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SUJET

***Routage dans les réseaux ad hoc véhiculaires
(VANETs)***

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Presented by: BENAICHA MEHDI

SUBJECT

***ROUTING IN VEHICULAR AD HOC NETWORKS
(VANETs)***

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Dedication

بسم الله الرحمن الرحيم

أرفع أكبر الشكر والتقدير لكل من ساهم في نجاحي وسانديني في هذه الرحلة العلمية الطويلة جدا. أدعو الله أن يجزيكم خير الجزاء وأن يمنَّ عليكم بالسعادة والنجاح في كل مجالات حياتكم. وأطلب منه أن يبارك لي هذا العمل العظيم ويجعله خطوة نحو بناء مستقبلٍ مشرقٍ ومثمرٍ للعلم والمعرفة:

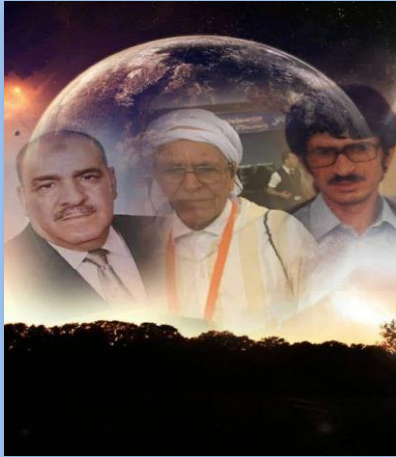
اولا, إلى أعز الناس في حياتي, أمي الجميلة وأبي الحاج قدور, أتوجه بأعذب الكلمات وأعمق الشكر والتقدير. أنتما أنموذجٌ للعطاء والتضحية, وأساس نجاحي وتفوقي في مسيرتي العلمية. فأنتما لم تدعوا يوماً الشدائد تثني عزمي, بل كنتما السند الذي اعتمدت عليه والقوة التي استمدت منها لتحقيق أحلامي.

ثانيا, أهدي هذه الأطروحة العلمية أيضاً إلى عائلتي الصغيرة, زوجتي الحبيبة وقرّة عيني, نور الهدى, وأولادي الأعراف: محمد المشاغب, جميلة الطيبة, خديجة الانيقة, و آخر عنقودي عبد الرحيم . لقد كنتم رموزاً للحب والدعم اللا متناهي. أطروحتي هذه تحمل رسالة حب لكم, فأنتم أسباب فخري وسعادي, وستكونون قادة مستقبل يحمل بصماتكم الخاصة. وإلى أخوتي الأعراف, فايذة ونذير وإبراهيم, وإلى العائلة الكبيرة وخاصة خالي محمد, الميلود, وزين العابدين, أهدي هذا العمل العظيم. لقد كنتم رموزاً للتعاون والتشجيع.

الى الذين ارواحهم بين يدي الرحمان, الحاظرين في وجداني وفي كل خطوة أخذها في حياتي, والدي محمد بن عيشة, جدي ابن الصديق و عمي عبد القادر, أدعو الله أن يتغمدكم بواسع رحمته ويسكنكم في جنات النعيم. واخيرا, الى الغالية "خيرات" جدتي العزيزة التي كانت دائما معي في كل مراحل حياتي, افتقدك اليوم وبشدة وانا على ابواب نيل اعظم شهادة فلا يسعني الا ان اهدي هذا العمل لروحك الطاهرة وان اسأل الله ان

يجمعنا مع بعض في جنات

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"انا لي اصل واصلي من الريحان** وشجرة نسي بازغة منتهاها الرضوان** الى الرسول محمد سيدنا اعظم انسان** فاذا نازعتني مقادير الدنيا كنت لها منازعا** ولا اقبل الا غلبة مساجلي باحسان** لا ارضى لنفسي الدنية الا علوا فهكذا**"

لقتن وهكذا احيا حتى القى الرحمان"

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List of symbols and abbreviations

#

2D	2 nd Dimension
3D	3 rd Dimension
2G	2 nd Generation
3G	3 rd Generation
4G LTE	4e Generation Long Term Evolution
5G	Fifth-Generation Wireless
6G	Sixth-Generation Wireless

A

ACK	Acknowledgement message
AODV	Ad hoc On-Demand Vector routing
A-STAR	Anchor based Street and Traffic Aware Routing
ASTM	American Society for Testing Materials

B

Beacon	Bluetooth low energy
BTA-GRP	Beaconless Traffic-Aware Geographical Routing Protocol

C

C2C-CC	Car-2-Car Communication Consortium
CAR	Connectivity-Aware Routing
CBDRP	Cluster Based Directional Routing Protocol
CBRP	Cluster Based Routing Protocol
CDP	Cell Data Packet
CDP-MC	Cell Density Packet and Multi-Junction Connectivity
CH	Cluster Head
CISRP	Connectivity-Aware Intersection-Based Shortest Path Routing Protocol
COVID-19	Coronavirus Disease 2019
CJBR	Connected Junction-based Routing Protocol

D

DGSR	Directional Geographic Source Routing
DSDV	Destination Sequenced Distance Vector Routing

List of symbols and abbreviations

DSR	Dynamic Source Routing
DSRC	Dedicated Short Range Communication
DV-CAST	Distributed Vehicular Broadcast Protocol
E	
ECDP	Enhanced Cell Data Packet
E-GyTAR	Enhanced Greedy Traffic Aware Routing Protocol
ERDP	Enhance Road Density Packet
LTD-FOR	Local Traffic Density of Flow-oriented Routing Protocol for VANETs
ETSI	European Telecommunications Standards Institute
F	
FCC	The Federal Communication Commission
G	
GLS	Grid Localization Systems
GPCR	Greedy Perimeter Coordination Routing
GPS	Global positioning system
GPSR	Perimeter Stateless Routing
GRBRT-MI	Geographic Routing Based on Road Traffic and Multi-hop Intersections
GRP-LTDLQ	Geographic routing protocol based on local traffic density and link quality
GSR	Global State Routing
GyTAR	Greedy Traffic Aware Protocol
H	
HARP	Hybrid Ad Hoc Routing
HLS	Hierarchical Location Service
HSR	Hierarchical State Routing
I	
IEEE	Institute of Electrical and Electronics Engineers
IGCR	Intersection Gateway and Connectivity based Routing
IoV	Internet of Vehicles
ITS	Intelligent Transportation Systems

List of symbols and abbreviations

IVC Inter-Vehicle Communication

M

MAC Medium Access Control Address

MANET Mobile Ad hoc Network

M-JCP Multi-Junction Connectivity Packet

MSN Mobile Service Node

N

NS2 Network Simulator 2

NS3 Network Simulator 3

NTIC New Technologies of Information and Communication

O

OBPF Opportunistic Beaconless Packet Forwarding Strategy Protocol

OBU On Board Unit

OLSR Optimized Link State Routing

OMNET Operation and Maintenance New Equipment Training

OSI Open System Interconnection

P

PBR Prediction-based Routing for vehicular ad hoc networks

PGB Preferred Group Broadcasting

R

RDP Road Density Packet

RSU Road Side Units

RTAR Reliable Traffic Aware Routing Protocol

RTISAR Real-Time Intersection-Based Segment Aware Routing

RTS Request-to-Send

S

SDARS Satellite Digital Audio Radio Systems

SNC Strength of Network Connectivity

SUMO Simulator of Urban Mobility.

List of symbols and abbreviations

T

TC	Total Connectivity
TFOR	Traffic Flow-Oriented Routing
TORA	Temporally Ordered Routing Algorithm

U

UMB	Universal Measurement Bus
-----	---------------------------

V

V2D	Vehicle-to-Device
V2I	Vehicle to Infrastructure
V2X	communication Vehicle-To-Everything
V2P	Vehicle-to-Pedestrian
V2V	Vehicle to Vehicle
VANETs	Vehicular Ad hoc Networks
VCC	Vehicle Cloud Computing
VEINS	Vehicle In Network Simulation

W

WAVE	Wireless Ability in Vehicular Environments
WIFI	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access

Z

ZRP	Zone Routing Protocol
-----	-----------------------

Chapter I: Introduction and thesis overview

1. Introduction

In this chapter, we provide an overview of the thesis. We deliver a brief introduction to the study conducted and explain the problem statement and motivation. Moreover, this chapter summarizes the thesis contributions and presents the thesis outlines.

2. Problem statement and motivation

An important development in the field of wireless telecommunications has made a significant impact on the world in recent years. This evolution is primarily driven by the increasing need for data availability and access from anywhere at any time, especially in the light of the unprecedented global health crisis caused by COVID-19 in the last two years [1]. These technologies have become essential for managing the world during this pandemic. As a result, numerous applications have emerged to enhance our daily lives, whether at home, in companies, or while traveling in vehicles [2]. However, this increase in vehicle production has also led to a rise in the number of road traffic accidents. According to a recent report by the World Health Organization (WHO), road traffic deaths have been on the rise, with 1.35 million people dying each year and 20 to 50 million people suffering non-fatal injuries and disabilities [3]. In response, scientists, industrialists, and governments have invested in new road projects that leverage modern technologies to reduce the number of deaths and improve traffic safety. Communication technologies, for example, help drivers identify and avoid various risks such as vehicle crashes, control vehicle speed, avoid traffic congestion [4], predict unseen obstacles, and alert drivers to other hazards on the road [5]. Several industrial players, including Daimler-Chrysler, Toyota, and BMW, have focused on enabling inter-vehicular communications through various projects such as CarTALK2000 [6], Car-to-Car Communication Consortium (C2CCC) [7], Advanced Driver Assistance Systems (ADASE2), California Partners for Advanced Transit and Highways (California PATH) [8], FleetNet [9], DEMO 2000 by Japan Automobile Research Institute (JARI) [9], Chauffeur in EU [10], and Crash Avoidance Metrics Partnership (CAMP) [11].

Wireless technology has been widely employed to enable communication among vehicles, commonly referred to as Wireless Access for Vehicular Environments (WAVE). This technology allows for the formation of Vehicular ad-hoc networks (VANETs) [34], which are a significant component of Intelligent Transportation Systems (ITS). VANETs, a special case of Mobile ad-hoc networks (MANETs), consist of intelligent vehicles equipped with computers, network cards, and sensors. These networks facilitate the transmission of road information and provide drivers

with a precise view of their routes. Due to the unique characteristics of VANETs, such as high mobility resulting in dynamic topology and radio signal propagation, routing protocols designed for MANETs cannot be directly applied to VANETs. Several research works have demonstrated the limitations of mobile network (MANET) protocols in establishing efficient and successful routing decisions [12, 13, 14, 15]. The primary objective of VANETs is to enhance the safety and comfort of driving vehicles by establishing secure, efficient, reliable, and responsive communication between vehicles and their surroundings. In VANETs, nodes move rapidly and randomly in all directions along the roads, which can lead to network partitioning and communication interruptions. VANETs employ short communication ranges not exceeding 1000 meters, often requiring intermediate nodes for communication between two distant nodes. Additionally, various other constraints such as the nature of the environment (city roads, highways), predictable mobility, and radio obstacles must be considered.

The research questions that arise are: How can we find the best route between two divergent nodes? How do we keep this route updated? How can we find alternative routes without interrupting the provided service? Failing to establish an efficient and successful routing connection renders the routing service ineffective, especially for real-time applications. To address these challenges, specialists in this field have developed specialized systems that adapt to the unique specifications of VANETs [14][16]. Over the years, thousands of research papers have been presented, addressing various aspects of vehicle networks. Some of these papers focused on designing and implementing efficient routing protocols suitable for VANETs, while others explored securing the network against potential security attacks [17][12]. There were also studies on key factors that facilitate the creation and integration of VANETs in smart cities [13], along with survey papers and other exciting topics. However, routing has emerged as the predominant concern in these research articles.

In this context, literature of this field has proposed several topology-based routing solutions, which can be classified into proactive [18, 19], reactive [20, 21], and hybrid protocols [22, 23]. Additionally, alternative routing protocols have been proposed to address communication challenges in VANETs, including clustering-based [24, 25], cloud-based [26, 27], and position-based routing protocols [28, 29, 30, 31, 32, 33]. Despite their advantages, these solutions have limitations related to packet delivery ratio, end-to-end delay, control message overhead, and energy consumption. As a result, routing remains an essential element in VANET networks and represents a significant challenge in its design. This challenge arises from general reasons that apply to all protocol classes, such as the high mobility of vehicles, spatio-temporal diversity in

traffic density and the propagation of radio waves in unfavorable external environments. Additionally, each protocol class has specific reasons that contribute to this challenge, which are discussed in this thesis along with appropriate solutions published in prestigious journals and conferences. The study and analysis conducted over the years of research have shown that geographical routing protocols are the most suitable for ad hoc vehicle networks. Therefore, our focus has been on this category of protocols. Geographical routing mechanisms rely on geographical data of the nodes without the need for route discovery processes or information about location link status. In particular, protocols belonging to the road traffic class outperform their competitors when the number of active routes is low or when there is high mobility in the network. The geographic routing protocol based on road traffic statistics includes a specific subclass based on intersections, which are crucial points in the routing process for calculating different candidate junctions that form the optimal path. This subclass offers many advantages; however, it remains poorly adapted to certain characteristics. For instance, the protocols in this class have some limitations, such as relying solely on total density between two junctions, neglecting important metrics like vehicle's local traffic density, speed, direction, and inter-vehicle distance, and relying exclusively on traffic statistics collected at the level of first-hop intersections. These limitations can lead to errors in calculating the optimal itinerary, impact the efficiency of the protocol, and restrict its application scope.

