Université Abou Bekr Belkaid
Tlemcen Algérie
جامعة أبي بكر بلقايد
تلمسان الجزائر

الجمهورية الجزائرية الديمقراطية الشعبية

DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA

وزارة التعليم العالي و البحث العلمي

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY OF TLEMCEN

COLLEGE OF SCIENCES

DEPARTEMENT OF COMPUTER SCIENCES

A Thesis

Presented for obtaining the degree of:

DOCTORATE in Science

In: Computer Science

Specialty: Computer Systems Engineering

By:

Lazhar KHAMER

Theme

Reliable data dissemination in Vehicular Ad-hoc Networks

Thesis will be publicly defended in front of a jury composed of:

Mr Azzedine CHIKH	Full Professor	University of Tlemcen	President
Mme Nabila LABRAOUI	Associate Professor	University of Tlemcen	Supervisor
Mr Mourad GUEROUI	Associate Professor	University of Versailles	Co-supervisor
Mr Samir KAMECHE	Full Professor	University of Tlemcen	Examiner
Mr Kaddour MEJDI	Full Professor	University of Oran 1	Examiner
Mr Omar Rafik MERAD BOUDIA	Associate Professor	University of Oran 1	Examiner

Academic Year 2021/2022

Dedication

I dedicate this dissertation to:

- My parents who gave me moral lessons on discipline and helped me to achieve all my successes in this life.
- To my dear wife who always encouraged me and believed in my abilities to earn a doctorate.
- To my dear children. May God give you health, happiness, and success.
- To you my sisters and brothers who have always supported and encouraged me during my studies.

KHAMER LAZHAR

Acknowledgements

Firstly, all praise and thanks to God for the inspiration and patience he has given me to complete this work. Praise be to God for every blessing he bestowed on me.

I want to express my gratitude to my father, mother, wife, sisters, and brothers for their unconditional love and support. I do not have the words to tell you how truly fortunate i feel to have you in my life. Thank you for supporting me.

I would like to express my thanks and my deep gratitude to my supervisor Mme Nabila LABRAOUI for accepting directing my thesis work. I sincerely thank him for his guidance, support, invaluable help and trust without which this work would not have been what it is.

My thanks also go to Mr Mourad GUEROUI for having co-supervised this work, for his valuable advice and trust.

I warmly thank all the members of the jury for their interest in my work. I thank them for having honored me by accepting the workload involved in the critical reading of this manuscript.

KHAMER LAZHAR

Abstract

In recent years, the decentralized wireless Vehicular Ad hoc Networks (VANETs) have emerged as a key technology for Intelligent Transportation Systems (ITS). Efficient and reliable multi-hop broadcast protocols are essential to support various services in VANETs such as road safety, traffic efficiency, entertainment, and advertising. The multi-hop broadcasting protocol intends to deliver data to a set of vehicles inside a region of interest (RoI). Data broadcasting requires different levels of quality of service, which can be specified based on the type of data included in the message. For instance, accident notification involves low latency and high packets delivery ratio, whereas congested road notification is tolerant to both end-to-end delay (around a couple of seconds) and packets delivery ratio without exposing road users to a dangerous situation. Besides, the delay, jitter, and packet loss ratio associated with data video broadcasting should not exceed strict thresholds for an acceptable quality of experience. Our main aim in this thesis is to design reliable multi-hop broadcast protocols for delay-tolerant applications and video streaming in urban VANETs.

Keywords Urban vehicular ad hoc networks, V2V communication type, Video streaming, Intelligent Transportation System, Multi-hop broadcasting protocol.

ملخص

خلال السنوات الأخيرة، برزت الشبكات اللاسلكية و اللامركزية المخصصة للسيارات (VANETs)كتقنية رئيسية لأنظمة النقل الذكية(ITS). تعتبر بروتوكولات البث متعددة القفزات الفعالة والموثوقة ضرورية لدعم الخدمات المختلفة في VANETs مثل السلامة على الطرق وكفاءة حركة المرور والترفيه والإعلان. الهدف من بروتوكولات البث متعددة القفزات هو تسليم البيانات إلى مجموعة من المركبات داخل منطقة الاهتمام (RoI). يتطلب نشر البيانات مستويات مختلفة من جودة الخدمة، و التي يمكن تحديدها بناء على نوع البيانات التي تنقلها الرسالة. على سبيل المثال، يتطلب الإخطار بالحوادث زمن ارسال منخفض ونسبة تسليم عالية، في حين أن إخطار الطريق المزدحم يبدي أكثر مرونة تجاه كل من زمن الارسال (حوالي ثانيتين) ونسبة تغطية الشبكة دون تعريض مستخدمي الطريق للخطر. أما فيما يخص بث محتويات الفيديو، فيجب ألا يتجاوز زمن الارسال، التقطع في تدفق الفيديو و نسبة فقدان الحزم العتبة المسموح بها للحصول على جودة مقبولة. هدفنا الرئيسي في أطروحة الدكتوراه هذه هو تصميم بروتوكولات بث متعددة القفزات ذات موثوقية عالية و الموجهة بصفة خاصة للتطبيقات المتساهلة مع زمن الارسال و تطبيقات تدفق الفيديو في شبكة السيارات الحظرية.

الكلمات المفتاحية الشبكات المخصصة للمركبات الحضرية، نوع الاتصال V2V، دفق الفيديو، نظام النقل الذكي ، بروتوكول البث متعدد القفزات.

Résumé

Ces dernières années, les réseaux véhiculaires ad-hoc (VANETs) sont devenus une technologie clé pour les systèmes de transport intelligents (STI). Des protocoles de diffusion multi-sauts efficaces et fiables sont essentiels pour prendre en charge divers services dans les VANETs tels que la sécurité routière, l'efficacité du trafic, les divertissements et la publicité. Les protocoles de diffusion multi-sauts visent à fournir des données à un ensemble de véhicules à l'intérieur d'une région d'intérêt (RoI). Le niveau de la qualité de service nécessaire pour la diffusion de données est établi en fonction du type de données incluses dans le message. Par exemple, la notification d'accident exige une faible latence et un taux de livraison de paquets élevé, tandis que la notification d'une route encombrée est tolérante au retard de bout en bout (environ quelques secondes) et au taux de livraison de paquets sans exposer les usagers de la route à une situation dangereuse. De plus, la latence, la gigue et le taux de perte de paquets associés au streaming vidéo ne doivent pas dépasser des seuils stricts pour obtenir une qualité d'expérience acceptable. L'objectif principal de cette thèse de doctorat est de concevoir des protocoles de diffusion multi-sauts fiables pour les applications tolérantes aux délais et le streaming vidéo dans les réseaux véhiculaires urbains.

Mots clés Réseaux ad-hoc véhiculaires urbains, Type de communication V2V, Streaming vidéo, Système de transport intelligent, Protocole de diffusion multi-sauts.

List of publications

The list of publications in the purposes of this thesis is given in the following.

Published Journal Papers

1. Khamer, L., Labraoui, N., Gueroui, A. M., Zaidi, S., & Ari, A. A. A. (2021). «Road network layout based multi-hop broadcast protocols for Urban Vehicular Ad-hoc Networks. Wireless Networks, 27(2), 1369-1388.
2. L. Khamer, N. Labraoui, A. M. Gueroui, and A. A. A. Ari, “Enhancing video dissemination over urban VANETs using line of sight and QoE awareness mechanisms,” *Ann. Telecommun.*, pp. 1–17, 2021.

Table of contents

Dedication i

Acknowledgements ii

Abstract iii

ملخص iv

Résumé v

List of publications vi

Table of contents vii

List of Figures xi

List of tables xiii

Chapter 1 Introduction 1

1.1 Background, motivation, and aims 1

1.1.1 Multi-hop broadcasting in urban VANETs 4

1.1.2 Video streaming in urban VANETs 6

1.2 Contributions 7

1.3 Thesis Organization 9

PART ONE: LITERATURE REVIEW 11

Chapter 2 Data dissemination in VANETs: literature review 12

2.1 Common VANET characteristics 12

2.1.1 Rapid change in network topology 12

2.1.2 Accessibility to positioning system 13

2.1.3 Mobility pattern 13

2.1.4 Several QoS prerequisites 13
2.2 Architecture of vehicular networks 14
2.2.1 Basic structure of On-Board Unit (OBU) 14
2.2.2 Road side Unit (RSU) 15
2.3 V2X communication in VANET 16
2.3.1 V2V communication type 16
2.3.2 V2I communication type 16
2.3.3 V2N communication type 16
2.3.4 V2P communication type 16
2.4 VANET applications 17
2.4.1 Active road safety applications 17
2.4.2 Traffic efficiency applications 18
2.4.3 Local services, internet and infotainment applications 18
2.5 Communication standards in vehicular networks 19
2.5.1 DSRC/WAVE standard 19
2.5.2 Cooperative intelligent transportation system standard (C-ITS) 22
2.6 Related works on broadcasting protocols in VANETs 26
2.6.1 Common problems in data dissemination over VANETs 26
2.6.2 One-hop broadcasting protocols 28
2.6.3 Multi-hop broadcasting protocols 30
2.6.4 Adaptive broadcasting protocols 40
2.7 Conclusion 41
Chapter 3 A state of art of video streaming over VANETs 42
3.1 Video streaming definition 42
3.2 Formal expression of video streaming 43
3.3 Video transmission characteristics 43
3.4 Routing solutions for Video broadcast in VANETs 45

3.5 Error control and recovery ... 47
3.5.1 Data level solutions ... 48
3.5.2 Control level solutions ... 54
3.5.3 Error recovery solutions for video broadcast in VANETs ... 55
3.6 Conclusion ... 57
PART TWO: SCIENTIFIC CONTRIBUTIONS ... 58
Chapter 4 Road network layout based multi-hop broadcast protocols for Urban Vehicular Ad-hoc Networks ... 59
4.1 Analysis of the stochastic behaviour of counter and distance heuristics ... 59
4.1.1 Analysis of counter-based protocol ... 60
4.1.2 Analysis of Distance-based protocol ... 62
4.2 Proposed methods ... 64
4.2.1 Network model, system requirements and general approach ... 65
4.2.2 Enhanced Counter-based broadcast protocol in Urban VANET (ECUV) ... 69
4.2.3 Enhanced Distance-based broadcast protocol in Urban VANET (EDUV) ... 71
4.3 Analytical model ... 72
4.3.1 Model requirements and assumptions ... 72
4.3.2 Model for EDUV protocol ... 73
4.3.3 Model for ECUV protocol ... 76
4.4 Performance evaluation ... 78
4.4.1 Metrics ... 78
4.4.2 Performance evaluation using analytical model ... 79
4.4.3 Performance analysis using network simulation ... 85
4.5 Conclusion ... 89
Chapter 5 Enhancing video dissemination over urban VANETs using line of sight and QoE awareness mechanisms ... 91
5.1 Requirements and assumptions ... 91

5.2 Receiver-based line-of-sight-aware broadcasting protocol 93
5.2.1 Scenario 1: Intra-road scenario 95
5.2.2 Scenario 2: Inter-road scenario 97
5.3 Quality-of-experience-aware store-carry-and-forward method 99
5.3.1 Distance distortion estimation 100
5.3.2 Beaconing message structure and exchange 101
5.3.3 QoESCF overview 103
5.4 Performance evaluation 105
5.4.1 Simulation parameters and evaluation metrics 105
5.4.2 Simulation results and discussion 108
5.5 Conclusion 117
Chapter 6 Conclusion and Perspectives 119
6.1 Conclusion 120
6.2 Perspectives 122
Bibliography 124

List of Figures

Figure 1-1 Example of VANETs in city environment 2
Figure 2-1 On-Board Unit structure 15
Figure 2-2 Communication types in VANETs 17
Figure 2-3 DSRC/WAVE communications Stack.. 21
Figure 2-4 ITS communication layers 23
Figure 2-5 GeoUnicast routing scheme 25
Figure 2-6 GeoBroadcast routing scheme 25
Figure 2-7 TSB routing scheme 26
Figure 2-8 Example of network partition problem 28
Figure 2-9 Extension works of Counter-Based and Distance- Based broadcast Protocols. 36
Figure 3-1 Bursty feature of an encoded video with Delta mechanism. 44
Figure 3-2 Typical sizes and bitrate of different types of frame. 44
Figure 3-3 Taxonomy of error recovery for video streaming... 47
Figure 3-4 Two layers coding structure.. 49
Figure 3-5 Multiple Descriptions Coding.. 49
Figure 3-6 Erasure Coding 52
Figure 3-7 Example of the impact of bursty losses in video stream 53
Figure 3-8 Interleaving method example with 2-distance 54
Figure 4-1 Flowchart of Counter-Based broadcast protocol. 61
Figure 4-2 Counter-Based protocol scenario.. 61
Figure 4-3 Flowchart of Distance-Based broadcast protocol. 63
Figure 4-4 Distance-Based protocol scenario.. 63
Figure 4-5 Road network layout example. 64
Figure 4-6 Road-based broadcast concealment mechanism.. 67
Figure 4-7 Manhattan-like topology.. 72
Figure 4-8 ECUV rebroadcast probability prediction when C_{thr} =1.................................. 81

Figure 4-9 ECUV rebroadcast probability prediction when C_{thr} =2. 81
Figure 4-10 EDUV rebroadcast probability prediction when D_{thr} =0.25R. 82
Figure 4-11 EDUV rebroadcast probability prediction when D_{thr} =0.5R. 82
Figure 4-12 EDUV rebroadcast probability prediction when D_{thr} =0.75R. 83
Figure 4-13 Erlangen road network. 85
Figure 4-14 Coverage capacity simulation results 87
Figure 4-15 Number of transmissions simulation results 87
Figure 4-16 End-to-End delay simulation results 88
Figure 5-1 ReLoS-flowchart when a vehicle receives a new packet. 94
Figure 5-2 ReLoS flowchart when a vehicle receives a duplicate packet. 95
Figure 5-3 Intra-Road scenario. 97
Figure 5-4 Inter-Road scenario. 98
Figure 5-5 Relationship among frames in MPEG GoPs. 98
Figure 5-6 Overview of distance distortion estimation process. 101
Figure 5-7 Beaconing message structure. 102
Figure 5-8 One-hop beaconing messages broadcast 102
Figure 5-9 Bologna city road map layout 107
Figure 5-10 Frame delivery percentage 110
Figure 5-11 Average end-to-end delay 113
Figure 5-12 Average peak signal-to-noise ratio 115
Figure 5-13 Average mean opinion score 117

List of tables

Table 2-1 Basic set of safety use cases that require high position accuracy 18
Table 2-2 Basic set of VANET applications and their requirements 19
Table 2-4 IEEE 1609 family for WAVE standard 21
Table 2-5 Summary of the relevant sender-based broadcast protocols in VANETs........... 34
Table 2-6 Summary of the relevant receiver-based multi-hop broadcast protocols in VANETs 40
Table 4-1 Notations used in the different algorithms. 65
Table 4-2 Analytical models parameters. 80
Table 4-3 Simulation experiments parameters. 86
Table 5-1 Notations used in the different Algorithms. 92
Table 5-2 ITU-R MOS scale. 106
Table 5-3 Physical and MAC layer parameters. 106
Table 5-4 Mobility simulation parameters. 108

Chapter 1 Introduction

1.1 Background, motivation, and aims

In recent years, Intelligent Transportation Systems (ITS) have contributed efficiently to the improvement of the urban and inter-urban traffic management, traffic security, driving safety, performance of transportation systems and commercial vehicle operations [1][2][3]. With the rapid evolution of the Micro-Electromechanical Systems (MEMS) [4], ITS have introduced smartness, connectivity, coordination, efficiency and automated response for transportation policy optimization[5][6].

The idea of introducing wireless communication in vehicles has attracted the scientific community since the 1980s [7]. In the last three decades, we have witnessed considerable advancement in research in this field. The fast evolution of different vehicle-oriented sensors, together with the wide adoption of 802.11series of wireless communication technologies, the embrace of the transportation authorities the wireless communication technology to integrate vehicles in ITS have led to facilitate the development of this field and the emergence of the Vehicular Ad-hoc NeTworks (VANETs) [8][9].

A VANET consists of interconnected vehicles that embark sensing technologies. They at least allow exchanging traffic, weather and emergency information. Therefore, they constitute an essential technology for the development of ITS. A VANET is a subclass of Mobile Ad hoc NETwork (MANET) that offers a communication infrastructure to share information between vehicles on the road and between vehicles and ITS components [10]. In order to make this infrastructure possible, vehicles and roads have to be equipped with a set of components recognized as On-Board Units (OBUs) and Road Side Units (RSUs), respectively [8][11][12]. Fundamentally, a VANET provides two types of wireless communication: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). V2V denotes the sort of wireless communication in which vehicles communicate with one another by means of wireless devices, whereas V2I allows the exchange of data between vehicles and the fixed ITS components such as base stations, hotspots, traffic lights and Electronic toll collection systems [13]. Figure 1-1 outlines a typical example of urban VANET.

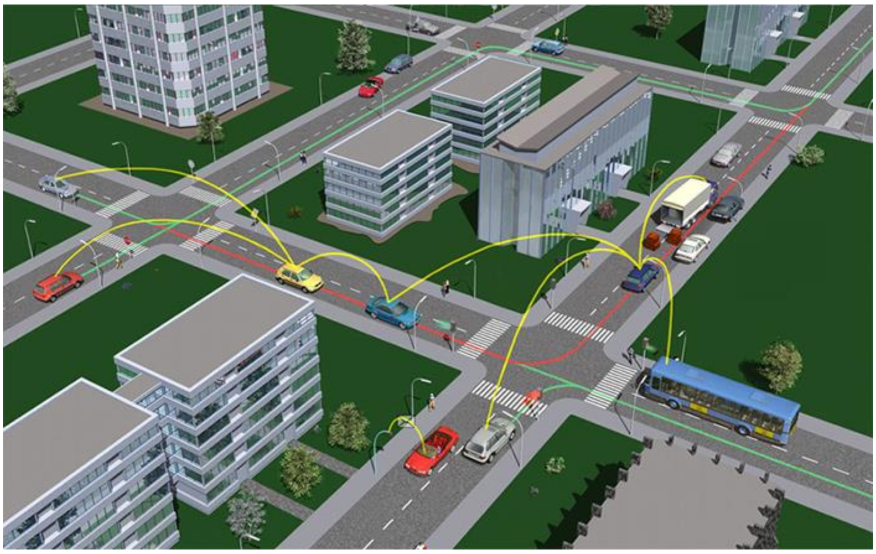


Figure 1-1 Example of VANETs in city environment

We have embraced this distinct type of MANETs as the scope of our thesis. It supports different and varied types of services and applications. ETSI organization classified the basic set of VANET applications into active road safety, traffic efficiency, local services, and infotainment applications. Based on this taxonomy and the intrinsic network features of VANETs, the cooperative ITS standard distinguish at least three disseminations modes that can arise in this type of network:

One-hop broadcasting mode: It aims to share status data between neighboring vehicles (vehicles in the same transmission range) through the periodic broadcast of geographical location, velocity, and the heading of each vehicle.

Multi-hop unicast mode: In this mode, the source node delivers the packet to one destination node over a path composed of V2V/V2I multiple hops.

Multi-hop broadcast mode: The Multi-hop broadcasting in VANET consists of the dissemination of data from a source vehicle to all vehicles inside a geographical region, called the region of interest (RoI), over a V2V/V2I multi-hop communication link. Notice that the source node has to be within the region of interest.

The purpose of our work is to design multi-hop broadcasting schemes. They require being efficient, reliable, and scalable. Several VANET applications need data broadcasting, such as the transmission of traffic-related information, accident notification, cooperative collision avoidance, video streaming, and cooperative autonomous driving application [11][14][15]. Furthermore, broadcasting is the main operation for route discovery and source paging in unicast routing protocols [16][17][18][19].

To create a multi-hop broadcasting protocol, we have to distinguish between three types of data content due to their differences in terms of resilience to the loss of data and latency: safety-related text messages, non-safety-related text messages, and video stream. Safety-related text messages should usually be broadcasted with low latency and high reachability, whereas the transmission of non-safety-related text messages is more tolerant to the latency. The transmission of video stream differs significantly from the one of text messages due to the large amount of data in the video stream and its more stringent requirements in terms of packet loss ratio (PLR) and the transmission delay. As recommended by CISCO, the PLR and transmission delay should not exceed 5% and 5s, respectively[20].

Viriyasitavat et al. sub-classified VANETs into two environments: urban and highway [21][22]. The dissemination of information in the urban environment is more prone to the wireless interference problem due to the high traffic density in city areas, especially at rush hours. Furthermore, the intermittent connection induced by obstacles, such as tower buildings, strengthens the network fragmentation issue.

In our thesis, we broadly focus on designing various solutions to improve the broadcasting of both non-safety-related text messages and video content in urban VANETs.

1.1.1 Multi-hop broadcasting in urban VANETs

The flooding schema is the most naive solution to broadcast data in both MANET and VANET. In this one, each node in the network blindly rebroadcasts the received message. Unfortunately, the unnecessary rebroadcast of messages cause excessive network resource consumption, this problem is known as the broadcast storm problem [23]. Moreover, in the case of dense ad hoc networks, the blindly message rebroadcasting produces a large number of collisions and interference in the network. This latter deteriorates the effectiveness and reliability of the broadcasting process. Therefore, reducing the number of relay nodes is the most often accepted solution to avoid the high number of collisions and interference. However, relay-nodes have to be selected by considering the trade-off between the coverage capability and the broadcast storm problem mitigation. The reliable broadcast heuristics aim to select a minimum number of relay-nodes to avoid the broadcast storm problem and maintain a maximum coverage capability.

Most heuristics are designed specifically for MANET in which the nodes are deployed in a free space environment. Thus, there are no exact constraints that affect the movement of the nodes. In such an environment, relay nodes selection methods are commonly based on traditional forwarding strategies like geographic-position based methods, statistical-based strategies, network traffic-aware methods, local neighborhood topology based strategies, etc [23]. However, in urban VANET, nodes movement and nodes spatial distribution are likely related to the road network topology. For this reason, there is a great need to use the road network topology to enhance traditional strategies.

Broadcasting techniques can be broadly classified into sender-based and receiver-based methods [24][25][26][27][28]. The main prerequisite for sender-based protocols is that a sender should obtain the topological information of one-hop neighbors, or more specifically node identities and kinetics information. It can be achieved through a simple exchange of beacon messages between the one-hop neighbors. The topological information enables the protocol to select the best set of forwarders. However, for enhanced efficiency, the neighborhood information should be updated at a high frequency to overcome the rapid change in the topology. Unfortunately, this may generate high beacon transmission overhead and lead to an unfavorable transmission condition and even collisions.

To overcome this issue, the receiver-based protocols are proposed. Each receiver node uses typically a local state variable to establish a waiting time. For example, the relative distance between the receiver and the precedent forwarder can be used to make a decision, whether to rebroadcast or not, based on the current state of the receiver and a threshold value. This can be the number of duplicate messages received within the waiting time that should not exceed a certain threshold. Another advantage of the receiver-based methods is that the anonymity mechanisms of the nodes can be easily achieved because they do not require exchanging vehicles' identifiers in the selection process of the relay-nodes [29]. Furthermore, a comparative study between broadcasting protocols showed that these methods at least outperform the sender-based ones in terms of latency, collisions and message overhead [30]. The drawback of the received-based protocols is that they are characterized by stochastic behavior and generally cannot cover the full network.

In the literature of receiver-based broadcasting protocols, many heuristics have been proposed to overcome collisions and interference problems while maintaining maximum coverage and connectivity. Among the most reliable methods, we can mention the ones proposed by Tseng et al. [23].

Their first approach is the well-known counter-based protocol. Tseng et al demonstrate a reverse relationship between the number of duplicate messages broadcasted by the immediate neighbors of a node and its capability to cover a new area when it rebroadcasts the received message. Specifically, a node in the counter-based protocol broadcasts a message if it receives during a backoff time a number of duplicate messages lower than a threshold value. This threshold value is used mainly to control the unsuitable redundant transmissions.

The second approach is the distance-based protocol. Its mechanism uses the minimum distance heuristic to select relay-nodes. Hence, this heuristic makes use of a threshold distance from the sender to each one-hop receiver to distinguish between relay nodes and none relay nodes. The heuristic is based on the fact that if two nodes are very close, their rebroadcasting will likely cover the same area of the network. Following this logic, the node acts as a relay if only this distance is large enough.

The advantages of these two protocols rely mainly on their receiver-based nature. Furthermore, counter-based and distance-based schemas are highly able to reduce unnecessary retransmissions in a fully distributed manner and without a need to overload the transmission channel by the beacon messages. Another advantage of these methods relies on the tuning operation. Tuning is a critical factor to improve the performance of broadcasting protocols. The tuning operation in counter and distance-based methods is an easy task as it requires only the adjustment of two parameters: the maximum waiting time and the threshold value. Consequently, many recent receiver-based broadcast protocols based their forwarding strategy on counter-based and distance based schemas [31].

For the above reasons, the counter-based and distance based schemas can be considered as promising broadcast algorithms. Like most received-based protocols, the downside of these two protocols is related to their stochastic nature that can negatively affect their coverage capacity.

1.1.2 Video streaming in urban VANETs

Video streaming in V2V/V2I environments is expected to significantly improve traffic management and provide value-added entertainment and advertising services [32]. For example, video notifications in active safety applications provide better information regarding accidents than a simple text message. In particular, video clips of an accident or a dangerous situation ahead would provide drivers with precise information, allowing them to make an informed decision (whether to proceed or to return) based on personal priorities and the capabilities of their vehicles. However, transmitting videos over VANETs is a sensitive task because of VANET specificities, such as dynamic topology, shadowing phenomena, mobility of nodes, and the lousy wireless environment. Besides, video streaming is a demanding application in terms of both service and experience quality. Many researchers have proposed different solutions to meet video streaming requirements.

Existing solutions can be classified into three categories: application-layer solutions (video coding and error-resilient techniques), network layer solutions (routing optimization and the store-carry-and forward mechanism), and link-layer solutions (medium access control, rate control, and congestion control) [33]. These solutions are proposed to help deliver videos over VANETs with high quality of experience by considering time-varying bandwidth, latency, jitter, and rate loss.

Technically and according to the use case scenario, videos can be broadcasted using one of the following routing paradigms: Unicast, Multi-cast, or Geocast/Broadcast. Unicast is a one-to-one type of communication, whereas multicast is a one-to-many type of communication. The Geocast/Broadcast routing protocols are used when a message is distributed by the sender to all nodes in a delimited geographic zone (zone of interest). In this study, we aim to enhance video content dissemination using a Geocast/Broadcast routing technique.

When the environment within which a VANET is deployed contains obstacles, such as buildings, in urban scenarios, a serious challenge in the form of a partitioned network is encountered. Therefore, many packets may be lost as the number of obstacles increases. In an urban VANET environment, direct communication between vehicles can be disturbed because of the existence of buildings, thus preventing vehicles in the same communication range from directly exchanging data and creating an obstructed line of sight (ObsLOS) between them. This prevents the packets transmitted by relay nodes to be well-received by many one-hop neighbors which can affect negatively the selection of relay nodes in the next hop. Therefore, ensuring that vehicles that contend to become relay-nodes are in a non-obstructed line-of-sight environment is more important. Several studies have been conducted in this context. However, all of them are based on the sender [34][35][36].

1.2 Contributions

In this PhD thesis, we mainly contribute to tackle the abovementioned downsides related to multi-hop data broadcasting and video streaming in urban VANETs;

- Our first contribution is to enhance the basic mechanism of counter-based and distance-based protocols. It is possible to alleviate the issue of their stochastic behavior by selecting a set of relay-nodes that have an enhanced spatial distribution. Specifically in urban VANET, vehicles' movement and vehicles' spatial distribution are likely related to the road network topology. Thus, a great need arises to use the road network topology to select a set of relay-nodes which have an enhanced coverage capacity. Therefore, we propose an Enhanced counter-based and Enhanced distance-based protocols for urban VANET, respectively [37]

ECUV and EDUV, to increase the connectivity among vehicles in the urban VANET. ECUV and EUDV are road-network-topology-based solutions that allow the deployment of relay nodes in all road segments to increase the coverage capacity and hence maximizing the broadcast reachability.

- Analytical models have in many cases significant advantages over simulation models, especially concerning the vision that they provide, the relative speed compared to simulations and their general approach to evaluate the performance under different conditions with just a numerical formulation [38][39]. One of the main contributions of this work is to propose analytical models that could be used to predict the performance of ECUV and EDUV. In order to capture the urban VANET particularities and the characteristics of the proposed protocols, we have considered various input parameters in the definition of the analytical models such as threshold parameter, vehicle density (The number of vehicles in the network), and the road network size(The number of the road segments). Besides, the proposed analytical models output the rebroadcast probability of a vehicle in the network when using ECUV and EDUV protocols. Based on our analytical models, we can study the ability of ECUV and EDUV to handle the broadcast storm problem and to analyze the influence of the various threshold values on the behavior of ECUV and EDUV.
- To solve the issue of ObsLOS by following a receiver-based approach, we propose a road-network-layout-based, line-of-sight aware, and reliable Bi-directional protocol (ReLoS) that automatically selects the vehicles with enhanced line-of-sight as relay-nodes while increasing the geographic coverage capabilities [40]. The proposed protocol is designed to enhance packet delivery in urban scenarios in very sensitive applications such as those involving video streaming. Indeed, coverage capability and line-of-sight are the most important factors that must be taken into account when selecting the set of relay-nodes. In ReLoS, the road-network is divided into a set of road sections, and a bi-directional schema is established in each road section to cover the whole network while selecting relay-nodes with enhanced line-of-sight in a fully distributed manner. If we compare ReLoS to the existing methods, ReLoS is the only broadcast routing solution that is based on both line-of-sight and road-network-topology. In the literature of routing protocols

in VANETs, the designed solutions are either based only on line-of-sight [22] or only on road-network-topology [37][41] or proposed to deal with unicast routing problems [42][43][44][45][46].

- Packet loss, resulting from collisions and the interrupted communication in the network, is one of the most serious issues associated with video streaming in vehicular networks. Because the end-to-end communication provided over the UDP/RTP transport layer for video streaming applications is unreliable (no mechanism of retransmissions), the Store Carry and Forward mechanism (SCF) is introduced to recover packet loss [33][47][22][48]. However, the different SCF solutions do not consider the video-coding parameters to schedule the retransmission of each lost packet according to its impact on video quality. Thus, we design a video-friendly and Quality of Experience aware SCF scheme (QoESCF) for packet loss recovery [40].

1.3 Thesis Organization

The remainder of this thesis is structured as follows:

In Chapter 2, we present a summary of the common characteristics of VANETs. We then provide an insight into their communication architecture, VANETs applications and their performance requirements, and the different efforts of standardization in the field of inter-vehicles communication. Next, we provide the related work of data dissemination in VANETs within two different aspects: one-hop data broadcasting class and multi-hop broadcasting class.

In Chapter 3, we present, survey, and explain the relevant works of video streaming in VANETs. This chapter introduces the current solutions proposed for video streaming in VANETs. We analyze and examine different works based on two scopes: routing solutions for video streaming and error control and recovery.

Chapter 4 provides the detailed steps and the design of the two first contributions which are intended to improve the coverage capabilities of multi-hop broadcasting in V2V urban scenario. It is the Enhanced Counter-based for urban VANETs protocol (ECUV), and the Enhanced distance-based for urban VANETs protocol (EDUV). These protocols are based on road network layout, traffic-aware heuristic and minimum distance heuristic. Their performance is evaluated using an analytical model and network simulation.

The chapter 5 introduces and describes our third contribution to enhancing video streaming over urban VANETs. We propose two solutions: the first one is a routing solution, named Receiver-based Line of Sight aware broadcast protocol (ReLoS), and it is proposed to tackle the obstructed line of sight problem and to enhance the coverage capacity. The second one is proposed for error recovery, and it is named Quality of Experience aware Store Carry and Forward scheme (QoESCF). These solutions have been widely evaluated using network simulation and were compared with two innovative protocols, in terms of frame delivery, end-to-end delay, PSNR, and MOS.

Chapter 6 concludes this manuscript by presenting our main contributions and fundamental outcomes and then enumerates our perspectives and main issues regarding data dissemination in VANETs.

PART ONE: LITERATURE REVIEW

Chapter 2 Data dissemination in VANETs: literature review

The main focus of this chapter is to obtain a comprehensive review of the different solutions in data dissemination topic in VANETs. We present the basic concepts of VANETs by providing a brief summary of VANETs and their general components, standards, architectures and features. Besides, we list VANETs applications based on their prerequisites and purposes. We classify the vehicular communication according to the different type of devices that can communicate with vehicles. Finally we review the related work on one-hop and multi-hop broadcasting protocols in VANETs.

2.1 Common VANET characteristics

VANETs have certain characteristics that make it different from other ad hoc networks such as MANETs. Thus, solutions proposed for MANETs are not consistently suited for VANETs [49]. In this section, we emphasize the general features of VANETs that should be considered when proposing new approaches for such networks.

2.1.1 Rapid change in network topology

Vehicular networks are characterized by a frequent change in topology due to the high mobility of nodes. The high mobility of nodes can negatively affect the wireless channel and also produces an intermittent connection in the network, conducting to packet loss and high transmission latency [50]. Furthermore, traffic density is likely to be high in urban areas, whereas the vehicle density becomes low upon vehicles move toward freeway or rural zone. Consequently, the scalability of any solution, proposed for VANETs, is very important to cope with the rapid change in topology.

2.1.2 Accessibility to positioning system

Availability of vehicle position is one of the main prerequisites of various geographic location based protocols in vehicular networks. Supplying timely and precise geographical location coordinates (latitude, longitude), vehicle speed, heading, and geocoding information permits geographic routing protocols to deliver packets to a Geo-located destination [51].

2.1.3 Mobility pattern

A mobility pattern is one of the most critical factors we have to consider to investigate the comportment of protocols in VANETs. It should precisely match the mobility of vehicles in the real world. Mobility pattern has specific features in VANETs such as the strict restrictions on the movement of vehicles, the clustering of vehicles at junctions and in the case of traffic congestions. In the simulation, determining the appropriate mobility pattern begins by selecting the environment of deployment and the constraints of movements. Two mobility models have to be considered [52][53]:

- Macroscopic Mobility Model: This class specifies the characteristics of the mobility environment such as highway, city, streets, intersections, junctions, buildings, and traffic lights during the creation of vehicle mobility traces.
- Microscopic Mobility Model: microscopic mobility models intend to provide an explicit representation of vehicular movement where the behavior of each vehicle is defined individually.

2.1.4 Several QoS prerequisites

In vehicular networks, QoS specifications vary considerably according to the type of the use case and application. For instance, video streaming applications, comprising use cases related to safety and traffic supervision services, have stringent requirements concerning reliability, latency and packet delivery ratio. By contrast, none-safety applications are more resilient on both delivery rate and end-to-end delay.

In summary, VANETs have different properties as compared to MANETs because of their particular prerequisites. Thus, the development of low transmission latency, high delivery, scalable, reliable, and efficient solutions for VANETs is a challenging task. Although, many VANET features, e.g., the tolerance in energy consumption and the constrained mobility patterns, serve to develop reliable protocols.

2.2 Architecture of vehicular networks

Typically, VANET includes two kinds of nodes: vehicles and RSUs. The On Board Unit (OBU) and the set of sensors are the most important components in the vehicle. The RSU acts as a services provider, whereas the OBU handles the information provided by the RSU to deliver it to road-passengers and drivers. In the subsequent sections, we detail the components of RSU and OBU.

2.2.1 Basic structure of On-Board Unit (OBU)

OBU is important for ensuring the smartness and connectivity of the vehicle. It includes an information and communication system that allows communication between vehicles or with the surrounding environment (Figure 2-1). OBU is basically made up of the following modules [54].

a) Control Unit (CU)

CU is an embedded calculator that controls physical devices within the OBU. It can process inputs transmitted by front radar when a forward obstacle is detected and likely communicate a warning to the user through the human device interface to react to the event based on the received information.

b) Geo-location module

This module works as a localization sensor. It is used to receive time and kinetic information (geographical position coordinates, speed, and heading) from global navigation satellite systems (GNSS) such as global position system (GPS).

c) Set of sensors and radars

Sensors enable vehicles to identify or measure the environmental properties, e.g., temperature, pressure, inclination, and Co2 emissions[55]. The set of radars help vehicles to detect and determine the position of an object in the road. The set of sensors and radars is connected to CU through CAN interface.

d) Human interface device (HID)

It allows drivers and passengers to interact with OBU, and it includes basically a screen and a keypad.

e) Communication network interfaces

This one allows the vehicle to communicate with the other nodes in the network. OBU has to include network interfaces with different access technologies such as ETSI G5, 3G, 4G, and 5G to permit the vehicle to communicate with different networks.

2.2.2 Road side Unit (RSU)

RSU is a DSRC or ITS communication device that is deployed along the streets or highways. It is used to provide connectivity between vehicles and the communications infrastructure to deliver safety and traffic information[56][57].

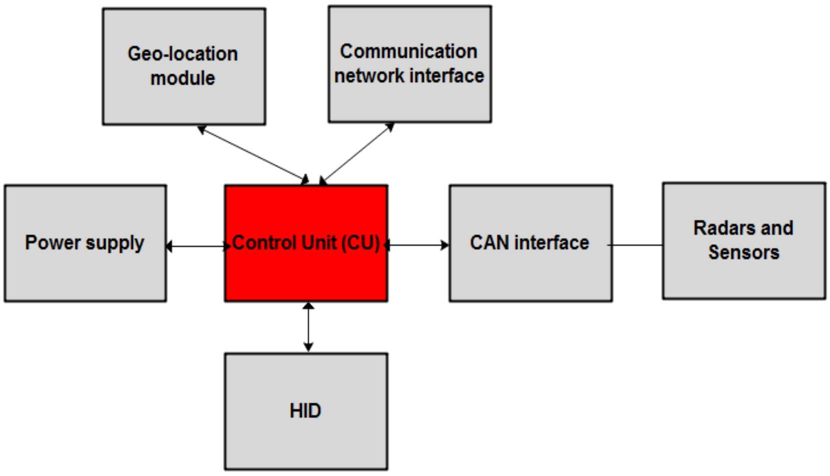


Figure 2-1 On-Board Unit structure

2.3 V2X communication in VANET

The term vehicle-to-X (V2X) designates the vehicle to everything communication system that allows a vehicle in the road to communicate with different kinds of devices, infrastructures, and networks (Figure 2-2). V2X is a scalable system and it includes all sorts of vehicular communication[58]. Namely, this system includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P) communication types. The main purposes of V2X are to provide communication support to secure drivers and passengers on the road, overcome congestion, and protect the ecosystem by reducing energy consumption. In the following sub-sections, we detail the above-cited vehicular communication types.

2.3.1 V2V communication type

Vehicles that support this type of communication can exchange information such as geographical position, velocity, heading, and any kind of state information. This exchange takes place directly between vehicles through 802.11p based devices without using any infrastructures.

2.3.2 V2I communication type

Different kinds of information are exchanged between the vehicle and the infrastructure that support this type of communication (E.g., Road-Side-Unit (RSU), ITS-component, etc.).

2.3.3 V2N communication type

It connects vehicles to the cellular network to supply certain services such as video streaming for entertainment and connectivity for dynamic traffic flow supervision.

2.3.4 V2P communication type

It connects vehicles to pedestrians equipped with mobile devices to provide alerts on potential surrounding risks.

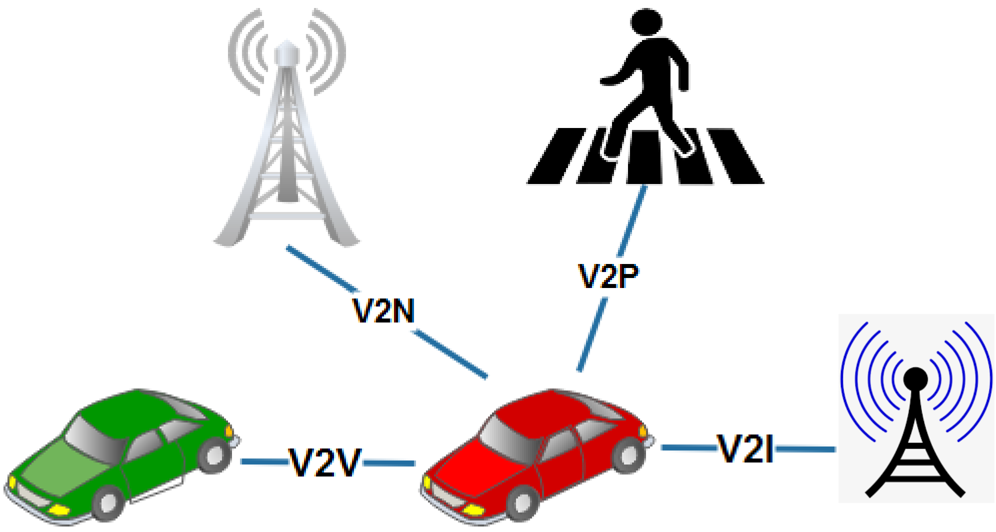


Figure 2-2 Communication types in VANETs

2.4 VANET applications

VANETs applications, as defined by ETSI organization in the ETSI ITS standards set, can be classified in active road safety, traffic efficiency, local services, and Global internet services [59]. This section describes the set of use cases and applications set that mainly based on V2V, V2I links in VANET-devoted frequency band (E.g, ITS-G5 and DSRC frequency bands). Table 2-2 lists a possible classification of VANETs applications. The system performance needs are also presented for each application class in terms of vehicle communications and positioning performances.

2.4.1 Active road safety applications

The main aim of the active road safety applications and services is to increase the safety of both passengers and drivers on the road. It provides the greatest possibility for reducing the number or gravity of road accidents. Fundamental infrastructure and support have to be supplied by transportation authorities to guarantee the successful deployment of safety applications. For instance, digital road map and positioning infrastructure are the main requirements of location-based safety applications. A typical example of active safety applications is Emergency electronic brake lights use case that offers for any car a capacity to notify an unexpected deceleration to its followers, which can restrict a hazard collision.

As outlined in Table 2-2, the latency of active safety applications has to be low. For instance, in the USA, the transportation authorities recommended that notification about an accident should be delivered through a vehicular network within 500 ms to the surrounding vehicles in a range of 500 m [60]. Furthermore the suitable value of broadcast frequency is set according to each use case requirement. Basically it ranges between 1Hz and 10 Hz for active safety applications. Particular safety use cases require strict relative position accuracy. Table 2-1 illustrates these applications and their relative geographical location precision as defined in ETSI ITS standard[61].

Table 2-1 Basic set of safety use cases that require high position accuracy

Use case	**Relative position accuracy**
Lane change assistance use case scenario	at least equal to 2 m
Co-operative glare reduction scenario	at least equal to 20 m
Co-operative merging assistance use case scenario	at least equal to 2 m.
Co-operative forward collision warning use case scenario	Less than 1 m

2.4.2 Traffic efficiency applications

The main aim of services in the Traffic efficiency category is the enhancement of traffic flexibility. It includes two sub-classes. The first one is related to speed management, such as Traffic light optimal speed advisory use case. The second one is the Co-operative navigation, E,g, Enhanced route guidance and navigation use case. By contrast to active road safety applications, most use cases are delay tolerant. Furthermore, the broadcasted messages, in this class, have to be transmitted periodically, and the minimum frequency is set according to triggered event (usually it ranges between 1Hz and 10Hz). Certain use cases involves high positioning accuracy (better than 5m), such as Traffic light optimal speed advisory.

2.4.3 Local services, internet and infotainment applications

Use cases in the local services, infotainment, and internet applications category deliver on-demand information to both drivers and road passengers for commercial and non-commercial purposes. This category could comprise entertainment, media downloading, and point of interest notification. Local services are obtained from the communication network of the transportation system, whereas Internet services may be accessible from an **i**nternet service provider **(**ISP**).**

Table 2-2 Basic set of VANET applications and their requirements

Application category	**Application**	**Requirements**	
		Latency	**broadcasting Frequency**
Active road safety	Co-operative awareness E,g Emergency vehicle warning	Low latency	From 1Hz to 10Hz according to the triggered event
	Road Hazard Warning E,g accident notification		
Traffic efficiency	Speed management E,g Traffic light optimal speed advisory	Delay resilient	
	Co-operative navigation E,g Traffic information and recommended itinerary		
Local services	E,g Location based services Point of Interest notification		
Internet and infotainment services	Communities services E,g Fleet management		-
	ITS station life cycle management. E,g Vehicle software update		

2.5 Communication standards in vehicular networks

In this section, we review and discuss the well-known standards in the field of vehicular networks. Namely, we present the American standard named Dedicated Short Range Communication (DSRC) and The Wireless Access in Vehicular Environments (WAVE) [12][62] and the European standard referred as to Cooperative intelligent transportation system standard (C-ITS) [63].

2.5.1 DSRC/WAVE standard

Dedicated Short Range Communication (DSRC) and The Wireless Access in Vehicular Environments (WAVE) standards are used together to define the vehicular network architecture, communications pattern, security aspect, management infrastructure, and access technology for high bit rate (from 3 to 27 Mb/s), and short communication range (less than 1000 m).

In 1999, the U.S. Federal Communication Commission have proposed the DSRC as the main reference standard for deploying VANETs, by specifically reserving 75 MHz radio frequency band at 5.9 GHz for this type of network [64], [65] . The spectrum of DSRC is divided into seven channels. The width of each channel is 10 MHz. The middle Channel (channel number 178) is the control channel (CCH), which is allocated to safety related transmission. The two channels at the extremities (Ch 172 and Ch 184) of the DSRC spectrum are attached to a particular purpose, such high power and long range communication. The channels number 174,176,180,182 are service channels (SCH) and they are accessible by all kinds of messages.

a) DSRC/WAVE communication protocols stack

IEEE 802.11p details PHY/MAC layer specification for DSRC based communication [66], whereas WAVE standard is defined through IEEE 1609 family for wireless access in vehicular environments [67][62]. Table 2-3 provides a short description of the IEEE 1609 set.

In DSRC/WAVE architecture, network and transport layers are defined by two distinct stacks to support different types of applications. As outlined in Figure 2-3, WAVE Short Message Protocol (WSMP) is assigned to the first stack and it is provided exclusively for safety applications. The safety messages are based on the Wave Short Message format (WSM) that is specifically defined for V2V and V2I communication type. Other services operate above the TCP and IPv6 layers.

Management-level entities detailed in IEEE 1609.3 are referred to as WME and involve application registration, WBSS management, channel usage monitoring, IPv6 configuration, Received Channel Power Indicator (RCPI) monitoring, and Management Information Base (MIB).

The IEEE 1609.2 standard provides details about the security mechanisms for all layers of the WAVE stack. Security mechanisms incorporate WAVE management messages authentication, encryption, confidentiality, integrity, and anonymity preservation. WAVE services deal with common safety limitations due to their comprehensive range of operations. For instance, active safety services require timely delivery. Consequently, the data processing and transmission overhead have to be kept under a strict threshold. Therefore, the security mechanisms have to be addressed with lightweight transmissions.

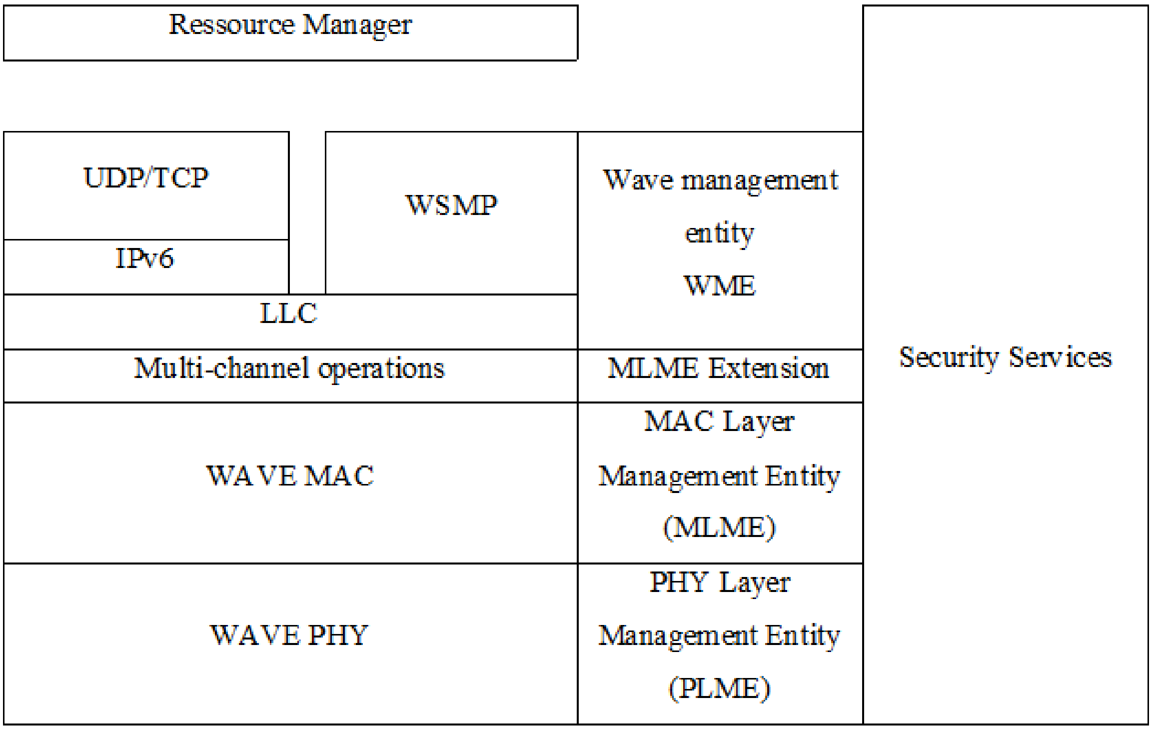


Figure 2-3 DSRC/WAVE communications Stack

Table 2-3 IEEE 1609 family for WAVE standard

Part	Scope	Description
IEEE 1609.1[68]	resource manager	Defines the services and interfaces of the WAVE Resource Manager application.
IEEE 1609.2[69]	security issues	Security support to preserve privacy of both application and management messages.
IEEE 1609.3[70]	Networking services	Describes the network and transport layers that are included in one protocol called Wave Short Message Protocol (WSMP). WSMP is designed specifically for V2X communications type.
IEEE 1609.4[71]	multi-channel operation	Introduces improvements to the IEEE 802.11p MAC layer to schedule and synchronize multi-channel operations.

b) Effort of standardizing multi-hop data dissemination in WAVE

WSMP protocol supports safety services in a single-hop local environment (up to 1000m) [62]. It allows safety services to broadcast short messages (WSM) toward the immediate neighbourhood. Therefore, the IEEE 1609.3 does not define any multiple hops broadcasting strategy. Any multi-hop dissemination is done through TCP (or UDP)/IPv6 protocols instead. The aim beyond this is to avoid double functionality. However, TCP/IPv6 is not defined to support VANET time-sensitive and high priority transmission due to the additional transmission delay resulted from the round-trip time.

2.5.2 Cooperative intelligent transportation system standard (C-ITS)

ETSI and CEN are the official European standards institutions dealing with the normalization aspect for the European countries. Their mixed group consisting of CEN TC 278 and ETSI TC ITS technical committees is in charge of designing and implementing ITS service delivery over the network, and its work was started in 2010. As a result of four years of work and coordination, the core kit of standards for Cooperative Intelligence Transport Systems (C-ITS), termed Release 1, was issued by May 2013[72].

The standard details the sub-system specification of each ITS component including the VANETs infrastructure components, such as Vehicle ITS and RSU ITS subsystems. An ITS station can be a router interconnecting two heterogeneous ITS subsystems stacks at network layer, a host that offers a minimum support required for ITS services and applications, a gateway that interconnects ITS subsystem stack to OSI protocols stack at layers 5, 6 and 7, or a border router that provides a connection between ITS subsystem and proprietary network at layer 3. Both vehicle station and RSU can work as host, router, or gateway, whereas border router is designed exclusively for RSU.

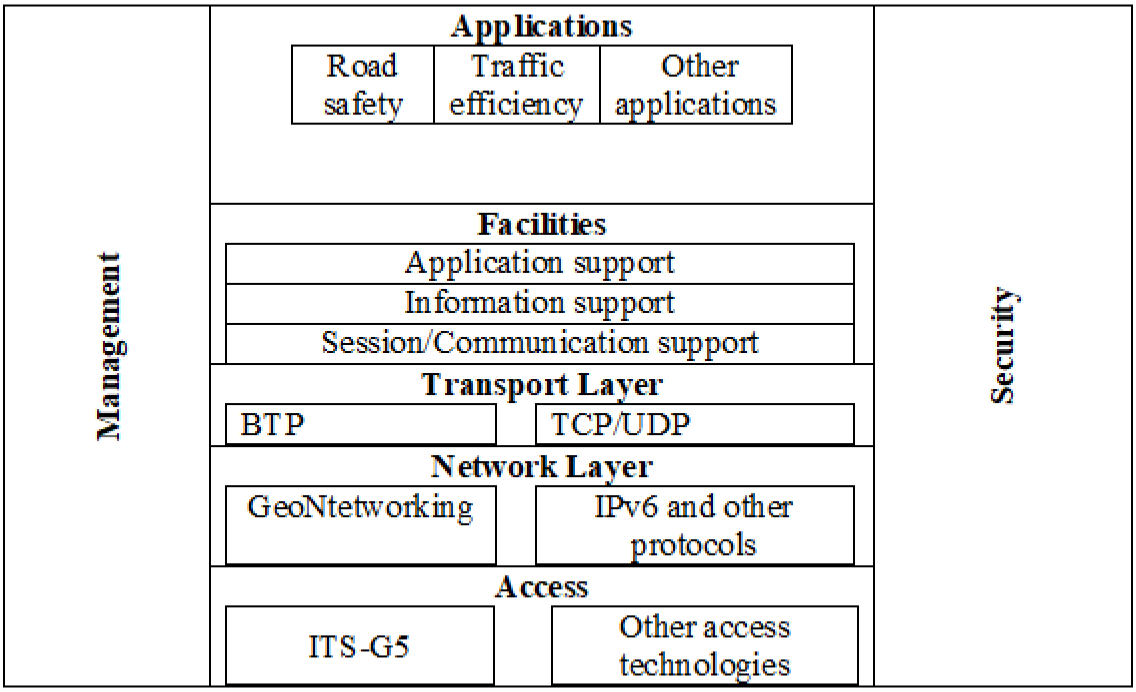


Figure 2-4 ITS communication layers

a) Communication protocols stack

As defined in [73], the common communications stack of ITS subsystem is outlined in Figure 2-4. It represents the full stack and can be customized according to the subsystem type (host, router, gateway, border router). The network interface is defined essentially to handle the direct connection to the 5 GHz ITS-G5 frequency band, reserved for V2V and V2I ad-hoc communications in Europe. The network interface involves both PHY and MAC layers, which are specified based on the 802.11p standard [74][75][76].

The transport and network layers are derived from the OSI model with improvements to assist ITS specific services. Various potential network protocols are designed for ITS till now. Namely, GeoNetworking protocol, IPv6 protocol extended with mobility functionalities, IPv6 combined with GeoNetworking , CALM FAST networking protocol [77].

The transport layer is defined either through the Basic Transport Protocol (BTP) or TCP/UDP protocol. BTP is used over the GeoNetworking protocol, whereas the TCP/UDP protocol is designed to work only over the IPv6 network protocol [75].

Although more than one transport and networking modes are enabled for ITS subsystems, the Basic Transport Protocol (BTP) together with GeoNetworking protocol is suitable for VANETs because they mainly designed for ad-hoc specific communications.

The facilities layer functionality is obtained from the three top OSI layers (Application, presentation, and session layers) with modifications devoted specifically to ITS subsystems. It includes various functionality supports, such as the addressing mode configuration, support for geographical location and time, inter-nodes communication handling, different kinds of data provision (e.g. geographical position, current time, etc), encoding and decoding messages, and others [78].

The application layer is in charge of generating Co-operative Awareness Messages (CAMs) and Decentralized Environmental Notification Messages (DENM). The former messages are sent periodically towards the one-hop neighbors and it carries information about the current state of ITS-node (Geographical location, current speed, etc) [79]. DENM message is sent, over multi-hop links, when an event is detected. Rules that determine the broadcasting coverage, frequency of repetition, and halt sending the message are defined based on the type of the detected event.

The security and management aspects are implemented via two vertical cross-layers. They are connected to the all horizontal layers. The management entity contains different tools that depend on information management base (MIB), e.g. Networking management, ITS application management, general congestion control management, etc. The security information base (SIB) is employed by the security entity to manage the security aspect of horizontal entities in the communication stack, such as protection against intrusion, firewall handling, authentication, privacy and confidentiality [80].

b) Effort of standardizing multi-hop data dissemination in C-ITS

Communication over VANETs is the keystone of many services, including those that enable road-safety, infotainment, road efficiency, and autonomous driving. Many VANETs services are mainly based on the dissemination of data through the direct wireless ad-hoc link (E.g., ITS-G5). It allows communication across a multi-hop link, where some nodes in the region of interest act as relays to deliver data packets to the destination nodes. The most appropriate method for data dissemination over VANETs is based on a geographical routing scheme, where information packets are targeted to a geographical region called the region of interest (RoI). Usually, a source node (vehicle or RSU) can designate a well-specified Geographic RoI to where data packets should be targeted.

BTP/Geonetworking is the network/transport layers dedicated for V2V and V2I communications over ITS-G5 spectrum band. They are defined to disseminate DENM messages. Unlike DSRC/WAVE architecture, the Geonetworking layer defines some forwarding strategies to disseminate data for each routing mode. As specified in this standard, VANETs involve the subsequent routing modes [51].

GeoUnicast: GeoUnicast (or simply called Unicast) is a one-to-one type of communication, in which data packets are delivered from a source node to a destination node over a path composed of multiple hops. Before attempting to send the desired packet, the source node has to designate the geographical position of the target node. Figure 2-5 shows a typical scenario of GeoUnicast.

