **then**
        P_g is deleted
    else
        if $D(V_j, A_R) < D(V_i, A_R)$ **then**
            $A_x = A_R$
        else
            $A_x = A_L$
        V_j calculates a random wait time T_w such that

$$T_w = \frac{D(V_j, A_x)}{D(V_i, A_x)} * T_r$$

        `// ` T_r`: random time uniformly chosen in` $[0, 1]$
        When the timer expires;
        if *(P_g is not relevant)* **then**
            P_g is deleted
        else
            if *($\exists V_k$, such that ($D(V_k, A_x) < D(V_j, A_x)$) and ($V_k$ in $Z(t)$))* **then**
                V_j broadcasts packet $P_g(V_j\ , TZ_{V_j}(t)$, m) `// avoid periodic exchange of packets`
            else
                if *($\exists V_k$, such that ($D(V_k, A_x) < D(V_j, A_x)$) and ($V_k$ outside $TZ(t)$))* **then**
                    V_j selects the closest neighbor V_l to A_x
                    V_l sends packet $P_g(V_j\ , TZ_{V_j}(t)$, m) by unicast to the closest neighbor in $TZ(t)$ `// solve internal network fragmentation`
                else
                    V_j repeats the same step after waiting for a random time

3.2.2.3 Expansion of $TZ(t)$ [RGRP-CA]

We solve the problem of ENF in the event of disconnection of a vehicle (after an acceleration or deceleration) in the group by enlarging the transmission zone $TZ(t)$. As shown in Fig. 3.3.B, the transmission zone is enlarged by estimating the new position of A_x after a time interval λ, where $x \in \{L, R\}$ and λ is the minimum time between two successive broadcasts of packet P_g from source V_s. To ensure the dissemination of the packet to A_x, the expansion of $TZ(t)$ is decided as follows:

- Vehicle V_j calculates the distances between its neighbors and A_x;
- Vehicle V_j verifies whether there is a neighbor V_k moving out of $TZ(t)$. Let v_s be the velocity of vehicle V_s, v_k and a_k be the velocity and acceleration of a vehicle V_k in front of V_s (V_k is closer to A_R), and v_l and a_l be the velocity and deceleration for a vehicle V_l behind V_s (V_l is closer to A_L). A vehicle moving out of $TZ(t)$ by an acceleration or a deceleration after time λ can be detected by one of the following conditions: if V_k is in front of V_s and $D(V_k, A_R) \leq (v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2$ is held, or if V_l is behind V_s and $D(V_l, A_L) \leq (v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2$ is held.
- Expand the transmission zone $TZ(t)$ by changing the position of A_x, and send a packet P_{A_xNew} by unicast to V_s to alert the change.

The procedure of Zone Expansion is detailed in Algorithm 2.

Algorithm 2: Expansion of $TZ(t)$

if $A_x = A_R$ **then**
  // V_j is closer to A_R than V_s (in front of V_s)
  V_j calculates the distances between its neighbors and A_R
  if *(one neighbor V_k satisfying $D(V_k, A_R) \leq (v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2$)* **then**
    // if a vehicle leaves $TZ(t)$ after an acceleration
    V_j selects the fastest neighbor vehicle V_k

$$A_{RNew}(t+\lambda) = A_R(t+\lambda) + ((v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2)$$

    // v_k: velocity of V_k, a_k: acceleration of V_k
else
  // V_j is closer to A_L than V_s (behind V_s)
  V_j calculates the distances between its neighbors and A_L
  if *(one neighbor V_l satisfying $D(V_l, A_L) \leq (v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2$)* **then**
    // if a vehicle leaves $TZ(t)$ after a deceleration
    V_j selects the slowest neighbor vehicle V_l

$$A_{LNew}(t+\lambda) = A_L(t+\lambda) - ((v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2)$$

    // v_l: velocity of V_l, a_l: deceleration of V_l
V_j sends a packet $P_{A_X New}$ by unicast to V_s to alert the change // solve external network fragmentation

3.3 Performance evaluation and numerical results

We use NS-2 [114] tool to evaluate the performance of our proposed protocols RGRP-SA and RGRP-CA. For road safety applications, we compare our algorithms with the renowned IVG algorithm [74] and the state-of-the-art MRPV algorithm [87] to show theirs advantages. Regarding comfort applications, our algorithms are compared with MCF algorithm [88]. Freeway mobility model is assumed in our simulation in highway environments. We use a highway with four lanes of 8000 m long as the simulation environment. Manhattan mobility model is utilized for urban environments in a 1500 $m \times$ 1500 m area. The physical and MAC layer protocol used in this simulation is the 802.11p protocol. The length L of transmission zone $TZ(t)$ is 2000 m in highway environments and 600 m in urban environments, while the transmission range of vehicles is set to 250 m. The speed of vehicles varies from 80 to 140 km/h for highway environments and

Table 3.3: Simulation configurations

Parameter	Value
Mobility Model (highway)	Freeway
Mobility Model (Urban)	Manhattan
Physical and MAC layer	802.11p
Number of Vehicles	50-500
Velocity (highway)	80-140 km/h
Velocity (Urban)	20-60 km/h
Simulated area (highway)	8000 m x 40 m
Simulated area (Urban)	1500 m x 1500 m
Number of lanes	4
Length of $TZ(t)$ (highway)	2000 m
Length of $TZ(t)$ (Urban)	600 m
Transmission range	250 m
Simulation time (safety)	180 seconds
Simulation time (comfort)	300 seconds

20 to 60 km/h for urban environments. We study the network performances while increasing gradually vehicle density. The number of vehicles ranges from 50 to 500. Simulation time is 180 seconds and 300 seconds for safety and comfort applications respectively. Simulation parameters are summarized in Table 3.3. The obtained results are the average of 5 simulations.

We are interested in the following performance metrics:

1. **Number of Sent Packets (NSP)**. This metric defines the number of messages required to route a packet to all members of a geocast group.

2. **Number of Retransmission Packets (NRP)**. This metric measures the number of relays to cover the zone of transmission.

3. **Packets Delivery Ratio (PDR)**. It is the number of packets successfully received divided by the number of packets generated.

4. **End-to-End Delay (EED)**. It is the average time (in seconds) needed for a packet to reach its destination.

5. **Throughput Utilization (TH)**. It is the total number of packets successfully transmitted in $TZ(t)$ divided by the simulation time.

6. **Protocol Overhead (PO)**. It is the total number of packets transmitted (not the size because we use the same format of messages for the expansion $TZ(t)$) with the assistance of $TZ(t)$ expansion divided by the total number of packets transmitted without the assistance of $TZ(t)$ expansion.

3.3.1 Performance of RGRP-SA for safety applications

We first compare the performance of the proposed RGRP-SA, the IVG algorithm and MRPV algorithm for safety applications. Simulation results are shown in Figs. 3.4 $\sim$ 3.8.

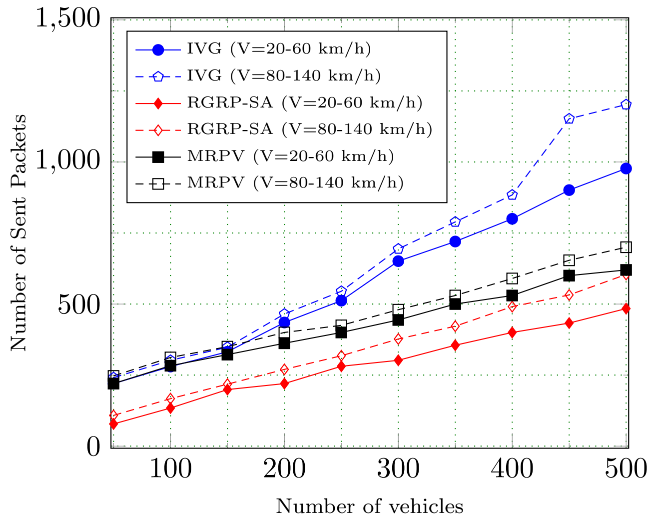


Figure 3.4: Number of sent packets vs. vehicle density (safety application)

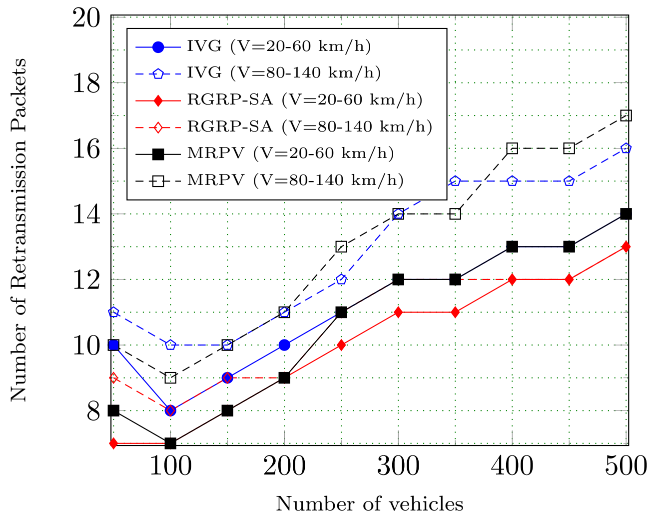


Figure 3.5: Number of retransmission packets vs. vehicle density (safety application)

We find that more packets can be delivered but more relays should be used for all protocols when the number of vehicles increases as shown in Figs. 3.4 and 3.5 respectively. The increase is almost linear. The curves show that the NSP is higher (up to 16%) and the number of relays is larger in highway as compared with urban environments for various densities, since it is easy for a vehicle to move out of the transmission range of relay vehicles. Consequently, the internal network fragmentation problem occurs frequently when the vehicle velocity is big. As a result, more packets are required to inform all vehicles in $TZ(t)$. They also show that RGRP-SA reduces half the number of packets exchanged and needs one or two fewer relays in comparison to IVG and MRPV. This can be explained by the method of packets forwarding. For RGRP-SA, the retransmission of packets is decided by the existence of neighbors and the network connectivity. However in MRPV, the packets are retransmitted by enlarging TZ, which increases the number of sent packets and which requires more retransmission packets (relays). In IVG, the packets are periodically retransmitted without any guarantee to have a good connectivity along the road. Consequently, some packets are rebroadcasted uselessly many times, which increases the overload of the network.

We also compare Packets Delivery Ratio of those protocols in Fig. 3.6. Clearly, PDR in highway is inferior to urban environments, which confirms the results in Figs. 3.4 and 3.5. The curves show that RGRP-SA has a packet delivery rate up to 15% larger than IVG and MRPV for all network densities and all environments. Thus, our solution provides the best results for safety applications. We demonstrate this by the sensitivity of IVG and MRPV to INF, which requires to transmit more safety packets. As the successful delivery of packets can not be guaranteed, packet delivery ratio decreases. However, in event of isolation of a vehicle in $TZ(t)$, RGRP-SA algorithm proposes to select one relay outside of $TZ(t)$ but in the opposite direction (Algorithm 1: lines 16 $\sim$ 19). This enables the successful oriented packet delivery to all vehicles in $TZ(t)$.

Fig. 3.7 illustrates the performance of end-to-end delay. It is noted that RGRP-SA is able to cut the end-to-end delay in half compared with IVG and MRPV protocols, and the delay decreases whenever the velocity decreases and the network density increases. There are two reasons for this. First, it is due to the correct orientation of the packet transmission (Algorithm 1: lines 5 $\sim$ 8). Second, the waiting time for a vehicle to rebroadcast a packet is well determined (Algorithm 1: line 9). This helps reducing the number of hops (relays) in the packet delivery. Consequently, the end-to-end delay decreases. The simulation results also show that EED of RGRP-SA is smaller than that of IVG and MRPV protocols when the vehicle velocity is low. This confirms the feasibility and advantage of RGRP-SA protocol for urban environments.

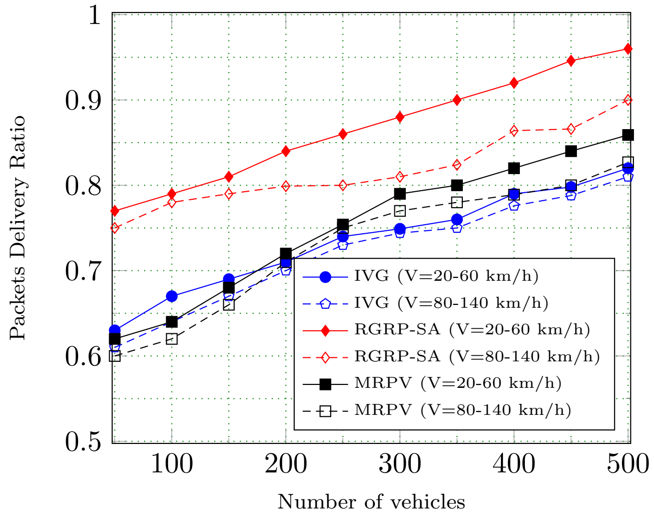


Figure 3.6: Packets delivery ratio vs. vehicle density (safety application)

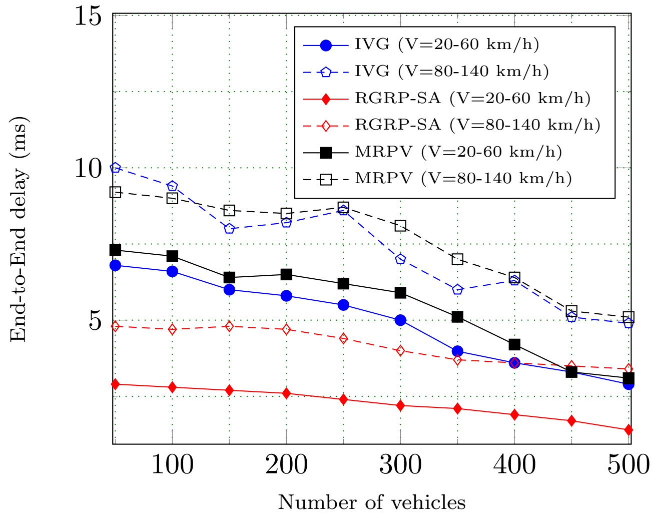


Figure 3.7: End-to-End delay vs. vehicle density (safety application)

The utilization of throughput is presented in Fig. 3.8. For all algorithms (IVG, MRPV and RGRP-SA), the network utilizes more throughput as the total number of vehicles grows and the velocity decreases. But, we can clearly find that our RGRP-SA approach achieves almost twice the throughput utilization of IVG and MRPV in both highway and urban environments, although IVG and MRPV protocols generate more packets (Fig. 3.4) and use more relays (Fig. 3.5). However in RGRP-SA, the number of packets successfully transmitted is about 15% larger than that of IVG and MRPV protocols (Fig. 3.6). RGRP-SA needs less time (Fig. 3.7) to route packets to all vehicles in $TZ(t)$. This helps to maximize the throughput. Thus, this metric also confirms the advantage of our RGRP-SA protocol for safety applications.

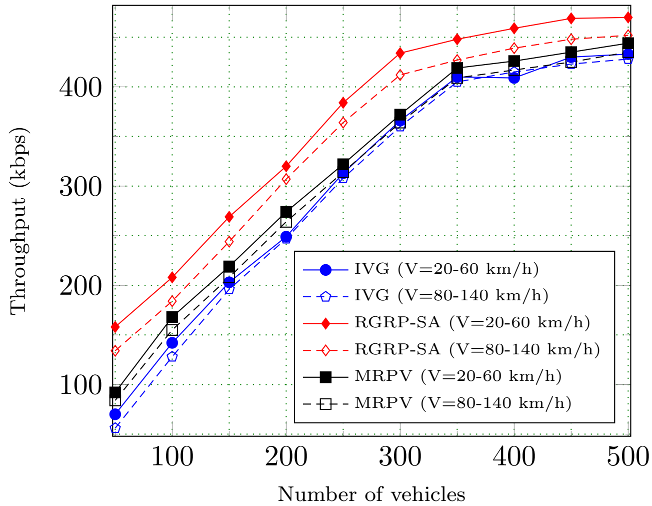


Figure 3.8: Throughput vs. vehicle density (safety application)

3.3.2 Performance of RGRP-CA for comfort applications

The performance of RGRP-CA and MCF algorithms for comfort applications are evaluated in Figs. 3.9 ∼ 3.14. To show the performance of the proposed RGRP-CA protocol, we also extend the RGRP-SA algorithm for comfort applications by dynamically changing the transmission source and the transmission zone. The extended version is referred to as RGRP-SC. We can find that the number of exchanged packets required by MCF protocol and RGRP-CA is larger than that of RGRP-SC (Fig. 3.9). Because the high mobility of vehicles leads to disconnection between vehicles, which requires the expansion of transmission zone to ensure the connectivity in the network. The curves also show that RGRP-CA reduces up to 22% exchanged packets in comparison to MCF. This is explained by the method of packets transmission in the case of INF. For RGRP-CA, the retransmission of packets is decided based on the existence of neighbors closest to A_x ($x \in \{L, R\}$) after waiting for an arbitrary time limit (Algorithm 1: lines 11 ∼

21). However in MCF, the packets are retransmitted using another neighbor outside of $TZ(t)$. Consequently, some packets are rebroadcasted uselessly several times in $TZ(t)$, which increases the overload of the network.

Fig. 3.10 shows that RGRP-SC uses the least relays and RGRP-CA requires fewer relays than MCF algorithm. As adding more relays in a wireless path may degrade the transmission reliability, we can say RGRP-CA and RGRP-SC are more reliable for wireless packet delivery.

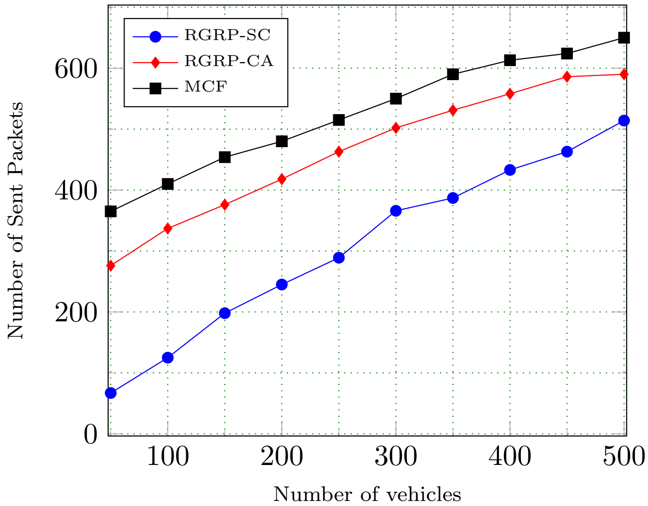


Figure 3.9: Number of sent packets vs. vehicle density (comfort application)

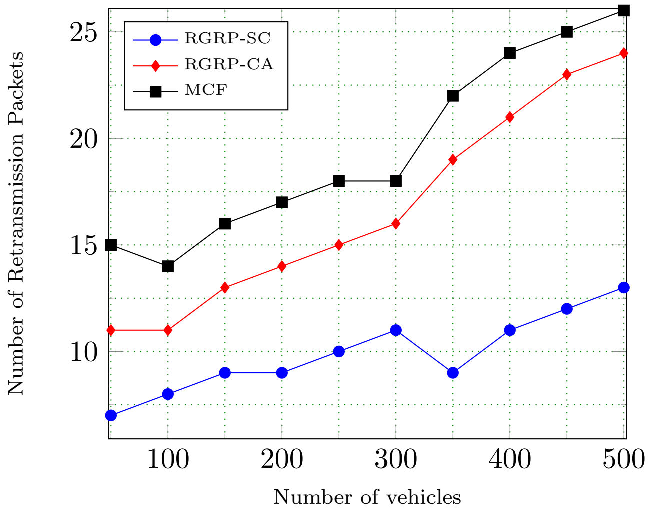


Figure 3.10: Number of retransmission packets vs. vehicle density (comfort application)

The effectiveness of packet delivery is observed with RGRP-CA in comparison to MCF and RGRP-SC in Fig. 3.11, i.e., 25% more packets can be delivered. This can be interpreted by using the mechanism of transmission zone expansion in case of vehicle disconnection from a geocast group to solve the external network fragmentation (Algorithm 2). To handle the problem of INF, RGRP-CA uses the same strategy as RGRP-SA (Fig. 3.6). So we can say that RGRP-CA overcomes both the INF and ENF of the network, what enables to increase the packet delivery ratio for all network densities. However, MCF although overcomes INF, it can not solve ENF.

In Fig. 3.12, it is noticed that RGRP-SC and RGRP-CA obtain smaller delay than MCF. This is because, with RGRP-SC only a small portion of vehicles are able to receive the packets. In contrary, good connectivity of vehicles is maintained by using RGRP-CA protocol. This is why the packets sent by the source reach the majority of the geocast group vehicles. However, MCF algorithm requires larger delay and can not overcome the external network fragmentation (Fig. 3.11). Thus, RGRP-CA is more timely than MCF algorithm for message delivery.

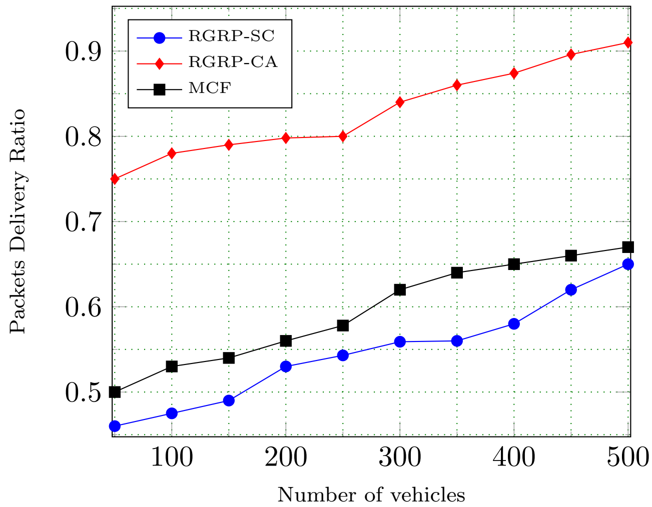


Figure 3.11: Packets delivery ratio vs. vehicle density (comfort application)

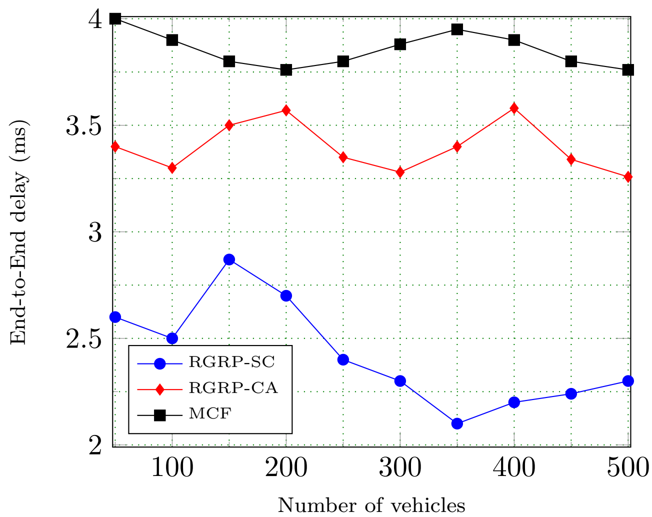


Figure 3.12: End-to-End delay vs. vehicle density (comfort application)

Fig. 3.13 illustrates that RGRP-CA utilizes better the throughput (with 50 Kbps higher) than MCF and RGRP-SC. This is because the number of successful transmitted packets is larger by RGRP-CA (Fig. 3.11), and the average transmission delay is smaller than in MCF (Fig. 3.12). These two facts increase the throughput utilization in RGRP-CA. This confirms the advantages of RGRP-CA for supporting comfort applications that require to transmit a big amount of data.