Therefore, this thesis primarily addresses the challenging problem of routing in vehicular ad hoc networks, considering the constraints associated with this network type, including high mobility of nodes, dynamic topology, and network fragmentation. Firstly, we propose a new classification paper that reviews, studies, and analyzes different routing protocols in VANETs. We also highlight the identified gaps and failures that need consideration in future research works. Subsequently, we present a new approach to inter-vehicular routing solution that utilizes local density instead of global traffic density and makes effective use of vehicular direction in selecting the next intersection. The third contribution of this thesis proposes another routing solution that discusses the selection of the next junction by considering the junction connectivity in multi-hop scenarios and analyzing its influence on various routing network parameters. Finally, we propose a routing solution that combines the two fundamental ideas presented in the third and fourth contributions. This combined solution aims to select the next intersection by considering both the connectivity of multi-hop intersections and connectivity metrics such as vehicles' local traffic density, speed, distance and direction.

3. Thesis contributions

In a VANET network, routing is a central task that plays a crucial role in the success of different network layers. However, routing in vehicle networks is far from being easy and straightforward due to various challenges. The main difficulty lies in the instability of paths caused by the high mobility of nodes and frequent network fragmentations. The partial or intermittent nature of the network indicates that routing management should differ from the topological approaches used in classical ad hoc networks (MANETs). This doctoral thesis focuses on analyzing the performance of different routing solution categories and, based on these analyses, presents our contributions aimed at enhancing routing services through new and modern techniques across various routing parameters. Specifically, the main contributions of this thesis are as follows:

- ✓ We propose a new survey paper that provides a comprehensive routing classification based on existing routing protocols in the literature. This work considers reliable and recent bibliographic sources and delves into previous routing protocols in VANETs. We analyze their contributions and limitations while taking into account VANET specifications. Additionally, we discuss the challenges and critical issues that need consideration in the design of different protocol types across different network layers in VANETs, considering the protocols reviewed in this work.
- ✓ To address the routing problem, we introduce Local Traffic Density of Flow-oriented Routing Protocol for VANETs (LTD-FOR) as an improved version of the traffic flow-oriented routing protocol (TFOR). This new approach utilizes local density instead of global traffic density and incorporates a better direction selection metric for choosing the next intersection. Our proposal demonstrates its superiority over the TFOR protocol and other routing protocols.
- ✓ Furthermore, we propose and discuss another routing solution called GRBRT-MI (Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs). Building upon the three mechanisms of the TFOR family, we propose improvements to the first mechanism by collecting statistics on road traffic. We also enhance the second mechanism responsible for selecting the next intersection by introducing a new formula to calculate the scores of different intersection candidates; this approach takes into consideration the junction connectivity of multi-hop routing. Simulation comparisons of GRBRT-MI against strong routing protocols demonstrate the dominance of our approach in terms of various network parameters, including packet delivery ratio, end-to-end delay, and packet overhead.

- ✓ We propose our final routing solution based on an intersection titled "GRBLTD-MI" (Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs), which is particularly suitable for smart cities. This protocol is the enhancing of the fundamental idea discussed in Chapter IV (GRBRT-MI). In the GRBLTD-MI protocol, we consider the selection of the next intersection, taking into account the connectivity of multi-hop intersections along with vehicle's local traffic density, speed, distance, and direction. Simulation evaluations of GRBLTD-MI against strong routing protocols demonstrate the superiority of our approach in terms of packet delivery ratio, end-to-end delay, and packet overhead.

4. Thesis outlines

This thesis comprises six chapters that encompass our entire study. In the first chapter, we introduce our motivation for conducting research on the routing challenges in VANETs. We also present our various papers' publication carried out during this thesis, which aimed to improve the inter-vehicle routing service. Additionally, a section is dedicated to defining the overall structure of this document.

Chapter II provides a general overview of VANET networks, including their characteristics, different communication standards, and the various application services offered by this network. We also discuss the state and direction of research in the area of routing in vehicular networks, highlighting the gaps and limitations that remain unresolved. It is important to note that the work presented in this chapter has been submitted to the journal « **Wireless Network** » journal and is currently awaiting acceptance.

Chapter III focuses on our first routing contribution, which is an enhanced version of the TFOR protocol called the Local Traffic Density of Flow-oriented Routing Protocol for VANETs (LTD-FOR). We discuss the main elements of the TFOR protocol, its operational principles, and the major limitations that restrict its efficiency. We explain our rationale for improving the protocol and present our more efficient version. The content of this chapter has been published as a conference paper **in the International Conference on Advanced Electrical Engineering 2022 (ICAEE 2022) [100]**.

In Chapter IV, we consolidate our efforts in the context of a new routing solution called GRBRT-MI (Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs). After introducing the problem in Section 2, we present our new solution in Section 3. The final section of this chapter focuses on evaluating the efficiency of our protocol through simulations, comparing it with other protocols in the "road traffic" class that are based on

intersection. These efforts have also been published as a conference paper in **the International Conference on Advanced Electrical Engineering 2022 (ICAEE 2022)** [101].

Chapter V concentrates on the integration of various initiatives to introduce another routing solution named GRBLTD-MI (Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs). After introducing the problem in Section 2, we present the system model and assumptions. In Section 3, we introduce our new solution. The final part of this chapter evaluates the effectiveness of our protocol through simulations, comparing it with other protocols in the "road traffic" category based on intersection. These efforts have also been published in **the "Wireless Network" journal** [102].

Finally, the last chapter summarizes the major points which present the eventual perspectives for future studies to improve the proposed solutions presented in this thesis.

Chapter II:

Vehicular ad hoc networks

1. Introduction

Vehicular networks are considered as an emerging class of Ad Hoc mobile networks (MANETs), enabling data exchange between vehicles and even vehicles and infrastructure. The main objective of this network is to improve road safety by reducing accidents and providing drivers and passengers with comfort and entertainment applications. Designing an efficient routing protocol for VANETs is a major challenge. Not all routing protocols used in Ad Hoc Mobile networks are suitable for VANETs due to their specific characteristics, such as high mobility leading to a dynamic topology and radio signal propagation. Over the years, numerous research papers have addressed various aspects of vehicle networks, but the routing problem has received significant attention.

In this chapter, we present the main characteristics of vehicular ad hoc networks. We explore the different routing protocols of VANET networks, which are presented using a new routing protocol classification. Moreover, this chapter discusses various issues and challenges of VANET routing that are still open and need to be considered in future research work.

2. Vehicular ad hoc networks

Vehicular ad-hoc networks (VANETs) are a special case for Mobile ad-hoc network (MANET) [33, 12, 14, 15] as Fig II.1 shows, where mobile nodes are (intelligent) vehicles equipped with computers, network cards and sensors of different types as illustrated in Fig II.3. This network allows the exchange of road information and gives a perfect view of the route to drivers.

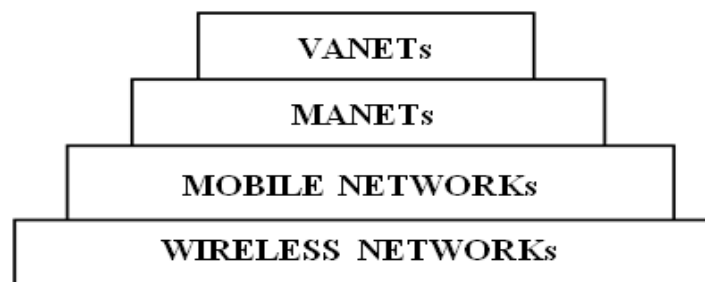


Fig II.1-Hierarchy of wireless networks.

As a result, we cannot use the routing protocols applied in MANET directly on VANET, this is due to a number of characteristics of VANET; Among the most important of them are:

✓ One of the differences that characterizes the two networks is the topologies of the network since there is in VANET a rapid change in network topologies (a node can joins or leaves the

network in a very short time) while in MANET, the network topologies changes very slowly which is mainly due to the rapid and random movement of the vehicles.

✓ There is a difference in the movement of vehicles and their direction. In VANET, vehicle movements are related to road structures (intersections, traffic light signals, etc.), road base stations (infrastructures) network, and driver behavior while in MANET, the movement of nodes is random spread, slow and in all directions.

✓ In VANET, we notice that the phenomenon of intermittent communications between vehicles is mainly due to the speed of vehicles and also to the random change in the direction of vehicles.

✓ The power consumption factor is not important in the VANET due to the availability of an unlimited source that can generates power continually. On the other hand, the power factor is very important in most types of MANET, especially in wireless sensor networks [35]. However, the impact of communication networks on our green environment cannot be ignored according to new studies [36] which call for taking into account the energy factor in VANETs during the implementation of their systems. Also, the reason for this is due to the existence of some devices and wireless sensor networks which are connected to the VANET and they have a limited power source. Therefore, it is suitable for other devices and networks whenever vehicle power consumption is low. In addition, whenever the system is green and unpolluted to the environment, the carbon dioxide emitted will be low [36].

✓ The elements of the VANET have a large processing capacity, storage and several communication interfaces (WIFI, Bluetooth and others). Thanks to the New Technologies of Information and Communication (NTIC), the driver can make a decision using the treatments and interpretations of the information collected.

2.1. The types of inter-vehicular communications

In VANET, vehicles can communicate with each other via inter-vehicle communication (IVC). This facilitates the development of an Intelligent Transport System (ITS) [37, 95, 96]. The purpose of this system is to secure passengers and minimize traffic accidents as much as possible. Through this intelligent system, vehicles can exchange data related to neighboring and distant vehicles. There are many standard communication methods provided by the ITS (Fig II.2+Fig II.3). The most important are:

2.1.1. Vehicle to vehicle (V2V)

This communication is made directly between vehicles by using a small electronic device called on-board unit (OBU) without any other electronic support [97].

2.1.3. Hybrid communication

The combination of these two types of communication enables the realization of a compelling hybrid communication system. As the communication ranges of the infrastructures are limited, utilizing vehicles as relays extends the reach for economic purposes and facilitates the deployment of this new technology [42, 43].

In addition to these three forms of communications, there are other communication models summarized as follows: Vehicle-to-Pedestrian (V2P), Vehicle-to-Device (V2D) and Vehicle-to-Network (V2N) collectively known as Vehicle-to-Everything (V2X) communication [44].

2.2. IEEE 802.11 standards for inter-vehicle communications

In order to enable communication between vehicles, there are several potential wireless technologies that can be utilized, such as IEEE 802.11 (Wi-Fi), Bluetooth, WiMAX, Cellular, and Satellite Digital Audio Radio Systems (SDARS). However, The Federal Communication Commission (FCC) adopted Dedicated Short Range Communication (DSRC) [45] for this purpose. DSRC operates in the frequency range of [5.850-5.92GHz] with a dedicated 5.9GHz band and a bandwidth of 75 MHz (licensed spectrum). DSRC was chosen due to its low latency and ability to broadcast messages in multiple directions [5]. Its range is typically between 100 to 1000 meters in ideal conditions, which is suitable for Vehicle-to-Vehicle (V2V) or Vehicle-to-Infrastructure (V2I) communication.

The IEEE 802.11 standard, commonly known as Wi-Fi, initially offered data rates of 1 or 2 Mbps. Over time, revisions have been made to optimize throughput (such as 802.11a, 802.11b, 802.11g, and 802.11p) and improve security and interoperability. It primarily focuses on the data link layer (Layer 2) and the physical layer (Layer 1) of the OSI model while maintaining compatibility with the upper layers. The table below provides an overview of the DSRC standards implemented in various countries.

Table II.1-DSRC standards used in some countries

Features	Europe (ECS)	USA (ASTM)	Japan (ARIB)
Communication	Half-duplex	Half-duplex	Half-duplex (OBU)/ full duplex (RSU)
Radio frequency	5.8GHz	5.9 GHz	5.8 GHz
Band	20 MHz	75 MHz	80 MHz
Channels separation	5 MHz	10 MHz	5 MHz

Coverage	15-20 m	1000 m	30 m
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2.3. Vehicular network applications

Research in the field of VANET Networks encompasses various types of applications that can be categorized into four main groups:

1. **Vehicle-oriented applications:** These applications provide vehicles with information to adapt their automated systems, such as automatic braking or speed control, primarily focusing on road safety.
2. **Driver-oriented applications:** This category focuses on applications that provide drivers with useful information for their route, driving behavior, or predicting critical situations during their journey. Examples include route information, traffic conditions, accidents, and other relevant data.
3. **Passenger-oriented applications:** These applications are designed to provide entertainment or infotainment services to passengers, utilizing the communication networks initially dedicated to driving safety. These services can include internet access, multimedia content, and other entertainment options.
4. **Infrastructure-oriented applications:** This category involves applications that aim to optimize the utilization of shared resources, such as road infrastructure and databases. By providing precise information about the current state and situation, public or private operators can make informed decisions. This can include travel time estimation, average speed monitoring, identification of speeding and CO2 emissions. Relevant advice can be provided to motorists to reduce the environmental impact.

All of these applications require an effective routing protocol to ensure fast and efficient information transfer among network nodes. The routing protocol should also be capable of maintaining routes in the event of network interruptions or changes in network topology.