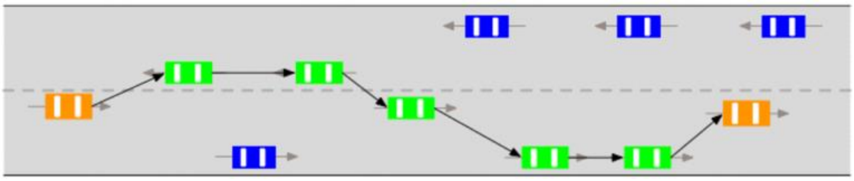


Figure 2-5 GeoUnicast routing scheme [51]

GeoBroadcast: This type of geographical routing is established when a source node is located outside of the region of interest. As outlined in Figure 2-6, packet propagates from hop to another until it arrives to the RoI, and each node inside the RoI forwards the received packet.

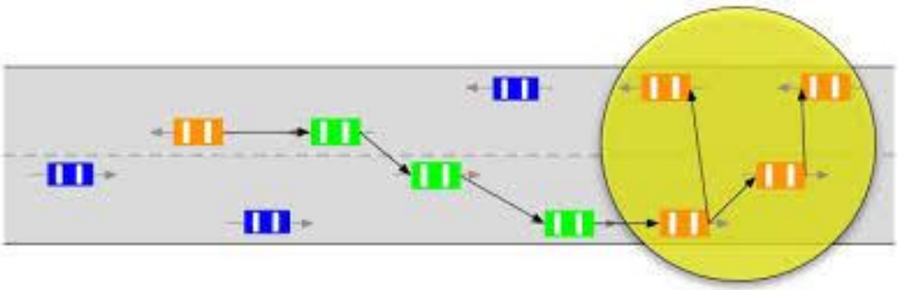


Figure 2-6 GeoBroadcast routing scheme [51]

Topologically-scoped broadcast (TSB): Generally, it is referred to as broadcast. In this scheme, a node in the network addresses packets to all nodes inside a geographical destination region. Notice that the source node has to be within the region of interest. Figure 2-7 shows a typical scenario of using TSB over K-hop ad-hoc link. One-hop dissemination is a particular case of TSB, where source node broadcast packets towards its immediate neighborhood. In TSB, DENM packets are broadcasted among the RoI as included in the packet header. The RoI is represented by the center c(latitude, longitude) of the RoI, two distances from c (a and b), and the azimuth angle. The shape of the RoI can be a rectangle, a circle, or an ellipsoid[81].

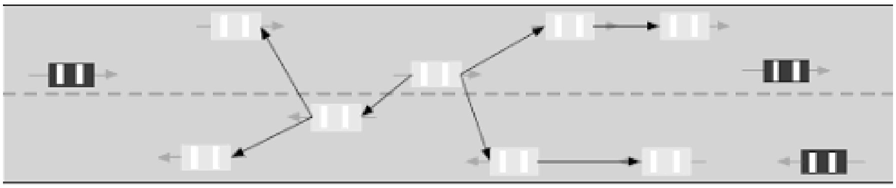


Figure 2-7 TSB routing scheme [51]

2.6 Related works on broadcasting protocols in VANETs

The characteristics of VANETs must be considered carefully in the design of reliable broadcast protocols. This section depicts the widely used broadcast protocols to disseminate information in VANETs and their specificities in terms of scalability, infrastructure requirements, and heuristics used to forward data. We have classified the related work based on the size of the region of interest (represented by the number of hops). Mainly, we have three types of dissemination protocols: 1) one-hop dissemination protocols, 2) k-hop dissemination protocols (k>1), and adaptive dissemination protocols. The latter adapts its strategy according to the requirement of the deployed application in terms of the size of the region of interest.

2.6.1 Common problems in data dissemination over VANETs

The current sub-section presents different issues that can influence data dissemination in VANETs such as Hidden terminal, broadcast storm, and network division.

a) Hidden terminal

The hidden node problem is more probably to happen due the lack of RTS/CTS exchange in the one-hop broadcast mode. Therefore, when two nodes have the same backoff time, the collision is more likely to occur [82].

b) Broadcast storm problem

The broadcast storm problem arises when all vehicles in the network try to transmit blindly and synchronously, thus leading to network overloading, collisions, denial of service and additional transmission latency due to the high contention between different nodes. This problem is more common in flooding-based broadcasting protocols [23].

c) Network division problem

Network division happens when the density and the spatial distribution of vehicles in the network is not adequate to share information between vehicles. Network division is a very prevalent problem in VANETs because vehicles, in the network, are usually dispersed and non-uniformly distributed. This generates serious difficulties to deliver information over VANET since information cannot be easily exchanged between disconnected clusters [83].

To represent this issue, we consider the divided VANET like it is illustrated in the Figure 2-8.The information could be shared between vehicles with red color (cluster 1) because each red vehicle is at least within the reach of one vehicle that belongs to the cluster1. We can say the same thing about the vehicles that make up the cluster 2. However, any node from cluster 1 cannot deliver messages to nodes in cluster 2

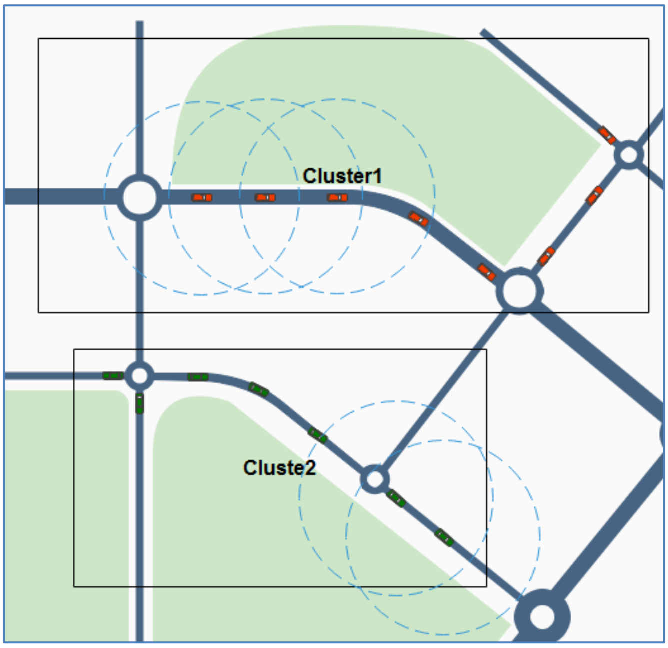


Figure 2-8 Example of network partition problem

2.6.2 One-hop broadcasting protocols

One-hop broadcasting protocols are typically proposed to allow neighboring vehicles to efficiently and reliably exchange basic information, such as kinetic information. Furthermore, hello messages broadcasting acts as the main support for many multi-hop dissemination protocols. The main factors that can influence the reliability of one-hop broadcast protocols over DSRC and ITS-G5 based wireless channels are vehicle density, the radius of the communication range, and the beaconing frequency.

ETSI proposed Cooperative Awareness Messages (CAM) to allow data broadcasting for awareness purposes, such as information delivery for Cooperative awareness use cases. According to the triggered event, the broadcasting frequency can be 1Hz, 2Hz, 10Hz, or 20Hz. The CAM message piggybacks vehicle state information, E.g. Location, velocity, and heading. Many works in the literature are provided to enhance safety and awareness on the road using periodic hello messages such as CAM messages. Most of them have introduced more control to enhance the awareness while keeping channel load at a low level.

ETSI proposed the dynamic handling of CAM messages generation frequency [84]. It modifies the CAM broadcasting period depending on the mobility variation, speed, and heading of the sender. This method intends to address the trade-off between the awareness accuracy of neighboring vehicles and efficiency. The main draw-back of this method is the deviation effect due to the fluctuation of the beacon interval [85][86].

The authors of [87] proposed an adaptive hello messages broadcasting protocol to exchange geographical location information between immediate neighboring vehicles. In this work, the transmission frequency parameter of hello messages is adapted to improve local awareness while minimizing wireless channel load. Authors used two mechanisms to adjust the frequency parameter: fast response mechanism and fast repetition mechanism. The former is used by a node to immediately notify a new discovered neighbor of its existence, whereas the latter is triggered to estimate the velocity and the heading of this new neighbor.

Sommer et al [88] proposed Adaptive Traffic Beacon (ATB) to meet the tradeoff between timely dissemination of one-hop hello message and an overload-free radio channel. The timely delivery of hello message can increase the local awareness by delivering more recent state information, whereas the aim of decreasing message overhead is to make the system more reliable. ATB reach this goal by applying two measures, the channel quality and the message utility, to determine the hello message broadcasting period. ATB determines channel quality through the linear association of three observable measures. The first one is the number of collisions (NC) that represent the channel state in the past time. The second one is the Signal-to-noise ratio (SNR). Each node in the network constantly calculates this metric to derive the actual channel utilization. The last one is the number of vehicles in the reach of the transmission range (N), which is derived by calculating the number of the received hello messages. This metric allow each node to predict the channel access in the close future. The channel quality increases when the value obtained from the linear combination of the above-cited metrics decreases. ATB considers two metrics to estimate the message utility: 1) the distance between the node and the geographical location of the triggered event, 2) the message Age. Both of these metrics bring knowledge about message priority.

Sommer et al.[89] proposed a solution to undertake the obstructed line of sight, shadowing phenomena, and signal attenuation (due to the obstacles such as buildings) particularly in urban and suburban environments. The authors focused on the improvement of cooperative awareness and safety applications that require data dissemination toward one or two-hop neighboring vehicles. Most methods in the literature require all vehicles to blindly forward each received message to increase awareness or by engaging RSUs in intersections to avoid the obstructed line of sight. Through comprehensive network simulation, the authors demonstrate that the awareness of vehicles can be significantly enhanced by replacing the RSUs with parked vehicles to act as forwarders. However,

In[85], Authors have designed a POSition-ACCuracy (POSACC) based adaptive beaconing algorithm. POSACC combined three distinct handling methods to ensure location precision and transmission reliability while keeping the transmission overhead and latency within the cooperative safety applications requirements range. POSACC adjusts the beacon transmission rate and transmission power based on the vehicle mobility and the minimum size of the contention window according to neighborhood table information. POSACC decreases the beacon transmission rate when the mobility of the vehicle is low to mitigate the channel overhead and minimize interferences. By contrast, when the mobility is high, the beacon transmission rate is increased to maximize position accuracy. The transmission power adaptation method adjusts the transmission power of the vehicle to increase the successful reception probability. The probability of collision is directly proportional to the number of neighbors N within the communication range of the transmitter. However, it is possible to reduce it by defining the minimum size of the contention window CW_{min} according to the value of N. In order to achieve this, POSACC introduces a linear function that adapts the size of CW_{min} based on the value of N. The drawback of POSACC is the lack of a mechanism to control the maximum contention window size CW_{max}.

2.6.3 Multi-hop broadcasting protocols

Multi-hop broadcast protocols are generally classified based on where the decision on the status of nodes (relay or not relay) is made. Namely, they are classified into sender-based and receiver-based. In the sender-based approaches, the sender node explicitly selects the next set of relay nodes. By contrast, in the receiver-based solutions, the decision on rebroadcasting the received packet is made at the receiver node.

In this section, we detail and discuss a set of recent sender-based and receiver protocols.

a) Sender-based protocols

In [90], a new link metric named expected progress distance (EPD) is provided by combining the distance from the current sender to the receiver in the next hop and the link quality. To minimize the effect of the path loss, and hence keeping the link quality, the sender considers only nodes that have a distance from it less than a predefined maximum distance as candidates. Then, from the list of candidates, the sender selects the node with the highest EPD as the next forwarder. The EPD measures the packet error rate (PER) for both sender-receiver (SR) and receiver-sender (RS) links. PER of SR link is returned by the neighboring nodes through the exchange of beaconing messages, whereas the PER of RS link is calculated at the receiver side. Therefore, the loss of a beacon message can negatively affect the selection of the next forwarding node.

Aiming to optimize bandwidth utilization and guarantee reliable and timely warning message reception, a sender-based forwarding mechanism to broadcast warning messages over a multi-hop path in VANETs was presented in [91] and it is termed enhanced selective forwarding scheme. In this method, the farthest nodes that have a lower speed difference with the sender are likely more suitable to become relay-node in the following hop. The performance evaluation of the selective scheme proved that the end-to-end delay, the packet delivery ratio, and the broadcast saving were improved considerably. However, the simulation experimentation was limited to the highway environment.

In [92], Wu et al. designed a fuzzy-based dissemination protocol (FUZZBR). It uses a fuzzy logic approach to select an optimal subset of forwarding vehicles by combining three metrics: the distance between vehicles, vehicles' mobility, and received signal strength (RSSI). FUZZBR also engages a lightweight retransmission mechanism to recover the loss of packets with minimum overhead. The main issue of this protocol is that it does not consider the MAC layer contention time in the forwarders selection process, which could produce inefficient dissemination in high vehicle density scenarios.

A greedy and sender-based scheme, called multiple candidate relays opportunistic broadcast protocol (MCROB), was suggested in [93] to timely deliver packets to the recipient nodes by dynamically scheduling the forwarding nodes. The MCROB protocol intends to avoid collisions by adaptively assigning a back-off time to the forwarding candidates before broadcasting the received packet. The back-off time is calculated according to a priority weight attributed to each candidate by the sender node. The forwarding candidates and their priorities are determined based on a new metric referred to as transmission speed (ETS). Furthermore, ETS was used to evaluate the timely delivery feature. Unlike end-to-end delay metric, ETS considers the distance between the sender and the receiver to determine the transmission speed. MCROB intended to decrease transmission latency by actively adjusting the back-off timer of each node according to its priority. Besides, a recovering mechanism by means of retransmissions is used to improve the packet delivery ratio.

Celimuge et al. [24] designed a path diversity scheme to deliver data with low end-to-end delay and high reliability. In the designed protocol, two paths are used to deliver packets over the network. In each hop, the sender node selects two nodes: relay node and auxiliary node. Both of them rebroadcast the received message. However, the task of selecting the next relay is exclusively assigned to the relay node. Although high coverage capability is potential when using a path diversity scheme, the dissemination of messages over two paths can lead to an additional channel overload.

Rehman et al. [94] proposed a Bi-Directional Stable communication schema (BDSC). It depends on bidirectional neighborhood-based link quality measure and geographic-greedy heuristic to establish the forwarding schema. BDSC is designed to enhance the coverage capability, packet ratio delivery and end-to-end transmission delay over high vehicle density scenarios. An exchange of beacon messages in association with lightweight implicit acknowledgment mechanism is used to estimate the link quality between source vehicle and its one-hop neighbors. As indicated by the Nakagami Fading Channel model, the further away is the receiver from the source vehicle, the more complicated for that receiver to decode correctly the received signal [12]. Consequently, BDSC protocol excludes, from the set of forwarding candidates, the vehicles that have a distance from the source vehicle higher than d_{mean}, where d_{mean} is the mean of Euclidian distances from the sender to each one-hop neighbor. The fundamental issues of this protocol lie in the way that it does not consider the distance between the candidates, which could lead to the selection of relay-nodes that cover the same area. Moreover, it does not take into consideration past observations to calculate the current link quality.

Focusing to improve single criterion based multi-hop broadcast scheme, Rehman et al. [91] proposed the idea of hybrid relay-nodes selection. The forwarding strategy of traditional sender-based approaches is generally built around a single criterion to select the next set of forwarders. For instance, if the farthest distance heuristic (FD) is used; the sender selects a group of forwarding nodes, which fall far away from it while the nearer ones can be dropped. As a result, the selected forwarders likely generate bit similar performance outcomes. In order to fill this gap, Rehman et al proposed to together use two mechanisms: hybrid FD and hybrid LQ × d to efficiently distribute data in VANETs.

Discussion on Sender-based protocols

Table 2-4 summarizes the main characteristics of sender-based multi-hop broadcasting protocols. The comparison is based on six classes of measures: broadcasting mechanism, the transmission frequency of beacon messages, treated problems, the required infrastructure, and preservation of vehicle anonymity. We note that most protocols use at least two metrics in their forwarding strategies. The main difference between them resides in the approach used to combine these metrics. For instance, EPD and FUZZBR protocols use the farthest distance and link quality to select relay nodes. EPD linearly combines these two metrics, whereas FUZZBR uses a fuzzy approach to combine them. Furthermore, the link quality metric in EPD is estimated through the exchange of the hello messages. Instead, in FUZZBR, the link quality is estimated by using the RSSI. Besides, all protocols require the transmission of beacon messages to be transmitted with high frequency. Indeed, the relay-nodes selection process in sender-based protocols is based on topological information, and their performance depends on the accuracy of such information. Thus, the beaconing messages have to be timely broadcasted to deal with the frequent changes in the network topology. Finally, the anonymity of vehicles is not conserved because the identifier of each vehicle is included in the hello messages.

Table 2-4 Summary of the relevant sender-based broadcast protocols in VANETs

Protocol	Broadcasting mechanism							TF-BM	Treated problems			MI	AV
	FD	MD	CEB	CB	LsB	LqB	MB		Bs	IC	HT		
EPD [90]	Yes	No	No	No	No	Yes	No	High	Yes	No	No	GPS	Not Conserved
FUZZBR [92]	Yes	No	No	No	No	Yes	Yes	High	Yes	Yes	No	GPS	Not Conserved
MCROB [93]	Yes	No	No	No	No	No	No	High	Yes	No	No	GPS	Not Conserved
Celimuge et al. [24]	Yes	No	No	No	No	No	No	High	Yes	No	No	GPS	Not Conserved
BDSC [94]	Yes	No	No	No	No	Yes	No	High	Yes	No	No	GPS	Not Conserved
Hybrid [91]	Yes	No	No	No	No	Yes	No	High	Yes	No	No	GPS	Not Conserved

TF-BM Transmission Frequency of Beacon Messages, *MI* Modules and Infrastructure,*AV* Anonymity of Vehicles.*FD* Furthest Distance, *MD* Minimum Distance, , *CB* Clustering-Based, *CEB* Centrality-Based, *LsB* Line-of sight-Based, *LqB* Link-quality-Based, *MB* Mobility-Based, *Bs* Broadcast storm, *IC* Intermittent Connection, Hidden Terminal.

b) Receiver-based protocols

The counter-based technique is proposed in [23]. The protocol uses a one-hop traffic-aware mechanism to reduce redundancy and concurrent access. Accordingly, when a node receives a message, it applies a random back-off time. During this period, the node counts the number of duplicate messages retransmitted by its one-hop neighbors. After the expiration of the back-off time, the node broadcast the message only if the calculated number of the listened messages during the waiting time is less than a predetermined threshold C_{thr} .

In [23] the authors proposed the distance based multi-hop broadcast protocol. This mechanism is based on the distance heuristic. Accordingly, if node A is very close to its neighbor node B, there is little additional coverage when node B will be the next broadcaster node. By contrast, if node A is far away from the node B, the extra coverage will be wider. Consequently, when the node B receives at the first time a message, it takes the broadcast decision of this message based on the distance between it and the node A. When this distance is lower than a predefined threshold (D_{thr}), the node B prevents the rebroadcasting of the received message. Otherwise, the node B rebroadcasts the received message after the timeout of a random delay, providing the same message has not been received from another node C where $\|BC\| \leq D_{thr}$ (D_{thr} is the distance threshold value). Variants of counter-based and distance-based schemes were proposed in [31] .Figure 2-9 shows the extension of these two schemes as defined by Tores et al. [31].

In [95] the authors designed Backfire scheme. Backfire scheme combines the farthest-distance and the minimum-distance heuristics to decrease the message overhead and hence this allows avoiding possible collisions.

Torres et al. [31] proposed a counter-adaptive dissemination schema named the Automatic Copies Distance Based broadcasting schema (ACDB). ACDB adjusts the values of its parameters to the variation of the traffic density. Specifically, the redundancy threshold and the maximum waiting time vary as needed when the number of one-hop neighbors changes. The density is estimated by using the neighborhood table and the number of queued packets in the MAC layer. The researchers overcame the excessive retransmissions problem in high-density scenarios by proposing to increase the value of the maximum waiting time and decreasing the value of the threshold.

In [41], Martinez et al. proposed a new distance-based broadcast scheme named the Enhanced Street Broadcast Reduction Scheme in Real Maps (eSBR). It improves the distance-based broadcast protocol to ensure the timely delivery of safety messages over urban VANETS. The proposed solution is based on some network information such as city structure to guarantee intelligent broadcasting. The drawback of this broadcast protocol is that interference and collisions are more probably to happen due to the lack of a mechanism against synchronous rebroadcasts.

Slavik et al. [29] designed a Distribution-Adaptive Distance with Channel Quality (DADCQ) protocol to address the need for the broadcast communications in VANETs. DADCQ protocol is based on the distance-based broadcast schema to choose the relay vehicles. The performance of distance-based broadcast schema widely depends on the estimation of the distance threshold value. But, it is hard to get an optimal value that deals with the tradeoff between efficiency and coverage capability. Typically, three factors affect the ideal value of the distance threshold, namely, traffic density, vehicles' spatial distribution, and the quality of the communication medium. These three factors summarize the main network characteristics that influence the performance of the broadcast protocol. The proposed protocol uses a threshold function that adapts its value to the variation of these three factors. The main disadvantage of DADCQ is the lack of a mechanism for recovering the lost packets.

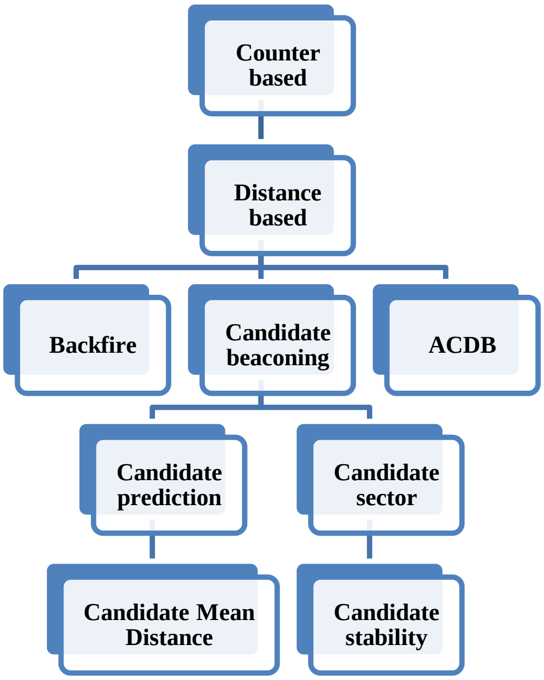


Figure 2-9 Extension works of Counter-Based and Distance- Based broadcast Protocols.

Korkmaz et al. proposed the Urban Multi-Hop Broadcast protocol (UMB) [96], which was intended to undertake the broadcast storm problem in urban VANET when the vehicle density is high. UMB requires the presence of Road-Side-Units (RSUs) at all intersections of the region of interest. This setting allows the propagation of the broadcasted message among all directions of each road. The RSUs have an enhanced line-of-sight when the network contains some obstacles such as tower buildings. In UMB, each relay node chooses the most distant neighbor vehicle within its communication range to broadcast data. Due to its reliable strategy, based on the line-of-sight and the farthest distance heuristics, UMB performs better in terms of efficiency and reachability in high traffic densities. The disadvantage of UMB is that it requires the presence of the RSUs at all street crossing points, which cannot always be possible.

Viriyasitavat et al. proposed the Urban Vehicular Broadcast (UV-CAST) protocol [22]. This is a broadcast-routing-level scheme that deals with the network fragmentation and collision problems in urban VANETs. The deployment of this solution is mainly based on two subroutines: store-carry-and-forward subroutine (SCF) and broadcast storm suppression mechanism (BSSM). UV-CAST introduced the store-carry-and-forward as a mechanism for recovering lost messages and connection disruption. This regime relies on the definition of the perimeter vehicles in the connected zone. UV-CAST supposes that the perimeter vehicles have a higher likelihood of encountering new neighbors. Therefore, these vehicles keep each received message in a local buffer and forward the saved message whenever they detect a new neighborhood vehicle. However, when a set of perimeter vehicles detects a not received message, they immediately proceed to send this message without any coordination. Consequently, redundant transmissions are highly increased. To solve this issue, UV-CAST introduced more coordination between SCF-vehicles and their immediate neighborhood by including the identifiers of newly received messages in periodic hello messages. With such a notification method, SCF-vehicle can take a decision on transmitting the message when it receives a hello message from the neighboring vehicle. The BSSM used in UV-CAST follows an intersection-based strategy. Accordingly, the intersection vehicles, in UV-CAST, have higher probability to become relaying nodes. Generally, the vehicle density around intersections is higher than non-intersection regions. Consequently, when an intersection-vehicle transmits a message, it reaches large number of vehicles.

In [97], Tonguz et al. proposed a new VANET reactive broadcast protocol named a Distributed Vehicular broadCAST protocol for vehicular ad hoc networks (DV-CAST). It disseminates the messages in highway VANET based on the neighborhood topology data. DV-CAST takes into consideration the various kinds of traffic conditions. It includes three noteworthy functions. Namely, one-hop neighborhood detection function, broadcast concealment mechanism, and store-carry-and-forward mechanism. One-hop topology information is used to estimate the current vehicle density in the road network. In a high vehicle density scenario, DV-CAST applies the broadcast concealment mechanism, where a vehicle broadcasts the message with a probability p directly proportional to the distance between this vehicle and the one-hop sender (Weighted p-Persistence forwarding heuristic) [98]. By contrast, if the traffic density is low, DV-CAST uses the store-carry-and-forward mechanism to deliver the received message across the disconnected clusters. The drawback of DV-CAST specifically lies in the scalability factor. It is only designed to operate in highway scenarios.

Villas et al. [83] suggested a novel Data dissemination pRotocol In VEhicular networks (DRIVE). DRIVE is a scalable protocol that works under different traffic densities and also over both urban and highway scenarios. Unlike the most existing broadcast protocols, which handle the broadcast storm issue in well-connected VANETs, DRIVE is designed to operate under any traffic conditions, including network partition scenarios. In high traffic density, DRIVE assigns the broadcast task to the vehicles inside a special forwarding zone called the sweet spot. To this end, the communication range of each sender is divided into four equal zones and one sub-region in each zone is designed as a sweet spot. The vehicles inside a sweet spot are most appropriate to forward data. Namely, among all vehicles within the communication range of a sender, the broadcast by a single node inside the sweet spot is sufficient to successfully delivering data. In low traffic density, where the network is likely partitioned, DRIVE delegates the task of disseminating data across network partitions to the vehicles that are outside the area of interest. The main drawback of DRIVE is the use of a backoff timer, which could increase the end-to-end delay.

Ravi et al. [14] assessed the random behavior of the traffic flow to determine the ability to build a multi-hop path over V2V communication links in VANET. The traffic flow data, which was collected from a two-lane highway, has shown that the arrival rate of vehicles obeys to the Poisson distribution law, and the E2E connectivity obeys to the binomial distribution law. Furthermore, the authors of this work proposed a stochastic multi-hop broadcasting method that takes into consideration the aforementioned distributions in the design of the new schema. Besides, Ravi et al. evaluated the connectivity between vehicles in the network by the M/M/1 queuing theory. They show that the connectivity relies on two factors: the spatial distance between vehicles and the number of V2V paths in the highway scenario.

Zhang et al. Designed a Concurrent Transmission based Broadcast protocol (CTB) [99]. CTB uses the receiver based schema wherein vehicles within the communication range of the current sender contend to be the next rebroadcaster in a fully distributed manner. To determine implicitly the most appropriate forwarders among the immediate neighbors of the current sender, each neighbor vehicle establishes a priority-based back-off timer when they receive the first copy of the disseminated message. However, the accumulated back-off time from hop to another could increase significantly the end-to-end delay. To solve this issue by CTB, the shape of the communication range is segmented into a certain number of parts and only vehicles within the same part contend between them to transmit the received message. In this manner, CTB could decrease the one-hop back-off time, which could reduce considerably the total end-to-end delay.

Summary on receiver-based multi-hop broadcasting protocols

Table 2-5 summarizes the main characteristics of the receiver-based multi-hop broadcasting protocols presented above. We note that most authors focus on the heuristics associated with the broadcasting strategy because the coverage capacity of any protocol directly depends on these heuristics. As outlined in Table 2-5, UMB, UV-CAST, DV-CAST, DRIVE, and CTB are based on the farthest distance heuristic. The main difference between them is in their scalability. DV-CAST is designed to work exclusively in highway scenarios, UMB and UV-CAST, and CTB are designed for urban scenarios, whereas DRIVE adapts its strategy to both highway and urban scenarios. We also notice that Distance-based, eSBR, and DADCQ are based on the minimum-distance-based strategy. Namely, they keep a minimum distance between the selected relay nodes to avoid redundant transmissions. As shown in Table 2-5 many authors have proposed new heuristics to enhance the broadcast coverage capabilities. For instance, link quality and signal strength heuristics are proposed in recent works. We also see that among all presented protocols, eSBR is the only one that uses road-network-topology-based strategy. However, eSBR is prone to collisions and interference due to the lack of a mechanism to avoid synchronous transmissions. In terms of anonymity preservation, almost all these protocols meet this requirement because the receive-based scheme is not dependent on the transmission of beaconing messages to select relay nodes.

Table 2-5 Summary of the relevant receiver-based multi-hop broadcast protocols in VANETs

Protocol	Broadcasting mechanism								BM	Problems treated			MI	AV
	FD	MD	CEB	CB	LsB	LqB	MB	NDP		Bs	IC	HT		
Counter-Based [22]	No	No	No	No	No	No	No	Yes	No	Yes	No	No	-	Conserved
Distance-based [22]	No	Yes	No	No	No	No	No	No	No	Yes	Yes	No	GPS	Conserved
Backfire scheme [85]	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	GPS	Conserved
ACDB [30]	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	-	Conserved
UMB [86]	Yes	No	No	No	Yes	No	No	No	No		Yes	Yes	GPS, RSU, Map	Conserved
DV-CAST [87]	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	No	GPS	Conserved
UV-CAST [21]	Yes	No	No	No	Yes	No	Yes	No	No	Yes	Yes	No	GPS	Conserved
DRIVE [89]	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	GPS	Conserved
eSBR [41]	No	Yes	No	No	No	No	No	No	No	Yes	No	No	GPS	Conserved
DADCQ [28]	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	GPS	Conserved
CTB [92]	Yes	No	No	No	No	No	No	No	Yes	Yes	No	No	GPS	Conserved

BM Beacon Messages, *MI* Modules and Infrastructure,*AV* Anonymity of Vehicles.*FD* Furthest Distance, *MD* Minimum Distance, *NDP Number of Duplicate packets*, *CB* Clustering-Based, *CEB* Centrality-Based, *LsB* Line-of sight-Based, *LqB* Link-quality-Based, *MB* Mobility-Based, *Bs* Broadcast storm, *IC* Intermittent Connection, Hidden Terminal.

2.6.4 Adaptive broadcasting protocols

According to our observations, the work of Tian et al. [100] is the only one that provided an adaptive scheme. Tian et al. designed a distributed Position-Based protocol for emergency messages broadcasting in VANETs. Because each type of emergency message has a specific zone of interest (ZoI), it is important to select the adequate broadcast direction and the number of hops required to deliver each message to its appropriate ZoI. Consequently, the authors have designed a protocol that adapts the broadcast schema according to the type of emergency message. It minimizes sufficiently network resources consumption and improves broadcast reliability because it disseminates exactly emergency messages across their zones of interest. However, this protocol is designed only for emergency-oriented applications.

2.7 Conclusion

As we have already discussed and compared different data dissemination solutions in 2.6.3, this conclusion provides just a summary of this chapter.

In this chapter, we have started by giving a short description of VANETs, including their main characteristics, the typical architecture, and the basic applications set. Next, we presented the efforts of standardization in the USA (WAVE standard) and EU (C-ITS standard) to support different communication types among vehicles and infrastructures. According to our observations, the WAVE architecture delegates the multi-hop data dissemination to the well-known IP protocol, whereas the ITS architecture involves some standards and protocols to assist data dissemination tasks.

The last part of this chapter reviews different techniques of data broadcasting in VANETs. We classify data broadcasting techniques from the perspective of the required number of hops to cover the region of interest. Namely, we classify them into one-hop broadcasting protocols, multi-hop broadcasting protocols, and adaptive broadcasting protocols.

In the next chapter, we address a specific case of multi-hop data dissemination in VANETs, which is video streaming.

Chapter 3 A state of art of video streaming over VANETs

Several basic problems negatively affect video streaming. Video streaming over VANETs is a difficult task because of the frequent change in topology, disconnected clusters, dynamic density, and channel fading. Thus, it yields no guarantees on the quality of service required by video streaming (latency, jitter, and delivery rate). Precisely, these features are unknown and dynamic in VANETs. Accordingly, the main aim of video streaming over VANETs is to design reliable solutions to deliver high-quality video while dealing with above cited VANET problems. In this chapter, we concentrate on the basic concepts of video streaming and different routing and recovery approaches to distribute video content over VANETs.

3.1 Video streaming definition

The primary purpose of video streaming is to divide the video into portions, send these portions in sequence, and allow the intended receivers to decode and playback the video sequence when a block of video is received, without being required to wait for the complete video to be received [101]. Video streaming can be designed to incorporate the following steps:

1) Dividing the encoded video into packets.

2) Beginning the transmission of these packets.

3) Decompressing video and starting the playback at the receiver node even if the sender has not finished delivering the complete video sequence.

Unlike video download, where all video packets must be delivered before the beginning of the playback, video streaming allows synchronization between distribution and playback of the video. In video streaming, there is habitually a little waiting time (on the scale of 5-15 seconds) between the start of the transmission and the start of video viewing at the receiver.

3.2 Formal expression of video streaming

More accurate knowledge can be obtained by expressing the video streaming problem through a formal description. Let *Int* be the time interval between consecutive viewed frames. Several frames have to be delivered and decompressed by the playback time. Consequently, the sequence of video frames has its strict timeout of delivering/decompressing/viewing:

- The frame number i has to be received and decompressed at T_i time.
- The frame number i+1 has to be received and decompressed at $T_i + Int$ time.
- The frame number i+k has to be received and decompressed at $T_i + k*Int$ time.

Any frame delivered after its time to leave (TTL) will be needless at the receiver side. More precisely, any frame that is received behind its decompressing and viewing timeout will not be viewed. The main aim of video streaming is to satisfy the constraints defined by the aforementioned formal description.

3.3 Video transmission characteristics

In this section, the common features of video streaming are detailed.

- **Video traffic is bursty**

  The bursty feature of video streaming is due to the form in which video is encoded. Encoding techniques used by MPEG and AVC organizations engage the Delta encoding method. This technique encodes pixel value by calculating the difference between consecutive samples instead of the pixel value itself. Thus, video is compressed, stored, and transmitted as a sequence of frames piggybacking only the motion components instead of complete frames. Depending on the difference between two consecutive frames and level of motion, encoded frames can considerably differ in size. Figure 3-1 depicts delta video encoding [20].

An I-frame is compressed by exploiting the similarity between neighboring blocks in the same image.

A Predicted frame (delta-frame or P-frame) keeps only the variations in the picture compared to the previous frame. For instance, the static pixels are not included in the P-frame, thus providing a picture compressed at a high rate.

A Bi-predictive frame (B-frame) is more compressed than I-frame and P-frame. It employs the differences between it and the previous and next frames to define the compressed content.

Figure 3-2 illustrates the size of different frame types [20]. The size of I-frame is typically between 1024 bytes and 1518 bytes, whereas the one of P-frame and B-frame is in the range of 128 to 256 bytes.

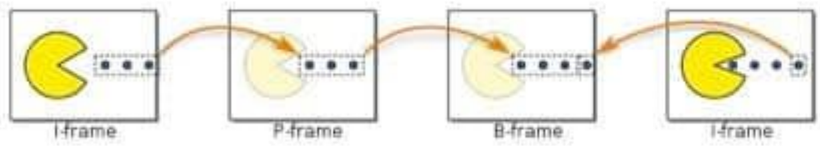


Figure 3-1 Bursty feature of an encoded video with Delta mechanism.

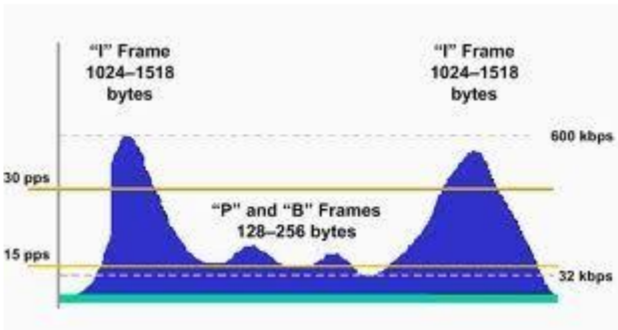


Figure 3-2 Typical sizes and bitrate of different types of frame.

-

- **Video packets can be quite large**

  Video streaming requires encoded packets to include a payload of large size. As a result, they hold a larger part of the available transmission slots, which leads them to be more prone to collisions.

3.4 Routing solutions for Video broadcast in VANETs

The routing solutions are used to create and update paths between source and destination nodes to deliver video packets with adequate quality. Broadcast aims to distribute data to all nodes within a region of interest. This section reviews the most recent routing solutions for video broadcasting in VANETs.

An efficient broadcast scheme, named VOV, was proposed in [45]. It combines the Distance-Defer-Transfer mechanism (DDT) and geographical-based approach. When a node receives a new message, it first determines whether its neighbors are within the transmission range of the sender. If this is the case, it simply saves the received message. Otherwise, the node triggers a timer for possible future rebroadcasting. VOV calculates the waiting time by determining the forwarding zones of the sender by using kinetic information. The nodes inside the forwarding zone initiate a shorter waiting time than the nodes located outside. Thus, VOV ensures that the nodes within the forwarding zones are best suited to rebroadcast the message.

In Reactive, Density-Aware and Timely Dissemination Protocol (REACT-DIS) [102], the decision of a node to become a rebroadcaster is based on the number of retransmissions of the same packet that have been heard during the waiting time. The waiting time is calculated using the geographic-greedy approach, in which a node located farther away has a shorter waiting time than one at a closer distance. In this manner, nodes that wait a short time are likely to have a high probability of receiving a small number of duplicates, making it more convenient to retransmit the received packets. Starting from the assumption that the expected additional coverage area of the scheduled node decreases when the number of duplicates increases, REACT-DIS follows a probabilistic density aware scheme. Specifically, when the waiting time expires, nodes try to rebroadcast the packet with a probability that exponentially decreases with the number of duplicates. To ensure timely delivery, REACT-DIS also maintains the relaying status during a window time instead of repeating the relay node selection process for each transmission.

Bradi et al. [48] proposed a solution named efficient VIdeo streaming over COgnitive radio VANETs (ViCoV), a video distribution method that disseminates different kinds of content in high dynamic topology networks and under different traffic densities. ViCoV chooses the most reliable Cognitive Radio channels to broadcast the data. Besides, it accurately selects a minimum number of nodes as forwarders to decrease collisions and to deliver video with high quality. ViCOV chooses The CR channels based on their accessibility across time. Furthermore, the set of forwarders is elected by considering the centrality of each node in the network. The decision to become a relay vehicle is based on a new centrality heuristic termed dissemination capacity. This heuristic provides high data delivery. It is designed to deal with the tradeoff between efficiency and reliability. However, VICOV doesn't consider the vehicles' spatial distribution factor in the relay vehicles selection process.

Rezende et al. proposed a solution named REDEC [103]. REDEC tackles the difficulty of distributing video packets with large sizes over high dynamic V2V multi-hop links. The challenges of satisfying video streaming strict prerequisites across a network with a frequently changed topology are addressed in this work. REDEC is a reactive approach in which the process of relay node election is separated from video content dissemination. This method exploits the reactivity of the receiver-based class where the decision of a vehicle to become a passive or active node is conducted at the receiving vehicles. Video packets are constituted of a large quantity of data and they are transmitted at a high data rate; this causes too many problems in the capacity of the receiver-based approach to limit redundant transmissions and to select relay nodes that have high coverage capabilities. For these purposes, REDEC substitutes the perspective of choosing new relay nodes per each transmitted packet to a time frame instead. Besides, it accomplishes the relay node election by periodically broadcasting control messages rather than performing relay-nodes selection task when the video is transmitted. In this manner, when video packets are broadcasted, each vehicle implicated in the dissemination has to check its current status assigned within the transmission of the control messages.

Quadros et al. proposed the Quality Of experience-driven REceiver-based approach (QORE) [104]. In order to keep the awareness of both quality of service and quality of experience parameters during the forwarding process, QORE is combined with the farthest distance receiver-based broadcast mechanism. The QORE strategy points to choose forwarders that can keep up better video quality from the point of view of the end-user. Therefore, when a vehicle receives a flow of video packets during a window time, a QoE function is calculated to determine the impact of the distorted packets on the quality of the received flow. Furthermore, The QoE function is added to the geographic position parameter to determine the suitability of the vehicle to become a forwarder. In this manner, QORE could handle the capacity of relay vehicles to deliver the video with high QoE and, at the same time, guarantee a better broadcast reachability.

Benmir et al. designed, in [105], a geographic-based routing protocol for video streaming in VANETs (GeoQoE-Vanet). In GeoQoE-Vanet, the forwarding nodes are selected according to the QoE factor. The decision of a node on whether or not to forward a packet is based on geographical location, heading, mobility, link volatility, packet loss rate, end-to-end delay, and jitter. The performance evaluation indicated that GeoQoE-Vanet outperforms GPSR and GPSR-2P protocols in terms of MOS, PSNR, and SSIM.

3.5 Error control and recovery

This section details the error control and recovery methods according to the taxonomy defined in Figure 3-3

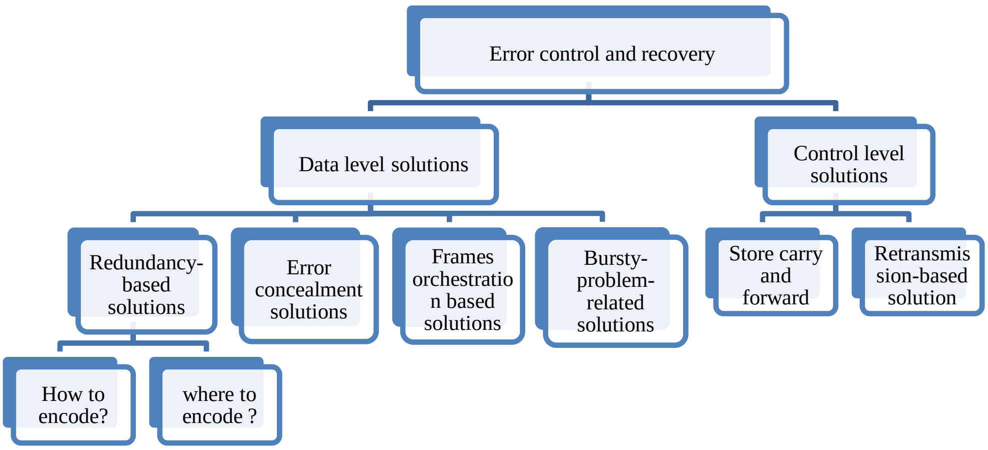


Figure 3-3 Taxonomy of error recovery for video streaming

3.5.1 Data level solutions

Data level solution is mainly classified into error concealment solutions, frames orchestration based solutions, redundancy-based solutions, and bursty-problem-related solutions.

a) Error concealment solutions

The error concealment is an error recovery method designed to recover a lost block of a video frame by simply replacing it with a region extracted from another frame in the same video sequence [106][107]. This method does not require any interaction with the sender because it is applied at the receiver side. For instance, some decoder replaces the not decoded frames with the last successfully decoded frame. The error concealment minimizes the message overhead and the latency because it overcomes errors without using any handshaking or redundancy. However, the error concealment creates some distortion in the decoded video.

b) Frames orchestration based solutions

Typically, Frames orchestration based techniques are broadly classified into Layer Coding and Multiple Description Coding.

- **Layer coding**

  In the layer coding technique [108], the sequence of frames is organized into multiple levels. The first level is called the base layer, and it includes frames of types I and P. The other levels are named enhancement layers, and they comprise B-frames. Figure 3-4 illustrates a typical layered structure generated by layer coding approach. We note that the base layer contains the most important frames, whereas the enhancement layers include less important frames that can be discarded when the network is overloaded.

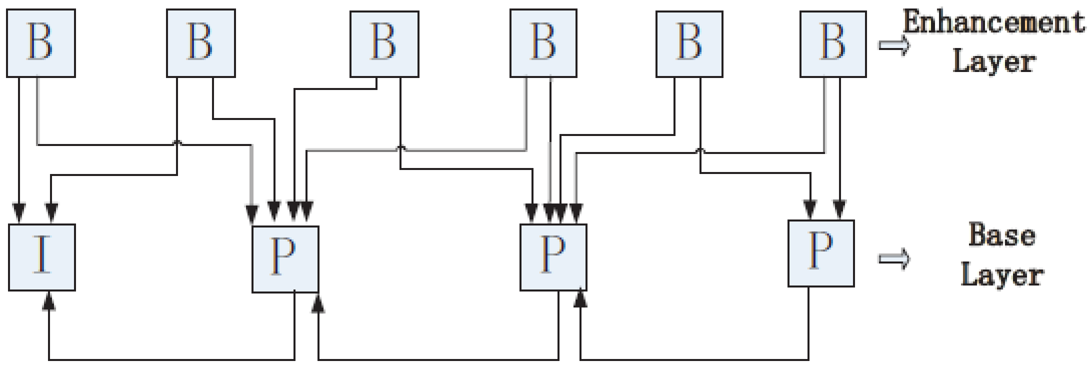


Figure 3-4 Two layers coding structure [109]

- **Multiple Descriptions Coding (MDC)**

  In MDC [110], the sequence of frames is fragmented into n sub-sets that are commonly referred to as descriptions. In contrast to layer coding, which suffers from variation in layers influence levels, all descriptions in MDC have the same level of importance. Receiving a single description is sufficient to provide an acceptable video quality. However, the joint decoding of multiple descriptors can significantly enhance the quality of the video. For instance, in Figure 3-5, the quality of the video stream obtained by receiving descriptions D1, D2, and D3 is better than the one obtained through jointly decoding D1 and D2.

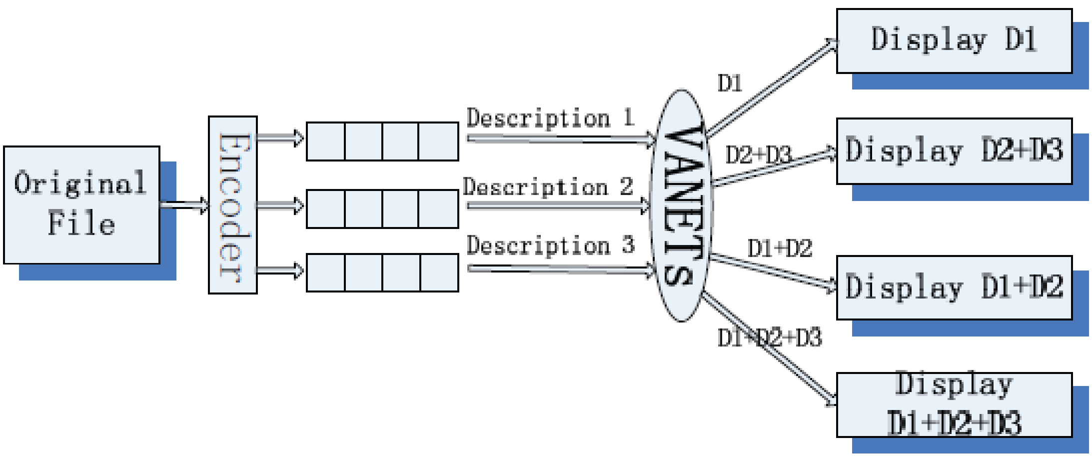


Figure 3-5 Multiple Descriptions Coding [109]

c) Redundancy-based solutions

In MPEG and H26X codec families, if a frame of type I or type P is dropped, the receiver node cannot decode the following frames in the GoPs even if they are well-received. Accordingly, a failure of receiving a single frame can lead to an immense influence on video quality at the decoder side. We can cope with this problem by using Redundancy-based techniques. Redundancy-based solutions can either be classified according to the function used to encode the data, such as linear coding (LC) and XOR functions [111][112], or based on where to encode data, e.g., Forward Error Checking (FEC), Erasure Coding (EC), and Network Coding.

- **Linear coding (LC)**

  In Linear Coding (LC) [113], the inputted data is divided into pieces, and each piece is then divided into data units. Besides, coded packets are further generated from the data units. Each coded packet is a linear combination of preselected coefficients and two or more data units. The encoder should send together the coefficients and the generated packet to allow the decoder on the receiver side to resolve the linear combination. Different LC schemes are typically classified based on how they select coefficients to generate the encoded packet.

  Random Linear Coding (RLC) [111] is based on the random generation of its coefficients to encode data; this has the advantage of enabling a fully distributed handling while keeping very low complexity. A piece of the original video stream is only fully decoded when all involved packets are received. Therefore, if the transmission delay taken to receive the required number of packets for correctly decoding the piece is high, the average latency could be excessive. Furthermore, the use of RLC for video streaming lead each set of encoded packets to be generated from one video block, which alters the nature of packet loss [114].

- **XOR-based coding**

  Exclusive OR (XOR) is useful for combining arrays of specific data into a single array that can then be used to collect the original data at decoders [115]. The techniques that use XOR functions vary primarily in terms of the number of fragments distribution and the specific parts used to compose encoded data. LT Code [116] [117] and Tornado Code [118], as well as Raptor Code [119], are examples of well-known coding methods based on the XOR function. These coding methods are intended to receive the entire original data content and are more suitable for networks with lower packet loss rates. In a lossy network, such as a VANET, coding functions that allow data decoding from partial data reception are needed [120].

- **FEC**

FEC [121] aims to add redundant data that can be used to restore lost data in an unreliable UDP/RTP-based video streaming. For instance, to deal with data losses in unreliable communication, FEC basically uses an encoding technique that generates I data packets from J data packets, where I-J is the number of redundant packets. For certain coding functions, if assuming that J packets of the I transmitted packets are received without errors, the original data can be decoded. However, the additional data increases the message overhead. Coding functions used in FEC can be broadly classified into two classes: the first class uses linear coding to generate redundant data (e.g., linear coding), while the second one applies bit by bit transformation, such as exclusive-OR function (XOR).

- **EC**

EC is an extension of FEC [122] that uses a coding technique, such as linear coding (LC) and XOR coding, to generate redundancy in the video stream. Namely, EC combines k packets (k>=2) through a function f(p1,p2,...,pk) to provide EC packet. In Figure 3-6, f(a,b), f(b,c) and f(c,d) generate EC1, EC2, EC3 packets, respectively. For example, if EC1 and EC3 are well received, we can decode them to generate all packets (a, b, c, and d packets).

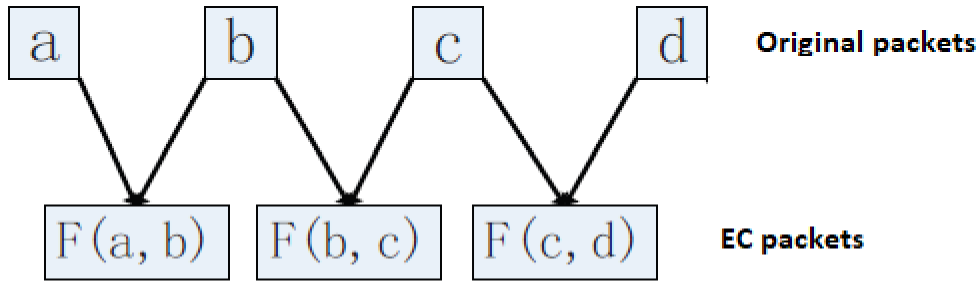


Figure 3-6 Erasure Coding

- **Network coding (NC)**

A relevant feature of wireless networks, including VANETs, is that communication medium is shared between neighboring nodes. This characteristic allows the neighboring vehicles to receive each transmitted packet at the same time. Many data dissemination solutions exploit the redundant broadcasts by neighbor vehicles that can communicate within the same wireless medium. Network Coding is one of these solutions.

Network Coding (NC) in wireless networks, and especially in vehicular networks, is intended to efficiently use the shared wireless medium by asking relay nodes to re-encode the received packets before forwarding them [123] [113]. In this manner, the not useful transmission of duplicate packets can be reduced significantly.

For instance, we consider relay-node *n* receives the set of packets *{p1, p2... pk}* required to decode an entire block. Rather than straight forwarding them as received without any modification, it decodes them and re-encodes the decoded block into a new set of packets by employing a coding function *E* to use the shared channel efficiently. Therefore, each relay node can likely generate packets with different content, which decreases the amount of redundant transmission. NC methods generate high diversity through the different packets encoded at each relay-node, which allows the recipient nodes to gather original data instead of duplicate packets. The coding function *E* can be either based on XOR or random linear coding (RLC), but the latter is more appropriate to NC. Indeed, RLC selects its coefficients randomly, which highly increases the diversity.

d) Bursty-problem-related solutions

The bursty nature of video has a great impact on the performance of video streaming. A mechanism that can deal with this issue is interleaving (IL) [104]. The principal purpose of IL is to convert the bursty frame losses with a big gap into uniform frames losses with multiple small gaps. Figure 3-7 outlines an example of how bursty loss affects the quality of the video sequence. For not received I-frame, 18 frames are affected. For not received P-frame at the beginning of the GoPs, 15 frames are distorted. When one b frame is lost, only one frame is affected. A possible solution to this issue is by using interleaving method.

As illustrated in Figure 3-8, the original video sequence is interleaved by reordering the frames. When a cluster of three frames is dropped (frames 1, 2, and 3) in the first reordered GoPs during the transmission, the Interleaving method converts the big gap into small gaps. Based on the frame-copy error concealment algorithm, the errors in the received GoPs at the decoder are suppressed by copying the preceding frame. By Contrast, if interleaving is not used, the loss of frames four, five, and six produces one lengthy gap.

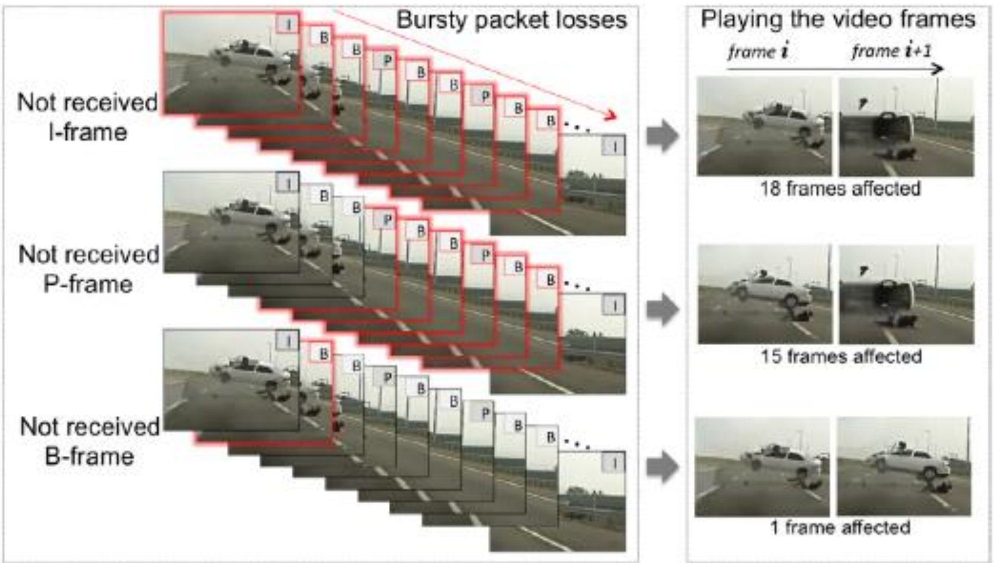


Figure 3-7 Example of the impact of bursty losses in video stream [104]

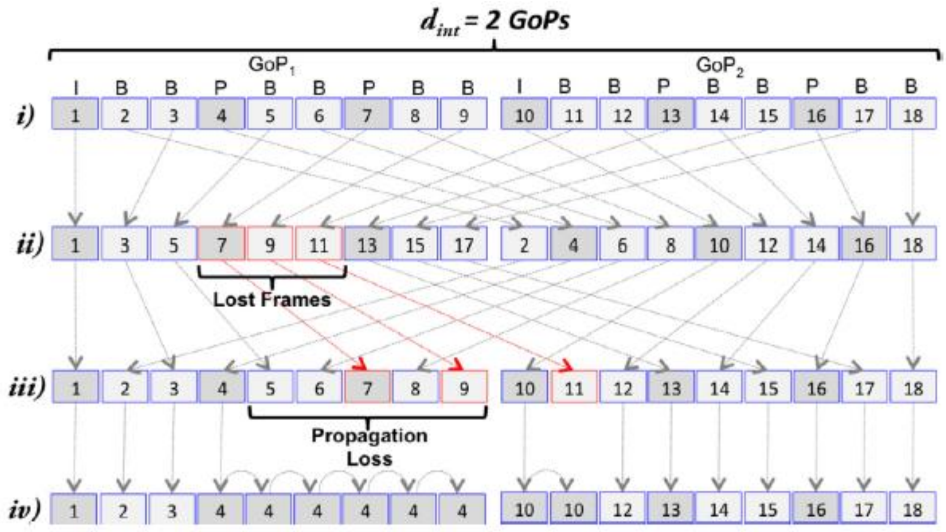


Figure 3-8 Interleaving method example with 2-distance [104]

3.5.2 Control level solutions

In the control level solution, the loss of packets is recovered through retransmissions. We classify the control level solutions into end-to-end retransmission-based and Store carry and Forward classes.

a) End-to-end retransmission

In the end-to-end retransmission-based method, the destination node uses a reverse path to either send a positive acknowledgment in the case of well-received packets or a negative notification when a packet is missed. The negative notification allows the source node to retransmit the lost packet. This method is only useful for unicast routing class. Although this approach efficiently recovers lost packets, it suffers from round trip time. Additionally, the use of end-to-end retransmission in broadcasting is restrictive because all nodes in the region of interest are receivers.

b) Store carry and forward (SCF)

SCF approach is only useful for broadcasting routing class among unreliable UDP/RTP transport layer, and it is designed as an alternative to end-to-end retransmission. SCF is hello-messages based method proposed to recover missed packets [33][47][48][22]. In the basic SCF approach, nodes store each correctly received packet in a local retransmission cache until the packet’s time-to-live (TTL) expires (TTL is usually an application layer-specific parameter). Furthermore, when a node sends a beacon message, it notifies its neighborhood regarding the packets that were correctly received, enabling the neighbors to resend the packets that were not yet received during the first phase of the broadcasting.