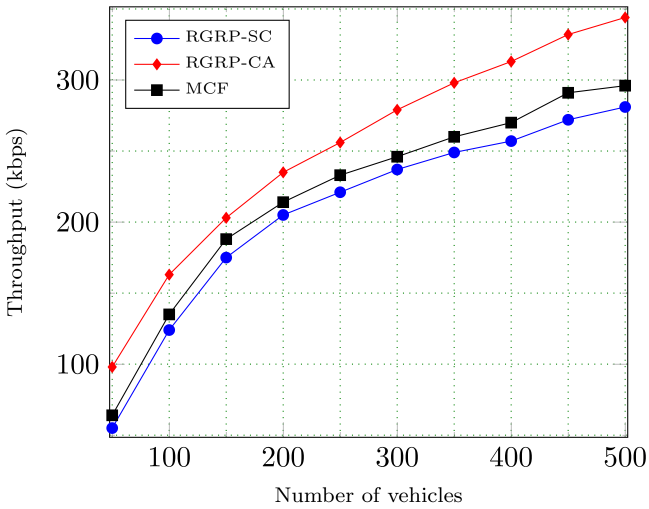


Figure 3.13: Throughput vs. vehicle density (comfort application)

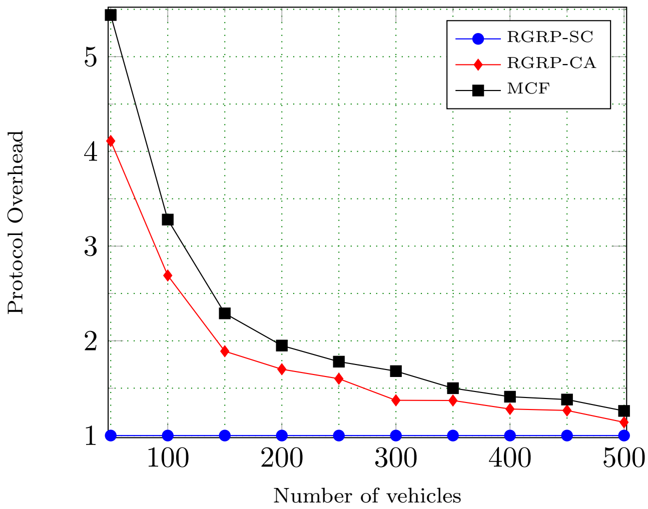


Figure 3.14: Protocol overhead vs. vehicle density (comfort application)

The simulation results of the Protocol Overhead (PO) is shown in Fig. 3.14. The protocol overhead of the forwarding strategy without zone expansion (i.e., RGRP-SC) is equal to 1. The protocol overhead of MCF is always much bigger than RGRP-CA especially when the vehicle density is small. As the vehicle density grows, the protocol overhead of both algorithms tends to decrease sharply. When there are more than 400 vehicles, the protocol overhead achieves almost one for both protocols, e.g., 1.2 for MCF and 1.1 for RGRP-CA. As a result, the proposed

RGRP-CA protocol only requires lightweight overhead to satisfy comfort applications.

In summary, our proposed safety-application oriented RGRP-SA protocol is able to better utilize the network throughput and cut the end-to-end delay in half compared with IVG and MRPV protocols. Thus, RGRP-SA protocol can serve better safety applications. To satisfy the comfort applications in VANET, the proposed RGRP-CA protocol is able to maintain good network connectivity along with the applications and utilize better network throughput by using only lightweight overhead. The simulation results confirm its advantages for routing comfort messages.

3.4 Conclusion

In this chapter, we presented our two geocast routing protocols for both road safety and comfort applications. The proposed safety-oriented geocast protocol RGRP-SA is designed for delivering delay-critical short safety packets while taking into account high mobility of vehicles and frequent internal network fragmentation. Simulation results demonstrated that RGRP-SA protocol outperforms Inter-Vehicle Geocast protocol (IVG) [74] and Mobicast Routing Protocol in VANET (MRPV) [87] by reducing more than 50% the end-to-end delay. It also makes a better use of the network bandwidth by avoiding unnecessary information exchanges between vehicles. Unlike prior geocast schemes, the proposed dynamic geocast scheme RGRP-CA incorporates the concept of adaptive dynamic transmission zone to cope with the frequent external network fragmentation problem. Simulation results evidence that RGRP-CA protocol is able to provide more reliable data delivery and higher throughput use compared with MCF protocol [88] by introducing only lightweight overhead. Thus, the proposed RGRP-CA protocol serves well comfort applications.

The following chapters hover the presentation and development of dynamic multicast and hybrid routing protocols in urban and highway environments, these proposals dynamically adjust the transmission range for relay vehicles so that exchanged messages and packet delivery delay can be clearly minimized.

Chapter 4

Multicast, hybrid routing strategies, and Quality of Service: A bird's view

Contents

4.1 Introduction

The delivery of safety and comfort messages is widely studied in already presented geocast-oriented protocols [19, 74, 79, 80, 81, 73, 77]. They assume that the transmission range is fixed for vehicles and the objective is to minimize the number of retransmissions with guaranteed timeliness of message delivery. In addition, some multicast and hybrid oriented protocols have been proposed for VANET, their common aim is to send packets from a source(s) vehicle(s) to all group vehicles. Thus, the principal objective of the majority of solutions is to reduce the transmission overhead [56]. In the rest of this chapter, we briefly summarize the different multicast and hybrid routing protocols with a detailed synthesizing and comparison of all discussed protocols and we illustrate the classification of QoS requirement in connected vehicles.

4.2 Multicast and hybrid routing strategies

4.2.1 Multicast-oriented protocols

Depending on the transmission source, multicast-oriented approaches are classified as: (i) single-source-based and (ii) multi-source-based as already shown in Fig. 2.3 (Chapter 2).

4.2.1.1 Single-source-based

In this category, we have protocols that enable transmission of messages from single source to a group of destination nodes of interest using a tree structure. For instance,

(i) A Multicast Routing Scheme for efficient safety message dissemination (MRS) is proposed [90]. This paper presents a multicast routing scheme that can disseminate a warning message from single source to all endangered vehicles in a timely manner. The multicast scheme incorporates two strategies for using the wireless channel more efficiently. The first strategy is to reduce unnecessary transmission by sending the warning messages only to endangered vehicles. The second strategy is to minimize the transmission range using adaptive transmitter power control. The problem finding the routing paths with minimum transmission power while ensuring timely delivery, is defined as a Delay-Constrained minimum Steiner Tree (D-CMST) problem. This method prioritizes receivers based on the delay constraint and reduces the number of unnecessary transmissions by selecting specific relays for retransmission. The analysis and arguments of these advantages are not presented in this work. Also, this method is not scalable for large VANET.

(ii) In [15], authors proposed Efficient Safety message dissemination with Minimum Energy (ESME), while guaranteeing timeliness of safety messages and transmission reliability of inter-vehicular communications, a Mixed Integer Linear Programming model (MILP) is proposed for solving the studied problem. However, this method is not suitable for dense and scalable VANET.

4.2.1.2 Multi-source-based

In this category, we have protocols that involve sending packets from multi-source vehicles to a group of vehicles using mesh structure. For instance,

(i) Qadri et al. [91], proposed Multi-source Video Streaming in VANETs (MVSV). MVSV developed a mesh architecture with all-to-all connectivity using a static overlay in VANET, mesh architecture is more robust than a tree-based architecture, because, when a stream comes from multiples sources, communication does not break down when a node disconnects. However, the overlay structure was static, which may suffer from FNF and high mobility of vehicles.

(ii) Dynamic Overlay Multicast (OMV) protocol for live multimedia streaming in urban VANET is proposed in [92]. OMV enhances an overlay's stability with two strategies: (i) QoS-satisfied dynamic overlay and (ii) mesh-structure overlay. The first strategy is to adjust the overlay selects potential new parents based on their streams packet loss rates and end-to-end delays. The second strategy allows a child to have multiple parents. However, the transmission interference and the power efficiency are not considered in this solution same as MVSV.

4.2.2 Hybrid protocols

The solutions presented in the last two categories (geocast-oriented protocols and multicast-oriented protocols) respond only to partial challenges and QoS requirements in group routing for VANET. Thus, recent hybrid protocols have been proposed. For instance,

(i) In [93], an advanced Mobility-aware Geocast (GeoMob) segmentation method is proposed for large-scale urban VANET. This scheme has many new features compared with the existing schemes, it is designed from a Delay-Tolerant-oriented (DT) network, enabling it to deal with the high mobility and transient connectivity in VANET. Also, different levels and aspects of vehicle mobility information is employed, making GeoMob very simple and scalable. Therefore, GeoMob may miss many cooperative delivery opportunities and lead to a long delay. Besides, GeoMob has no scheme of adjusting the regions with the dynamic change of traffic flows in a day, but in general such a scheme is supposed to help improve the effectiveness of routing [115].

(ii) Authors of [94] proposed an hybrid communication (V2V and V2I) through a geocast method, which can be adapted in both urban and highway environments. A message can be delivered from an infrastructure or a vehicle to the interested vehicles, which resides in a geographic area (DZ) specified in the data packet. If the DZ is not directly reachable from the source, the data has to be relayed in the vehicular network from the source until the geographic area, where it is disseminated to the group members. This approach largely reduces the number of retransmissions. But, it cannot be adapted for highly urban dense scenarios.

4.3 Quality of Service in group-based communication

In the field of computer networking, QoS is the ability to provide different priority to different applications, users, data flows, or to guarantee a certain level of performance to a data flow [116].

The United Nations Consultative Committee for International Telephony and Telegraphy (CCITT) Recommendation 'E.800', has defined QoS as: "The collective effect of service performance which determines the degree of satisfaction of a user of the service" [117].

QoS routing requires not only finding a route from a source to one or multiple destinations, but a route that satisfies the end-to-end QoS requirement, often given in terms of bandwidth or delay. QoS is more difficult to guarantee in VANET than in most other type of networks. The importance of getting an understanding of QoS routing over VANET has been highlighted in various works [118, 119, 120, 121].

A QoS enabled routing protocols is expected to support several metrics in terms of delay, reliability, throughput as well as overhead and jitter. These metrics are described below:

- **Reliability and delay:** Reliability (described by Packed Delivery Ratio (PDR)) is an important issue for group-based services, especially for safety applications, which usually require highly reliable and timeliness communications among all vehicles in the group, e.g., Cooperative Collision Warning System (CCWS), that requires achieving high frequent transmissions in very short time interval. The delay of safety applications is normally from a few hundred milliseconds to tens of milliseconds. The frequent transmissions and short delay would lead to a number of collisions that can influence the reliability of applications.

- **Scalability:** It is an important factor in the design of new group-based protocol in both very light and in highly overloaded networks [122]. It is always expected that any solution must work in very low and medium density areas such as rural and highways environments, as well as in dense areas, such as urban environments where vehicles mobility is high and intersections are multiple on roads.

- **Throughput:** This metric represents the total amount of data a receiver actually receives from the sender divided by the time taken by the receiver to obtain the last bit.

- **Jitter or delay variation:** As packet sent from source to destination can follow different routes to get to their destination and the buffering time in files is not constant, packets delay differs and so the disparity in packet arriving time at the destination is known as packet delay variation.

- **Routing overhead:** This metric describes how many routing packets for route discovery and route maintenance need to be sent so as to propagate the data packets. It represents also the amount of control bits or packets added to ensure data packets delivery.

4.3.1 Quality of Service classification

The classification of various QoS-awareness group-based protocols has been done on the basis of various previous parameters. A fairly comprehensive overview of the state of the field of QoS in group-based protocols, especially for broadcasting was provided by Mchergui et al. [53].

We can classify QoS-awareness group-based communication according to the already presented classification of group-based applications into: (i) QoS for infotainment applications, (ii) QoS for safety applications, and (iii) QoS for comfort applications.

4.3.1.1 Quality of Service for Infotainment Applications (QoS-IA)

Infotainment applications can have different communication requirements. On one hand, in terms of throughput, a collaborative path planning application which can use maps updates needs higher throughput than that of a parking availability notification application. On the other hand, infotainment applications also have different delay requirements and scalability, from scalable and no special real-time requirements of information sharing service (e.g., restaurant announcement) to guaranty real time needs of some interactive and no scalable infotainment applications (e.g., platooning).

4.3.1.2 Quality of Service for Safety Applications (QoS-SA)

Because road safety messages are generally very short and delay-critical, the number of road accidents (i.e, vehicles are expected to be warned as quickly as possible in case of accidents) can decrease significantly. For that, the safety applications has stringent requirements on delay and highly reliable real-time transmissions compared to non-safety applications. The short delay may lead to a number of collisions that can influence the reliability of applications. Dedicated algorithms or mechanisms of IVC protocols need to be designed for the qualified reliability. To this end, the principal objective of the majority of solutions proposed for delivering safety messages is to maximize reliability and to minimize transmission delay [21, 74, 79, 77].

4.3.1.3 Quality of Service for Comfort Applications (QoS-CA)

In this category, QoS is a very important factor to consider during the deployment of CA. QoS requirements usually differ from application to application. *Delay-tolerant* applications can enhance PDR by enabling opportunistic transmission in a group with a restricted additional overhead. For multimedia content downloading application key QoS parameters are power requirement, packet loss rate, and throughput. While *delay-sensitive* applications such as multi-player gaming or online and video streaming diffusion need higher throughput and little delay. Also, the transmission quality of these applications can be determined by two major factors: packet loss and jitter. Due to its real time delivery nature, it requires huge bandwidth and strict performance service quality, any variation in the packet arrival time can generate large numbers of unacceptable error that can lead to poor or no service delivery [123].

4.3.2 Taxonomy of Quality of Service-awareness in group-based protocols

The objective of the protocols in this category is to consider QoS requirements (such as, end-to-end delay, reliability, scalability, throughput, jitter and packet loss) by using different routing solutions:

(i) The aim of the authors in most of already presented safety-oriented protocols [19, 74, 79, 80, 81, 73, 77] is to maximize the reliability and to minimize the transmission delay by minimizing the number of relays using different techniques. For instance, authors of [74] select the furthest vehicle as the relay. In [19], the retransmission of packets is decided by the existence of neighbors and the network connectivity. In [79], the selection of forwarding vehicles depends on traffic situation. Authors of [77] chose to select best relay vehicles having high successful delivery probability. While these solutions maintain high data delivery ratio, they still suffer from high overhead, either due to the high percentage of redundant data such as in [74, 73, 81], or because of the beaconing requirements, such as in [19, 80, 79, 77].

(ii) Authors of already presented non-safety-oriented protocols [63, 88, 94, 20] maximize the throughput not only over a single-hop, but also over the entire wireless multi-hop, which increases the bandwidth consumption.

(iii) Sun et al. [101] presented a QoS geocast routing protocol. It constructs a route on demand from a source (a fixed vehicle or a base station) to vehicles that reside in or drive through a specified geographic region. The aim is to provide robust and high quality route for V2V and V2I communications. Simulation results show that the routes lifetime is longer than other existing VANET routing protocols [124]. However, this protocol is not suitable for highways where vehicle speed is high because it is designed especially for congested traffic. Also, it does not develop new routes on broken links. It excludes the broken link and complements the missing node by another one. Therefore, it recovers the route efficiently and quickly rather than searching the whole network for new routes. It finds the alternate nodes against missed nodes successfully. Therefore, route lifetime becomes longer along with the improvement in packet delivery ratio [56].

(iv) Solutions proposed in [44, 97] to improve packet delivery and reduce the overhead under dense and sparse networks through beaconing in multi-hop strategy. In dense scenarios, the first method selects vehicles inside the destination zone to retransmit messages to further vehicles. Moreover, it employs implicit acknowledgements to guarantee robustness in message delivery under sparse scenarios. While in the second solution, unicast routing is employed to transmit data to the destination zone, and then flooding is used within the region for data dissemination. The results showed that the proposed approaches significantly reduce the overhead and increase the delivery ratio which may have several drawbacks on the networking performance such as, wasted bandwidth and increased network congestion.

(v) Adaptive Routing Protocol based on QoS and vehicular Density (ARP-QD) is developed in [95], it is an intersection-based routing protocol to find the best path for end-to-end data delivery, which can satisfy diverse QoS requirements based on hop count, link duration and connectivity. To reduce the network overhead, an adaptive neighbor discovery algorithm is proposed to obtain neighbors' information based on local vehicular density. However, connectivity is estimated by broadcasting beacon packets which may cause channel congestion in the case of high traffic load, and this metric is an instant value and it is not accurate in dynamic scenarios. In addition, using only global distance is not enough to reflect the complete QoS of a routing path, and packets may suffer from FNF in the road segments.

(vi) MUlti-hop Routing protocol for Urban VANET (MURU) [96] is a completely distributed routing protocol without the need of any pre-installed infrastructure and it is able to find robust paths in urban VANET to achieve high end-to-end packet delivery ratio with low overhead. In order to reduce the overhead, MURU is proposed with a backoff mechanism by utilizing the road map geometry to suppress unnecessary control messages. However, MURU is susceptible to local optimums which would significantly decrease the scalability of the routing protocol.

(vii) Road-Topology based Broadcast Protocol (RTBP) is proposed in [98], which aims to reduce delay and increase reachability and save system resources in urban context were vehicles density can be very high. Also, RTBP aims at assigning the highest forwarding priority to a vehicle, called a mobile repeater, having the greatest capability to send the packet in multiple directions. Although RTBP is dedicated for urban context, it shows good performance in low densities but this performance decreases as soon as the number of vehicles increases.

(viii) Proposals of solutions in [99, 100] are an examples of a video streaming. These solutions generally propose mechanisms such as, network coding to increase robustness in terms of throughput and jitter, when disseminating data to a group of vehicles on the road. Authors of [99] utilize random network coding techniques for data communication in VANET. Each group vehicle broadcasts its resource information to its one-hop neighbors periodically. In addition, group vehicles exchange coded pieces instead of original pieces. If a coded piece is linearly independent of the coded pieces in a vehicle's local memory, then the vehicle stores it. This approach may need a long time to collect enough pieces to decode if group vehicles are not dense enough.

(ix) Yang et al. [100] improved the collision problem of network coding based approach [99] by adopting a local push scheme that only selected vehicles allowed to push data packets to other vehicles in the same road segment. However, this technique still did not resolve the problem when the network is not dense enough.

4.4 Comparison and summary

Table 4.1 summarizes the main characteristics of the discussed categories, where multicast and hybrid routing protocols are classified according to their transmission strategies and others criteria: (i) modified beacon packet, (ii) DZ, (iii) TR, (iv) intersections awareness, (v) segmentation awareness, (vi) centralized or distributed method, (vii) INF, (viii) ENF, (ix) power consumption, (x) transmission interference, (xi) communication environments, and (xii) application.

In addition, in Table 4.2, we elaborated a detailed comparative study of the above listed QoS-awareness protocols based on different parameters (delay, PDR, reliability, scalability, throughput, jitter, overhead, and bandwidth consumption).

By studying these protocols, we can say that: First, multicast and hybrid routing protocols can be compared in several aspects (c.f. Tab. 4.1). On the one hand, the majority of multicast-oriented protocols are related to safety applications and can reduce end-to-end delay, transmission overhead, and maximize the reliability. However, the power efficiency and the transmission interference are partially considered in this category. On the other hand, most of hybrid protocols are related to non-safety applications. Network bandwidth is mainly reserved for safety applications and comfort data packets are usually delay tolerant. However, they generate larger data volumes. Due to the limited channel capacity, the data must be transmitted by minimizing transmission interferences. Furthermore the power efficiency and the transmission interference are not considered in hybrid protocols.

Table 4.1: Classification of multicast-based and hybrid routing protocols

	Communication Type			Routing Strategy[1]			Other Criteria[2]												
	V2I	V2V	Hybrid	Multicasting		Hybrid	MBP	DZ	TR	Intersections	Segmentation	Centralized/Distributed	INF	ENF	Power Consumption	Transmission interference	Environment	Application	
Protocols				S-Sc	M-Sc													Safety	Comfort
[90]	✗	✓	✗	✓	✗	✗	✗	S	D	✗	✗	C	✓	/	✓	✗	H	✓	✗
[15]	✗	✓	✗	✓	✗	✗	✗	S	D	✗	✗	C	✗	/	✓	✗	H	✓	✗
[91]	✗	✓	✗	✗	✓	✗	✗	D	D	✗	✗	C	✗	/	✗	✗	H	✓	✗
[92]	✗	✓	✗	✗	✓	✗	✗	D	D	✗	✗	C	✓	/	✗	✗	H	✓	✗
[93]	✗	✓	✗	✗	✗	✓	✓	D	D	✗	✓	Dd	✗	✗	✗	✗	H	✗	✓
[94]	✗	✗	✓	✗	✗	✓	✓	D	D	✗	✗	Dd	✓	✗	✗	✗	U	✗	✓
TRBIP: [21]	✗	✓	✗	✓	✗	✗	✓	D	D	✗	✗	C	✓	/	✓	✓	H	✓	✗
DTRBIP: [22]	✗	✗	✓	✗	✗	✓	✓	D	D	✓	✓	Dd	✓	✓	✓	✓	U & H	✓	✓

[1] Routing Strategy (S: Single, M: Multi, Sc: source).

[2] Other Criteria (MBP: Modified Beacon Packet, S: Static, D: Dynamic, DZ: Destination Zone, TR: Transmission Range, C: Centralized, Dd: Distributed, INF: Internal Network Fragmentation, ENF: External Network Fragmentation, H: Highway, U: Urban).

Table 4.2: Quality of Service-awareness in the existing group-based communication protocols

	Application			Quality of Service-awareness						
Protocols	SA	IA	CA	Delay	PDR	Scalability	Throughput	Jitter	Overhead	Bandwidth
[19], [74], [79], [80], [81], [73], [77]	✓	✗	✗	✓	✓	✗	✗	✗	✗	✗
[63], [88], [94], [20]	✗	✓	✓	✓	✓	✗	✓	✗	✗	✗
[101]	✗	✓	✗	✗	✓	✗	✓	✗	✓	✗
[82]	✗	✓	✗	✓	✓	✗	✗	✗	✗	✓
[44], [97]	✓	✗	✗	✓	✓	✗	✗	✗	✓	✗
[95], [96]	✓	✗	✗	✓	✗	✗	✗	✗	✓	✗
[98]	✓	✗	✗	✓	✗	✗	✗	✗	✗	✓
[99], [100]	✗	✗	✓	✓	✗	✗	✓	✓	✓	✗
[93]	✗	✗	✓	✓	✗	✓	✓	✓	✓	✗
TRBIP: [21]	✓	✗	✗	✓	✓	✗	✓	✗	✗	✗
DTRBIP: [22]	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓

Second and from the observations in QoS-awareness protocols (c.f. Tab. 4.2), we can say that it is very important to solve the following problems: (i) by means of appropriately selected QoS, how to efficiently explore networks and search routing paths with little delay, overhead, and high throughput, and (ii) how to estimate reliable and scalable real-time roads in dynamic environments by using optimal costs (power and bandwidth consumption).

Third, due to the large requirements of group-based communications such as, low power consumption and highly scalable factor for city and highway environments, distributed group-based communications can be alleviated by making a hybrid methods more attractive, that's what motivated us to propose the two following works:

(i) Time-Limited Reliable Broadcast Incremental Power (TRBIP) algorithm [21] (Chapter 5): The principal objective of this solution is to design an optimal multicast tree for delivering emergency messages that: (1) reduce the total interference by minimizing the total power consumption and (2) bound the end-to-end delay from the abnormal vehicle S to all endangered vehicles by a threshold H.

(ii) A distributed version of TRBIP is developed [22] (Chapter 5), called Distributed TR-BIP (DTRBIP). This hybrid solution handles both DS and DT applications via multicast scheme in urban and highway environments. DTRBIP is designed for delivering multicast packets initiated by RSUs installed on a city scale to serve specific DZ.

The following chapter describes the details of these two contributions.

Chapter 5

Multicast and hybrid routing protocols: Our contributions

Contents

5.1 Introduction

The main aim of this chapter is to reduce transmission interference for safety message delivery in VANET, which can be done by minimizing power consumption for inter-vehicular communications. Our objective is to design a time-limited tree for delivering safety messages such that each vehicle is able to receive emergency messages in a given time with a minimal total energy. Bounding the end-to-end delivery delay permits a vehicle to take efficient actions timely to avoid potential accidents, while minimizing the total transmission power and maximizing the reliability help to reduce the communication interference between vehicles. Since, this problem is NP-hard, we propose a heuristic algorithm called Time-Limited Reliable Broadcast Incremental Power (TRBIP) algorithm.