2.4. VANETs with other technologies (cloud computing, smart cities, 5G/6G network and IoV)

Vehicular Ad hoc Networks (VANETs) are an emerging technology with significant potential for future development. The research problems associated with VANETs are diverse and expanding. However, there are several key points worth highlighting. One of these points is the adaptation of Cloud Computing, a well-established method in computer science, to mobile and vehicular environments. Vehicular Cloud Computing can either leverage existing forms or introduce new ones. It has applications in various domains, including the implementation of smart cities. These conceptual or nascent cities will generate substantial volumes of data,

inevitably intertwining research on smart cities with the field of Big Data. In this context, vehicles play a pivotal role as both generators and consumers of data. Consequently, it is crucial to identify communication methods that adhere to the constraints imposed by physical technologies like ITS-G5, as well as the specific data flow requirements of Big Data. Information Centric Networking (ICN) is one such method that merits exploration. The ITS-G5 standard, which serves as the foundation for the European Telecommunications Standards Institute (ETSI) standards, has been adopted for the deployment of connected vehicles across Europe. These standards cannot be disregarded and must be taken into account during the research process.

Another traditional form of cloud computing for vehicles involves utilizing a remote cloud infrastructure capable of delivering essential services. This approach proves valuable, particularly during the widespread adoption of connected vehicles [46, 13]. Moreover, the inability of VANETs to effectively address the numerous challenges posed by new technologies has given rise to the Internet of Vehicles (IoV). The IoV was primarily introduced to manage the limitations and shortcomings that arise when integrating the classic VANET network with new technologies such as smart cities, e-cloud, and 5G/6G. These challenges stem from the vast and heterogeneous data generated by different components within the global network.

The IoV represents an extension of the traditional VANETs, sharing the common goal of prioritizing transportation system safety. Unlike VANETs, IoVs possess the computational power to handle large volumes of global information. They can analyze, transform and evaluate the wealth of data collected from vehicles within the network. Consequently, accident avoidance and traffic management have become more straightforward tasks within IoVs compared to the capabilities offered by classic VANETs [47].

3. Overview of routing protocols in VANETs

Routing in VANETs serves as a fundamental building block to ensure network connectivity, enabling vehicles to communicate with each other and share information about their link state and topology. This facilitates the identification of optimal, reliable, and efficient paths. Consequently, vehicles within VANETs must define a routing protocol. Unicast routing becomes necessary when terminal nodes are beyond the direct radio transmission range of a source node, enabling communication between two vehicles or between a vehicle and an RSU. In VANETs, each vehicle can assume the role of a sender, a receiver or, a router.

However, routing in VANETs poses significant challenges. The primary difficulty arises from the path instability caused by the high mobility of nodes and frequent network fragmentations. The partial or intermittent connectivity within the network necessitates a departure from the topological approaches employed in conventional MANETs. Information dissemination plays

a crucial role in conveying data from a source to one or more destinations, requiring short delivery time, high reliability, and efficient resource utilization [48].

By analyzing the services and applications provided within VANETs [49], it becomes evident that certain applications, such as car tracking and internet connection, necessitate point-to-point communication (unicast), while others rely on one-to-many communication (traffic information, alert messages, etc.). Therefore, the communication architectures of vehicle networks must integrate efficient routing and data dissemination mechanisms [98] tailored to meet the specific requirements of envisioned services and applications.

When designing new routing or dissemination solutions, it is essential to consider several parameters, including the characteristics of targeted applications (comfort applications or road safety applications) [50], the movement environment (highway, city, and rural areas), standard communication modes (V2V, V2I, and hybrid), type-hop communication (unicast, broadcast, and multicast), and the specificities of VANETs as mentioned in Section II.2. Various taxonomic studies [50, 51, 52, 53, 54, 55] have categorized the currently proposed routing protocols into different approach models. These approaches share some common sections while differing in others. Figure II.4 illustrates the most common taxonomy of routing protocols, which takes into account the diverse and numerous characteristics of VANETs and the mechanism of the existing routing solutions.

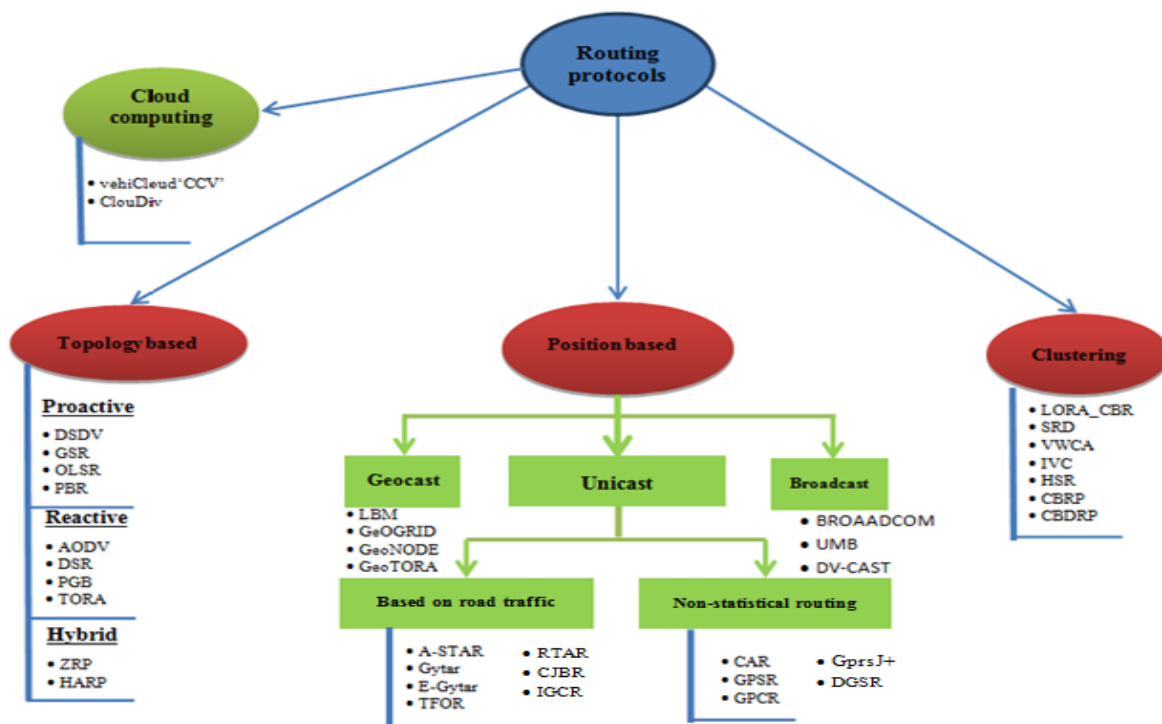


Fig II.4-Taxonomy of routing protocols in VANETs.

3.1. Topology-based routing protocols

In this approach, the routing protocol relies on the topology of road networks, obstacles, and signal links that connect nodes together. Primarily designed for MANETs, these protocols have been the subject of several studies [56, 57, and 58] aiming to extend their applicability to VANETs and assess their ability to accommodate VANET characteristics.

However, it has been confirmed that the high mobility of vehicles has a detrimental impact on network performance in terms of quickly discovering, maintaining, and updating routes. Within this class, three sub-approaches can be identified:

3.1.1. Proactive Routing Protocols (PRP)

The primary concept behind this approach is that a proactive protocol maintains all possible routes for each destination in the network. These routes are available immediately, even before the presence of a message to send, in order to manage and store road data. One or more tables contain routing information for every node, and the routes are updated periodically. Several proactive routing protocols have been developed, including Destination Sequenced Distance Vector (DSDV) [18], Global State Routing (GSR) [19], Optimized Link State Routing (OLSR) [59], and Prediction-based Routing for vehicular ad hoc networks (PBR) [60] among others. The advantage of such protocols is the time saved during a route request. However, the issue is that route changes may occur more frequently than the demand for routes, and the traffic generated by control and update messages in the routing tables can be costly and partly unnecessary, resulting in a waste of wireless network capacity in terms of bandwidth and resources. Additionally, the size of the routing tables increases linearly with the number of nodes.

3.1.2. Reactive Routing Protocols (RRP)

This type of routing is often referred to as on-demand routing, where routing is initiated by the source when it wants to transmit packets. These protocols utilize classical algorithms, and routes are established only upon request and maintained only for routes in use. In this case, an additional delay is necessary at the start of every session for path discovery. When a node wants to send packets, it initiates a route discovery process by broadcasting a route search message. Any node that receives this message and does not have information about the destination then broadcasts the message. Examples of reactive protocols include Ad hoc On-Demand Distance Vector (AODV) [20], Dynamic Source Routing (DSR) [21], Preferred Group Broadcasting (PGB) [61], and Temporally Ordered Routing Algorithm (TORA) [62]. In contrast to proactive protocols, reactive protocols do not burden the network with control messages for unused routes, thus avoiding the waste of network resources. However, the

establishment of routes through flooding can be expensive and leads to significant delays in connecting two distant nodes.

3.1.3. Hybrid Routing Protocols (HRP)

Hybrid routing protocols combine the advantages of proactive and reactive routing protocols. These protocols typically divide the network into regions called "zones." Routing is initially established in a proactive manner with pre-planned routes to maintain local knowledge of the topology up to a predefined number of hops. On the other hand, routes to the most distant nodes are obtained through a reactive scheme, utilizing broadcast request packets. This means that inter-zone routing is used to discover paths to nodes outside the zone. Among the most important hybrid routing protocols are Zone Routing Protocol (ZRP) [63] and Hybrid Ad Hoc Routing (HARP) [23]. The advantage of hybrid protocols is their adaptability to larger networks. However, this type of protocol combines the disadvantages of proactive and reactive protocols, such as the regular exchange of control packets and flooding of the entire network to search for a route to a remote node, which consumes significant bandwidth.

3.2. Routing protocols based on clustering

In this type of protocol, the objective is to cluster the network into groups to enhance the dissemination of routing information. Clustering involves categorizing the network nodes into clusters in a hierarchical manner based on certain common parameters such as address, geographical area, capacities, direction, speed, etc. [64]. This routing approach assigns varying levels of authority to the nodes, with some nodes responsible for specific areas to facilitate routing. These responsible nodes are called Cluster Heads (CH) and are responsible for intra- and inter-cluster communication. The CH summarizes the information within its cluster and sends it to neighboring cluster heads through gateways. Each cluster comprises three types of nodes: ordinary nodes, cluster heads, and gateways. Hierarchical routing protocols such as Cluster-Based Routing Protocol (CBRP) [25], Hierarchical State Routing (HSR) [24], and Cluster-Based Directional Routing Protocol (CBDRP) [65] are designed to reduce the size of the routing table, which depends on the clustering structure used. The clustering algorithm typically involves steps like cluster head election, cluster head communication, and cluster head maintenance.

Considering that VANETs are known for their highly dynamic mobility, group formation is an effective solution for maintaining links between vehicles, thereby enhancing scalability in large networks and managing the increased overhead due to high mobility features of VANETs [66]. However, this approach can lead to significant delays in data packet delivery, especially with a large number of clusters, resulting in increased overhead. Additionally, the selection of the cluster head can be a complex process.

3.3. Routing protocols based on cloud computing technology

Protocols belonging to this category leverage cloud computing to handle inter-vehicle communications and overcome the limited computing capabilities of mobile devices. One such approach is Vehicle Cloud Computing (CCV) [26, 27], which represents a hybrid technology with significant implications for traffic management and road safety. CCV utilizes vehicle resources such as processing power, storage, and internet connectivity in real-time decision-making processes. The primary objective of this integration is to provide unified platforms that facilitate communication between vehicles and enable efficient information processing. In this case, VANET is transformed into a service-oriented architecture within a cloud-vehicle framework, addressing various network challenges, including routing and data dissemination.

Within CCV, each vehicle is treated as a mobile service node (MSN) that monitors its own movement and predicts future locations. Extensive research has demonstrated that CCV is capable of making globally optimal routing decisions for inter-vehicle communication in a dynamic and time-sensitive manner, leveraging the elastic computing resources offered by underlying cloud platforms. However, it is important to note that the global adoption of this technology can be costly and complex, considering the unique requirements and regulations of each country [67].

3.4. Routing protocols based on position

This class of protocols has gained significant attention due to the notable improvements that location information can bring to routing performance. A position-based routing protocol typically consists of two main elements: a location service and a geographic forwarding process. Communication between nodes in this type of protocol occurs in three phases. In the "path selection" phase, the shortest path between the source and destination nodes is determined. Once the path is established, the second phase involves forwarding messages between the two nodes. If the connection is interrupted, the recovery phase initiates to reestablish and strengthen the path between the nodes. Nodes determine their geographical location, direction, and speed using native systems like GPS, Galileo, and ZigBee [68]. Beacon messages are used to share information, such as location, speed, direction, and other necessary details, with neighboring nodes.