3.5.3 Error recovery solutions for video broadcast in VANETs

Wang et al. created an EC-based relaying scheme [124]. They confirmed through simulation that the overhead produced by k relays when using the EC-based relaying method is the same one generated by one relay when using a basic forwarding method. Nevertheless, the authors of [125] proved that EC could not improve overall reliability due to the lack of a partial recovery strategy. A minimum number of packets must be received in order to decode the video block.

In [126], the researchers integrated EC in Real-time Transport Protocol (RTP) to cope with the excessive loss of video packets in vehicular networks. Furthermore, RTP was adapted to VANETs by adding two new converters. The first one transforms the RTP packet to the EC-RTP packet before transmitting it. The second one transforms the EC-RTP packet to the RTP packet to can be used by the decoder.

In [127], the authors proposed FEC and Interleaving Real-Time Optimization (FIRO) in VANETs. This approach combines three techniques: FEC to deal with uniform losses, interleaving to cope with burst losses, and an estimating technique to predict the loss ratio in the communication medium. The parameters of FIRO are dynamically adjusted according to the predicted loss ratio. FIRO outperforms both FEC and interleaving methods in terms of video quality. Besides, the researchers illustrated that XOR-based EC could considerably decrease the packet loss ratio with an acceptable end-to-end delay.

The authors in [104] combine the interleaving method with their proposed QoE-aware and driven Receiver-based (QORE) routing protocol to alleviate the effect of large gap losses.

In [102], Rezende et al. combine REACT-DIS with RLC-NC. They showed, through network simulation, that REACT-DIS/RLC-NC reduces the network throughput compared with the used transmission data rate. However, REACT-DIS/RLC-NC satisfied video streaming needs for data rates higher than 1 Mbps, which was not possible when REACT-DIS was used alone. REACT-DIS and Network Coding together satisfies video streaming needs while limiting the network overload caused by unnecessary transmissions. This is expected due to the error recovering features of Network Coding and the reactiveness of the receiver-based approach.

In [114], Rezende et al. have conducted a complete investigation on the use of EC and NC for video streaming over VANETs. They have created a coding method based on the XOR function with a policy that considers both the level of distribution and selection of proper segments for video streaming over VANETs. Moreover, they have introduced a new approach to improve video broadcast that uses EC at the source node and NC at other nodes. Furthermore, they have provided a selective mechanism that was proved to be very efficient. The redundant data was only added when packets include data from I-frames. The simulation results showed that the selective approach did not improve the delivery ratio. However, the message overhead was decreased significantly compared to when the redundancy was used for all packets.

Maia et al. [47] proposed an SCF method to deal with the data loss in VoV protocol. In VoV, each vehicle stores any received message in its cache for a slot of time. Additionally, vehicles use hello messages to send identifiers of all received packets towards the immediate neighborhood. If a neighbor detects that the vehicle failed to receive packets in the first step of dissemination, it sends them to this vehicle. To introduce more control and avoid not useful redundant transmission caused by basic SCF proposed by Viriyasitavat et al. [22], the SCF in VoV provides a broadcast concealment method that follows a timer-based approach. Thus, each vehicle determines its waiting time based on the closest distance heuristic. The waiting time is directly proportional to the distance between the sender and the receiver. Consequently, the closest node is likely more appropriate to retransmit the lost packets. Finally, the retransmission of the closest node conceals the one of the other nodes.

Li and Boukerche. [33] use jointly interleaving and store-carry-and-forward (SCF) methods to cope with channel losses. On one side, the first solution is used to change the distribution of error from a lengthy loss pattern to a single loss pattern. On the other side, SCF is used to deal with a single loss pattern. Furthermore, the authors introduced more control of redundancy in SCF by providing three new mechanisms: involving only backbone nodes in the SCF scheme, avoiding the retransmission of nodes that have a distance less than *2/3R* from the sender (*R* is the transmission range), and keeping packets in the local cache for a limited time.

In [48], Bradai et al. proposed a table neighborhood-based suppression mechanism to provide more coordination and avoid possible collision due to the redundant rebroadcasting in SCF. In this approach, when a node receives a hello message, it retransmits the required packet if it is a relay node. Otherwise, it checks if there is a relay node within its transmission range that can rebroadcast the required packet. If it is not the case, the node retransmits the packet. In this way, not useful retransmits are avoided.

3.6 Conclusion

This chapter provides the background of video streaming, specifically in VANETs. Most works focus on enhancing the video streaming quality through reliable routing protocol along with error-resilient methods to recover the loss of packets. Furthermore, this chapter involves video streaming definition, the characteristics of an encoded stream, routing protocols for video streaming over VANETs, and the two levels of error recovery solutions: data level and control level. In the next chapter, we will present our first contribution to improving counter-based and distance-based multi-hop broadcast protocols in urban VANETs. The proposed solutions are based on road network topology to enhance the coverage capabilities.

PART TWO: SCIENTIFIC CONTRIBUTIONS

Chapter 4 Road network layout based multi-hop broadcast protocols for Urban Vehicular Ad-hoc Networks

In chapter 2, we reviewed many one-hop and multi-hop dissemination methods. In this chapter, we analyze the well-known counter-based and distance-based heuristics in urban VANETs as the core of our proposition.

These schemes are characterized by their stochastic behavior, which negatively influences their coverage capacity. Presently, we design special schemes for the urban environment using the counter and distance heuristic as the primary point. Thus, we propose two road network layout based solutions: Enhanced Counter-based broadcast protocol in Urban VANET (ECUV) and Enhanced distance-based broadcast protocol in Urban VANET (EDUV). These two protocols are created in the aim of improving the coverage capacity in urban VANETs.

The remainder of this chapter is organized as follows. Section 4.1 presents our contribution. Section 4.2 presents and details the proposed analytical models. The analytical models and network simulation results are detailed and discussed in section 4.3. Finally, a conclusion is presented in section 4.4.

4.1 Analysis of the stochastic behaviour of counter and distance heuristics

In this sub-section, we analyze the basic schemas of counter-based and distance-based protocols. First, an overview of these protocols is provided. Next, two examples that show

how the stochastic behavior of these schemas could prevent the message propagation among the different directions of the road network are given.

4.1.1 Analysis of counter-based protocol

The counter-based technique uses a one-hop traffic-aware mechanism to reduce redundancy and concurrent access. Accordingly, when a node receives a message, it applies a random backoff time. During this period, the node counts the number of duplicate messages retransmitted by its one-hop neighbors. After the expiration of the backoff time, the node broadcast the message only if the calculated number of the listened messages during the waiting time is less than a predetermined threshold C_{thr}. Figure 4-1 outlines the main steps of this algorithm.

Figure 4-2 outlines a special case when counter-based schema disseminates a message in urban VANET. We assume in this case that the value of the threshold C_{thr} is set to one. We point up that the bold-lines (in Figure 4-2 and Figure 4-4) represent the one-hop links between the vehicles. As shown in Figure 4-2, the vehicle S broadcasts a message to its one-hop neighbor vehicles (A, B, C and D) for the first time. When these neighbor vehicles receive the message, they wait for an arbitrary time (random waiting time) before taking a decision to either rebroadcast or left behind the received message. In this example, we have considered the worst case in which the waiting time of the vehicle A expires before the ones of the vehicles B, C and D. Upon the waiting time of the vehicle A expires, it rebroadcasts the received message. As a result, the rebroadcasts of the vehicles B, C, and D are suppressed. Hence, the propagation of the message across the roads 2, 3, and 4 is prevented (because the number of duplicate messages is equal to the threshold value). This problem occurs because of the stochastic behavior of this protocol that negatively affects the spatial deployment of the relay-nodes in the network.

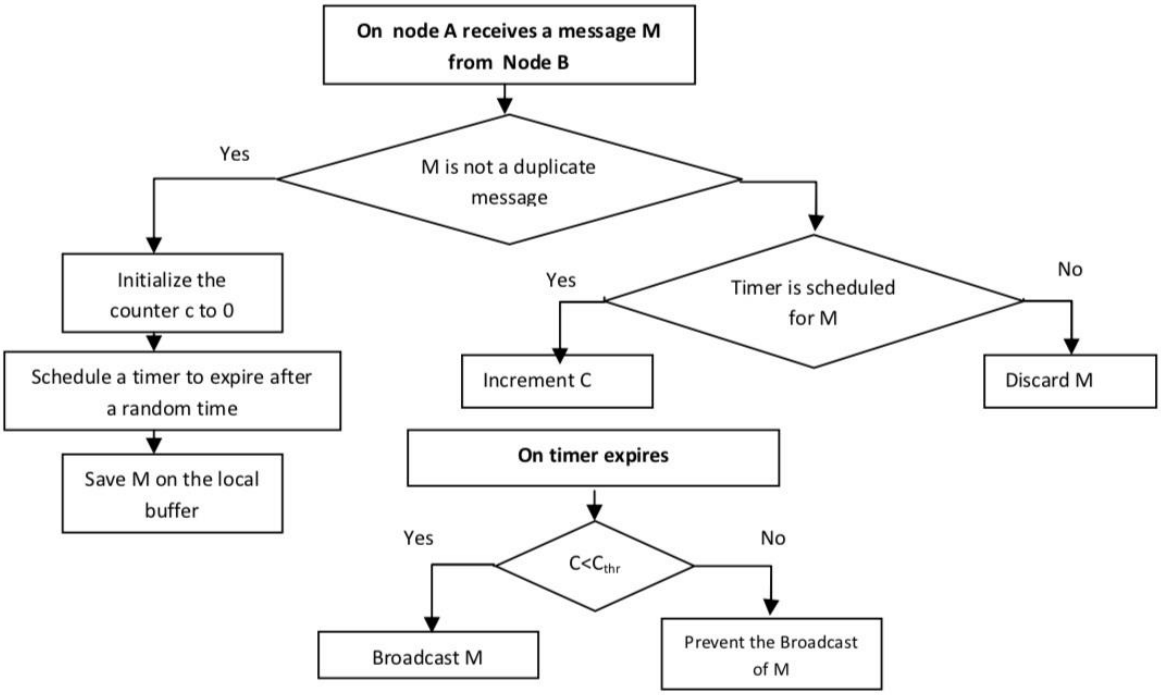


Figure 4-1 Flowchart of Counter-Based broadcast protocol.

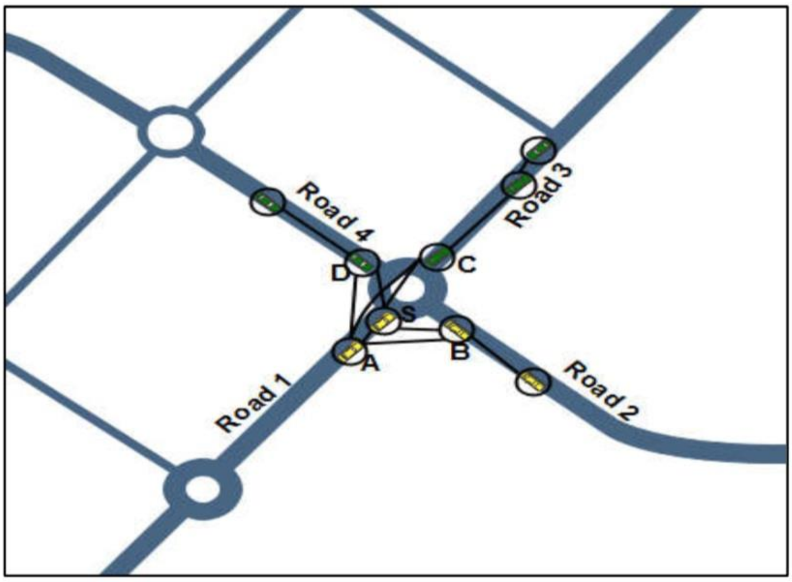


Figure 4-2 Counter-Based protocol scenario.

4.1.2 Analysis of Distance-based protocol

The second schema is the distance-based broadcast protocol. Figure 4-3 outlines the main steps of this algorithm. This mechanism is based on the distance heuristic. Accordingly, if node A is very close to its neighbor node B, there is little additional coverage when node B will be the next broadcaster node. By contrast, if node A is far away from the node B, the extra coverage will be wider. Consequently, when the node B receives at the first time a message, it takes the broadcast decision of this message based on the distance between it and the node A. When this distance is lower than a predefined threshold (D_{thr}), the node B prevents the rebroadcasting of the received message. Otherwise, the node B rebroadcasts the received message after the timeout of a random delay, providing that the same message has not been received from another node C where $\| BC \| \leq D_{thr}$ (D_{thr} is the distance threshold value).

Figure 4-4 outlines a very serious scenario when the distance-based schema is used. We assume in this scenario that the distance between the vehicles S and B is higher than D_{thr}, the distance between the vehicles S and C is higher than D_{thr} and the distance between the vehicles C and B is lower than D_{thr}. For instance, the vehicle S initially broadcasts a message toward its immediate neighbor vehicles (A, B and C). When these latter receive the broadcasted message, they wait for a random time (waiting time). If the waiting time of C expires before the one of B, vehicle C rebroadcasts the received message to its one-hop neighbors. Therefore, the vehicle B inhibits the rebroadcasting of this message because the distance from C to B is lower than D_{thr}. Consequently, the broadcasted message cannot propagate in the Road 3.

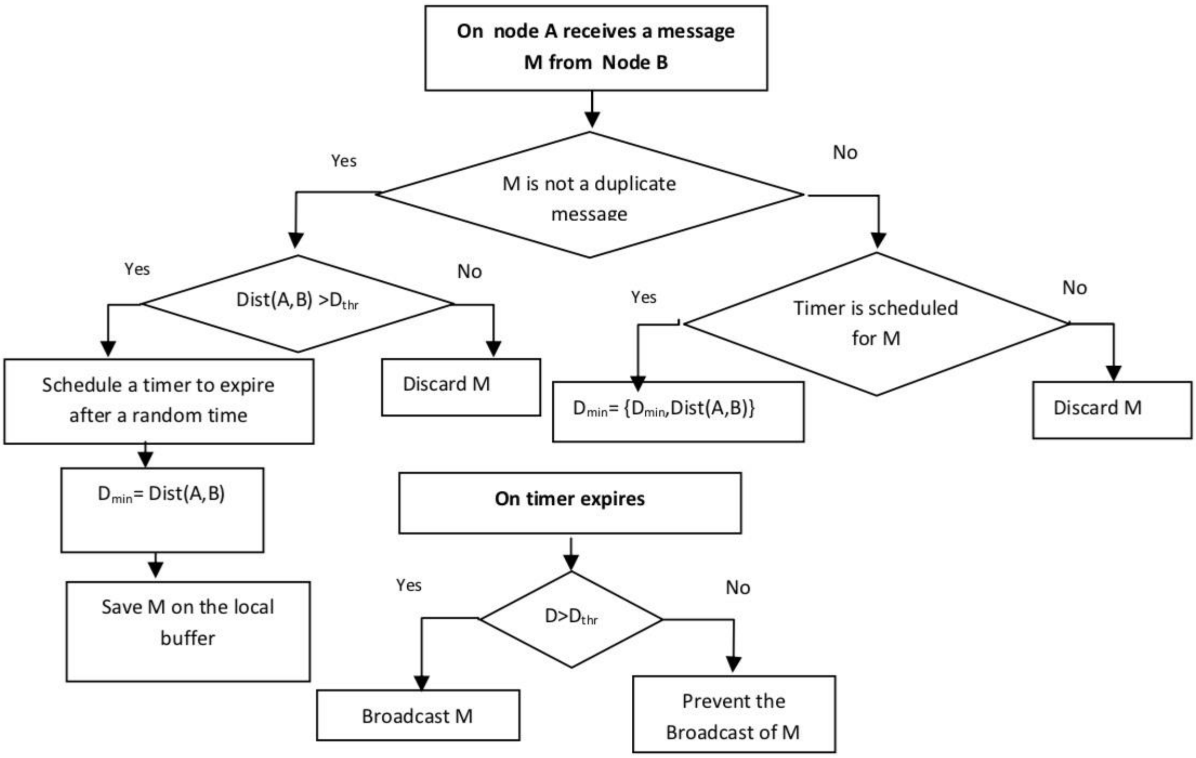


Figure 4-3 Flowchart of Distance-Based broadcast protocol.

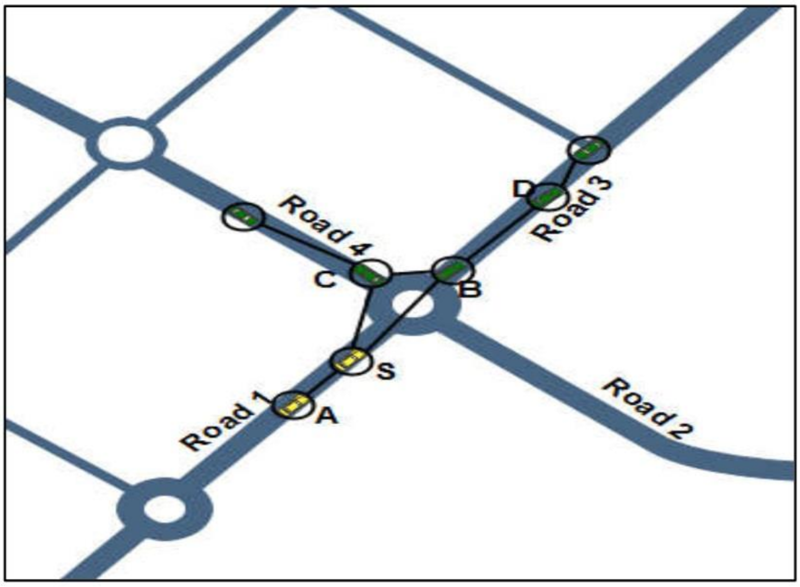


Figure 4-4 Distance-Based protocol scenario.

4.2 Proposed methods

As it is shown in sub-section 4.1 , the drawback of the conventional schemas of receiver-based broadcast protocols is mainly related to their stochastic behavior, which can prevent message propagation across all road segments. Consequently, one cannot ensure that they always meet the coverage capacity requirement. The main aim of this work is to alleviate this issue by taking into consideration the relative positions of relay nodes with respect to the layout of the urban road network. In an urban scenario, vehicles cannot move freely and anywhere in their environment, but they are imposed to roll according to the road network topology. Therefore, the road network topology is a very important characteristic of urban VANETs that cannot be omitted in the design of a reliable broadcast protocol. Unfortunately, most receiver-based protocols do not consider the road network layout in the definition of relay nodes selection strategy. In this section, we present two new receiver-based protocols (ECUV and EDUV protocols), designed to handle the broadcast process in an urban scenario. ECUV and EDUV use the road-network-layout information to enhance broadcast reachability and coverage capabilities in urban VANET. The list of notations utilized in the different algorithms is given in Table 4-1

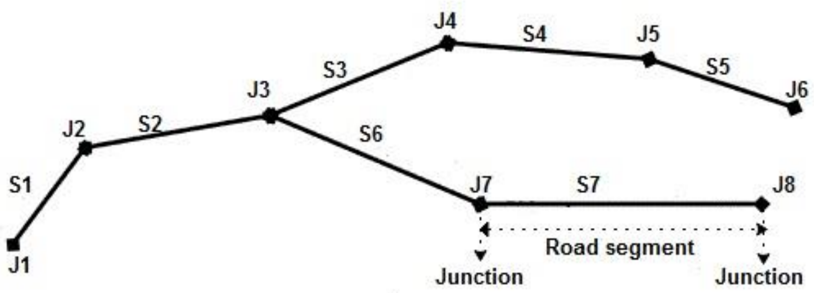


Figure 4-5 Road network layout example.

Table 4-1 Notations used in the different algorithms.

Notations	Descriptions
S	Node state variable.
H	The heuristic that defines the suitability of nodes for rebroadcasting a received message.
(X_{RN},Y_{RN})	Geographical position coordinates of the receiver node.
(X_{SN},Y_{SN})	Geographical position coordinates of the sender node.
Id_road_{RN}	Road segment identifier of the receiver node.
Id_road_{SN}	Road segment identifier of the sender node.
Map_to_SI(X,Y)	The function that maps the geographical position coordinates to the corresponding road segment identifier.
$Min(x_1,x_2)$	Return the minimum value between two numbers x_1 and x_2
Thr	Threshold parameter
C_{Thr}	Counter threshold parameter.
D_{Thr}	Distance threshold parameter
c	Counter variable.
d_{min}	d_{min}Minimum distance variable

4.2.1 Network model, system requirements and general approach

We consider a set of n vehicles $V = \{v_1, v_2, \dots, v_n\}$ that move over an urban area. A VANET can be defined as a graph represented by a set of vertices and a set of edges, where each vehicle $v_i \in V, i = 1..n$ denotes a vertex, and each DSRC wireless link between two vehicles v_i and v_j, $i \neq j$ represents an edge. The immediate neighborhood of a vehicle v_i is a subset $\mathrm{IN}(v_i)$ of the set V, where each element of $\mathrm{IN}(v_i)$ lies within the transmission range of vehicle v_i.

All vehicles in the network are equipped with a localization sensor (e.g., a GPS receiver), a digital map of the road network, a geo-coding module, and an 802.11p WAVE/DSRC network interface controller. The geo-coding module is used to recover the nearest road segment in the road network map for given geo-position coordinates. By convention, a road segment refers to a street bounded by two consecutive junctions. Thus, we define the road network layout as a graph $G(VG, EG)$, where vertices $VG = \{vg_1, vg_2, \ldots, vg_n\}$ are the set of junctions in the road network and edges $EG = \{eg_1, eg_2, \ldots, eg_p\}$ are the set of road segments (streets) connecting these junctions. Figure 4-5 illustrates an example of how to segment the road network to show the layout feature. Besides, the system complies with the protocol requirements, by using a digital map, to provide a unique identity to each road segment. Also, to be included, the header field of each transmitted packet requires the position coordinates of the sender and the sequence number of the transmitted message.

Multi-hop broadcasting protocols in urban VANETs are intended to support the requirement of vehicles to share data with one other within a two-dimensional urban area. The information is shared by delivering data to vehicles within an urban region over a multi-hop V2V link. The typical use case is the point of interest notification service, in which a roadside unit announces the availability of a point of interest to the surrounding vehicles. E.g., the broadcast of information regarding vehicle energy supply station, such as its location, the types of the available energies and the associated waiting time. Thus, the main requirement of this type of broadcasting protocols is to select a subset of relay nodes $R = \{r_1, r_2, \ldots\ldots, r_k\}$ from the set V, such that$IN(r_1) \cap IN(r_2) \cap IN(r_3) \cap \ldots \cap IN(r_k) = V$. A very high value of k can lead to the broadcast storm problem, whereas a very low value can negatively affect the coverage capacity.

Most receiver-based multi-hop broadcast protocols are designed around a broadcast concealment mechanism. The main purpose of this mechanism is to avoid the not useful transmission redundancy while maximizing the coverage capacity of the broadcast protocol.

Our methods combine a new road-based broadcast concealment mechanism and the common design of the received-based approach, wherein vehicles calculate the value of a state variable at their positions and compare the value of this variable to a threshold value to determine their suitability to rebroadcast a received packet. If we assume that *v* is an element of a given cluster *C*, the vehicle *v* determines the value of its state variable based only on the duplicate packets received from members of this cluster. E.g., in Figure 4-6, to extract the layout feature of the road network in the vicinity of vehicle *A*, the shape of the transmission range of *A* is decomposed into five segments and the vehicles in each segment are grouped into the same cluster. In this manner, we obtain 5 clusters: $\mathrm{SEG1} = \{\mathrm{A,B,C}\}$, $\mathrm{SEG2} = \{\mathrm{D}\}$, $\mathrm{SEG3} = \{\mathrm{E,F}\}$, $\mathrm{SEG4} = \{\mathrm{G}\}$,$\mathrm{SEG5} = \{\mathrm{H,I,G}\}$. According to the road-based concealment broadcast mechanism, the state variable of *A* could only be affected by the duplicate packets received from vehicles *B* and *C* because they are in the same cluster as *A*. Namely, the packets broadcasted by members of clusters$\mathrm{SEG2}$, $\mathrm{SEG3}$, $\mathrm{SEG4}$, and $\mathrm{SEG5}$ cannot suppress the rebroadcast of vehicle *A*. When this process is repeated in each hop, it allows the deployment of the relay nodes in all road segments.

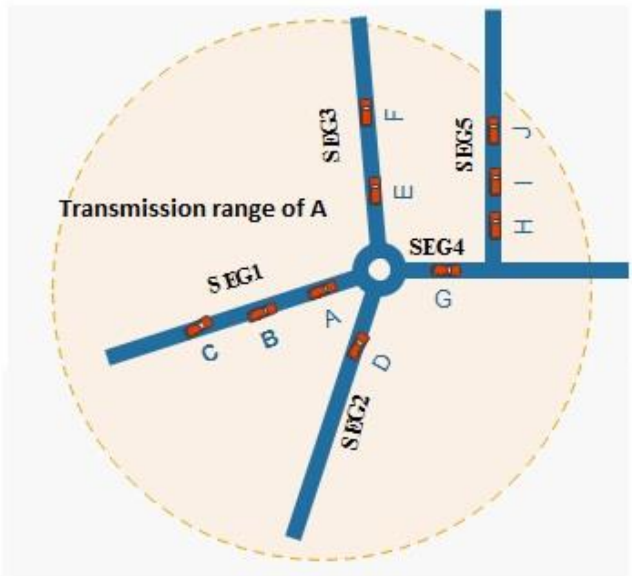


Figure 4-6 Road-based broadcast concealment mechanism.

Algorithm 1 The general approach of Road-based broadcast concealment mechanism.

```
Begin
1. On receive a message m
2.      if m is a new message then
3.      begin
4.        Initialize the node state variable S according
          to the heuristic H
5.        Save m in the internal cache
6.        Schedule a timer to expire after random
          t seconds
7.      end
8.      else
9.      begin
10.       Id_road_RN =Map_to_SI(X_RN,Y_RN)
11.       Id_road_SN =Map_to_SI(X_SN,Y_SN)
12.       if a timer is scheduled for m and
           Id_road_RN==Id_road_SN then
13.        update the value of S according to the
           heuristic H
14.       else
15.        discard m
16.     end
17.  On timer expire
18.    Compare the values of S and Thr and accordingly
       decide whether to rebroadcast the message m or not
End
```

Algorithm. 1 details the main steps of the Road-based broadcast concealment mechanism. Like most receiver-based broadcast protocols, once the first copy of the message *m* is received, the receiving node initializes the state variable *S* according to the heuristic *H*, saves *m* in the internal cache, and schedules a timer to expire after random *t* seconds (Algorithm. 1 lines (2-7)). *H* is the heuristic that defines the suitability of nodes for rebroadcasting a received message. As shown in Algorithm. 1 lines (8-16), the new feature of the road-based broadcast concealment mechanism arises when a candidate vehicle receives a duplicate message. Namely, it updates the value of the state variable *S*, according to the heuristic *H*, only if the sender and the receiver are on the same road segment, provided that the timer is currently scheduled. Finally, upon the timer expires, the node makes its decision to become a relay-node based on the value of *S* relative to the threshold *Thr*.

Algorithm 2 ECUV protocol

```
Begin
1. On receive a message m
2.       if m is a new message then
3.       begin
4.         Initialize the counter of duplicate message c=0
5.         Save m in the internal cache
6.         Schedule a timer to expire after random
           t seconds
7.       end
8.       else
9.       begin
10.        Id_road_RN =Map_to_SI(X_RN,Y_RN)
11.        Id_road_SN =Map_to_SI(X_SN,Y_SN)
12.        if a timer is scheduled for m and
            Id_road_RN==Id_road_SN then
13.          Increment c
14.        else
15.         discard m
16.      end
17.  On timer expire
18.    if c ≥ C_Thr then
19.        Cancel the transmission of m
20.    else
21.        Broadcast m
End
```

4.2.2 Enhanced Counter-based broadcast protocol in Urban VANET (ECUV)

In this section, we present our first contribution to support message broadcasting in urban VANET. Our solution uses counter-based heuristic in association with the road-based broadcast concealment mechanism to enhance the coverage capacity in urban VANET. To this purpose, each vehicle utilizes a counter to keep aware of how many times the disseminated message is received from the members of its cluster. Algorithm. 2 presents the main steps of ECUV protocol. As shown in this algorithm, when a vehicle receives a new disseminated message for the first time, it initializes a local counter c to 0. Besides, this vehicle stores the received message in a local buffer for a possible future rebroadcasting and schedules a timer to expire after a random number of seconds (lines 2-

7). When the vehicle receives a duplicate message from a member of its cluster (road segment), it increments the counter *c* if a timer is currently scheduled for the received message (lines 8 to 16). When the timer expires (line 17), the value of c is checked to decide whether or not to rebroadcast the message. If the value of c is higher or equal to the value of the threshold C_{thr}, the vehicle prevents the message rebroadcasting (lines 18-19). Otherwise, it rebroadcasts the received message (lines 20-21).

Algorithm 3 EDUV protocol

```
Begin
1. On receive a message m
2.       if m is a new message then
3.       begin
4.         Id_roadRN =Map_to_SI(XRN,YRN)
5.         Id_roadSN =Map_to_SI(XSN,YSN)
6.         if Id_roadRN==Id_roadSN then
7.           Initialize dmin by the distance between
             the sender and the current node(receiver)
         else
8.           dmin = R
9.         if dmin > DThr then
10.         begin
11.           Save m on the local buffer
12.           Schedule a timer to expire after random
              t seconds
13.         end
14.      end
15.      else
16.      begin
17.        Id_roadRN =Map_to_SI(XRN,YRN)
18.        Id_roadSN =Map_to_SI(XSN,YSN)
19.        if a timer is scheduled for m and
            Id_roadRN==Id_roadSN then
            begin
20.          Set d to the distance between the current
             vehicle and the sender of m
21.          dmin = Min{dmin,d}
            end
22.         discard m
23.      end
24.  On timer expire
25.    if dmin > DThr then
         Broadcast m
26.    else
         Cancel the broadcast of m
End
```

4.2.3 Enhanced Distance-based broadcast protocol in Urban VANET (EDUV)

This section presents our second contribution which combines the minimum Distance-based heuristic and the framework of the new road-based broadcast concealment mechanism to handle the broadcasting process in urban VANET. Namely, the protocol updates the value of the state variable only if the sender and receiver are on the same road segment (sender and receiver are one-hop neighbors). The state variable in EDUV is the minimum distance d_{min}.

Algorithm. 3 presents the proposed EDUV protocol. As outlined in Algorithm. 3 (lines 1-14), when the vehicle receives a new message, it initiates a timer for this received message only if one of the following two cases is satisfied.

- The two vehicles (sender and receiver) are on the same road segment and the distance between them is higher than the threshold D_{thr}.
- The two vehicles (sender and receiver) are located on different road segments.

During the waiting time, each vehicle observes the duplicate packets received from its vicinity. If this vehicle receives a duplicate packet from a sender that lies within the range of its road segment, it updates the value of the state variable d_{min}. The new value of d_{min} is set to the distance from the sender to the receiver only if this distance is less than the current value of d_{min} Algorithm. 3 (lines 15-23). The process in which a vehicle decides whether to rebroadcast or not the received packet is depicted in Algorithm. 3 (lines 24-26). This process is triggered when the timer expires. The vehicle checks if the distance d_{min} is not less than the permitted minimum-distance D_{thr}. In the event where d_{min} is greater than D_{thr}, the vehicle broadcasts the received message. By contrast, if d_{min} is less or equal to D_{thr}, the vehicle drops the message.

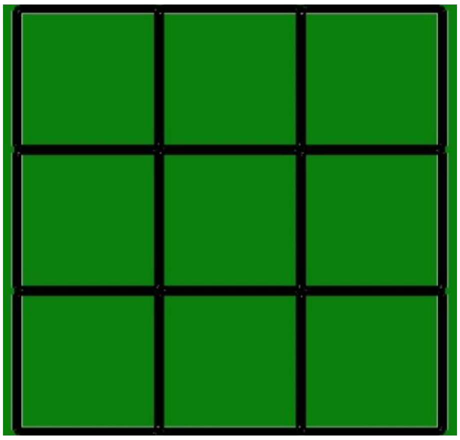


Figure 4-7 Manhattan-like topology.

4.3 Analytical model

This section presents the theoretical analyses of the proposed ECUV and EDUV broadcast protocols. An analytical model is provided to predict the behavior of these protocols. The model is inspired by the work of Williams et al. [128]. In their work, the authors designed a probability model to predict the broadcast probability for counter-based and distance-based broadcast protocols in MANET. They assumed that the nodes are deployed in an obstacle-free area where there is no constraint on the mobility of nodes. In this work, we adapt the analytical model of Williams et al. to predict the behavior of ECUV and EDUV in the urban Manhattan-like topology.

4.3.1 Model requirements and assumptions

Because it is difficult to establish the model under complex and irregular road-map layout of urban VANET, the following assumptions are introduced to simplify the problem.

- The distribution of road segments follows a Manhattan-like topology. Figure 4-7 illustrates the Manhattan-like road map for the proposed analytical model. The topology of this roadmap consisted of n segments that have the same length and the same width. Moreover, the road segments are distributed according to a rectangular grid topology.

- We assume that the communication radius has the same value for all vehicles in the network, and the length of each road segment is lower or equal to this radius. Therefore, when two vehicles are on the same road segment, they will necessarily be one-hop neighbors (for more details, refer to sub-section 4.3.2 and sub-section 4.3.3).
- Vehicles are uniformly distributed over the network. The initial geographical positions of the vehicles are randomly distributed over the road map. When a vehicle reaches an intersection, it goes straight, turns to the left, turns to the right, or turns backward with the same probability (the model is built around a stochastic feature). Namely, the probability of taking a specific direction is 1/4 (the probability is randomly and uniformly distributed).
- As defined in [128], the probability of forwarding is the same for all the vehicles in the networks.

4.3.2 Model for EDUV protocol

This section presents the proposed analytical model that predicts the behavior of EDUV protocol. Let v_1 and v_2 two vehicles that circulate on the same road segment. We assume that the timers of v_1 and v_2 are scheduled. We give the following elementary events to calculate the probability of v_1 receiving a message from the vehicle v_2 during the waiting time such that the distance between them is lower or equal to the threshold D_{thr}.

- C1: The vehicles v_1 and v_2 move along the same road segment.
- C2: The distance between the vehicles v_1 and v_2 is lower or equal to the threshold D_{thr}.
- C3: The vehicle v_2 sends the message.
- C4: The scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.

It is important to remember that v_1 receives directly the message transmitted by v_2 only if the two vehicles are one-hop neighbors. In our model, we assume that the length of each road segment is less or equal to the communication range radius (the second assumption in sub-section 4.3.1). Therefore, this condition is implicitly fulfilled by C1.

Let n is the number of road segments in the roadmap. The geographical positions of the vehicles are uniformly distributed in the network. Consequently, the probability that the vehicles v_1 and v_2 are located together on the road segment i (event C1) is given by Equation 4.1.

$$\boldsymbol{p_i(C_1)} = \frac{\boldsymbol{A_i}}{\sum_{k=1}^{n} \boldsymbol{A_k}} \tag{4.1}$$

Where A_k is the area of the road segment k.

By considering the first assumption defined in sub-section 4.3.1 (all the road segments have the same length and the same width, and hence they have the same area A, we can deduce the Equation 4.2.

$$p(C_1) = p_1(C_1) = p_2(C_1) = \cdots = p_n(C_1) = \frac{A}{n \times A} = \frac{1}{n} \tag{4.2}$$

The probability that the distance between the vehicles v_1 and v_2 is lower or equal to the threshold D_{thr} (event C2) is given by Equation 4.3.

$$p(C_2) = \frac{D_{thr}}{L_{seg}} \tag{4.3}$$

Where D_{thr} is the distance threshold and L_{seg} is the length of the road segment.

We assume that the probability p to broadcast a received message is the same for all vehicles in the network. Therefore, the probability that the vehicle v_2 sends the received message (event C3) is given by Equation 4.4.

$$p(C_3) = p \tag{4.4}$$

Let S be a sample space which is composed of two events E_1 and E_2.

- *E1*: the scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.
- *E2*: the scheduled timer of the vehicle v_1 expires before the scheduled timer of the vehicle v_2.

Because the waiting time value is uniformly distributed in the same interval for the vehicles v_1 and v_2, the probability of any outcome of the sample space S is likely the same. Thus,

$$p(C_4) = p(E_1) = p(E_2) = \frac{1}{2} \tag{4.5}$$

The four events C1, C2, C3, and C4 are independent. Thus, the probability that the vehicle v_1 inhibits the transmission of the received message is given in Equation 4.6.

$$p(C_1 \cap C_2 \cap C_3 \cap C_4) = p(C_1) \times p(C_2) \times p(C_3) \times p(C_4) = \frac{1}{n} \times \frac{D_{thr}}{L_{seg}} \times p \times \frac{1}{2} = \frac{p \times D_{thr}}{2 \times n \times L_{seg}} \tag{4.6}$$

Consequently, the probability that the vehicle v_1 broadcasts the received packet is given by Eq. 4.7.

$$p = (1 - p(C_1 \cap C_2 \cap C_3 \cap C_4))^{N-2} \tag{4.7}$$

Where N is the number of vehicles on the road map. In the Equation 4.7, we use *N-2*, because the vehicle v_1 and the vehicle from which v_1 gets the first copy of the message (the vehicle that initialized the timer) are both excluded.

We also note that the vehicle that initializes the timer of the vehicle v_1 must have a distance to v_1 higher than D_{Thr}, when v_1 and this vehicle are on the same road segment. This condition has a probability x given in Equation 4.8. As a result, p is given by Equation 4.9.

$$x = 1 - \frac{D_{thr}}{n \times L_{seg}} \tag{4.8}$$

$$p = x \times (1 - \frac{p \times D_{thr}}{2 \times n \times L_{seg}})^{N-2} \tag{4.9}$$

Finally, the broadcast probability is calculated according to the following formula.

$$p - \left(1 - \frac{D_{thr}}{n \times L_{seg}}\right) \times \left(1 - \frac{p \times D_{thr}}{2 \times n \times L_{seg}}\right)^{N-2} = 0 \tag{4.10}$$

4.3.3 Model for ECUV protocol

This section presents the proposed analytical model that predicts the behavior of ECUV protocol. In our proposed analytical model, the following three conditions (elementary events) must be satisfied to increment the counter of v_1.

- C1: The vehicles v_1 and v_2 move along the same road segment.
- C2: The vehicle v_2 sends the received message.
- C3: The scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.

Let n is the number of road segments in the roadmap. The positions of the vehicles are randomly and uniformly distributed in the network. Thus, the probability that v_1 and v_2 are on the same road segment (event C1) is given by Equation 4.11.

$$p(C_1) = \frac{1}{n} \tag{4.11}$$

The probability that the vehicle v_2 broadcasts the received message is given by Equation 4.12.

$$p(C_2) = p \tag{4.12}$$

We assume that S is a sample space composed of the following two events.

- E1: the scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.
- E2: the scheduled timer of the vehicle v_1 expires before the scheduled timer of the vehicle v_2.

The values of the scheduled timers are uniformly distributed in the same interval for the vehicles v_1 and v_2. Consequently, the probability of any outcome of the sample space S is likely the same. Thus,

$$p(C_3) = p(E_1) = p(E_2) = \frac{1}{2} \tag{4.13}$$

The vehicle v_1 increments its counter based on the probability p_{inc} (Equation 4.14).

$$p_{inc} = p(C_1 \cap C_2 \cap C_3) \quad (4.14)$$

The three events C1, C2 and C3 are independent. As a result, p_{inc} is given by the following equation.

$$p_{inc} = p(C_1) \times p(C_2) \times p(C_3) \quad (4.15)$$

Based on Equations 4.11, 4.12 and 4.13, we can deduce Equation 4.16.

$$p_{inc} = \frac{1}{n} \times p \times \frac{1}{2} = \frac{p}{n \times 2} \quad (4.16)$$

The probability that the vehicle v_1 exactly receives i duplicate packets (from vehicles that are on the same road segment where v_1 is located) is given by Equation 4.17.

$$p_i = C_i^{N-2} \times p_{inc} \times (1 - p_{inc})^{N-2-i} = C_i^{N-2} \times \frac{p}{n \times 2} \times (1 - \frac{p}{n \times 2})^{N-2-i} \quad (4.17)$$

Where N is the number of vehicles in the network.

As defined in [128], N-2 is used in Equation 4.17, because the vehicle v_1 and the vehicle from which v_1 get the first copy of message are excluded.

The probability to receive a number of duplicate packets lower than C_{Thr} is given in Equation 4.18.

$$p(Z < C_{thr}) = \sum_{k=0}^{C_{thr}-1} C_k^{N-2} \times (\mathrm{p(Y)})^k \times (1 - \mathrm{p(Y)})^{N-2-k} \quad (4.18)$$

Where Z is the number of duplicate packets variable and ($\mathrm{Y} = \mathrm{C1} \cap \mathrm{C2} \cap \mathrm{C3}$).

Based on Equation 4.16 and Equation 4.18, we can deduce Equation 4.19.

$$p(Z < C_{thr}) = \sum_{k=0}^{C_{thr}-1} C_k^{N-2} \times (\frac{p}{2 \times n})^k \times (1 - \frac{p}{2 \times n})^{N-2-k} \quad (4.19)$$

Finally, the probability to broadcast a message is calculated by the following equation.

$$p - \sum_{k=0}^{C_{thr}-1} C_k^{N-2} \times \left(\frac{p}{2 \times n}\right)^k \times \left(1 - \frac{p}{2 \times n}\right)^{N-2-k} = 0 \quad (4.20)$$

4.4 Performance evaluation

This part analyses the performance of ECUV and EDUV protocols through both the analytical model and network simulation experiments. For this aim, we investigate the performance over two urban network topologies: (i) Synthetic Manhattan Topology for the analytical model, (ii) Real network topology for the simulation experiments. The next sub-sections depict the evaluation metrics, the performance assessment through the analytical model and the performance assessment using network simulation experiments.

4.4.1 Metrics

To determine the reliability and effectiveness of the proposed protocols, we assess the following metrics:

- **Coverage capacity:** Represents the ratio between the number of vehicles that well received the broadcasted packet and the number of vehicles in the network. We note that our analytical models do not give an explicit formulation of this metric. However, because the network size and the number of vehicles in the network are the main parameters of our models, we can implicitly assess the coverage capacity.
- **Number of relay nodes (number of transmissions):** The total number of vehicles that forward the disseminated message throughout the broadcasting process. A high value of this metric is a serious sign of a strong redundancy that can lead to the broadcast storm problem. The derived analytical models give an explicit value of this metric, because the probability calculated through the equations Equation 4.10 and Equation 4.20 represents the ratio of vehicles that rebroadcast the disseminated message, and consequently it represents the number of transmissions.
- **End-to-end delay:** The average delay that takes a packet to go from the source vehicle to the receiver vehicles. This metric is only assessed through the network simulation experiments.

4.4.2 Performance evaluation using analytical model

This section presents the performance evaluation of ECUV and EDUV through analytic simulation. EDUV and ECUV processes are modeled by Equation 4.10 and Equation 4.20, respectively. These equations were solved using the Symbolic Math Toolbox of MATLAB to find the broadcasting probability of each vehicle in the network. This probability represents the main characteristic of the proposed protocols. The experiment should enable us to assess both coverage capacities, cost (number of transmissions) and to select the appropriate threshold values for each traffic density (low density and high density).

a) Scenario description and parameters

This part presents the scenario and parameters used to evaluate the performance of ECUV and EDUV protocols through the analytic expressions defined by Equations 4.10 and 4.20. As shown in the Equation 4.10, the performance of EDUV protocol is influenced by the configuration of three parameters. Namely, the threshold D_{thr}, the number of vehicles N and the number of road segments n. Thus, the 3-tuple (D_{thr},N,n) determines the configuration of the EDUV analytical model. Similarly, ECUV was evaluated through the 3-tuple (C_{thr},N,n).

The network topology was Manhattan city. The number of road segments in this city map was varied by 3×3, 6×6, 9×9 roads. Moreover, the number of vehicles in the network was varied from 25 to 150 vehicles. We evaluated the proposed protocols under different traffic densities to investigate their behavior towards the broadcast storm problem. Additionally, the variation of the road-network size (the number of road segments), from experimental instance to another, allowed us to examine the coverage capabilities. For simplicity reasons, we set the length of each road segment to be equal to the communication range radius R.

In our study, the density d is defined by the ratio of the number of vehicles N to the number of road segments in the road-network n:

$$d = \frac{N}{n} \tag{4.21}$$

We have two levels of density:

- **Low density:** defined by the configurations $(6 \times 6\ \text{topology}, \mathrm{N} = 25)$ and $(9 \times 9\ \text{topology}, \mathrm{N} <= 75)$ because the ratio *d* is lower than 1.
- **High density:** defined by the configurations $(3 \times 3\ \text{topology}, \mathrm{N} >= 25)$, $(6 \times 6\ \text{topology}, \mathrm{N} >= 50)$, $(9 \times 9\ \text{topology}, \mathrm{N} >= 100)$because the ratio d is higher than 1.

Furthermore, the proposed models were used to evaluate the global protocol's criteria. In such a case, the level of details (Namely, MAC layer parameters and the interaction between the communication layers) is not required. Table 4-2 presents a summary of the main parameters and their settings.

Table 4-2 Analytical models parameters.

Parameter	Value
Communication range radius	a constant value equal to R
Road network topology	Manhattan topology
Length of each road segment	R
Size of the network	3×3 , 6×6 , 9×9
Number of vehicles	varies from 25 to 150
Initial vehicles positions	uniformly distributed
C_{Thr}	varies from 1 to 2
D_{Thr}	0.25R, 0.5R , 0.75R

b) Results and discussion

Figure 4-8 and Figure 4-9 outlines the results of the ECUV analytical model for C_{thr} equals to 1 and C_{thr} equals to 2, respectively.

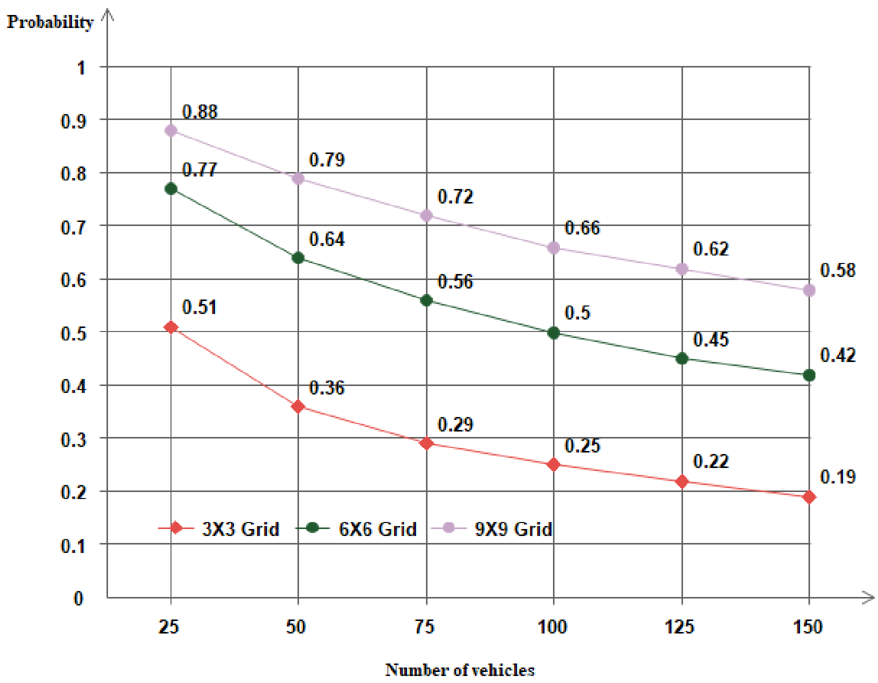


Figure 4-8 ECUV rebroadcast probability prediction when C_{thr} =1.

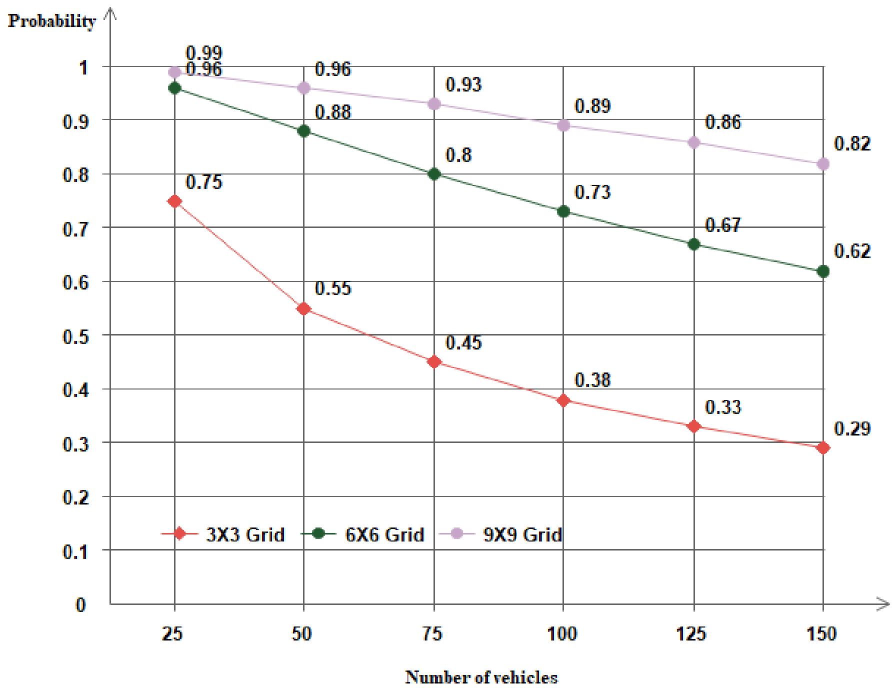


Figure 4-9 ECUV rebroadcast probability prediction when $\mathbf{C_{thr}}$ =2.

The results of the EDUV analytical model are plotted in Figure 4-10, Figure 4-11 and Figure 4-12 for D_{thr}=0.25R, D_{thr} =0.50R, and D_{thr} =0.75R, respectively.

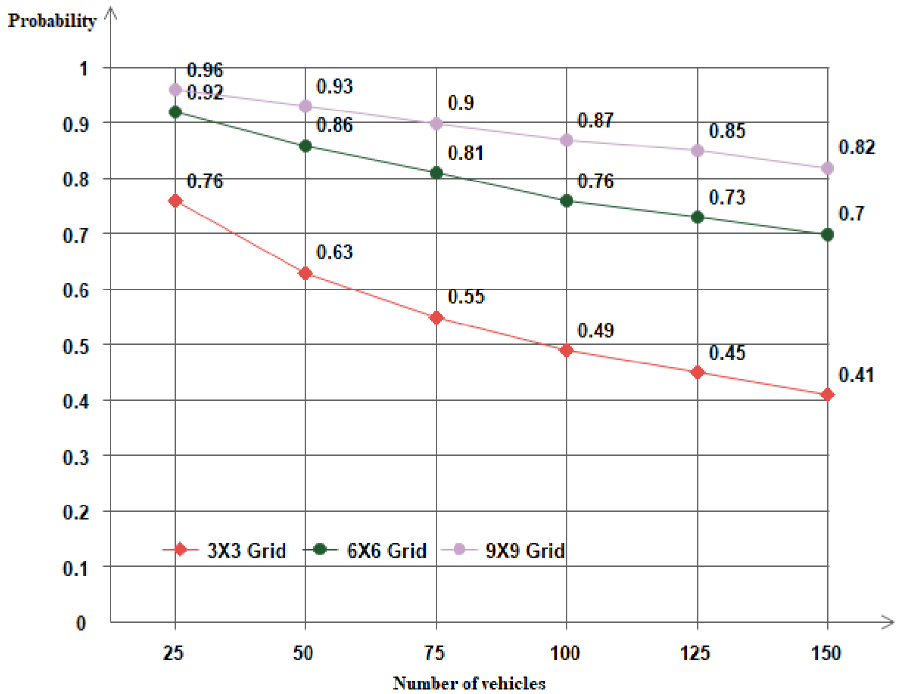


Figure 4-10 EDUV rebroadcast probability prediction when D_{thr} =0.25R.

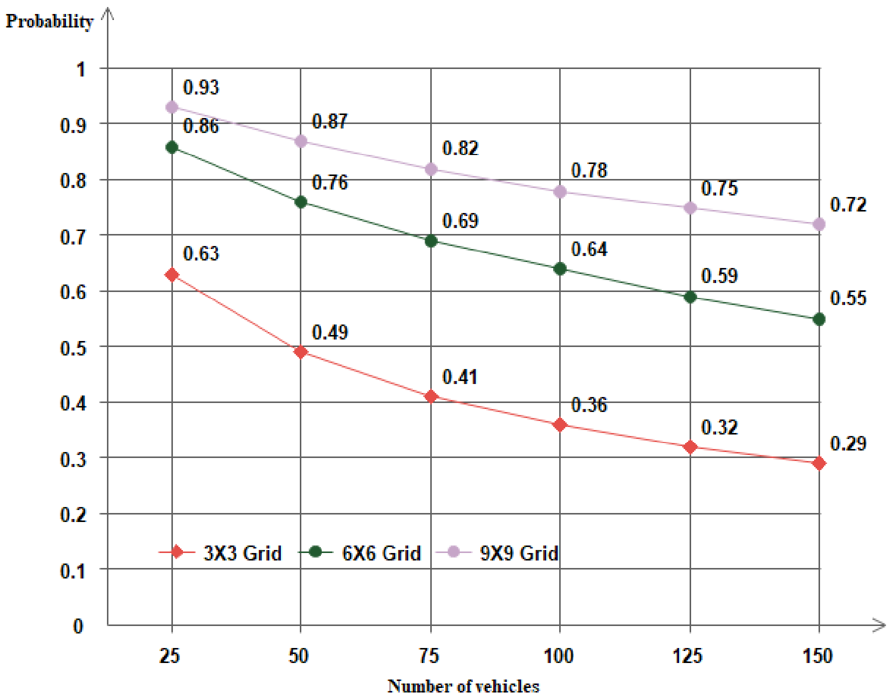


Figure 4-11 EDUV rebroadcast probability prediction when D_{thr} =0.5R.

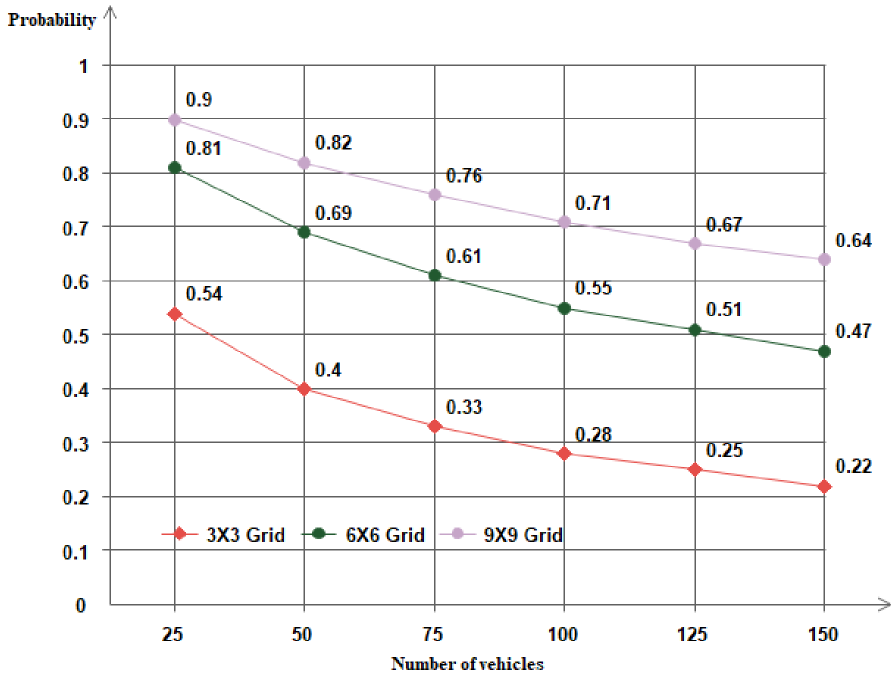


Figure 4-12 EDUV rebroadcast probability prediction when D_{thr} =0.75R.

We note that the x- and y-axes in the different figures represent the vehicles density and the rebroadcast probability, respectively.

As shown in Figure 4-8, Figure 4-9, Figure 4-10,Figure 4-11 and Figure 4-12, when the vehicles density was low, the two protocols increased the number of broadcasters to ensure the maximum degree of the coverage capacity. Whereas, when it was high, the number of broadcasters was decreased to avoid the broadcast storm problem.

We also note that the behavior of these protocols was influenced by the different threshold values. The broadcast probability of ECUV was proportional to the value of C_{thr} (Figure 4-8 and Figure 4-9). By contrast, the broadcast probability of EDUV protocol was inversely proportional to the value of D_{thr} (Figure 4-10,Figure 4-11 and Figure 4-12).

The network size had a great influence on the behavior of EDUV and ECUV. We noted that the number of broadcasters was directly proportional to the network size. Because the network size mainly depends on the number of the road segments, the increase in broadcast probability (due to the increase in network size) can only be explained by the need of these protocols to cover the newly added road segments. Consequently, this can allow better fulfilling the coverage capability requirement.

Because the proposed analytical models do not give explicit values of the coverage capacity metric, the evaluation of this metric requires reference values. As outlined in sub-section 4.2.1, we have assumed that the geographical positions of vehicles are uniformly distributed in the road network, and the length of each road segment is lower or equal to the communication range radius. Based on these assumptions, the total coverage of the road network is ensured by just selecting a single vehicle in each road segment to act as a relay node. Consequently, the number of relay nodes that guarantee the total coverage will be equal to the number of road segments in the road network. Therefore, the reference values for 3×3, 6×6, and 9×9 Manhattan topologies are 9, 36, and 81, respectively. We can use these values as references to analyze and check the obtained results, and hence to select the appropriate values of C_{Thr} and D_{Thr} for each density (low density and high density).