In addition, we develop a Distributed version of TRBIP (DTRBIP) by partitioning the map roads into segments (*sub-multicast-trees*) to manage the problem of maintaining big tree and to adapt high mobility of vehicles. We apply our heuristic method TRBIP in each segment to reduce the total power consumption, and the transmission interference, and to maximize the reliability by minimizing the number of hops. The frequent network fragmentation problems are also taken into account by using store-carry-and-forward within and between segments.

The rest of this chapter is organized as follows: time-limited safety message delivery tree algorithm is proposed in Section 5.2. In Section 5.3, we provide the details of our proposed DTRBIP algorithm. Then, the performance of our proposed algorithms is evaluated and discussed in Section 5.4. Finally, Section 5.5 concludes the chapter.

5.2 Reducing transmission interferences for multicast safety messages

The Cooperative Collision Warning System (CCWS) [90] is one of the most important road safety applications in VANET. In CCWS, vehicles are equipped with DSRC, which enables to exchange safety messages among vehicles and road side infrastructures, such as collision warning, emergency warning, intersection movement assist, blind spot caution and etc. In the United States, up to 82% of all crashes can be avoided and thousands of lives can be saved with the help of safety applications in VANET [15, 13].

In CCWS systems, once a vehicle detects anomalies, for instance break failure or unconsciousness drivers, its intelligent on-board system will automatically generate emergency safety messages and send them out immediately to surrounding vehicles within limited time and with high reliability. Furthermore, radio interference is a big issue for reliable wireless communications, especially for the reliable safety application based on DSRC devices in VANET. **Therefore, inter-vehicular transmission interference is a critical problem for VANET, which can be reduced by minimizing the total transmission power**. In this section, we first describe the emergent safety message delivery problem, and then present the details of our proposed algorithm.

5.2.1 System model

In the considered VANET, the set of endangered vehicles are noted V and the abnormal vehicle is $v_s \in V$, who generates emergency safety messages. With the help of GPS and a pre-loaded digital map, each node gets knowledge of its location and is aware of its trajectory. The maximum transmission range of each vehicle v_i is limited by TR_i^M, which represents the communication range that can be achieved using maximum transmission power. From regular beacon messages, the abnormal vehicle can obtain the distance for each pair of vehicles, $v_i, v_j \in V$. A vehicle v_i may establish a connection with vehicle v_j, if v_j is covered by the transmission range of vehicle

v_i. In our model, we adopt the Friis' power transmission formula defined as:

$$\frac{P_j}{P_i} = G_i G_j \left(\frac{\lambda}{4\pi \mathbb{D}_{(v_i,v_j)}} \right)^{\alpha} \tag{5.1}$$

Where P_i is the emission power of the sender vehicle v_i, P_j is the received power by vehicle v_j. G_i and G_j are the antenna gains of the transmitter and the receiver respectively. λ is the wavelength used by DSRC-based devices. The parameter α is typically in the range of 2 to 4, depending on the characteristics of the communication medium [125]. In VANET applications α is set to 2. $\mathbb{D}_{(v_i,v_j)}$ is the distance between vehicles v_i and v_j.

When constructing a delivery tree from the abnormal vehicle v_s to all endangered vehicles, it is necessary to consider the Signal-to-Noise-and-Interference Ratio (SNIR) requirement for wireless communications. The SNIR ratio requirement should be satisfied for each vehicle to receive emergency safety messages. Thus, the received signal power level at each vehicle should be above the minimum sensitivity level noted as P_{MinS}. As specified in IEEE 802.11p, the minimum sensitivity level equals -68 dBm for the throughput of 27 Mb/s, and the 5.9 GHz band is used for V2V communications [15]. Hence, the transmitting power should hold:

$$P_i \geq \frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi \mathbb{D}_{(v_i,v_j)}}{\lambda} \right)^2 \tag{5.2}$$

Our principal objective is to design an optimal multicast tree for delivering emergency safety messages such that (1) the total interference can be maximally reduced by minimizing the total power consumption, (2) the end-to-end delay from the abnormal vehicle v_s to all endangered vehicles is bounded by a threshold H. In the simplest case, we can use the number of hop-counts to estimate the end-to-end delay. Bounding the end-to-end delay enables the CCWS systems to guarantee the timeliness and the high reliability of the message delivery. Let $\delta_T^+(v_i)$ be the set of outgoing wireless links of vehicle v_i in tree, then the objective function can be expressed by

$$\min \left[\frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi}{\lambda} \right)^2 \cdot \sum_{v_i \in V} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2 \right] \tag{5.3}$$

As shown in [126, 127], minimizing the transmission energy is an NP-hard. Our problem is more complicated, since we should take into account more constraints, *i.e.*, the limitation of transmission range and the bound of end-to-end delay in not well-connected VANET due to the high mobility of vehicles. Therefore, time-efficient heuristic algorithms should be developed. We present in the next section the details of Time-Limited Reliable Broadcast Incremental Power (TRBIP) algorithm for safety applications in VANET.

5.2.2 Our approach: TRBIP

Considering radio interference, bounded end-to-end delay and the aforementioned constraints in VANET, we propose two heuristic algorithms called Reliable Broadcast Incremental Power (Reliable Broadcast Incremental Power (RBIP)) and Time-Limited RBIP to construct an optimal multicast tree for emergency messages in VANET. In the following, we explain the two phases of TRBIP algorithm.

5.2.2.1 Reliable broadcast incremental power algorithm

The main idea of RBIP is to design an optimal multicast tree for delivering emergency messages such that the total interference can be reduced by minimizing the total power consumption. The formal description of the tree construction process is presented in Algorithm 3. The RBIP process is carried out in three phases:

(1) Initially, the tree only contains the source vehicle. We begin by adding the vehicle that the source can reach with minimum transmission power (*i.e.*, the nearest neighbor of source).

(2) We then determine which new vehicle will be added to the tree with minimal additional power (Algorithm 3: line 9 $\sim$ 16, Function CNL). There are two alternatives: (i) Either nearest neighbor v_i of source can transmit to its own nearest neighbor that is not yet in the tree, or (ii) source vehicle can increase its power to reach another vehicle.

(3) The procedure continues until all vehicles are included in the tree.

During the Tree (T) construction, RBIP looks for the nearest path between each pair of vehicles (Algorithm 3: line 17 $\sim$ line 20). If it finds a new path with less energy, it changes the path to the new one (Algorithm 3: line 22). This allows us to reduce the power consumption. Meanwhile, it also helps to reduce the number of hops (relays) for packet delivery and thus-forth reduces height of the tree.

We describe the tree construction of RBIP by presenting a simple example in Fig. 5.1. Let S be the source vehicle.

- The nearest neighbor of the source is vehicle B. This node is added to the tree. At this point two vehicles are included in the tree, namely S and B. The notation $S \rightarrow B$ means that the tree construction at this step is the transmission from vehicle S to vehicle B, with transmission power $P[S][B]$=2 (step 1 in Fig. 5.1). The nearest neighbor of vehicle B is vehicle A, with transmission power $P[B][A]$=4. When adding the vehicle C to the tree, the power is adjusted to the sufficient level allowing communication with both C and B. The incremental cost associated with adding vehicle C to the preliminary tree consisting of source vehicle S and vehicle B is $P[S][C] - P[S][B]$=1. Thus, vehicle C ($S \rightarrow C$) is

Algorithm 3: Reliable Broadcast Incremental Power

```
S ← {Source};
TREE[Source] ← Source;
HOP[Source] ← 0;
Search ← False;
for (i ← 1; i <= NV; i++) do
    for (j ← 1; j <= NV; j++) do
        LCM[i][j] ← P[i][j];
        // NV: Number of Vehicles; LCM:link Cost Matrix; N:neighbor
while (|S| < NV) do
    (I, J) ← CNL(TREE, LCM);
    // CNL: Compute Nearest Link
    S ← S ∪ J;
    TREE[J] ← I;
    HOP[J] ← HOP[I] + 1;
    while (j ∉ S) do
        LCM[I][j] ← P[I][j] − P[I][J];
    for (u ∈ N(I)) do
        if (P[I][J] > P[I][u] and TREE[u] ≠ I and TREE[I] ≠ u) then
            search ← True;
            U ← u;
    if (Search = True) then
        CHP(I, U, TREE, HOP);
        // CHP: CHange Parent
```

```
Function CNL(TREE, LCM):
    // CNL: Compute Nearest Link
    lm ← infinity;
    // For all i on TREE and all j outside TREE
    for i ∈ TREE do
        for j ∉ TREE do
            if LCM[i][j] < lm then
                lm ← LCM[i][j];
                I ← i;
                J ← j;
    return (I,J);
```

```
Procedure CHP(I, U, TREE, HOP)
    // CHP: CHange Parent
    TREE[U] ← I;
    H ← HOP[U];
    HOP[U] ← HOP[I] + 1;
    if {CR(U)} ≠ ϕ then
        for (k ∈ CR(U)) do
            HOP[k] ← (HOP[k] − H) + HOP[U];
            // U not in leafs(TREE)
```

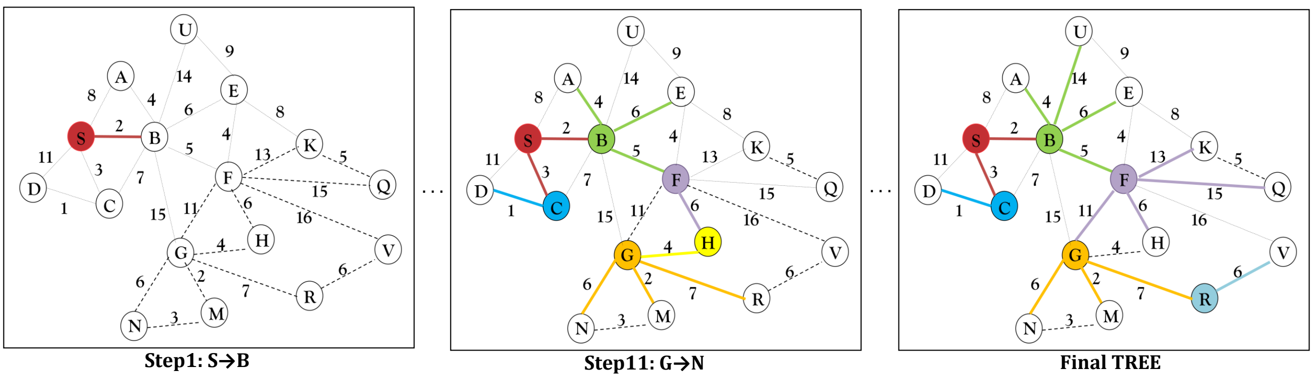


Figure 5.1: Example of tree construction using RBIP

added to the tree and S can transmit messages directly to vehicle C.

- The same procedure is repeated as shown in Fig. 5.1 (Step 11): $C \to D$; $B \to A$; $B \to F$; $B \to E$; $F \to H$; $H \to G$; $G \to M$; $M \to N$; $G \to R$. When increasing the power of a Relay node R_i, we will verify whether its neighbor (say v_i) that is already in tree can be covered by this relay vehicle. If this neighbor can be covered and the hop-counts to the source vehicle S can be reduced, we will change the delivery path for v_i and change its parent to R_i. In this example, if we take $G \to R$, the required transmission power is $P[G][R]$=7, and if we take $G \to N$, the transmission power is $P[G][N]$=6. Thus, the new parent of vehicle N is vehicle G (step 11 in Fig. 5.1). The parent of vehicle G is changed to vehicle F (Final tree in Figure 5.1). This is because the transmission power of $F \to K$ ($P[F][K]$=13), vehicle F can reach vehicle G, while the transmission power of $F \to G$ is $P[F][G]$=11.

- The tree construction procedure is continued until all vehicles are included in T. Furthermore, the tree is constructed regularly to maintain good network connectivity and hence achieves better application functionality.

5.2.2.2 Time-limited RBIP (TRBIP)

In order to improve the performances of RBIP, we proposed another strategy Time-Limited RBIP (TRBIP) for limiting the number of hops (Algorithm 4: line 3 $\sim$ line 10). We check the height of the constructed delivery tree by RBIP. If it is not bigger than H, then the obtained tree can be used directly for safety message diffusion. If it is not the case, we will try to decrease the tree height (Algorithm 4: line 11 $\sim$ line 18) by increasing the power of some relay vehicles, if we reach a new path with minimum energy and minimum height, we change the path with the new one (Algorithm 4: line 19 $\sim$ line 23). The same procedure will be repeated until the tree height is bounded by H. Figure 5.2 gives an example showing how to reduce the hop-counts. Initially, we begin with the final tree obtained from the RBIP algorithm. Let the delay bound be $H = 3$. The longest path from vehicle S to endangered vehicles is $S \to B \to F \to G \to R \to V$, which has a delay of 5. We try to reduce the number of hops in this path. To this end, we increase the transmission power of vehicle B from $P[B][U] = 14$ to $P[B][G] = 15$. Thus, we reduce one hop (step 1 in Figure 5.2). Then we continue the same procedure as shown in step 2 of Figure 5.2, until the number of hop-counts is bounded by $H = 3$.

Table 5.1 [21] illustrates the performance in terms of average delay and the average reliability of TRBIP. It is worth noting that the average delay increases with the hop-count and the average reliability decreases whenever the hop-count increases, which decreases the performance

Algorithm 4: Hops limited RBIP

```
Search ← False;
(M_H^T, I) ← max_hops(HOP);
while M_H^T > hops_limited and Search = False do
    i ← 2;
    PR[1] ← I;
    while I ≠ source do
        PR[i] ← TREE[I];
        I ← TREE[I];
        i ← i + 1;
    j ← i − 1;
    while j > 2 and search = False do
        m ← PR[j];
        for k ← j − 2 To 1 do
            if (PR[k] ∈ (N(m))) then
                Search ← True;
                I ← PR[k];
            else
                j ← j − 1;
    if (Search = True) then
        P_m^T ← Max{P_m^T, P[m][I]};
        CHP(m, I, TREE, HOP);
        (M_H^T, I) ← max_hops(HOP);
        Search ← False;
```

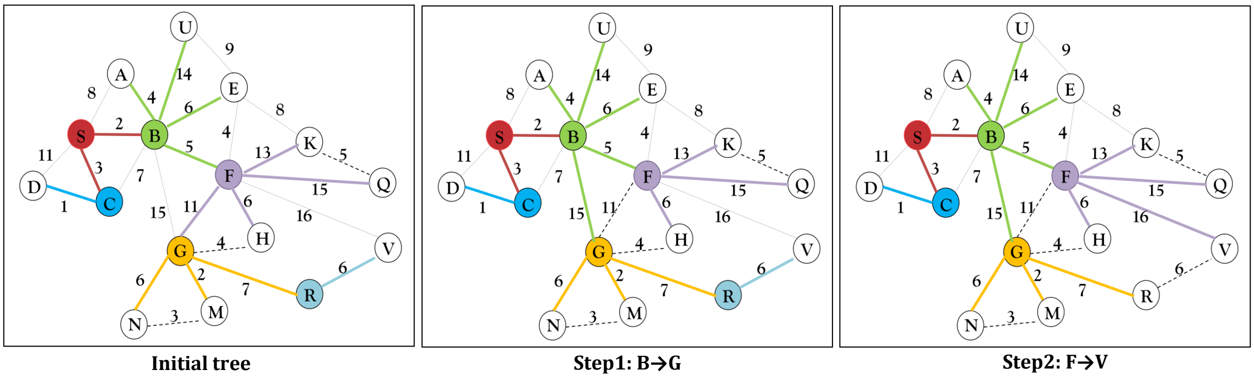


Figure 5.2: Time-limited RBIP

of TRBIP when we need to use TRBIP in high density urban VANET. To take into account the mobility of vehicles, TRBIP reconstructs the multicast delivery tree regularly. However, the reconstruction of multicast tree is hard to maintain in urban environments due to obstacles, high node density of VANET (large trees), and the possibility of changing directions in intersections. Thus, TRBIP is not scalable for large-scale urban VANET because it is a centralized algorithm by design. To the best of our knowledge, none of the existing works consider both the reduction of transmission interference and the guaranteed timeliness of message delivery in urban VANET which is the main objective of our next work.

Table 5.1: Performance of the proposed TRBIP algorithm

	Hop-Count Constraint		
	7	**9**	**11**
Average Delay (ms)	11.015	17.681	21.623
Average Reliability	0.96	0.92	0.84

5.3 A distributed time-limited multicast algorithm

We propose a Distributed version of TRBIP called DTRBIP, this solution handles both delay-sensitive and delay-tolerant applications through multicast scheme in urban and highway environments. DTRBIP is designed to deliver multicast packets initiated by RSU installed on a city scale to serve a specific destination zone. In our proposal, a multicast packet can be delivered to the destination zone through two mechanisms. First, when the destination zone is within the range of RSU, the later broadcasts messages to the destination zone directly. Otherwise, the Greedy Perimeter Stateless Routing (GPSR) protocol [110] is employed to carry the packets to the destination zone. We chose to use GPSR protocol which is one of the best examples of position-based routing [128], that uses the closest neighbors to the destination as packets forwarders. When a message is received by a vehicle in destination zone, all vehicles located in this zone will uniformly receive the packet. DTRBIP allows the partitioning of the destination zone into segments to manage the problem of maintaining higher node density (tree) in urban VANET while ensuring the scalability. We then apply our heuristic method TRBIP in each segment to minimize the power consumption and the transmission interferences while guaranteeing the message timeliness and transmission reliability. The frequent network fragmentation is also taken into account by using *store-carry-and-forward* in and between segments. In the following, we describe the system model, discuss the assumptions and explain in detail the phases of DTRBIP algorithm.

5.3.1 System model

We consider VANET applications using multicast approach in urban environment. Multicast packets are delivered from Roadside Units (RSU_i), installed on a city scale to serve specific Destination Zones $DZ_i(t)$ at time t (as shown in Fig. 5.3). Individual message may include information about road status (congested or otherwise, as in Fig. 5.3: RSU_1 *to Destination Zone*$_1$), an advertisement of a new restaurant (as in Fig. 5.3: RSU_3 *to Destination Zone*$_3$) or information about parking facilities in a specific zone (as in Fig. 5.3: RSU_2 *to Destination Zone*$_2$). The shape of destination zone $DZ_i(t)$ is a rectangle (as shown in Fig. 5.3: *Destination Zone*$_2$, *Destination Zone*$_3$) or a union of sub-rectangles. More precisely, $DZ_1(t)$ in Fig. 5.3 is constructed by a union of two destination Sub-Zones $SZ_1(t)$ and $SZ_2(t)$, where $DZ_1(t) = \cup_{i\in\{1,2\}} SZ_i(t)$. When an RSU_i generates a message, it may be delivered to the $DZ_i(t)$ by two mechanisms: (i) if $DZ_i(t)$ is in the transmission range of the RSU_i, the RSU_i broadcasts the message to $DZ_i(t)$ directly. (ii) otherwise, unicast routing protocol is employed to transmit message to the $DZ_i(t)$. Whenever the message is received by a vehicle in $DZ_i(t)$, all vehicles $v_i \in V$ located between $DZ_{i\_Min}(t)$ and $DZ_{i\_Max}(t)$ will receive the message as well. Where V is a set of vehicles, $DZ_{i\_Min}(t)$ and $DZ_{i\_Max}(t)$ are the minimum and maximum coordinates of $DZ_i(t)$. We furthermore, divide $DZ_i(t)$ into N segments between S_i and $S_{i+(N-1)}$ with equal length $L_{Si} \mid L_{Si} = K \times TR_i^M$. N is calculated as follows:

$$N = \begin{cases} L_{DZi}\ div\ L_{Si}\ , \text{ if } (L_{DZi}\ mod\ L_{Si}) = 0; \\ L_{DZi}\ div\ L_{Si} + 1, \text{ otherwise.} \end{cases} \tag{5.4}$$

Where L_{DZi} is the length of the destination zone $DZ_i(t)$.

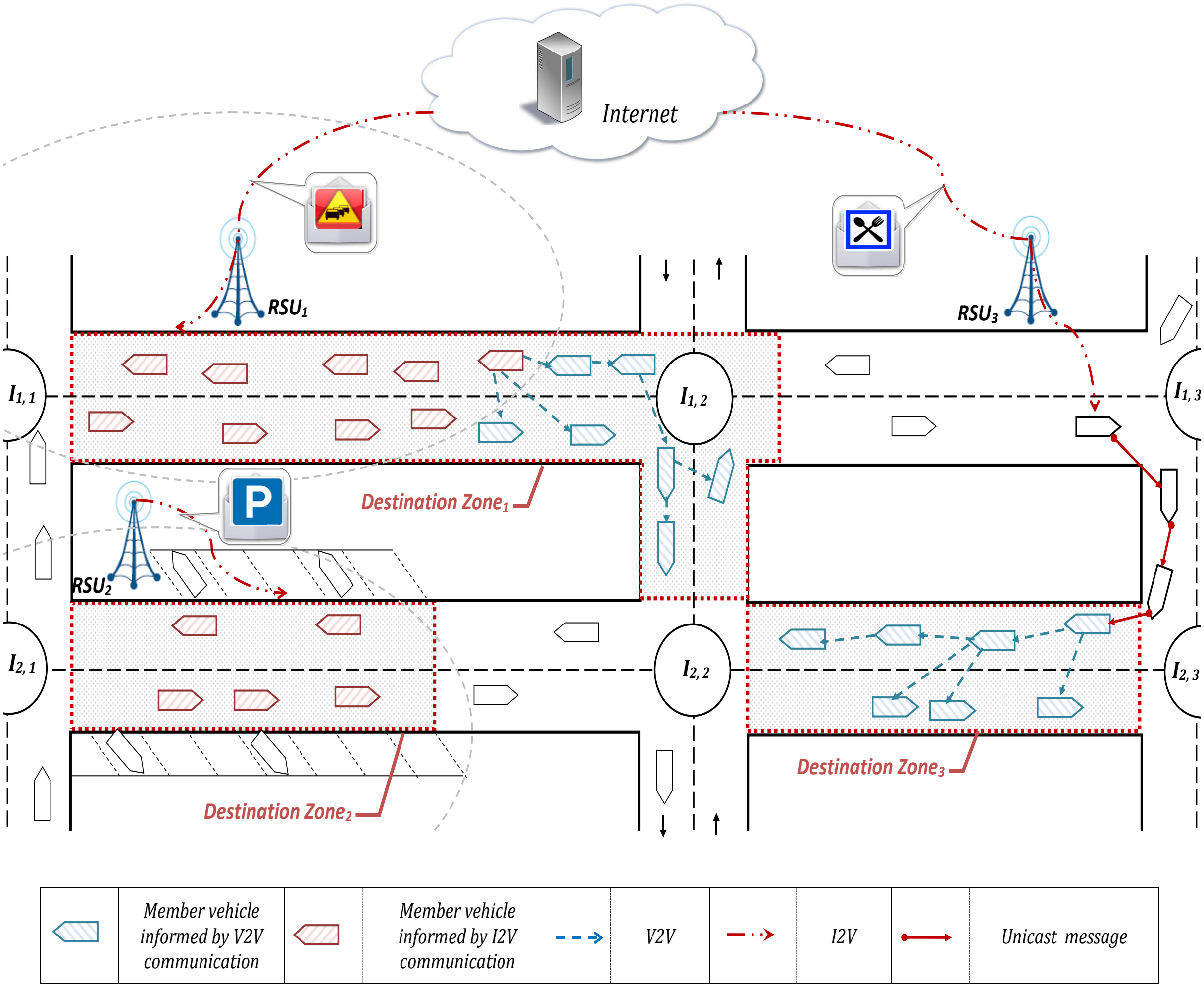


Figure 5.3: Internet to urban VANET multicast scenario

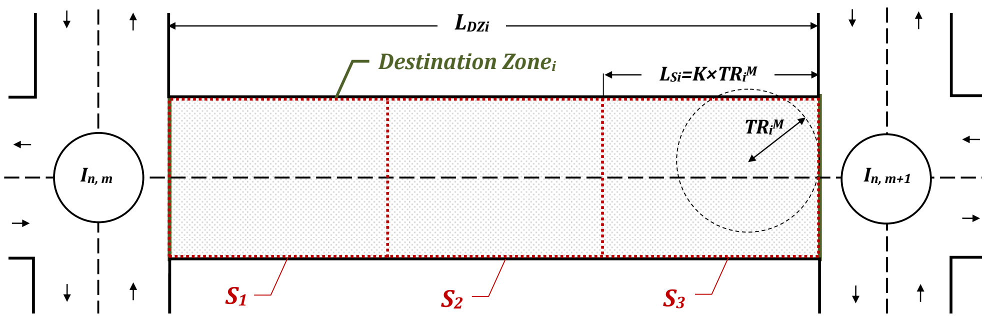


Figure 5.4: Segmentation of destination zone $DZ_i(t)$

A simple example of $DZ_i(t)$ segmentation is presented in Fig. 5.4. The chosen $DZ_i(t)$ is located between two intersections $I_{n,m}$ and $I_{n,m+1}$. $DZ_i(t)$ is partitioned into three segments S_1, S_2, and S_3. The connectivity of the vehicles in S_i depends on the transmission power. Each vehicle $v_i \in S_i$ can adapt its transmission range according to the requirements without exceeding the maximum power level P_i^M. Where $P_i^M = Max\{\mathbb{P}_{(v_i,v_j)} | v_j \in N^T(v_i)\}$, $N^T(v_i)$ are the neighbors of v_i in the Tree T, $\mathbb{P}_{(v_i,v_j)}$ is the power level for which vehicle v_i is transmitting messages to the vehicle v_j (if v_i is currently a leaf node, $P_i^M = 0$). When constructing a delivery tree in each segment S_i, it is necessary to consider the SNIR requirement for wireless communications. Hence, the transmitting power should hold (same as Equation.5.2):

$$P_i \geq \frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi \mathbb{D}_{(v_i,v_j)}}{\lambda} \right)^2 \tag{5.5}$$

Our objective is to design an optimal Sub-multicast-trees for delivering multicast messages such that: (1) overhead and end-to-end delay from the RSU_i to all vehicles $v_i \in DZ_l(t)$ can be decreased by using unicast method outside $DZ_l(t)$ and multicast strategy within it, (2) the interference in each segment $S_k \in DZ_l(t)$ is reduced by minimizing the total power consumption in S_k. The objective function in each segment S_k can be expressed by:

$$\min \left[\frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi}{\lambda} \right)^2 \cdot \sum_{v_i \in S_k} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2 \right] \tag{5.6}$$

The total interference can be maximally reduced by minimizing the total power consumption in all $DZ_l(t)$. The objective function in $DZ(t)$ can be expressed by:

$$\min \left[\frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi}{\lambda} \right)^2 \cdot \sum_{l=1}^{N_d} \sum_{S_k \in DZ_L(t)} \sum_{v_i \in S_k} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2 \right] \tag{5.7}$$

Where $DZ(t) = \cup_{l \in \{1,\ldots,N_d\}} DZ_l(t)$ and N_d is the number of zones $DZ_l(t)$.
As mentioned above, minimizing the transmission power is an NP-hard problem. Our problem is even harder, since we should take into consideration more constraints (*i.e.*, the high mobility of vehicles, the large number of vehicles and various paths in intersections). Therefore, Distributed time-efficient heuristic algorithms should be developed. Thus, we present in the next section the details of a Distributed Time-Limited Reliable Broadcast Incremental Power (DTRBIP) algorithm for muticast-applications in urban VANET. For the sake of clarity, Table 5.2 summarizes the used notations.