The receiver node's location is determined by an internal software system (e.g., HLS [69], RLS [70], and GLS [71]) that operates independently of the data forwarding process. In cases where GPS coverage is limited, such as tunnels or areas with poor GPS signal, this internal location system is used to determine or enhance the node's location. Additionally, routing position schemes utilize street maps and on-board units (OBU) for data transmission. It is not necessary for a node to perform topology maintenance functions beyond its immediate

neighbors [72]. Therefore, position routing is particularly suitable for large-scale networks. So, three location-based routing protocols could be presented as below:

3.4.1. Geocast routing protocols

This type of protocol [28] aims to inform vehicles in a specific region about potential dangers on the road, such as accidents. The risk area is defined based on the precise location of the obstacle and the potentially affected directions. A vehicle in the risk zone broadcasts a warning message, and neighboring vehicles assess its relevance based on their location in relation to the risk area. Vehicles within the risk zone calculate a reception time difference interval (Differ time back off) for relaying the message, ensuring the farthest neighbor which becomes the relay based on the principle of "the further, the better". Geocast protocols face complexities in determining the geographical area and developing an efficient relaying mechanism to reduce network overload while adapting to different densities [73].

3.4.2. Broadcast routing protocols

Unlike geocast routing protocols, broadcast routing protocols are commonly used in VANETs to disseminate various information related to traffic conditions, such as traffic updates, weather conditions, road status, entertainment, and advertising. Broadcasting is used when a vehicle wants to send a packet to all its direct neighbors or within a specific radius determined by the number of hops or geographical coordinates. Inundation or flooding is a commonly used technique to ensure message delivery to all vehicles in the network, but it can result in considerable bandwidth loss. The efficiency of the flooding technique depends on the number of vehicles, with smaller numbers yielding better outcomes. Some examples of broadcast routing protocols include BROADCAST [29], UMB [30], and DV-CAST [74].

3.4.3. Unicast geographical routing protocols

These protocols focus on transmitting data packets from a single source to a single destination with a precise or approximate known location within a specified range in the network. The source node waits for an acknowledgment (ACK) within a defined time period. If the source node doesn't receive an ACK, it waits for an additional random interval within a larger range. Unicast communications are typically used for applications like file transfers and games. These protocols form the essential routing protocols in VANETs, and proposed works can be divided into two categories:

3.4.3.1. Routing protocols without road traffic statistics utilization

Protocols without road traffic statistics utilization [31, 32, 33, and 75] employ simple metrics, such as inter-vehicle distance, for routing and communication between nodes. These protocols do not utilize metrics like density, speed, or direction. Let's begin by discussing the reference

protocol in this class, called Greedy Perimeter Stateless Routing (GPSR) [31]. GPSR utilizes the positions of relay and destination nodes in a packet to make routing decisions. It relies solely on this information without requiring additional network topology details. Packet transmission in GPSR employs two methods: greedy forwarding, used whenever possible, and perimeter forwarding, employed in regions where greedy forwarding is not applicable. The greedy method selects the node closest to the destination to route the packet. If a local optimum is encountered, a recovery operation is triggered by applying the right-hand rule to select nodes for the recovery path. However, using the right-hand rule alone without cross-link removal heuristics can lead to an infinite loop. To address this, the author proposed two approaches: randomly eliminating one cross-link or using Gabriel's graph for eliminating cross-links and preventing infinite loops. GPSR performs well in highly dynamic environments like highways but faces challenges in urban areas with radio obstacles, which adversely affect its performance.

The limitations of GPSR in urban areas are addressed in Greedy Perimeter Coordination Routing (GPCR) [32]. This protocol is designed for city environments and consists of two phases: restricted greedy forwarding and the repair strategy. GPCR introduces the concept of a coordinator node, which is a node close to a junction area. If the coordinator node is within the coverage area of the forwarding node, it is preferred over the nearest destination node. If the coordinator node is absent, the nearest node to the destination is selected. In the event of a local optimum, a recovery strategy is employed to guide the packet back to the nearest junction and apply the right-hand rule. Despite the advantages of GPCR in reducing local optima and emphasizing the importance of intersections in routing, it introduces additional hops and time compared to simple greedy forwarding. To address this issue, GpsrJ+ [33] improves GPCR's performance in terms of hop count and packet delivery ratio. GpsrJ+ utilizes a two-hop neighbor table in its packet forwarding mechanism to anticipate the intersection the packet should take. If there is a possibility of changing direction, the packet is forwarded to the coordinator node; otherwise, it continues in the same direction through the nearest node to the destination that the coordinator node is aware of. Results show that GpsrJ+ outperforms GPCR in terms of hop count and packet delivery ratio, although it is more resource-intensive due to the use of a two-hop neighborhood table.

In [75], Naumov et al. proposed a new location-based routing protocol called Connectivity-Aware Routing (CAR), which is suitable for urban and highway traffic. CAR consists of four phases: position and path discovery, packet transmission, path maintenance using guard information (nodes in areas with curved roads like turns and intersections), and recovery in case of connectivity loss. When a packet arrives at an intersection, the node with guard information updates the packet header with the new anchor point. If connectivity is lost, two proposals are presented to address this issue. In the first proposal, the intermediate node holds

the packet for a specific period (P) and triggers the classic recovery algorithm if a route is still not found. In the second proposal, the intermediate node informs the source node about the lack of a route to the destination, prompting the source node to initiate the discovery process again. CAR exhibits a high packet delivery rate and lower average packet delays compared to GPSR and GPSR+AGF. However, the path discovery phase introduces a high overhead.

It is important to note that all of these protocols [31, 32, 33, and 75] do not incorporate road traffic statistics, such as the number of vehicles, their direction, or spread, in their routing decisions [53].

3.4.3.2. Routing protocols with traffic statistics utilization

These protocols aim to enhance the performance of geographic routing protocols by incorporating a digital map of city roads and various parameters such as vehicle direction, density, and speed. By utilizing this map, the protocols can obtain information about the street topology, allowing the source node to calculate potential junctions for reaching the destination.

One such protocol is Geographic Source Routing (GSR) [76], which maintains a list of neighborhoods, a network topology table, next hop node addresses, and a distance table for shortest path calculation using Dijkstra's algorithm based on the street map. This results in an optimal path in the form of a sequence of junctions from the source to the destination. GSR has shown superior performance in terms of packet delivery ratio and end-to-end delay compared to protocols like AODV and DSR. However, GSR does not consider vehicular traffic, relying only on the distance metric to choose paths, which leads to connectivity issues and packet loss.

To address this limitation, the Anchor-based Street and Traffic Aware Routing (A-STAR) protocol [77] utilizes both a static map and real-time dynamic map information, such as regularly traveling vehicles or public transport. This additional data helps create efficient routing decisions by establishing anchor paths with higher connectivity and introducing a novel recovery strategy. A-STAR outperforms GSR and GPSR in terms of performance. However, it also suffers from connectivity issues, packet loss, and the inability to reach intended destinations due to the lack of consideration for vehicle velocity and direction.

The GyTAR protocol [78] improves upon A-STAR by considering the structure of routes and using road intersections as potential points for constructing and maintaining the routing path. GyTAR incorporates road traffic conditions, selecting the densest roads as optimal for relaying packets towards the destination vehicle. It calculates a score for each road-neighboring junction and chooses the junction with the highest score as the next junction. GyTAR has demonstrated effectiveness in terms of routing overhead, packet delivery ratio,

and end-to-end delay. However, it suffers from a local optimum problem due to neglecting vehicle direction in calculating the next intersection.

To overcome the local optimum problem, the Enhanced Greedy Traffic Aware Routing Protocol (E-GyTAR) [79] selects dynamically junctions one by one, considering the number of vehicles moving towards the destination. Each candidate junction is scored, and the one with the highest score, geographically closer to the destination, is chosen as the next destination junction. Although E-GyTAR considers road traffic information, it neglects non-directional density flows on multi-lane roads and only utilizes directional density for selecting the best intersection. This approach helps E-GyTAR avoid local optima in certain city scenarios.

A robust approach called Traffic Flow-Oriented Routing (TFOR) protocol [80] aims to address the deficiencies of E-GyTAR. TFOR consists of two modules: a junction selection mechanism based on traffic flows and routing between junctions based on two-hop neighbor information. TFOR considers both directional and non-directional traffic density flows and treats them equally, as ignoring any part of traffic density would lead to connectivity issues and inefficient routing paths. Simulation results have shown that TFOR minimizes average end-to-end delay and routing overhead compared to GPSR, reduces routing overhead compared to GSR, and maximizes packet delivery ratio compared to GPSR, GSR, and E-GyTAR.

Moreover, the Geographic Source Routing (DGSR) [81] protocol enhances the GSR protocol by incorporating a location service to determine the position of the destination node and calculate the shortest itinerary using the Dijkstra algorithm. DGSR employs directional greedy forwarding and the carry-and-forward strategy to overcome the local maximum problem. While DGSR exhibits better routing performance than GSR, it still suffers from the local optimum problem.

The RTAR [82] protocol makes routing decisions at intersections, considering traffic and network status on adjacent routes. Control packets are transmitted between consecutive intersections to evaluate the road state in terms of vehicle density and inter-vehicle communication link lifetime. Scores are calculated for each adjacent road, and these scores are used for routing decisions. RTAR provides a score-based routing mechanism that considers traffic conditions and network status.

Other notable routing protocols, such as CJBR [83] and IGCR [84], have also focused on using intersections as key decision points for selecting the best path in VANETs. CJBR employs a multi-metric junction selection mechanism, considering metrics like remaining distance, number of RSUs, and relative direction to calculate scores for intersection

candidates. IGCR utilizes location information, maps, and a fixed gateway node to build the best routing table based on connectivity probability or most linked routes.

A new routing solution, the Shadowing-Fading-Based Intersection Geographic Opportunistic Routing Protocol (SIGO), addresses the presence of obstacles like buildings and trees in the urban environment, which can interfere with radio wave propagation. SIGO actively selects street intersection nodes as relay nodes based on factors such as distance to the destination, connection quality, and an index of street intersection (IRI). Simulation results have shown improved packet delivery ratio and decreased end-to-end delay using SIGO.

In summary (Table II.2), various routing protocols have been developed to improve VANET performance. These protocols incorporate digital maps, consider road traffic conditions, and utilize intersections as decision points to enhance routing efficiency. Each protocol offers unique features and addresses different limitations, aiming to optimize packet delivery ratio, reduce end-to-end delay, and overcome local optimum problems.

Table II.2- Summary of VANET routing protocols.

Protocols (year)	Type	Traffic awareness	Simulator	Archite	Beacon	Junction based	Map Use	Scenario	Mobility model	Forward strategy	Propagation model Arch
DSDV (1994)	Topology (proactive)	no	MARS	V2V	Yes	no	No	highway	Random	Distance victor	Free space
ZRP (1997)	Topology (hydrice)	no	Qualnet	V2V	Yes	no	No	urban	Random	Link sates	-
CBRP (1999)	Cluster based	no	-	V2V	Yes	no	No	urban	Random	Unidirectional links	-
AODV (2000)	Topology (reactive)	no	Linux's netlink	V2V	Yes	no	No	urban	random	Distance victor	-
DSR (2000)	Topology (proactive)	no	ns-2	V2V		no	No	urban	random	Source flooding	Free space
GPSR (2000)	geographic	no	ns-2	V2V	Yes	no	No	urban	Random waypoint	Greedy	Free space
HARP (2001)	Topology (hydrice)	no	mathematical analysis	V2V	Yes	no	No	-	random	Link sates	Free space
OLSR (2003)	Topology (proactive)	no	-	V2V	Yes	no	No	urban	random	Link sates	Free space
GSR (2003)	geographic	no	ns-2	V2V	Yes	Yes (Static)	Yes	Real city (map)	Daimler Chrysler's videlio	Greedy	road blocking
UMB (2004)	Geographic (broadcast)	-	Wireless Simulator + MATLAB.	V2V	RTS/CTS	yes	Yes	urban	-	Directed flooding	road blocking
A-STAR (2004)	Geographic (traffic based)	yes	ns-2	V2V	Yes	Yes (Static)	yes	urban	M-Grid	Grid city model	road blocking
BROAD-COMM (2005)	Geographic (broadcast)	no	-	V2V	Yes	no	no	highway	hierarchy	Flooding	-
GPCR (2005)	Geographic	no	ns-2	V2V	Yes	yes	yes	urban	Daimler Chrysler's videlio	A restricted greedy	-

GpsrJ+ (2007)	Geographic	no	Qualnet	V2V	Yes(2 hops)	yes	yes	urban	VanetMobiSim	enhanced restricted greedy(prediction-based)	road blocking
CAR (2007)	Geographic	no	ns-2	V2V	Yes	no	no	Highway and urban	Drivers behaviors of Switzerland	Greedy	Probabilistic shadowing
GyTAR (2007)	Geographic	yes	Qualnet	V2V	Yes	Yes (dynamic)	yes	urban	VanetMobiSim	Improved greedy, junction-based	Two-ray Ground Reflexion
GRANT (2008)	Geographic	no	-	V2V	Yes(x hops)	yes	no	urban	Static traces	Based on metric	road blocking
LOUVRE (2008)	Geographic	yes	Qualnet	V2V	Yes	yes	yes	urban	VanetMobiSim	Greedy along the shortest path	road blocking
CBD RP (2010)	Cluster based	no	ns-2	V2V	Yes	no	no	highway	hierarchy	Store and forward	-
E-GyTAR (2011)	Geographic	yes	GLOMOSIM	V2V	Yes	Yes (dynamic)	yes	urban	VanetMobiSim	directional greedy	-
VehiCloud (2012)	Cloud based	yes	real-world experiments	V2V+ V2I	Yes	no	yes	urban	real-world experiments	carry-and-forward	Heterogeneous
TFOR (2014)	Geographic	yes	GLOMOSIM	V2V	Yes(2 hops)	Yes (dynamic)	yes	urban	VanetMobiSim	Greedy	-
DGSR (2016)	Geographic	no	ONE simulator+SUMO	V2V	Yes(2 hops)	Yes (Static)	yes	Urban+ highway	car mobility	directional greedy	-
RTAR (2018)	Geographic	yes	OMNET++ + SUMO	V2V	Yes	Yes (dynamic)	yes	urban	Car following model	greedy based on multi metrics	Two Ray Ground reflection
CJBR (2019)	Geographic	yes	ns-3+SUMO	V2V+ V2I	Yes	Yes (dynamic)	yes	urban	A generated mobility	Greedy	Two Ray Ground reflection
IGCR (2021)	Geographic	yes	ns-2+SUMO	V2V+ V2I	Yes	Yes (dynamic)	yes	urban	A generated mobility	Greedy	Nakagami radio propagation model
SIGO (2022)	Geographic (broadcast)	No	ns-3	V2V	yes	Yes (dynamic)	yes	urban	A generated mobility	greedy based on multi metrics	obstacle shadowing model

4. Challenges, critical issues and research direction

VANETs are still in the experimental phase, and there are numerous technical, societal, and economic challenges that need to be studied and addressed [92, 93]. We explore here both the socio-economic challenges and critical technical issues related to VANETs:

4.1. Socio-economic challenges:

✓ **Market Penetration:** Achieving market penetration is a primary social challenge. Services and applications based on simple inter-vehicle communication can only function effectively when a sufficient penetration rate of equipped vehicles is reached. Due to the long life cycles of vehicles, it may take several years to achieve this rate, even if all newly produced cars are adequately equipped. Gradual market introduction strategies should be considered to overcome this challenge.