When the density is low (6×6 topology, N=25) and (9×9 topology, N=25)), the reasonable value of the broadcast probability is 1 (all vehicles must act as relay nodes), because the number of vehicles is lower than the reference value (see Equation 4.21). For this situation, we have to select a threshold value that gives the highest value of the broadcast probability. As outlined in Figure 4-9 and Figure 4-10, the threshold values $C_{Thr}=2$ and $D_{Thr}=R/4$ fulfill this requirement because they give a probability near to 1.

In high traffic density (represented by the configurations (3×3 topology, N>=25), (6×6 topology, N>=50), (9×9 topology, N>=100)), we note that for all threshold values, the number of relay-nodes corresponding to each broadcast probability is higher than the reference value. (We can check that by calculating the number of relay nodes for each broadcast probability). However, we have to choose the threshold value that generates the smallest value of the broadcast probability because it has a lower message overhead. Namely, we select $C_{Thr}=1$ (Figure 4-8) and $D_{Thr}= 3/4R$ (Figure 4-12) for high-density scenarios. However, we have to choose the threshold value that generates the smallest value of the broadcast probability because it has a lower message overhead. Namely, we select $C_{Thr}=1$ (Figure 4-8) and $D_{Thr}= 3/4R$ (Figure 4-12) for high-density scenarios.

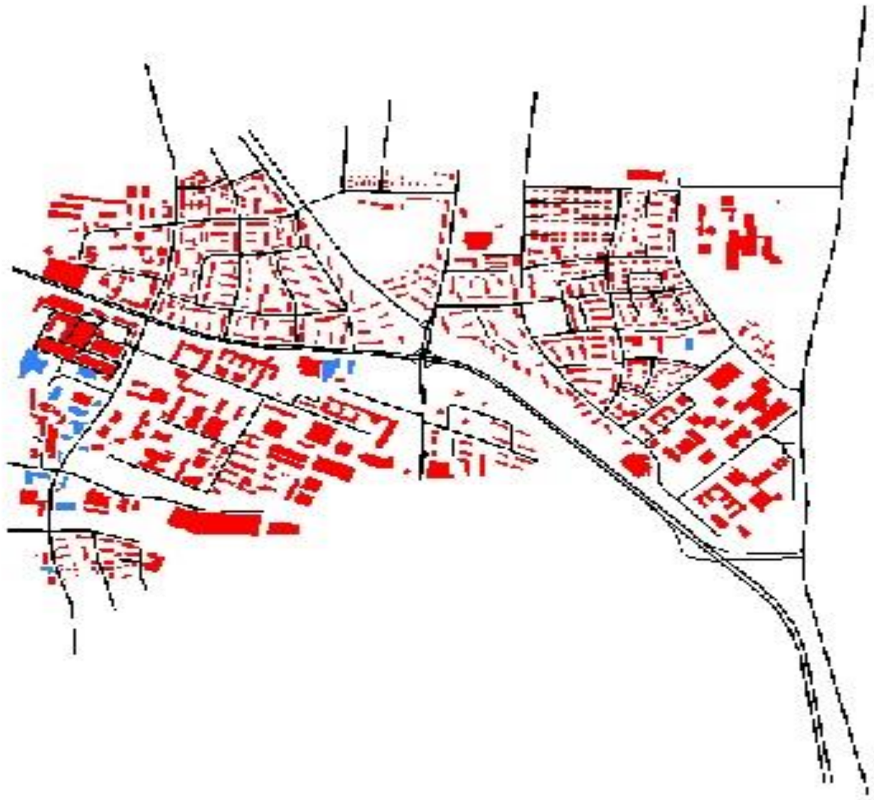


Figure 4-13 Erlangen road network.

4.4.3 Performance analysis using network simulation

a) Scenario description and parameters

In this section, we evaluate the proposed schemes in a real urban scenario. We used Objective Modular Network Testbed in C++ simulator (Omnet++) [129]. It is widely used to perform discrete network simulation. It was coupled with the VEINS framework [130] to implement and simulate vehicle behavior for each broadcast protocol. The simulation of vehicle mobility is carried out by SUMO, which has a high capacity to generate full road traffic scenarios by considering both macroscopic and microscopic models. Several traffic flows were generated in 2.5×2.5 Km^2 real urban topology. This topology is based on the Erlangen city (Figure 4-13). Furthermore, we took into account the impact of the Shadow fading phenomenon caused by buildings to achieve a more realistic simulation. Therefore, we integrated the simple obstacle shadowing model provided by the VEINS framework to generate the effect of signal attenuation [89]. The maximum radio range, the bit rate, the channel sensitivity, and the thermal noise were set to 150 meters, 6 Mps, -89 dBm, and -119 dBm, respectively. Table 4-3 summarizes the main parameters of the simulation experiments.

The quality of Multi-hop broadcasting protocols highly-depends on the number of vehicles in the region of interest and the threshold value. Thus, the number of vehicles was varied to check the performance of the proposed protocols over two traffic densities. We had 200 vehicles that represent the high-density scenario and 100 vehicles that represent the low-density scenario. When the desired number of vehicles for each density scenario was reached, an RSU at (1800,850) position initiated the broadcasting of a 1024-byte data message to each vehicle in the road network.

Table 4-3 Simulation experiments parameters.

Parameter	Value
Playground Size	$2.5\times2.5Km^2$
Source Location (x, y)	x=1800,y=850
Radio Propagation Model	- Simple Path loss Model . - Simple Obstacle Shadowing model.
Transmission range	150m
Bite rate	6 Mps
Sensitivity	-89 dBm
Thermal Noise	-119 dBm
Antenna	Monopole antenna
Number of runs	10
Confidence interval	95%

The proposed ECUV and EDUV protocols were compared to Counter-based protocol[23], Distance-based protocol[23], and probabilistic scheme of React-Dis[102]. Note that the values of thresholds D_{thr} and C_{thr} in our simulation were selected purposely according to the values obtained through the tuning operation (sub-section 4.4.2b)). Namely, we used D_{thr}=0.25R and C_{thr} =2 for the low-density scenario. Besides, D_{thr} =0.75R and C_{thr} =1 were used for the high-density scenario. Finally, each plotted point was the mean of 10 iterations with a confidence level of 95%.

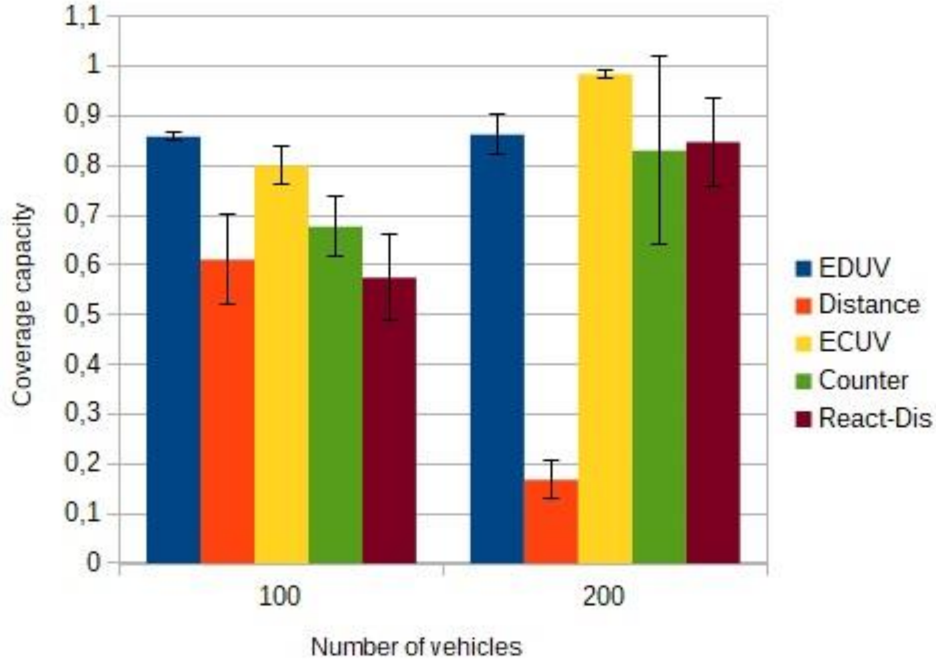


Figure 4-14 Coverage capacity simulation results

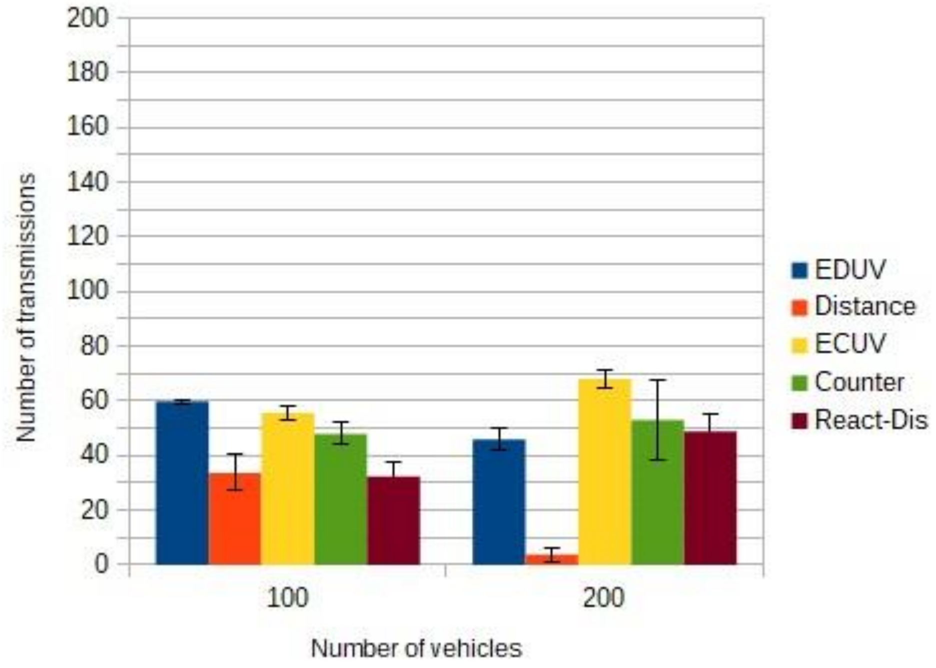


Figure 4-15 Number of transmissions simulation results

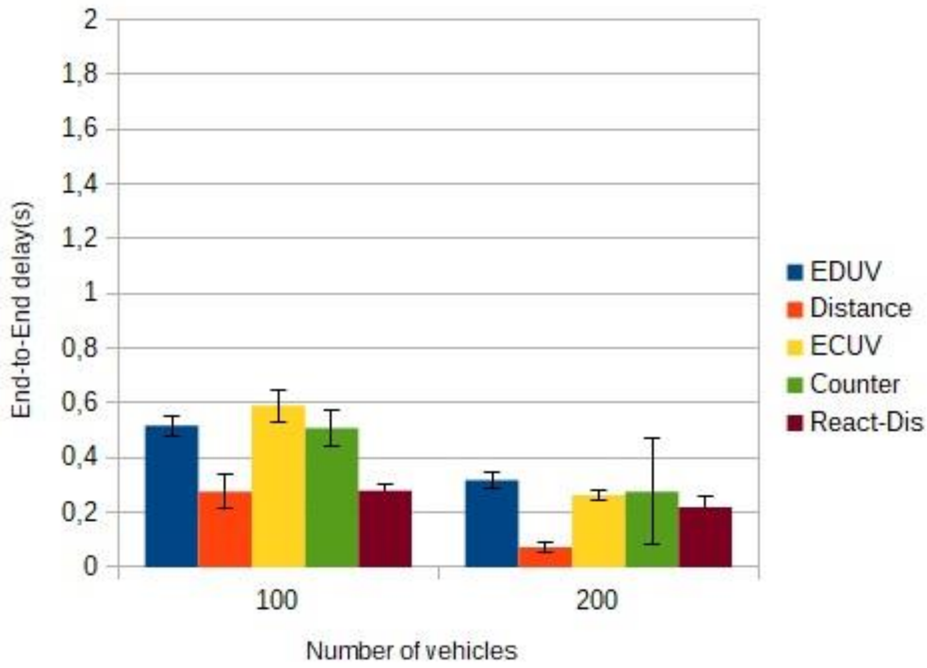


Figure 4-16 End-to-End delay simulation results

b) Results and discussion

Figure 4-14, Figure 4-15, and Figure 4-16 introduces all outcomes for the Erlangen scenario. Specifically, Figure 4-14 outlines the coverage capacity for all schemes under low and high traffic densities. As shown in this figure, ECUV and EDUV outperform all other protocols in all cases. By comparing EDUV and distance-based protocol, we see that EDUV provided better coverage in the two densities. For instance, the difference between them was 69%, when the number of vehicles was 200. This is because the value 0.75R assigned to D_{thr} is too aggressive and produced low coverage for distance-based protocol. Indeed, the very high value of D_{thr} is not the best choice for distance-based protocol even in the high-density scenario. The high delivery of EDUV and ECUV was due to the use of the minimum-distance and counter-based heuristics in association with the road-based broadcast concealment mechanism, which considerably enhanced the coverage capacity even when the value of the threshold was very aggressive. As we can see in Figure 4-14, React-Dis performs better only in high traffic density. The reason is that the probabilistic scheme used by React-Dis is not good for low vehicle density.

Figure 4-15 shows the number of transmissions. We have noted that ECUV and EDUV slightly exceeded other protocols in terms of the number of transmitted messages. Certainly, these protocols utilize a road-based broadcast suppression mechanism, which has increased the number of forwarders in each hop. However, this increase in the number of transmissions has produced higher performance in terms of coverage capability.

Figure 4-16 outlines the average latency. All protocols use a timer-based approach, in which vehicles make their decision about rebroadcasting of the received message after a waiting time. This extra time accumulates from hop to another along the transmission path thereby increasing the total end-to-end delay. We have noted that ECUV, EDUV, and counter-based protocols had almost the same end-to-end delay in low traffic density. The obtained results were between 0.51s and 0.59s. We have noted also that distance-based protocol and React-Dis protocol sacrificed the coverage capacity to minimize the end-to-end delay in low traffic density.

In high traffic density, the distance-based protocol was the protocol with the lowest end-to-end delay. This is expected because the disseminated message reached a small number of vehicles, and these vehicles may be very close to the source node. Consequently, the disseminated message reached these vehicles across a small number of hops. For this reason, the distance-based protocol had the lowest delay among all other protocols. Also, note that EDUV, ECUV, Distance-based protocol, and React-Dis had nearly the same end-to-end delay in high traffic density (between 0.22s and 0.31s).

4.5 Conclusion

In this chapter, the well-known counter and distance-based broadcast protocols have been adapted to the Urban VANETs. First, the scenarios in which the messages cannot be propagated on different roads, when counter and distance-based schemas have been identified. Next, new road-based approaches (EDUV and ECUV) have been derived from these protocols to mitigate the effect of the identified issue. Then, analytical models are proposed to measure the broadcast probability of the proposed protocols in accordance with the density of the vehicles, the road-network size, and the threshold parameter. The Mathematical model analyses and simulation results prove that EDUV and ECUV protocols ensure the tradeoff between the reachability and the broadcast storm problem mitigation. We undertake in future work to analyze the performance of ECUV and EDUV protocols through the Monte-Carlo simulation. In the next chapter we will present a solution for enhancing video dissemination in urban VANETs. The proposed scheme combines two techniques. The first one is intended to address simultaneously the problem of the obstructed line of sight in city environments and the coverage capacity. The second one is a new version the store-carry-and forward (SCF) method that allow transmission differentiation between the video packets based on their effects on the video quality

Chapter 5 Enhancing video dissemination over urban VANETs using line of sight and QoE awareness mechanisms

In an urban environment, wireless signals experience attenuation when obstructed by buildings. In the worst case, this problem can lead to a network partition. Consequently, packet losses may occur and the video quality may deteriorate. Our aim to solve this problem led us to design a receiver-based broadcasting protocol for urban VANETs, namely a receiver-based line-of-sight-aware broadcasting protocol (ReLoS). This protocol facilitates the selection of nodes with an improved line of sight to rebroadcast the video content in a completely distributed manner. Considering that video content is likely transmitted over an unreliable transport layer, we propose an enhanced version of the store-carry-and forward (SCF) method to overcome the packet losses in the network layer. We then extend the traditional SCF to provide transmission differentiation between the video packets based on their effects on the video quality. The new SCF method is termed the quality of experience-aware store-carry-and-forward (QoESCF). In the following subsections, we present the detailed designs of ReLoS and QoESCF.

5.1 Requirements and assumptions

In this work, we design a broadcast solution for urban scenario that depends only on the vehicle-to-vehicle (V2V) ad hoc communication type. This conforms to the assumptions defined in the IEEE 802.11p standard. Thus, the proposed protocol is not based on any infrastructure, such as roadside units (RSUs), 3G, and 4G infrastructure. 3G/4G networks are broadly accessible, but the V2V communication type is the more suitable solution because it does not rely on the backbone network for a certain level of data transmission. For instance, it enables information exchange among vehicles without introducing extra burden to the backbone network.

We represent VANET as graph $GV = \{\{VP\} \cup V, IL\}$, where *VP* is the video streaming provider, and *V* is a set of vehicles moving along a 2D urban road-network. *VP* can be either an RSU or a stationed vehicle. *IL* is the set of one-hop communications links. IL_{ij} is a one-hop link between two vehicles v_i and v_j if the Euclidean distance between them is less than the transmission range radius.

We represent the road network according to its topology. Thus, it is modeled as a graph $RN = \{J, SEG\}$. *J* is the set of junctions/intersections in the road network, and *SEG* is the set of segments. A *SEGij* exists if there is a street that connects directly the two junctions *i* and *j*. Notice that each junction represents an extremity of all segments connected to it. Furthermore, a junction has an improved line-of-sight as compared to other locations on the segments connected to it. The road network segmentation based on the topology helps us to design the proposed Bi-directional scheme.

Table 5-1 Notations used in the different Algorithms.

Notation	Description
PS(A ; B)	Position side of the vehicle A with respect to the vehicle B
Fr	Front side
Re	Rear Side
$\overrightarrow{V_B}$	Movement direction vector of the vehicle B
$\overrightarrow{BA}$	The vector that begins at the position of vehicle B and ends at the position of vehicle A
T_{min}	Minimum waiting time
T_{max}	Maximum waiting time
S	Sender vehicle
R	Receiver vehicle
SV	The source vehicle: the vehicle that broadcast the first copy of the message to its immediate neighborhood
Distance(S,R)	The spatial distance between the vehicle S and the vehicle R
R	The communication range
$angle(\overrightarrow{V_S}, \overrightarrow{SR})$	Angle between $\overrightarrow{V_S}$ and $\overrightarrow{SR}$
Id_road_S	Road segment identifier of the sender vehicle S
Id_road_R	Road segment identifier of the receiver vehicle R
Itra	Intra road scenario
Iter	Inter road scenario

We also assume that each vehicle in the network is equipped with a navigation system. This system is based on a localization sensor (e.g., a GPS receiver). A digital cartography system is employed to recover the nearest road segment in the road network map for given geo-location coordinates. The system complies with the protocol requirements by using a digital map to provide a unique identity to each road segment. Furthermore, the header field of each transmitted packet requires certain information about the sender, such as the road segment identifier, sender position coordinates, and sender moving direction, to be included. For ease of use, Table 5-1 explains different notations that are utilized in this section.

5.2 Receiver-based line-of-sight-aware broadcasting protocol

In previous receiver-based broadcasting protocols, the rebroadcasting decision of node is made on the receiver side rather than on the sender side. To achieve this, when a node receives a new packet, it triggers a timer that expires after a specific time period *t*. The value of *t* is determined by the rule that discerns the preference of the node to become a forwarder (the node with the shortest period is likely the more suitable candidate). For example, the reasoning of the geographic greedy broadcasting algorithm is based on the fact that the neighborhood nodes of a sender with the largest distance from it are likely to have a greater probability to cover a new area. Thus, the value of *t* is inversely proportional to the distance between the sender and the next one-hop receiver.

In our solution (ReLoS), the t value is defined based on the Line-of-sight heuristic and the Bi-directional schema. ReLoS's response is established according to the position of the source node (node that initializes the Bi-directional process within its transmission range) in relation to its immediate neighborhood. This can occur in two possible scenarios. The first one is when the source node and the receivers are on the same road segment (intra-road scenario). The second scenario is when the source node and the receivers are on different road segments (inter-road scenario). Furthermore, ReLoS aims to construct a backbone that connects the two extremities of each road segment. To this end, ReLoS engages the position side of the receiver node with the respect to the source node to establish the Bi-Directional process.

Definition 1 Position side of node *A* with respect to another node *B*. Assuming $\underset{V_B}{\rightarrow}$ is the movement direction vector of *B* and $\underset{\mathrm{BA}}{\rightarrow}$ is the vector that begins at the position of *B* and ends at the position of *A* (relative position vector), the position side of *A* with respect to *B* is given by Equation 5.1.

$$PS(A,B) = \begin{cases} front & \left|angle(\overrightarrow{V_B}, \overrightarrow{BA})\right| < 90° \\ rear & else \end{cases} \quad (5.1)$$

Figure 5-1 describes the ReLoS process when a vehicle receives a new packet. This process is triggered to calculate the waiting time and accordingly schedules the corresponding timer. Figure 5-2 describes the behavior of ReLoS when a duplicate packet is received. It's at this level where a decision is made on the rebroadcasting of the received packet. Upon receiving a not duplicate packet, the vehicle determines the current scenario and calculates the corresponding waiting time. This can be achieved by comparing the road segment identifiers of the sender and the receiver (Figure 5-1 Step A).

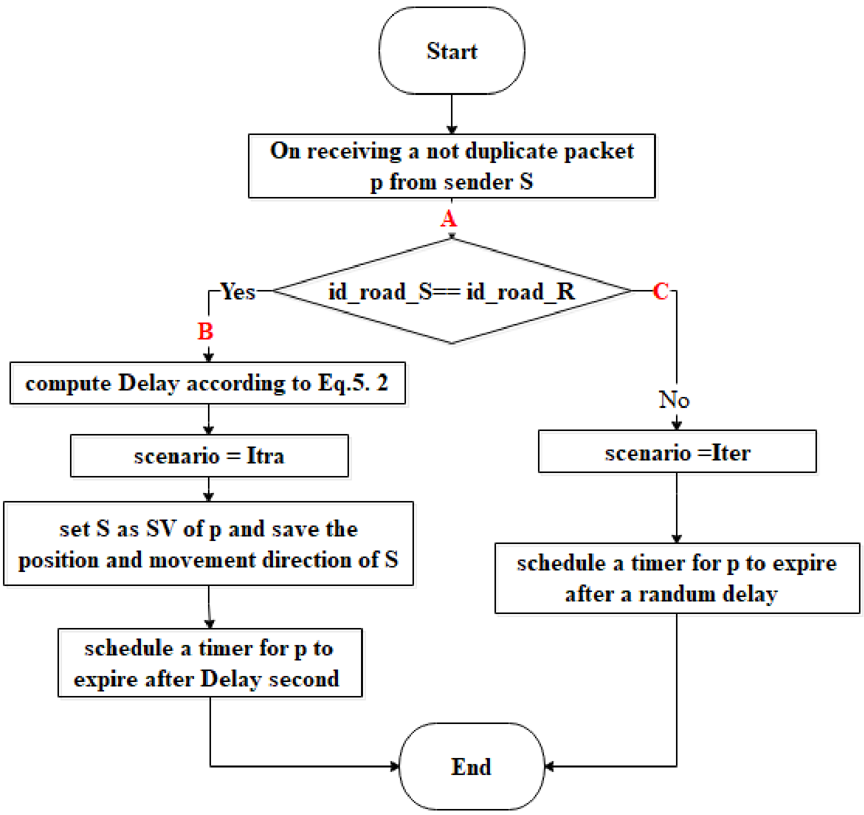


Figure 5-1 ReLoS-flowchart when a vehicle receives a new packet.

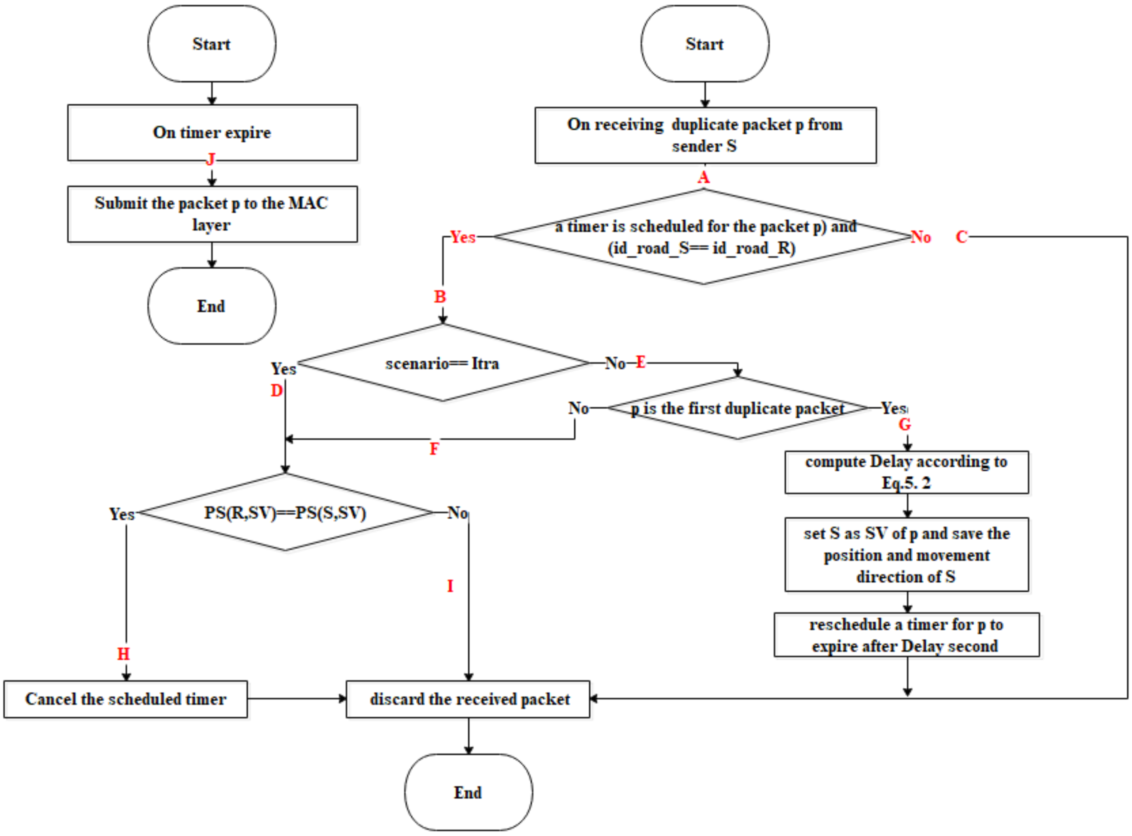


Figure 5-2 ReLoS flowchart when a vehicle receives a duplicate packet.

5.2.1 Scenario 1: Intra-road scenario

ReLoS selects implicitly vehicles that appear in the extremities of each road segment as relays. To this end, it establishes the waiting time according to the farthest distance-based approach (Eq. 5.2). Consequently, the waiting time is inversely proportional to the distance between the sender and the current receiver. However, to allow the protocol to choose vehicles near intersections as forwarders (relay nodes), ReLoS engages the position side of the receiver relative to the movement direction (front or rear) of the source node as defined in Eq. 5.1. That is the farthest vehicle at the front side and the farthest vehicle at the rear side have to suppress the broadcasting of the intermediate vehicles.

$$Delay = T_{min} + \left(1 - \frac{distance(S,R)}{r}\right) \times T_{max} \qquad (5.2)$$

Where S is the sender node, R is the receiver node, r the communication range, T_{min} the minimum waiting time and T_{max} is the maximum waiting time.

Now we give a formal description of this scenario. Let S_i be the set which are formed by the vehicles that are located on the road segment i and let v_k be the source vehicle (the source vehicle is the vehicle that broadcasts the first copy of the message to its immediate neighborhood). v_k's immediate neighbor vehicles that are located on the road segment i are defined by the elements of the subset S_i^k of the set S_i (Eq. 5.3). The intra-road process is applied when v_k is an element of the set S_i.

$$S_i^k = \{v_j / \, distance(v_j, v_k) \leq r \; ; \; v_j \in S_i \; and \; v_j \neq v_k\} \tag{5.3}$$

Once the vehicles of the set S_i^k receive a new packet from the source vehicle v_k, they store the geographical position and the movement direction of v_k. This information will be used later to determine their position side (front or rear) relative to v_k when they receive a duplicate packet. Next, a timer is triggered according to Eq. 5.2 (Figure 5-1 steps *A* to *B*). During the waiting time, if a scheduled vehicle from the set S_i^k receives a duplicate packet from a sender that belongs to the set S_i^k , it checks whether it is on the same side as this sender (relative to v_k) (Figure 5-2 steps *A* ,*B*, *D*). If it is the case, it cancels the broadcast and the scheduled timer (Figure 5-2 steps *H*). Otherwise, it keeps tracking the duplicate packets received from its immediate neighborhood. When the timer expires, it broadcasts the received packet (Figure 5-2 step *J*).

For example, in Figure 5-3, *E* and *F* are located on the front side of the source vehicle *A*. In contrast, *B* and *C* are located on the rear side. When vehicles *B*, *C*, *E*, and *F* receive a message from the source vehicle *A*, they schedule themselves to rebroadcast after a delay time. Moreover, the vehicle *F* has the lowest waiting time compared to the vehicles on the front side of vehicle *A*. On the rear side, it is *C* that has the lowest waiting time. Consequently, when *F* broadcasts, the transmission of *E* is canceled. The same observation is made for *B*; its transmission is suppressed by the broadcasting of *C*. This process is repeated for the other vehicles to construct a backbone directed to nodes near the intersections (Bi-directional mechanism). For instance, in Figure 5-3, the backbone of the front side comprises the vehicles *F*, *G*, and *I*. On the rear side, the backbone comprises vehicles *C* and *D*. Note that if there is a vehicle near or at the intersection, it will be selected as a relay (vehicles *I* and *D* in our example).

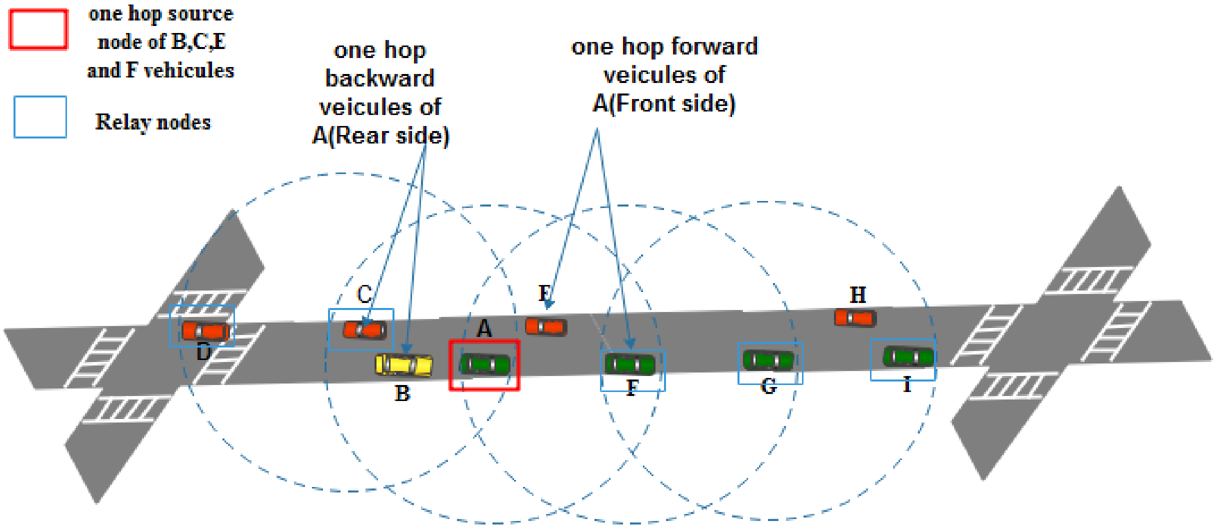


Figure 5-3 Intra-Road scenario.

5.2.2 Scenario 2: Inter-road scenario

The inter-road scenario will be established if the source vehicle and its one-hop receivers are on different road segments. Specifically, it is triggered when the source vehicle v_k is not an element of the set S_i^k .

To establish the Bi-directional process, we have to select a vehicle, from the set S_i^k that initializes the process. The simplest way to accomplish this task is to select a random vehicle from the set S_i^k . Thus, when the vehicles of the set S_i^k receive a new message from v_k, they initialize a timer with a random value (Figure 5-1 steps *A* to *C*). Moreover, the vehicle that has the shortest waiting time broadcast the first duplicate copy and consequently initializes the Bi-directional process. More specifically, the vehicles of the set S_i^k schedule themselves to broadcast after a delay according to the farthest distance heuristic, upon they receive the first duplicate packet (Figure 5-2 steps *A* to *G*).

We notice that the duplicate packets which are received after the first duplicate packet is handled according to the Bi-directional scheme (Figure 5-2 steps *E*, *F*,. . .). Based on the Bi-directional method, the farthest vehicles on the front and rear side of the vehicle that initializes the Bi-directional process will be selected as a relay nodes (Figure 5-2 step *J*) and the broadcast of the intermediate vehicles will be suppressed (Figure 5-2 steps *E*, *F*,*H*. . .).

Figure 5-4 illustrates the inter-road scenario. Initially, source node *A* directly sends a new packet to the vehicles located within its communication range (*E*, *F*, and *G*).When these vehicles receive the packet from *A*, they schedule a random timer. In this example we assume that the timer of *G* expires before the timer of *F* and *E*. Consequently, *G* is the first that broadcast the first duplicate packet to its neighborhood (*F*, *E*, and *H*). When *F*, *E*, and *H* receive the broadcast, they initialize the Bi-directional process. Based on the Bi-directional method, the vehicles *E* and *H* will be selected as relays.

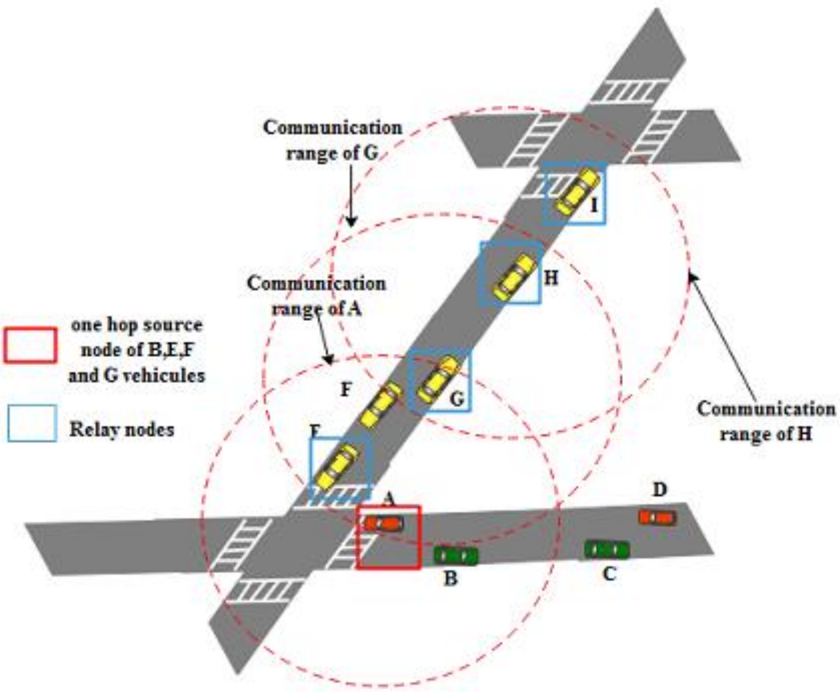


Figure 5-4 Inter-Road scenario.

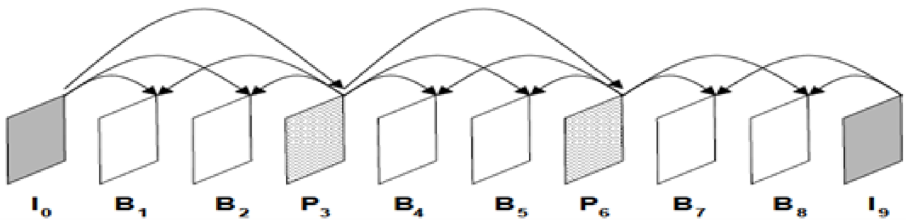


Figure 5-5 Relationship among frames in MPEG GoPs.

5.3 Quality-of-experience-aware store-carry-and-forward method

Several video compression standards exist, among which the H.264/MPEG-4 family is the most widely used [131]. The technique exploits two types of redundancies: redundancy between neighboring blocks of the same picture (Intra-coding) and redundancy between successive pictures (Inter-coding).

As outlined in Figure 5-5, the compressed sequence video includes three types of frames: I-frame, P-frame, and B-Frame. In the intra-coding, there is only one frame to consider (I-frame), and the redundancy is suppressed in two steps. Firstly, the picture is divided into small N×M blocks. Next, the discrete cosine transform (DCT) is used to represent the signal energy of each block in the form of reduced coefficients.

To compress and decompress the P–frame, the previous I–frame and/or P–frames in the same Group of Pictures (GoPs) are required. To compress and decompress B–frame, the previous and following I–frames and P–frames are needed. Therefore, if I-frame is lost, the remaining frames in the GoPs cannot be decoded. The loss of a P-frame at the beginning of the GoPs creates a huge distortion in the video sequence as compared to the loss of a P-frame at the end of the GoPs. By contrast, the distortion, due to the loss of a B-frame, has only a slight effect on the quality of the reconstructed video.

By considering the degree of distortion due to the loss of each video packet and the effect of this loss on the other frames within the GoPs, we define the Quality of Experience aware Store Carry and forward method (QoESCF). This scheme prioritizes the transmission of video packets that have a greater influence on the quality of the GoPs over those with lower QoE impact. Thus, we have to assign a weight to each video packet using the Peak Signal-to-Noise Ratio (PSNR) and the error propagation in subsequent frames. PSNR is a measure of distortion used in image compression, video compression, and video streaming. It quantifies the performance of the encoders and the video streaming systems by measuring the reconstruction quality of the compressed image (or video) as compared to the original image. Thus we can quantify the channel error loss as given in Eq. 5.4.

$$PSNR = 10 \times \log_{10} \frac{LM^2}{MSE} \tag{5.4}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2$$

Where LM is maximum luminance value (255 for 8bits), *MSE* is the mean square error, n represents the number of pixels in the video frame (or image), x_i and y_i are the i − th pixels of the original and the degraded frame introduced after a possible channel loss, respectively.

If a loss of information occurs in a single frame, the error due to this loss not only affects this frame but can propagate to the subsequent frames in the same GoPs. To quantify the channel loss error and the propagation error, we employ the distance distortion model as defined in Eq. 5.5.

$$d = \sum_{i=1}^{L} PSNR(i) \tag{5.5}$$

Where i = 1...L denotes the position of the frame in the GoPs, and L represents the length of the GoPs.

The weight of a given packet is calculated according to the Eq. 5.6

$$w = \frac{d}{L \times MAXPSNR} \tag{5.6}$$

Where MAXPSNR is the maximum value of the PSNR in the video sequence. Typically, the maximum value of P SNR is 50dB, provided the pixel size is 8 bit. For 16-bit pixel size, the maximum value is 80dB.

5.3.1 Distance distortion estimation

In this sub-section, we consider the transmitted video to be encoded according to MPEG-4/H.264 standard, where each I-frame is divided into multiple packets because of its large size, whereas a frame with small size, such as P-frame and B-frame, is included in a single packet. In addition, we consider that the encoder can design the packet payload such that the slices in each packet are independently decodable.

Furthermore, we assume a basic loss concealment approach wherein the loss of a P-frame is replaced by the previous correctly decoded frame by applying temporal interpolation at the decoder output. For the loss of an I-packet, the error is recovered by copying the pixels at the same location space of the previous correctly received frame.

By simulating the channel loss of each packet followed by applying the concealment algorithm, we can estimate the distance distortion value using Eq. 6. This value serves as the basis for retransmission differentiation in the QoESCF protocol. Figure 5-6 shows the process followed to estimate the distance distortion introduced by the loss of a given packet.

First the raw video is compressed using the MPEG-4 codec and a packetized video is created according to the designed payload size. The next step is the simulation of the channel error, achieved by deleting the desired packet. In this way a stream of packets with a gap is obtained. This stream of packets is then decoded to create a distorted video. The distorted sequence is compared with the reference video to calculate the distance distortion that further used by QoESCF to calculate the waiting time.

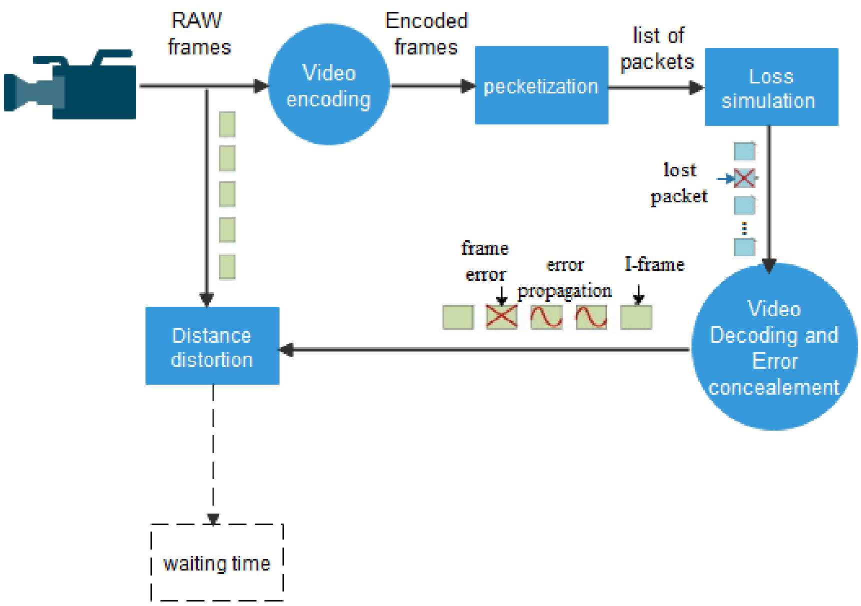


Figure 5-6 Overview of distance distortion estimation process.

5.3.2 Beaconing message structure and exchange

All nodes in the network periodically broadcast beaconing messages to share information with their one-hop neighbors. The beaconing message includes information about the kinetic state of the one-hop sender (sender ID, geographical position coordinates), Timestamp, and an updated list of video packet identifiers that are well-received by the sender called the Well-Received Packets List (WRPL). We can express The ID of the beaconing message sender by the MAC address of the network interface controller, and we can get the geographical position coordinates via global navigation satellite systems, E.g., Global Positioning System (GPS) or Galileo satellite systems. Figure 5-7 depicts the structure of a typical beaconing message.

When a neighboring node receives a beacon message, it either updates the sender information or creates a new entry in the neighborhood table. Furthermore, the entry of a sender in the neighborhood table will be deleted if the receiver does not receive a beacon message within $N_b \times I$ Seconds [87], where I is the beacon interval and N_b is the number of times the beacon message is missed. Figure 5-8 presents an example of the neighborhood table content at each one-hop neighbor node. For instance, when node *A*, in Figure 5-8, receives beaconing messages from nodes *B*, *C*, and *E*, it updates its neighborhood table by the identifier, the geographical position coordinates, and the WRPL of each of these nodes.

Sender ID	Latitude	Longitude	WRPL	Timestamp

Figure 5-7 Beaconing message structure.

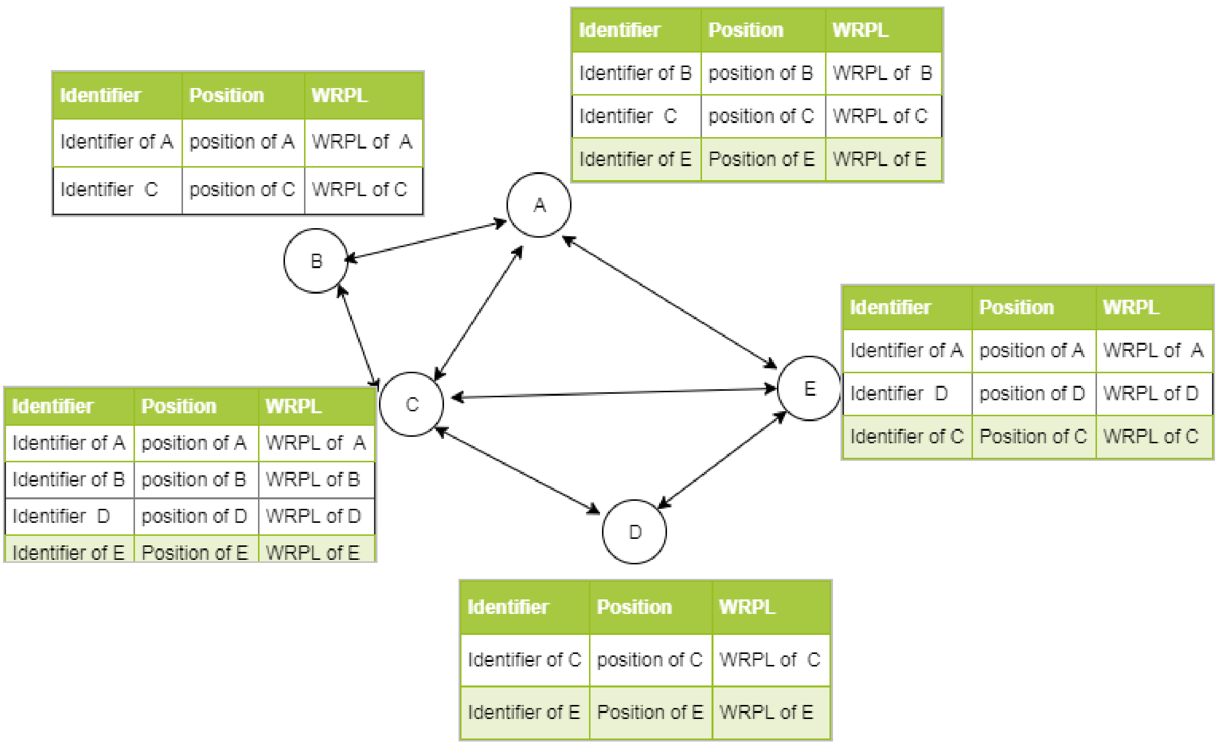


Figure 5-8 One-hop beaconing messages broadcast

5.3.3 QoESCF overview

Although the line-of-sight-based broadcasting protocol is designed to ensure a high delivery ratio, packets are prone to lost due to the unreliable UDP/RTP transport layer used for the video streaming applications, collisions, and the intermittent connection. Therefore, many researchers proposed a network-layer error-recovery method through retransmissions, i.e., the Store Carry-and-Forward method (SCF) [33][47][48][22].

In the basic SCF approach, nodes store each correctly received packet in a local retransmission cache until the packet's time-to-live (TTL) expires (TTL is usually an application layer specific parameter). Furthermore, when a node sends a beacon message, it notifies its neighborhood regarding the packets that were correctly received, enabling the neighbors to resend the packets that were not yet received during the first phase of the broadcasting. In this sub-section, we detail the proposed Quality-of-Experience-aware Store-Carry-and-Forward method (QoESCF).

In contrast to the basic schema of the SCF method, the QoESCF method adopts a priority-based retransmission mechanism, where more important packets are likely scheduled to be retransmitted before the less important packets. In this regard, it is important to consider the degree of distortion that affects the video quality when a given packet is lost, as expected, to prioritize the retransmission. To achieve this goal, we employ the perspective of the waiting time where the vehicles spend less time waiting before the transmission of the most important packets than before those that are less important. In other words, the waiting time is inversely proportional to the normalized packet-distance distortion value defined in Eq. 5.6. The waiting time t_k for a packet p_k is modeled using Eq.5. 7.

$$t_k = (1 - w_k) \times T_{max} \tag{5.7}$$

Where w_k is the weight of the packet p_k (Eq. 5.6) and T_{max} is the maximum waiting time. Algorithm 1 describes the main steps of the QoESCF method.

When a vehicle receives a beacon message from a neighbor *V* (Algorithm 1 line 1), it updates the neighborhood table by the information included in the beacon message (Algorithm 1 lines 2). Next, it matches its retransmission cache with the WRPL list piggybacked by the beacon message (Algorithm 1 lines 3). If there is in the retransmission cache of the receiver node a packet *p* that has not yet been received by *V*, it checks whether or not it is the closest vehicle to *V* among the neighboring vehicles that can retransmit *p*. To accomplish this task, the receiver vehicle confirms, through the neighborhood table, whether there is an immediate neighbor that it well received the packet *p* and that has a distance to *V* smaller than the distance between the receiver vehicle and *V* (Algorithm 1 lines 4-10). If there is such a neighbor, the receiver vehicle does not retransmit *p*, hence avoiding unnecessary rebroadcast of *p* and introducing more coordination. Otherwise, the receiver vehicle calculates the waiting time t_p according to equation 5.7 and schedules a timer to expire after t_p (Algorithm 1 lines 11-14). When the waiting time elapses the packet p is retransmitted (Algorithm 1 lines 17-18).

Algorithm 1 QoESCF

```
Begin

1. on receiving a beacon message b from a neighbor v
2. update the neighborhood table
3. for each packet p in the retransmission cache do
4.     if p is not acknowledged in the WRPL list
          piggybacked by b then
5.        schedule to transmit=true
6.        for each node n in the neighborhood table do
7.            if (p is in the WRPL list of n) and
                 (n is in the communication range of v)and
                 (distance to v > distance(n,v)) then
8.                 Schedule_to_transmit=false
9.            end if
10.       end for
11.       if schedule_to_transmit==true then
12.          Calculate the waiting time t_p
             according to Eq 5.7
13.          Schedule to transmit p after t_p
14.      end if
15.    end if
16.  end for
17.  on timer expire
18.   Transmit the scheduled packet

End
```

5.4 Performance evaluation

5.4.1 Simulation parameters and evaluation metrics

We verified the validity of the proposed method by comparing its results with those obtained using two important video broadcasting protocols, namely REDEC [103] and REACT-DIS [102]. As highlighted in [102] [103], REACT-DIS and REDEC simulations are related to the definition of the levels of certain parameters. To provide the best possible performance, we used the configuration defined elsewhere [102] [103]. In ReLoS/QoESCF, we set T_{min} to 100ms and T_{max} to 250ms.

The feasibility of any broadcasting protocols to improve the video dissemination performance is evaluated using several Metrics. One of them involves determining the quality of service (QoS) level, namely the frame delivery ratio and latency (end-to-end delay) metrics.

The frame delivery ratio is the percentage of frames correctly received to the total sent. The end-to-end delay (or latency) is the time required by a packet to reach the receiving endpoint. As recommended by CISCO, the minimum frame delivery and maximum latency for streaming video are 95% and 5s, respectively [20].

These measures are indicative but cannot alone give sufficient information regarding the video quality perceived by the end-user. Thus, we need to use metrics that help to measure the quality of experience (QoE) level provided to the end-user. In our study, different schemes were evaluated using the mean of two objectives QoE metrics, namely the peak signal-to-noise ratio (PSNR) and mean opinion score (MOS).

The PSNR is a distortion measure used in digital images, particularly in image compression and video transmission. It quantifies the performance of the encoders by measuring the quality of the reconstructed image or video sequence with respect to the original image. The MOS is a value given to a reconstructed image or video sequence to characterize its quality on a five-point scale. Table 5-2 outlines the interpretation of each MOS scale [132]. The QoS and QoE metrics were calculated as a function of the data rate and the density of the vehicles.

Table 5-2 ITU-R MOS scale.

MOS scale	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Different broadcasting protocols were implemented and evaluated using the discrete-event network simulator OMNeT++ [129] along with the VEINS plug-in [130]. VEINS is an open-source framework dedicated to run a vehicular network simulation, and it includes the main components to simulate 802.11p MAC and physical layers.

Table 5-3 lists the values of the main parameters associated with the network simulation. We set the two-ray ground as the path loss model, which considers the destructive and constructive effects of signal interference with ground reflections [133][134]. The transmission range is set to 200meters. The effect of buildings on the signal attenuation is determined using the default preloaded model in the VEINS framework. Beacon messages exchanged between vehicles at a frequency of 1Hz were employed in the QoESCF to recover the lost packets. The N_b parameter of the beaconing system was set to 2.

Table 5-3 Physical and MAC layer parameters.

Parameter	Value
MAC layer	802.11p
Transmission range	200 Meter
Bandwidth	20 Mbps
Sensitivity	- 89 dBm

The framework EvalVid [132] is exploited to generate the video transmission file trace and assess the quality of the received video. The PSNR tool of Evalvid was used to provide the weight of each video packet (by following the steps described in the subsection 5.3.1).

EvalVid is a set of tools that can be used to evaluate the quality of a video transmitted over a real or simulated communication network. In our simulation, the streaming video application uses a raw video known as akiyo_cif, which is selected from the video trace library of Arizona State University [135]. Before sending the video, we created a compressed video file in the MPEG-4/H.264 format comprising 300 frames generated at a frame rate of 30 fps. The compressed video stream consists of consecutive GOPs which contain I- and P-frames. The size of each GoPs was set to 30 frames. The video frames were segmented to generate 327 packets with a maximum payload size of 1024 bytes.

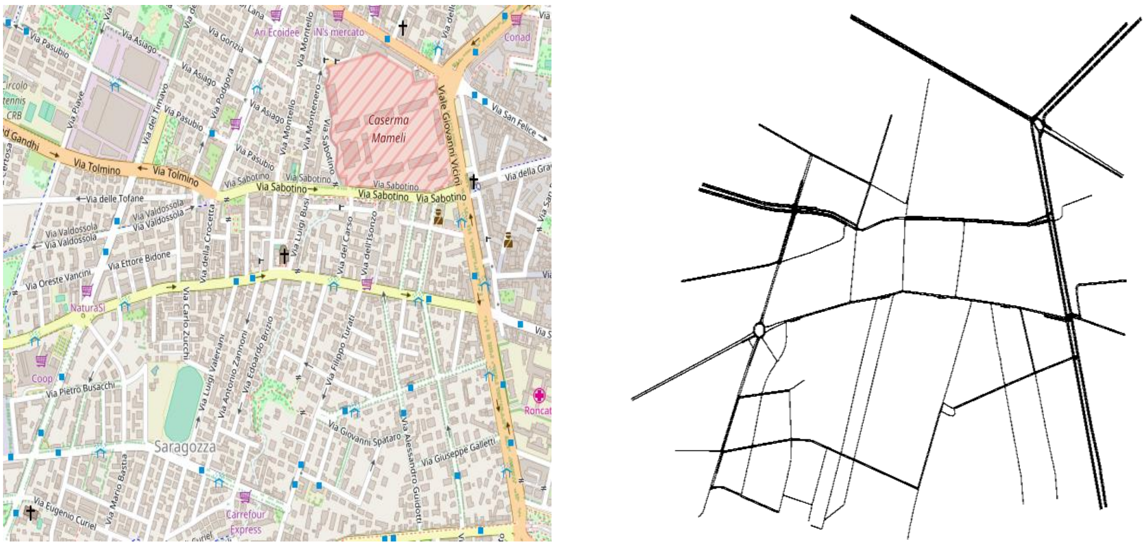


Figure 5-9 Bologna city road map layout

We increased the credibility of our experiments by generating a real-world vehicular traffic scenario using SUMO tools [136]. The environment considered for the simulation is the urban road network of Bologna City, as shown in Figure 5-9. The city comprises various types of segments, including highways, roads with one and two lanes, bus lanes, bus stops, roundabouts, and intersections with traffic lights. We also generated a complicated environment for signal propagation by filling the free space between the roads using synthetic blocs, which represent tower buildings. The mobility was simulated on a space with dimensions of 1900m × 1700m. The vehicle mobility was based on the Krauss car-following model [137] to ensure that the experimental study was carried out in a realistic scenario. In other words, a vehicle moves according to the speed of the leading vehicle in the same lane, and the driver is required to maintain a safe distance from this vehicle. Table 5-4 lists the parameter values of the mobility simulation.

We evaluated the effectiveness of the methods by varying the arrival rate of the vehicles to realize low (60 vehicles), medium (110 vehicles), and high densities (230 vehicles).Each obtained result is the average of 10 executions with a confidence interval of 95%.

Table 5-4 Mobility simulation parameters.