Table 5.2: Main notations

Parameter	Signification
V	A set of vehicles
v_i	A vehicle with an identifier i
T	Delivery tree for sending multicast messages
N_v	Number of Vehicles $N_v = \|V\|$
$N(v_i)$	Neighbors of v_i
$N^T(v_i)$	Neighbors of v_i in T
$\mathbb{D}_{(v_i,v_j)}$	Distance between vehicles v_i and v_j
RSU_i	A Roadside Unit with an identifier i
$DZ_i(t)$	Destination Zone i at current local time t
N_d	Number of Destinations Zones $N_d = \|DZ_i(t)\|$
$DZ(t)$	Union of Destinations Zones | $DZ(t) = \cup_{i\in\{1,\ldots,N_d\}} DZ_i(t)$
$SZ_i(t)$	Destination Sub-Zone i at current local time t
S_i	A segment with an identifier i
$I_{i,j}$	An intersection with identifiers i, j
SL_i	Leader of segment S_i
TR_i	Transmission Range of vehicle v_i
TR_i^M	Maximum Transmission Range of vehicle v_i
$\mathbb{P}_{(v_i,v_j)}$	Required transmission power for Vehicle v_i to reach Vehicle v_j
P_i^M	Maximum transmission power of vehicle v_i | $P_i^M = Max\{\mathbb{P}_{(v_i,v_j)} \| v_j \in N^T(v_i)\}$
P_{MinS}	Minimum sensitivity level

5.3.2 Assumptions

We consider the following assumptions:

1. All vehicles are equipped with a GPS device to find their accurate location. So, this information can be broadcasted to k-hop neighboring vehicles through beacon messages.

2. All vehicles possess a pre-loaded digital map, by which the detailed road topology can be obtained.

3. The intersection $I_{n,m}$ is a neighbor of intersections $I_{n-1,m}$, $I_{n+1,m}$, $I_{n,m-1}$, and $I_{n,m+1}$.

4. The transmission power of each vehicle $v_i \in V$ can be adjusted.

5. The maximum transmission range of each vehicle v_i is limited by TR_i^M, which represents

Table 5.3: Format of RSU_i packet (P_{RSU_i})

$DZ_{i\_Min}(t)$	$DZ_{i\_Max}(t)$	$Start_t$	End_t	RSU_{i_Info}

$DZ_{i\_Min}(t)$: Minimum coordinate of $DZ_i(t)$ at current local time t;
$DZ_{i\_Max}(t)$: Maximum coordinate of $DZ_i(t)$ at current local time t;
$Start_t$: Start time of application;
End_t: End time of application;
RSU_{i_Info}: Content of RSU_i Information.

the communication range that can be achieved using maximum transmission power P_i^M.

6. The received signal power level at each vehicle equals the minimum sensitivity level P_{MinS}.

5.3.3 Phases of DTRBIP algorithm

In dissemination routing protocols for VANET, overhead, transmission interference, and the delivery ratio are three significant and challenging parameters especially when $DZ_i(t)$ is not in the range of RSU_i. To consider these parameters, we use GPSR-based method [110] (a unicast routing protocol) to disseminate the RSU_i message to $DZ_i(t)$. In addition, a heuristic method DTRBIP is proposed to improve the delivery ratio and minimize the total transmission interference.

5.3.3.1 Packet delivering to destination zone $DZ_i(t)$

An RSU_i attempting to launch the delivery process of a multicast message of VANET application must inform all vehicles in the destination zone by sending a packet P_{RSU_i} (the contents of the packet are shown in Table 5.3). P_{RSU_i} contains essentially the coordinates of the targeted destination zone $DZ_{i\_Min}(t)$ and $DZ_{i\_Max}(t)$, the time interval of data application specified [$Start_t$ - End_t] to ensure the liveliness of application, and the content of information RSU_{i_Info}. When a packet P_{RSU_i} is generated at an RSU_i, it may be delivered through one of the following techniques:

- The packet P_{RSU_i} is transmitted to $DZ_i(t)$ directly (Fig. 5.3. RSU_1 to $Destination\ Zone_1$, RSU_2 to $Destination\ Zone_2$) if the RSU_i cover some parts of $DZ_i(t)$ (i.e, $DZ_i(t)$ in the range of the RSU_i).
- As the transmission range of an RSU_i may not cover the destination zone ($DZ_i(t)$ being far from the RSU_i), it may need to be relayed multiple times through several relays (as in Fig. 5.3. RSU_3 to $Destination\ Zone_3$) before reaching the closest relay to destination

zone. When the RSU_i has a packet P_{RSU_i} for a new $DZ_i(t)$, it creates a path using GPSR protocol [110]. In GPSR protocol, each node knows its current position and also the neighboring nodes. The knowledge about nodes' positions provides better routing towards the destination zone. On the other hand, neighboring nodes also assist to make the forwarding decisions more correctly with less interference risk.

In our work, the closest vehicles to the destination zone $DZ_i(t)$ are selected as greedy packets forwarders. The greedy relays forward the packets to the vehicles that are closer to their $DZ_{i\_X}(t)$, $X \in$ [Minimum coordinate of $DZ_i(t)$, Maximum coordinate of $DZ_i(t)$]. This process repeats until the packet P_{RSU_i} is successfully delivered to the desired destination. The formal description of this delivering process is presented in Algorithm 5.

Algorithm 5: P_{RSU} delivering to $DZ_i(t)$

```
RSU_i message is generated;
if DZ_i(t) in the range of the RSU_i then
    RSU_i broadcasts P_RSU_i
else
    RSU_i applies GPSR algorithm [110] to disseminate P_RSU_i to DZ_i(t) // Avoid overhead
```

5.3.3.2 Packet dissemination on sub-multicast-trees in destination zone $DZ_i(t)$

Before discussing the packet dissemination process, we give the following definitions.

- **Power Matrix.** For N_v vehicles, the power matrix P is an $N_v \times N_v$ matrix. The $(i,j)th$ element of the power matrix defines the power required for vehicle v_i to transmit messages to vehicle v_j, which is given by:

$$P[i][j] = \begin{cases} \mathbb{P}_{(v_i,v_j)} & \text{, if } v_j \in N(v_i); \\ -1, \text{otherwise.} \end{cases} \tag{5.8}$$

For example, the power matrix of the segment S_2 of Fig. 5.5a is:

$$\mathcal{P} = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \end{array} \begin{array}{c} \begin{array}{cccccccc} A & B & C & D & E & F & G & H \end{array} \\ \begin{pmatrix} 0 & 5 & 4 & 6 & -1 & -1 & -1 & -1 \\ 5 & 0 & 4 & 2 & -1 & -1 & -1 & -1 \\ 4 & 4 & 0 & 3 & 5 & -1 & -1 & -1 \\ 6 & 2 & 3 & 0 & 4.5 & 5 & 8 & -1 \\ -1 & -1 & 5 & 4.5 & 0 & 5 & 4 & -1 \\ -1 & -1 & -1 & 5 & 5 & 0 & 5 & 6 \\ -1 & -1 & -1 & 8 & 4 & 5 & 0 & 4 \\ -1 & -1 & -1 & -1 & -1 & 6 & 4 & 0 \end{pmatrix} \end{array}$$

- **Link Cost Matrix.**

  When a new node is added to the tree, the incremental cost is updated for all neighbors. Let us consider an example in which vehicle v_i is already in the tree (it may be either a relay node or a leaf node), and vehicle v_j is not yet a part of the tree. For all such vehicles v_i (i.e., all nodes already in the tree) and vehicles v_j (i.e., nodes not yet in the tree), the following link cost matrix is evaluated using equation 5.9.

$$LCM[i][j] = P[i][j] - P_i^M \tag{5.9}$$

  The quantity $LCM[i][j]$ represents the incremental cost associated to v_i transmission power in order to reach vehicle v_j.

In order to disseminate the packet P_{RSU_i} to the vehicles in $DZ_i(t)$, following steps are performed.

1. $DZ_i(t)$ is divided into N segments (see Algorithm 6)

Algorithm 6: $DZ_i(t)$ segmentation

```
if ((L_DZi mod L_Si) = 0) then
    N = L_DZi / L_Si
else
    N = L_DZi / L_Si + 1
```

2. When a vehicle within $DZ_i(t)$ receives a packet P_{RSU_i}, it first verifies the relevance of P_{RSU_i}. A packet is considered to be *relevant* if and only if the following three conditions

are satisfied:

$$\begin{cases} v_i \text{ in } DZ_i(t) \\ v_i \text{ receives } P_{RSU_i} \text{ for the first time} \\ t \in [Start_t, End_t] \end{cases}$$

If P_{RSU_i} is not relevant, it will be rejected, otherwise, v_i should not retransmit it immediately but has to wait a time T_w. We note $\mathbb{D}_{(v_i,CDZ_i(t))}$ as the distance between vehicle v_i and the center of $DZ_i(t)$. The waiting time is then calculated by equation 5.10.

$$T_w = \frac{\mathbb{D}_{(v_i,CDZ_i(t))}}{\mathbb{D}_{(v_i,RSU_i)}} \times T_r \tag{5.10}$$

T_r is a random time uniformly chosen in $[0, 1]$. The waiting time of vehicle v_i receiving a packet P_{RSU_i} from Roadside Unit RSU_i is proportional to $\frac{\mathbb{D}_{(v_i,CDZ_i(t))}}{\mathbb{D}_{(v_i,RSU_i)}}$. This is to give priority to the vehicle that is closest to the center of $DZ_i(t)$, we call this vehicle Segment Leader SL_i which will wait less time for the oriented multicast packet in order to reduce overload. SL_i computes multicast tree on its K-hop neighborhood in current segment S_i using the same strategy of Optimized Link State Routing (OLSR) protocol [129]. Each node periodically constructs and maintains the set of neighbors that can be reached through 1-hop and 2-hops. These relays are called Multi-Point Relays (MPR). A vehicle forwards a packet if and only if it has been elected as MPR by the SL_i. In order to construct and maintain its routing tables, SL_i periodically transmit link state information over the MPR backbone. Upon convergence, an active route is created at each vehicle to reach any $v_i \in S_i$. Based on this fact, the dedicated MPR algorithm minimizes the number of active relays needed to cover all K-hops neighbors in S_i. The multicast tree is constructed by applying the TRBIP algorithm [21] (see Section 5.2.2) in the current segment.

3. In order to disseminate the packet P_{RSU_i} to other road segments, the closest vehicles to the borders of the current segment are selected as a new Segments-Leaders to disseminate the P_{RSU_i} to next S_{i+1} and previous S_{i-1} segments. The procedure is continued until all vehicles in current $DZ_i(t)$ are informed. The formal description of this dissemination process is presented in Algorithm 7.

5.3.3.3 DTRBIP recovery strategy

The recovery strategy of DTRBIP in case of disconnection is based on the idea of carry-and-forward. Unlike the original carry-and-forward algorithm, a packet is stored along the current selected segment when there is no neighboring vehicle in the transmission range of the SL, the packet is carried until it reaches a new neighboring vehicle. Thus, a new multicast tree is created.

Algorithm 7: P_{RSU} dissemination in $DZ_i(t)$

When a vehicle v_i within the $DZ_i(t)$ receives a packet P_{RSU_i} ;
if *(P_{RSU_i} is not relevant)* **then**
    P_{RSU_i} is deleted
else
    v_i calculates a wait time T_w such that

$$T_w = \frac{\mathbb{D}_{(v_i,CDZ_i(t))}}{\mathbb{D}_{(v_i,RSU_i)}} \times T_r$$

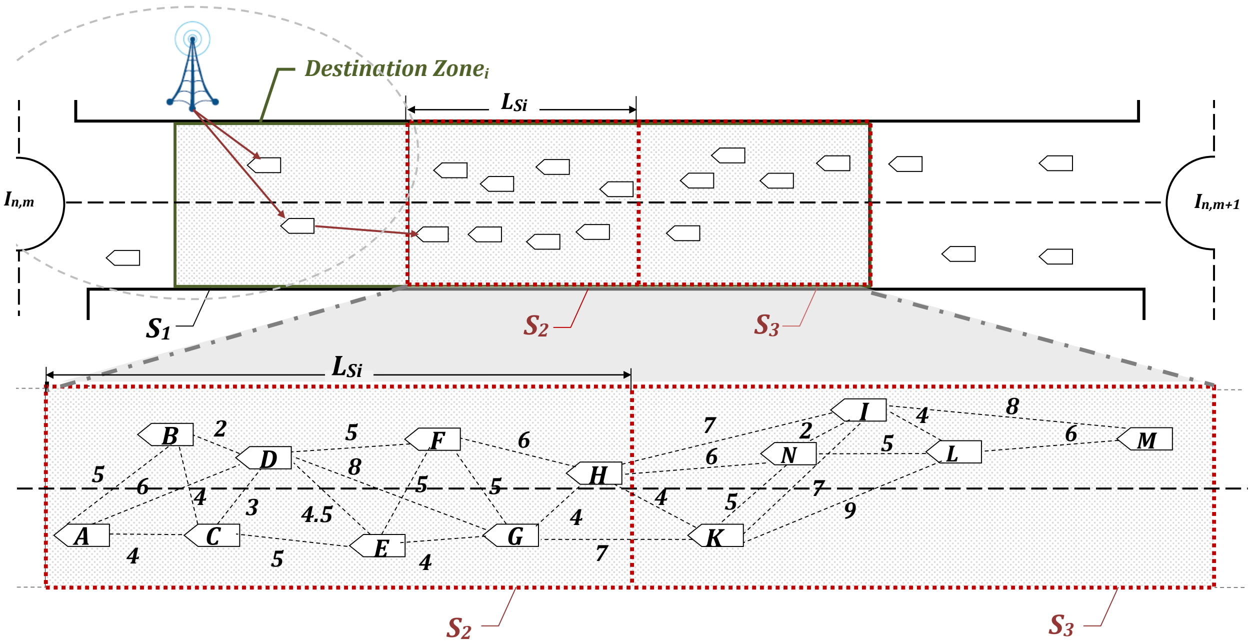
    When the timer expires;
    if *(P_{RSU_i} is not relevant)* **then**
        P_{RSU_i} is deleted
    else
        v_i applies TRBIP algorithm [21] in current segment S_i;
        The closest v_j to the S_i is selected as a new SL_j `//` v_j `relays the` P_{RSU_i} `to the next/previous segment (`S_{i+1}`,` $S_{i-1} \in DZ_i(t)$ `)`

5.3.4 Example of DTRBIP method

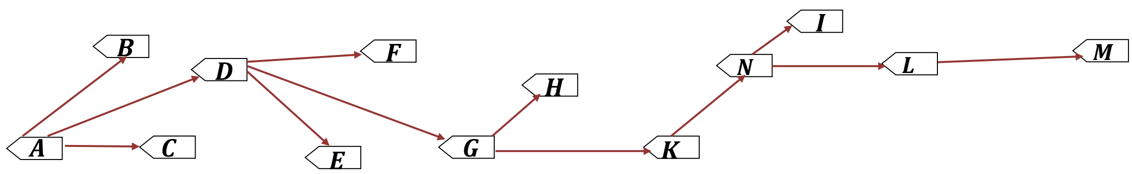
To illustrate the functionality of DTRBIP compared to TRBIP, we consider the simple example presented in Fig. 5.5a. The packet P_{RSU} is transmitted to $DZ_i(t)$ directly because the RSU covers some parts of $DZ_i(t)$ ($S_1 \subset DZ_i(t)$ in the range of the RSU). $DZ_i(t)$ contains 3 segments S_1, S_2, and S_3. The vehicles in S_1 are informed by RSU (same procedure in DTRBIP and TRBIP). The nearest neighbor of S_2 relays the packet to the vehicle A, which is Leader of the Segment 2 (SL_2). Segment S_2 contains 8 vehicles $A \sim H$. The nearest neighbor of vehicle A is vehicle C. Hence, this node is added to the tree. The nearest neighbor of C is vehicle D with transmission power $P[C][D]$=3. The cost associated with the addition of vehicle B to the tree is $LCM[A][B]$=$P[A][B]$-$P[A][C]$=1. Thus, vehicle B ($A \rightarrow B$) is added to the tree. The same procedure is repeated as shown in both Fig. 5.5b and Fig. 5.5c: $A \rightarrow \{C,\ B\ and\ D\}$; $D \rightarrow \{E,\ F\ and\ G\}$; $G \rightarrow H$. In order to disseminate packet P_{RSU_i} to S_3, The same procedure is repeated in TRBIP as shown in Fig. 5.5b: $G \rightarrow \{K\}$; $K \rightarrow \{N\}$; $N \rightarrow \{I\ and\ L\}$; $L \rightarrow M$.

However, in DTRBIP vehicle H is selected as a new Segment Leader SL_3. In this case a new sub-tree can be created. The tree construction procedure is continued until all vehicles in current segment are informed as shown in Fig. 5.5c: $G \rightarrow \{K,\ N\ and\ I\}$; $I \rightarrow \{L\ and\ M\}$.

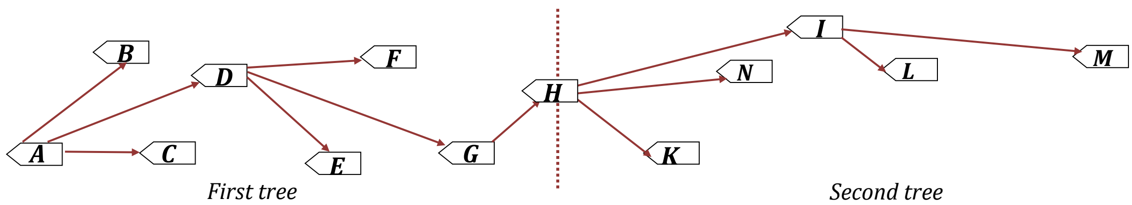
Table 5.4 shows the performance of the segmentation strategy of DTRBIP algorithm com-



(a) Packet delivering from an RSU to $DZ_i(t)$



(b) Packet dissemination in $DZ_i(t)$ using TRBIP



(c) Packet dissemination on sub-multicast-trees in $DZ_i(t)$ using DTRBIP

Figure 5.5: Packet dissemination on sub-multicast-trees in destination zone

pared to TRBIP as shown in Fig. 5.5b and Fig. 5.5c. Therefore, we find that our DTRBIP algorithm saves one-hop compared with the TRBIP algorithm. Furthermore, the table also shows that DTRBIP reduces the total emission energy.

Table 5.4: Performance of the proposed DTRBIP algorithm

	TRBIP	DTRBIP
Hop-count	7	6
Total emission energy (dBm)	165,078	164,581

5.4 Performance evaluation and numerical results

To evaluate our proposal performances, we used the NS-2 [114] simulator. Freeway mobility model is assumed in highway with four lanes of 10 Km long. Whereas, Manhattan mobility model is used for urban environments in a 5 $Km \times 5$ Km area. The length of destination zone $DZ_i(t)$ is 2400 m, while the maximum transmission range of vehicles is set to 300 m (according to dedicated short range communications- DSRC standard). The speed of vehicles varies from 80 to 140 km/h for highway environments and 00 to 60 km/h for urban environments. Simulation time is 300 seconds and 500 seconds for urban and highway environments respectively. The obtained results are the average of 10 simulations. Furthermore, we exploited a linear energy model [130].

$$\text{Cost} = m \times \text{size} + f \tag{5.11}$$

As mentioned in equation 5.11, this model represents fixed costs with f, which are the costs for accessing the channel, while m represents incremental costs, which depend on the packet size. These parameter values were empirically obtained. Simulation parameters are summarized in Table 5.5.

We evaluate the following performance metrics:

1. **Total emission energy (in dBm)**: The total energy obtained from equation (5.3) is in Watt unit and we transform it to regular dBm expression as follows:

$$10log\left(\frac{P_{MinS}}{G_iG_j}\left(\frac{4\pi}{\lambda}\right)^2 \cdot \sum_{l=1}^{N_d} \sum_{S_k \in DZ_L(t)} \sum_{v_i \in S_k} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2\right) + 30 \tag{5.12}$$

2. **Average delay**: It is the average time needed for a message to reach its destination.

3. **Height**: It is the length of the path (number of relays) from RSU_j to v_i .

Table 5.5: Simulation configurations

Parameter	Value
Mobility model for highway	Freeway
Mobility model for urban environment	Manhattan
Physical and MAC layer	802.11p
Number of vehicles	50-500
Simulated area (highway) (km)	10
Simulated area (urban) (km x km)	5 x 5
Velocity (highway) (km/h)	80-140
Velocity (Urban) (km/h)	00-60
Number of $DZ_i(t)$	3
Length of $DZ_i(t)$ (m)	2400
Hop-count constraint in $DZ_i(t)$	7-11
Number of lanes (urban)	6
Number of lanes (highway)	4
Length of S_i (m)	800
Maximum transmission range TR_v^M (m)	300
G_i, G_j	1
α	2
Packet size (bytes)	512
Simulation time (urban) (seconds)	300
Simulation time (highway)(seconds)	500

4. **Average reliability**: It is the average successful delivery ratio of messages for all involved vehicles.