✓ **Interoperability and Universal Services:** Ensuring technology interoperability and the universality of services for vehicle networks is crucial. A vehicle equipped with an Inter-Vehicle Communication (IVC) system should be able to operate on roads worldwide. This requires governments to agree on a common frequency band for inter-vehicle communications globally. Additionally, designing new services should consider the specificities of driving in different countries, such as left-hand drive and right-hand drive.

✓ **Economic Considerations:** The Business Model and economic aspects represent major challenges for commercializing services based on vehicle networks. VANET services create a new market based on new technology, necessitating mechanisms that allow various actors (operators, software manufacturers, OEMs, car manufacturers, etc.) to create value for customers and capture that value as profits.

✓ **Business Model Development:** The business model summarizes how a company plans to serve its customers. It involves identifying target segments, formulating competitive strategies, defining advertising and distribution strategies, specifying revenue generation mechanisms, and developing strategies for customer acquisition and retention (e.g., incentivizing cooperation through remuneration).

✓ **Most geographic routing protocols** rely heavily on GPS for various location-based operations. However, GPS devices are ineffective in certain areas like tunnels. Moreover, this technology may be unsuitable for some vehicles or provide only partial accuracy in position calculation, especially in safety-critical applications. Consequently, a dedicated location service tailored specifically for VANETs needs to be defined and implemented in collaboration with vehicles and RSUs that form these networks.

✓ **The implementation of more precise algorithms** is essential for accurately modeling driver behavior. This is crucial as driver behavior significantly impacts the performance of routing protocols [36].

4.2. Critical technique issues

✓ **Road Network Forms:** Many previously proposed inter-vehicular routing solutions are designed for 2D road networks, while numerous countries have 3D road networks with suspension bridges, tunnels, and intersections. VANETs need to consider the different forms of road networks for efficient administration and operation.

✓ **Traffic Density Estimation:** Some geographic routing protocols rely on real-time traffic density estimation to achieve reliable inter-vehicular routing. However, this can lead to additional network overhead. Future research should focus on improving the energy efficiency of traffic-aware routing protocols to address this issue.

- ✓ **Vehicle Density and Packet Loss:** High vehicle density can lead to packet loss due to collisions between control messages generated by a large number of vehicles. This issue needs to be considered to ensure proper signal transmission in the presence of obstacles caused by vehicles themselves.
- ✓ **Energy Consumption:** Energy consumption is an essential consideration for VANETs, aligning with the growing emphasis on green systems and environmental preservation. Future VANET solutions should take energy consumption into account, considering the call for reduced toxic gases' emissions and the limited energy sources of some RSUs.
- ✓ **Technical Parameters:** Various technical parameters, such as link quality/distance, congestion, transmission quality, duplication removal mechanisms, and beaconless routing, should be taken into consideration in future research to ensure the proper functioning of VANETs.
- ✓ **Evaluation and Comparison of Algorithms:** Precise evaluation and comparison of geographic routing algorithms are necessary, specifically regarding the accuracy of density estimation. Simulations should be conducted to highlight the best algorithm for each simulation environment.
- ✓ **Other Technical Challenges:** VANETs pose various technical challenges, including channel access, data routing and dissemination, self-organization, security, addressing, and more. These challenges require ongoing efforts to develop effective solutions.

5. Conclusion

In this chapter, we have presented and discussed the specificities, communication models, and applications of VANETs systems, along with numerous projects and research in this field. We have also identified the limitations of existing solutions. While vehicle networks share similarities with environmental ad hoc networks (MANETs), we have closely examined vehicle networks and reviewed some existing ad hoc network solutions. Additionally, we have presented a significant number of recent proposals that address data routing and dissemination. Based on this, we have proposed a new classification of these routing works, providing a fresh perspective on the features of new inter-vehicular routing protocols.

The substantial amount of scientific production in this area necessitates critical and classification studies to evaluate these works, highlighting their advantages, disadvantages, and identifying persistent challenges. By doing so, we can discuss and offer appropriate solutions in the near future. Based on our comprehensive study of VANETs, particularly inter-vehicular routing solutions, we have highlighted the most important issues currently

faced by this network. We believe that special attention should be given to the following aspects:

- ✓ Mobility models that better represent the real context, considering parameters such as channel changes, traffic lights, influential locations, and the utilization of topographic information from maps.
- ✓ Encouraging VANETs research communities to propose green routing solutions that protect the environment.
- ✓ Incorporating socio-economic aspects, such as city forms, driver behavior, and common frequency bands, into research work through collaboration with different specialties to promote the global adoption of this technology.
- ✓ Leveraging sophisticated systems and methods (e.g., cloud computing, Markov chains, queues, Petri networks, probabilistic techniques, reinforcement learning) to perform complex calculations, leading to more accurate and appropriate inter-vehicular solutions for the challenges faced by VANETs networks.
- ✓ Developing safety mechanisms that establish trust relationships between communicating entities, ensuring access control, and guaranteeing the security of data transfers. This is of utmost importance and a major challenge that significantly impacts the future deployment of vehicular networks.

To address the issue of inter-vehicle communication discussed in this chapter, the next chapter will focus on a new inter-vehicle routing solution.

Chapter III:
**Local traffic density of flow-oriented
routing protocol for VANETs**

1. Introduction

Geographic routing protocols are highly suitable for ad-hoc vehicle networks, especially those classified under the road traffic category. These protocols demonstrate superior performance compared to other alternatives in scenarios where the number of active routes is low or when vehicle mobility is high. In this chapter, we present a novel location-based routing protocol called Local Traffic Density of Flow-oriented Routing Protocol for VANETs (LTD-FOR) [100]. This protocol builds upon the existing TFOR [80] and overcomes its limitations. LTD-FOR aims to minimize end-to-end delays and overhead while maximizing packet delivery rates.

2. Related work

Various VANET routing protocols have been proposed, including topology-based protocols categorized as proactive, reactive, hybrid, and geographic protocols based on location. Additionally, there are cluster-based protocols, geocast routing protocols, broadcast routing protocols, and routing protocols based on road traffic flow. The latter category improves the performance of geographic protocols by utilizing a digital map of city roads and factors like direction, density, and speed of vehicles. The map provides information about street topology, allowing source nodes to calculate possible path junctions to reach the destination. The classic geographic protocol is then used along the road to reach each junction, resulting in an optimal path between the source and destination.

One such protocol is the Geographic Source Routing (GSR) [76], which maintains lists of neighborhoods, network topology, next node tables, and distance tables to determine the shortest path using Dijkstra's algorithm. GSR has shown greater efficiency than AODV and DSR in terms of packet transmission ratio and end-to-end delay. However, GSR neglects vehicular traffic, leading to connectivity issues and high packet loss rates. This flaw is addressed in the Anchor-based Street and Traffic Aware Routing (A-STAR) protocol, which utilizes statistically scored maps of transit routes to create effective route decisions and improve connectivity.

Despite improvements, A-STAR [77] still faces connectivity issues, packet loss, and failure to reach intended destinations due to disregarding vehicle speed and direction. The GyTAR [78] protocol overcomes this limitation by considering road structure in the routing mechanism, treating road intersections as potential points for constructing and maintaining routes. GyTAR consists of two methods: one chooses dynamically intersections, while the other employs gourmet routing mechanism for packet transmission between selected intersections. GyTAR

has demonstrated effectiveness in urban scenarios, reducing routing overhead and end-to-end delay.

However, in certain urban scenarios, GyTAR suffers from a local optimum problem due to neglecting vehicle direction when selecting the best next junction. This issue is resolved in the Enhanced Greedy Traffic Aware Routing Protocol (E-GyTAR), which dynamically chooses junctions based on the number of vehicles moving towards the destination. E-GyTAR avoids local optima by using a carry-and-forward approach.

To further address shortcomings, the Traffic Flow-Oriented Routing (TFOR) protocol has been proposed. TFOR [80] is a geographic routing protocol that manages traffic flow and routing simultaneously, specifically designed for two-way multi-lane urban roads. It incorporates both directional and non-directional traffic flow without differentiation. TFOR consists of three modules: urban road data collection, junction selection based on traffic flows, and routing between selected junctions using two-hop neighborhood information. Simulations in urban scenarios have shown that TFOR minimizes end-to-end delay and routing overhead compared to GPSR, GSR, and E-GyTAR. It also maximizes packet delivery ratio compared to GPSR, GSR, and E-GyTAR.

3. Local Traffic Density of Flow-oriented Routing Protocol for VANETs (LTD-FOR)

3.1. Motivation

Our initial focus was on geographical routing protocols, specifically those based on traffic flow orientation, due to the significant advantages offered by this category compared to others. These protocols effectively reduce control traffic by minimizing the content of signaling packets, limited to basic identification and location information of the sending node. They do not exchange state information or require the creation and maintenance of global routes like topology-based protocols. This class of protocols excels in managing highly dynamic mobility, resulting in energy savings, reduced bandwidth usage, and scalability.

Among the geographical protocols, TFOR stands out for its advantages and improvements over existing protocols. TFOR utilizes road topology and traffic density to optimize data relay in the network. It considers factors such as density, curve-metric distance, and direction of traffic flows to make informed decisions about the next junction and efficiently dispatch data packets to their destination. During the forwarding of data between the current carrier and the next node, TFOR leverages two-hop neighborhood information to ensure the optimal selection of the next hop. This innovative approach introduces a new junction selection mechanism that considers both directional and non-directional traffic flows based on real-time urban traffic conditions. Ultimately, these flow determinations contribute to identifying the shortest routing path based on density.

Simulations conducted in a realistic urban environment with vehicular traffic have demonstrated the effectiveness of TFOR, as mentioned in the previous chapter. TFOR outperforms GPSR, GSR, GyTAR, and E-GyTAR, providing conclusive results and showcasing its superiority in terms of performance.

3.2. Problem statement

To collect statistics and calculate traffic density on a road between two junctions, TFOR employs a road traffic statistics collection mechanism with the following steps:

- **Cell Division:** The road segment is divided into small circular cells, each with a radius of 250 meters, which matches the transmission range. This division occurs when a node (vehicle) reaches the intersection at the end of the road.
- **Cell Grouping:** The created cells are superimposed, ensuring that each vehicle belongs to a specific cell. Vehicles within the same cell form a group.
- **Cluster Head Selection:** The node closest to the center of each cell is designated as the Cluster Head (CH). Only the CH is responsible for generating and updating the Cell Data Packet (CDP). The CDP contains the count of directional vehicles (moving toward the beginning of the road) and non-directional vehicles (moving in the opposite direction) within its associated cell.
- **CDP Initiation:** Each node arriving at the end junction of the road (or when a vehicle leaves the road) triggers the initiation of the CDP. The CDP format is depicted in Figure III.1.

Road Id		Cell Id	
Direction	cell's centre position	cell's total density	
Time	cell directional density	cell non directional density	

Fig III.1- CDP packet.

Upon reaching the beginning of the junction, the CDP is transformed into a Road Density Packet (RDP). The RDP includes the route identifier, propagation time, total density, directional density, and non-directional density of the road. Once constructed, the RDP is propagated around the junction by transmitting it from one node (neighbor) closer to the center of the intersection to another, until the next CDP arrives, which contains statistics for the same road. This process is repeated, and the new RDP replaces its predecessor.

The junction selection mechanism is triggered when a "data" type packet is created and reaches an intersection. Each junction is assigned a score to determine the optimal junction

for the "data" packet concerned by the next routing process. The candidate junction with the highest score, geographically closest to the recipient vehicle, and having the highest traffic density is selected as the next junction.