Parameter	**Value**
Number of vehicles	Low density(60). medium density (110). High density(230)
Road Network Size	1900m × 1700m
Mobility model	Krauss car-following model
Acceleration	2.6m/s^2
Deceleration	4.5m/s^2
Driver imperfection	0.5
Maximum speed	30m/s

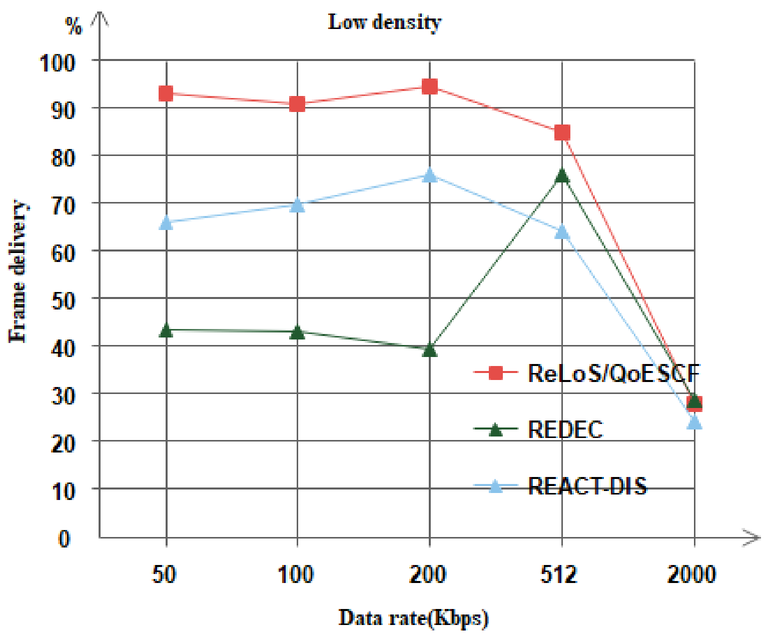
5.4.2 Simulation results and discussion

Frame delivery

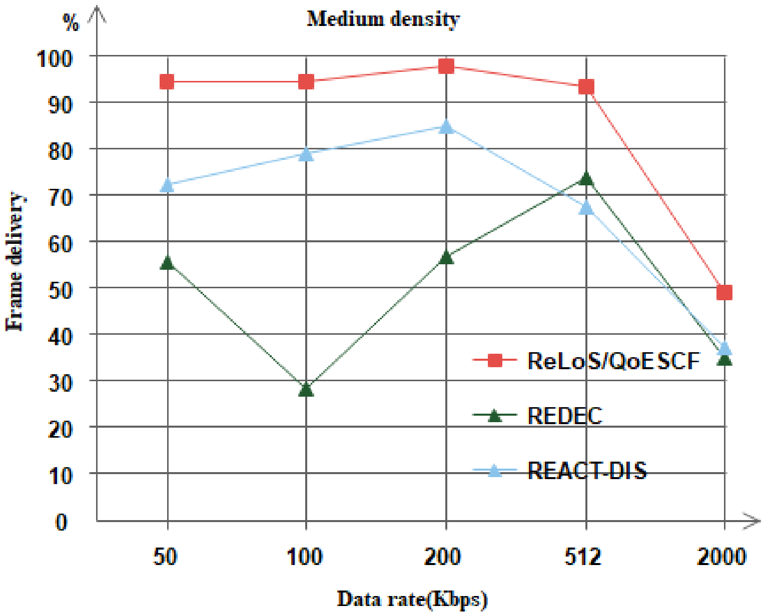
Figure 5-10 shows the frame delivery percentages for three different vehicle densities. The results depicted in Figure 5-10 show that all protocols achieve low frame deliveries at high data rates. The results are in good agreement with those of other studies wherein a higher data rate was often not an optimal choice for broadcasting videos over VANETs.

The common observation for the REDEC protocol is that the frame delivery is very low for low and medium densities, confirming that the REDEC can be used to obtain a reasonable frame delivery percentage for only high densities. For scenarios with a low vehicle density, the network is intermittently connected because of the high mobility of vehicles and the presence of walls that obstruct line-of-sight; these vehicles form disconnected clusters. However, REDEC has no strategy for recovering packet loss in the case of intermittent connections. Moreover, the frame delivery ratio improved only slightly when using the REACT-DIS for low and medium densities compared to the REDEC protocol. This is because the density-aware scheme adapts the number of relay nodes with the density of the vehicles in the road network.

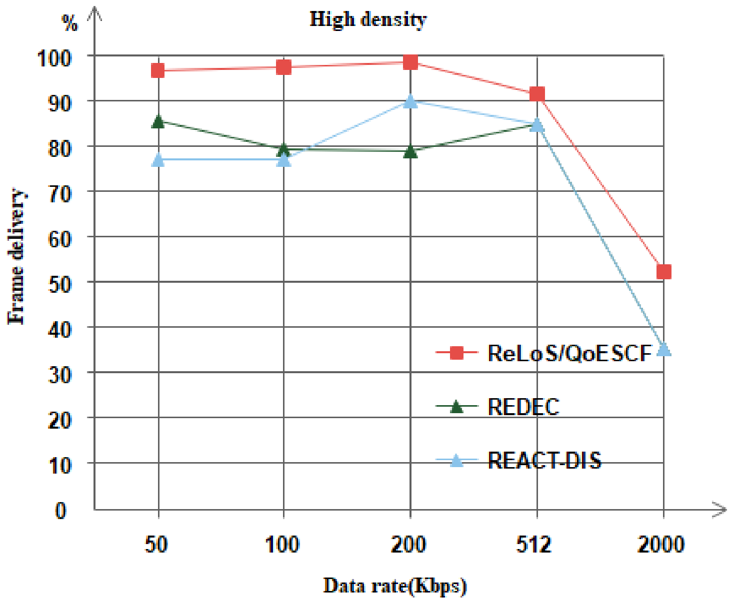
Overall, the combined ReLoS and QoESCF scheme performs the best among the presented protocols. Even in low-density scenarios, the frame delivery ratio is close to 90% at low data rates. There are several reasons for the loss of packets in the VANETs, including network fragmentation (due to the high mobility of the vehicles and the effect of buildings on the transmission signal) and the broadcast storm problem, which leads to network congestion, denial of services, and collisions. Unlike other algorithms, the combined ReLoS and QoESCF solves all the problems cited above, i.e., it facilitates the selection of relay nodes with a good line-of-sight, relay nodes are distributed across all the roads to maximize the network coverage area, and packets lost due to the intermittent connection and collisions are recovered using the QoESCF mechanism.



(a) Low-density vehicle scenario



(b) Medium-density vehicle scenario



(c) High-density vehicle scenario

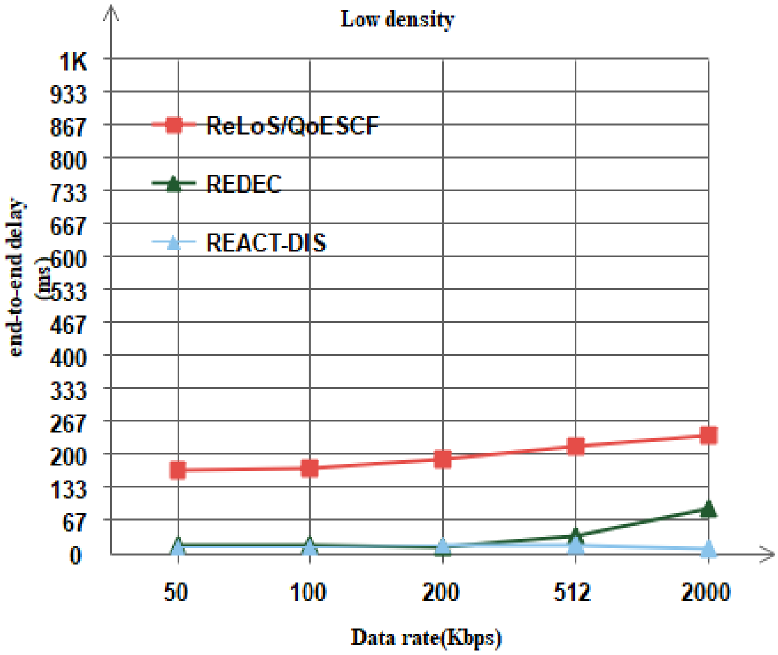
Figure 5-10 Frame delivery percentage

Average end-to-end delay

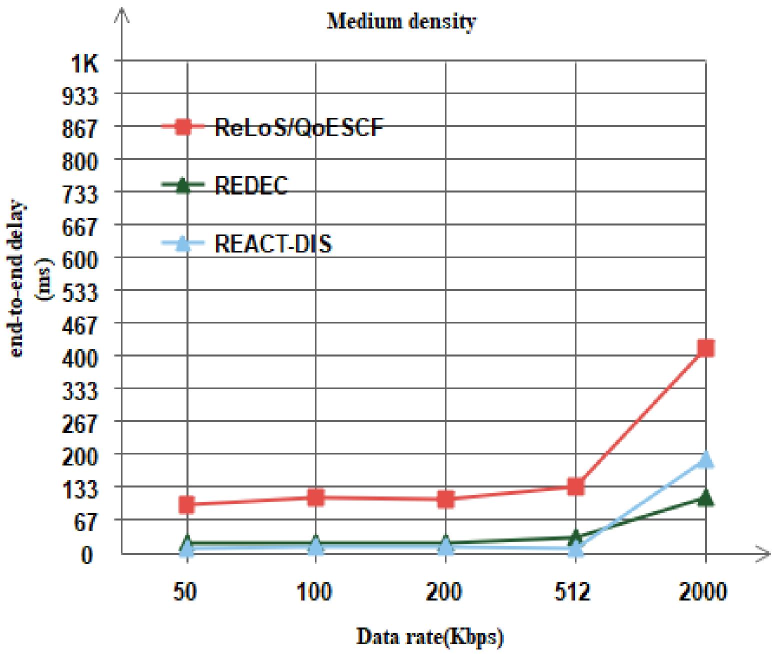
Figure 5-11 shows the average end-to-end delay results for REACT-DIS, REDEC, and combined ReLoS/ QoESCF protocols. The results show that REACT-DIS and REDEC slightly outperform the ReLoS/QoESCF in terms of the end-to-end delay.

As mentioned previously, the three protocols follow timer-based approaches, where the relaying (forwarding) nodes are selected at the receiver side through a distributed contention phase. Thus, when a sender broadcasts a packet to its immediate neighbors, each node schedules itself to be a relay after a waiting time *t*. Consequently, the additional delay due to the contention phase in the forwarding process leads to an increase in the total end-to-end delay. This additional time accumulates in each hop, thereby adversely affecting the transmission durations. To solve this issue, a timely mechanism is implemented in both the REDEC and REACT-DIS methods to maintain the forwarding status throughout the course of a window time, instead of repeating the contention process for each transmitted packet. Therefore, the REDEC and REACT-DIS methods provide videos with shorter delays compared to ReLoS.

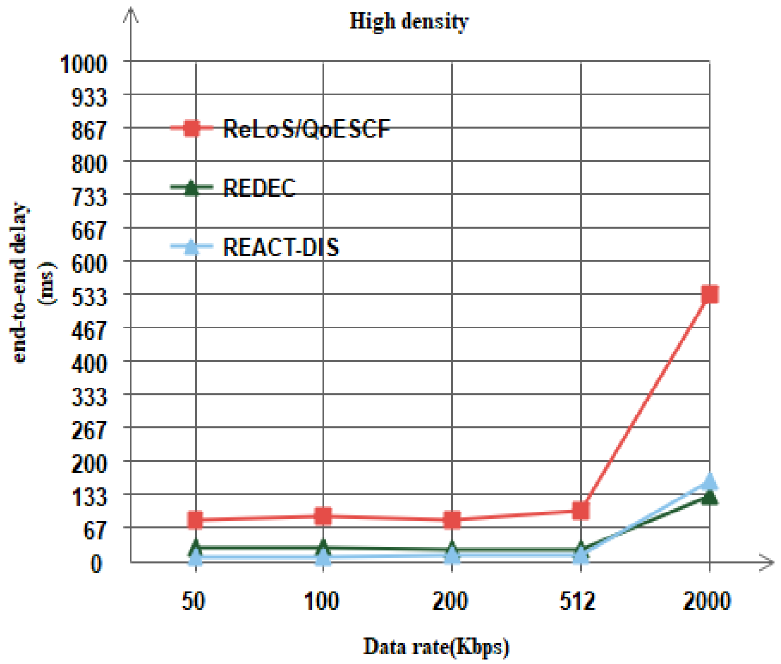
However, the obtained delay levels of the ReLoS/QoESCF method are negligible and are significantly lower than the requirements defined by CISCO for video streaming (the obtained end-to-end delay is less than 5 seconds). Furthermore, REDEC and REACT-DIS fail to address the trade-off between frame delivery and end-to-end delay in low and medium densities. Consequently, their good results in terms of end-to-end delay have not any impact to enhance the quality of the received video.



(a) Low-density vehicle scenario



(b) Medium-density vehicle scenario



(c) High-density vehicle scenario

Figure 5-11 Average end-to-end delay

QoE indicators

As mentioned previously, the QoS indicators help to measure network performance. However, they cannot be used to assess the video quality as perceived by the end-user. Therefore, the effects of QoE metrics, specifically PSNR and MOS, are analyzed, as shown in Figure 5-12 and Figure 5-13, respectively.

We need the PSNR and MOS values of the reference video to assess the video quality. They represent the PSNR and MOS values of the compressed video file before the transmission, and in our simulation, their values are 32.21dB and 4.02, respectively.

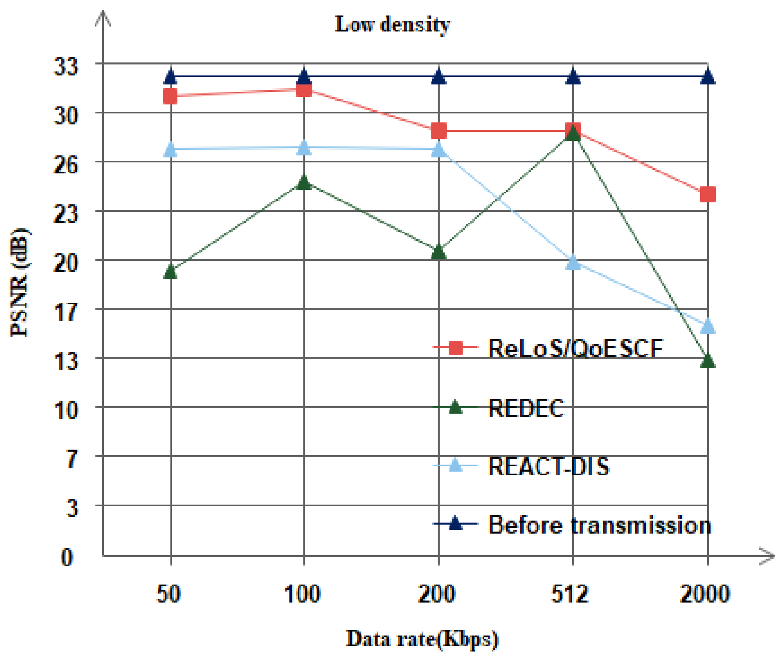
Figure 5-12 shows the results in terms of the average PSNR of the decoded video at the receiver sides for different data rates and vehicle densities. The ReLoS/QoESCF outperforms the REDEC and REACT-DIS methods in terms of the PSNR for low and medium densities. For high density, the results obtained using the REDEC exceed slightly those obtained using ReLoS/QoESCF.

Figure 5-12a shows the results for the low-density scenario, where the ReLoS/QoESCF maintains PSNR values between 28.54dB and 30.85dB for a data rate of up to 512 Kbps. The average degradation obtained using the proposed method is 2.47dB compared to the PSNR value of the reference video, whereas those obtained using the REDEC and REACT-DIS methods are 8.99dB and 6.79dB, respectively.

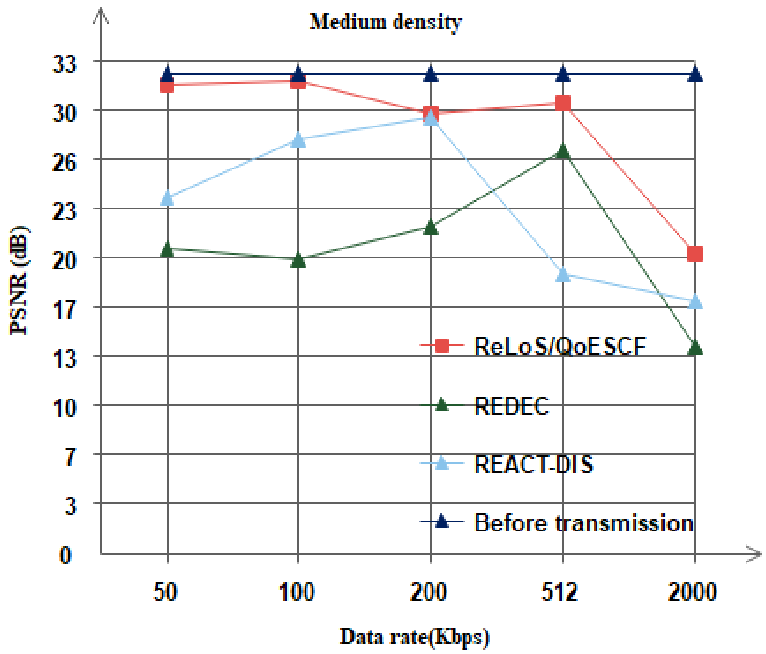
Figure 5-12b shows the PSNR results for the medium-density scenario. The ReLoS/QoESCF protocol can provide the best quality for a data rate of up to 512 Kbps, with a PSNR value of more than 30.35dB. The performance of the REDEC method is the poorest among the given methods. In contrast, for high-density scenarios, the PSNR obtained using the REDEC is significantly improved when it is compared to the low and medium densities results.

As shown in Figure 5-12c, the results obtained using the three protocols are largely similar.

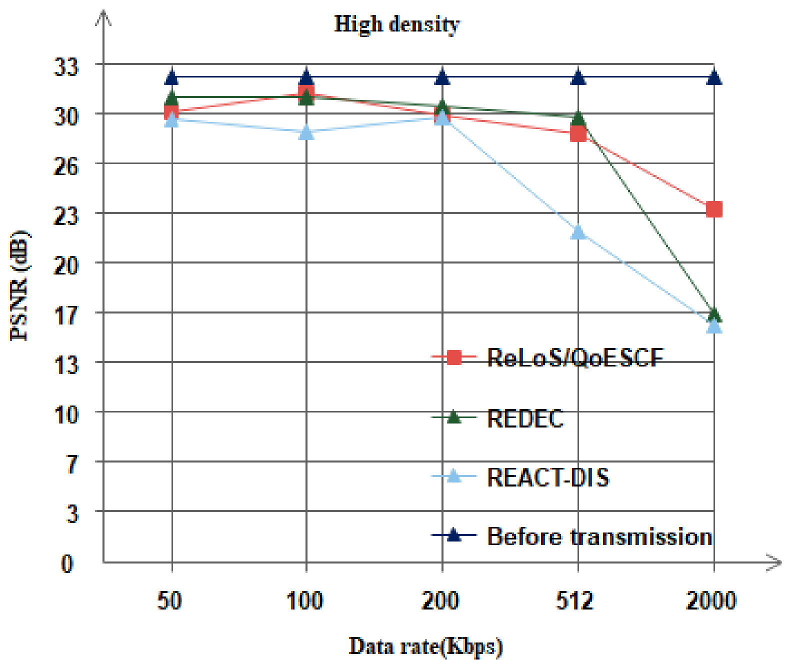
For a data rate of 2 Mbps, the overall video quality degrades for the three protocols. However, the ReLoS/QoESCF ensures the best quality compared to the other protocols. For example, for high-density scenarios, the PSNR of the video delivered using the ReLoS/QoESCF is enhanced by 6.98dB compared to the REDEC protocol. This confirms the effectiveness of the relay node selection mechanism (ReLoS) and the retransmission method (QoESCF) proposed in this study.



(a) Low-density vehicle scenario



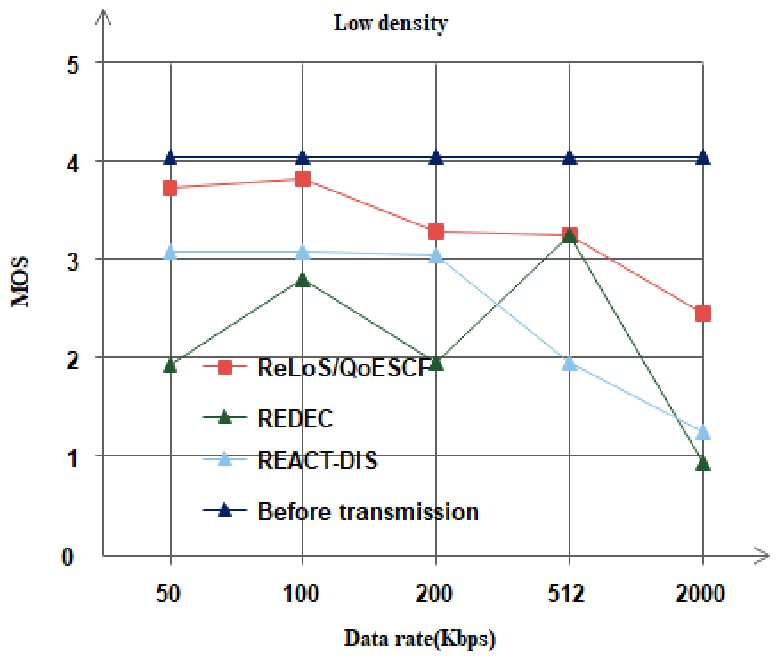
(b) Medium-density vehicle scenario



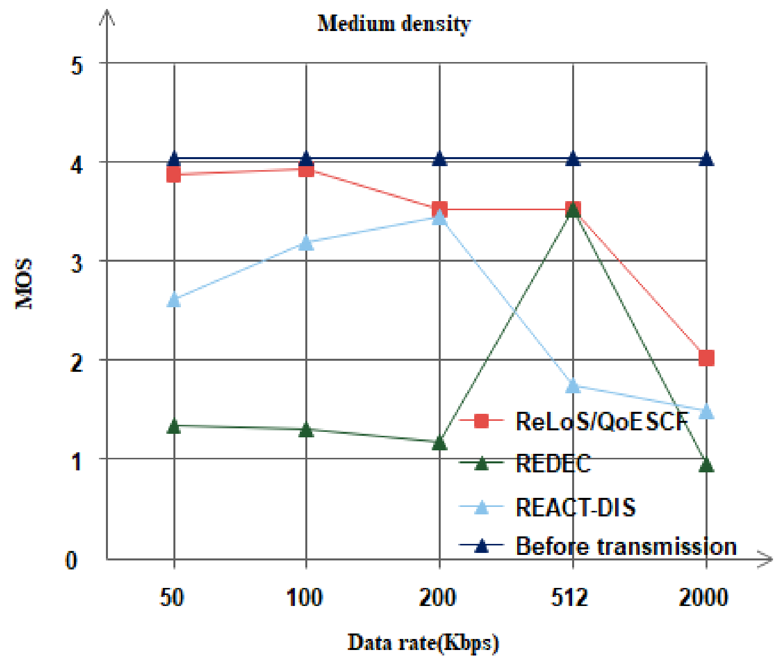
(c) High-density vehicle scenario

Figure 5-12 Average peak signal-to-noise ratio

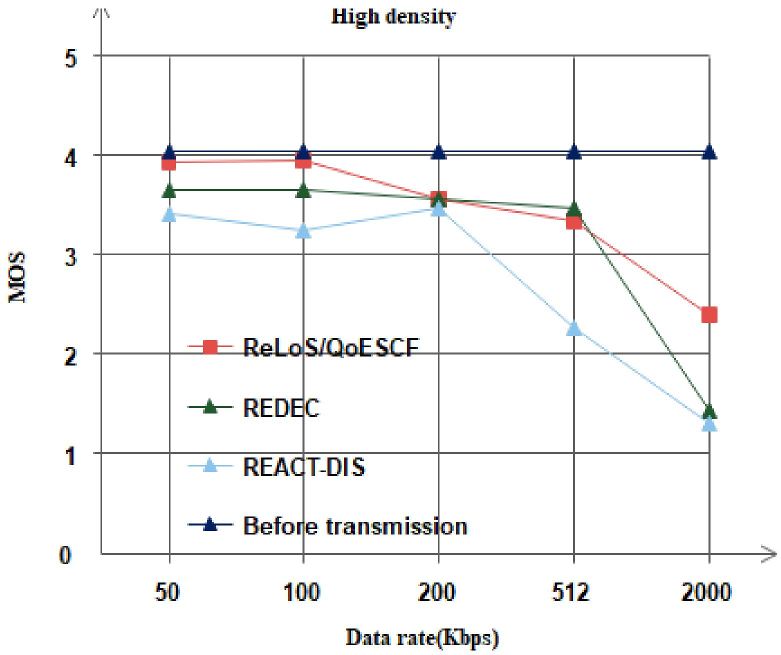
As the PSNR metric does not reflect the structural quality of the video, it is important to consider the MOS to calculate the frame-by-frame difference between the quality of the transmitted video and the possibly corrupted video in the receiver vehicles. Figure 5-13 shows that the ReLoS/QoESCF allows for the dissemination of videos with good quality at lower data rates, which compliments the PSNR results.



(a) Low-density vehicle scenario



(b) Medium-density vehicle scenario



(c) High-density vehicle scenario

Figure 5-13 Average mean opinion score

5.5 Conclusion

Transmitting videos over VANETs is a challenging task due to the specificities of VANET, such as dynamic topology, shadowing phenomena, and lossy environments.

In this chapter, we proposed the ReLoS method for video streaming with line-of-sight awareness for urban VANETs. ReLoS disseminates videos with improved reachability relative to existing methods because it uses a reactive receiver-based scheme and a line-of-sight heuristic to select the relay nodes.

Compared to the two related protocols (REDEC and REACT-DIS), the combined ReLoS/QoESCF enables a significant enhancement of the quality of the transmitted video in terms of the PSNR, MOS, and frame delivery. However, the proposed method causes greater end-to-end delay than the other protocols; nevertheless, the obtained end-to-end delay does not exceed the threshold defined by CISCO. Furthermore, our solution to cope with packet loss due to the communication disconnection and collisions was provided through the

QoESCF scheme. This scheme supports packet retransmission differentiation, wherein the priority of the retransmission is set to the most important packets.

With the aim to design a collision-free solution, we intend in the future to exploit the multi-channel architecture defined in the DSRC standard, to schedule concurrent transmissions in separate channels. The goal is to improve frame ratio delivery without incurring the additional message overhead caused by the SCF method. Furthermore, we plan to investigate the stability of vehicles located near intersections to design a timely broadcasting protocol.

Chapter 6 Conclusion and Perspectives

The emergence of intelligent cities switches urban environments into connected digital space, making daily activities of people easy in different area of life. Nowadays, intelligent transportation systems (ITS) have been the most important component in smart cities. The main goal of intelligent transportation systems is to handle and share information that can limit possible collisions, hold traffic easy, and reduce the negative environmental influences of the transport sector on society. However, sharing information between ITS components can only be fully leveraged through VANETs integration.

Through multi-hop data dissemination over VANETs, ITS can support wide set of transportation applications, such as emergency vehicle warning, accident notification, co-operative navigation, location services, video streaming. Nevertheless, one of the principal challenges of VANETs is creating a reliable and efficient multi-hop dissemination protocol that can deal with high mobility of vehicles, intermittent communication, shadowing phenomena caused by obstacles such as building in city scenarios.

Multi-hop broadcasting schemes should be designed to improve at least one of the three metrics: reachability, message overhead, and latency. Solutions designed for safety applications focus on improving both reachability and latency, whereas those created to support non-safety services can be more resilient to the latency. Thus, they should be designed to enhance reachability as the primary aim while keeping the latency in an acceptable range. Concerning video streaming, it has a stringent quality of service requirements. According to CISCO, the loss ratio and latency should not exceed 5% and 5s to get an acceptable video quality. Furthermore, any designed solution has to minimize the message overhead to avoid broadcast storm problem.

In VANETs, there are two different environments: highway and urban scenarios. The principal difference between them is the layout of the road network and the spatial distribution of vehicles. The mobility of vehicles on the highway is limited to uni-dimensional topology, while the mobility on the urban environment is constrained by a grid-like pattern.

This thesis focuses on designing new solutions to improve the dissemination of two kinds of data in urban VANETs: non-safety message and video stream.

6.1 Conclusion

All along this PhD thesis, we have obtained valuable information about data dissemination in VANETs along with other related scopes such as video streaming.

We have started by recapitulating the basic concepts of VANETs in. We mainly focused on the normalization aspect and the communication architecture. Furthermore, we reviewed the recent works in data dissemination according to a new taxonomy. Thus we classify these works based on the size of the region of interest: one-hop, multi-hop, and adaptive protocols, and we have sub-classified the multi-hop protocols into sender-based and receiver-based. Moreover, we have qualitatively analyzed multi-hop broadcast methods based on forwarding strategy, their requirements in terms of modules and infrastructures (E.g., beaconing system, GPS, RSU, and MAP), the handled problems (hidden terminal, broadcast problems, and intermittent communication), and their ability to self-preserve the anonymity of nodes. According to our observations, receiver-based methods have more advantages than sender-based ones. Thus, all proposed methods in this thesis follow a receiver-based scheme.

Furthermore, we highlight a special case of data dissemination which is video streaming in VANETs. Recent works are reviewed, including routing protocols and error recovery methods.

Next, we present and detail our first contribution to improving data dissemination in VANETs. We focus mainly on urban VANETs. Based on our examination in forgoing chapters, we have noted that counter-based and minimum-distance-based heuristics are used in many works due to their high ability to address the broadcast storm problem. However, they mainly suffer from intrinsic stochastic behavior, which negatively affects the reachability metric. We provided extended versions of the distance-based protocol and counter-based protocol, aiming to enhance their coverage capacity using the road-network layout feature and hence to alleviate the effect of the stochastic behavior. The proposed protocols are Enhanced

Counter-based broadcast protocol in Urban VANET (ECUV) and Enhanced distance-based broadcast protocol in Urban VANET (EDUV). Furthermore, an analytical model is designed to evaluate these protocols. Unlike most related works that only evaluated broadcasting protocols using network simulation, ECUV and EDUV are evaluated through both analytical models and network simulation. The analytical results explicitly proved that the broadcasting probability in EDUV and ECUV was inversely proportional to the density of vehicles. More specifically, the broadcasting probability was increased when the traffic density was low to meet the coverage capability requirement, and it was decreased when the traffic density was high to address the broadcast problem. Furthermore, EDUV and ECUV performance was compared through network simulation with the performance of the basic schemes of counter and distance heuristics and the probabilistic forwarding strategy used in the REACT-DIS protocol. The simulation results clearly showed that the proposed protocols outperform the other solutions in terms of coverage capabilities while holding the end-to-end delay and message overhead at an acceptable level.

This thesis also focuses on designing multi-hop broadcasting solutions for video streaming in urban VANETs. Thus we propose a receiver-based broadcasting solution that combines a line-of-sight-aware mechanism and a road-based bi-directional scheme to deal with both the shadowing phenomena and the need for coverage capabilities in urban VANETs. Our solution is termed Receiver-based Line-of-Sight-aware broadcasting protocol (ReLoS). Furthermore, we design an error recovery method through local retransmissions to deal with packets loss. Our solution enhances a retransmission method named store-carry-and-forward (SCF). Unlike the basic SCF, the proposed one is video-friendly and schedules the retransmission of each video packet based on its impact on the reconstructed video. The new SCF is named QoESCF. The combined ReLoS/QoESCF scheme showed a higher video streaming quality in terms of video packet delivery ratio, PSNR, and MOS while keeping the latency under the threshold recommended by CISCO.

Chapter 6 concludes the work presented in the previous chapters and gives some future research directions. We finish with some perspectives that are deduced from the obtained results.

6.2 Perspectives

To enhance data dissemination and more specifically video streaming in VANET, we intend to focus on the following perspectives as future works.

- **Stability of nodes:** We have proposed in this work the ReLos/QoESCF mechanism that improves significantly the performance of video streaming in terms of frame delivery ratio, PSNR, and MOS. Though, ReLos/QoESCF follows a timer-based mechanism that increases the delay of transmission as compared to REACT-DIS and REDEC protocols. A promising way to deal with this issue could be by keeping the status of relay-node for a slot of time instead of repeating the process of selecting relay nodes for each transmitted packet. The slot of time can be determined according to the stability of the relay nodes. For instance, relay nodes near intersections are likely more stable, whereas nodes which are far away from intersections are less stable. Thus the time slot assigned to each relay node can be directly proportional to its stability. Besides, in our performance evaluation, we do not investigate the impact of vehicles' speed and how ReLos/QoESCF behaves in different urban scenarios. In future work, we plan to investigate the performance of ReLos/QoESCF by taking into consideration different mobility scenarios. More specifically, we project to check how ReLos/QoESCF would perform in a scenario with higher maximal velocity? How long are the contact times between the vehicles? How is this influencing the performance of our algorithm?

- **Cognitive radio for Vehicular Ad hoc Networks (CR-VANETs):** Cognitive Radio (CR) can expand the capacity of communications in VANETs. CV checks the availability of the communication channel and accordingly adapts the transmission parameters based on the knowledge collected from the environment. The purpose is to adequately schedule the channels of the spectral band to minimize congestion in the network. The reliability and efficiency of multi-hop broadcast protocols can be improved using cognitive radio techniques. We intend in the future to focus on conducting our research in this direction.
- **Analytical models:** Many analytical models follow a probabilistic scheme, such as the one proposed in our thesis. These models calculate only the probability of a node to

become a relay node and cannot provide the delivery ratio and message overhead of the evaluated broadcast protocols. We project in future work to design a new methodology to tackle this issue. This can be achieved by combining the probabilistic model and Monte Carlo simulation.

- Several sender-based broadcast solutions use beaconing messages to select relay nodes. This class of solutions depends highly on the accuracy of the positioning information delivered through the beaconing messages to work correctly. However, nodes should broadcast these messages with high frequency to get accurate and timely information, but this can highly overload the wireless channel. In chapter 2, we have reviewed many adaptive beacon messages broadcast protocols proposed to find an optimal trade-off between the burden of the transmission overload and information accuracy. In future work, we project to conduct a comparison study between these works to select a suitable protocol that will be used to assist sender-based multi-hop broadcasting protocols.

Bibliography

[1] M. L. Mfenjou, A. A. A. Ari, W. Abdou, F. Spies, and others, "Methodology and trends for an intelligent transport system in developing countries," *Sustain. Comput. Informatics Syst.*, vol. 19, pp. 96–111, 2018.

[2] H. Gao, W. Huang, and X. Yang, "Applying probabilistic model checking to path planning in an intelligent transportation system using mobility trajectories and their statistical data," *Intell. Autom. Soft Comput.*, vol. 25, no. 3, pp. 547–559, 2019.

[3] L. Kuang, C. Hua, J. Wu, Y. Yin, and H. Gao, "Traffic Volume Prediction Based on Multi-Sources GPS Trajectory Data by Temporal Convolutional Network," *Mob. Networks Appl.*, pp. 1–13, 2020.

[4] A. A. A. Ari, A. Gueroui, N. Labraoui, and B. O. Yenke, "Concepts and evolution of research in the field of wireless sensor networks," *Int. J. Comput. Networks Commun.*, vol. 7, no. 1, pp. 81–98, 2015.

[5] A. A. Ganin, A. C. Mersky, A. S. Jin, M. Kitsak, J. M. Keisler, and I. Linkov, "Resilience in Intelligent Transportation Systems (ITS)," *Transp. Res. Part C Emerg. Technol.*, vol. 100, pp. 318–329, 2019.

[6] H. Khelifi *et al.*, "Named Data Networking in Vehicular Ad hoc Networks: State-of-the-Art and Challenges," *IEEE Commun. Surv. Tutorials*, 2019.

[7] H. Kawashima, "Japanese perspective of driver information systems," *Transportation (Amst).*, vol. 17, no. 3, pp. 263–284, 1990.

[8] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETS): status, results, and challenges," *Telecommun. Syst.*, vol. 50, no. 4, pp. 217–241, Aug. 2012, doi: 10.1007/s11235-010-9400-5.

[9] H. Gao, W. Huang, and Y. Duan, "'The cloud-edge based dynamic reconfiguration to

service workflow for mobile ecommerce environments: A QoS prediction perspective," *ACM Trans. Internet Technol*, 2020.

[10] A. B. Tambawal *et al.*, "Time division multiple access scheduling strategies for emerging vehicular ad hoc network medium access control protocols: a survey," *Telecommun. Syst.*, pp. 1–22, 2019.

[11] J. A. Guerrero-Ibáñez, C. Flores-Cortés, and S. Zeadally, "Vehicular Ad-hoc Networks (VANETs): Architecture, Protocols and Applications," Springer, London, 2013, pp. 49–70.

[12] H. Hartenstein and K. P. Laberteaux, "A tutorial survey on vehicular ad hoc networks," *IEEE Commun. Mag.*, vol. 46, no. 6, pp. 164–171, Jun. 2008, doi: 10.1109/MCOM.2008.4539481.

[13] F. Arena and G. Pau, "An Overview of Vehicular Communications," *Futur. Internet*, vol. 11, no. 2, p. 27, 2019.

[14] B. Ravi, J. Thangaraj, and S. Petale, "Data Traffic Forwarding for Inter-vehicular Communication in VANETs Using Stochastic Method," *Wirel. Pers. Commun.*, pp. 1–17, 2019.

[15] K. Zheng, Q. Zheng, H. Yang, L. Zhao, L. Hou, and P. Chatzimisios, "Reliable and efficient autonomous driving: the need for heterogeneous vehicular networks," *IEEE Commun. Mag.*, vol. 53, no. 12, pp. 72–79, 2015.

[16] P. V Patel and B. Kadhiwala, "Broadcasting techniques for route discovery in mobile Adhoc network—A survey," in *2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom)*, 2016, pp. 671–674.

[17] D. B. Johnson, D. A. Maltz, J. Broch, and others, "DSR: The dynamic source routing protocol for multi-hop wireless ad hoc networks," *Ad hoc Netw.*, vol. 5, pp. 139–172, 2001.

[18] C. Perkins, E. Belding-Royer, and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing," Jul. 2003. doi: 10.17487/rfc3561.

[19] A. Ksentini, A. Gueroui, and M. Naimi, "Enhancing the DCF mechanism in noisy environment," in *IEEE VEHICULAR TECHNOLOGY CONFERENCE*, 2005, vol. 62,

no. 1, p. 650.

[20] "Video Quality of Service (QOS) Tutorial - Cisco." https://www.cisco.com/c/en/us/support/docs/quality-of-service-qos/qos-video/212134-Video-Quality-of-Service-QOS-Tutorial.html (accessed May 18, 2021).

[21] W. Viriyasitavat, O. K. Tonguz, and F. Bai, "Network connectivity of VANETs in urban areas," in *2009 6th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks*, 2009, pp. 1–9.

[22] W. Viriyasitavat, O. Tonguz, and F. Bai, "UV-CAST: an urban vehicular broadcast protocol," *IEEE Commun. Mag.*, vol. 49, no. 11, pp. 116–124, Nov. 2011, doi: 10.1109/MCOM.2011.6069718.

[23] Y.-C. Tseng, S.-Y. Ni, Y.-S. Chen, and J.-P. Sheu, "The Broadcast Storm Problem in a Mobile Ad Hoc Network," *Wirel. Networks*, vol. 8, no. 2/3, pp. 153–167, 2002, doi: 10.1023/A:1013763825347.

[24] C. Wu, S. Ohzahata, and T. Kato, "A low latency path diversity mechanism for sender-oriented broadcast protocols in VANETs," *Ad Hoc Networks*, vol. 11, no. 7, pp. 2059–2068, Sep. 2013, doi: 10.1016/j.adhoc.2012.02.007.

[25] F. Naeimipoor, C. Rezende, and A. Boukerche, "Performance evaluation of video dissemination protocols over Vehicular Networks," in *37th Annual IEEE Conference on Local Computer Networks -- Workshops*, Oct. 2012, pp. 694–701, doi: 10.1109/LCNW.2012.6424052.

[26] R. Ghebleh, "A comparative classification of information dissemination approaches in vehicular ad hoc networks from distinctive viewpoints: A survey," *Comput. Networks*, vol. 131, pp. 15–37, 2018.

[27] T. Marinov, M. Nenova, and G. Iliev, "Comparative Analysis of Broadcasting Protocols in VANET," in *2018 IX National Conference with International Participation (ELECTRONICA)*, 2018, pp. 1–4.

[28] S. Latif, S. Mahfooz, B. Jan, N. Ahmad, Y. Cao, and M. Asif, "A comparative study of scenario-driven multi-hop broadcast protocols for VANETs," *Veh. Commun.*, vol. 12, pp. 88–109, 2018.

[29] M. Slavik and I. Mahgoub, "Spatial Distribution and Channel Quality Adaptive Protocol for Multihop Wireless Broadcast Routing in VANET," *IEEE Trans. Mob. Comput.*, vol. 12, no. 4, pp. 722–734, Apr. 2013, doi: 10.1109/TMC.2012.42.

[30] F. Xie, K. A. Hua, W. Wang, and Y. H. Ho, "Performance Study of Live Video Streaming Over Highway Vehicular Ad Hoc Networks," in *2007 IEEE 66th Vehicular Technology Conference*, Sep. 2007, pp. 2121–2125, doi: 10.1109/VETECF.2007.445.

[31] A. Torres, C. T. Calafate, J.-C. Cano, P. Manzoni, and Y. Ji, "Evaluation of flooding schemes for real-time video transmission in VANETs," *Ad Hoc Networks*, vol. 24, pp. 3–20, Jan. 2015, doi: 10.1016/J.ADHOC.2014.07.030.

[32] N. Zribi, B. Alaya, and T. Moulahi, "Video Streaming in Vehicular Ad Hoc Networks: Applications, Challenges and techniques," in *2019 15th International Wireless Communications & Mobile Computing Conference (IWCMC)*, 2019, pp. 1221–1226.

[33] Y. Li and A. Boukerche, "{QuGu}: A quality guaranteed video dissemination protocol over urban vehicular ad hoc networks," *ACM Trans. Multimed. Comput. Commun. Appl.*, vol. 11, no. 4, p. 55, 2015.

[34] S. Khakbaz and M. Fathy, "A reliable broadcast method for vehicular ad hoc networks considering fragmentation and intersection problems," in *2008 The Second International Conference on Next Generation Mobile Applications, Services, and Technologies*, 2008, pp. 379–384.

[35] D. Li, H. Huang, X. Li, M. Li, and F. Tang, "A distance-based directional broadcast protocol for urban vehicular ad hoc network," in *2007 international conference on wireless communications, networking and mobile computing*, 2007, pp. 1520–1523.

[36] L.-C. Tung and M. Gerla, "An efficient road-based directional broadcast protocol for urban {VANETs}," in *2010 IEEE Vehicular Networking Conference*, 2010, pp. 9–16.

[37] L. Khamer, N. Labraoui, A. M. Gueroui, S. Zaidi, and A. A. A. Ari, "Road network layout based multi-hop broadcast protocols for Urban Vehicular Ad-hoc Networks," *Wirel. Networks*, vol. 27, no. 2, pp. 1369–1388, 2021.

[38] S. S. Gokhale and K. S. Trivedi, "Analytical modeling," *Encycl. Distrib. Syst.*, 1998.

[39] H. Gao, C. Liu, Y. Li, and X. Yang, "V2VR: Reliable Hybrid-Network-Oriented V2V

Data Transmission and Routing Considering RSUs and Connectivity Probability," *IEEE Trans. Intell. Transp. Syst.*, 2020.

[40] L. Khamer, N. Labraoui, A. M. Gueroui, and A. A. A. Ari, "Enhancing video dissemination over urban VANETs using line of sight and QoE awareness mechanisms," *Ann. Telecommun.*, pp. 1–17, 2021.

[41] F. J. Martinez, M. Fogue, M. Coll, J.-C. Cano, C. T. Calafate, and P. Manzoni, "Evaluating the impact of a novel warning message dissemination scheme for VANETs using real city maps," in *International Conference on Research in Networking*, 2010, pp. 265–276.

[42] Y.-L. Hsieh and K. Wang, "A road-based QoS-aware multipath routing for urban vehicular ad hoc networks," in *2012 IEEE Global Communications Conference (GLOBECOM)*, 2012, pp. 189–194.

[43] N. Alsharif, S. Céspedes, and X. S. Shen, "iCAR: Intersection-based connectivity aware routing in vehicular ad hoc networks," in *2013 IEEE international conference on communications (ICC)*, 2013, pp. 1736–1741.

[44] F. Goudarzi, H. Asgari, and H. S. Al-Raweshidy, "Traffic-aware VANET routing for city environments—A protocol based on ant colony optimization," *IEEE Syst. J.*, vol. 13, no. 1, pp. 571–581, 2018.

[45] T. S. J. Darwish, K. A. Bakar, and K. Haseeb, "Reliable intersection-based traffic aware routing protocol for urban areas vehicular ad hoc networks," *IEEE Intell. Transp. Syst. Mag.*, vol. 10, no. 1, pp. 60–73, 2018.

[46] H. Saleet, R. Langar, K. Naik, R. Boutaba, A. Nayak, and N. Goel, "Intersection-based geographical routing protocol for VANETs: A proposal and analysis," *Ieee Trans. Veh. Technol.*, vol. 60, no. 9, pp. 4560–4574, 2011.

[47] G. Maia *et al.*, "Traffic aware video dissemination over vehicular ad hoc networks," in *Proceedings of the 16th ACM international conference on Modeling, analysis & simulation of wireless and mobile systems*, 2013, pp. 419–426.

[48] A. Bradai, T. Ahmed, and A. Benslimane, "ViCoV: Efficient video streaming for cognitive radio VANET," *Veh. Commun.*, vol. 1, no. 3, pp. 105–122, Jul. 2014, doi: 10.1016/J.VEHCOM.2014.05.002.

[49] W. Liang, Z. Li, H. Zhang, S. Wang, and R. Bie, “Vehicular ad hoc networks: architectures, research issues, methodologies, challenges, and trends,” *Int. J. Distrib. Sens. Networks*, vol. 11, no. 8, p. 745303, 2015.

[50] A. Rhattoy, M. Lahmer, and I. Chana, “Impact of the Smart City Architecture, Speed and Traffic Density of Vehicles on the Performances of Vanets.,” *J. Comput. Sci.*, vol. 13, no. 11, pp. 633–646, 2017.

[51] E. Standard, “Intelligent Transport Systems (ITS); Vehicular Communications; GeoNetworking; Part 1: Requirements,” 2013. Accessed: Mar. 15, 2021. [Online]. Available: http://portal.etsi.org/chaircor/ETSI_support.asp.

[52] J. Harri, F. Filali, and C. Bonnet, “Mobility models for vehicular ad hoc networks: a survey and taxonomy,” *IEEE Commun. Surv. Tutorials*, vol. 11, no. 4, pp. 19–41, 2009.

[53] D. S. Gaikwad and M. Zaveri, “VANET routing protocols and mobility models: A survey,” *Trends Netw. Commun.*, pp. 334–342, 2011.

[54] M. Vaculik, M. Franekova, P. Vestenicky, and M. Vestenicky, “On-board unit and its possibilities of communications on safety and security principles,” *Adv. Electr. Electron. Eng.*, vol. 7, no. 1–2, pp. 235–238, 2011.

[55] M. VACULÍK, P. VESTENICKÝ, and M. VESTENICKÝ, “Vehicle On-board Unit,” in *Proceedings of international conference ITS Bratislava*, 2007, vol. 7.

[56] J. M. De Fuentes, A. I. González-Tablas, and A. Ribagorda, “Overview of security issues in vehicular ad-hoc networks,” in *Handbook of research on mobility and computing: Evolving technologies and ubiquitous impacts*, IGI global, 2011, pp. 894–911.

[57] F. Kamoun, H. Chaabani, F. Outay, and others, “A survey of approaches for estimating meteorological visibility distance under foggy weather conditions,” in *Global advancements in connected and intelligent mobility: emerging research and opportunities*, IGI Global, 2020, pp. 65–92.

[58] Z. MacHardy, A. Khan, K. Obana, and S. Iwashina, “V2X access technologies: Regulation, research, and remaining challenges,” *IEEE Commun. Surv. Tutorials*, vol. 20, no. 3, pp. 1858–1877, 2018.

[59] T. R. ETSI, “102 638 v1. 1.1,” *Intell. Transp. Syst.*, pp. 2006–2009, 2009.

[60] F. Cunha *et al.*, “Data communication in VANETs: Protocols, applications and challenges,” *Ad Hoc Networks*, vol. 44, pp. 90–103, 2016.

[61] “Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions,” 2009.

[62] R. A. Uzcátegui, A. J. De Sucre, and G. Acosta-Marum, “Wave: A tutorial,” *IEEE Commun. Mag.*, vol. 47, no. 5, pp. 126–133, 2009.

[63] P. Karkhanis, M. G. J. van den Brand, and S. Rajkarnikar, “Defining the C-ITS reference architecture,” in *2018 IEEE International Conference on Software Architecture Companion (ICSA-C)*, 2018, pp. 148–151.

[64] H. Hasrouny, A. E. Samhat, C. Bassil, and A. Laouiti, “VANet security challenges and solutions: A survey,” *Veh. Commun.*, vol. 7, pp. 7–20, 2017.

[65] D. Jiang, V. Taliwal, A. Meier, W. Holfelder, and R. Herrtwich, “Design of 5.9 GHz DSRC-based vehicular safety communication,” *IEEE Wirel. Commun.*, vol. 13, no. 5, pp. 36–43, 2006.

[66] “IEEE Standard for Information technology--Telecommunications and information exchange between systems Local and metropolitan area networks--Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,” *IEEE Std 802.11-2012 (Revision IEEE Std 802.11-2007)*, pp. 1–2793, 2012, doi: 10.1109/IEEESTD.2012.6178212.

[67] “IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture,” *IEEE Std 1609.0-2019 (Revision IEEE Std 1609.0-2013)*, pp. 1–106, 2019, doi: 10.1109/IEEESTD.2019.8686445.

[68] “Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager,” *IEEE Std 1609.1-2006*, pp. 1–71, 2006, doi: 10.1109/IEEESTD.2006.246485.

[69] “IEEE Standard for Wireless Access in Vehicular Environments--Security Services for Applications and Management Messages,” *IEEE Std 1609.2-2016 (Revision IEEE Std 1609.2-2013)*, pp. 1–240, 2016, doi: 10.1109/IEEESTD.2016.7426684.

[70] "IEEE Standard for Wireless Access in Vehicular Environments (WAVE) -- Network Systems Corrigendum 2: Miscellaneous Corrections," *IEEE Std 1609.3-2010/Cor 2-2014 (Corrigendum to IEEE Std 1609.3-2010)*, pp. 1–33, 2014, doi: 10.1109/IEEESTD.2014.6998915.

[71] "IEEE Standard for Wireless Access in Vehicular Environments (WAVE)--Multi-Channel Operation - Corrigendum 1: Miscellaneous Corrections," *IEEE Std 1609.4-2016/Cor 1-2019 (Corrigendum to IEEE Std 1609.4-2016)*, pp. 1–13, 2019, doi: 10.1109/IEEESTD.2019.8875006.

[72] Its, "TR 101 607 - V1.1.1 - Intelligent Transport Systems (ITS); Cooperative ITS (C-ITS); Release 1," 2013. Accessed: Mar. 14, 2021. [Online]. Available: http://portal.etsi.org/chaircor/ETSI_support.asp.

[73] ETSI, "Intelligent transport systems (ITS); communications architecture," 2010.

[74] ITS, "ETSI ES 202 663 V1.1.0-Intelligent Transport Systems (ITS); European profile standard for the physical and medium access control layer of Intelligent Transport Systems operating in the 5 GHz frequency band," 2009. Accessed: Mar. 15, 2021. [Online]. Available: https://www.etsi.org/deliver/etsi_es/202600_202699/202663/01.01.00_50/es_202663v010100m.pdf.

[75] A. Festag, "Cooperative intelligent transport systems standards in Europe," *IEEE Commun. Mag.*, vol. 52, no. 12, pp. 166–172, 2014.

[76] ETSI, "ETSI EN 302 663 V1.2.1-Intelligent Transport Systems (ITS); Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band," 2013.

[77] ETSI, "EN 302 665 - V1.1.1 - Intelligent Transport Systems (ITS); Communications Architecture," 2010. Accessed: Mar. 15, 2021. [Online]. Available: http://portal.etsi.org/chaircor/ETSI_support.asp.

[78] H. Aniss, "Overview of an ITS project: SCOOP@ F," in *International Workshop on Communication Technologies for Vehicles*, 2016, pp. 131–135.

[79] A. Brakemeier, "Co-operative ITS-standardization," in *European Wireless 2012; 18th European Wireless Conference 2012*, 2012, pp. 1–3.

[80] B. Lonc and P. Cincilla, “Cooperative its security framework: Standards and implementations progress in europe,” in *2016 IEEE 17th International Symposium on A World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, 2016, pp. 1–6.

[81] ETSI, “EN 302 931 - V1.0.0 - Intelligent Transport Systems (ITS); Vehicular Communications; Geographical Area Definition,” 2010. Accessed: Mar. 15, 2021. [Online]. Available: http://portal.etsi.org/chaircor/ETSI_support.asp.

[82] C. L. Fullmer and J. J. Garcia-Luna-Aceves, “Solutions to hidden terminal problems in wireless networks,” *ACM SIGCOMM Comput. Commun. Rev.*, vol. 27, no. 4, pp. 39–49, 1997.

[83] L. A. Villas, A. Boukerche, G. Maia, R. W. Pazzi, and A. A. F. Loureiro, “DRIVE: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks,” *Comput. Networks*, vol. 75, pp. 381–394, Dec. 2014, doi: 10.1016/J.COMNET.2014.10.012.

[84] Its, “EN 302 637-2 - V1.4.1 - Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service,” 2019.

[85] S. Bolufé, C. A. Azurdia-Meza, S. Céspedes, S. Montejo-Sánchez, R. D. Souza, and E. M. G. Fernandez, “POSACC: position-accuracy based adaptive beaconing algorithm for cooperative vehicular safety systems,” *IEEE Access*, vol. 8, pp. 15484–15501, 2020.

[86] T. Lorenzen and H. Tchouankem, “Evaluation of an awareness control algorithm for VANETs based on ETSI EN 302 637-2 V1.3.2,” in *2015 IEEE International Conference on Communication Workshop (ICCW)*, 2015, pp. 2458–2464, doi: 10.1109/ICCW.2015.7247546.

[87] E. de Velde and C. Blondia, “Adaptive REACT protocol for emergency applications in vehicular networks,” in *32nd IEEE Conference on Local Computer Networks (LCN 2007)*, 2007, pp. 613–619.

[88] C. Sommer, O. K. Tonguz, and F. Dressler, “Traffic information systems: efficient message dissemination via adaptive beaconing,” *IEEE Commun. Mag.*, vol. 49, no. 5, pp. 173–179, 2011.

[89] C. Sommer, D. Eckhoff, and F. Dressler, "IVC in cities: Signal attenuation by buildings and how parked cars can improve the situation," *IEEE Trans. Mob. Comput.*, vol. 13, no. 8, pp. 1733–1745, 2013.

[90] H. Okada, A. Takano, and K. Mase, "A proposal of link metric for next-hop forwarding methods in vehicular ad hoc networks," in *2009 6th IEEE Consumer Communications and Networking Conference*, 2009, pp. 1–5.

[91] D. H. Lee, S. N. Bai, D. Y. Kwak, and J. I. Jung, "Enhanced selective forwarding scheme for alert message propagation in vehicular ad hoc networks," *Int. J. Automot. Technol.*, vol. 12, no. 2, pp. 251–264, 2011.

[92] C. WU, S. OHZAHATA, and T. KATO, "VANET Broadcast Protocol Based on Fuzzy Logic and Lightweight Retransmission Mechanism," *IEICE Trans. Commun.*, vol. E95-B, no. 2, pp. 415–425, Feb. 2012, doi: 10.1587/transcom.E95.B.415.

[93] G.-S. Li, W.-L. Wang, and X.-W. Yao, "An adaptive and opportunistic broadcast protocol for vehicular ad hoc networks," *Int. J. Autom. Comput.*, vol. 9, no. 4, pp. 378–387, 2012.

[94] O. Rehman, M. Ould-Khaoua, and H. Bourdoucen, "An adaptive relay nodes selection scheme for multi-hop broadcast in VANETs," *Comput. Commun.*, vol. 87, pp. 76–90, 2016.

[95] T. Osafune, L. Lin, and M. Lenardi, "Multi-hop vehicular broadcast (MHVB)," in *2006 6th international conference on ITS telecommunications*, 2006, pp. 757–760.

[96] G. Korkmaz, E. Ekici, F. Özgüner, and Ü. Özgüner, "Urban multi-hop broadcast protocol for inter-vehicle communication systems," in *Proceedings of the first ACM workshop on Vehicular ad hoc networks - VANET '04*, 2004, p. 76, doi: 10.1145/1023875.1023887.

[97] O. Tonguz, N. Wisitpongphan, and F. Bai, "DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks," *IEEE Wirel. Commun.*, vol. 17, no. 2, pp. 47–57, Apr. 2010, doi: 10.1109/MWC.2010.5450660.

[98] Wisitpongphan, "Broadcast storm mitigation techniques in vehicular ad hoc networks," *IEEE Wirel. Commun.*, vol. 14, no. 6, pp. 84–94, Dec. 2007, doi: 10.1109/MWC.2007.4407231.

[99] X. M. Zhang, L. Yan, H. Zhang, and D. K. Sung, “A concurrent transmission based broadcast scheme for urban VANETs,” *IEEE Trans. Mob. Comput.*, vol. 18, no. 1, pp. 1–12, 2019.

[100] D. Tian *et al.*, “A distributed position-based protocol for emergency messages broadcasting in vehicular ad hoc networks,” *IEEE Internet Things J.*, vol. 5, no. 2, pp. 1218–1227, 2018.

[101] J. G. Apostolopoulos, W. Tan, and S. J. Wee, “Video streaming: Concepts, algorithms, and systems,” *HP Lab. Rep. HPL-2002-260*, 2002.

[102] C. Rezende, R. W. Pazzi, and A. Boukerche, “A reactive solution with a redundancy-based error correction mechanism for video dissemination over vehicular ad hoc networks,” in *Proceedings of the 15th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems*, 2012, pp. 343–352.

[103] C. Rezende, A. Mammeri, A. Boukerche, and A. A. F. Loureiro, “A receiver-based video dissemination solution for vehicular networks with content transmissions decoupled from relay node selection,” *Ad Hoc Networks*, vol. 17, pp. 1–17, 2014.

[104] C. Quadros, A. Santos, M. Gerla, and E. Cerqueira, “QoE-driven dissemination of real-time videos over vehicular networks,” *Comput. Commun.*, vol. 91, pp. 133–147, 2016.

[105] A. Benmir, A. Korichi, A. Bourouis, M. Alreshoodi, and L. Al-Jobouri, “GeoQoE-Vanet: QoE-Aware Geographic Routing Protocol for Video Streaming over Vehicular Ad-hoc Networks,” *Computers*, vol. 9, no. 2, p. 45, 2020.

[106] Y. Chen, Y. Hu, O. C. Au, H. Li, and C. W. Chen, “Video error concealment using spatio-temporal boundary matching and partial differential equation,” *IEEE Trans. Multimed.*, vol. 10, no. 1, pp. 2–15, 2007.

[107] Y. Xiang, N. Lei, L. Feng, and S. i Xie, “Video Error Concealment Using Spatio-Temporal Boundary Matching,” in *2009 2nd International Congress on Image and Signal Processing*, 2009, pp. 1–5.