5. **Generated overhead**: It is evaluated as the ratio between extra bits that represent the additional information required (for route discovery/maintenance) to route the packet towards the desired $DZ(t)$ and also the number of total bits.

To show the performance of the segmentation strategy of DTRBIP algorithm, we studied both version of our proposal with and without segmentation. To this end, we vary the hop-counts in the range of $[7, 11]$ in the $DZ(t)$. The performance of DTRBIP is shown in Figures 5.9 to 5.12.

We first compare the performance of our proposed DTRBIP to RGRP-SA [20], RBIP, and TRBIP algorithms [21] (Figures 5.6 $\sim$ 5.8). We study the network performances when vehicular density is gradually increased. The number of vehicles ranges from 50 to 500.

Figures 5.6 and 5.7 represent the total energy emission and the number of relays (i.e., Height of tree in RBIP, TRBIP and DTRBIP) respectively with respect of the number of vehicles. The total emission energy and the number of relays (height of the tree) increase while increasing velocity and vehicles density. The increase is almost linear. For various vehicles densities, resulted curves depicted that both total emission energy and relays number are higher in highway scenarios than the ones in urban scenarios. This is mainly due to the large speed deviation between vehicles resulting in a reduced contact-time in highway. As a result, more packets and relays are required to inform all vehicles in $DZ(t)$, which increases the total emission energy. Figure 5.6 also shows that TRBIP reduces the total emission energy and has a height inferior to RGRP-SA and RBIP algorithms for all network densities. This is because of the use of carry-and-forward mechanism in the case of isolated vehicle(s). Thus the radio interference is accordingly reduced.

We also observe that DTRBIP significantly reduces the total emission energy (Fig.5.6) significantly (at least by 150 dBm) and needs fewer relays (Fig. 5.7) compared to TRBIP algorithm. Thus, our solution achieves better results for delivering messages in VANET because of our packets forwarding strategy. For TRBIP, the multicast delivery tree is regularly reconstructed. However, the re-constructing of big tree is hard to maintain and requires more packets especially when vehicular density is high, which also increases the total energy emission of the network. DTRBIP uses segmentation to manage the problem of maintaining big tree (see Algorithm 6). We can say that DTRBIP is more reliable and more timely for messages delivery in VANET.

We also compare the average delay of our protocols with afore-mentioned schemes in Fig. 5.8. Clearly, the average delay in highway is superior than in urban environments, which confirms the results of Figs. 5.6 and 5.7. Figure 5.8 illustrate that the delay of DTRBIP is smaller than those of RGRP-SA, RBIP and TRBIP algorithms for all network densities and both environments. It is also worth noting that DTRBIP is able to reduce the end-to-end delay by 52% as compared to other protocols. There are two reasons for this: first, DTRBIP uses the same strategy as TRBIP to limit the maximum number of hop-counts in the delivery tree. Second, the waiting time for a vehicle to retransmit a packet is well determined (see Algorithm 7). This fact reduces the number of relays in packet delivery, hence, the average delay decreases.

From figures 5.9 and 5.10, it is worth noting that in highway environment, more emission energy is consumed ($\geq$ 86 dBm) and a higher average delay is also increased (up to 7.98%) compared to urban case. There is a big difference between the power consumption and average

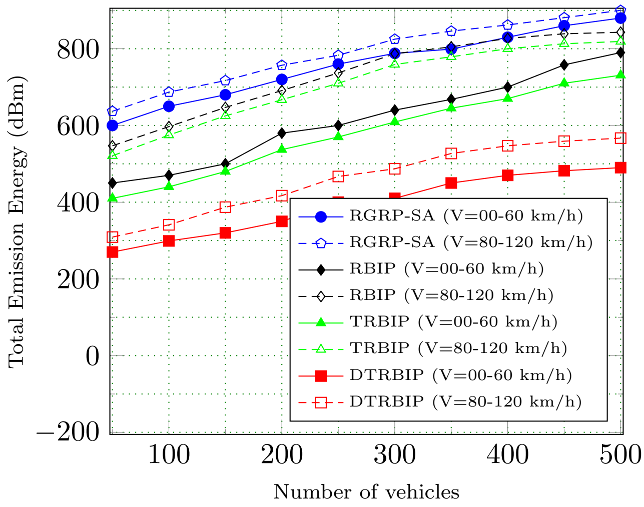


Figure 5.6: Total emission energy vs. vehicle density

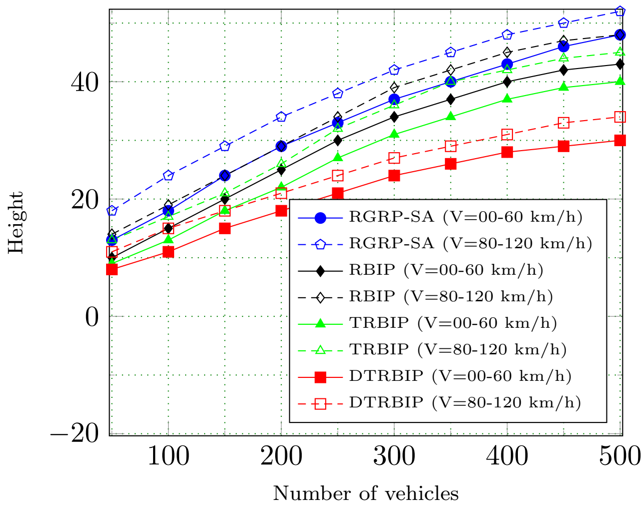


Figure 5.7: Height of the tree vs. vehicle density

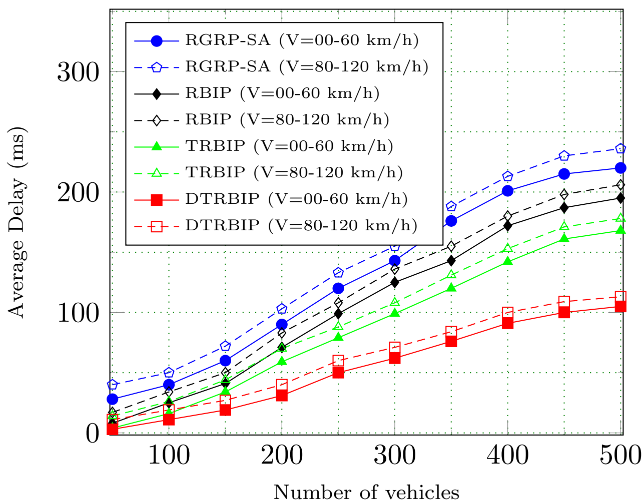


Figure 5.8: Average delay vs. vehicle density

delay in different environments. The frequent fragmentation of VANET may happen due to the high mobility of nodes in highway environment. This leads to disconnections between vehicles. Consequently, the tree(s) cannot connect all vehicles in $DZ(t)$. To overcome this problem, more packets should be used to ensure the connectivity in $DZ(t)$, which increases the end-to-end delay and the total power (consumed energy). Simulation results also show that the total energy emission and the average delay decrease with the hop-count from 11 to 7 for the two versions of DTRBIP (with/without segmentation). It will be constant if the hop-count is small enough. This confirms the advantage of using the strategy of limiting the hop-count (reduce the total power while guaranteeing the end-to-end delay). Since DTRBIP always searches the nearest path, the number of relays can be decreased. Therefore, it decreases the number of transmitted messages, and consequently decreases the total power and the message delivery delay.

We also note that DTRBIP with segmentation reduces the total energy emission (at least by 160 dBm, as shown in Fig. 5.9) and incurs smaller delay (up to 34.56%, as shown in Fig. 5.10) than DTRBIP without segmentation. This is because of the tree(s) construction mechanism in multicast group(s). DTRBIP with segmentation uses the distributed tree(s) construction strategy to manage the problem of maintaining big trees. It also uses segment leader to store the message at disconnected network scenarios which is carried along the road until finding a member of the multicast group in and between segments. This decreases the total energy emission and the message delivery delay.

Simulation results of the average reliability and the generated overhead are shown in Figs. 5.11 and 5.12 respectively. We obtained a good average reliability (Fig. 5.11) in DTRBIP with segmentation for both environments (from 91% to 97% in highway environment and from 94% to 99% in urban environment). Generated overhead of the forwarding strategy with and without segmentation is shown in Fig. 5.12. DTRBIP without segmentation generates up to 3% more overhead than DTRBIP with segmentation for both environments.

Figure 5.12 also depicts that the reliability is superior and the generated overhead is inferior in an urban environment compared with a highway environment. Because the low mobility of vehicles allows good network connectivity. This is why the packets sent by the RSU reach the majority of vehicles in $DZ(t)$, which increases the average reliability and reduces the generated overhead.

In addition, the average reliability decreases to around 91% in highway environment and 94% in urban environment whenever the hop-count increases from 7 to 11. This is due to the increasing number of collisions when the hop-count increases, especially for high vehicular density.

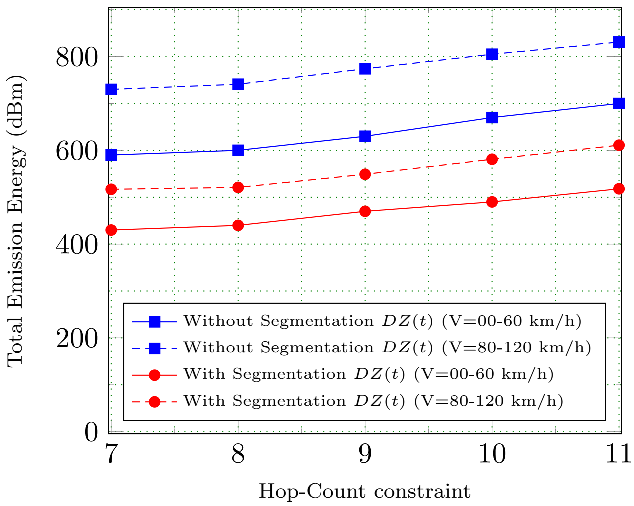


Figure 5.9: Total emission energy vs. hop-count constraint

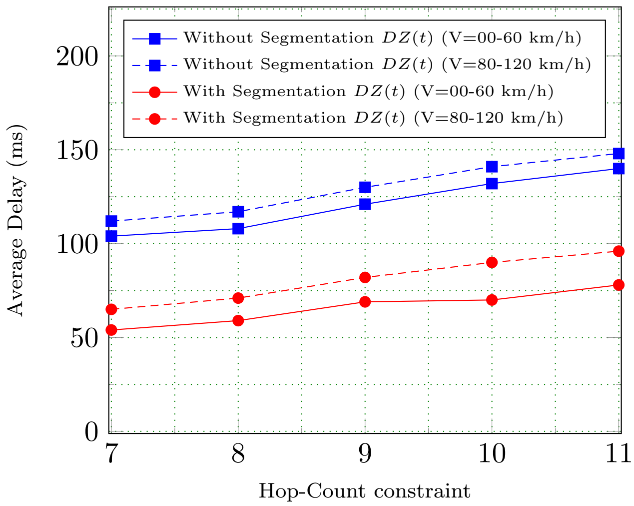


Figure 5.10: Average delay vs. hop-count constraint

Moreover, the average reliability of DTRBIP with segmentation is always much higher and the generated overhead goes down to around 7% with a decreasing hop-count in urban environment compared to highway environment. Thus, we can say DTRBIP with segmentation is more adaptive for urban environments.

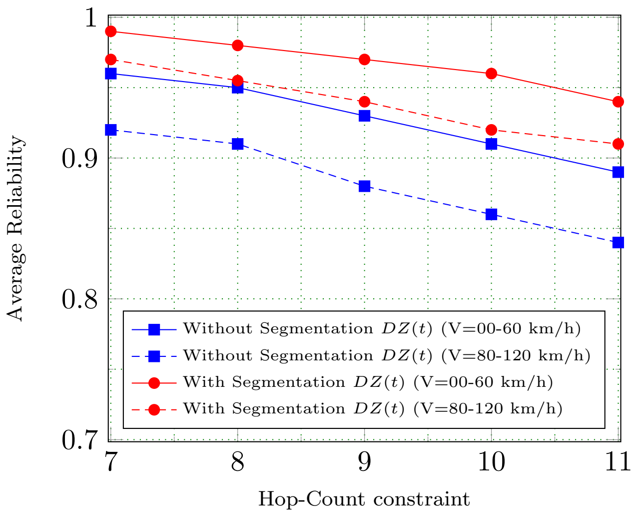


Figure 5.11: Average reliability vs. hop-count constraint

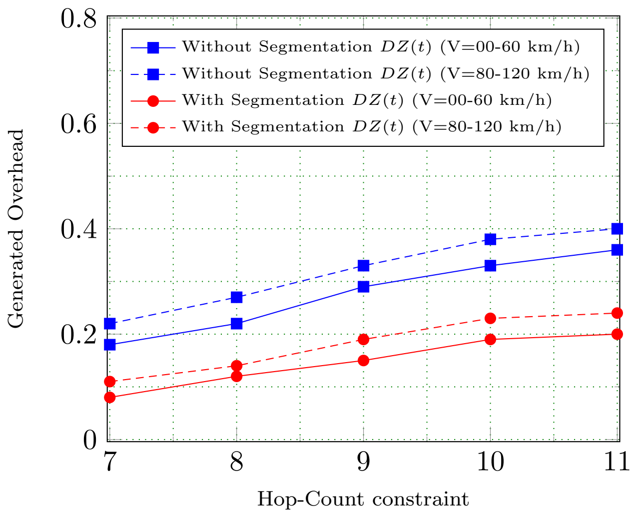


Figure 5.12: Generated overhead vs. vehicle density

In summary, our proposal DTRBIP algorithm is able to reduce both total energy emission and average delay in half compared to RGRP-SA, RBIP and TRBIP algorithms. Thus, DTRBIP algorithm is more reliable and more timely for messages delivery in VANET by incurring less overhead. The simulation results confirm its advantages for routing messages in both urban and highway environments.

5.5 Conclusion

In this chapter, we presented a centralized and distributed time-limited algorithms. The proposed dynamic multicast routing protocol is designed for delivering both Delay-sensitive and Delay-tolerant messages. In addition, DTRBIP is adaptive to highly dynamic situations of VANET in highway and urban environments and it reduces the communication interference through minimizing the total power consumption for inter-vehicular communications.

Simulation results demonstrated that DTRBIP algorithm is able to reduce the total energy emission (at least by 150 dBm) and also able to provide more reliable data delivery (sending up to 5% more packets) with smaller delay (reducing the end-to-end delay by 52%) compared to RGRP-SA, RBIP and TRBIP algorithms, by introducing only lightweight overhead.

Chapter 6

Conclusion and suggested future research

Contents

This chapter concludes the dissertation with a summary of accomplishments and of the future research works. The first section highlights the contributions made towards the goal of classifying group-based approaches in order to develop new robust geocast, multicast, and hybrid routing protocols. The second section discusses follow-up works and sample new perspectives of this work.

6.1 Summary of contributions

The main obtained results of my thesis are divided into three parts:

- Establishing the state of the art survey on different group data communication in VANET: we have presented its benefits, features, challenges, and applications, described in Chapter 1. we have classified group-based data communication into: (i) routing strategy-based and (ii) QoS-awareness. The existing group-based routing strategies are classified into five categories: (i) broadcast-oriented protocols, (ii) cluster-oriented protocols, (iii) geocast-oriented protocols, (iv) multicast-oriented protocols, and (v) hybrid protocols. The first three classifications are described in Chapter 2. In this classification, the comparisons between the different existing solutions are detailed, some related protocols with a brief showing to their transmissions strategies are illustrated and their limitations are highlighted. This motivates our two geocast proposals to enhance the robustness and leverage the need of solving the mobility and the frequent network fragmentation problems to reduce the network overhead. The rest of strategies and QoS class are explained along with the used routing protocols in Chapter 4. We have briefly summarized the different multicast and hybrid routing protocols with a detailed synthesizing and comparison of all discussed protocols and we have illustrated the classification of QoS requirements in connected vehicles based on different parameters (delay, PDR, reliability, scalability, throughput, jitter, overhead, and bandwidth consumption). This motivates our two multicast and hybrid methods to (i) efficiently explore networks and search routing paths with low delay, overhead, and high throughput, and to (ii) estimate reliable and scalable real-time roads in dynamic environments by using optimal power consumption.

- Solving the internal and external network fragmentation problems: we have presented two novel and robust geocast routing protocols for road safety applications and comfort applications respectively in Chapter 3. The proposed safety-oriented geocast protocol RGRP-SA is designed for delivering delay-critical short safety packets while taking into account the high mobility of vehicles and frequent internal network fragmentation without expansion of transmission zone, which has not been yet achieved in the literature. The simulation results confirmed the performance advantage of RGRP-SA compared to competing schemes. Unlike prior geocast schemes, the proposed dynamic geocast scheme RGRP-CA incorporates the concept of adaptive dynamic transmission zone to cope with the frequent external network fragmentation problem. The simulation results also demonstrated that RGRP-CA protocol is able to provide more reliable data delivery and higher throughput utilization by using only light overhead. Thus, the proposed RGRP-CA protocol serves well comfort applications.

- Reducing transmission interference and partitioning the map roads into segments: we have proposed two new multicast and hybrid routing protocols in Chapter 5. The first proposal illustrates the problem of reducing transmission interferences for multicast safety messages in VANET. The second solution describes the distributed version of our designed multicast routing protocol DTRBIP. To manage the problem of maintaining big tree and to adapt high mobility of vehicles, this routing protocol is adaptive to the high dynamic topology of VANET in highway and urban environments by partitioning the map roads into segments. In addition, DTRBIP reduces the communication interference through minimizing the total power consumption in VANET. The simulation results have proved the superiority of DTRBIP compared to contemporaries solutions.

6.2 Limitations

As all protocols, some limitations of our works are identified. In fact, RGRP-CA is not really scalable, even is able to maintain good network connectivity among vehicles. However, in a large network, the DZ is may be still large uselessly. On the other hand, the results of DTRBIP showed that static segmentation achieves a very good scalability for both delay-sensitive and delay-tolerant messages. However, this solution is not able to adapt the sizes of the destinations zones and segments to application's types (especially, to support safety-critical applications, since the delay is on the order of seconds).

6.3 Future work

To build on the thesis accomplishments, some future perspectives should be considered to design new group-communication approaches. One of the future work directions is to implement other geocast, multicast and hybrid routing protocols that would provide more realistic comparative results. Another direction for extending RGRP-CA by limiting transmission zone expansion. In addition, we plan to extend DTRBIP by considering other parameters and new heuristic methods to achieve more reliability and timeliness. We also plan to study the case of application-based dynamically adjusted destinations zones and segments sizes. A third direction for extending our geocast, multicast, and hybrid approaches considering the paradigm of Unmanned Aerial Vehicles (UAVs).

Finally, future work will be mainly focused on the performance analysis of our new protocols in real scenarios using mobility traces taken from real experiments. In addition, it is worth considering using another simulator. Since, NS-2 simulator requires a significant development time in the case of integrating new routing protocols in a group of vehicles.

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RÉSUMÉ

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THÈME

Les protocoles de routage multicast/geocast pour les applications de sécurité et de confort dans les réseaux de véhicules

Multicast/geocast routing protocols for safety and comfort applications in VANET

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THÈSE

N° d'ordre: ....../2020-D/INF

بسم الله الرحمن الرحيم

Résumé de la thèse

Résumé

Au cours de ces dernières années, la communication de groupe entre les véhicules intelligents devient un sujet brûlant dans l'industrie automobile et la communauté scientifique. Cependant, il y a encore des défis à résoudre dans la communication coopérative de groupe inter-véhicules (Inter-Vehicle Communication (IVC)), tels que la robustesse, le passage à l'échelle, et la qualité de service (la fiabilité, le délai et throughput en particulier).

En plus, la mobilité des noeuds dans les réseaux véhiculaires (Vehicular Ad-hoc NETwork (VANET)) provoque des fragmentations fréquentes du réseau, liées à la vitesse et la variation de densité des véhicules qui sont très importantes dans les routes, par conséquent, le problème de routage est loin d'être évident dans les réseaux véhiculaires. Le degré de dificulté du problème augmente dans le cas où l'acheminement de données concerne un groupe de noeuds (routage geocast/multicast) et tous ces derniers peuvent se déplacer avec une variation de vitesse.

Cette thèse contribuera à développer des protocoles IVC pour les VANET, en particulier en mettant l'accent sur les protocoles de routage geocast et multicast qui sont les techniques les plus adaptées à la communication coopérative du groupe au sein de VANET, ce sont les types de communications un-à-plusieurs ou plusieurs-à-plusieurs sur lesquels de nombreux services véhiculaires sont basés.

Pour ce faire, cette thèse examine d'abord des méthodes existantes de communication de données dans un groupe, ensuite propose des techniques efficaces de dissémination d'informations utilisant des approches multi-métriques basées sur différentes mesures en temps-réel. Deux méthodes robustes de routage geocast sont proposées (RGRP-SA et RGRP-CA) qui permettent de diminuer les délais d'acheminement prenant en compte la forte mobilité des véhicules et les problèmes des fragmentations interne et externe du réseau.

Dans un troisième volet, cette thèse propose deux méthodes heuristiques (TRBIP et DTR-BIP) afin de palier au problème de routage multicast et hybride des messages de sécurité routière et de confort dans VANET. L'objectif principal est de minimiser la consommation d'énergie afin de réduire les interférences de communication inter-véhiculaires et de diminuer les émissions de gaz carbonique prenant en compte le délai, la fiabilité de transmission des messages et le passage à l'échelle par l'utilisation d'une nouvelle technique de segmentation de la route.

Nous analysons la performance des solutions proposées en utilisant le simulateur NS-2, nous présentons des séries d'expérimentations que nous avons conduites pour valider nos contributions. Les résultats de simulation montrent que nos approches permettent effectivement de surmonter les contraintes inhérentes aux réseaux de véhicules. Les validations de simulation montrent également l'avantage de performance de nos solutions par rapport aux protocoles qui traitent des mêmes problèmes.

Mots clés: VANET, communications de groupe, geocast, multicast, hybride, fragmentation interne et externe, RGRP-SA, RGRP-CA, TRBIP, DTRBIP, segmentation, consommation d'énergie, qualité de service, applications de sécurité et de confort.

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Chapitre 1

Introduction Générale

Sommaire

1.1 Contexte et objectifs

Les systèmes de transport intelligent coopératif (C-Intelligent Transportation System (ITS)) ont reçu une attention toute particulière ces dernières années [1, 2, 3]. Dans ce contexte, le développement des technologies de l'information et de la communication a ouvert de nouvelles perspectives pour améliorer la sécurité routière, l'efficacité du trafic, le confort des usagers de la route et réduire l'impact écologique négatif causé par les émissions des gaz polluants générés par le trafic routier. L'une des principales forces des C-ITS est de permettre un niveau de coopération entre les automobilistes en équipant les véhicules de systèmes de communications sans fil. Cette coopération est réalisée grâce à une architecture de réseaux véhiculaires sans fil appelée réseaux véhiculaires ad-hoc (VANET) [4].

Les réseaux véhiculaires constituent un domaine de recherche prometteur qui attire de plus en plus l'attention des chercheurs, des constructeurs automobiles et des opérateurs des télécommunications. Ces réseaux rendent possible la communication entre véhicules et infrastructure (Vehicle-to-Infrastructure (V2I)) et la communication dans une architecture collaborative entre véhicules (Vehicle-to-Vehicle (V2V)) afin de diminuer le nombre d'accidents de la route, d'améliorer le trafic routier et de l'optimiser grâce à leurs applications de sûreté et divertissements sur routes (informations sur la route, alerte d'un accident, météo, emplacement des stations de services,...etc.). En plus, ces réseaux pourront fournir des applications ludiques qui participent à l'amélioration du confort au sein du véhicule (jeux interactifs entre les passagers de voitures proches, service de chat, flux multimedia,...etc.) [5, 6, 7, 8, 9, 10].