Once the next junction is determined, another mechanism comes into play for routing the "data" packet between the current junction and the previously selected junction. The data packet is marked with the position of the next junction to ensure the same route for subsequent packet transfers with the same source and destination, until a "local optimum" is reached.

Despite the advantages and improvements of TFOR, there are significant disadvantages, including:

1. Use of Total Density: TFOR protocols (GYTAR, E-GYTAR, and TFOR) rely solely on the total density of traffic between two junctions, neglecting the distribution of vehicles along the considered road segment. Calculating local density of traffic instead of total density would provide a better estimate for connectivity.
2. Limited Information in CDP: The current CDP lacks useful information that could enhance connectivity estimation. Adding additional fields to collect information such as cell size (for calculating means and variance), speed, and inter-vehicle distance would improve connectivity estimation.
3. Frequency of "Local Optimum": The optimal route calculated by the road traffic statistics collection mechanism remains valid until a "local optimum" is encountered. This phenomenon can occur multiple times during a communication session, resulting in significant time loss and reduced packet delivery ratio.
4. Equal Importance to Vehicle Directions: TFOR assigns equal importance to vehicles moving toward the destination node and vehicles traveling in the opposite direction. However, the former case is more likely to remain valid for a longer duration. It is preferable for the optimal route to consist of vehicles moving toward the destination, with the option of using vehicles traveling in the opposite direction if needed.

In the next sections, an improved version of the TFOR protocol will be presented, addressing these limitations and aiming to achieve efficient VANET routing in the three key network performance metrics: packet delivery ratio, end-to-end delay, and routing overhead.

3.3. LTD-FOR Assumptions

The proposed solution [100] belongs to the category of position-based geographical protocols in VANETs and is part of the same protocol family as TFOR, GyTAR, and E-GyTAR, which are all based on traffic flow orientation. This solution utilizes the geographic positions of the source and destination nodes to establish connectivity between them. The solution is specifically designed and developed for urban environments, which include two-way bidirectional roads, junctions, and obstacles in the form of buildings.

Each node in the network is assumed to be aware of its own geographical position using GPS technology, as well as the positions of its neighboring nodes through periodic exchange of control messages known as “Beacons”.

The recipient's position is determined using the Geographic Location Services (GLS) offered by the system. Additionally, each vehicle is equipped with an embedded navigation system that enables it to determine the locations of nearby intersections and share this information with other vehicles using pre-installed digital maps.

By leveraging the geographic positions of nodes, the proposed solution aims to improve routing and connectivity in urban environments, taking into account the specific characteristics and challenges associated with city scenarios.

3.4. LTD-FOR concepts

Our LTD-FOR [100] is an enhanced version of TFOR that incorporates three mechanisms, which operate in a similar manner to the previous TFOR version, with a significant difference in the road traffic statistics collection mechanism. The first mechanism, known as the road traffic statistics collection mechanism, operates periodically and introduces improved formulas to calculate scores for each intersection. The calculations have been modified and enhanced compared to the previous version.

The second mechanism, which involves intersection selection, remains unchanged from the previous version. It follows the same procedure to select the optimal junction based on predefined criteria.

Finally, once the optimal junction is selected, the last step involves routing the packets between the two intersections. This routing process continues in a sequence until the transmitted packet reaches its intended destination.

LTD-FOR builds upon the foundation of TFOR by refining the road traffic statistics collection mechanism and maintaining the same intersection selection mechanism. These enhancements aim to improve the overall performance and effectiveness of the protocol, ensuring that packets are efficiently routed between intersections until they reach their desired destinations.

3.4.1. Collection of road traffic statistics

In this section, we introduce a new method for collecting statistics and data on road traffic. We have adopted a new equation that considers parameters such as the total number of vehicles on a route, as well as the number of directional and non-directional vehicles in each cell. By neglecting these parameters, certain problems arise, which we discuss in the following illustrations. However, when these parameters are taken into account,

improvements are observed, leading to a more accurate estimation of connectivity and the assignment of specific scores to each junction.

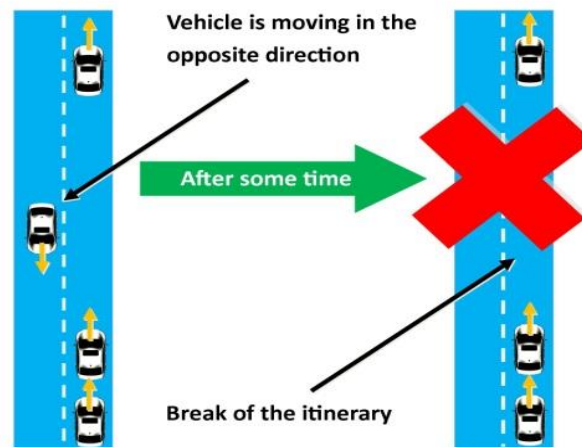


Fig III.2-The effect of direction on the ideal itinerary.

Figure III.2 demonstrates the impact of direction on route stability and connectivity between nodes. It illustrates a route with vehicles moving in opposite directions. Over time, it becomes evident that the vehicle moving in the opposite direction is unable to ensure connectivity, resulting in a disruption of the optimal itinerary. Conversely, a route composed of nodes moving in the same direction exhibits better connectivity and ensures greater strength and durability. These scenarios highlight the importance of having nodes circulating in the same direction to maintain robust vehicular connectivity.

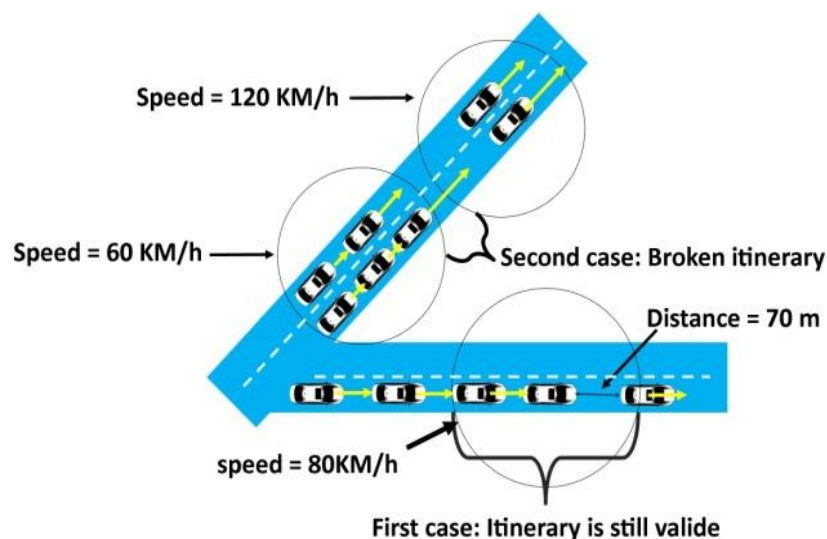


Fig III.3-The effect of the heterogeneous distribution of vehicles on the strength and durability of the optimal itinerary.

Figure III.3 focuses on the influence of global density on itinerary stability and connectivity between nodes. In the first case, despite having fewer vehicles (5 nodes) compared to the

second case (7 nodes), the connectivity remains established and the route remains stable over time. Conversely, in the second case, despite a higher global traffic density, vehicles traveling at high speeds (120 km/h) move out of range of the group of vehicles behind them, resulting in a disruption of the itinerary. Thus, calculating local traffic density instead of global density provides a more accurate estimation of connectivity.

To address these disadvantages of the TFOR protocol, we introduce a new message called Enhanced Cell Data Packet (ECDP). When a vehicle reaches the end of an intersection, a new ECDP message is initiated, collecting data on the number of directional and non-directional vehicles in each cell within the road segment between the two junctions. The format of the ECDP message is shown in Figure III.4.

Road Id		Cell Id	
Direction	cell's centre position	Time density	
Local directional cell densities		Local non directional cell densities	

Fig III.4-Enhance Cell Data Packet (ECDP).

The ECDP contains various information, including the route identifier, transmission time, direction of movement, cell center positions, directional densities, non-directional densities of each cell, and the identifier of the current cell being processed. The "Local directional cell densities" and "Local non-directional cell densities" variables concatenate numbers representing the number of vehicles in each cell with the same direction as the ECDP message and the opposite direction, respectively. The ECDP packets are transmitted from one cell center to another, being updated by the Cluster Head (CH) along the way.

Upon reaching the beginning of the road, the ECDP packet is transformed into an Enhanced Road Density Packet (ERDP) at the junction (JStart). The ERDP is then propagated around the junction by transmitting it from one node to another (neighbor) closer to the center of the intersection. The format of the ERDP is illustrated in Figure III.5.

Road Id	Time
Mean	Variance

Fig III.5- Format of the ERDP packet.

To calculate the average and deviation, we use the following mathematical formulas:

$$\text{Mean} = \left(\frac{\sum_{i=1}^{I=n} \text{cell_denst_direct}(i)}{n} \right) + \text{DC} * \left(\frac{\sum_{i=1}^{I=n} \text{cell_denst_nondirect}(i)}{n} \right) \quad (\text{III}, 1)$$

$$\text{Variance} = \left(\frac{\sum_{i=1}^{l=n} (\text{cell_denst_direct}(i) - \text{mean})^2}{n} \right) + \left(\frac{\sum_{i=1}^{l=n} (\text{cell_denst_non_direct}(i) - \text{mean})^2}{n} \right) \quad (\text{III}, 2)$$

To mitigate the disadvantages of non-directional vehicles, we have introduced a direction factor called DC. Through simulations, we determine the optimal value for this factor, its range is defined as follows: $0 < \text{DC} \leq 0.5$.

The total connectivity (TC) is calculated as follows:

$$\text{TC} = \frac{1}{\text{variance} + 1} * \text{mean} \quad (\text{III}, 3)$$

This indicates that good connectivity is characterized by several factors: Firstly, there is a significant presence of vehicles in the particular section of the road, indicating a relatively high traffic volume. Secondly, these vehicles are evenly distributed among the different cells, ensuring a balanced distribution of traffic. Additionally, this route comprises a substantial number of vehicles traveling towards the destination vehicle compared to other roads, indicating a higher likelihood of successful data transmission and effective communication.

3.4.2. Junction selection mechanism

Similar to the TFOR protocol, the junction selection mechanism in our approach comes into play when a data packet arrives at an intersection. For each junction, a score is assigned, which determines the next junction to which the data packet will be routed. The scoring algorithm used is based on the same principles as depicted in Figure II.3 of the TFOR protocol, with slight modifications in the calculation equation. These changes involve adjusting certain parameters to enhance the accuracy of the score calculation:

$$\text{Score} = \alpha * (1 - \text{Dp}) + \beta * \text{TC} \quad (\text{III}, 4)$$

With:

$$dp = dn / dc$$

dn: Curve Metric between candidate junctions and destination.

Dc: Metric Curve distance between current junction and destination.

TC "Total Connectivity": Value of the total connectivity of road traffic between the current junction CJ and the next candidate NDJ junction recovered from the packet.

α and β : weight factors such as $\alpha + \beta = 1$;

However, the calculation of the junction score, as we have seen, takes into consideration various parameters, including the local traffic density and the direction of vehicles. By incorporating these factors, we can obtain a more accurate estimation of connectivity.

3.4.3. Routing between junctions

Immediately after determining the next junction towards which the "data" packet is routed, a transfer or routing mechanism is employed, similar to the TFOR protocol. In this mechanism, our solution leverages the two-hop neighborhood to transmit data packets between the current intersection and the selected optimal junction. This approach offers a high transmission rate and optimizes the end-to-end delay.

Each packet-bearing node aims to transfer the packet to its neighbor at one hop, which is closest to the destination junction (direct neighbor), until the packet reaches the destination intersection. If the same node does not find any intermediate node closer to the destination than itself (in the case of a local optimum), it will hold onto the packet until it encounters another node (carry-and-forward case). Subsequently, a new path will be determined for the next packet transmission.

In the simulation section, we will demonstrate the efficiency and contributions of our proposed solution through detailed explanations of the results obtained from the conducted simulations.

4. Simulation

Currently, simulation is the most practical and effective tool for assessing the behavior of a complex system whose formalization using analytical methods is difficult. In this regard, in this section, we present the different simulators tools that have been used to evaluate the different inter-vehicle routing solutions proposed during this thesis:

4.1. Simulation setup

Table III.1-The simulation parameters.

Simulation/scenario		Mac/Routing	
Simulation time	200 s	MAC protocol	802.11 P
Map size	3000×2900 m ²	Channel capacity	2Mbps
Mobility model	A generated mobility	Transmission range	250 m
Number of intersections	24	Traffic model	16 CBR connections
Number of roads	38	Packet sending rate	0.1 to 0.9 s
Number of vehicles	30-225	Weight factors (α , β , DC, γ)	$\alpha+\beta+\gamma=1$ DC=1/2
Vehicle speed	30 - 120Km/h	Packet size	128 byte

In our simulations (see Table III.1 and fig III.6), we use realistic urban scenarios that closely resemble real-world conditions [90, 91]. These scenarios consist of urban environments with

various obstacles such as buildings, along with two-way bidirectional roads and intersections, replicating a specific city environment. The urban simulation zone employed in this study comprises a total of 38 bidirectional routes (multi-way) and 24 intersections, as described in detail in the previous section. These carefully designed scenarios aim to accurately represent the challenges and complexities encountered in urban vehicular networks.