[108] M. Lindeberg, S. Kristiansen, T. Plagemann, and V. Goebel, “Challenges and techniques for video streaming over mobile ad hoc networks,” *Multimed. Syst.*, vol. 17, no. 1, pp. 51–82, 2011.

[109] Y. Li, "A quality guaranteed video dissemination protocol over urban vehicular Ad Hoc networks," Université d'Ottawa/University of Ottawa, 2014.

[110] M. Kazemi, S. Shirmohammadi, and K. H. Sadeghi, "A review of multiple description coding techniques for error-resilient video delivery," *Multimed. Syst.*, vol. 20, no. 3, pp. 283–309, 2014.

[111] T. Ho *et al.*, "A random linear network coding approach to multicast," *IEEE Trans. Inf. Theory*, vol. 52, no. 10, pp. 4413–4430, 2006.

[112] D. A. Luby, Michael G and Mitzenmacher, Michael and Shokrollahi, Mohammad Amin and Spielman, "Efficient erasure correcting codes," *IEEE Trans. Inf. Theory*, vol. 47, no. 2, pp. 569–584, 2001.

[113] S.-Y. Li, R. W. Yeung, and N. Cai, "Linear network coding," *IEEE Trans. Inf. theory*, vol. 49, no. 2, pp. 371–381, 2003.

[114] C. Rezende, A. Boukerche, M. Almulla, and A. A. F. Loureiro, "The selective use of redundancy for video streaming over Vehicular Ad Hoc Networks," *Comput. Networks*, vol. 81, pp. 43–62, 2015.

[115] J. Bloemer, M. Kalfane, R. Karp, M. Karpinski, M. Luby, and D. Zuckerman, "An XOR-based erasure-resilient coding scheme," 1995.

[116] S. Puducheri, J. Kliewer, and T. E. Fuja, "Distributed LT codes," in *2006 IEEE International Symposium on Information Theory*, 2006, pp. 987–991.

[117] M. Luby, "LT codes," in *The 43rd Annual IEEE Symposium on Foundations of Computer Science, 2002. Proceedings.*, 2002, p. 271.

[118] A. Khisti, "Tornado codes and luby transform codes," *Semant. Org. web-site*, pp. 1–12, 2003.

[119] A. Shokrollahi, "Raptor codes," *IEEE Trans. Inf. theory*, vol. 52, no. 6, pp. 2551–2567, 2006.

[120] R. Mahajan, J. Padhye, S. Agarwal, and B. Zill, "High performance vehicular connectivity with opportunistic erasure coding," in *2012 {USENIX} Annual Technical Conference ({USENIX}{ATC} 12)*, 2012, pp. 237–248.

[121] A. Nafaa, T. Taleb, and L. Murphy, “Forward error correction strategies for media streaming over wireless networks,” *IEEE Commun. Mag.*, vol. 46, no. 1, pp. 72–79, 2008.

[122] M. S. Srouji, Z. Wang, and J. Henkel, “RDTS: A reliable erasure-coding based data transfer scheme for wireless sensor networks,” in *2011 IEEE 17th International Conference on Parallel and Distributed Systems*, 2011, pp. 481–488.

[123] R. Ahlswede, N. Cai, S.-Y. Li, and R. W. Yeung, “Network information flow,” *IEEE Trans. Inf. theory*, vol. 46, no. 4, pp. 1204–1216, 2000.

[124] Y. Wang, S. Jain, M. Martonosi, and K. Fall, “Erasure-coding based routing for opportunistic networks,” in *Proceedings of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*, 2005, pp. 229–236.

[125] C. Rezende, R. W. Pazzi, A. Boukerche, and S. Nikoletseas, “The effect of redundancy on video broadcasting in vehicular networks,” in *2011 IEEE International Conference on Communications (ICC)*, 2011, pp. 1–5.

[126] A. Mammeri, A. Boukerche, and Z. Fang, “Video streaming over vehicular ad hoc networks using erasure coding,” *IEEE Syst. J.*, vol. 10, no. 2, pp. 785–796, 2015.

[127] P. Bucciol, J. L. Zechinelli-Martini, and G. Vargas-Solar, “Optimized transmission of loss tolerant information streams for real-time vehicle-to-vehicle communications,” in *2009 Mexican International Conference on Computer Science*, 2009, pp. 142–145.

[128] B. Williams, D. P. Mehta, T. Camp, and W. Navidi, “Predictive models to rebroadcast in mobile ad hoc networks,” *IEEE Trans. Mob. Comput.*, vol. 3, no. 3, pp. 295–303, Jul. 2004, doi: 10.1109/TMC.2004.25.

[129] “OMNeT++ Discrete Event Simulator, https://omnetpp.org/, 2020-05-15 .” Accessed: May 15, 2020. [Online]. Available: https://omnetpp.org/.

[130] C. Sommer, R. German, and F. Dressler, “Bidirectionally Coupled Network and Road Traffic Simulation for Improved IVC Analysis,” *IEEE Trans. Mob. Comput.*, vol. 10, no. 1, pp. 3–15, Jan. 2011, doi: 10.1109/TMC.2010.133.

[131] “H.264 : Advanced video coding for generic audiovisual services.” https://www.itu.int/rec/T-REC-H.264/en (accessed Apr. 18, 2019).

[132] J. Klaue, B. Rathke, and A. Wolisz, "Evalvid--A framework for video transmission and quality evaluation," in *International conference on modelling techniques and tools for computer performance evaluation*, 2003, pp. 255–272.

[133] C. Sommer and F. Dressler, "Using the Right Two-Ray Model? A Measurement-based Evaluation of PHY Models in VANETs," doi: 10.1007/s11235-010-9396-x.

[134] C. Sommer, D. Eckhoff, R. German, and F. Dressler, "A computationally inexpensive empirical model of IEEE 802.11p radio shadowing in urban environments," in *2011 Eighth International Conference on Wireless On-Demand Network Systems and Services*, Jan. 2011, pp. 84–90, doi: 10.1109/WONS.2011.5720204.

[135] "YUV Sequences." http://trace.eas.asu.edu/yuv/index.html (accessed May 18, 2021).

[136] "{SUMO - Simulation of Urban Mobility}, {https://sumo.dlr.de/index.html},{2019-05-15}." Accessed: Apr. 18, 2019. [Online]. Available: https://sumo.dlr.de/index.html.

[137] J. Song, Y. Wu, Z. Xu, and X. Lin, "Research on car-following model based on SUMO," in *The 7th IEEE/International Conference on Advanced Infocomm Technology*, Nov. 2014, pp. 47–55, doi: 10.1109/ICAIT.2014.7019528.

Wireless Networks (2021) 27:1369–1388
https://doi.org/10.1007/s11276-020-02531-9

Road network layout based multi-hop broadcast protocols for Urban Vehicular Ad-hoc Networks

Lazhar Khamer[1,2,4] · Nabila Labraoui[1] · Abdelhak Mourad Gueroui[4] · Sofiane Zaidi[3] · Ado Adamou Abba Ari[4,5]

Accepted: 17 December 2020 / Published online: 2 January 2021

Abstract

In recent years, the decentralized wireless Vehicular Ad hoc Networks (VANETs) have emerged as a key technology for Intelligent Transportation Systems (ITS). The need for an efficient and reliable broadcast protocol, mainly in urban VANETs, is of great importance to support different services such as road safety, traffic efficiency, entertainment and advertisement. This paper proposes two new routing broadcast protocols: the Enhanced Counter-based broadcast protocol in Urban VANET (ECUV) and the Enhanced distance-based broadcast protocol in Urban VANET (EDUV). Both of them improve the distribution of data on urban VANETs. ECUV and EDUV use a road-network-topology-based approach to select a set of relay nodes with enhanced coverage capabilities during the data delivery in urban Vehicle to Vehicle (V2V) scenarios. They also improve the performance of the receiver-based protocols by alleviating the negative effect of their stochastic behavior. We study the behavior of these protocols with an analytical model, which shows that the enhanced versions reduce the transmission probability in high vehicle density to avoid the broadcast storm problem. Moreover, the obtained results proved that these proposed protocols increase the transmission probability in low vehicle density to satisfy the reachability requirement of data broadcasting. The network simulation results show clearly that ECUV and EDUV outperform other methods in terms of coverage capacity and efficiency.

Keywords Urban VANETs · Broadcasting protocol · Intelligent transportation system · Analytical model

✉ Lazhar Khamer
l.khamer@univ-soukahras.dz

Nabila Labraoui
nabila.labraoui@mail.univ-tlemcen.dz

Abdelhak Mourad Gueroui
mourad.gueroui@uvsq.fr

Sofiane Zaidi
zaidi.sofiane@univ-oeb.dz; s.zaidi@univ-soukahras.dz

Ado Adamou Abba Ari
adoadamou.abbaari@gmail.com

1 Department of Computer Science, University Abou Bekr Belkaid Tlemcen, P.O. Box 230, 13000 Chetouane Tlemcen, Algeria

2 Department of Mathematics and Computer Science, Mohamed Cherif Messaadia University, 41000 Souk Ahras, Algeria

3 Department of Mathematics and Computer Science, Research Laboratory on Computer Sciences Complex Systems (RELA(CS)2), University of Oum El Bouaghi, Oum El Bouaghi, Algeria

4 LI-PaRAD Lab, Université Paris Saclay, University of Versailles Saint-Quentin-en-Yvelines, 45 Avenue des États-Unis, 78035 Versailles cedex, France

5 LaRI Lab, University of Maroua, P.O. Box 814, Maroua, Cameroon

1 Introduction

In recent years, ITS have contributed efficiently to the improvement of the urban and inter-urban traffic management, traffic security, driving safety, performance of transportation systems and commercial vehicle operations [1–4]. With the rapid evolution of the Micro-Electro-Mechanical Systems (MEMS) [5], ITS have introduced smartness, connectivity, coordination, efficiency and automated response for transportation policy optimization [6, 7].

VANETs consist of interconnected vehicles that embark sensing technologies. They at least allow exchanging traffic, weather and emergency information. Therefore, they constitute an essential technology for the development of ITS. Furthermore, the fast evolution of different vehicle-oriented sensors, together with wireless communication technologies, the Internet of Things (IoT) and Cloud/Fog computing have led to facilitate the emergence of the VANETs [8, 9]. A VANET is a sub-class of Mobile Ad hoc NETwork (MANET) that offers a communication infrastructure to share information between vehicles on the road and between vehicles and ITS components [10]. In order to make this infrastructure possible, vehicles and roads have to be equipped with a set of components recognized as On-Board Units (OBUs) and Road Side Units (RSUs), respectively [8, 11, 12]. Fundamentally, a VANET provides two types of wireless communication: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). V2I allows the exchange of data between vehicles and the fixed ITS components such as base stations, hotspots, traffic lights and Electronic toll collection systems [13].

The broadcasting in VANET consists of the dissemination of data from a source vehicle to many destination vehicles over a V2V multi-hop communication link. Several VANET applications need data broadcasting such as the transmission of traffic-related information, accident notification, cooperative collision avoidance, and cooperative autonomous driving application [11, 14, 15]. Furthermore, broadcasting is the main operation for route discovery and source paging in unicast routing protocols [16–19].

The flooding schema is the most naive solution to broadcast data in both MANET and VANET. In this one, each node in the network blindly rebroadcasts the received message. Unfortunately, the unnecessary rebroadcast of messages cause excessive network resource consumption, this problem is known as the broadcast storm problem [20]. Moreover, in the case of dense ad hoc networks, the blindly message rebroadcasting produces a large number of collisions and interference in the network. This latter deteriorates the effectiveness and reliability of the broadcasting protocol. Therefore, reducing the number of relay nodes is the most often accepted solution to avoid the high number of collisions and interference. However, relay-nodes have to be selected by considering the trade-off between the coverage capability and the broadcast storm problem mitigation. The reliable broadcast heuristics aim to select a minimum number of relay-nodes to avoid the broadcast storm problem and maintain a maximum coverage capability.

Most heuristics are designed specifically for MANET in which the nodes are deployed in a free space environment. Thus, there are no exact constraints that affect the movement of the nodes. In such an environment, relay nodes selection methods are commonly based on traditional forwarding strategies like geographic-position-based methods, statistical-based strategies, network-traffic-aware methods, local neighborhood topology based strategies, etc [20]. However, in urban VANET, nodes movement and nodes spatial distribution are likely related to the road network topology. For this reason, there is a great need to use the road network topology to enhance traditional strategies.

Broadcasting techniques can be broadly classified into sender-based and receiver-based methods [21–25]. The main prerequisite for sender-based protocols is that a sender should obtain the topological information of one-hop neighbors. This has to do with node identities and kinetics information. It can be achieved through a simple exchange of beacon messages between the one-hop neighbors. The topological information enables the protocol to select the best set of forwarders. However, for enhanced efficiency, the neighborhood information should be updated at a high frequency to overcome the rapid change in the topology. Unfortunately, this may generate high beacon transmission overhead and lead to an unfavorable transmission condition and even collisions. To overcome this issue, the receiver-based protocols are proposed. Each receiver node uses typically a local state variable to establish a waiting time. For example, the relative distance between the receiver and the precedent forwarder can be used to make a decision, whether to rebroadcast or not, based on the current state of the receiver and a threshold value. This can be the number of duplicate messages received within the waiting time that should not exceed a certain threshold. Another advantage of the receiver-based methods is that the anonymity mechanisms of the nodes can be easily achieved because they do not require exchanging vehicles identifiers in the selection process of the relay-nodes [26]. Furthermore, a comparative study between broadcasting protocols showed that these methods at least outperform the sender-based ones in terms of latency, collisions and message overhead [27]. The drawback of the received-based protocols is that they are characterized by stochastic behavior and generally can not cover the full network.

In the literature of receiver-based broadcasting protocols, many heuristics have been proposed to overcome collisions and interference problems while maintaining maximum coverage and connectivity. Among the most reliable methods, we can mention the ones proposed by Tseng et al. [20]. Their first approach is the well-known counter-based protocol. Tseng et al demonstrate a reverse relationship between the number of duplicate messages broadcasted by the immediate neighbors of a node and its capability to cover a new area when it rebroadcasts the received message. Specifically, a node in the counter-based protocol broadcasts a message if it receives during a backoff time a number of duplicate messages lower than a threshold value. This threshold value is used mainly to control the unsuitable redundant transmissions.

The second approach is the distance-based protocol. Its mechanism uses the minimum distance heuristic to select relay-nodes. Hence, this heuristic makes use of a threshold distance from the sender to each one-hop receiver to distinguish between relay nodes and none relay nodes. The heuristic is based on the fact that if two nodes are very close, their rebroadcasting will likely cover the same area of the network. Following this logic, the node acts as a relay if only this distance is large enough.

The advantages of these two protocols rely mainly on their receiver-based nature. Furthermore, counter-based and distance-based schemas are highly able to reduce unnecessary retransmissions in a fully distributed manner and without a need to overload the transmission channel by the beacon messages. Another advantage of these methods relies on the tuning operation. Tuning is a critical factor to improve the performance of broadcasting protocols. The tuning operation in counter and distance-based methods is an easy task as it requires only the adjustment of two parameters: the maximum waiting time and the threshold value. Consequently, many recent receiver-based broadcast protocols based their forwarding strategy on counter-based and distance-based schemas. Figure 1 shows the extension of these two schemas as defined by Tores et al. [28].

For the above reasons, the counter-based and distance-based schemas can be considered as promising broadcast algorithms. Like most received-based protocols, the downside of these two protocols is related to their stochastic nature that can negatively affect their coverage capacity.

It is possible to alleviate the issue of stochastic behavior by selecting a set of relay-nodes that have an enhanced spatial distribution. Specifically in urban VANET, vehicles' movement and vehicles' spatial distribution are likely related to the road network topology. Thus, a great need arises to use the road network topology to select a set of relay-nodes which have an enhanced coverage capacity.

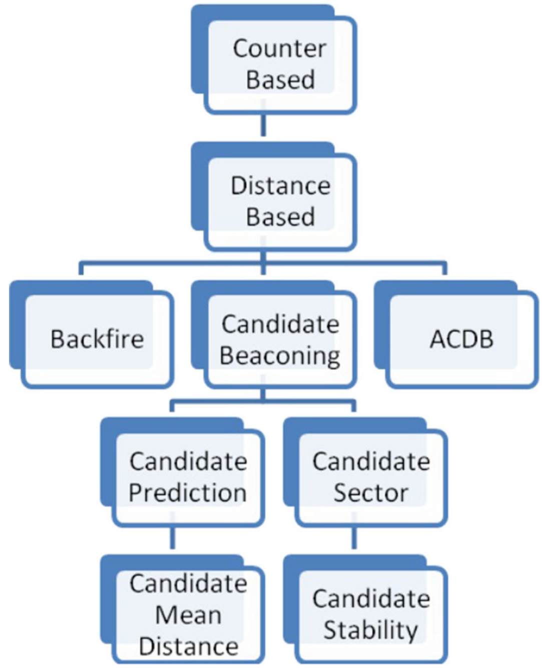


Fig. 1 Extension works of counter-based and distance-based broadcast protocols

In this paper, we firstly give counterexamples that show how stochastic behavior prevents a message to disseminate throughout particular road segments when these two schemes are used in urban VANET. Next, we propose an Enhanced counter-based and Enhanced distance-based protocols for urban VANET, respectively ECUV and EDUV, to increase the connectivity among vehicles in the urban VANET. ECUV and EUDV are road-network-topology-based solutions that allow the deployment of relay nodes in all road segments to increase the coverage capacity and hence maximizing the broadcast reachability.

Analytical models have in many cases significant advantages over simulation models, especially concerning the vision that they provide, the relative speed compared to simulations and their general approach to evaluate the performance under different conditions with just a numerical formulation [29, 30]. One of the main contributions of this work is to propose analytical models that could be used to predict the performance of ECUV and EDUV.

In order to capture the urban VANET particularities and the characteristics of the proposed protocols, we have considered various input parameters in the definition of the analytical models such as threshold parameter, vehicle density (The number of vehicles in the network), and the road network size (The number of the road segments). Besides, the proposed analytical models output the rebroadcast probability of a vehicle in the network when using ECUV and EDUV protocols. Based on our analytical models, we can study the ability of ECUV and EDUV to handle the broadcast storm problem and to analyze the influence of the various threshold values on the behavior of ECUV and EDUV.

The remainder of this paper is organized as follows. Section 2 reviews the literature of the main VANET broadcast protocols. Section 3 presents our contribution. Section 4 presents and details the proposed analytical models. The analytical models and network simulation results are detailed and discussed in Sect. 5. Finally, the conclusion and future works are presented in Sect. 6.

2 Related work

The characteristics of VANETs must be considered carefully in the design of reliable broadcast protocols. This section depicts the widely used broadcast protocols to disseminate information in VANETs and their specificities in terms of scalability, infrastructure requirements, and heuristics used to forward data.

Korkmaz et al. [31] proposed the Urban Multi-Hop Broadcast protocol (UMB), which was intended to undertake the broadcast storm problem in urban VANET when the vehicle density is high. UMB requires the presence of Road-Side-Units (RSUs) at all intersections of the region of interest. This setting allows the propagation of the broadcasted message among all directions of each road. The RSUs have an enhanced line-of-sight when the network contains some obstacles such as tower buildings. In UMB, each relay node chooses the most distant neighbor vehicle within its communication range to broadcast data. Due to its reliable strategy, based on the line-of-sight and the farthest distance heuristics, UMB performs better in terms of efficiency and reachability in high traffic densities. The disadvantage of UMB is that it requires the presence of the RSUs at all street crossing points, which cannot always be possible.

Viriyasitavat et al. [32] proposed the Urban Vehicular Broadcast (UV-CAST) protocol that deals with the network fragmentation and collision problems. UV-CAST introduced the store-carry-and-forward as a mechanism for recovering lost messages. This regime relies on the definition of the perimeter vehicles in the connected zone. UV-CAST supposes that the perimeter vehicles have a higher likelihood of experiencing new neighbors. Therefore, these vehicles keep each received message in a local buffer and forward the saved message whenever they detect a new neighborhood vehicle. However, when a set of perimeter vehicles detects a lost message, they immediately proceed to send this message without any coordination. Consequently, redundant transmissions are highly increased.

In [33], Tonguz et al. proposed a new VANET reactive broadcast protocol named a Distributed Vehicular broadCAST protocol for vehicular ad hoc networks (DV-CAST). It disseminates the messages in highway VANET based on the neighborhood topology data. DV-CAST takes into consideration the various kinds of traffic conditions. It includes three noteworthy functions. Namely, one-hop neighborhood detection function, broadcast concealment mechanism, and store-carry-and-forward mechanism. One-hop topology information is used to estimate the current vehicle density in the road network. In a high vehicle density scenario, DV-CAST applies the broadcast concealment mechanism, where a vehicle broadcasts the message with a probability p directly proportional to the distance between this vehicle and the one-hop sender (Weighted p-Persistence forwarding heuristic) [34]. By contrast, if the traffic density is low, DV-CAST uses the store-carry-and-forward mechanism to deliver the received message across the disconnected clusters. The drawback of DV-CAST specifically lies in the scalability factor. It is only designed to operate in highway scenarios.

Villas et al. [35] suggested a novel Data dissemination pRotocol In VEhicular networks (DRIVE). DRIVE is a scalable protocol that works under different traffic densities and also over both urban and highway scenarios. Unlike the most existing broadcast protocols, which handle the broadcast storm issue in well-connected VANETs, DRIVE is designed to operate under any traffic conditions, including network partition scenarios. In high traffic density, DRIVE assigns the broadcast task to the vehicles inside a special forwarding zone called the sweet spot. To this end, the communication range of each sender is divided into four equal zones and one sub-region in each zone is designed as a sweet spot. The vehicles inside a sweet spot are most appropriate to forward data. Namely, among all vehicles within the communication range of a sender, the broadcast by a single node inside the sweet spot is sufficient to successfully delivering data. In low traffic density, where the network is likely partitioned, DRIVE delegates the task of disseminating data across network partitions to the vehicles that are outside the area of interest. The main drawback of DRIVE is the use of a backoff timer, which could increase the end-to-end delay.

In [36], Martinez et al. proposed a new distance-based broadcast scheme named the Enhanced Street Broadcast Reduction Scheme in Real Maps (eSBR). It improves the distance-based broadcast protocol to ensure the timely delivery of safety messages over urban VANETS. The proposed solution is based on some network information such as city structure to guarantee intelligent broadcasting. The drawback of this broadcast protocol is that interference and collisions are more probably to happen due to the lack of a mechanism against synchronous rebroadcasts.

Slavik et al. [26] designed a Distribution-Adaptive Distance with Channel Quality (DADCQ) protocol to address the need for the broadcast communications in VANETs. DADCQ protocol is based on the distance-based broadcast schema to choose the relay vehicles. The performance of distance-based broadcast schema widely depends on the estimation of the distance threshold value. But, it is hard to fix an optimal value that deals with the tradeoff between efficiency and coverage capability. Typically, three factors affect the ideal value of the distance threshold. Namely, traffic density, vehicles' spatial distribution and the quality of the communication medium. These three factors summarize the main network characteristics that influence the performance of the broadcast protocol. The proposed protocol uses a threshold function that adapts its value to the variation of these three factors. The main disadvantage of DADCQ is the lack of a mechanism for recovering the lost packets.

In [37], Wu et al. designed a fuzzy-based dissemination protocol (FUZZBR). It uses a fuzzy logic approach to select an optimal subset of forwarding vehicles by combining three metrics: the distance between vehicles, vehicles' mobility, and received signal strength (RSSI). FUZZBR also engages a lightweight retransmission mechanism to recover the loss of packets with minimum overhead. The main issue of this protocol is that it does not consider the MAC layer contention time in the forwarders selection process, which could produce inefficient dissemination in high vehicle density scenarios.

In an other research, named The Reactive Density-Aware and Timely Dissemination Protocol (REACT-DIS) [38], the decision of a node to become a rebroadcaster is based on the number of retransmissions of the same packet during a waiting time. The waiting time is calculated based on the geographic greedy approach, where the farthest node has a shorter waiting time. The farthest nodes are likely to have a high probability of receiving a small number of duplicates, making them more convenient to retransmit the received packets. Starting from the assumption that the expected additional coverage area of the candidate node decreases when the number of duplicate packets increases, REACT-DIS follows a probabilistic density aware scheme. Specifically, when the waiting time expires, nodes try to rebroadcast the packet with a probability that exponentially decreases with the number of duplicate packets.

Bradai et al. [39] proposed "Efficient video streaming for cognitive radio VANET" (VICOV). It selects an optimal set of forwarding vehicles to mitigate the effect of the broadcast storm problem and to achieve high data delivery ratio. The decision to become a relay vehicle is based on a new centrality heuristic termed dissemination capacity. This heuristic provides high data delivery. It is designed to deal with the tradeoff between efficiency and reliability. However, VICOV doesn't consider the vehicle's spatial distribution factor in the relay vehicles selection process.

Rehman et al. [40] proposed a Bi-Directional Stable communication schema (BDSC). It depends on bidirectional neighborhood-based link quality measure and geographic-greedy heuristic to determine the forwarding schema. BDSC is designed to enhance the coverage capability, packet ratio delivery and end-to-end transmission delay over high vehicle density scenarios. An exchange of beacon messages in association with lightweight implicit acknowledgment mechanism is used to estimate the link quality between source vehicle and its one-hop neighbors. As indicated by the Nakagami Fading Channel model, the further away is the receiver from the source vehicle, the more complicated for that receiver to decode correctly the received signal [12]. Consequently, BDSC protocol excludes, from the set of forwarding candidates, the vehicles that have a distance from the source vehicle higher than d_{mean}, where d_{mean} is the mean of euclidian distances from the sender to its one-hop neighbors. The fundamental issues of this protocol lie in the way that it does not consider the distance between the candidates, which could lead to the selection of relay-nodes that cover the same area. Moreover, it does not take into consideration past observations to calculate the current link quality.

Tian et al. [41] designed a distributed Position-Based protocol for emergency messages broadcasting in VANETs. Because each type of emergency message has a specific zone of interest (ZoI), it is important to select the adequate broadcast direction and the number of hops required to deliver each message to its appropriate ZoI. Consequently, the authors have designed a protocol that adapts the broadcast schema according to the type of emergency message. It minimizes sufficiently network resources consumption and improves broadcast reliability because it disseminates exactly emergency messages across their zones of interest. However, this protocol is designed only for emergency-oriented applications.

Ravi et al. [14] assessed the random behavior of the traffic flow to determine the ability to build a multi-hop path over V2V communication links in VANET. The traffic flow data, which was collected from a two-lane highway, has shown that the arrival rate of vehicles obeys to the Poisson distribution law, and the E2E connectivity obeys to the binomial distribution law. Furthermore, the authors of this work proposed a stochastic multi-hop broadcasting method that takes into consideration the aforementioned distributions in the design of the new schema. Besides, Ravi et al. evaluated the connectivity between vehicles in the network by the M/M/1 queuing theory. They show that the connectivity relies on two factors: the spatial distance between vehicles and the number of V2V paths in the highway scenario.

Table 1 summarizes the main characteristics of the broadcast protocols presented above. We note that most authors focus on the heuristics associated with the broadcasting strategy because the coverage capacity of any protocol directly depends on these heuristics. As outlined in table 1, UMB, UV-CAST, DV-CAST,

Table 1 Summary of the relevant broadcast protocols for urban VANETs in the literature

Protocol	Broadcasting mechanism							RB/SB	BM	TF-BM	Problems treated			MI	AV
	FD	MD	CEB	CB	LsB	LqB	MB				Bs	IC	HT		
UMB [31]	Yes	No	No	No	Yes	No	No	RB	No	-	Yes	Yes	Yes	GPS, RSU, Map	Conserved
DV-CAST [33]	Yes	No	No	No	No	No	No	RB	Yes	High frequency	Yes	Yes	No	GPS	Conserved
UV-CAST [32]	Yes	No	No	No	Yes	No	Yes	RB	No	–	Yes	Yes	No	GPS	Conserved
DRIVE [35]	Yes	No	No	No	No	No	No	RB	No	–	Yes	Yes	No	GPS	Conserved
eSBR [36]	No	Yes	No	No	No	No	No	RB	No	–	Yes	No	No	GPS	Conserved
DADCQ [26]	No	Yes	No	Yes	No	No	No	RB	Yes	Low frequency	Yes	No	No	GPS	Conserved
FUZZBR [21]	Yes	No	No	No	No	Yes	Yes	SB	Yes	High frequency	Yes	Yes	No	GPS	Not Conserved
VICOV [39]	No	No	Yes	No	No	Yes	No	RB	Yes	High frequency	Yes	Yes	No	–	Not Conserved
BDSC [12]	No	No	No	No	No	Yes	No	SB	Yes	High frequency	Yes	No	No	GPS	Not Conserved
Tian et al. [41]	No	No	No	No	No	No	No	RB	No	–	Yes	No	No	GPS, Map	Conserved
React-Dis. [38]	Yes	No	No	No	No	No	No	RB	No	–	Yes	No	No	GPS	Conserved

BM Beacon Messages, *TF-BM* Transmission Frequency of Beacon Messages, *MI* Modules and Infrastructure,*AV* Anonymity of Vehicles.

FD Furthest Distance, *MD* Minimum Distance, *RB/SB* Receiver-Based/Sender-Based, *CB* Clustering-Based, *CEB* Centrality-Based, *LsB* Line-of sight-Based, *LqB* Link-quality-Based, *MB* Mobility-Based, *Bs* Broadcast storm, *IC* Intermittent Connection, Hidden Terminal

and DRIVE are based on the farthest distance heuristic. The principal difference between them is when considering the scalability criterion. DV-CAST is designed to work exclusively in highway scenarios. UMB and UV-CAST are designed for urban scenarios. Whereas DRIVE adapts its strategy to both highway and urban scenarios. We also notice that eSBR and DADCQ are based on the minimum-distance-based strategy. Namely, they keep a minimum distance between the selected relay nodes to avoid redundant transmissions. As shown in table 1 many authors have proposed new heuristics to enhance the broadcast coverage capabilities. For instance, link quality, node centrality and signal strength heuristics are proposed in recent works. Furthermore, most protocols follow receiver-based approaches in which the decision about rebroadcasting of each received message is taken on the receiver side rather than on the sender side. We also see that among all presented protocols, eSBR is the only one that uses road-network-topology-based strategy. However, because of the lack of a mechanism to avoid synchronous transmissions, eSBR is prone to collisions and interference. Unlike eSBR, our proposed approach (EDUV) tackle this kind of problem while combines the minimum-based and the road-network-topology-based strategies to enhance the coverage capability.

3 ECUV and EDUV protocols

3.1 Analysis of the stochastic behavior

In this sub-section, we analyze the basic schemas of counter-based and distance-based protocols. First, an overview of these protocols is provided. Next, two examples that show how the stochastic behavior of these schemas could prevent the message propagation among the different directions of the road network are given.

3.1.1 Analysis of counter-based protocol

The counter-based technique uses a one-hop traffic-aware mechanism to reduce redundancy and concurrent access. Accordingly, when a node receives a message, it applies a random backoff time. During this period, the node counts the number of duplicate messages retransmitted by its one-hop neighbors. After the expiration of the backoff time, the node broadcast the message only if the calculated number of the listened messages during the waiting time is less than a predetermined threshold C_{thr}. Figure 2 outlines the main steps of this algorithm.

Figure 3 outlines a special case when counter-based schema disseminates a message in urban VANET. We assume in this case that the value of the threshold C_{thr} is set to one. We point up that the bold-lines (in Figs. 3, 5) represent the one-hop links between the vehicles. As shown in Fig. 3, the vehicle S broadcasts a message to its one-hop neighbor vehicles (A, B, C and D) for the first time. When these neighbor vehicles receive the message, they wait for an arbitrary time (random waiting time) before taking a decision to either rebroadcast or left behind the received message. In this example, we have considered the worst case in which the waiting time of the vehicle A expires before the ones of the vehicles B, C and D. Upon the waiting time of the vehicle A expires, it rebroadcasts the received message. As a result, the rebroadcasts of the vehicles B, C, and D are suppressed. Hence, the propagation of the message across the roads 2, 3, and 4 is prevented (because the number of duplicate messages is equal to the threshold value). This problem occurs because of the stochastic behavior of this protocol that negatively affects the spatial deployment of the relay-nodes in the network.

3.1.2 Analysis of distance-based protocol

The second schema is the distance-based broadcast protocol. Figure 4 outlines the main steps of this algorithm. This mechanism is based on the distance heuristic. Accordingly, if node A is very close to its neighbor node B, there is little additional coverage when node B will be the next broadcaster node. By contrast, if node A is far away from the node B, the extra coverage will be wider. Consequently, when the node B receives at the first time a message, it takes the broadcast decision of this message based on the distance between it and the node A. When this distance is lower than a predefined threshold (D_{thr}), the node B prevents the rebroadcasting of the received message. Otherwise, the node B rebroadcasts the received message after the timeout of a random delay, providing that the same message has not been received from another node C where $||BC|| \leq D_{thr}$ (D_{thr} is the distance threshold value).

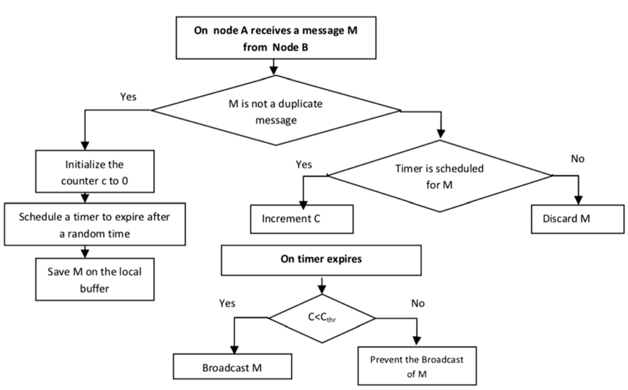


Fig. 2 Flowchart of counter-based broadcast protocol

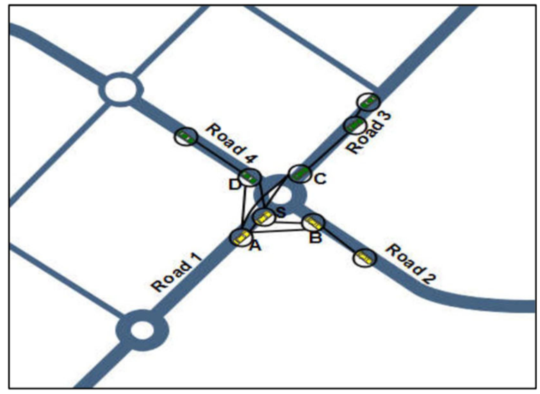


Fig. 3 Counter-based protocol scenario

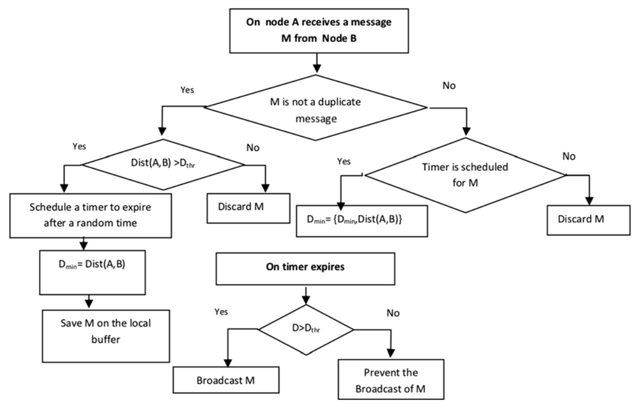


Fig. 4 Flowchart of distance-based broadcast protocol

Figure 5 outlines a very serious scenario when the distance-based schema is used. We assume in this scenario that the distance between the vehicles S and B is higher than D_{thr}, the distance between the vehicles S and C is higher than D_{thr} and the distance between the vehicles C and B is lower than D_{thr}. For instance, the vehicle S initially broadcasts a message toward its immediate neighbor vehicles (A, B and C). When these latter receive the broadcasted message, they wait for a random time (waiting time). If the waiting time of C expires before the one of B, vehicle C rebroadcasts the received message to its one-hop neighbors. Therefore, the vehicle B inhibits the rebroadcasting of this message because the distance from C to B is lower than D_{thr}. Consequently, the broadcasted message can not propagate in the Road 3.

3.2 Proposed methods

As it is shown in Sect. 3.1, the drawback of the conventional schemas of receiver-based broadcast protocols is mainly related to their stochastic behavior, which can prevent message propagation across all road segments. Consequently, one can not ensure that they always meet the coverage capacity requirement. The main aim of this work

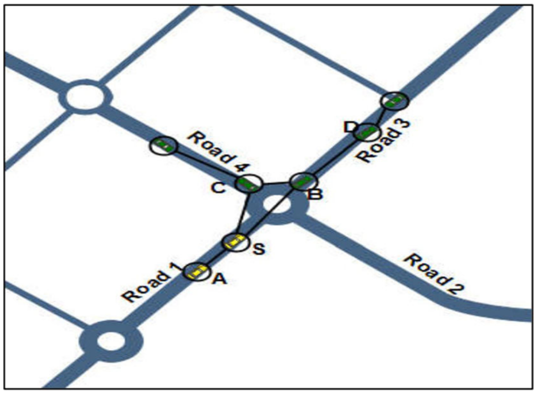


Fig. 5 Distance-Based protocol scenario

is to alleviate this issue by taking into consideration the relative positions of relay nodes with respect to the layout of the urban road network. In an urban scenario, vehicles can not move freely and anywhere in their environment, but they are imposed to roll according to the road network topology. Therefore, the road network topology is a very important characteristic of urban VANETs that can not be omitted in the design of a reliable broadcast protocol. Unfortunately, most receiver-based protocols do not consider the road network layout in the definition of relay nodes selection strategy. In this section, we present two new receiver-based protocols (ECUV and EDUV protocols), designed to handle the broadcast process in an urban scenario. ECUV and EDUV use the road-network-layout information to enhance broadcast reachability and coverage capabilities in urban VANET. The list of notations utilized in the different algorithms is given in Table 2.

3.2.1 Network model, system requirements and general approach

We consider a set of n vehicles $V = \{v_1, v_2, \ldots, v_n\}$ that move over an urban area. A VANET can be defined as a graph represented by a set of vertices and a set of edges, where each vehicle $v_i \in V, i = 1..n$ denotes a vertex, and each DSRC wireless link between two vehicles v_i and $v_j, i \neq j$ represents an edge. The immediate neighborhood of a vehicle v_i is a subset $IN(v_i)$ of the set V, where each element of $IN(v_i)$ lies within the transmission range of vehicle v_i.

All vehicles in the network are equipped with a localization sensor (e.g., a GPS receiver), a digital map of the road network, a geo-coding module, and an 802.11p wave/DSRC network interface controller. The geo-coding module is used to recover the nearest road segment in the road network map for given geo-position coordinates. By convention, a road segment refers to a street bounded by two consecutive junctions. Thus, we define the road network layout as a graph $G(VG, EG)$, where vertices

Table 2 Notations used in the different algorithms

Notations	Descriptions
S	Node state variable.
H	The heuristic that defines the suitability of nodes for rebroadcasting a received message.
(X_{RN}, Y_{RN})	Geographical position coordinates of the receiver node.
(X_{SN}, Y_{SN})	Geographical position coordinates of the sender node.
Id_road_{RN}	Road segment identifier of the receiver node.
Id_road_{SN}	Road segment identifier of the sender node.
$Map\_to\_SI(X, Y)$	The function that maps the geographical position coordinates to the corresponding road segment identifier.
$Min\{x_1, x_2\}$	Return the minimum value between two numbers x1 and x2.
Thr	Threshold parameter
C_{thr}	Counter threshold parameter.
D_{thr}	Distance threshold parameter.
c	Counter variable.
d_{min}	Minimum distance variable.

$VG=\{vg_1, vg_2, \ldots, vg_n\}$ are the set of junctions in the road network and edges $EG=\{eg_1, eg_2, \ldots, eg_p\}$ are the set of road segments (streets) connecting these junctions. Figure 6 illustrates an example of how to segment the road network to show the layout feature. Besides, the system complies with the protocol requirements, by using a digital map,to provide a unique identity to each road segment. Also, to be included, the header field of each transmitted packet requires the position coordinates of the sender and the sequence number of the transmitted message.

Multi-hop broadcasting protocols in urban VANETs are intended to support the requirement of vehicles to share data with one other within a two-dimensional urban area. The information is shared by delivering data to vehicles within an urban region over a multi-hop V2V link. The typical use case is the point of interest notification service, in which a roadside unit announces the availability of a point of interest to the surrounding vehicles. E.g., the broadcast of information regarding vehicle energy supply station, such as its location, the types of the available energies and the associated waiting

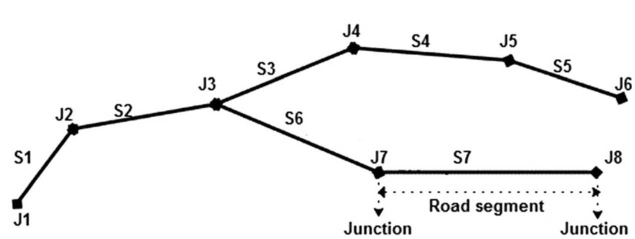


Fig. 6 Road network layout example

time. Thus, the main requirement of this type of broadcasting protocols is to select a subset of relay nodes $R = \{r_1, r_2, \ldots, r_k\}$ from the set V, such that $IN(r_1) \cup IN(r_2) \cup IN(r_3) \cup \cdots \cup IN(r_k) = V$. A very high value of k can lead to the broadcast storm problem, whereas a very low value can negatively affect the coverage capacity.

Most receiver-based multi-hop broadcast protocols are designed around a broadcast concealment mechanism. The main purpose of this mechanism is to avoid the not useful transmission redundancy while maximizing the coverage capacity of the broadcast protocol.

Our methods combine a new road-based broadcast concealment mechanism and the common design of the received-based approach, wherein vehicles calculate the value of a state variable at their positions and compare the value of this variable to a threshold value to determine their suitability to rebroadcast a received packet. If we assume that v is an element of a given cluster C, the vehicle v determines the value of its state variable based only on the duplicate packets received from members of this cluster. E.g., in Figure. 7, to extract the layout feature of the road network in the vicinity of vehicle A, the shape of the transmission range of A is decomposed into five segments, and the vehicles in each segment are grouped into the same cluster.In this manner, we obtain 5 clusters :$SEG1 = \{A, B, C\}$, $SEG2 = \{D\}$, $SEG3\{E, F\}$, $SEG4 = \{G\}$, $SEG5 = \{H, I, G\}$. According to the road-based concealment broadcast mechanism, the state variable of A could only be affected by the duplicate packets received from vehicles B and C because they are in the same cluster as A. Namely, the packets broadcasted by members of clusters SEG2, SEG3, SEG4, and SEG5 can not suppress the rebroadcast of vehicle A. When this process is repeated in each hop, it allows the deployment of the relay nodes in all road segments.

Algorithm. 1 details the main steps of the Road-based broadcast concealment mechanism. Like most receiver-based broadcast protocols, once the first copy of the message m is received, the receiving node initializes the state variable S according to the heuristic H, saves m in the internal cache, and schedules a timer to expire after random t seconds (Algorithm. 1 lines (2-7)). H is the heuristic that defines the suitability of nodes for rebroadcasting a received message. As shown in Algorithm. 1 lines (8-16), the new feature of the Road-based broadcast concealment mechanism arises when a candidate vehicle receives a duplicate message. Namely, it updates the value of the state variable S, according to the heuristic H, only if the sender and the receiver are on the same road segment, provided that the timer is currently scheduled. Finally, upon the timer expires, the node makes its decision to become a relay-node based on the value of S relative to the threshold Thr.

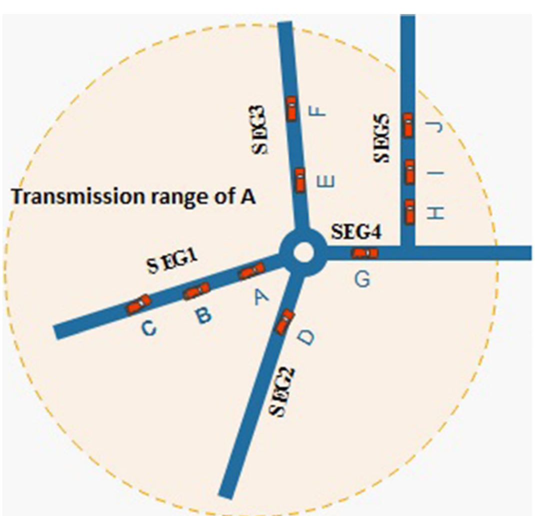


Fig. 7 Road-based broadcast concealment mechanism

Algorithm 1 The general approach of Road-based broadcast concealment mechanism.

Begin

1. On receive a message m
2. **if** m is a new message **then**
3. **begin**
4. Initialize the node state variable S according to the heuristic H
5. Save m in the internal cache
6. Schedule a timer to expire after random t seconds
7. **end**
8. **else**
9. **begin**
10. $Id\_road_{RN} = Map\_to\_SI(X_{RN}, Y_{RN})$
11. $Id\_road_{SN} = Map\_to\_SI(X_{SN}, Y_{SN})$
12. **if** a timer is scheduled for m **and** $Id\_road_{RN} == Id\_road_{SN}$ **then**
13. update the value of S according to the heuristic H
14. **else**
15. discard m
16. **end**
17. On timer expire
18. Compare the values of S and Thr and accordingly, decide whether to rebroadcast the message m or not

End

3.2.2 Enhanced Counter-based broadcast protocol in Urban VANET (ECUV)

In this section, we present our first contribution to support message broadcasting in urban VANET. Our solution uses counter-based heuristic in association with the road-based broadcast concealment mechanism to enhance the coverage capacity in urban VANET. To this purpose, each vehicle utilizes a counter to keep aware of how many times the disseminated message is received from the members of its cluster. Algorithm. 2 presents the main steps of ECUV protocol. As shown in this algorithm, when a vehicle receives a new disseminated message for the first time, it initializes a local counter c to 0. Besides, this vehicle stores the received message in a local buffer for a possible future rebroadcasting and schedules a timer to expire after a random number of seconds (lines 2-7). When the vehicle receives a duplicate message from a member of its cluster (road segment), it increments the counter c if a timer is currently scheduled for the received message (lines 8 to 16). When the timer expires (line 17), the value of c is checked to decide whether or not to rebroadcast the message. If the value of c is higher or equal to the value of the threshold C_{thr}, the vehicle prevents the message rebroadcasting (linse 18-19). Otherwise, it rebroadcasts the received message (lines 20-21).

Algorithm 2 . ECUV protocol

```
Begin

1. On receive a message m
2.     if m is a new message then
3.     begin
4.         Initialize the counter of duplicate message c = 0
5.         Save m in the internal cache
6.         Schedule a timer to expire after a random t seconds
7.     end
8.     else
9.     begin
10.        Id_road_RN =Map_to_SI(X_RN, Y_RN)
11.        Id_road_SN =Map_to_SI(X_SN, Y_SN)
12.        if a timer is scheduled for m and
             Id_road_RN==Id_road_SN then
13.          Increment c
14.        else
15.          discard m
16.    end
17. On timer expire
18.    if c ≥ C_Thr then
19.        Cancel the transmission of m
20.    else
21.        Broadcast m

End
```

3.2.3 Enhanced Distance-based broadcast protocol in Urban VANET (EDUV)

This section presents our second contribution which combines the minimum Distance-based heuristic and the framework of the new road-based broadcast concealment mechanism to handle the broadcasting process in urban VANET. Namely, the protocol updates the value of the state variable only if the sender and receiver are on the same road segment (sender and receiver are one-hop neighbors). The state variable in EDUV is the minimum distance d_{min}.

Algorithm. 3 presents the proposed EDUV protocol. As outlined in Algorithm. 3 (lines 1-14), when the vehicle receives a new message, it initiates a timer for this received message only if one of the following two cases is satisfied.

- The two vehicles (sender and receiver) are on the same road segment and the distance between them is higher than the threshold D_{thr}.
- The two vehicles (sender and receiver) are located on different road segments.

During the waiting time, each vehicle observes the duplicate packets received from its vicinity. If this vehicle receives a duplicate packet from a sender that lies within the range of its road segment, it updates the value of the state variable d_{min}. The new value of d_{min} is set to the distance from the sender to the receiver only if this distance is less than the current value of d_{min} Algorithm. 3 (lines 15-23). The process in which a vehicle decides whether to rebroadcast or not the received packet is depicted in Algorithm. 3 (lines 24-26). This process is triggered when the timer expires. The vehicle checks if the distance d_{min} is not less than the permitted minimum-distance D_{thr}. In the event where d_{min} is greater than D_{thr}, the vehicle broadcasts the received message. By contrast, if d_{min} is less or equal to D_{thr}, the vehicle drops the message.

Algorithm 3 . EDUV protocol

```
Begin

1. On receive a message m
2.     if m is a new message then
3.     begin
4.         Id_road_RN =Map_to_SI(X_RN, Y_RN)
5.         Id_road_SN =Map_to_SI(X_SN, Y_SN)
6.         if Id_road_RN==Id_road_SN then
7.             Initialize d_min by the distance between
               the sender and the current node(receiver)
8.         else
              d_min = R
9.         if d_min > D_thr then
10.        begin
11.            Save m on the local buffer
12.            Schedule a timer to expire after
               a random value of seconds
13.        end
14.    end
15.    else
16.    begin
17.        Id_road_RN =Map_to_SI(X_RN, Y_RN)
18.        Id_road_SN =Map_to_SI(X_SN, Y_SN)
19.        if a timer is scheduled for m and
             Id_road_RN==Id_road_SN then
             begin
20.              Set d to the distance between the current
                 vehicle and the sender of m
21.              d_min = Min{d_min, d}
             end
22.        discard m
23.    end
24.On timer expire
25.        if d_min > D_thr then
             broadcast m
26.        else
             cancel the Broadcast of m

End
```

4 Analytical model

This section presents the theoretical analyses of the proposed ECUV and EDUV broadcast protocols. An analytical model is provided to predict the behavior of these protocols. The model is inspired by the work of Williams et al. [42]. In their work, the authors designed a probability model to predict the broadcast probability for counter-based and distance-based broadcast protocols in MANET. They assumed that the nodes are deployed in an obstacle-free area where there is no constraint on the mobility of nodes. In this work, we adapt the analytical model of Williams et al. to predict the behavior of ECUV and EDUV in the urban Manhattan-like topology.

4.1 Model requirements and assumptions

Because it is difficult to establish the model under complex and irregular road-map layout of urban VANET, the following assumptions are introduced to simplify the problem.

1. The distribution of road segments follows a Manhattan-like topology. Figure 8 illustrates the Manhattan-like road map for the proposed analytical model. The topology of this roadmap consisted of n segments that have the same length and the same width. Moreover, the road segments are distributed according to a rectangular grid topology.
2. We assume that the communication radius has the same value for all vehicles in the network, and the length of each road segment is lower or equal to this radius. Therefore, when two vehicles are on the same road segment, they will necessarily be one-hop neighbors (for more details, refer to Sects. 4.2 and 4.3).
3. Vehicles are uniformly distributed over the network. The initial geographical positions of the vehicles are randomly distributed over the road map. When a vehicle reaches an intersection, it goes straight, turns to the left, turns to the right, or turns backward with the same probability (the model is built around a stochastic feature). Namely, the probability of taking a specific direction is $\frac{1}{4}$ (the probability is randomly and uniformly distributed).
4. As defined in [42], the probability of forwarding is the same for all the vehicles in the networks.

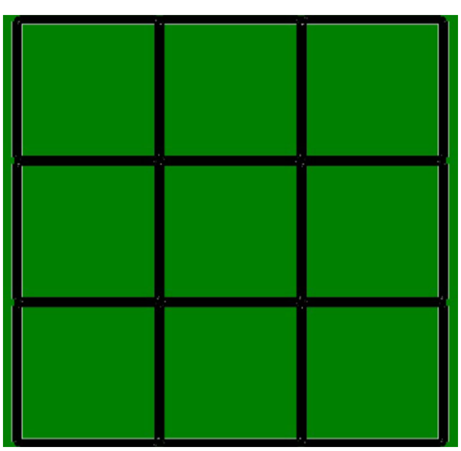


Fig. 8 3×3 Manhattan-like topology

4.2 Model for EDUV protocol

This section presents the proposed analytical model that predicts the behavior of EDUV protocol. Let v_1 and v_2 two vehicles that circulate on the same road segment. We assume that the timers of v_1 and v_2 are scheduled. We give the following elementary events to calculate the probability of v_1 receiving a message from the vehicle v_2 during the waiting time such that the distance between them is lower or equal to the threshold D_{thr}.

- C1: The vehicles v_1 and v_2 move along the same road segment.
- C2: The distance between the vehicles v_1 and v_2 is lower or equal to the threshold D_{thr}.
- C3: The vehicle v_2 sends the message.
- C4: The scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.

It is important to remember that v_1 receives directly the message transmitted by v_2 only if the two vehicles are one-hop neighbors. In our model, we assume that the length of each road segment is less or equal to the communication range radius (the second assumption in Sect. 4.1). Therefore, this condition is implicitly fulfilled by C_1.

Let n is the number of road segments in the roadmap. The geographical positions of the vehicles are uniformly distributed in the network. Consequently, the probability that the vehicles v_1 and v_2 are located together on the road segment i (event $C1$) is given by Eq. 1.

$$p_i(C_1) = \frac{A_i}{\sum_{k=1}^{n} A_k} \quad (1)$$

Where A_k is the area of the road segment k.

By considering the first assumption defined in Sect. 4.1 (all the road segments have the same length and the same width, and hence they have the same area A), we can deduce the Eq. 2.

$$p(C1) = p_1(C1) = p_2(C1) = \ldots = p_n(C1) = \frac{A}{n \times A} = \frac{1}{n} \quad (2)$$

The probability that the distance between the vehicles v_1 and v_2 is lower or equal to the threshold D_{thr} (event C_2) is given by Eq. 3.

$$p(C_2) = \frac{D_{thr}}{L_{seg}} \tag{3}$$

Where D_{thr} is the distance threshold and L_{seg} is the length of the road segment.

We assume that the probability p to broadcast a received message is the same for all vehicles in the network. Therefore, the probability that the vehicle v_2 sends the received message (event C_3) is given by Eq. 4.

$$p(C_3) = p \tag{4}$$

let S be a sample space which is composed of two events E_1 and E_2.

- E_1: the scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.
- E_2: the scheduled timer of the vehicle v_1 expires before the scheduled timer of the vehicle v_2.

Because the waiting time value is uniformly distributed in the same interval for the vehicles v_1 and v_2, the probability of any outcome of the sample space S is likely the same. Thus,

$$p(C_4) = p(E_1) = p(E_2) = \frac{1}{2} \tag{5}$$

The four events C_1, C_2, C_3, and C_4 are independent. Thus, the probability that the vehicle v_1 inhibits the transmission of the received message is given in Eq. 6.

$$\begin{aligned} p(C_1 \cap C_2 \cap C_3 \cap C_4) &= p(C_1) \times p(C_2) \times p(C_3) \times p(C_4) \\ &= \frac{1}{n} \times \frac{D_{thr}}{L_{seg}} \times p \times \frac{1}{2} \\ &= \frac{p \times D_{thr}}{2 \times n \times L_{seg}} \end{aligned} \tag{6}$$

Consequently, the probability that the vehicle v_1 broadcasts the received packet is given by Eq. 7.

$$p = \left(1 - p(C_1 \cap C_2 \cap C_3 \cap C_4)\right)^{N-2} \tag{7}$$

Where N is the number of vehicles on the road map. In the Eq. 7, we use $N-2$, because the vehicle v_1 and the vehicle from which v_1 gets the first copy of the message (the vehicle that initialized the timer) are both excluded.

We also note that the vehicle that initializes the timer of the vehicle v_1 must have a distance to v_1 higher than D_{thr}, when v_1 and this vehicle are on the same road segment. This condition has a probability π given in Eq. 8. As a result , p is given by Eq. 9.

$$\pi = 1 - \frac{D_{thr}}{n \times L_{seg}} \tag{8}$$

$$p = \pi \times \left(1 - \frac{p \times D_{thr}}{2 \times n \times L_{seg}}\right)^{N-2} \tag{9}$$

Finally, the broadcast probability is calculated according to the following formula.

$$p - \left(1 - \frac{D_{thr}}{n \times L_{seg}}\right)\left(1 - \frac{p \times D_{thr}}{2 \times n \times L_{seg}}\right)^{N-2} = 0 \tag{10}$$

4.3 Model for ECUV protocol

This section presents the proposed analytical model that predicts the behavior of ECUV protocol. In our proposed analytical model, the following three conditions (elementary events) must be satisfied to increment the counter of v_1.

- C_1: The vehicles v_1 and v_2 move along the same road segment.
- C_2: The vehicle v_2 sends the received message.
- C_3: The scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.

Let n is the number of road segments in the roadmap. The positions of the vehicles are randomly and uniformly distributed in the network. Thus, the probability that v_1 and v_2 are on the same road segment (event C_1) is given by Eq. 11.

$$p(C_1) = \frac{1}{n} \tag{11}$$

The probability that the vehicle v_2 broadcasts the received message is given by Eq. 12.

$$p(C_2) = p \tag{12}$$

We assume that S is a sample space composed of the following two events.

- E_1: the scheduled timer of the vehicle v_2 expires before the scheduled timer of the vehicle v_1.
- E_2: the scheduled timer of the vehicle v_1 expires before the scheduled timer of the vehicle v_2.

The values of the scheduled timers are uniformly distributed in the same interval for the vehicles v_1 and v_2. Consequently, the probability of any outcome of the sample space S is likely the same. Thus,

$$p(C_3) = p(E_1) = p(E_2) = \frac{1}{2} \tag{13}$$

The vehicle v_1 increments its counter based on the probability p_{inc} (Eq. 14).

$$p_{inc} = p(C_1 \cap C_2 \cap C_3) \tag{14}$$

The three events C_1, C_2 and C_3 are independent. As a result, p_{inc} is given by the following equation.

$$p_{inc} = p(C_1) \times p(C_2) \times p(C_3) \tag{15}$$

Based on Eqs. 11, 12 and 13, we can deduce Eq. 16.

$$\begin{aligned} p_{inc} &= \frac{1}{n} \times p \times \frac{1}{2} \\ &= \frac{p}{2 \times n} \end{aligned} \tag{16}$$

The probability that the vehicle v_1 exactly receives i duplicate packets (from vehicles that are on the same road segment where v_1 is located) is given by Eq. 17.

$$\begin{aligned} p_i &= C_i^{N-2} \times p_{inc} \times (1 - p_{inc})^{N-2-i} \\ &= C_i^{N-2} \times \frac{p}{2 \times n}\left(1 - \frac{p}{2 \times n}\right)^{N-2-i} \end{aligned} \tag{17}$$

Where N is the number of vehicles in the network.