Ces applications néccessitent le partage d'informations dans un groupe, avec une certaine qualité de service (Quality of Service (QoS)), afin de créer un système collaboratif de prévention et de communication. Cependant les caractéristiques des réseaux VANET compliquent la dissémination et l'acheminement des données dans le groupe.

Par conséquent, dans cette thèse nous nous intéressons à l'échange de messages de sécurité et de confort, dans un schéma de communication collaboratif V2V, V2I et hybride qui se basent sur des communications multi-sauts et se situe en continuité des travaux initiés par d'autres chercheurs. Nous visons deux principaux objectifs: (i) proposer de nouvelles approches pour un routage fiable, efficace et à faible surcoût d'informations dans les VANET tout en respectant les contraintes sur les délais d'acheminement, et (ii) introduire de nouvelles techniques qui visent à minimiser la consommation d'énergie afin de réduire les interférences, diminuer les émissions de gaz carbonique et protéger notre planète.

1.2 Problématique, motivations et contributions

L'impact de la mobilité sur la connectivité dans le groupe reste l'une des difficultés majeures des VANET. En outre, la densité du réseau peut varier en fonction de l'environnement (i.e. urbain, rural et autoroutes), ce qui rend la topologie très instable et provoque des fragmentations fréquentes du réseau (Frequent Network Fragmentation (FNF)). La fragmentation du réseau peut apparaitre en deux possibilités:

- **La fragmentation interne du réseau (Internal Network Fragmentation (INF)):** Elle se produit quand un véhicule dans la zone de transmission (Destination Zone (DZ)) ne peut pas recevoir un message du véhicule source.
- **La fragmentation externe du réseau (External Network Fragmentation (ENF)):** Elle se produit quand un véhicule sort de DZ après une accélération ou une décélération, il est donc déconnecté du groupe.

Pour cela, les protocoles et les solutions conçues pour les réseaux véhiculaires doivent donc prendre en compte ces spécificités. En plus, la communication dans un groupe inter-véhicules soulève de nombreux challenges. En terme de qualité de service (QoS) et d'énergie, malgré la capacité énergétique importante d'un véhicule, celui-ci doit y faire attention. En effet, avec l'ajout de nouveaux capteurs, d'interfaces réseau, d'applications, la gestion énergétique du véhicule se complique. De nos jours, le véhicule doit être de plus en plus écologique et engagé dans le développement durable. Il faut donc développer des protocoles avec ce souci d'économie d'énergie.

Cette thèse vise à développer des techniques de communication véhiculaires pour le routage geocast et multicast d'informations de manière fiable et à faible délai entre groupe de véhicules. Ces techniques devront permettre de respecter des challenges et des contraintes temporelles sévères afin d'envisager leur utilisation dans des applications de sécurité et de confort sur la route. Nos contributions dans ce contexte peuvent être résumées comme suit:

(i) Communication de données dans un groupe de véhicules (Group data communication in connected vehicles: A Survey) [11]

Dans ce travail, nous examinons les méthodes existantes de communication de données dans un groupe, ainsi qu'une étude comparative permettant de montrer les avantages et les inconvénients de chacune. Pour cela, nous classons ces méthodes en basant sur: (i) le type de communication et (ii) la stratégie de routage. De plus, la performance de tous les protocoles est analysée en comparant (iii) leurs exigences en terme de qualité de service (QoS). Enfin, des améliorations de recherche futures sont discutées.

(ii) Nouveaux protocoles robustes de routage geocast pour les applications de sécurité et de confort dans VANET (Robust geocast routing protocols for safety and comfort applications in VANET) [12] [13]

Ce travail est consacré à l'étude du problème de routage geocast. Effectivement, de nombreux protocoles de routage geocast sont proposés, mais surmontent partielement les contraintes inhérentes aux communications sans fil spécialement aux réseaux de véhicules (mobilité et fragmentations fréquentes du réseau en particulier). Des mécanismes et des protocoles spécifiques doivent donc être utilisés. Dans ce contexte, nous proposons deux nouveaux protocoles robustes de routage geocast: (i) le premier adapté aux applications de sécurité (Robust Geocast Routing Protocol for Safety Applications (RGRP-SA)) et (ii) le deuxième adapté au confort (Robust Geocast Routing Protocol for Comfort Applications (RGRP-CA)) dans les réseaux ad-hoc véhiculaires.

(iii) Minimisation d'interférences dans les messages multicast de sécurité inter-véhicules (Reducing transmission interferences for multicast safety messages in VANET) [14]

Dans ce travail, nous étudions le problème de routage multicast des messages de sécurité routière dans VANET. L'objectif principal est de réduire les interférences de communication inter-véhicules prenant en compte le délai et la fiabilité de transmission des messages. Par conséquent, nous proposons un algorithme heuristique appelé Time-Limited Reliable Broadcast Incremental Power (TRBIP) pour construire l'arbre d'acheminement des messages de sécurité routière.

(iv) Version distribuée de TRBIP (A distributed time-limited multicast algorithm for VANET using incremental power strategy) [15]

Dans ce travail, nous nous intéressons à l'amélioration de la proposition précédente [14] en utilisant une méthode hybride (geo-multicast). Cette dernière est une version distribuée de TRBIP (DTRBIP) qui est basée sur une technique de segmentation afin de surmonter les problèmes mentionnés dans l'ancienne version.

1.3 Organisation de la thèse

Hormis l'introduction, cette thèse comporte quatre chapitres répartis de la manière suivante:

- Dans **le deuxième chapitre** (2), nous introduisons les concepts de bases des communications de groupe dans les réseaux de véhicules, nous décrivons les applications diverses de ces réseaux et les manières qui permettent de former un groupe, nous présentons une classification d'ensemble de protocoles de routage geocast, multicast et hybride, ainsi qu'une étude comparative permettant de montrer les avantages et les inconvénients de chacun.

- Dans **le troisième chapitre** (3), nous présentons deux nouveaux protocoles geocast qu'on a proposé, et qui englobent certains avantages des techniques existantes et utilisent de nouvelles techniques leurs permettant de s'adapter aux spécificités des applications de sécurité et de confort dans les VANET.

- **Le quatrième chapitre** (4), présente deux autres protocoles: (i) une méthode multicast et (ii) une autre version distribuée de la première en utilisant une méthode hybride afin de surmonter les problèmes mentionnés dans l'ancienne version.

- Dans **le cinquième chapitre** (5), nous présentons une synthèse des aspects abordés dans cette thèse, dressons un bilan des principaux résultats de nos travaux et concluons sur les perspectives des travaux présentés.

Chapitre 2

Communication du groupe dans les réseaux de véhicules: État de l'art

Sommaire

2.1 Introduction

Au cours de cette dernière décennie, il existe une quantité très importante d'informations utiles pour informer les conducteurs lorsqu'un événement survient (les accidents, les embouteillages, les freinages d'urgence, les places de stationnement disponibles, les véhicules d'intervention d'urgence,...etc). Ces événements peuvent être observés directement et en temps réel par le véhicule. Il est par ailleurs intéressant que toutes ces données soient partagées entre les véhicules dans le cadre d'une conduite collaborative basée sur un échange de renseignements entre véhicules munis d'instruments (capteurs par exemple) leur permettant de percevoir ce qui les entoure et de collaborer en groupes formés dynamiquement. Le conducteur peut ainsi obtenir une meilleure connaissance des caractéristiques du réseau routier sur lequel il évolue.

Dans ce qui suit, nous débutons par la description des principales applications et des manières qui permettent de former un groupe dans les VANET. Par la suite, nous présentons une classification d'ensemble de protocoles de routage geocast, multicast et hybride, ainsi qu'une étude comparative.

2.2 Applications de groupe véhiculaire

2.3.1 Applications de sécurité routière

Les applications de cette catégorie visent à réduire les risques d'accidents routiers en fournissant aux conducteurs des informations pertinentes qui leur permettent de prendre une décision adéquate à temps. En effet, les véhicules collectent d'abord des données sur l'état de la route, après ils les analysent pour avoir une idée sur la situation courante. Si un risque d'incident ou de collision est détecté, alors le véhicule diffuse un message d'alerte aux autres véhicules présents dans sa zone de risque (DZ) afin de les avertir de cette situation. Le délai de propagation de ces messages joue un rôle crucial pour ce type d'applications.

2.3.2 Applications de divertissement

Les applications de cette catégorie utilisent les communications V2V ou V2I afin de partager des informations de publicité et ainsi d'améliorer le trafic routier en fournissant des informations sur l'état des routes telles que des travaux ou des obstacles. Cela permet la réduction du temps de trajet et une répartition efficace du trafic routier. Ces applications sont moins exigeantes en termes de délai de délivrance que les applications de sécurité.

2.3.3 Applications de confort du conducteur et des passagers

L'objectif principal de cette catégorie est de rendre les voyages plus agréables en permettant aux passagers de communiquer soit avec d'autres véhicules ou avec des infrastructures. Comme exemple de ce type d'applications, nous pouvons citer les applications du partage de musique ou vidéo entre les passagers qui voyagent ensemble. De plus, ces applications peuvent fournir un accès à Internet, des messages instantanés, des jeux en réseau et d'autres services.

2.3 Techniques de communication de groupe véhiculaire

Les différentes techniques d'acheminement des données dans un groupe véhiculaire sont les suivantes:

1. **Broadcasting:** l'information du noeud source est envoyée à tous les noeuds atteignables. Cependant le broadcast cause un problème connu sous le nom "the broadcast storm problem", il se produit de la rediffusion systématique des messages inutiles qui causent une consommation excessive de la bande passante vu que chaque noeud va recevoir plusieurs fois la même information via le canal sans fil. De plus, dans le cas des réseaux ad-Hoc denses, le fait que chaque noeud rediffuse systématiquement génère un nombre important de collisions. Ce qui réduit donc l'efficacité et la fiabilité de la diffusion. Pour éviter ce

phénomène, la solution la plus souvent retenue est la diffusion des données vers un groupe bien défini (multicasting ou geocasting).

2. **Multicasting:** ce mode de communication permet à une source de transmettre une seule copie d'un paquet vers un ensemble de récepteurs appartenant au groupe multicast. Ce mode a connu un succès important dans les applications multi-utilisateurs (vidéo-conférence, télé-enseignement,...etc.), où l'objectif principal est de diffuser la même information, en temps réel, à un ensemble d'utilisateurs.

3. **Geocasting:** le routage geocast est un mécanisme similaire au multicasting dans lequel les destinataires sont identifiés par des contraintes géographiques. Il est utilisé par les applications diffusant des données qui ne sont utiles que pour les véhicules se trouvant dans une zone géographique spécifique. Par exemple, l'information sur un accident n'est pertinente que pour les véhicules qui se dirigent vers le lieu de l'accident. La diffusion des paquets vers tous autre véhicules cause une surcharge inutile du réseau.

4. **Geo-multicasting:** ce mode de communication permet à un noeud de joindre un groupe multicast s'il est dans une certaine zone géographique designé par le noeud source.

2.4 Étude de l'existant

De nombreux travaux ont été proposés ces dernières années pour étudier et classifier différentes solutions d'acheminement des informations à un groupe de destinataires via un réseau véhiculaire. Les travaux de la communication de données dans un groupe sont généralement classés en deux grandes classes [16, 17, 18]: (i) travaux basés sur les communications directes des véhicules (V2V) et (ii) travaux basés sur les communications V2I, qui permettent aux véhicules de communiquer indirectement par l'intermédiaire des infrastructures.

Selon le type d'application, d'autres travaux ont classé la communication de données dans un groupe véhiculaire en deux catégories [19, 20, 21, 12, 14]: (i) applications orientées sécurité routière qui permettent d'améliorer la sécurité des passagers et de réduire les accidents mortels, et (ii) applications non-orientées sécurité routière qui visent principalement à améliorer le confort des conducteurs et des passagers.

En outre, d'autres travaux en se basant sur la stratégie de routage, ils ont classé le routage de données dans un groupe véhiculaire en trois catégories [22, 23]: (i)unicast, (ii) broadcast, et (iii) geocast/multicast. En revanche, d'autres travaux les ont classé en cinq catégories: (i) topology-based routing protocols, (ii) position-based routing protocols, (iii) cluster-based routing protocols, (iv) geocast-based routing protocols, and (v) broadcast-based routing protocols [24, 25, 26, 27].

Dans les travaux décrits dans [28, 29, 30, 31], les auteurs offrent un aperçu des différents protocoles de communication inter-groupe dans les VANET. Sanguesa et al. [28] ont classé les protocoles broadcast en deux catégories: (i) one-hop et (ii) multi-hop. Dans [29, 30], les auteurs proposent une classification selon l'environnement du trafic utilisé où il y a deux catégories: (i) urban et (ii) highway. Farooq et al. [31], fournissent une taxonomie des protocoles de routage multicast où il y a principalement trois familles de protocoles: (i) multicast routing methods, (ii) multicast routing approaches, and (iii) multicast routing types.

A notre connaissance, après une recherche bibliographique exhaustive, peu de travaux ont classé les protocoles de communication inter-groupe dans les VANET considérant les caractéristiques et les contraintes de communication inter-groupe tels que: la mobilité, les fragmentations fréquentes du réseau et la minimisation de consommation d'énergie. Il est aussi important de mentionner qu'il n'existe pas encore (à notre connaissance) dans la littérature des travaux qui s'intéressent au contraintes de communication inter-groupe (QoS: délai, fiabilité, evolutivité,...etc.).

Dans le tableau 2.1, nous comparons différents travaux qui ont été menés dans le contexte de communication inter-groupe, en se basant sur les critères suivants: type de communication, contraintes, application et stratégie de routage. En comparant ces travaux, nous pouvons dire que: (i) le type de communication, (ii) la stratégie de routage, et (iii) la qualité de service sont des critères essentielles pour la classification des travaux inter-groupe. Par conséquent, nous classons ces derniers dans la section suivante en tenant compte de toutes les caractéristiques mentionnées précédemment.

Table 2.1: Comparaison de différents travaux de communication inter-groupe

	Classe													
	Communications			Contraintes				Applications		Strategies de routage				
Travaux	V2V	V2I	hybride	FNF	Fiabilité	Evolutivité	Consommation d'énergie	Sécurité routière	Non-Sécurité routière	Broadcasting	Clustering	Multicasting	Geocasting	Hybride
[16][17][18]	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
[19][20][21]	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✗	✗
[12][14]	✗	✗	✗	✓	✗	✗	✗	✓	✓	✓	✗	✓	✓	✗
[22][23]	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗	✓	✓	✗
[24][25][26][27]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✗	✓	✗
[28]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗
[29][30]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
[31]	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗	✗
Notre classification	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

2.5 Classifications et synthèse

Nous pouvons classer la communication de données dans un group-VANET en: (i) stratégie de routage et (ii) la qualité de service comme le montre la figure 2.1. D'après l'étude qu'on a effectuée sur les protocoles de routage existants, on constate que:

- Premièrement, les protocoles orientés broadcasting sont simples à mettre en oeuvre et délivrent des messages de manière fiable. Cependant, la diffusion consomme beaucoup de bande passante et d'énergie en raison de messages redondants qui augmentent la charge du réseau et la congestion du trafic.

- Deuxièmement, le clustering est très efficace pour réduire la consommation d'énergie, l'évolutivité et la durée de vie d'un réseau avec un plus grand nombre de noeuds. Cependant, les protocoles de routage en cluster présentent également des inconvénients car la construction et la maintenance des clusters est une tâche difficile et les coûts de communication supplémentaires peuvent ajouter un surcoût en terme de délai.

- Troisièmement, les phénomènes très courants et répandus dans le geocasting sont la forte mobilité et les fragmentations interne et externe du réseau. Pour cela, toute solution proposée devra offrir un mécanisme qui permet de gérer la mobilité et le partitionnement fréquent du réseau. Cependant, les différentes solutions proposées dans les VANET ont résolu partiellement ces problèmes. C'est pour cela nous proposons deux nouvelles approches de routage geocast (RGRP-SA et RGRP-CA: Chapitre 3).

- En plus, d'après l'étude qu'on a effectuée sur les protocoles de routage multicast et hybride existants, on constate que: D'une part, les protocoles orientés multicasting peuvent réduire le délai de bout en bout et maximiser la fiabilité. D'autre part, l'efficacité énergétique et les interférences de transmission ne sont pas prises en compte dans les protocoles de routage multicast et hybride. Ce qui nous a motivé à proposer deux nouvelles approches de routage multicast et hybride (TRBIP et DTRBIP: Chapitre 4).

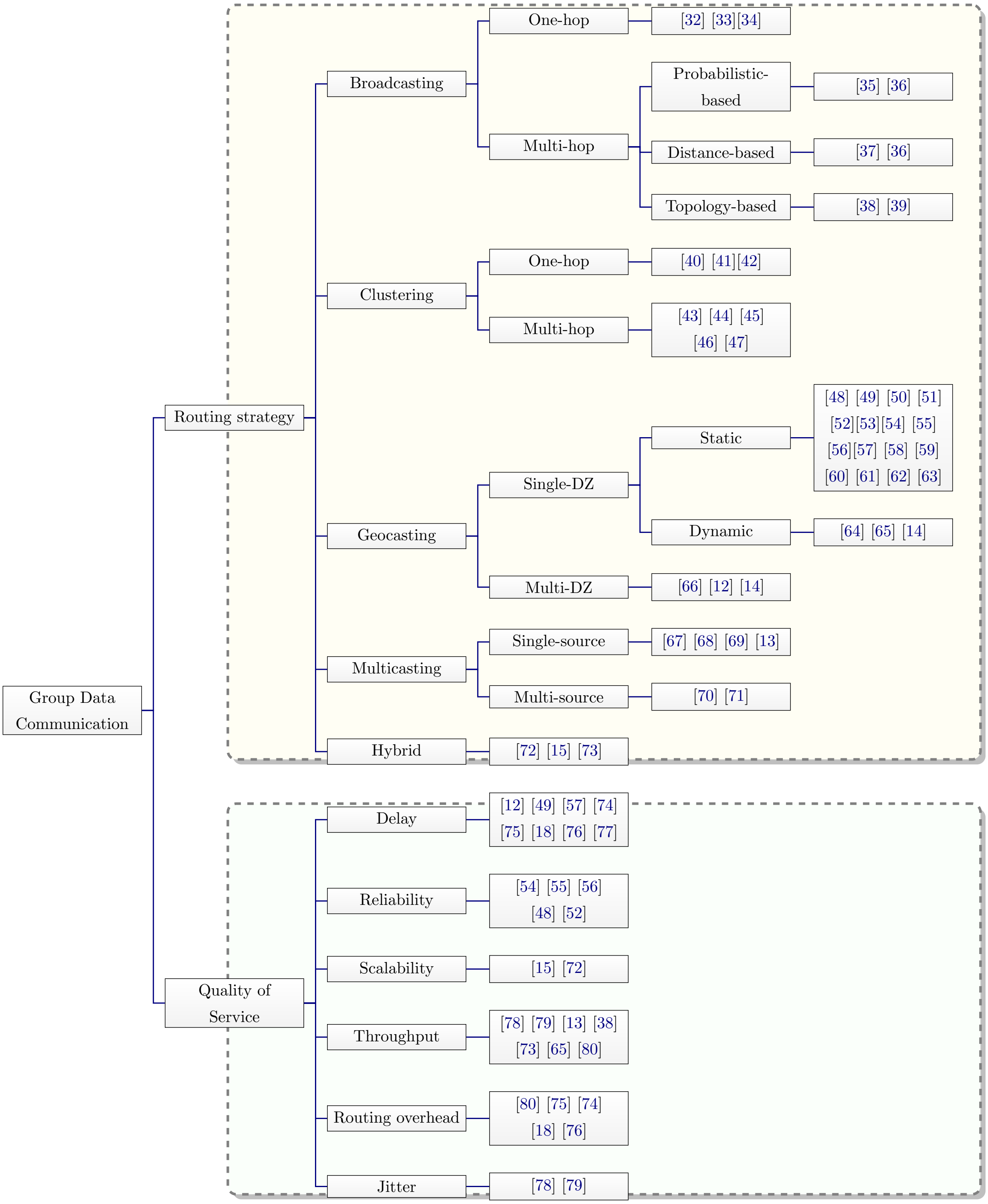


Figure 2.1: Classification des travaux de communication dans un groupe véhiculaire

Chapitre 3

Protocoles de routage geocast (RGRP-SA et RGRP-CA): Nos contributions

Sommaire

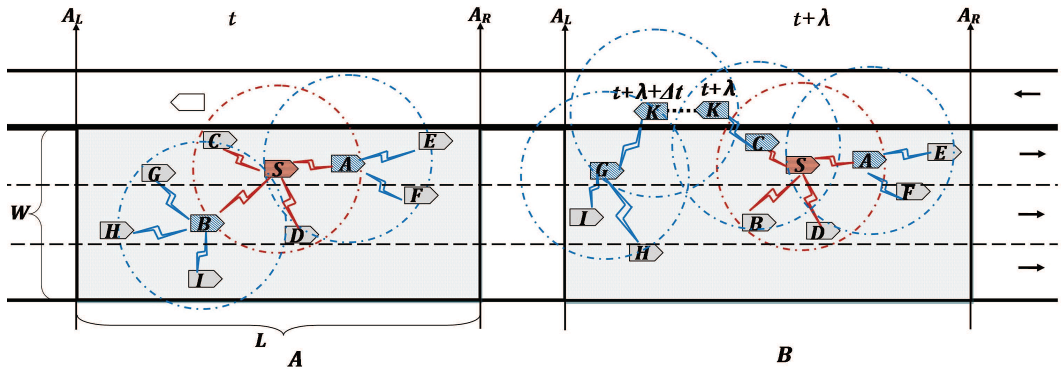
3.1 Introduction

Dans ce chapitre, nous abordons les problèmes de routage geocast où nous proposons deux protocoles: (i) RGRP-SA (Robust Geocast Routing Protocol for Safety Applications) et (ii) RGRP-CA (Robust Geocast Routing Protocol for Comfort Applications). Ils consistent à acheminer des messages aux véhicules situés dans une zone géographique $ZT(t)$ (Zone de Transmission) au temps t, en considérant les deux facteurs spécifiques aux réseaux de véhicules (la forte mobilité des véhicules, et les fragmentations fréquentes interne et externe du réseau).

3.2 Nos protocoles: Robust Geocast Routing Protocols

1. **Le premier protocole RGRP-SA**, supporte les applications de sécurité routière dans une autoroute ou environnement urbain, il est capable de vérifier la présence des véhicules voisins avant la retransmission du paquet geocast, afin d'éviter d'utiliser l'échange périodique des paquets, ce qui va diminuer le nombre des paquets échangés. Pour résoudre le problème de la fragmentation interne du réseau, RGRP-SA utilise un relai dynamique qui est situé dans la direction opposée pour router le paquet aux autres véhicules dans $ZT(t)$. Dans le cas négatif, RGRP-SA utilise la stratégie dénommée

store-carry-and-forward dans laquelle les relais transportent les paquets jusqu'à ce qu'ils trouvent d'autres véhicules dans $ZT(t)$.
La figure 3.1 illustre un exemple de diffusion du paquet geocast à tous les véhicules dans la zone de risque $ZT(t)$ à travers les relais les plus proches de l'axe gauche A_L et l'axe droit A_R. Les véhicules $V_A \sim V_I$ sont situés dans $ZT(t)$ doivent recevoir le paquet de V_s.



→	Driving direction	(red)	Source vehicle	A_L	Left axis
▭	Transmission Zone	(hatched)	Relay vehicle	A_R	Right axis
—·—	Transmission Range	(grey)	Member vehicle in geocast group	L	Length of the risk area
W	Width of the road	t	Time t	λ	the minimum time between two successive broadcast of packets from vehicle S

Figure 3.1: (A) Dissémination de paquet dans $ZT(t)$, (B) Dissémination de paquet pour résoudre le problème de la fragmentation interne du réseau (cas d'isolement des véhicules : V_G, V_I et V_H).