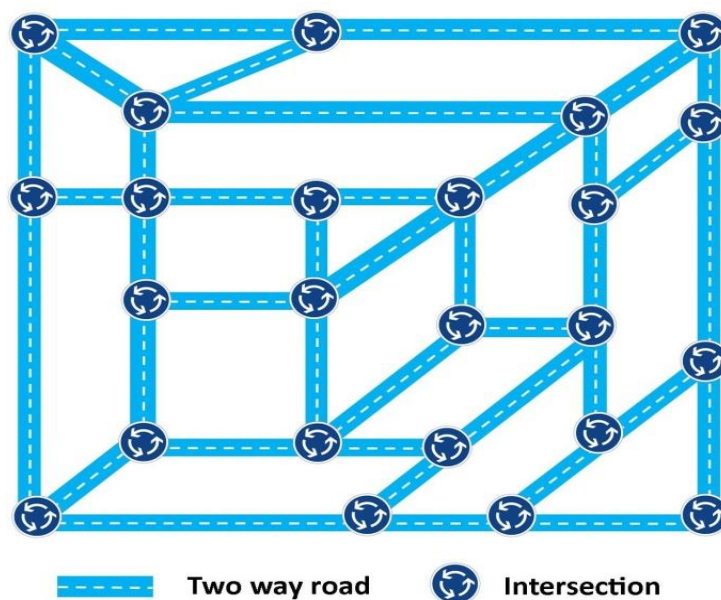


Fig III.6-the city of urban simulation

It should be noted that Table III.1 and the map of the figure III.7 are the basis of all simulations that have been made to validate the different routing proposed protocols. However, there are certain differences and some parameters that differ from a solution to another which we will add, talk and show them in each simulation section setup dedicated to that.

4.2. Simulation tools

To determine the performance of our proposed approach (LTD-FOR), we carried out simulations using OMNET++ [85, 86], SUMO [87, 88] and VEINS simulator [89]. VEINS for the simulation of network traffic and sumo for the simulation of road traffic.

4.3. Simulation results

To validate the effectiveness of our proposed LTD-FOR solution, we conducted a comparative analysis with three other protocols: TFOR, GSR, and GPSR. We evaluated these protocols using three networking metric keys: packet delivery ratio, end-to-end delay, and routing overhead. It is important to note that the results presented here represent the average of multiple simulation runs.

- **Packet delivery ratio**, also known as the packet success rate, is defined as the ratio of successfully received data packets at the destination to the total number of packets sent by the source node. This metric provides a quantitative measure of how effectively packets are delivered in the network. The numerator of the ratio increases for each data packet received by the destination, while the denominator increases for each data packet transmitted by the source.

- **The end-to-end delay** is the average time taken for a data packet to traverse the network from its source to its destination. It measures the overall delay experienced by packets during their transmission. Lower end-to-end delay values indicate faster and more efficient data delivery.

- **Overhead Routing** evaluates the total control packets generated in comparison to the number of data packets received at the destinations throughout the simulation. This metric helps assess the efficiency of the routing protocol by considering the additional overhead imposed on the network due to control packet exchanges.

4.3.1. Packet delivery ratio

Figure III.7 illustrates the packet delivery ratio as a function of vehicle density. It is observed that GSR and GPSR protocols have a lower transmission rate compared to TFOR and the LTD-FOR protocol. However, all protocols show an increasing trend in the packet delivery ratio as the number of vehicles increases.

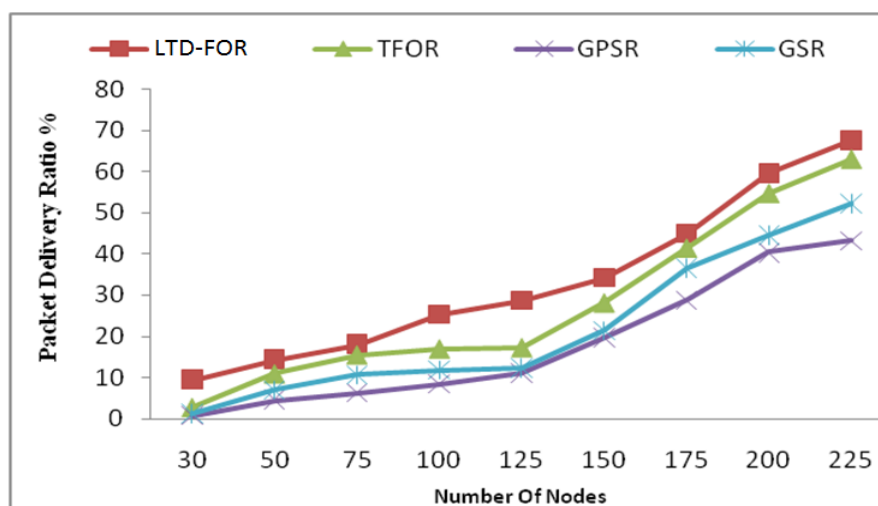


Fig III.7- the packet delivery ratio according to the number of circulating vehicles (at 5 packets/s).

It is important to note that the GSR protocol does not consider road traffic flow in its itinerary calculations, relying solely on curvometric distance. Consequently, if there are no vehicles along the chosen path, the delivery of packets will be compromised. On the other hand, GPSR selects intersections based on the destination position and the positions of relay nodes at each

hop. In the absence of such relay nodes, local optima can occur, affecting the packet delivery performance.

In contrast, TFOR and the LTD-FOR protocol utilize the total density of the road, incorporating both directional and non-directional traffic information to determine the next junction for packet routing. This approach leads to a higher transmission rate. The LTD-FOR protocol, in particular, leverages the local density of the road and prioritizes roads with a dense and homogeneous distribution of vehicles, especially those aligned with the direction of the destination. This strategy ensures strong and sustainable connectivity along the selected route.

The superiority of the LTD-FOR protocol's transmission rate highlights the significance of considering road traffic flow and optimizing connectivity for efficient packet delivery. By incorporating local density and promoting routes with a high density of vehicles moving towards the destination, the LTD-FOR protocol achieves improved performance compared to GSR and GPSR protocols.

4.3.2. End-to-end delay

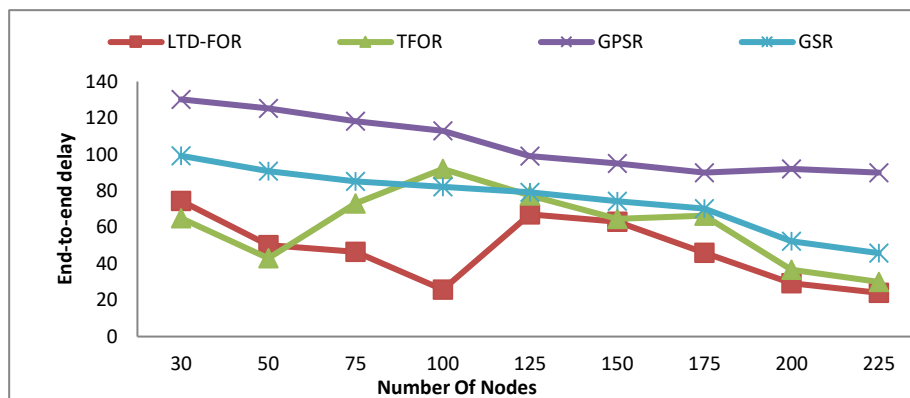


Fig III.8-End-to-end delay according to the number of circulating vehicles (at 5 packets/s).

Based on the graph presented in Figure III.8, it can be observed that the increasing number of vehicles has a positive impact on the end-to-end delay for all protocols. Furthermore, the end-to-end delay of the LTD-FOR and TFOR protocols, which utilize the two-hop neighborhood table information, is consistently lower compared to that of GSR and GPSR.

The use of two-hop neighborhood information in LTD-FOR and TFOR effectively minimizes the routing delay by selecting the nearest neighbor to the destination. This reduction in the number of hops contributes to a decrease in the overall end-to-end delay. Additionally, LTD-FOR exhibits a lower end-to-end delay compared to TFOR, primarily due to its selection of optimal roads with a dense vehicle distribution. This optimal road selection facilitates the efficient transmission of data packets within a shorter time frame.

In contrast, the GPSR protocol experiences an end-to-end delay that is influenced by the local optimum phenomenon, requiring additional time to overcome it and successfully transmit the data packet. On the other hand, the GSR protocol relies on curvometric distance for routing, enabling quicker operations. However, its transmission time is longer than that of LTD-FOR and TFOR due to the lack of consideration for road traffic statistics.

Overall, the results highlight the advantages of using the two-hop neighborhood table and incorporating traffic statistics in the LTD-FOR and TFOR protocols, leading to lower end-to-end delays compared to GSR and GPSR.

4.3.3. Routing overhead

Based on the data presented in Figure III.9, it is evident that the increasing density of vehicles leads to higher routing overheads for all four protocols, including the LTD-FOR protocol. However, the incorporation of new metrics, such as local density (measured by average and standard deviation) and direction, has played a crucial role in selecting better itineraries for completing data routing.

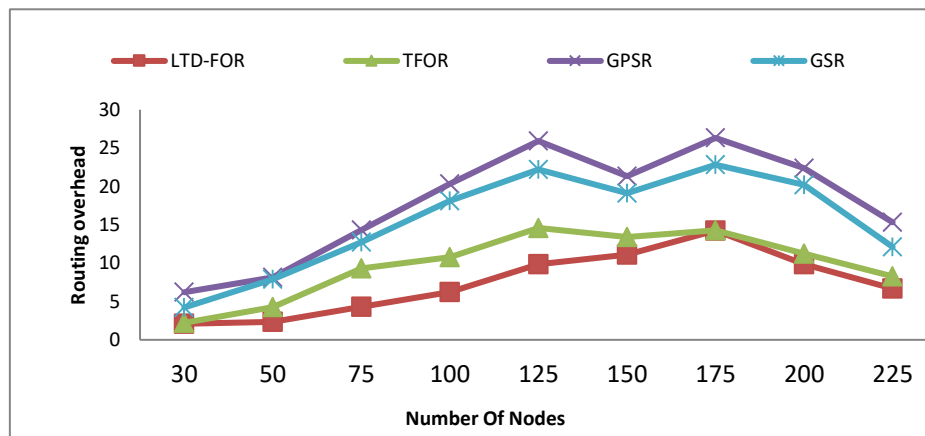


Fig III.9-Routing overhead according to the number of circulating vehicles (at 5 packets/s).

The LTD-FOR protocol, which utilizes these new metrics, achieves a higher data packet rate and therefore exhibits lower overhead compared to the standard TFOR protocol. By considering local density and direction, LTD-FOR is able to make more informed decisions in selecting optimal routes, resulting in improved efficiency and reduced routing overhead.

It is important to note that both the LTD-FOR and TFOR protocols still consume system resources due to the significant number of control messages they require, such as “**Beacon**” and “**Neighbor**” messages. However, the LTD-FOR protocol shows lower resource consumption compared to the TFOR protocol.

In contrast, the GPSR protocol exhibits the highest overhead rate among the four protocols. This can be attributed to the large number of control messages needed to overcome the local

optimal problem. On the other hand, the GSR protocol has the lowest overhead requirement, as it relies less on control messages generated for managing location neighbor services.

Overall, the incorporation of new metrics in the LTD-FOR protocol has led to improved routing efficiency, reduced overhead, and better resource utilization compared to the TFOR and GPSR protocols.

5. Conclusion

This chapter focuses on the design of a new routing approach aimed at improving the TFOR geographic protocol by addressing its identified limitations and failures discussed in this thesis. The research presents a new position-based routing algorithm that falls under the "road traffic" family, introducing novel concepts to efficiently route data packets through densely populated urban areas by selecting the shortest possible routes.

To gain a comprehensive understanding of vehicle distribution and quantity on a road segment, mathematical formulas such as the "average" and "standard deviation" are employed. These formulas enable the calculation of local density, a critical metric used in the selection of the best intersection for the data packet to traverse. Additionally, the direction of the vehicles is considered as a parameter in determining the optimal itinerary. This metric proves its significance, particularly in choosing vehicles that are heading towards the destination node, leading to the construction of improved routes.

The results of this solution demonstrate that inter-vehicular routing can be enhanced by leveraging local density and vehicular direction. Moreover, making a routing decision based solely on the various statistics accumulated on the first segments of the route can lead in well-determined cases to a false routing choice. Consequently, we have degradation in the various routing parameters. Therefore, in the next chapter, we want to know the effect of the use of road traffic statistics which can be collected on the intersections which come after the candidate intersections of the first level (1-hop) and which are currently under evaluation.

Chapter IV:
A Geographic Routing Based on
Road Traffic and Multi-hop
Intersections

1. Introduction

As mentioned earlier in the previous chapters, the location of the recipient node holds great significance in routing decisions. Additionally, road intersections play a pivotal role in selecting the optimal path for various geographic routing protocols. These protocols utilize a scoring mechanism to calculate the optimal intersection and establish the best route. However, relying solely on determining the first best intersection can lead to errors in calculating the optimal itinerary, particularly in certain scenarios.