As defined in [42], $N-2$ is used in Eq. 17, because the vehicle v_1 and the vehicle from which v_1 get the first copy of message are excluded.

The probability to receive a number of duplicate packets lower than C_{thr} is given in Eq. 18.

$$P(Z < C_{thr}) = \sum_{k=0}^{C_{thr}-1} C_k^{N-2}\Big(p(Y)\Big)^k\Big(1 - p(Y)\Big)^{N-2-k} \tag{18}$$

where Z is the number of duplicate packets variable and $(Y = C_1 \cap C_2 \cap C_3)$.

Based on Eqs. 16 and 18, we can deduce Eq. 19.

$$P(Z < C_{thr}) = \sum_{k=0}^{C_{thr}-1} C_k^{N-2}\left(\frac{p}{2 \times n}\right)^k\left(1 - \frac{p}{2 \times n}\right)^{N-2-k} \tag{19}$$

Finally, the probability to broadcast a message is calculated by the following equation.

$$p - \sum_{k=0}^{C_{thr}-1} C_k^{N-2}\left(\frac{p}{2 \times n}\right)^k\left(1 - \frac{p}{2 \times n}\right)^{N-2-k} = 0 \tag{20}$$

5 Performance evaluation

This part analyses the performance of ECUV and EDUV protocols through both the analytical model and network simulation experiments. For this aim, We investigate the performance over two urban network topologies: (i) Synthetic Manhattan Topology for the analytical model, (ii) Real network topology for the simulation experiments. The next sub-sections depict the evaluation metrics, the performance assessment through the analytical model and the performance assessment using network simulation experiments.

5.1 Metrics

To determine the reliability and effectiveness of the proposed protocols, we assess the following metrics:

- *Coverage capacity*: Represents the ratio between the number of vehicles that well received the broadcasted packet and the number of vehicles in the network. We note that our analytical models do not give an explicit formulation of this metric. However, because the network size and the number of vehicles in the network are the main parameters of our models, we can implicitly assess the coverage capacity metric.
- *Number of relay nodes (number of transmissions)*: The total number of vehicles that forward the disseminated message throughout the broadcasting process. A high value of this metric is a serious sign of a strong redundancy that can lead to the broadcast storm problem. The derived analytical models give an explicit value of this metric, because the probability calculated through the equations Eqs. 10 and 20 represents the ratio of vehicles that rebroadcast the disseminated message, and consequently it represents the number of transmissions.
- *End-to-end delay*: The average delay that takes a packet to go from the source vehicle to the receiver vehicles. This metric is only assessed through the network simulation experiments.

5.2 Performance evaluation using analytical model

This section presents the performance evaluation of ECUV and EDUV through analytic simulation. EDUV and ECUV processes are modeled by Eqs. 10 and 20, respectively. These equations were solved using the Symbolic Math Toolbox of MATLAB to find the broadcasting probability of each vehicle in the network. This probability represents the main characteristic of the proposed protocols. The experiment should enable us to assess both coverage capacity, cost (number of transmissions) and to select the appropriate threshold values for each traffic density (low density and high density).

5.2.1 Scenario description and parameters

This part presents the scenario and parameters used to evaluate the performance of ECUV and EDUV protocols through the analytic expressions defined by Eqs. 10 and 20. As shown in the Eq. 10, the performance of EDUV protocol is influenced by the configuration of three parameters. Namely, the threshold D_{thr}, the number of vehicles N and the number of road segments n. Thus, the 3-tuple (D_{thr}, N, n) determines the configuration of the EDUV analytical model. Similarly, ECUV was evaluated through the 3-tuple (C_{thr}, N, n).

The network topology was Manhattan city. The number of road segments in this city map was varied by $3 \times 3, 6 \times 6, 9 \times 9$ roads. Moreover, the number of vehicles in the network was varied from 25 to 150 vehicles. We evaluated the proposed protocols under different traffic densities to investigate their behavior towards the broadcast storm problem. Additionally, the variation of the road-network size (the number of road segments), from experimental instance to another, allowed us to examine the coverage capabilities. For simplicity reasons, we set the length of each road segment to be equal to the communication range radius R.

In our study, the density d is defined by the ratio of the number of vehicles N to the number of road segments in the road-network n:

$$d = \frac{N}{n} \tag{21}$$

We have two levels of density:

- *Low density*: defined by the configurations (6×6 topology, $N = 25$) and (9×9 topology, $N <= 75$) because the ratio d is lower than 1.
- *High density*: defined by the configurations (3×3 topology, $N >= 25$), (6×6 topology, $N >= 50$), (9×9 topology, $N >= 100$) because the ratio d is higher than 1.

Furthermore, the proposed models were used to evaluate the global protocol's criteria. In such a case, the level of details (Namely, MAC layer parameters and the interaction between the communication layers) is not required. Table 3 presents a summary of the main parameters and their settings.

5.2.2 Results and discussion

Figures 9 and 10 outlines the results of the ECUV analytical model for C_{thr} equals to 1 and C_{thr} equals to 2, respectively.

The results of the EDUV analytical model are plotted in Figs. 11, 12 and 13 for $D_{thr} = 0.25R$, $D_{thr} = 0.50R$, and $D_{thr} = 0.75R$, respectively.

We note that the x- and y-axes in the different figures represent the vehicles density and the rebroadcast probability, respectively. As shown in Figs. 9, 10, 11, 12 and 13, when the vehicles density was low, the two protocols increased the number of broadcasters to ensure the maximum degree of the coverage

Table 3 Analytical models parameters

Parameter	Value
Communication range radius	A constant value equal to R
Road network topology	Manhattan topology
Length of each road segment	R
Size of the network	3×3 , 6×6 , 9×9
Number of vehicles	Varies from 25 to 150
Initial vehicles positions	Uniformly distributed
C_{thr}	Varies from 1 to 2
D_{thr}	$0.25R$, $0.5R$, $0.75R$

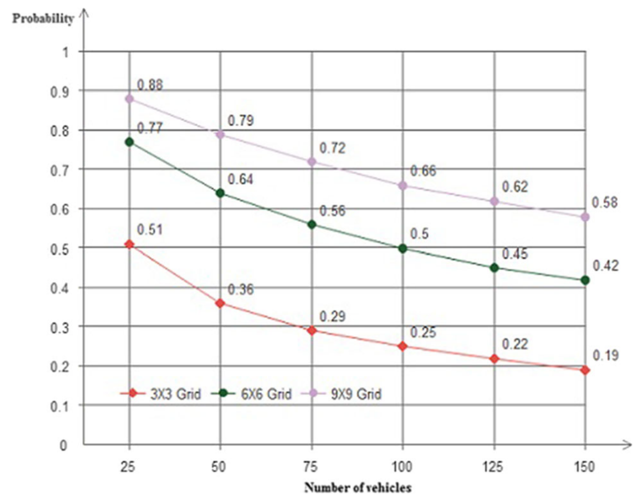


Fig. 9 ECUV rebroadcast probability prediction when $C_{thr} = 1$

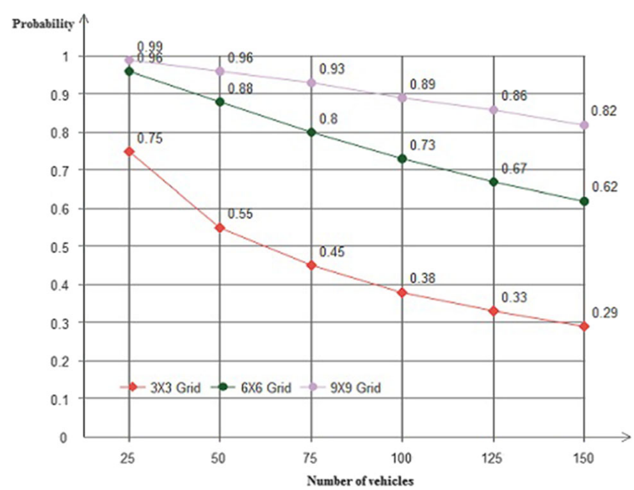


Fig. 10 ECUV rebroadcast probability prediction when $C_{thr} = 2$

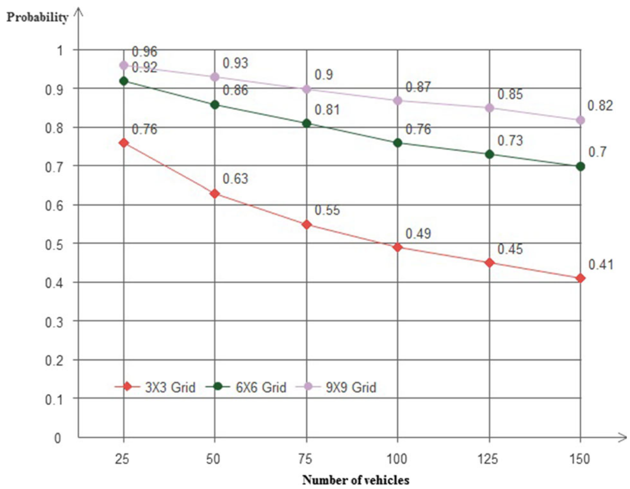


Fig. 11 EDUV rebroadcast probability prediction when $D_{thr} = \frac{R}{4}$

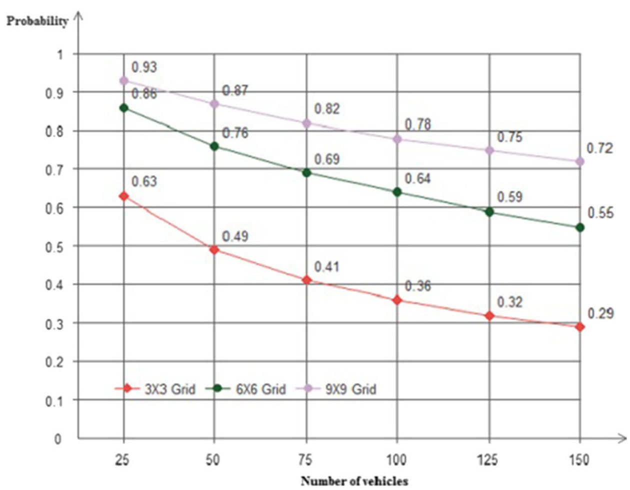


Fig. 12 EDUV rebroadcast probability prediction when $D_{thr} = \frac{R}{2}$

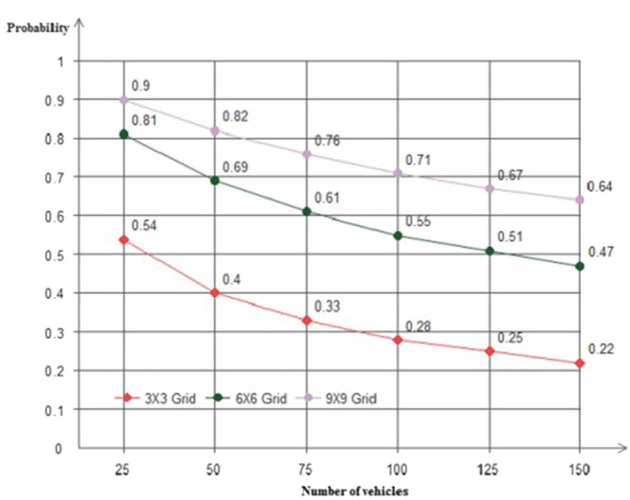


Fig. 13 EDUV rebroadcast probability prediction when $D_{thr} = \frac{3 \times R}{4}$

capacity. Whereas, when it was high, the number of broadcasters was decreased to avoid the broadcast storm problem.

We also note that the behavior of these protocols was influenced by the different threshold values. The broadcast probability of ECUV was proportional to the value of C_{thr} (Figs. 9, 10). By contrast, the broadcast probability of EDUV protocol was inversely proportional to the value of D_{thr} (Figs. 11, 12, 13).

The network size had a great influence on the behavior of EDUV and ECUV. We noted that the number of broadcasters was directly proportional to the network size. Because the network size is mainly depends on the number of the road segments, the increase in broadcast probability (due to the increase in network size) can only be explained by the need of these protocols to cover the newly added road segments. Consequently, this can allow to better fulfill the coverage capability requirement.

Because the proposed analytical models do not give explicit values of the coverage capacity metric, the evaluation of this metric requires reference values. As outlined in Sect. 4.1, we have assumed that the geographical positions of vehicles are uniformly distributed in the road network, and the length of each road segment is lower or equal to the communication range radius. Based on these assumptions, the total coverage of the road network is ensured by just selecting a single vehicle in each road segment to act as a relay node. Consequently, the number of relay nodes that guarantee the total coverage will be equal to the number of road segments in the road network. Therefore, the reference values for 3×3, 6×6, and 9×9 Manhattan topologies are 9, 36, and 81, respectively. We can use these values as references to analyze and check the obtained results, and hence to select the appropriate values of C_{thr} and D_{thr} for each density (low density and high density).

When the density is low ((6×6 topology, N=25) and (9×9 topology, N=25)), the reasonable value of the broadcast probability is 1 (all vehicles must act as relay nodes), because the number of vehicles is lower than the reference value (see Eq. 21). For this situation, we have to select a threshold value that gives the highest value of the broadcast probability. As outlined in Figs. 10 and 11, the threshold values C_{thr}=2 and $D_{thr} = R/4$ fulfill this requirement because they give a probability near to 1.

In high traffic density (represented by the configurations (3×3 topology, $N >= 25$), (6×6 topology, $N >= 50$), (9×9 topology, $N >= 100$)), we note that for all threshold values, The number of relay-nodes corresponding to each broadcast probability is higher than the reference value. (we can check that by calculating the number of relay nodes for each broadcast probability). However, we have to choose the threshold value that generates the smallest value of the broadcast probability because it has a lower message overhead. Namely, we select C_{thr}=1 (Fig. 9) and $D_{thr} = 3/4R$ (Fig. 13) for high-density scenarios.

5.3 Performance analysis using network simulation

5.3.1 Scenario description and parameters

In this section, we evaluate the proposed schemes in a real urban scenario. We used Objective Modular Network Testbed in C++ simulator (Omnet++) [43]. It is widely used to perform discrete network simulation. It was coupled with the VEINS framework [44] to implement and simulate vehicle behavior for each broadcast protocol. The simulation of vehicle mobility is carried out by SUMO, which has a high capacity to generate full road traffic scenarios by considering both macroscopic and microscopic models [45]. Several traffic flows were generated in 2.5×2.5 Km^2 real urban topology. This topology is based on the Erlangen city (Fig. 14). Furthermore, we took into account the impact of the Shadow fading phenomenon caused by buildings to achieve a more realistic simulation. Therefore, we integrated the simple obstacle shadowing model provided by the VEINS framework to generate the effect of signal attenuation [46]. The maximum radio range, the bit rate, the channel sensitivity, and the thermal noise were set to 150 *meters*, 6 *Mps*, −89 *dBm*, and −119 *dBm*, respectively. Table 4 summarizes the main parameters of the simulation experiments.

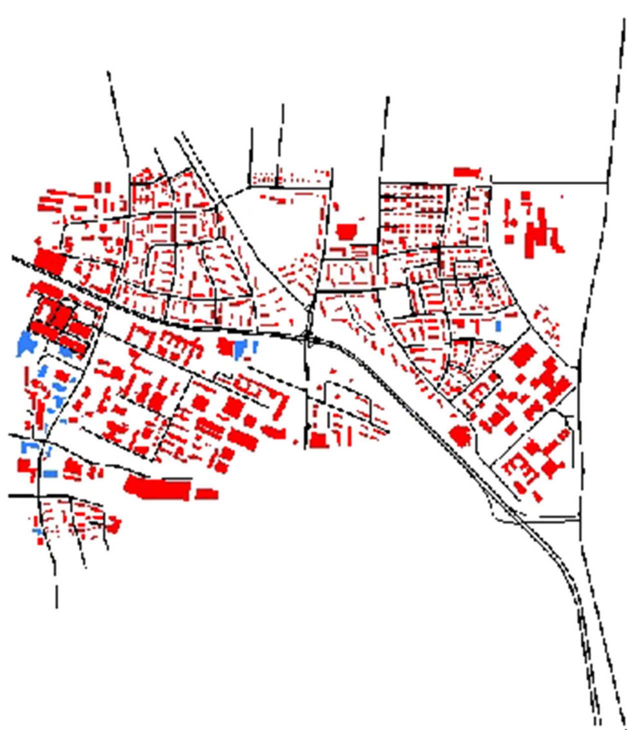


Fig. 14 Erlangen road network

Table 4 Simulation experiments parameters

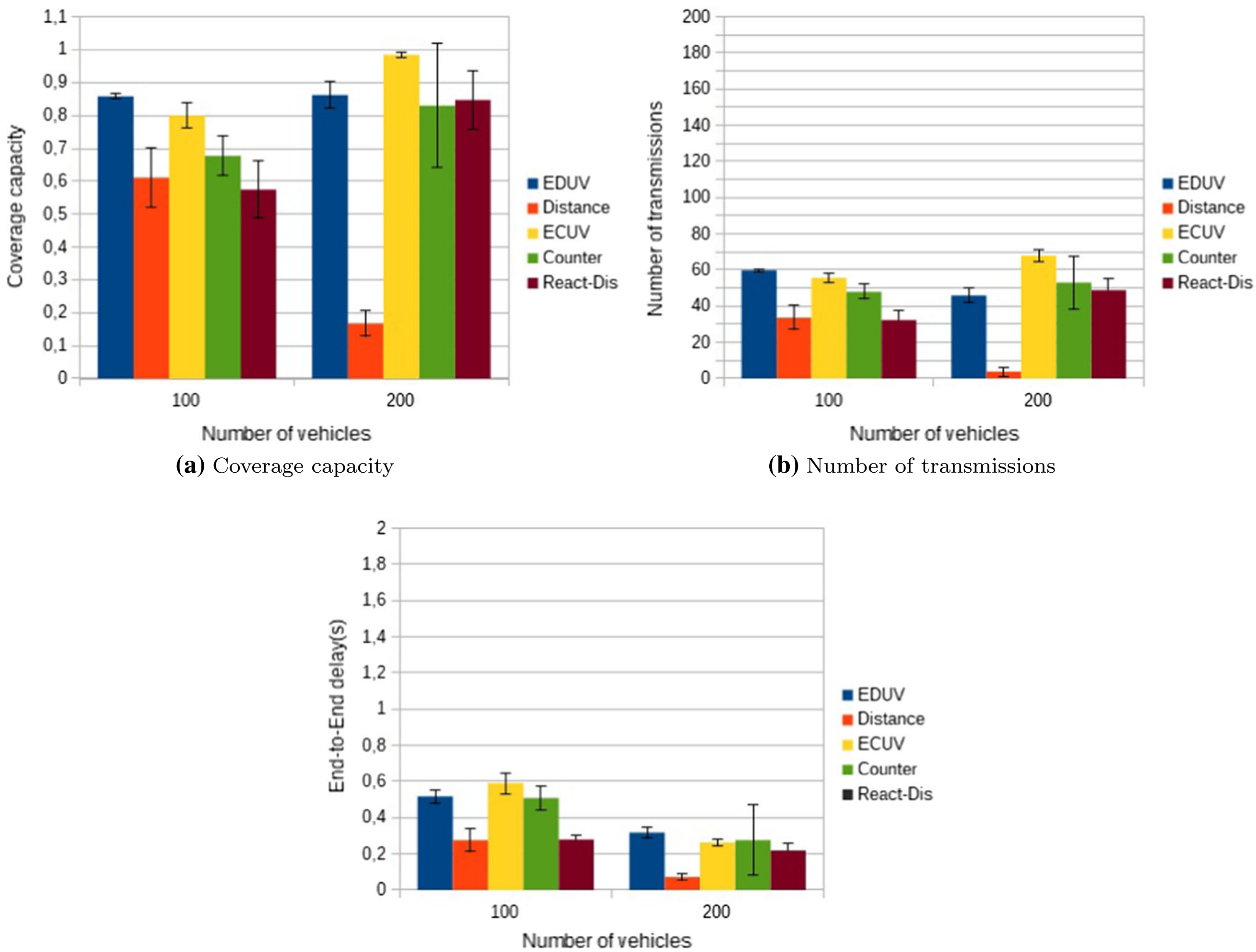
Parameter	Value
Playground size	2.5×2.5 Km^2
Source location (x, y)	$x = 1800, y = 850$
Radio propagation model	- SimplePathlossModel. - Simple Obstacle Shadowing model.
Transmission range	150 m
Bite rate	6 Mps
Sensitivity	−89 dBm
Thermal Noise	−119 dBm
Antenna	Monopole antenna
Number of runs	10
Confidence interval	95%

The quality of Multi-hop broadcasting protocols highly-depends on the number of vehicles in the region of interest and the threshold value. Thus, the number of vehicles was varied to check the performance of the proposed protocols over two traffic densities. We had 200 vehicles that represent the high-density scenario and 100 vehicles that represent the low-density scenario. When the desired number of vehicles for each density scenario was reached, an RSU at (1800, 850) position initiated the broadcasting of a $1024 - byte$ data message to each vehicle in the road network.

The proposed ECUV and EDUV protocols were compared to Counter-based protocol [20], Distance-based protocol [20], and React-Dis [38]. Note that the values of thresholds D_{thr} and C_{thr} in our simulation were selected purposely according to the values obtained through the tuning operation (Sect. 5.2.2). Namely, we used $D_{thr} = 0.25R$ and $C_{thr} = 2$ for the low-density scenario. Besides, $D_{thr} = 0.75R$ and $C_{thr} = 1$ were used for the high-density scenario. Finally, each plotted point was the mean of 10 iterations with a confidence level of 95%.

5.3.2 Results and discussion

Figure 15 introduces all outcomes for the Erlangen scenario. Specifically, Fig. 15a outlines the coverage capacity for all schemes under low and high traffic densities. As shown in this figure, ECUV and EDUV outperform all other protocols in all cases. By comparing EDUV and distance-based protocol, we see that EDUV provided better coverage in the two densities. For instance, the difference between them was 69%, when the number of vehicles was



(a) Coverage capacity **(b)** Number of transmissions

(c) End-to-End delay

Fig. 15 Simulation results for urban scenario

200. This is because the value 0, 75R assigned to D_{thr} is too aggressive, and produced low coverage for distance-based protocol. Indeed, the very high value of D_{thr} is not the best choice for distance-based protocol even in the high-density scenario. The high delivery of EDUV and ECUV was due to the use of the minimum-distance and counter-based heuristics in association with the road-based broadcast concealment mechanism, which considerably enhanced the coverage capacity even when the value of the threshold was very aggressive. As we can see in Fig. 15a, React-Dis performs better only in high traffic density. The reason is that the probabilistic scheme used by React-Dis is not good for low vehicle density.

Figure 15b shows the number of transmissions. We have noted that ECUV and EDUV slightly exceeded other protocols in terms of the number of transmitted messages. Certainly, these protocols utilize a road-based broadcast suppression mechanism, which has increased the number of forwarders in each hop. However, this increase in the number of transmissions has produced higher performance in terms of coverage capability.

Figure 15c outlines the average latency. All protocols use a timer-based approach, in which vehicles make their decision about rebroadcasting of the received message after a waiting time. This extra time accumulates from hop to another along the transmission path thereby increasing the total end-to-end delay. We have noted that ECUV, EDUV, and counter-based protocols had almost the same end-to-end delay in low traffic density. The obtained results were between 0.51s and 0.59s. We have noted also that distance-based protocol and React-Dis protocol sacrificed the coverage capacity to minimize the end-to-end delay in low traffic density.

In high traffic density, the distance-based protocol was the protocol with the lowest end-to-end delay. This is expected because the disseminated message reached a small number of vehicles, and these vehicles may be very close to the source node. Consequently, the disseminated message reached these vehicles across a small number of hops. For this reason, the distance-based protocol had the lowest delay among all other protocols. Also, note that EDUV, ECUV, Distance-based protocol, and React-Dis had nearly the same end-to-end delay in high traffic density (between 0.22s and 0.31s).

6 Conclusion

In this paper, the well-known counter and distance-based broadcast protocols have been adapted to the Urban VANETs. First, the scenarios in which the messages cannot be propagated on different roads, when counter and distance-based schemas are used, have been identified. Next, new road-based approaches (EDUV and ECUV) have been derived from these protocols to mitigate the effect of the identified issue. Then, analytical models are proposed to measure the broadcast probability of the proposed protocols in accordance with the density of the vehicles, the road-network size, and the threshold parameter. The Mathematical model analyses and simulation results prove that EDUV and ECUV protocols ensure the tradeoff between the reachability and the broadcast storm problem mitigation. We undertake in future work to analyze the performance of ECUV and EDUV protocols through the Monte-Carlo simulation.

References

1. Mfenjou, M. L., Ari, A. A. A., Abdou, W., Spies, F., et al. (2018). Methodology and trends for an intelligent transport system in developing countries. *Sustainable Computing: Informatics and Systems*, *19*, 96–111.
2. Gao, H., Huang, W., & Yang, X. (2019). Applying probabilistic model checking to path planning in an intelligent transportation system using mobility trajectories and their statistical data. *Intelligent Automation and Soft Computing*, *25*(3), 547–559.
3. Yang, X., Zhou, S., & Cao, M. (2019). An approach to alleviate the sparsity problem of hybrid collaborative filtering based recommendations: The product-attribute perspective from user reviews. *Mobile Networks and Applications*, *25*, 376–390.
4. Kuang, L., Hua, C., Wu, J., Yin, Y., & Gao, H. (2020). Traffic volume prediction based on multi-sources gps trajectory data by temporal convolutional network. *Mobile Networks and Applications*, pp. 1–13
5. Ari, A. A. A., Gueroui, A., Labraoui, N., & Yenke, B. O. (2015). Concepts and evolution of research in the field of wireless sensor networks. *International Journal of Computer Networks & Communications*, *7*(1), 81–98.
6. Ganin, A. A., Mersky, A. C., Jin, A. S., Kitsak, M., Keisler, J. M., & Linkov, I. (2019). Resilience in intelligent transportation systems (its). *Transportation Research Part C: Emerging Technologies*, *100*, 318–329.
7. Khelifi, H., Luo, S., Nour, B., Moungla, H., Faheem, Y., Hussain, R., & Ksentini, A. (2019). Named data networking in vehicular ad hoc networks: State-of-the-art and challenges. *IEEE Communications Surveys & Tutorials*
8. Zeadally, S., Hunt, R., Chen, Y.-S., Irwin, A., & Hassan, A. (2012). Vehicular ad hoc networks (vanets): Status, results, and challenges. *Telecommunication Systems*, *50*(4), 217–241.
9. Gao, H., Huang, W., & Duan, Y. (2020). The cloud-edge based dynamic reconfiguration to service workflow for mobile ecommerce environments: A qos prediction perspective. *ACM Transactions on Internet Technology*.
10. Tambawal, A. B., Noor, R. M., Salleh, R., Chembe, C., Anisi, M. H., Michael, O., & Lloret, J. (2019). Time division multiple access scheduling strategies for emerging vehicular ad hoc network medium access control protocols: A survey. *Telecommunication Systems*, pp. 1–22
11. Guerrero-Ibá nez, J. A., Flores-Cortés, C., & Zeadally, S. (2013). Vehicular ad-hoc networks (vanets): Architecture, protocols and applications. In *Next-generation wireless technologies*, pp. 49–70. Springer
12. Hartenstein, H., & Laberteaux, L. P. (2008). A tutorial survey on vehicular ad hoc networks. *IEEE Communications Magazine*, *46*(6), 164–171.
13. Arena, F., & Pau, G. (2019). An overview of vehicular communications. *Future Internet*, *11*(2), 27.
14. Ravi, B., Thangaraj, J., & Petale, S. (2019). Data traffic forwarding for inter-vehicular communication in vanets using stochastic method. *Wireless Personal Communications*, pp. 1–17,
15. Zheng, K., Zheng, Q., Yang, H., Long, Z., Hou, L., & Chatzimisios, P. (2015). Reliable and efficient autonomous driving: The need for heterogeneous vehicular networks. *IEEE Communications Magazine*, *53*(12), 72–79.
16. Patel, P. V., & Kadhiwala, B. (2016). Broadcasting techniques for route discovery in mobile adhoc networka survey. In *2016 3rd International conference on computing for sustainable global development (INDIACom)*, pp. 671–674. IEEE
17. Johnson, D. B., Maltz, D. A., Broch, J., et al. (2001). Dsr: The dynamic source routing protocol for multi-hop wireless ad hoc networks. *Ad hoc Networking*, *5*, 139–172.
18. Perkins, C., Belding-Royer, E., & Das, S. (2003). Ad hoc on-demand distance vector (aodv) routing. Technical report
19. Ksentini, A., Gueroui, A., & Naimi, M. (2005). Enhancing the DCF mechanism in noisy environment. In *IEEE vehicular technology conference*, Vol. 62, pp. 650. IEEE 1999
20. Tseng, Y.-C., Ni, S.-Y., Chen, Y.-S., & Sheu, J.-P. (2002). The broadcast storm problem in a mobile ad hoc network. *Wireless Networks*, *8*(2–3), 153–167.
21. Celimuge, W., Ohzahata, S., & Kato, T. (2013). A low latency path diversity mechanism for sender-oriented broadcast protocols in vanets. *Ad Hoc Networks*, *11*(7), 2059–2068.
22. Naeimipoor, F., Rezende, C., & Boukerche, A. (2012). Performance evaluation of video dissemination protocols over vehicular networks. In *37th Annual IEEE conference on local computer networks-workshops*, pp. 694–701. IEEE
23. Ghebleh, R. (2018). A comparative classification of information dissemination approaches in vehicular ad hoc networks from distinctive viewpoints: A survey. *Computer Networks*, *131*, 15–37.
24. Marinov, T., Nenova, M., & Iliev, G. (2018.) Comparative analysis of broadcasting protocols in vanet. In *2018 IX national conference with international participation (ELECTRONICA)*, pp. 1–4. IEEE
25. Latif, S., Mahfooz, S., Jan, B., Ahmad, N., Cao, Y., & Asif, M. (2018). A comparative study of scenario-driven multi-hop broadcast protocols for vanets. *Vehicular Communications*, *12*, 88–109.
26. Slavik, M., & Mahgoub, I. (2013). Spatial distribution and channel quality adaptive protocol for multihop wireless broadcast

routing in vanet. *IEEE Transactions on Mobile Computing*, *12*(4), 722–734.
27. Xie, F., Hua, K. A., Wang, W., & Ho, Y. H. (2007). Performance study of live video streaming over highway vehicular ad hoc networks. In *2007 IEEE 66th vehicular technology conference*, pp. 2121–2125. IEEE
28. Torres, A., Calafate, C. T., Cano, J.-C., Manzoni, P., & Ji, Y. (2015). Evaluation of flooding schemes for real-time video transmission in vanets. *Ad Hoc Networks*, *24*, 3–20.
29. Gokhale, S. S., & Trivedi, K. S. (1998). Analytical modeling. *Encyclopedia of distributed systems*
30. Honghao, G., Can, L., Youhuizi, L., & Xiaoxian, Y. (2020). V2vr: Reliable hybrid-network-oriented v2v data transmission and routing considering rsus and connectivity probability. *IEEE Transactions on Intelligent Transportation Systems*.
31. Korkmaz, G., Ekici, E., Özgüner, F., & Özgüner, U. (2004). Urban multi-hop broadcast protocol for inter-vehicle communication systems. In *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, pp. 76–85. ACM
32. Viriyasitavat, W., Tonguz, O. K., & Bai, F. (2011). Uv-cast: An urban vehicular broadcast protocol. *IEEE Communications Magazine*, *49*(11), 116–124.
33. Tonguz, O. K., Wisitpongphan, N., & Bai, F. (2010). DV-CAST: A distributed vehicular broadcast protocol for vehicular ad hoc networks. *IEEE Wireless Communications*, *17*(2), 47–57.
34. Wisitpongphan, N., Tonguz, O. K., Parikh, J. S., Mudalige, P., Bai, F., & Sadekar, V. (2007). Broadcast storm mitigation techniques in vehicular ad hoc networks. *IEEE Wireless Communications*, *14*(6), 84–94.
35. Villas, L. A., Boukerche, A., Maia, G., Pazzi, R. W., & Loureiro, A. A. F. (2014). DRIVE: An efficient and robust data dissemination protocol for highway and urban vehicular ad hoc networks. *Computer Networks*, *75*, 381–394.
36. Martinez, F. J., Fogue, M., Coll, M., Cano, J.-C., Calafate, C. T., & Manzoni, P. (2010). Evaluating the impact of a novel warning message dissemination scheme for vanets using real city maps. In *International conference on research in networking*, pp. 265–276. Springer
37. Celimuge, W., Ohzahata, S., & Kato, T. (2012). Vanet broadcast protocol based on fuzzy logic and lightweight retransmission mechanism. *IEICE Transactions on Communications*, *95*(2), 415–425.
38. Rezende, C., Pazzi, R. W., & Boukerche, A. (2012). A reactive solution with a redundancy-based error correction mechanism for video dissemination over vehicular ad hoc networks. In *Proceedings of the 15th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems*, pp. 343–352. ACM
39. Bradai, A., Ahmed, T., & Benslimane, A. (2014). ViCoV: Efficient video streaming for cognitive radio vanet. *Vehicular Communications*, *1*(3), 105–122.
40. Rehman, O., Ould-Khaoua, M., & Bourdoucen, H. (2016). An adaptive relay nodes selection scheme for multi-hop broadcast in vanets. *Computer Communications*, *87*, 76–90.
41. Tian, D., Liu, C., Duan, X., Sheng, Z., Ni, Q., Chen, M., et al. (2018). A distributed position-based protocol for emergency messages broadcasting in vehicular ad hoc networks. *IEEE Internet of Things Journal*, *5*(2), 1218–1227.
42. Williams, B., Mehta, D. P., Camp, T., & Navidi, W. (2004). Predictive models to rebroadcast in mobile ad hoc networks. *IEEE Transactions on Mobile Computing*, *3*(3), 295–303.
43. OMNeT++ Discrete Event Simulator, https://omnetpp.org/,2020-05-15.
44. Sommer, C., German, R., & Dressler, F. (2011). Bidirectionally Coupled network and road traffic simulation for improved IVC analysis. *IEEE Transactions on Mobile Computing*, *10*(1), 3–15.
45. SUMO - Simulation of Urban Mobility, https://sumo.dlr.de/index.html,2019-05-15.
46. Sommer, C., Eckhoff, D., & Dressler, F. (2013). Ivc in cities: Signal attenuation by buildings and how parked cars can improve the situation. *IEEE Transactions on Mobile Computing*, *13*(8), 1733–1745.

Lazhar Khamer is an Associate Professor at the Mathematics and Computer Science department, University of Souk Ahras, Algeria and a Ph.D. student At University of Tlemcen, Algeria. He received his degree of Engineer (2000), M.Sc. degree (2011). From Nov. 2018 to Nov. 2019, he was a Visiting researcher at LI-PaRAD Lab of the University of Versailles Saint-Quentin-en-Yvelines, France. His main research interests include vehicular internet of things, Wireless networks, Cognitive Radio, and Vehicular ad hoc networks.

Nabila Labraoui is an Associate Professor in Computer Engineering at the University of Tlemcen, Algeria. She received her Dr. Eng. Degree in computer science from ESI (Ecole Nationale Supérieure d' Informatique), Algiers and her Ph.D. Degree from the University of Tlemcen. She is president of the scientific committee of the computer science department. Her current research interests include Wireless Ad hoc Sensor Networks, Vehicular Networks, Drones, E-health, Network Security, Cognitive Radio, Cloud and Fog computing.

Abdelhak Mourad Gueroui is an Associate Professor in Computer Engineering at the University of Versailles Saint-Quentin-en-Yvelines, France. He received his M.Sc. degree from Université Paris 6 and his Ph.D. in Networking And Computer Engineering in 2000 from the University of Versailles Saint-Quentin-en-Yvelines, France. He has authored more than 100 publications in international conferences and journals, as well as book chapters, including ACM, IEEE, Elsevier and has both chaired and served in numerous program committees in prestigious international conferences. He received several awards, including best papers and serves/served on several journals and conferences executive committees. His research interests are in the area of wireless networks (WATM, WIMAX, LTE, 5G, Cloud Computing, WLAN, MESH, VANET and WSNs), particularly performance evaluation and QoS provisioning.

Sofiane Zaidi is an Associate Professor at the Mathematics and Computer Science department, University of Oum El Bouaghi, Algeria and a Researcher in the Research Laboratory on Computer Science's Complex Systems (RELA(CS)2) at the same university. He received his degree of Engineer (2008), M.Sc. degree (2014), and a PhD in Computer Science (2018). From Oct. 2016 to Oct. 2017, he was a Visiting Student with LISSI Laboratory, University of Paris Est Créteil, France. His main research interests are in Internet of Flying Things, Flying ad hoc networks, and Vehicular ad hoc networks. He is a reviewer in many international journals and a TPC member in many international conferences.

Ado Adamou Abba Ari is a Research Associate at the LI-PaRAD Lab of the University of Versailles Saint-Quentin-en-Yvelines, France and at the LaRI Lab of the University of Maroua, Cameroon, where he leads the networks and telecommunications services team. He received his Ph.D. degree in computer science in 2016 from Université Paris-Saclay in France with the higher honors. Dr Ado Adamou Abba Ari also received the master degree of business administration (MBA) in 2013, the Master of Science (M.Sc.) degree in computer engineering in 2012 and the Bachelor of Science (B.Sc.) degree in mathematics and computer science in 2010 from the University of Ngaoundéré, Cameroon. He served/serving on several journals and conferences program and reviewing committees. His current research is focused on Wireless Networks, Artificial Intelligence and IoT.

Annals of Telecommunications
https://doi.org/10.1007/s12243-021-00867-7

Enhancing video dissemination over urban VANETs using line of sight and QoE awareness mechanisms

Lazhar Khamer[1,2,3] · Nabila Labraoui[1] · Abdelhak Mourad Gueroui[3] · Ado Adamou Abba Ari[3,4]

Received: 1 February 2021 / Accepted: 25 June 2021

Abstract

Video broadcasting in Vehicular Ad Hoc Networks (VANETs) is beneficial for traffic management, entertainment, and advertising services because video notifications in active safety applications provide more information regarding accident scenarios than simple text messages. However, broadcasting videos over urban VANETs is challenging because of specificities, e.g., dynamic topology, shadowing phenomena, node mobility, and network partition. Moreover, the delay, jitter, and packet loss ratio associated with video streaming should not exceed strict thresholds for an acceptable quality of experience. To meet video streaming requirements, we propose a receiver-based, line-of-sight-aware and reliable bi-directional broadcasting protocol that obtains a tradeoff between broadcast reliability and coverage capabilities. The road network is segmented into a set of straight sections and the bi-directional broadcast method is applied to each section to address the obstructed line of sight problem and the coverage capacity simultaneously. Our protocol selects a sub-set of forwarders likely to have the best line of sight in a fully distributed manner. Furthermore, we overcame packet loss by designing an enhanced version of the store-carry-and-forward method that prioritizes the retransmission of packets containing more important video blocks. The simulation shows that our solution outperforms two innovative video broadcasting protocols in terms of frame loss, peak signal-to-noise ratio, and mean opinion score while keeping the end-to-end delay within the video streaming requirement range.

Keywords V2V communication type · Video streaming · Intelligent transportation system · Smart City · Broadcasting protocol · Line of sight · Quality of experience

1 Introduction

The emergence of intelligent cities switches urban environments into connected digital space, making daily activities of people easy in different areas of life [1]. Nowadays, intelligent transportation systems (ITS) have been the most important component in smart cities [2]. The main goal of intelligent transportation systems is to handle and share information that can limit possible collisions, hold traffic easy, and reduce the negative environmental influences of the transport sector on society [3, 4]. However, sharing information between ITS components can only be fully leveraged through VANETS integration.

✉ Lazhar Khamer
l.khamer@univ-soukahras.dz

Extended author information available on the last page of the article.

In the last few years, we have witnessed a significant increase in research and development activities in the field of VANETs. The concept of VANETs has been extended to a wide variety of applications that can profit from wireless communication between vehicles [5, 6]. These networks have tremendous potential to improve vehicle and road safety, traffic efficiency, and convenience, including comfort to both drivers and passengers. VANETs are foreseen to be a major step toward realizing intelligent transportation systems. In recent years, several car manufacturers have introduced vehicles with onboard computing and wireless communication devices, in-car sensors, and navigation systems (e.g., GPS and Galileo) in preparation for the deployment of large-scale vehicular networks. The use of different sensors, cameras, computing devices, and communication capabilities enables vehicles to collect, interpret information, and assist drivers, particularly via driver assistance systems. Typically, a VANET comprises onboard units (OBUs) installed on the vehicles and roadside units (RSUs) deployed along the sides of urban roads and highways, facilitating both vehicle-to-vehicle (V2V) communication between vehicles and vehicle-to-infrastructure (V2I) communication between vehicles and RSUs [5].

Video streaming in V2V and V2I environments is expected to significantly improve traffic management and provide value-added entertainment and advertising services [7]. For example, video notifications in active safety applications provide better information regarding accidents than a simple text message. In particular, video clips of an accident or a dangerous situation ahead would provide drivers with precise information, allowing them to make an informed decision (whether to proceed or to return) based on personal priorities and the capabilities of their vehicles. However, transmitting videos over VANETs is a sensitive task because of VANET specificities, such as dynamic topology, shadowing phenomena, mobility of nodes, and the lousy wireless environment. Besides, video streaming is a demanding application in terms of both service and experience quality. Many researchers have proposed different solutions to meet video streaming requirements. Existing solutions can be classified into three categories: application-layer solutions (video coding and error-resilient techniques), network layer solutions (routing optimization and the store-carry-and forward mechanism), and link-layer solutions (medium access control, rate control, and congestion control) [8]. These solutions are proposed to help deliver videos over VANETs with high quality of experience by considering the time-varying bandwidth, latency, jitter, and rate loss.

Technically and according to the use case scenario, videos can be broadcasted using one of the following routing paradigms: Unicast, Multi-cast, or Geocast/Broadcast. Unicast is a one-to-one type of communication, whereas multicast is a one-to-many type of communication. The Geocast/Broadcast routing protocols are used when a message is distributed by the sender to all nodes in a delimited geographic zone (zone of interest). In this study, we aim to enhance video content dissemination using a Broadcast routing technique. The objective of any broadcasting protocol is to reduce the effects of the "broadcast storm problem" by selecting the minimum set of vehicles that can ensure a successful broadcast to all nodes in a region of interest with minimum end-to-end delay cost [9].

Broadcasting routing techniques can be broadly classified into sender-based and receiver-based methods [10]. The main requirement for sender-based protocols is that a sender should reach the topological data of its immediate neighbors (node identities and kinetics information). This can be performed by a simple exchange of beacon messages between the immediate neighbors. The topological data allows the protocol to choose the best set of forwarders. However, for improving performance, the neighborhood data should be refreshed at a high frequency to cope with the fast change in the network topology. Unfortunately, this may produce high beacon transmission overhead and lead to inappropriate transmission conditions and collisions.

Receiver-based protocols are proposed to cope with the downside of sender-based protocols. In these protocols, each node makes its choice to rebroadcast or drop the received packet through the value of a local state variable and a threshold parameter. E.g., before making a decision, the receiver node waits for a frame of time. When the waiting time expires, this node takes a decision whether to rebroadcast or not based on the number of duplicate messages that are received during the waiting time. Therefore, it rebroadcasts the message if only the number of duplicate messages does not exceed a threshold value. Another advantage of the receiver-based approaches is that the anonymity mechanisms can be efficiently achieved because the receiver-based techniques do not claim the vehicle identity in the relay-node selection process [11]. Furthermore, a comparative study confirmed that the receiver-based broadcasting techniques outperform the sender-based broadcasting techniques, at least in terms of latency, collisions, and the number of transmissions [12].

In this work, we propose a video broadcasting solution that takes advantage of the reactive nature of the receiver-based approach while dealing with most urban VANET challenges: intermittent connection, shadowing phenomena, geographic coverage capabilities, and collisions.

When the environment within which a VANET is deployed contains obstacles such as buildings in urban scenarios, a serious challenge in the form of a partitioned network is encountered. Therefore, many packets may be lost as the number of obstacles increases. In an urban VANET environment, direct communication between vehicles can be disturbed because of the existence of buildings, thus preventing vehicles in the same communication range from directly exchanging data and creating an obstructed line of sight (ObsLOS) between them. This problem can negatively affect the selection of relay nodes in the next hop (Fig. 1). Therefore, ensuring that vehicles that contend to become relay nodes are in a non-obstructed line-of-sight environment is more important. Several studies have been conducted in this context. However, all of them are based on the sender [13–15].

To solve this issue by following a receiver-based approach, we propose a road-network-layout-based, line-of-sight aware, and reliable bi-directional protocol (ReLoS) that automatically selects the vehicles with enhanced line-of-sight as relay-nodes while increasing the geographic coverage capabilities. The proposed protocol is designed to enhance packet delivery in urban scenarios in very sensitive applications such as those involving video streaming. Indeed, coverage capability and line-of-sight are the most important factors that must be taken into account when selecting the

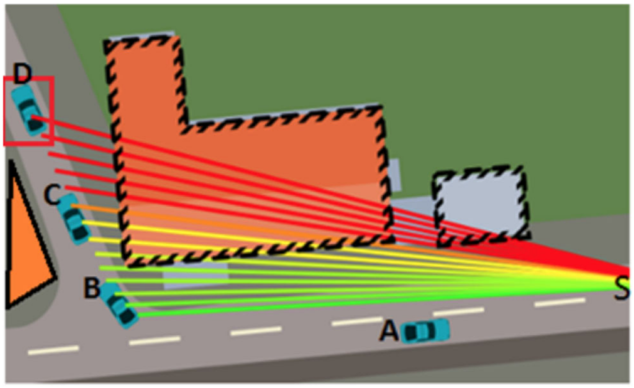


Fig. 1 Geographic greedy broadcasting protocol wherein vehicle D is more likely to become a relay node, despite vehicle B being more suitable, as the latter has improved LOS to all roads connected to the intersection

set of relay nodes. In ReLoS, the road network is divided into a set of road sections, and a bi-directional schema is established in each road section to cover the whole network while selecting relay nodes with enhanced line-of-sight in a fully distributed manner. According to our observations, ReLoS is the only broadcast routing solution that is based on both line-of-sight and road-network-topology. In the literature of routing protocols in VANETs, the designed solutions are either based only on line-of-sight [16] or only on road-network-topology [17, 18] or proposed to deal with unicast routing problems [19–23] .

Packet loss, resulting from collisions and the interrupted communication in the network, is one of the most serious issues associated with video streaming in vehicular networks. Because the end-to-end communication provided over the UDP/RTP transport layer for video streaming applications is unreliable (no mechanism of retransmissions), the Store Carry and Forward mechanism (SCF) is introduced to recover packet loss [8, 16, 24, 25]. However, the different SCF solutions do not consider the video-coding parameters to schedule the retransmission of each lost packet according to its impact on video quality. Thus, we design a video-friendly and Quality of Experience aware SCF scheme (QoESCF) for packet loss recovery.

The remainder of the paper is organized as follows. Section 2 introduces the related work. The protocol description and requirements are presented in Section 3. In Section 4, we present and discuss the performance of the proposed solution. Finally, the paper is concluded in Section 5.

2 Related work

Current research on data dissemination and specifically video dissemination focused on VANETs characteristics and the peculiarities of video compression standards to develop suitable solutions. Researchers typically aim to solve the broadcast storm issue by focusing on the selection of a limited number of nodes that forward broadcasting data. Furthermore, the procedure whereby relay nodes are selected needs to take into consideration the intermittent connection and the network partition problems.

Many receiver-based protocols are based on the Distance-Defer-Transfer mechanism (DDT). DTT aims to timely disseminate information by proposing by relaying the information via the farthest nodes, assuming that the intermediate nodes simply listen to the broadcasted message. The receivers calculate the distance from the one-hop transmitter to elect these nodes as relays. A waiting time inversely proportional to this distance is then engaged before the retransmission. Thus, the farthest node will be the first to retransmit, and the other nodes will cancel their retransmission upon receipt of the duplicate message.

An efficient broadcast scheme, named VOV, was proposed in [24]. It combines the Distance-Defer-Transfer mechanism (DDT) and geographical-based approach. When a node receives a new message, it first determines whether its neighbors are within the transmission range of the sender. If this is the case, it simply saves the received message. Otherwise, the node triggers a timer for possible future rebroadcasting. VOV calculates the waiting time by determining the forwarding zones of the sender by using kinetic information. The nodes inside the forwarding zone initiate a shorter waiting time than the nodes located outside. Thus, VOV ensures that the nodes within the forwarding zones are best suited to rebroadcast the message.

Viriyasitavat et al. [16] developed the Urban Vehicular Broadcast (UV-CAST) protocol for a well-connected regime and disconnected regime. UV-CAST assigns the task of store-carry-and-forward for the border nodes in which a border node, upon receipt of a beacon message from a newly arrived neighbor, assumes that it is probably disconnected from the network in the region of interest and broadcast the message to this neighbor. On the other side, a suppression mechanism is used by nodes that are not considered boundary nodes. The latter combines DDT and intersection-based suppression techniques. UV-CAST assigns shorter waiting to intersection vehicles to ensure they have a higher broadcasting probability.

Torres et al. [26] proposed a counter-adaptive dissemination schema named the Automatic Copies Distance Based broadcasting schema (ACDB). ACDB adjusts the values of its parameters to the variation of the traffic density. Specifically, the redundancy threshold and the maximum waiting time vary as needed when the number of one-hop neighbors changes. The density is estimated using the neighborhood table and the number of queued packets in the MAC layer. The researchers overcame the excessive retransmissions problem in high-density scenarios by proposing to increase the value of the maximum waiting time and decreasing the value of the threshold.

In Reactive, Density-Aware and Timely Dissemination Protocol (REACT-DIS) [27], the decision of a node to become a rebroadcaster is based on the number of retransmissions of the same packet that have been heard during the waiting time. The waiting time is calculated using the geographic-greedy approach, in which a node located farther away has a shorter waiting time than one at a closer distance. In this manner, nodes that wait a short time are likely to have a high probability of receiving a small number of duplicates, making it more convenient to retransmit the received packets. Assuming that the expected additional coverage area of the scheduled node decreases when the number of duplicates increases, REACT-DIS follows a probabilistic density aware scheme. Specifically, when the waiting time expires, nodes try to rebroadcast the packet with a probability that exponentially decreases with the number of duplicates. REACT-DIS also maintains the relaying status during a window time instead of repeating the relay node selection process for each transmission to ensure timely delivery.

Bradi et al., [25] proposed a solution named efficient VIdeo streaming over COgnitive radio VANETs (ViCoV), a video distribution method that disseminates different kinds of content in high dynamic topology networks and under different traffic densities.ViCoV chooses the most reliable Cognitive Radio channels to broadcast the data. Besides, it accurately selects a minimum number of forwarders to decrease collisions and deliver video with high quality. ViCOV chooses The CR channels based on their accessibility across time. Furthermore, the set of forwarders is elected by considering the centrality of each node in the network.

Rezende et al. proposed a solution named REDEC [28]. REDEC undertakes the difficulty of establishing the distribution of large sizes video packets over high dynamic V2V multi-hop links. The challenges in this task repose in how to satisfy video streaming strict prerequisites across a network with a frequently changed topology. REDEC is a reactive approach in which the process of relay node election is separated from video content dissemination. This method exploits the reactivity of receiver-based class where the decision of a vehicle to become a passive or active node is conducted at the receiving vehicles. Despite, video packets are constituted of a large quantity of data and they are transmitted at a high data rate; this causes too many problems in the capacity of receiver-based approach to limit redundant transmissions and to select relay nodes that have high coverage capabilities. For these purposes, REDEC substitutes the perspective of choosing new relay nodes per each transmitted packet to a time frame instead. Besides, it accomplishes the relay node election by engaging to broadcast periodically control messages rather than performing the relay nodes selection task when the video is transmitted. In this manner, when video packets are broadcasted, each vehicle implicated in the dissemination has simply to check its current status assigned within the transmission of the control messages.

Zhang et al. designed a Concurrent Transmission based Broadcast (CTB) protocol [29]. CTB uses the receiver-based schema wherein vehicles within the communication range of the current sender contend to be the next rebroadcaster in a fully distributed manner. Each neighbor vehicle establishes a priority-based backoff timer when they receive the first copy of the disseminated message to implicitly determine the most appropriate forwarders among the immediate neighbors of the current sender. However, the accumulated backoff time from one hop to another could significantly increase the end-to-end delay. To solve this issue by CTB, the shape of the communication range is segmented into a certain number of parts, and only vehicles within the same part contend between them to transmit the received message. In this manner, CTB could decrease the one-hop backoff time, which could considerably reduce the total end-to-end delay.

Quadros et al. propose the Quality Of experience driven receiver-based approach (QORE) [30]. In order to keep the awareness of both quality of service and quality of experience parameters during the forwarding process, QORE is combined with the farthest distance receiver-based broadcast mechanism. The QORE strategy points to choose forwarders that can keep up better video quality from the point of view of the end-user. Therefore, when a vehicle receives a flow of video packets during window time, a QoE function is calculated to determine the impact of the distorted packets on the quality of the received flow. Furthermore, the QoE function is added to the geographic position parameter to determine the suitability of the vehicle to become a forwarder. In this manner, QORE could handle the capacity of relay vehicles to deliver the video with high QoE and at the same time guarantee better broadcast reachability.

In Stable CDS-Based Routing Protocol for Urban Vehicular Ad Hoc Networks (SCRP) [31], the authors tackle the concern of establishing end-to-end multi-hop paths with low latency for non-safety VANETs use cases in cities environments. Most protocols in current routing-related works intend to minimize latency through the use of opportunistic heuristics, such as shortest path, connections stability, and the number of hops. However, opportunistic routing protocols are suffering from local optima issues. To deal with this problem, SCRP estimates the latency of each path between the source node and destination node before starting the transmission of the data packet. For this purpose, a backbone is established in each road segment, and they are connected through nodes inside intersections (Bridge nodes). Besides, SCRP attributes to each road segment a weight that is calculated based on delay and connectivity information. Path composed of nodes with the lowest accumulated weights is used to relay messages.

Network simulation results show that SCRP has the lowest latency and the highest delivery ratio compared to three greedy-based routing protocols. Nevertheless, SCRP mainly bases on kinetic information included in hello messages regardless of its accuracy. To deal with this issue, Darwish et al proposed Reliable Intersection-Based Traffic-Aware Routing Protocol for Urban Areas Vehicular Ad Hoc Networks [22]. In this work, the forwarding nodes are selected according to the city topology, neighboring vehicles predicted geographical locations, receiver-sender link quality, and freshness of neighbors' kinetic data.

One of the principal differences between our solution and the protocols described above is the engagement of the road network layout feature to increase geographic coverage capability: a fully distributed bi-directional method is applied in each road segment to ensure the coverage of the entire network while selecting relay-nodes with enhanced line-of-sight. Furthermore, some of the above-cited protocols solve the problem of the loss of packets (due to collisions and intermittent connection) by proposing the store-carry-and-forward method (SCF). The SCF approach is utilized by the node to assist the neighbors that missed receiving the messages in the initial broadcast phase. However, all of these solutions don't take into consideration the video codec features in their strategies. To address this issue, the proposed QoESCF method assigns a weight for each video packet according to its impact on the quality of video when it is lost. Besides, QoESCF uses these weights to schedule the retransmission of lost packets.

3 Proposed ReLoS and QoESCF

In an urban environment, wireless signals experience attenuation when obstructed by buildings. In the worst case, this problem can lead to a network partition. Consequently, packet losses may occur and the video quality may deteriorate. Our aim to solve this problem led us to design a receiver-based broadcasting protocol for urban VANETs, namely a receiver-based line-of-sight-aware broadcasting protocol (ReLoS). This protocol facilitates the selection of nodes with an improved line of sight to rebroadcast the video content in a completely distributed manner. Considering that video content is likely transmitted over an unreliable transport layer, we propose an enhanced version of the SCF method to overcome the packet losses in the network layer. We then extend the traditional SCF to provide transmission differentiation between the video packets based on their effects on the video quality. The new SCF method is termed the quality of experience-aware store-carry-and-forward (QoESCF).In the following subsection, we present the detailed designs of ReLoS and QoESCF. For ease of use, Table 1 explains different notations that are utilized in this section.

3.1 Requirements and assumptions

In this paper, we design a broadcast solution for urban scenario that depends only on the V2V ad hoc communication type. This conforms to the assumptions defined in the IEEE 802.11p standard. Thus, the proposed protocol is not based on any infrastructure, such as roadside units (RSUs),3G, and 4G infrastructure. V2V communication type is the more suitable solution because it does not rely on the backbone network for a certain level of data transmission. For instance, it enables information exchange among vehicles without introducing extra burden to the backbone network.

We represent VANET as graph $GV = \{\{VP\} \cup V, IL\}$, where VP is the video streaming provider, and V is a set of vehicles moving along a 2D urban road-network. VP can be either an RSU or a stationed vehicle. IL is the set of one-hop

Table 1 Notations used in the different algorithms

Notations	Descriptions
PS(A ; B)	Position side of the vehicle A with respect to the vehicle B
Fr	Front side
Re	Rear Side
$\overrightarrow{V_B}$	Movement direction vector of the vehicle B
$\overrightarrow{BA}$	The vector that begins at the position of vehicle B and ends at the position of vehicle A
T_{min}	Minimum waiting time
T_{max}	Maximum waiting time
S	Sender vehicle
R	Receiver vehicle
SV	The source vehicle: the vehicle that broadcast the first copy of the message to its immediate neighborhood
Distance(S,R)	The spatial distance between the vehicle S and the vehicle R
r	The communication range
angle($\overrightarrow{V_S}$, $\overrightarrow{SR}$)	Angle between $\overrightarrow{V_S}$ and $\overrightarrow{SR}$
id_road_S	Road segment identifier of the sender vehicle S
id_road_R	Road segment identifier of the receiver vehicle R
Itra	Intra road scenario
Iter	Inter road scenario

communications links. IL_{ij} is a one-hop link between two vehicles v_i and v_j if the Euclidean distance between them is less than the transmission range. We represent the road network according to its topology. Thus, it is modeled as a graph $RN = \{J, SEG\}$. J is the set of junctions/intersections in the road network, and SEG is the set of segments. A SEG_{ij} exists if there is a street that connects directly the two junctions i and j. Figure 2 presents an example of the road network topology. Notice that each junction represents an extremity of all segments connected to it. Furthermore, a junction has an improved line-of-sight as compared to other locations on the segments connected to it.