A l'instant t (cf. fig 3.1. A), le véhicule V_s diffuse le paquet dans sa portée de transmission, V_A, V_B, V_C, et V_D, reçoivent ce message. Les véhicules V_A et V_B sont plus proches respectivement de A_R et A_L, donc ils retransmettent le paquet aux autres véhicules ($V_E \sim V_I$).
La fragmentation interne du réseau se pose quand un noeud dans $ZT(t)$ ne peut pas recevoir le message à partir du V_s par exemple, le cas de V_G, V_H et V_I dans la figure 3.1. B. Pour résoudre ce problème, RGRP-SA utilise le relai V_K pour transporter le message au V_G, V_H et V_I.

Avantages

- ✓ RGRP-SA évite l'échange périodique de paquets afin de réduire la surcharge du réseau.
- ✓ RGRP-SA surmonte les problèmes de fragmentation interne du réseau.

2. **Le deuxième protocole RGRP-CA**, est une adaptation de RGRP-SA aux applications de confort. Il est basé sur le principe suivant: Tous les véhicules qui sont situés dans la zone de transmission forment un groupe geocast (cf. Fig 3.2. A), ces véhicules doivent conserver

la connectivité pour assurer la communication le long de l'application. La connectivité d'un véhicule est perdue s'il sort de $ZT(t)$ après une accélération (cas de V_E dans la figure 3.2.(B)) ou décélération. Pour résoudre ce problème (fragmentation externe du réseau), la zone de transmission $ZT(t)$ est agrandie chaque fois qu'il est nécessaire.

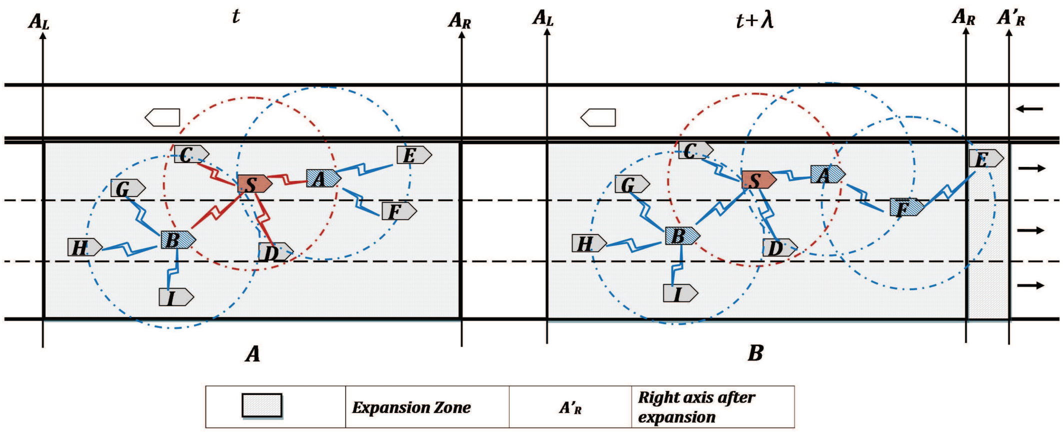


Figure 3.2: (A) Dissémination de paquet dans $ZT(t)$, (B) Agrandissement de $ZT(t)$ pour résoudre le problème de la fragmentation externe du réseau.

Avantages:

✓ RGRP-CA surmonte à la fois la fragmentation interne (même principe de RGRP-SA) et la fragmentation externe du réseau.

3.3 Description détaillée de nos protocoles

Le premier protocole RGRP-SA est composé de deux phases:

1. - La création de $ZT(t)$.
2. - La dissémination de paquet.

L'approche RGRP-CA est une version améliorée du protocole RGRP-SA. Cette méthode est basée sur le principe suivant: Les véhicules qui sont situés dans la zone de transmission représentent un groupe geocast. La connectivité entre les véhicules doit être conservée dans la zone de transmission le long de l'application (l'application peut être un partage des informations entre un groupe de touristes qu'ils déplacent vers la même destination), donc, si un véhicule V_i a le risque de quitter la zone $ZT(t)$ à cause d'une accélération ou une décélération, $ZT(t)$ est agrandie. Ce protocole est composé de trois phases:

1. - La création de $ZT(t)$.
2. - La dissémination de paquet.

3. - L'agrandissement de $ZT(t)$ si nécessaire.

Dans ce qui suit, on va expliquer en détail les différentes phases :

1. **La création de la zone** $ZT(t)$

   - Initialement, le véhicule source V_s est situé au centre de $ZT(t)$, par conséquent $ZT(t)$ se déplace à la même vitesse et dans la même direction que V_s.
   - La forme de $ZT(t)$ pour un véhicule V_s est un rectangle, la longueur L de $ZT(t)$ doit être supérieure ou égale $2R$ ($L \geq 2R$), où R est la portée de transmission, la largeur W est définie comme étant la largeur de la route.
   - Chaque véhicule V_i peut acquérir sa position ($x_i(t)$, $y_i(t)$) à l'instant t à partir de son GPS.
   - A_L (left axis) et A_R (right axis) sont les deux axes passant par les extrémités de $ZT(t)$. Ce protocole assure la dissémination d'un paquet vers un véhicule virtuelle dans A_x , $x = \{L \text{ ou } R\}$.

   La procédure de la création de $ZT(t)$ est réalisé en trois étapes:

   Étape 1: le véhicule source V_S acquiert sa position ($x_s(t)$, $y_s(t)$) à partir de son GPS.
   Étape 2: $ZT(t)$ est déterminée selon la largeur W de la route et la valeur initiale de L.
   Étape 3: V_S envoie le premier paquet geocast G_p.

2. **La dissémination de paquet dans** $ZT(t)$ **:**
   Lorsqu'un véhicule V_j reçoit le paquet geocast G_p de V_i, il vérifie la pertinence du G_p. Un paquet G_p est « pertinent » si et seulement si:

   $$\begin{cases} V_j \text{ dans } ZT(t) \\ V_j \text{ reçoit } G_p \text{ pour la première fois} \end{cases}$$

   Si G_p n'est pas pertinent, V_j rejette G_p. Sinon V_j vérifie sa position par rapport à V_i, s'il est avant V_i, $A_x = A_R$ (l'acheminement de paquet est orienté vers A_R), sinon $A_x = A_L$, ensuite V_j attend un certain temps T_w (wait time) pour prendre une décision, tel que :

   $$T_w = \frac{D(V_j, A_x)}{D(V_i, A_x)} * T_r$$

   T_r: random time (valeur aléatoire uniformément choisie dans [0,1]). $D(V_j, A_x)$ est la distance qui sépare V_j et A_x.
   Une fois T_w expire, si G_p reste pertinent, V_j déduit qu'il est le relai le plus proche de A_x (Ceci pour favoriser le véhicule le plus proche de A_x attendre moins de temps et

de retransmettre plus rapide), Donc, il doit s'auto-désigner comme relai, et rediffuse le message après la vérification de l'existence de(s) voisin(s) plus proche(s) de A_x.

Pour résoudre le problème de la fragmentation fréquente interne (en cas d'isolement de véhicule(s)), un relai situé dans la direction opposée est utilisé pour acheminer le paquet aux autres véhicules dans $ZT(t)$. Dans le cas négatif, la stratégie store-carry-and-forward est utilisée dans laquelle un relai transporte le paquet jusqu'à se qu'il trouve d'autre(s) véhicule(s) plus proche(s) de A_x. Le paquet est rediffusé continuellement jusqu'à ce qu'il atteint les deux axes A_R et A_L. la procédure de dissémination est décrite dans l'algorithme 1.

Algorithm 1: Packet Dissemination in $Z(t)$

```
while vehicle V_j receives packet P_g from V_i do
    if (P_g is not relevant) then
        P_g is deleted
    else
        if D(V_j, A_R) < D(V_i, A_R) then
            A_x = A_R
        else
            A_x = A_L
        V_j calculates a random wait time T_w such that

            T_w = D(V_j, A_x) / D(V_i, A_x) * T_r

        // T_r: random time uniformly chosen in [0, 1]
        When the timer expires;
        if (P_g is not relevant) then
            P_g is deleted
        else
            if (∃V_k, such that (D(V_k, A_x) < D(V_j, A_x)) and (V_k in Z(t))) then
                V_j broadcasts packet P_g(V_j , TZ_{V_j}(t), m) // avoid periodic exchange of packets
            else
                if (∃V_k, such that (D(V_k, A_x) < D(V_j, A_x)) and (V_k outside Z(t))) then
                    V_j selects the closest neighbor V_l to A_x
                    V_l sends packet P_g(V_j , TZ_{V_j}(t), m) by unicast to the closest neighbor in Z(t) // solve internal network fragmentation
                else
                    V_j repeats the same step after waiting for a random time
```

3. **L'agrandissement de $ZT(t)$:**

   Afin de résoudre le problème de la fragmentation externe du réseau, $ZT(t)$ est agrandie selon l'estimation de la nouvelle position de A_x après un temps λ, où : $x \in \{L, R\}$ et λ est le temps minimal qui sépare les diffusions des deux paquets G_p successives de V_s. Pour assurer la dissémination du paquet G_p vers A_x, l'agrandissement de $ZT(t)$ suit les étapes suivantes :

   Étape 1: Le véhicule V_j calcule les distances entre ses voisins et A_x;

Étape 2: Le véhicule V_j vérifie s'il y a un voisin V_k qui risque de sortir de $ZT(t)$.
Soit v_s la vitesse du véhicule V_s, v_k et a_k soient la vitesse et l'accélération d'un véhicule V_k devant V_s (V_k est plus proche de A_R) et v_l et a_l soient la vitesse et la décélération pour un véhicule V_l derrière V_s (V_l est plus proche de A_L).
Un véhicule a le risque de quitter $ZT(t)$ après une accélération ou une décélération après un temps λ, peut être détectée par l'une des conditions suivantes:

- Si V_k situe avant V_s et $D(V_k, A_R) \leq (v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2$,
- Si V_l est derrière V_s et $D(V_l, A_L) \leq (v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2$.

Si l'une des deux conditions est vérifiée, V_j envoie un paquet P_{AxNew} à V_s pour alerter le changement. La procédure d'agrandissement de $ZT(t)$ est décrite dans l'algorithme 2.

Algorithm 2: Expansion of $TZ(t)$

if $A_x = A_R$ **then**
  // V_j is closer to A_R than V_s (in front of V_s)
  V_j calculates the distances between its neighbors and A_R
  if *(one neighbor V_k satisfying $D(V_k, A_R) \leq (v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2$)* **then**
    // if a vehicle leaves $TZ(t)$ after an acceleration
    V_j selects the fastest neighbor vehicle V_k

$$A_{RNew}(t+\lambda) = A_R(t+\lambda) + ((v_k - v_s)\lambda + \frac{1}{2}a_k\lambda^2)$$

    // v_k: velocity of V_k, a_k: acceleration of V_k
else
  // V_j is closer to A_L than V_s (behind V_s)
  V_j calculates the distances between its neighbors and A_L
  if *(one neighbor V_l satisfying $D(V_l, A_L) \leq (v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2$)* **then**
    // if a vehicle leaves $TZ(t)$ after a deceleration
    V_j selects the slowest neighbor vehicle V_l

$$A_{LNew}(t+\lambda) = A_L(t+\lambda) - ((v_s - v_l)\lambda + \frac{1}{2}a_l\lambda^2)$$

    // v_l: velocity of V_l, a_l: deceleration of V_l
V_j sends a packet $P_{A_X New}$ by unicast to V_s to alert the change // solve external network fragmentation

3.4 Résultats et interprétations des simulations

Cette section concerne l'étude des performances de nos protocoles de routage. Pour cela, un ensemble de simulations est réalisé en utilisant l'outil NS-2 [81]. Les performances de nos approches sont comparées:

- La première approche RGRP-SA est adaptée aux applications de sécurité routière, elle est comparée avec deux approches IVG [49] et MRPV [64] comme références des protocoles de routage geocast.
- La deuxième approche RGRP-CA est adaptée aux applications de confort, elle est comparée avec un protocole similaire MCF [65].

Le tableau 3.1 récapitule l'ensemble des paramètres de simulation utilisés.

Table 3.1: Paramètres de simulation

Paramètre	Valeur
Mobility Model (highway)	Freeway
Mobility Model (Urban)	Manhattan
Physical and MAC layer	802.11p
Number of Vehicles	50-500
Velocity (highway)	80-140 km/h
Velocity (Urban)	20-60 km/h
Simulated area (highway)	8000 m x 40 m
Simulated area (Urban)	1500 m x 1500 m
Number of lanes	4
Length of $ZT(t)$ (highway)	2000 m
Length of $ZT(t)$ (Urban)	600 m
Transmission range	250 m
Simulation time (safety)	180 seconds
Simulation time (comfort)	300 seconds

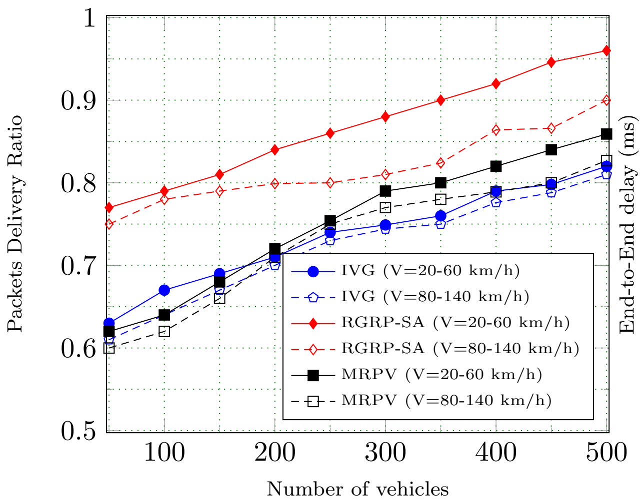


Figure 3.3: Taux de délivrance de paquets vs. densité du réseau (application de sécurité)

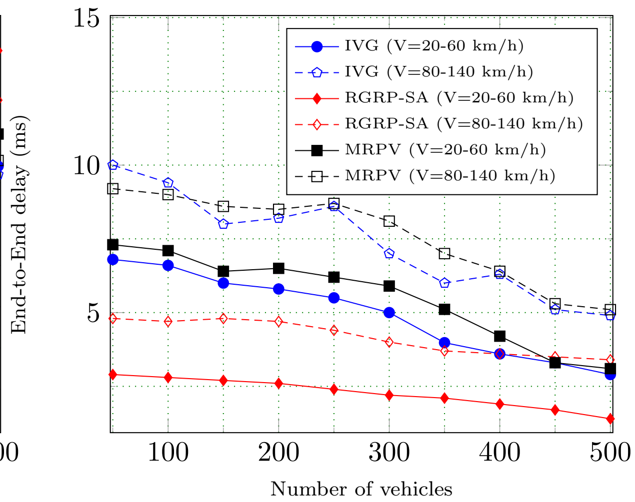


Figure 3.4: Délai moyen de bout en bout vs. densité du réseau (application de sécurité)

Les résultats de simulations présentés dans les figures 3.3 et 3.4 ont montré que, par rapport à IVG et MRPV notre protocole RGRP-SA minimise: le délai moyen de bout en bout, le taux de pertes des paquets, ainsi que la surcharge du réseau. Par conséquent, RGRP-SA permet de répondre aux besoins des applications de sécurité routière tels que la transmission des informations concernant la situation de la route, la météo,...etc.

D'après les résultats de simulation présentés dans les figures 3.5 et 3.6, nous pouvons dire que les performances de notre protocole RGRP-CA qui permet de fournir des informations à tous les véhicules qui sont situés dans la même zone sont très satisfaisantes en terme d'augmenter: le taux moyen de délivrance des paquets, et throughput par rapport à MCF. Les résultats de la simulation confirment ses avantages pour le routage des messages de confort.

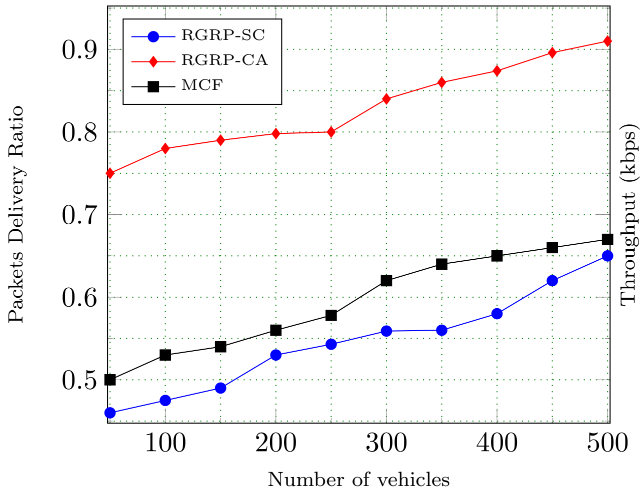


Figure 3.5: Taux de délivrance de paquets vs. densité du réseau (application de confort)

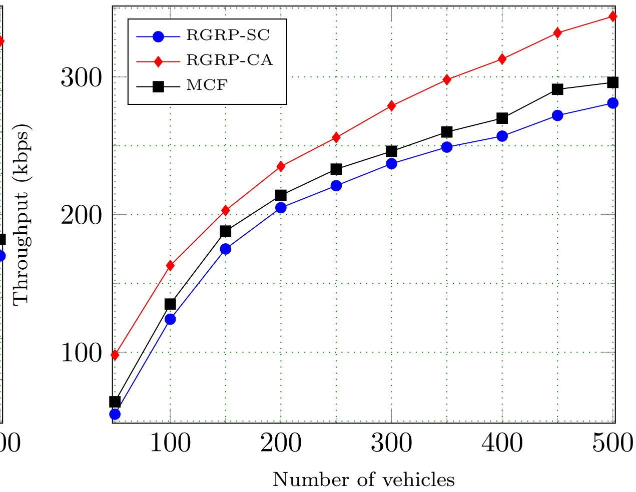


Figure 3.6: Throughput vs. densité du réseau (application de confort)

3.5 Conclusion

Dans ce chapitre, nous avons proposé deux nouveaux protocoles de routage geocast pour les VANET, ces derniers prennent en considération les principales caractéristiques des VANET, à savoir la forte mobilité, la fragmentation interne et externe du réseau. Les mécanismes qu'on a proposés permettent de pallier aux inconvénients déjà mentionnés et les simulations présentées mettent en évidence ces caractéristiques.

Chapitre 4

Protocoles de routage multicast et hybride (TRBIP et DTRBIP): Nos contributions

Sommaire

4.1 Introduction

Dans ce chapitre, nous étudions le problème de routage multicast et hybride dans VANET. L'objectif principal est de réduire les interférences de communication inter-véhiculaires prenant en compte le délai et la fiabilité de transmission des messages. Par conséquent, nous proposons un algorithme heuristique appelé Time-Limited Reliable Broadcast Incremental Power (TRBIP) pour construire l'arbre d'acheminement des messages. Nous proposons aussi, une version distribuée de l'algorithme TRBIP en utilisant une méthode hybride afin de surmonter les problèmes mentionnés dans l'ancienne version.

4.2 Nos protocoles: TRBIP et DTRBIP

4.2.1 TRBIP: Time-limited multicast algorithm using incremental power strategy

Dans ce travail, nous nous intéressons au problème de la minimisation des interférences de transmission des messages de sécurité dans VANET, ce qui peut être fait en minimisant la consommation d'énergie pour les communications inter-véhiculaires. Notre objectif est de concevoir

un arbre dans un délai limité pour diffuser des messages de sécurité de sorte que chaque véhicule peut recevoir les messages d'urgence et que l'énergie totale soit minimale. La limitation du délai de bout en bout afin d'éviter les accidents potentiels, tout en minimisant la puissance totale de transmission et en maximisant la fiabilité a pour but de réduire les interférences de communication entre véhicules. Puisque ce problème est NP-complet, nous proposons un algorithme heuristique appelé Time-Limited Reliable Broadcast Incremental Power (TRBIP). Les contraintes de groupe véhiculaire, tels que la mobilité des véhicules et la fragmentation fréquente du réseau sont également pris en compte en utilisant la stratégie de store-carry-and-forward et la reconstruction régulière de l'arbre de diffusion multicast.
TRBIP algorithme est divisé de deux versions:

1. RBIP: L'idée principale de RBIP est de construire un arbre multicast optimal pour délivrer des messages d'urgence afin de réduire l'interférence en minimisant la consommation d'énergie totale. La description formelle du processus de construction de l'arbre est présentée dans l'Algorithme 3. Le processus RBIP est dévisé en trois phases:

   - (1) Initialement, l'arbre ne contient que le véhicule source. Pour ajouter un nouveau noeud dans l'arbre, le véhicule source choisit le noeud qu'il peut atteindre avec une puissance de transmission minimale (i.e. le plus proche voisin à la source).
   - (2) Pour déterminer ensuite quel nouveau véhicule v_j sera ajouté à l'arbre avec une puissance supplémentaire minimale (Algorithm 3: line 9 $\sim$ 16, Function CNL) . Il y a deux possibilités: (i) soit le plus proche voisin v_i de v_j qui n'est pas encore dans l'arbre, ou (ii) le véhicule source peut augmenter sa puissance pour atteindre un autre véhicule.
   - (3) La procédure se poursuit jusqu'à ce que tous les véhicules soient inclus dans l'arbre.

   Pendant la construction de l'arbre (T), RBIP cherche le chemin le plus proche entre chaque paire de véhicules (Algorithm 3: line 17 $\sim$ line 20). S'il trouve un nouveau chemin avec moins d'énergie, il le change (Algorithm 3: line 22). Cela nous permet de réduire la consommation d'énergie, cela permet également de réduire le nombre de sauts (relais) pour la transmission des paquets et donc réduire le niveau de l'arbre.

2. Time-Limited RBIP (TRBIP): Afin d'améliorer les performances de RBIP, nous proposons une autre stratégie Time-Limited RBIP (TRBIP) pour limiter le nombre de sauts (Algorithm 4: line 3 $\sim$ line 10). Nous vérifions la hauteur de l'arbre construit par RBIP. Si elle n'est pas supérieure à une valeur H, l'arbre obtenu peut directement être utilisé pour la diffusion de messages de sécurité. Si ce n'est pas le cas, nous essayons de diminuer la hauteur de l'arbre (Algorithm 4: line 11 $\sim$ line 18) en augmentant la puissance de certains véhicules relais, si nous atteignons un nouveau chemin avec un minimum d'énergie et une

Algorithm 3: *Reliable_Broadcast_Incremental_Power*

```
S ← {Source};
TREE[Source] ← Source;
HOP[Source] ← 0;
Search ← False;
for (i ← 1; i <= NV; i++) do
    for (j ← 1; j <= NV; j++) do
        LCM[i][j] ← P[i][j];
        // NV: Number of Vehicles; LCM:link Cost Matrix; N:neighbor
while (|S| < NV) do
    (I, J) ← CNL(TREE, LCM);
    // CNL: Compute Nearest Link
    S ← S ∪ J;
    TREE[J] ← I;
    HOP[J] ← HOP[I] + 1;
    while (j ∉ S) do
        LCM[I][j] ← P[I][j] − P[I][J];
    for (u ∈ N(I)) do
        if (P[I][J] > P[I][u] and TREE[u] ≠ I and TREE[I] ≠ u) then
            search ← True;
            U ← u;
    if (Search = True) then
        CHP(I, U, TREE, HOP);
        // CHP: CHange Parent
```

```
Function CNL(TREE, LCM):
    // CNL: Compute Nearest Link
    lm ← infinity;
    // For all i on TREE and all j outside TREE
    for i ∈ TREE do
        for j ∉ TREE do
            if LCM[i][j] < lm then
                lm ← LCM[i][j];
                I ← i;
                J ← j;
    return (I,J);
```

hauteur minimale, nous changeons le chemin avec le nouveau (Algorithm 4: line 19 ∼ line 23). La même procédure sera répétée jusqu'à ce que la hauteur de l'arbre soit limitée par H.

Algorithm 4: *Hops_Limited_RBIP*

```
1  Search ← False;
2  (M_H^T, I) ← max_hops(HOP);
3  while M_H^T > hops_limited and Search = False do
4      i ← 2;
5      PR[1] ← I;
6      while I ≠ source do
7          PR[i] ← TREE[I];
8          I ← TREE[I];
9          i ← i + 1;
10     j ← i − 1;
11     while j > 2 and search = False do
12         m ← PR[j];
13         for k ← j − 2 To 1 do
14             if (PR[k] ∈ (N(m))) then
15                 Search ← True;
16                 I ← PR[k];
17             else
18                 j ← j − 1;
19     if (Search = True) then
20         P_m^T ← Max{P_m^T, P[m][I]};
21         CHP(m, I, TREE, HOP);
22         (M_H^T, I) ← max_hops(HOP);
23         Search ← False;
```

4.2.2 DTRBIP: La version distribuée de TRBIP

Nous développons une version distribuée de TRBIP (DTRBIP) en utilisant une méthode hybride (geo-multicast). Afin de l'adapter à un environnement urbain, nous dévisons les routes en segments (sous-multicast-arbres) pour gérer le problème de la maintenance de grands et dynamiques arbres dans un grand réseau. Nous appliquons notre méthode heuristique TRBIP dans chaque segment pour réduire la consommation d'énergie totale, les interférences de transmission et maximiser la fiabilité en minimisant le nombre de sauts. Les problèmes de la fragmentation du réseau sont également pris en compte en utilisant la stratégie de store-carry-and-forward dans et entre les segments.

Un exemple simple de segmentation de $DZ_i(t)$ est présenté dans la Figure 4.1. $DZ_i(t)$ est situé entre deux intersections $I_{n,m}$ et $I_{n,m+1}$. $DZ_i(t)$ est divisé en trois segments S_1, S_2 et S_3. La connectivité des véhicules en S_i dépend de la puissance d'émission. Chaque véhicule $v_i \in S_i$ peut adapter sa portée de transmission selon les exigences pour ne pas dépasser un niveau de puissance maximal P_i^M. Où $P_i^M = Max\{\mathbb{P}_{(v_i,v_j)} | v_j \in N^T(v_i)\}$, $N^T(v_i)$ sont les voisins de v_i dans l'arbre T, $\mathbb{P}_{(v_i,v_j)}$ est le niveau de puissance pour lequel le véhicule v_i transmet des messages

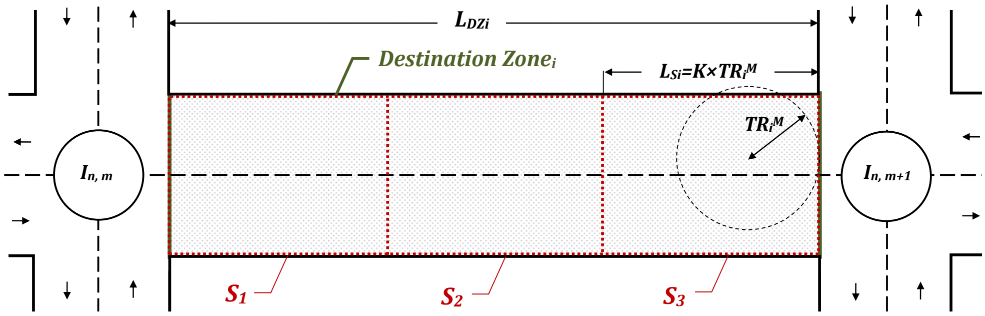


Figure 4.1: Segmentation de la zone de transmission $DZ_i(t)$

au véhicule v_j (si v_i est actuellement un noeud feuille, $P_i^M = 0$). Un véhicule $v_i \in S_i$ peut établir une connexion avec le véhicule $v_j \in S_i$, si v_j est couvert par la portée de transmission du véhicule v_i. Dans notre modèle, nous adoptons la formule de Friis pour la puissance de transmission qui est définie comme suit:

$$\frac{P_j}{P_i} = G_i G_j \left(\frac{\lambda}{4\pi \mathbb{D}_{(v_i,v_j)}} \right)^{\alpha} \tag{4.1}$$

Où P_i est la puissance d'émission du véhicule émetteur v_i, P_j est la puissance de réception par le véhicule v_j. G_i et G_j sont les gains linéaires d'antenne de l'émetteur et du récepteur respectivement. λ est la longueur d'onde utilisée par DSRC. Le paramètre α est typiquement compris entre 2 et 4, selon les caractéristiques du support de communication [82]. Dans VANET α est égale 2. $\mathbb{D}_{(v_i,v_j)}$ est la distance entre les véhicules v_i et v_j.

Lors de la construction d'un arbre DTRBIP dans chaque segment S_i, il est nécessaire de prendre en compte les interférences (Signal-to-Noise-and-Interference Ratio (SNIR)) pour les communications sans fil. L'exigence de rapport SINR doit être satisfaite pour chaque véhicule pour recevoir un paquet multicast. Ainsi, le niveau de puissance du signal reçu à chaque véhicule devrait être supérieur au niveau de sensibilité minimal P_{MinS}. Comme spécifié dans IEEE 802.11p, le niveau de sensibilité minimal est égal à -68 dBm pour le débit de 27 Mb/s, et la bande 5,9 GHz est utilisée pour les communications entre véhicules (V2V) [69]. Par conséquent, la puissance d'émission devrait comme suit:

$$P_i \geq \frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi \mathbb{D}_{(v_i,v_j)}}{\lambda} \right)^2 \tag{4.2}$$

Notre objectif est de construire des arbres multicast optimaux pour transmettre des messages tels que: (1) le délai de bout en bout de RSU_i à tous les véhicules $v_i \in DZ_l(t)$ peut être réduit en utilisant une méthode unicast en dehors de $DZ_l(t)$ et une stratégie multicast dans $DZ_l(t)$, (2) l'interférence dans chaque segment $S_k \in DZ_l(t)$ peut être réduite en minimisant la consommation d'énergie totale dans S_k. Soit $\delta_T^+(v_i)$ l'ensemble des liens sans fil sortants du véhicule v_i dans l'arbre. La fonction objective dans chaque segment S_k peut être exprimée par:

$$\min \left[\frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi}{\lambda}\right)^2 \cdot \sum_{v_i \in S_k} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2 \right] \tag{4.3}$$

L'interférence totale peut être réduite en minimisant la consommation d'énergie totale dans tous les $DZ_l(t)$. La fonction objectif dans $DZ(t)$ peut être exprimée par:

$$\min \left[\frac{P_{MinS}}{G_i G_j} \left(\frac{4\pi}{\lambda}\right)^2 \cdot \sum_{l=1}^{N_d} \sum_{S_k \in DZ_L(t)} \sum_{v_i \in S_k} \max_{e \in \delta_T^+(v_i)} \mathbb{D}_e^2 \right] \tag{4.4}$$

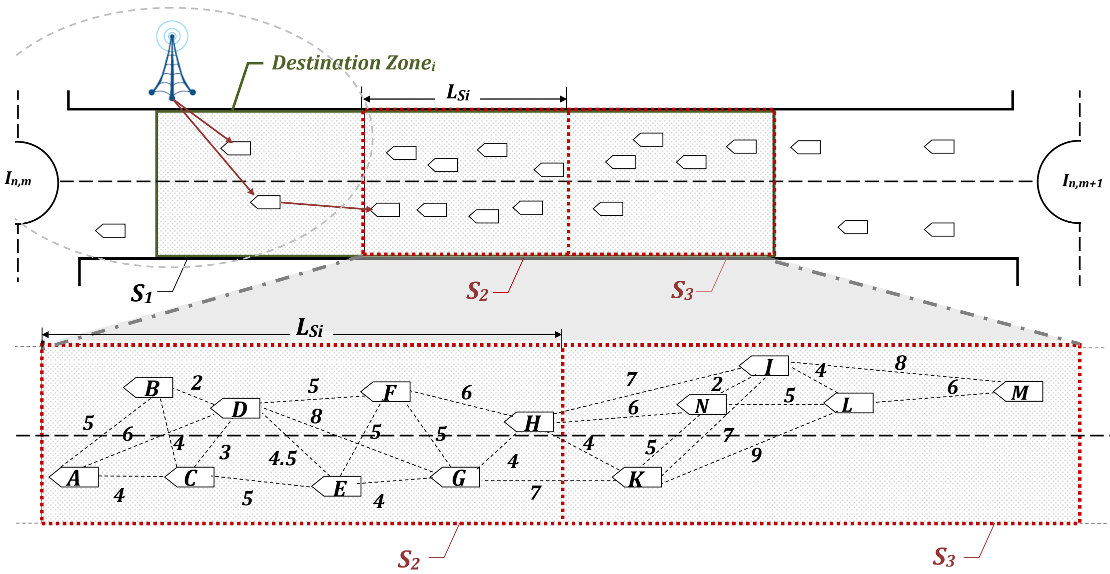
Où $DZ(t) = \cup_{l \in \{1,\ldots,N_d\}} DZ_l(t)$ et N_d est le nombre de zones $DZ_l(t)$.

4.2.3 Exemple de fonctionnement de la méthode DTRBIP

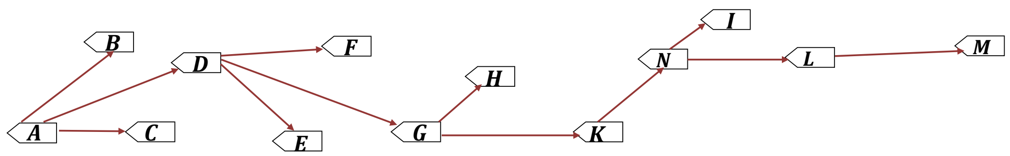
Pour illustrer la fonctionnalité de DTRBIP par rapport à TRBIP, nous considérons un exemple simple présenté dans la Figure 4.2a. Le paquet P_{RSU} est transmis directement à $DZ_i(t)$ car RSU couvre certaines parties de $DZ_i(t)$ ($S_1 \subset DZ_i(t)$ dans la portée de RSU). $DZ_i(t)$ contient 3 segments S_1, S_2 et S_3. Les véhicules dans S_1 sont informés par RSU (même procédure dans DTRBIP et TRBIP). Le voisin le plus proche de S_2 relaie le paquet au véhicule A, qui est le leader du segment 2 (SL_2). Le segment S_2 contient 8 véhicules $A \sim H$. Le voisin le plus proche du véhicule A est le véhicule C. Par conséquent, ce noeud est ajouté à l'arbre. Le voisin le plus proche de C est le véhicule D avec la puissance d'émission $P[C][D]$ =3. Le coût associé à l'ajout du véhicule B à l'arbre est $LCM[A][B] = P[A][B]$-$P[A][C] = 1$. Ainsi, le véhicule B ($A \to B$) est ajouté à l'arbre. La même procédure est répétée comme le montrent les Figures 4.2b et 4.2c: $A \to \{C,\ B\ et\ D\}$; $D \to \{E,\ F\ and\ G\}$; $G \to H$. Afin de disséminer le paquet P_{RSU_i} à S_3, la même procédure est répétée dans TRBIP comme le montre la Figure 4.2b: $G \to \{K\}$; $K \to \{N\}$; $N \to \{I\ and\ L\}$; $L \to M$. Mais, dans DTRBIP, le véhicule H est le leader de SL_3, dans ce cas, un nouveau sous arbre est crée. La procédure de construction se poursuit jusqu'à ce que tous les véhicules du segment SL_3 soient inclus dans l'arbre comme le montre la Figure 4.2c: $G \to \{K,\ N\ et\ I\}$; $I \to \{L\ et\ M\}$. Le tableau 4.1 illustre les performances de la stratégie de segmentation de l'algorithme DTRBIP par rapport à TRBIP, comme le montre les Figures 4.2b et 4.2c. Par conséquent, nous constatons que notre algorithme DTRBIP minimise un saut par rapport à TRBIP. En plus, le tableau montre également que DTRBIP réduit l'énergie d'émission totale.

Table 4.1: Performance de l'algorithme proposé DTRBIP

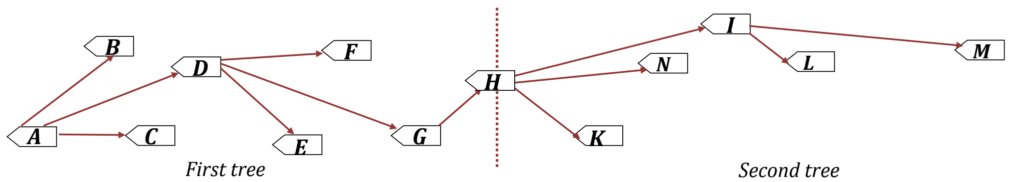
	TRBIP	**DTRBIP**
Hop-count	7	6
Total emission energy (dBm)	165,078	164,581



(a) Packet Delivering from an RSU to $DZ_i(t)$



(b) Packet Dissemination in $DZ_i(t)$ Using TRBIP



(c) Packet Dissemination on Sub-Multicast-Trees in $DZ_i(t)$ using DTRBIP

Figure 4.2: Dissémination de paquets dans $DZ(t)$

4.3 Résultats et interprétations des simulations

Dans cette section, nous étudions les performances de notre protocole en réalisant des simulations. Pour ce faire, nous utilisons le simulateur NS-2 [81] et les modèles de mobilité Freeway et Manhattan. Les performances de notre approche sont comparées avec les performances des protocoles similaires: RGRP-SA [14], RBIP et TRBIP [13]. Le tableau 4.2 récapitule l'ensemble des paramètres de simulation utilisés.

Les résultats de la simulation (figures 4.3 et 4.4) ont démontré que l'algorithme DTRBIP est capable de réduire l'énergie d'émission totale (au moins de 150 dBm) et de transmettre des données plus fiables (envoi de 5% de paquets en plus) avec un délai plus court (optimisation du délai de bout en bout de 52%) par rapport aux algorithmes RGRP-SA, RBIP et TRBIP.

Table 4.2: Paramètres de simulation

Paramètre	Valeur
Mobility Model for Highway	Freeway
Mobility Model for Urban environment	Manhattan
Physical and MAC layer	802.11p
Number of vehicles	50-500
Simulated area (highway) (km)	10
Simulated area (Urban) (km x km)	5 x 5
Velocity (highway) (km/h)	80-140
Velocity (Urban) (km/h)	00-60
Number of $DZ_i(t)$	3
Length of $DZ_i(t)$ (m)	2400
Hop-Count constraint in $DZ_i(t)$	7-11
Number of lanes (Urban)	6
Number of lanes (highway)	4
Length of S_i (m)	800
Maximum Transmission range TR_v^M (m)	300
G_i, G_j	1
α	2
Packet size (bytes)	512
Simulation time (Urban) (seconds)	300
Simulation time (highway)(seconds)	500

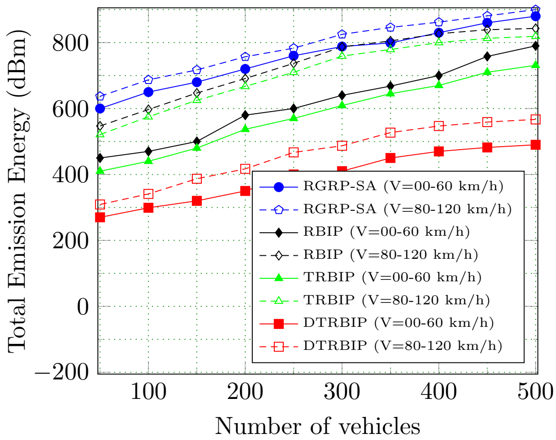


Figure 4.3: Énergie d'émission totale vs. densité du réseau

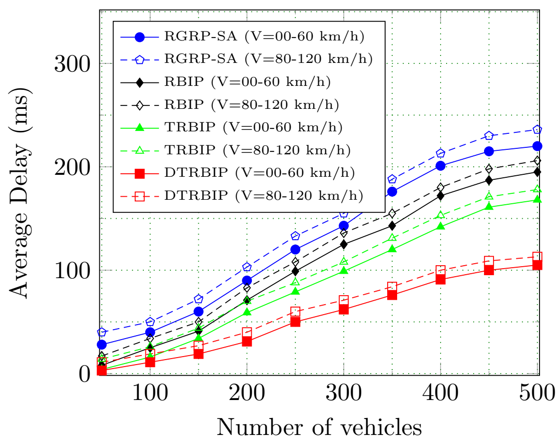


Figure 4.4: Délai moyen de bout en bout vs. densité du réseau

4.4 Conclusion

Dans ce chapitre, nous avons proposé une version distribuée de l'algorithme TRBIP en utilisant une méthode hybride (geo-multicast). Le protocole dynamique proposé est basé sur une technique de segmentation afin de surmonter les problèmes mentionnés dans l'ancienne version: (i) DTRBIP est adapté au environnements autoroutiers et urbains et (ii) il réduit les interférences de communication en minimisant la consommation d'énergie totale pour les communications inter-véhiculaires.

Chapitre 5

Conclusion générale

Sommaire

Après avoir présenté et analysé les résultats de nos recherches, il nous revient maintenant de conclure la thèse. Dans cette conclusion, nous présentons une synthèse des résultats, puis nous précisons les différentes limitations de nos travaux, ce qui nous amènera à discuter des travaux futurs.

5.1 Synthèse des résultats

Dans un premier temps, nous avons étudié les communications de données dans un groupe de véhicules. Nous avons effectué un état de l'art de ce type de communications. Pour cela, nous avons détaillé les caractéristiques et les contraintes spécifiques au groupe dans VANET, puis nous avons détaillé les différentes applications qu'il est possible de mettre en place à travers ces réseaux. Enfin, nous avons étudié les techniques qu'ils utilisent a travers une étude comparative.

Ensuite, nous avons analysé le problème de routage geocast dans les réseaux véhiculaires. Pour cela, nous avons identifié les principaux protocoles utilisés par la littérature afin d'en dégager leurs différents avantages et inconvenients. Grâce à l'étude réalisée précédemment, nous avons pu remarquer que les protocoles de routage geocast proposés jusqu'à présent offrent différents avantages qui sont en réalité préférables pour différents types d'applications de sécurité routière. Mais cela reste insuffisant par rapport aux applications de confort, parce que certaines techniques sont peu adaptées à la mobilité et la plupart de ces protocoles ne peuvent pas remédier complètement au problème de la fragmentation fréquente du réseau. C'est pourquoi nous avons proposé deux nouveaux protocoles de routage geocast, qui prennent en compte la majorité des limitations dans les solutions proposées, et qui ne dégradent pas les performances des protocoles de routage. En plus, la proposition des nouveaux protocoles a été motivée non seulement par une nécessité de robustesse, mais aussi pour économiser le nombre de messages échangés, minimiser le taux de pertes des paquets, augmenter le taux de délivrance des paquets et throughput afin de garantir une meilleure utilisation de la bande passante.

Enfin, d'après l'étude qu'on a effectuée sur les protocoles de routage multicast et hybride existants, on constate que la consommation d'énergie et les interférences sont partiellement considérées dans les protocoles multicast et ils ne sont pas pris en compte dans les protocoles hybrides. En plus, la protection de notre planète contre les émissions de gaz carbonique introduit des contraintes supplémentaires pour les concepteurs de protocoles, ce qui nous a motivé à proposer deux nouvelles approches de routage multicast et hybride (TRBIP et DTRBIP). Nos solutions permettent de fournir une communication avec un minimum délai, une fiabilité maximale et une évolutivité, en utilisant une consommation d'énergie optimale.

5.2 Limitations

Nous avons identifié deux principales limitations de nos travaux. D'abord, notre solution geocast RGRP-CA est capable d'assurer une bonne connectivité entre les véhicules le long de l'application. Mais, dans un grand réseau, l'agrandissement illimité de la zone de transmission (i.e. la zone de transmission peut être volumineuse sans qu'il ne soit nécessaire) peut dégrader les performances de ce protocole. De plus, Les résultats de notre solution de routage hybride DTRBIP ont montré que la segmentation statique permet d'atteindre une très bonne évolutivité. Mais, ne permettent pas d'adapter les tailles des zones de transmission et des segments aux types d'application.

5.3 Travaux futurs

Ces modestes travaux sont loin d'être parfaits, mais concernant le premier travail, il peut être considéré comme une petite ouverture vers l'étude comparative des protocoles de routage d'un groupe véhiculaire. Par conséquent, implementer d'autres protocoles de routage geocast, multicast et hybride permettrait d'avoir des résultats comparatifs plus réalistes.

Par ailleurs, comme extension future à notre protocole RGRP-CA, nous proposons d'utiliser d'autres nouvelles techniques afin de limiter l'agrandissement de la zone de transmission. En outre, Nous prévoyons d'étendre le protocole DTRBIP prenant en compte d'autres paramètres et de nouvelles méthodes heuristiques afin d'améliorer la fiabilité et le delai de transmission. Nous prévoyons aussi d'étudier le cas des zones de transmission et des segments ajustés dynamiquement en fonction de l'application.

De plus, l'utilisation de données plus réelles à travers un nouveau modèle de mobilité permettrait l'obtention de résultats plus pertinents. De même, le choix d'un nouveau simulateur, dans la mesure où NS-2 demande un temps de développement important dans le cas d'ajout de nouveaux protocoles de routage dans un groupe de véhicules.

Finalement, une autre perspective qui pourrait prolonger les travaux de cette thèse serait l'intégration d'autres types de réseaux avec les réseaux véhiculaires. La communication d'un véhicule ne devrait passe limiter aux autres véhicules qui se déplacent. Ainsi, il serait intéressant de permettre même à des drones (Unmanned Aerial Vehicles (UAVs)) de pouvoir communiquer et informer les véhicules automatiquement avec les informations collectées. Cela permet d'étendre les réseaux véhiculaires et de minimiser les fragmentations frequentes qui peuvent survenir.

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Cooperative Vehicular Ad-hoc NETwork (VANET) has yielded remarkable research results to enable the Intelligent Transportation System (ITS) for a safe, reliable, convenient, and comfortable driving experience. However, the high vehicular mobility and frequent network fragmentation hinder the reliable and successful data communication in cooperative vehicular networks. In this dissertation, we are interested to data communication strategies in cooperative vehicular networks, their common aim is to deliver data to vehicles within a specific group. As the transmission bandwidth is restricted in wireless environments of VANET same as all mobile wireless networks, developing group communications is a very challenging problem due to the aforementioned challenges (i.e., high mobility of vehicles and frequent network fragmentation) together with the transmission range limitation of the Dedicated Short Range Communication (DSRC) devices. Thus, a multi-hop relaying system based on cooperation between vehicles is adopted for the communication of group messages. The multi-hop relaying strategy can extend the transmission range of DSRC devices. However, it also introduces a lot of challenges such as, power consumption and Quality of Service (QoS) requirements (delay, reliability, and scalability).

To address the aforementioned issues, we pay specific attention to geocasting and multicasting routing techniques which are the most adapted strategies to multi-hop group communications. In this dissertation, after elaborating an extensive study of group data communication protocols in connected vehicles, we propose two new robust geocast routing protocols: the first one, called Robust Geocast Routing Protocol for Safety Applications (RGRP-SA), is designed for delivering delay-critical short safety packets while taking into account the high mobility of vehicles and the frequent internal network fragmentation, while the second, namely, Robust Geocast Routing Protocol for Comfort Applications (RGRP-CA), is designed to maintain good network connectivity among vehicles along with comfort applications and solve the problem of frequent external network fragmentation.

Moreover, in order to reduce transmission interferences for multicast messages in VANET, we propose two new routing protocols. Hence, we develop a heuristic algorithm called Time-Limited Reliable Broadcast Incremental Power (TRBIP) to construct a safety message delivery tree. By reducing the total transmission energy and the number of hops, TRBIP is able to reduce the transmission interference and thus-forth it maximizes the reliability. In the second contribution, we propose a distributed hybrid version of TRBIP called DTRBIP. Our proposal is based on a road segmentation technique through hybrid scheme, DTRBIP is extended to handle both delay-sensitive and delay-tolerant applications respectively in urban and highway environments.

The results of the simulation conducted using NS-2 simulator demonstrate the effectiveness of our protocols proposed in this dissertation in terms of solving the internal and external network fragmentation problems, increasing the packet delivery ratio, reducing the total emission energy, the average delay, and the transmission overhead. The simulation validation confirms also the performance advantage of our solutions compared to the up to date protocols in the literature that tackle the same problems.

Keywords: VANET, group communications, geocast, multicast, hybrid, internal and external network fragmentation problems, RGRP-SA, RGRP-CA, TRBIP, DTRBIP, road segmentation, total transmission energy, QoS, safety and comfort applications.

ABSTRACT