We also assume that each vehicle in the network is equipped with a localization sensor (e.g., a GPS receiver). A digital cartography system is employed to recover the nearest road segment in the road network map for given geo-location coordinates. The system complies with the protocol requirements by using a digital map to provide a unique identity to each road segment. Furthermore, the header field of each transmitted packet requires certain information about the sender, such as the road segment identifier, sender position coordinates, and sender moving direction, to be included.

3.2 Description of receiver-based line-of-sight-aware broadcasting protocol

In previous receiver-based broadcasting protocols, the rebroadcasting decision of node is made on the receiver side rather than on the sender side. To achieve this, when a node receives a new packet, it triggers a timer that expires after a specific time period t. The value of t is determined by the rule that discerns the preference of the node to become a forwarder (the node with the shortest period is likely the more suitable candidate). For example, the reasoning of the geographic greedy broadcasting algorithm is based on the fact that the neighborhood nodes of a sender with the largest distance from it are likely to have a greater probability to cover a new area. Thus, the value of t is inversely proportional to the distance between the sender and the next one-hop receiver.

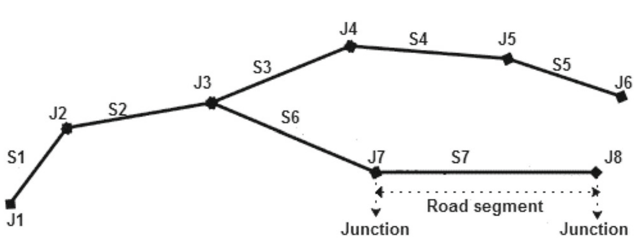


Fig. 2 An example of road network topology

In our solution (ReLoS), the t value is defined based on the line-of-sight heuristic and the bi-directional schema. ReLoS's response is established according to the position of the source node (node that initializes the bi-directional process within its transmission range) in relation to its immediate neighborhood. This can occur in two possible scenarios. The first one is when the source node and the receivers are on the same road segment (intra-road scenario). The second scenario is when the source node and the receivers are on different road segments (inter-road scenario). Furthermore, ReLoS aims to construct a backbone that connects the two extremities of each road segment. To this end, ReLoS engages the position side of the receiver node with the respect the source node to establish the bi-directional process.

Definition 1 Position side of node A with respect to another node B Assuming $\overrightarrow{V_B}$ is the movement direction vector of B and $\overrightarrow{BA}$ is the vector that begins at the position of B and ends at the position of A (relative position vector), the position side of A with respect to B is given by Eq. 1.

$$PS(A, B) = \begin{cases} front, & \left|angle(\overrightarrow{V_B}, \overrightarrow{BA})\right| < 90^\circ \\ rear, & else \end{cases} \tag{1}$$

Figure 3 describes the ReLoS process when a vehicle receives a new packet. This process is triggered to calculate the waiting time and accordingly schedules the corresponding timer. Figure 4 describes the behavior of ReLoS when a duplicate packet is received. It's at this level where a decision is made on the rebroadcasting of the received packet. Upon receiving a not duplicate packet, the vehicle determines the current scenario and calculates the corresponding waiting time. This can be achieved by comparing the road segment identifiers of the sender and the receiver (Fig. 3 Step A).

3.2.1 Scenario 1: Intra-road scenario

ReLoS selects implicitly vehicles that appear in the extremities of each road segment as relays. To this end, it establishes the waiting time according to the farthest-distance-based approach (2) . Consequently, the waiting time is inversely proportional to the distance between the sender and the current receiver. However, to allow the protocol to choose vehicles near intersections as forwarders (relay nodes), ReLoS engages the position side of the receiver relative to the movement direction (front or rear) of the source node as defined in Eq. 1. That is the farthest vehicle at the front side and the farthest vehicle at the rear

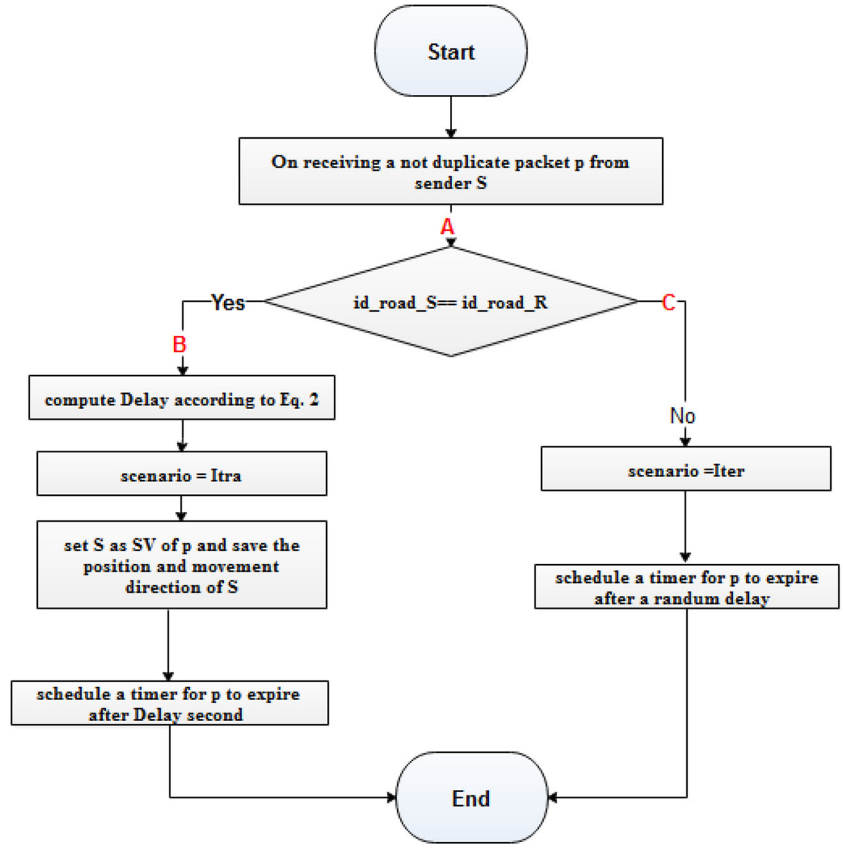


Fig. 3 ReLoS-flowchart when a vehicle receives a new packet

side have to suppress the broadcasting of the intermediate vehicles.

$$Delay = T_{min} + \left(1 - \frac{distance(S, R)}{r}\right) \times \left(T_{max} - T_{min}\right) \quad (2)$$

where S is the sender node, R is the receiver node, r the communication range, T_{min} the minimum waiting time and T_{max} is the maximum waiting time.

Now, we give a formal description of this scenario. Let S_i be the set which are formed by the vehicles that are located on the road segment i and let v_k be a source vehicle (the source vehicle is the vehicle that broadcasts the first copy of the message to its immediate neighborhood). v_k's immediate neighbor vehicles that are located on the road segment i are defined by the elements of the subset S_i^k of the set S_i (3.). The intra-road process is applied when v_k is an element of the set S_i.

$$S_i^k = \{v_j/distance(v_j, v_k) \leq r; v_j \in S_i \wedge v_j \neq v_k\} \quad (3)$$

Once the vehicles of the set S_i^k receive a new packet from the source vehicle v_k, they store the geographical position and the movement direction of v_k. This information will be used later to determine their position side (front or rear) relative to v_k when they receive a duplicate packet. Next, a timer is triggered according to Eq. 2 (Fig. 3 steps A to B). During the waiting time, if a scheduled vehicle from the set S_i^k receives a duplicate packet from a sender that belongs to the set S_i^k, it checks whether it is on the same side as this sender (relative to v_k) (Fig. 4 steps A ,B, D). If it is the case, it cancels the broadcast and the scheduled timer (Fig. 4 steps H). Otherwise, it keeps tracking the duplicate packets received from its immediate neighborhood. When the timer expires, it broadcasts the received packet (Fig. 4 step J). For example, in Fig. 5, E and F are located on the front side of the source vehicle A. In contrast, B and C are located on the rear side. When vehicles B, C, E, and F receive a message from the source vehicle A, they schedule themselves to rebroadcast after a delay time. Moreover, the vehicle F has the lowest waiting time compared to the vehicles on the front side of vehicle A. On the rear side, it is C that has the lowest waiting time. Consequently, when F broadcasts, the transmission of E is canceled. The same observation is made for B, its transmission is suppressed by the broadcasting of C. This process is repeated for the other vehicles to construct a backbone directed to nodes near the intersections (bi-directional mechanism). For instance, in Fig. 5, the backbone of the front side comprises the vehicles F, G, and I. On the rear side, the backbone comprises vehicles C and D. Note that if there is a vehicle near or at the intersection, it will be selected as a relay (vehicles I and D in our example).

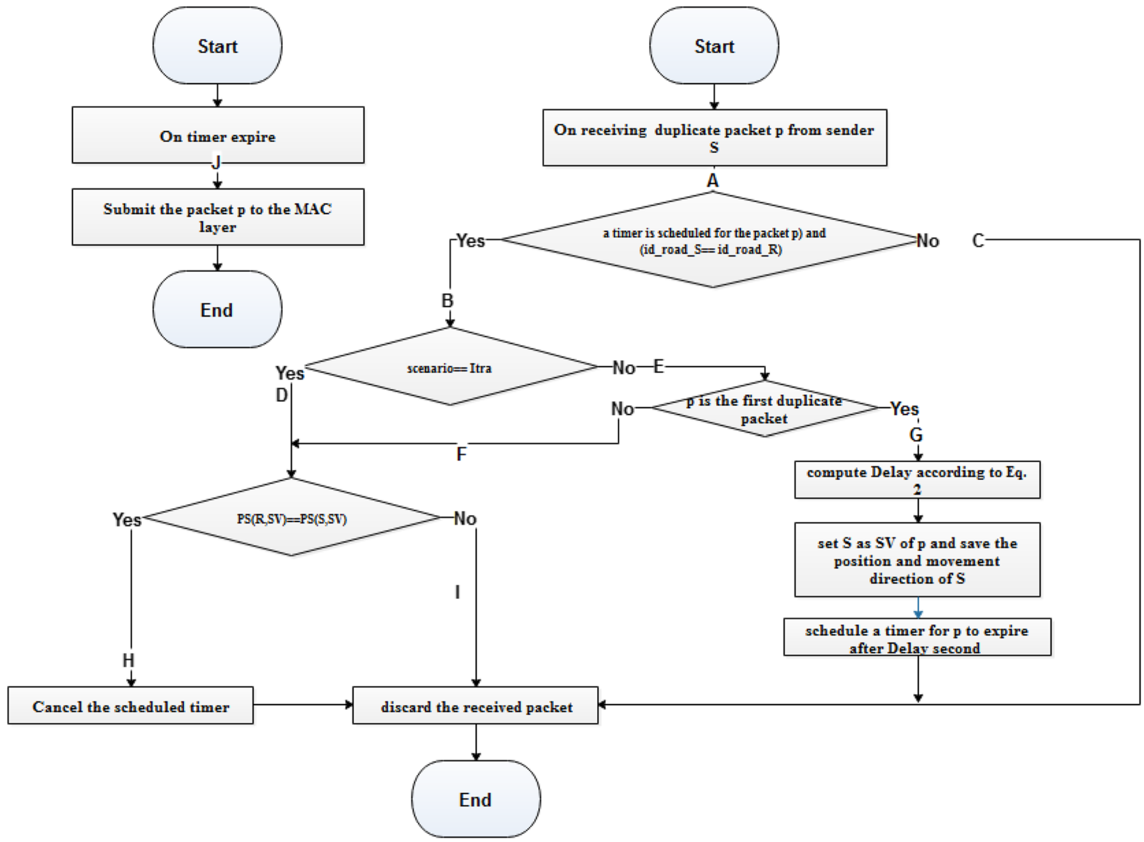


Fig. 4 ReLoS flowchart when a vehicle receives a duplicate packet

3.2.2 Scenario 2: Inter-road scenario

The inter-road scenario will be established if the source vehicle and its one-hop receivers are on different road segments. Specifically, it is triggered when the source vehicle v_k is not an element of the set S_i^k. To establish the bi-directional process, we have to select a vehicle, from the set S_i^k that initializes the process. The simplest way to accomplish this task is to select a random vehicle from the set S_i^k. Thus, when the vehicles of the set S_i^k receive a new message from v_k, they initialize a timer with a random value (Fig. 3 steps A to C). Moreover, the vehicle that has the shortest waiting time broadcast the first duplicate copy and consequently initializes the bi-directional process. More specifically, the vehicles of the set S_i^k schedule themselves to broadcast after a delay according to the farthest distance heuristic, upon they receive the first duplicate packet (Fig. 4 steps A to G).We notice that the duplicate packets which are received after the first duplicate packet is handled according to the bi-directional scheme (Fig. 4 steps E, F,...). Based

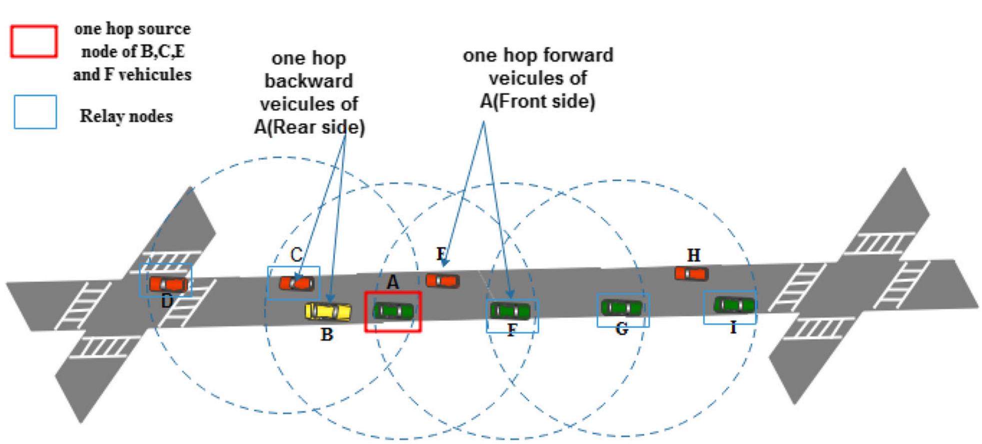


Fig. 5 Intra-road scenario

on the bi-directional method, the farthest vehicles on the front and rear side of the vehicle that initializes the Bi-directional process will be selected as a relay nodes (Fig. 4 step J) and the broadcast of the intermediate vehicles will be suppressed (Fig. 3 steps E, F,H…). Figure 6 illustrates the inter-road scenario. Initially, source node A directly sends a new packet to the vehicles located within its communication range (E, F, and G).When these vehicles receive the packet from A, they schedule a random timer. In this example we assume that the timer of G expires before the timer of F and E. Consequently, G is the first that broadcast the first duplicate packet to its neighborhood (F, E, and H). When F, E, and H receive the broadcast, they initialize the Bi-directional process. Based on the bi-directional method, the vehicles E and H will be selected as relays.

3.3 Quality-of-experience-aware store-carry-and-forward method

Several video compression standards exist, among which the H.264/MPEG-4 family is the most widely used [32]. The technique exploits two types of redundancies: redundancy between neighboring blocks of the same picture (Intra-coding) and redundancy between successive pictures (Inter-coding). As outlined in Fig. 7, the compressed sequence video includes three types of frames: I-frame, P-frame, and B-Frame. In the intra-coding, there is only one frame to consider (The I-frame), and the redundancy is suppressed in two steps. Firstly, the picture is divided into small N × M blocks. Next, the discrete cosine transform (DCT) is used to represent the signal energy of each block in the form of reduced coefficients. To compress and decompress the P–frame, the previous I–frame and/or P–frames in the same Group of Pictures (GoPs) are required. To compress and decompress B–frame, the previous and following I–frames and P–frames are needed. Therefore, if I-frame is lost, the remaining frames in the GoPs cannot be decoded. The loss of a P-frame at the beginning of the GoPs creates a huge distortion in the video sequence as compared to the loss of a P-frame at the end of the GoPs. By contrast, the distortion, due to the loss of a B-frame, has only a slight effect on the quality of the reconstructed video.

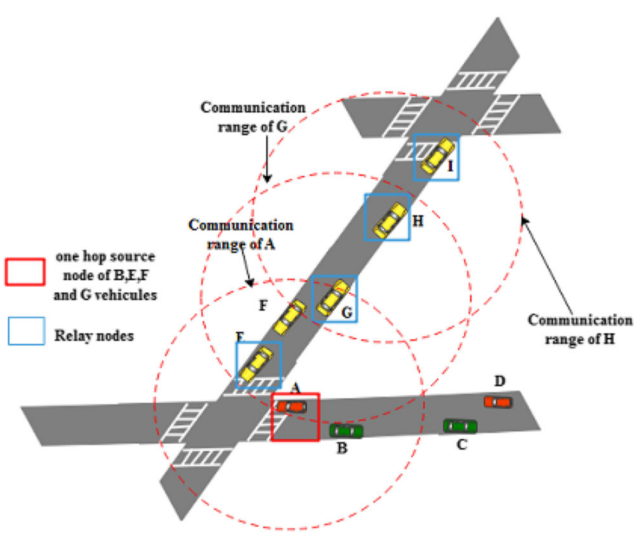


Fig. 6 Inter-road scenario

By considering the degree of distortion due to the loss of each video packet and the effect of this loss on the other frames within the GoPs, we define the Quality of Experience aware Store Carry and forward method (QoESCF). This scheme prioritizes the transmission of video packets that have a greater influence on the quality of the GoPs over those with lower QoE impact. Thus, we have to assign a weight to each video packet using the Peak Signal-to-Noise Ratio (PSNR) and the error propagation in subsequent frames.

PSNR is a measure of distortion used in video streaming. It quantifies the performance of the video streaming system by measuring the reconstruction quality of the compressed video as compared to the original video. Thus we can quantify the channel error loss as given in Eq. 4.

$$PSNR = 10 \log \frac{LM^2}{MSE} \tag{4}$$

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (x_i - y_i)^2 \tag{5}$$

where LM is maximum luminance value (255 for 8 bits), MSE is the mean square error (5), n represents the number of pixels in the video frame (or image), and x_i and y_i are the $i - th$ pixels of the original and the degraded frame introduced after a possible channel loss, respectively.

If a loss of information occurs in a single frame, the error due to this loss not only affects this frame but can propagate to the subsequent frames in the same GoPs. To quantify the channel loss error and the propagation error, we employ the distance distortion model as defined in Eq. 6.

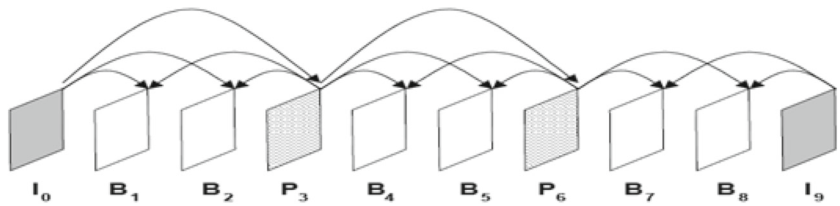
$$d = \sum_{i=1}^{L} PSNR(i) \tag{6}$$

where $i = 1, .., L$ denotes the position of the frame in the GoPs, and L represents the length of the GoPs. The weight of a given packet is calculated according the Eq. 7.

$$w = \frac{d}{L \times MAXPSNR} \tag{7}$$

where $MAXPSNR$ is the maximum value of the $PSNR$ in the video sequence. Typically, the maximum value of $PSNR$ is 50 dB, provided the pixel size is 8 bit. For 16-bit pixel size, the maximum value is 80 dB.

Fig. 7 Relationship among frames in MPEG GoPs



3.3.1 Distance distortion estimation

In this sub-section, we consider the transmitted video to be encoded according to MPEG-4/H.264 standard, where each I-frame is divided into multiple packets because of its large size, whereas a frame with small size, such as P-frame and B-frame, is included in a single packet. In addition, we consider that the encoder can design the packet payload such that the slices in each packet are independently decodable. Furthermore, we assume a basic loss concealment approach wherein the loss of a P-frame is replaced by the previous correctly decoded frame by applying temporal interpolation at the decoder output. For the loss of an I-packet, the error is recovered by copying the pixels at the same location space of the previous correctly received frame. By simulating the channel loss of each packet followed by applying the concealment algorithm, we can estimate the distance distortion value using Eq. 6.This value serves as the basis for retransmission differentiation in the QoESCF protocol. Figure 8 shows the process followed to estimate the distance distortion introduced by the loss of a given packet. First the raw video is compressed using the MPEG-4 codec and a packetized video is created according to the designed payload size. The next step is the simulation of the channel error, achieved by deleting the desired packet. In this way, a stream of packets with a gap is obtained. This stream of packets is then decoded to create a distorted video. The distorted sequence is compared with the reference video to calculate the distance distortion that further used by QoESCF to calculate the waiting time.

3.3.2 Beaconing message structure and exchange

All nodes in the network periodically broadcast beaconing messages to share information with their one-hop neighbors. The beaconing message includes information about the kinetic state of the one-hop sender (sender ID, geographical position coordinates), Timestamp, and an updated list of video packet identifiers that are well-received by the sender called the Well-Received Packets List (WRPL).

When a neighboring node receives a beacon message, it either updates the sender information or creates a new entry in the neighborhood table. Furthermore, the entry of a sender in the neighborhood table will be deleted if the receiver does not receive a beacon message within $N_b \times I$ Seconds [33], where I is the beacon interval and Nb is the number of times the beacon message is missed. Figure 9 presents an example of the neighborhood table content at each one-hop neighbor node. For instance, when node A, in Fig. 9, receives beaconing messages from nodes B, C, and E, it updates its neighborhood table by the identifier, the geographical position coordinates, and the WRPL of each of these nodes.

3.3.3 Beaconing messages overhead

The transmission overhead generated by sending beaconing messages from a node to its neighborhood can be modeled by Eq. 8, where F_{BM}, TD, BM_{size} are beaconing messages transmission frequency, the total time in which the overhead is calculated, and the size of beacon message, respectively.

$$BO = F_{BM} \times TD \times BM_{size} \quad (8)$$

According to Eq. 8, the overhead is influenced by F_{BM} and BM_{size}. Nevertheless, beaconing messages are only used for packet loss recovery. Thus, it is not required to broadcast them in high frequency and we can use a low value of F_{BM} to decrease overhead. Furthermore, the size of WRPL is the principal factor of BM_{size}. If we assume that the packet ID is coded into n bits and the video sequence is packetized into P_{Number}, the maximum size of WRPL is $P_{Number} \times n$ bits. To decrease the size of WRPL, we propose to divide the WRPL into groups composed of consecutive

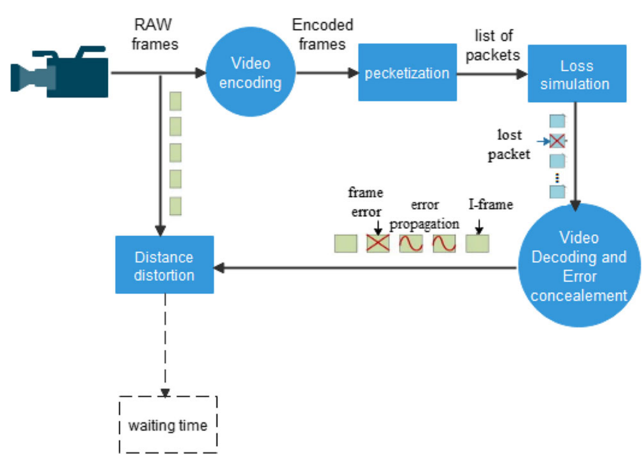


Fig. 8 Overview of distance distortion estimation process

IDs and represent each group with its first and last IDs instead of piggybacking all IDs of the group into the WRPL.

Algorithm 1 QoESCF.

Begin

1. on receiving a beacon message b from a neighbor v
2. update the neighborhood table
3. **for** each packet p in the retransmission cache **do**
4. **if** p is not acknowledged in the $WRPL$ list piggybacked by b **then**
5. schedule_to_transmit=true
6. **for** each node n in the neighborhood table **do**
7. **if** = (p is in the $WRPL$ list of n) and (n is in the communication range of v) and (distance to v > distance(n,v)) **then**
8. schedule_to_transmit=false
9. **end if**
10. **end for**
11. **if** schedule_to_transmit==true **then**
12. calculate the waiting time t_p according to Eq. 9
13. schedule to transmit p after t_p
14. **end if**
15. **end if**
16. **end for**
17. **on timer expire**
18. transmit the scheduled packet

End

3.3.4 QoESCF overview

Although the line-of-sight-based broadcasting protocol is designed to ensure a high delivery ratio, packets are prone to lost due to the unreliable UDP/RTP transport layer used for the video streaming applications, collisions, and the intermittent connection. Therefore, many researchers proposed a network-layer error-recovery method through retransmissions, i.e., the Store Carry-and-Forward method (SCF) [8, 16, 24, 25]. In the basic SCF approach, nodes store each correctly received packet in a local retransmission cache until the packet's time-to-live (TTL) expires (TTL is usually an application layer specific parameter). Furthermore, when a node sends a beacon message, it notifies its neighborhood regarding the packets that were correctly received, enabling the neighbors to resend the packets that were not yet received during the first phase of the broadcasting.

In this sub-section, we detail the proposed Quality-of-Experience-aware Store-Carry-and-Forward method (QoESCF). In contrast to the basic schema of the SCF method, the QoESCF method adopts a priority-based retransmission mechanism, where more important packets are likely scheduled to be retransmitted before the less important packets. In this regard, it is important to consider the degree of distortion that affects the video quality when a given packet is lost, as expected, to prioritize the retransmission. To achieve this goal, we employ the perspective of the waiting time where the vehicles spend less time waiting before the transmission of the most important packets than before those that are less important. In other words, the waiting time is inversely proportional to the normalized packet-distance distortion value defined in Eq. 7. The waiting time t_k for a packet p_k is modeled using Eq. 9.

$$t_k = \left(1 - w_k\right) \times T_{max} \tag{9}$$

where w_k is the weight of the packet p_k (7) and T_{max} is the maximum waiting time.

Algorithm 1 describes the main steps of the QoESCF method. When a vehicle receives a beacon message from a neighbor V (Algorithm 1 line 1), it updates the neighborhood table by the information included in the beacon message. Next, it matches its retransmission cache to the $WRPL$ list piggybacked by the beacon message (Algorithm 1 lines 2-3). If there is in the retransmission cache of the received node a packet p that has not yet been received by V, it checks whether or not it is the closest vehicle to V among the neighboring vehicles that can retransmit p. To accomplish this task, the receiver vehicle confirms, through the neighborhood table, whether there is an immediate neighbor that it is well received this packet p and that has a distance to V smaller than the distance between the receiver vehicle and V (Algorithm 1 lines 4-10). If there is such a neighbor, the receiver vehicle does not retransmit p, hence avoiding unnecessary rebroadcast of p and introducing more coordination. Otherwise,the receiver vehicle calculates the waiting time t_p according to Eq. 9 and schedules a timer to expire after t_p (Algorithm 1 lines 11–14). When the waiting time elapses the packet p is retransmitted (Algorithm 1 lines 17–18).

4 Performance evaluation

4.1 Simulation parameters and evaluation metrics

We verified the validity of the proposed method by comparing its results with those obtained using two important video broadcasting protocols, namely REDEC [28] and REACT-DIS

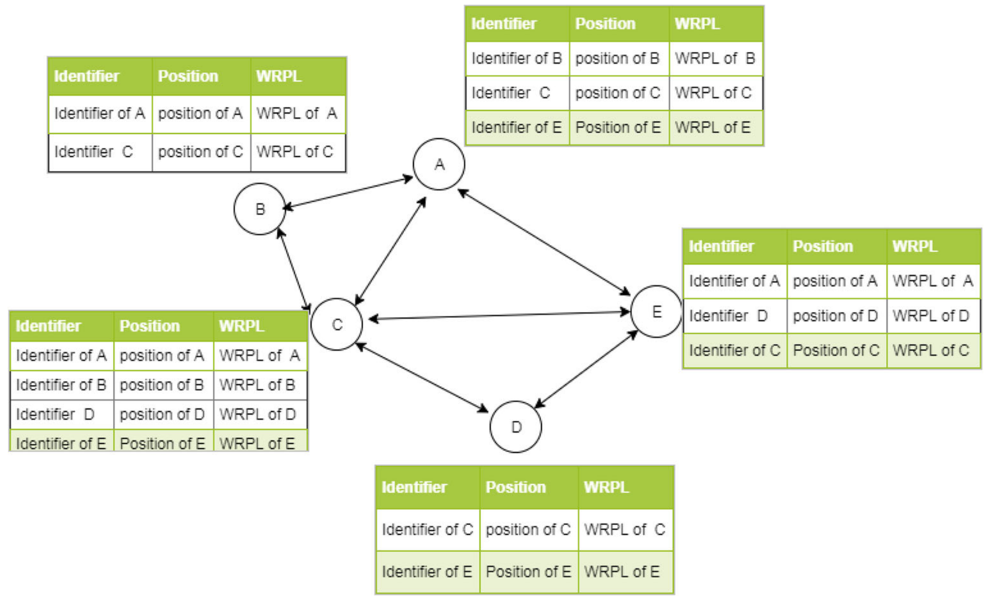


Fig. 9 One-hop beaconing messages broadcast

[27]. As highlighted in [27, 28], REACT-DIS and REDEC simulations are related to the definition of the levels of certain parameters. To provide the best possible performance, we used the configuration defined elsewhere [27, 28]. In ReLoS/QoESCF, we set T_{min} to $100ms$ and T_{max} to $250ms$.

The feasibility of any broadcasting protocols to improve the video dissemination performance is evaluated using several metrics. One of them involves determining the quality of service (QoS) level, namely the frame delivery ratio and latency (end-to-end delay) metrics. The frame delivery ratio is the percentage of frames correctly received to the total sent. The end-to-end delay (or latency) is the time required by a packet to reach the receiving end point. The minimum frame delivery and maximum latency CISCO recommendations for streaming video are 95% and $5s$, respectively [34].These measures are indicative but cannot alone give sufficient information regarding the video quality perceived by the end-user. Thus, we need to use metrics that help measure the quality of experience (QoE) level provided to the end-user. In our study, different schemes were evaluated using the mean of two objectives QoE metrics, namely the peak signal-to-noise ratio (PSNR) and mean opinion score (MOS). The PSNR is a distortion measure used in digital images, particularly in image compression and video transmission. It quantifies the performance of the encoders by measuring the quality of the reconstructed compressed image or video sequence with respect to the original image. The MOS is a value given to a reconstructed image or video sequence to characterize its quality on a five-point scale. Table 2 outlines the interpretation of each MOS scale [35]. The performance of the protocols was measured in terms of the QoS and QoE metrics as a function of the data rate and the density of the vehicles on the road network.

Different broadcasting suppression methods were implemented and evaluated using the discrete-event network simulator OMNeT++ [36] with respect to the 802.11p MAC and physical layers recommended by the IEEE organization for VANETs. We used the OMNeT++ plugin known as VEINS [37], which is an open-source framework dedicated to run a vehicular network simulation. Table 3 lists the values of the main parameters associated with the network simulation. We set the two-ray ground as the path loss model, which considers the destructive and constructive effects of signal interference with ground reflections [38, 39]. The transmission range is set to 200 m. The effect of buildings on the signal attenuation is determined using the default preloaded model in the VEINS framework. Beacon messages exchanged between vehicles at a frequency of $1Hz$ were employed in the QoESCF to recover the lost packets. The N_b parameter of the beaconing system was set to 2.

The framework EvalVid [40] is exploited to generate the video transmission file trace and assess the quality of the received video. The PSNR tool of Evalvid was used to provide the weight of each video packet (by following the steps described in the Section 3.3.1). EvalVid is a set of

Table 2 ITU-R MOS scale

MOS scale	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Table 3 Physical and MAC layer parameters

Parameter	Value
MAC layer	802.11p
Transmission range	200 m
Bandwidth	20 Mbps
Sensitivity	– 89 dBm

tools that can be used to evaluate the quality of a video transmitted over a real or simulated communication network. In our simulation, the streaming video application uses a raw video known as akiyo_cif, which is selected from the video trace library of Arizona State University [41]. Before sending the video, we created a compressed video file in the MPEG-4/H.264 format comprising 300 frames generated at a frame rate of 30 fps. The compressed video stream consists of consecutive GOPs which contain I- and P-frame types. The size of each GoPs was set to 30 frames. The video frames were segmented to generate 327 packets with a maximum payload size of 1024 bytes.

We increased the credibility of our experiments by generating a real-world vehicular traffic scenario using SUMO tools [42]. The environment considered for the simulation is the urban road network of Bologna city, as shown in Fig. 10. The city comprises various types of segments, including highways, roads with one and two lanes, bus lanes, bus stops, roundabouts, and intersections with traffic lights. We also generated a complicated environment for signal propagation by filling the free space between the roads using synthetic blocs, which represent tower buildings. The mobility was simulated on a space with dimensions of 1900 m × 1700 m . The vehicle mobility was based on the Krauss car-following model [43] to ensure that the experimental study was carried out in a realistic scenario. In other words, a vehicle moves according to the speed of the leading vehicle in the same lane, and the driver is required to maintain a safe distance from this vehicle. Table 4 lists the parameter values of the mobility simulation. We evaluated the effectiveness

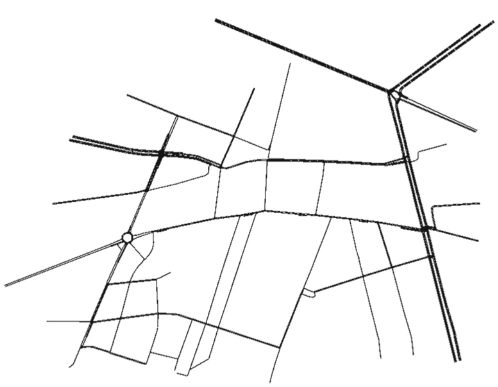


Fig. 10 Bologna city road map layout

Table 4 Mobility simulation parameters

Parameter	Value
Number of vehicles	Low density (60).
	Medium density (110).
	High density (230)
Road network size	1900 m × 1700 m
Mobility model	Krauss car-following model
Acceleration	2.6 m/s^2
Deceleration	4.5 m/s^2
Driver imperfection	0.5
Maximum speed	30 m/s

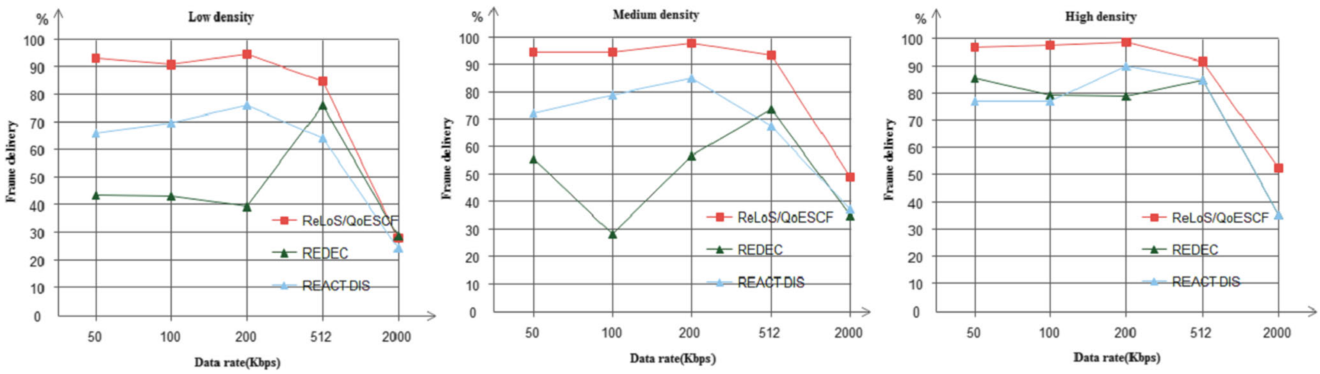
of the methods by varying the arrival rate of the vehicles to realize low (60 vehicles), medium (110 vehicles), and high densities (230 vehicles).Each obtained result is the average of 10 executions with a confidence interval of 95%.

4.2 Simulation results and discussion

Frame delivery Figure 11 shows the frame delivery percentages for three different vehicle densities. The results depicted in Fig. 11 show that all protocols achieve low frame deliveries at high data rates. The results are in good agreement with those of other studies wherein a higher data rate was often not an optimal choice for broadcasting videos over VANETs.

The common observation for the REDEC protocol is that the frame delivery is very low for low and medium densities, confirming that the REDEC can be used to obtain a reasonable frame delivery percentage for only high densities. For scenarios with a low vehicle-density, the network is intermittently connected because of the high mobility of vehicles and the presence of walls that obstruct line-of-sight; these vehicles form disconnected clusters. However, REDEC has no strategy for recovering packets lost in the case of intermittent connections. Moreover, the frame delivery ratio improved only slightly when using the REACT-DIS for low and medium densities compared to the REDEC protocol. This is because the density-aware scheme adapts the number of relay nodes with the density of the vehicles in the road-network.

Overall, the combined ReLoS and QoESCF scheme performs the best among the presented protocols. Even in low-density scenarios, the frame delivery ratio is close to 90% at low data rates. There are several reasons for the loss of packets in the VANETs, including network fragmentation (due to the high mobility of the vehicles and the effect of buildings on the transmission signal) and the broadcast storm problem, which leads to network congestion, denial of services, and collisions. Unlike other algorithms, the combined ReLoS and QoESCF solves all the problems cited



(a) low-density vehicle scenario (b) medium-density vehicle scenario (c) high-density vehicle scenario

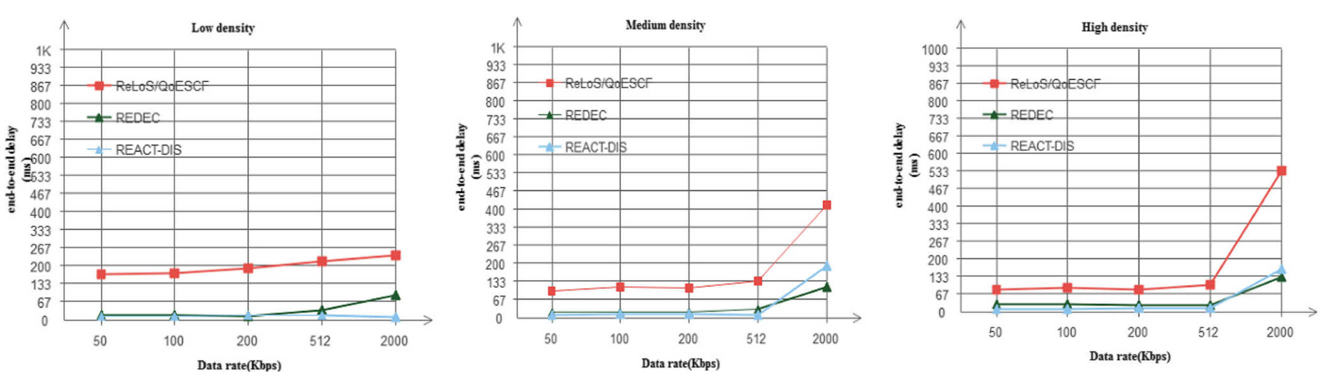
Fig. 11 Frame delivery percentage

above, i.e., it facilitates the selection of relay nodes with a good line-of-sight, relay nodes are distributed across all the roads to maximize the network coverage area, and packets lost due to the intermittent connection and collisions are recovered using the QoESCF mechanism.

Average end-to-end delay Figure 12 shows the average end-to-end delay results for REACT-DIS, REDEC, and combined ReLoS/ QoESCF protocols. The results show that REACT-DIS and REDEC slightly outperform the ReLoS/QoESCF in terms of the end-to-end delay. As mentioned previously, the three protocols follow timer-based approaches, wherein the relaying (forwarding) nodes are selected at the receiver side through a distributed contention phase. Thus, when a sender broadcasts a packet to its immediate neighbors, each node schedules itself to be a relay after a waiting time t. Consequently, the additional delay due to the contention phase in the forwarding process leads to an increase in the total end-to-end delay. This additional time accumulates in each hop, thereby adversely affecting the transmission durations. To solve this issue, a timely mechanism is implemented in both the REDEC and REACT-DIS methods to maintain the forwarding status throughout the course of the window time, instead of repeating the contention process for each transmitted packet. Therefore, the REDEC and REACT-DIS methods provide videos with shorter delays compared to ReLoS. However, the obtained delay levels of the ReLoS/QoESCF method are negligible and are significantly lower than the requirements defined by CISCO for video streaming (the obtained end-to-end delay is less than 5 s). Furthermore, REDEC and REACT-DIS fail to address the trade-off between frame delivery and end-to-end delay in low and medium densities. Consequently, their good results in terms of end-to-end delay have not any impact to enhance the quality of the received video.

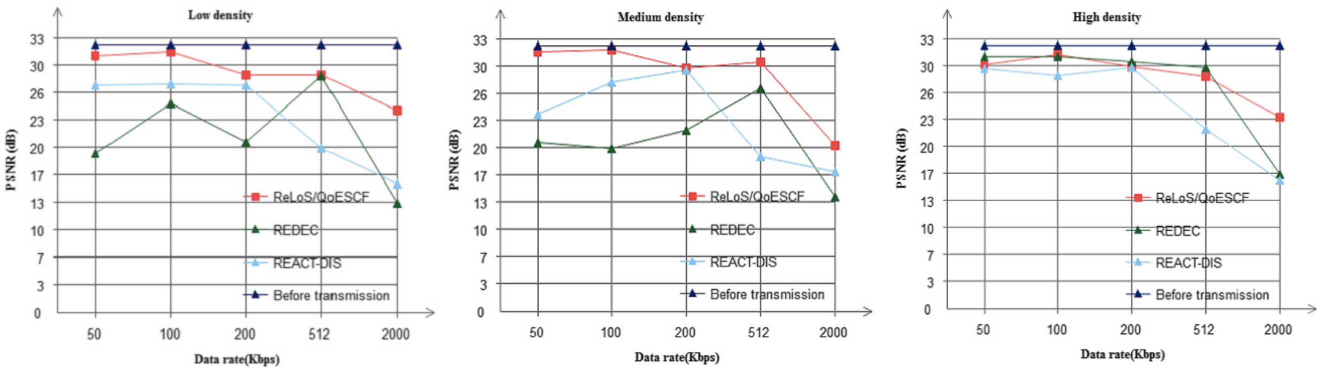
QoE indicators As mentioned previously, the QoS indicators help measure network performance. However, they cannot be used to assess the video quality as perceived by the end-user. Therefore, the effects of QoE metrics, such as the PSNR and MOS, are analyzed, as shown in Figs. 13 and 14, respectively.

Figure 13 shows the results in terms of the average PSNR of the decoded video at the receiver sides for different data rates and vehicle densities. We need the PSNR and MOS



(a) low-density vehicle scenario (b) medium-density vehicle scenario (c) high-density vehicle scenario

Fig. 12 Average end-to-end delay



(a) low-density vehicle scenario (b) medium-density vehicle scenario (c) high-density vehicle scenario

Fig. 13 Average peak signal-to-noise ratio

values of the reference video to assess the video quality. This is the PSNR and MOS value of the compressed video file before the transmission. In our simulation, the PSNR and MOS values of the reference video are 32.21 dB and 4.02, respectively.

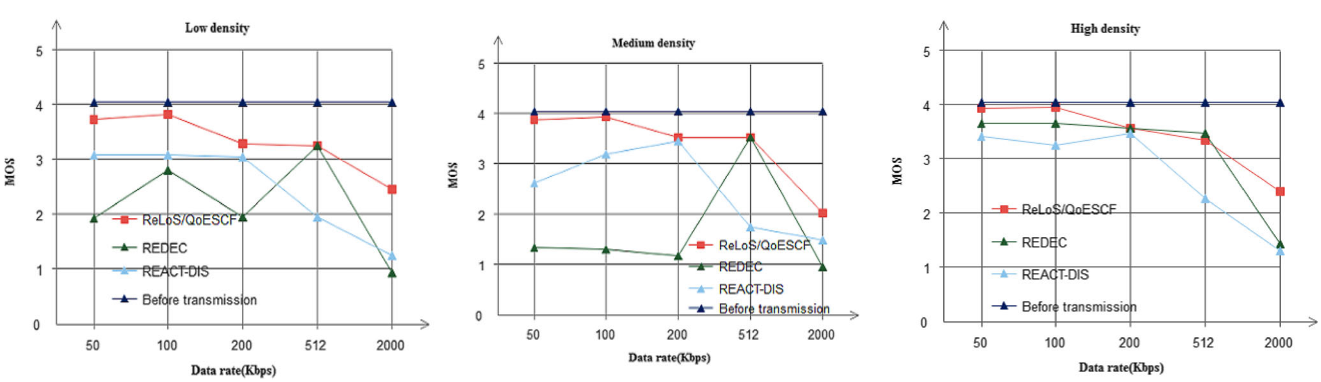
The ReLoS/QoESCF outperforms the REDEC and REACT-DIS methods in terms of the PSNR for low and medium densities. For high densities, the results obtained using the REDEC exceed slightly those obtained using ReLoS/QoESCF.

Figure 13a shows the results for the low-density scenario, wherein the ReLoS/QoESCF maintains PSNR values between 28.54 dB and 30.85 dB for a data rate of up to 512 Kbps. The average degradation obtained using the proposed method is 2.47 dB compared to the PSNR value of the reference video, whereas those obtained using the REDEC and REACT-DIS methods are 8.99 dB and 6.79 dB, respectively.

Figure 13b shows the PSNR results for the medium-density scenario. In this scenario, the ReLoS/QoESCF protocol can provide the best quality for a data rate of up to 512 Kbps, with a PSNR value of more than 30.35 dB. The performance of the REDEC method is the poorest among the given methods. In contrast, for high-density scenarios, the PSNR obtained using the REDEC is improved significantly when it is compared to the low- and medium-density results. As shown in Fig. 13c, the results obtained using the three protocols are largely similar.

For a data rate of 2 Mbps, the overall video quality degrades for the three protocols. However, the ReLoS/QoESCF ensures the best quality compared to the other protocols. For example, for high-density scenarios, the PSNR of the video delivered using the ReLoS/QoESCF is enhanced by 6.98 dB compared to the REDEC protocol. This confirms the effectiveness of the mechanism for relay node selection (ReLoS) and the retransmission method (QoESCF) proposed in this study.

As the PSNR metric does not reflect the structural quality of the video, it is important to consider the MOS to calculate the frame-by-frame difference between the quality of the transmitted video and the possibly corrupted video in the receiver vehicles. Figure 14 shows that the ReLoS/QoESCF allows for the dissemination of videos with good quality at lower data rates. This compliments the PSNR results.



(a) low-density vehicle scenario (b) medium-density vehicle scenario (c) high-density vehicle scenario

Fig. 14 Average mean opinion score

5 Conclusion

Transmitting videos over VANETs is a challenging task because of VANET specificities such as their dynamic topology, shadowing phenomena, and packet loss. In this paper, we proposed the ReLoS method for video streaming with line-of-sight awareness for urban VANETs. ReLoS aims to disseminate videos with improved reachability relative to existing methods, as it uses a reactive receiver-based scheme and a line-of-sight heuristic to select the relay nodes. Compared to the two related protocols (REDEC and REACT-DIS), the combined ReLoS/QoESCF enables a significant enhancement of the quality of the transmitted video in terms of the PSNR, MOS, and frame delivery. However, the proposed method causes greater end-to-end delay than the other protocols ; nevertheless, this obtained end-to-end delay does not exceeds the threshold defined by CISCO. Furthermore, our solution to overcome the intermittent disconnection and collisions was to propose the QoESCF scheme to resolve the packet loss. This scheme supports packet retransmission differentiation, wherein the priority of the retransmission is set to the most important packets. With the aim to design a collision-free solution, we intend in future to exploit the multi-channel architecture defined in the DSRC standard, to schedule concurrent transmissions in separate channels. The goal is to improve frame ratio delivery without incurring the additional message overhead caused by the SCF method. Furthermore, we plan to investigate the stability of vehicles located near intersections to design a timely broadcasting protocol.

References

1. Macke J, Casagrande R, Sarate JAR, Silva KA (2018) Smart city and quality of life: citizens' perception in a brazilian case study. J Clean Prod 182:717–726
2. Latif S, Afzaal H, Zafar NA (2018) Intelligent traffic monitoring and guidance system for smart city. In: 2018 International conference on computing, mathematics and engineering technologies (icoMET). IEEE, pp 1–6
3. Mfenjou ML, Ari AAA, Abdou W, Spies F et al (2018) Methodology and trends for an intelligent transport system in developing countries. Sustain Comput Inform Syst 19:96–111
4. Ganin AA, Mersky AC, Jin AS, Kitsak M, Keisler JM, Linkov I (2019) Resilience in intelligent transportation systems (its). Transport Res Part C Emerg Technol 100:318–329
5. Guerrero-Ibáñez JA, Flores-Cortés C, Zeadally S (2013) Vehicular ad-hoc networks (vanets): architecture, protocols and applications. In: Next-generation wireless technologies. Springer, pp 49–70
6. Hartenstein H, Laberteaux LP (2008) A tutorial survey on vehicular ad hoc networks. IEEE Commun Magaz 46(6):164–171
7. Zribi N, Alaya B, Moulahi T (2019) Video streaming in vehicular ad hoc networks: applications, challenges and techniques. In: 2019 15th international wireless communications & mobile computing conference (IWCMC). IEEE, pp 1221–1226
8. Li Y, Azzedine B (2015) QuGu: A quality guaranteed video dissemination protocol over urban vehicular ad hoc networks. ACM Trans Multimed Comput Commun Appl (TOMM) 11(4):55
9. Tseng Y-C, Ni S-Y, Chen Y-S, Sheu J-P (2002) The broadcast storm problem in a mobile ad hoc network. Wirel Nnetw 8(2-3):153–167
10. Naeimipoor F, Rezende C, Boukerche A (2012) Performance evaluation of video dissemination protocols over vehicular networks. In: 37th annual IEEE conference on local computer networks-workshops. IEEE, pp 694–701
11. Slavik M, Mahgoub I (2013) Spatial distribution and channel quality adaptive protocol for multihop wireless broadcast routing in vanet. IEEE Trans Mob Comput 12(4):722–734
12. Xie F, Hua KA, Wang W, Ho YH (2007) Performance study of live video streaming over highway vehicular ad hoc networks. In: 2007 IEEE 66Th vehicular technology conference. IEEE, pp 2121–2125
13. Khakbaz S, Fathy M (2008) A reliable broadcast method for vehicular ad hoc networks considering fragmentation and intersection problems. In: 2008 The second international conference on next generation mobile applications, services, and technologies. IEEE, pp 379–384
14. Li D, Huang H, Li X, Li M, Tang F (2007) A distance-based directional broadcast protocol for urban vehicular ad hoc network. In: 2007 International conference on wireless communications, networking and mobile computing. IEEE, pp 1520–1523
15. Tung L-C, Gerla M (2010) An efficient road-based directional broadcast protocol for urban VANETs. In: 2010 IEEE Vehicular networking conference. IEEE, pp 9–16
16. Viriyasitavat W, Tonguz OK, Bai F (2011) UV-CAST: An urban vehicular broadcast protocol. IEEE Commun Mag 49(11):116–124
17. Khamer L, Labraoui N, Gueroui AM, Zaidi S, Ari AAA (2021) Road network layout based multi-hop broadcast protocols for urban vehicular ad-hoc networks. Wireless Networks, 1–20
18. Martinez FJ, Fogue M, Coll M, Cano J-C, Calafate CT, Manzoni P (2010) Evaluating the impact of a novel warning message dissemination scheme for vanets using real city maps. In: International conference on research in networking. Springer, pp 265–276
19. Hsieh Y-L, Wang K (2012) A road-based qos-aware multipath routing for urban vehicular ad hoc networks. In: 2012 IEEE Global communications conference (GLOBECOM). IEEE, pp 189–194
20. Alsharif N, Céspedes S, Shen XS (2013) Icar: Intersection-based connectivity aware routing in vehicular ad hoc networks. In: 2013 IEEE international conference on communications (ICC). IEEE, pp 1736–1741
21. Goudarzi F, Asgari H, Al-Raweshidy HS (2018) Traffic-aware vanet routing for city environments—a protocol based on ant colony optimization. IEEE Syst J 13(1):571–581
22. Darwish TSJ, Bakar KAbu, Haseeb K (2018) Reliable intersection-based traffic aware routing protocol for urban areas vehicular ad hoc networks. IEEE Intell Transp Syst Mag 10(1):60–73
23. Saleet H, Langar R, Naik K, Boutaba R, Nayak A, Goel N (2011) Intersection-based geographical routing protocol for vanets A proposal and analysis. Ieee Trans Vehic Technol 60(9):4560–4574
24. Maia G, Rezende C, Villas LA, Boukerche A, Viana AC, Aquino AL, Loureiro AA (2013) Traffic aware video dissemination over vehicular ad hoc networks. In: Proceedings of the 16th ACM international conference on Modeling, analysis & simulation of wireless and mobile systems. ACM, pp 419–426
25. Bradai A, Ahmed T, Abderrahim B (2014) Vicov Efficient video streaming for cognitive radio VANET. Vehicular Commun 1(3):105–122

26. Torres A, Calafate CT, Cano J-C, Manzoni P, Ji Y (2015) Evaluation of flooding schemes for real-time video transmission in VANETs. Ad Hoc Netw 24:3–20
27. Rezende C, Pazzi RW, Boukerche A (2012) A reactive solution with a redundancy-based error correction mechanism for video dissemination over vehicular ad hoc networks. In: Proceedings of the 15th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems. ACM, pp 343–352
28. Rezende C, Mammeri A, Boukerche A, Loureiro AAF (2014) A receiver-based video dissemination solution for vehicular networks with content transmissions decoupled from relay node selection. Ad Hoc Netw 17:1–17
29. Zhang XM, Yan L, Zhang H, Sung DK (2019) A concurrent transmission based broadcast scheme for urban vanets. IEEE Trans Mob Comput 18(1):1–12
30. Quadros C, Santos A, Gerla M, Cerqueira E (2016) Qoe-driven dissemination of real-time videos over vehicular networks. Comput Commun 91:133–147
31. Togou MA, Hafid A, Lyes K (2016) Scrp: Stable cds-based routing protocol for urban vehicular ad hoc networks. IEEE Trans Intell Transp Syst 17(5):1298–1307
32. H.264 (2021) Advanced video coding for generic audiovisual services. https://www.itu.int/rec/T-REC-H.264. (Accessed on 01/31/2021)
33. Van de Velde E, Blondia C (2007) Adaptive react protocol for emergency applications in vehicular networks. In: 32nd IEEE conference on local computer networks (LCN 2007). IEEE, pp 613–619
34. Video quality of service (qos) tutorial (2020) https://www.cisco.com/c/en/us/support/docs/quality-of-service-qos/qos-video/212134-Video-Quality-of-Service-QOS-Tutorial.html. (Accessed on 10/04/2020)
35. Klaue J, Rathke B, EvalVid Wolisz A (2003) A framework for video transmission and quality evaluations. In: Proceedings of the international conference on modelling techniques and tools for computer performance evaluation, Urbana, IL, USA, pages 2–5
36. OMNeT++ Discrete Event Simulator (2019). https://omnetpp.org/. (Accessed on 2019-04-18)
37. Sommer C, German R, Dressler F (2011) Bidirectionally coupled network and road traffic simulation for improved IVC analysis. IEEE Trans Mob Comput 10(1):3–15
38. Sommer C, Dressler F (2011) Using the right two-ray model? A measurement-based evaluation of PHY Models in VANETs
39. Sommer C, Eckhoff D, German R, Dressler F (2011) A computationally inexpensive empirical model of IEEE 802.11p radio shadowing in urban environments. In: 2011 Eighth international conference on wireless on-demand network systems and services. IEEE, pp 84–90
40. Klaue J, Rathke B, Wolisz A (2003) Evalvid–a framework for video transmission and quality evaluation. In: International conference on modelling techniques and tools for computer performance evaluation. Springer, pp 255–272
41. YUV Sequences (2020) http://trace.eas.asu.edu/yuv/index.html. (Accessed on 2020-04-10)
42. SUMO - Simulation of Urban Mobility (2019) https://sumo.dlr.de/index.html. (Accessed on 2019-04-10)
43. Song Jie, Yi Wu, Zhexin Xu, Lin Xiao (2014) Research on car-following model based on SUMO. In: The 7th IEEE/international conference on advanced infocomm technology. IEEE, pp 47–55

Affiliations

Lazhar Khamer[1,2,3] · Nabila Labraoui[1] · Abdelhak Mourad Gueroui[3] · Ado Adamou Abba Ari[3,4]

Nabila Labraoui
nabila.labraoui@mail.univ-tlemcen.dz

Abdelhak Mourad Gueroui
mourad.gueroui@uvsq.fr

Ado Adamou Abba Ari
adoadamou.abbaari@gmail.com

1 Department of Computer Science, University Abou Bekr Belkaid Tlemcen, P.O. Box 230, Chetouane, Tlemcen 13000, Algeria

2 Department of Mathematics and Computer Science, Mohamed-Cherif Messaadia University, Souk Ahras 41000, Algeria

3 LI-PaRAD Lab, Université Paris Saclay, University of Versailles Saint-Quentin-en-Yvelines, 45 Avenue des États-Unis 78035 Versailles, cedex, France

4 LaRI Lab, University of Maroua, P.O. Box 814 Maroua, Cameroon