In this chapter, we introduce a novel approach called "A Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs" (GRBRT-MI) [101]. Our approach focuses on utilizing bi-directional roads with multiple lanes in a city environment. We estimate the score for the optimal next intersection by taking into account the scores of one or multiple subsequent intersections. This approach aims to enhance the VANET routing process in terms of end-to-end delay, packet delivery ratio, and routing overhead. Building upon the three mechanisms of the TFOR versions, we propose an enhancement to the first mechanism, which involves collecting statistics on road traffic. Furthermore, we modify the second mechanism responsible for selecting the next intersection by introducing a new formula to calculate the score of different intersection candidates.

2. A geographic routing based on road traffic and multi-hop intersections in VANETs (GRBRT-MI)

2.1. Related work

We focus in this study [101] on geographic routing protocols that rely on intersections as crucial points in the routing process. Additionally, these protocols incorporate other types of information, such as road traffic statistics and curvometric distance. When a data packet is generated and arrives at an intersection, different VANET routing protocols handle the selection of the next best node in various ways:

One such protocol is A-STAR [77], which follows an anchor-based routing approach utilizing street knowledge obtained from the street map. It calculates the sequence of junctions (anchors) through which a data packet must pass to reach its final destination using the Dijkstra algorithm. Unlike GSR [76], A-STAR considers traffic awareness provided by vehicles with fixed trajectories.

GPCR [32] protocol requires data packets to be forwarded to a coordinator node located at a junction instead of the node closest to the destination, as done in the GPSR protocol. This strategy helps GPCR avoid local optimum problems encountered by GPSR, thus enhancing the routing process in important parameters.

GpsrJ+ [33] combines the advantages of GPSR and GPCR. It eliminates unnecessary junction nodes while maintaining the effective flatness of the topological plane. The protocol uses a two-hop neighbor table, and depending on the scenario, either the coordinator node or a neighboring node closer to the destination is selected for packet forwarding. However, the use of two-hop neighborhood tables introduces a significant cost.

Certain protocols for ad-hoc vehicle networks consider not only the geographical data of vehicles but also the road network map and traffic. Examples of such protocols are GyTAR [78], E-GyTAR [79], and TFOR [80]. These protocols take into account the route structure and road traffic statistics in the routing mechanism. They utilize two methods: a method for dynamically choosing route intersections and an improved greedy routing mechanism for sending packets between selected intersections.

DGSR [81] aims to improve the GSR protocol. It utilizes location service to determine the shortest itinerary to the destination using the Dijkstra algorithm. The best itinerary consists of a series of junctions, and each packet follows this sequence to reach the destination. DGSR employs directional greedy forwarding and a carry-and-forward strategy to address the local maximum problem.

The RTAR [82] protocol makes routing decisions at intersections by considering traffic and network status on adjacent routes. Control packets are transmitted between consecutive intersections to assess the state of the road, including vehicle density and inter-vehicle communication link lifetime. A score is calculated for each adjacent road based on its evaluation results, and the road evaluation results are announced at intersections for routing decisions.

Other attempts have been made to improve VANET routing protocols, focusing on intersections as key locations for selecting the best path to the final destination. For example, the CJBR [83] protocol introduces a multi-metric junction selection mechanism that considers metrics like remaining distance, number of RSUs, and relative direction to calculate scores for intersection candidates. The IGCR [84] protocol utilizes multi-hop routing and a fixed gateway node to determine intersections and network routes. It suggests the best route based

on probability of connectivity or most linked routes, considering recorded route information and disconnected route history. Simulation results demonstrate improvements in packet delivery ratio, end-to-end delay, and data throughput for these protocols compared to existing routing protocols.

2.2. Problem statement

Geographic routing techniques in inter-vehicular communication prioritize intersections as crucial factors in making routing decisions for data in the network. Intersections serve as key locations where vehicle nodes determine the optimal next road to follow.

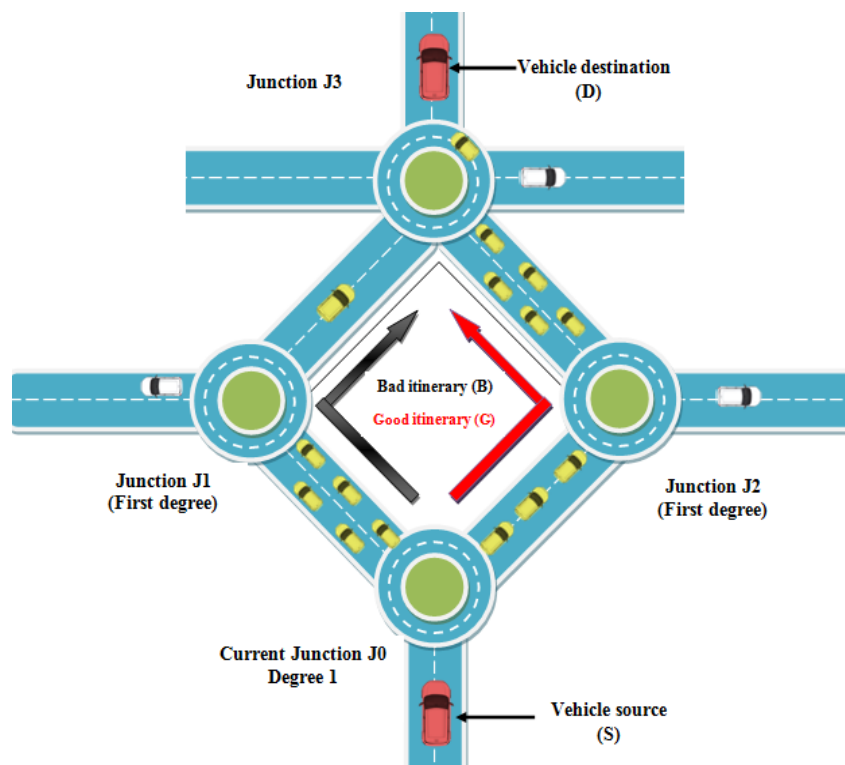


Fig IV.1-Illustration of the problematic

However, in certain scenarios, solely relying on connectivity calculations to determine the best next intersection (one-hop intersection) while neglecting subsequent intersections (second-hop, third-hop, etc.) can lead to interruptions in vehicular communication. This disregards the availability of alternative routes that could ensure reliable data transmission.

Figure IV.1 illustrates this problem through a map segment consisting of four junctions (current junction J0, junctions J1, J2, and J3) connected by ten multi-lane, bi-directional roads. To illustrate the issue at hand, let's consider the following scenario: a group of vehicles randomly dispersed along different routes forming two itineraries (Itinerary G and Itinerary B) that can connect the source node S with the destination node D. After adjusting factors like

speed, direction, and inter-vehicular distance, all the routing protocols mentioned in Section 2.1 (Related work) would choose junction J1 (Itinerary B) as the best next intersection based on vehicle density (five vehicles) in the road segment (J0, J1) compared to the density (three vehicles) in the road segment (J0, J2). However, once the data packet arrives at junction J1, it encounters a local optimum situation where there is no forwarding node available to ensure the continuous transmission of data towards the final destination node D. Simultaneously, an alternative route (Itinerary G) exists, which could provide a better connection between the source node and the destination node. Unfortunately, the aforementioned protocols failed to select this alternative route. This results in reduced packet delivery ratio, increased end-to-end delay, and higher routing overhead. Similar scenarios also present similar issues. Therefore, there is a need to develop a new routing technique that considers the selection of routing paths and intersections based on different hop categories whenever possible. To address this challenge, in this section of the thesis, we introduce our second routing protocol called "A Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs" (GRBRT-MI). This proposed protocol focuses on selecting the next best intersection while considering the connectivity of both first-order (one-hop) and second-order (two-hop) intersections. Generalizing this method will be the subject of future research work.

2.3. GRBRT-MI assumptions

We propose a new routing solution for VANETs [101] that falls under the category of geographic protocols based on junctions and traffic flow. This solution is specifically designed and developed for urban cities, where urban scenarios are characterized by obstacles such as buildings, two-way bidirectional roads, and intersections. We assume that each node is equipped with a GPS device that provides its own geographical position information. Additionally, the location of neighboring nodes is determined through periodic control messages (Beacon). The recipient's position is indicated by GLS (Geographic Location Service). Each vehicle is equipped with an embedded navigation system that can identify the locations of neighboring junctions and transmit this information using pre-installed digital maps.

2.4. GRBRT-MI Overview

GRBRT-MI [101] is based on the anchor-based routing approach, which incorporates street awareness and consists of three separate mechanisms. The first mechanism involves collecting road traffic statistics periodically. It assigns a score to each intersection based on the road traffic statistics of the next candidate junctions (one-hop), as well as the statistics of

the two-hop intersection candidate. This mechanism aims to enhance the accuracy of scoring by considering traffic information from multiple intersections.

The second mechanism is responsible for selecting the best next intersection when a data packet reaches an intersection. It evaluates the scores of the candidate intersections and chooses the most favorable one as the next hop for routing.

Finally, once the best junction is selected, the routing of packets between the two intersections takes place. In case the local optimum problem occurs, the recovery mode is triggered to address the issue. This sequence of selecting intersections and routing packets continues until the emitted packet reaches the preferred destination.

By incorporating these mechanisms, GRBRT-MI aims to improve the efficiency and effectiveness of routing in VANETs, ensuring that data packets are successfully delivered to their intended destinations.

2.5. GRBRT-MI protocol

The GRBRT-MI protocol operates through three distinct stages. These stages include the collection of road traffic statistics, the junction selection mechanism, and the routing between selected junctions. By incorporating these stages, GRBRT-MI aims to optimize the routing process and improve overall performance in urban VANET environments.

2.5.1. Road traffic statistics collection

In our approach, we explore the impact of leveraging road traffic statistics. The focus extends beyond one-hop junctions and incorporates the road traffic statistics of n-hop junctions, which are assigned to different junctions and distributed across the entire network map. To materialize this concept, our interest lies specifically in the connectivity of one-hop intersections in combination with the connectivity of second-hop intersections.

To achieve this, we adopt the same concepts utilized in the GyTAR, E-GyTAR, and TFOR protocols, which involves dividing roads into cells and designating a Cluster Header (CH) responsible for internal and external management of control messages exchanged between vehicles within and outside the cluster. To ensure accurate comparison, we employ the same algorithm as TFOR for collecting road traffic statistics of one-hop junctions, with a modification to the cell density packet (CDP) control message format. This modification allows the CDP to accommodate additional information about the connectivity of two-hop junctions. In order to facilitate the collection of inter-junction statistics, we introduce a new message called the cell density packet and multi-junction connectivity (CDP-MC). Each node triggers the transmission of a CDP-MC when it reaches the end junction of a road or when a vehicle exits the road. The format of the CDP-MC is depicted in Figure IV.2.

Road Id		Cell Id	
Direction	Cell's centre position		Multi-Junction connectivities
Time	Cell directional density		Cell non directional density

Fig IV.2- CDP-MC packet.

The CDP-MC packet includes several fields: road ID, cell ID, transmission time, a list of cell-center positions (route anchors), total cell density, directional and non-directional traffic density within the cell, and a dedicated field for multi-junction connectivity.

The "Multi-junction connectivity" field comprises concatenated values that represent the connectivity of each road segment connected to one of the candidate intersections, thereby describing the connectivity of two-hop intersections. Upon reaching the starting point of the junction, the CDP-MC packet undergoes conversion into another packet called the Multi-Junction Connectivity Packet (M-JCP). Subsequently, the M-JCP is disseminated within the junction's region. The format of the M-JCP is depicted in Figure IV.3.

Road Id	Time
Total Connectivity	Mean Multi-Junction Connectivities

Fig IV.3- M-JCP packet.

The M-JCP is a packet containing the route identifier, the propagation time, the total connectivity (TC) and mean multi-junction connectivity (MMC).

The mathematical formulas used to calculate the total connectivity (TC):

$$\text{mean} = \left(\frac{\sum_{i=1}^{l=n} \text{Cell_Dens_Direct}(i)}{n} \right) + \left(\frac{\sum_{i=1}^{l=n} \text{Cell_Dens_NonDirect}(i)}{n} \right) \quad (\text{IV, 1})$$

$$\text{variance} = \left(\frac{\sum_{i=1}^{l=n} (\text{Cell_Dens_Direct}(i) - \text{mean})^2}{n} \right) + \left(\frac{\sum_{i=1}^{l=n} (\text{Cell_Dens_Non_Direct}(i) - \text{mean})^2}{n} \right) \quad (\text{IV, 2})$$

The total connectivity (TC) and MMC are calculated as follows:

$$\text{TC} = \frac{1}{\text{variance} + 1} * \text{mean} \quad (\text{IV, 3})$$

$$\text{MMC} = \left(\frac{\sum_{i=1}^{l=n} \text{MultijunctionConnectivities}(i)}{n} \right) \quad (\text{IV, 4})$$

Where

n: indicates the number of roads connected to one of the candidate intersection.

Total connectivity (TC): indicates the value of the total connectivity of road traffic between the current junction CJ and the next candidate NDJ junction recovered from the packet.

MMC: mean multi-junction connectivityies that describe connectivity average of second-hop intersections;

After the Multi-Junction Connectivity Packet (M-JCP) is constructed, it is propagated throughout the junction by transmitting it from one node to another, moving closer to the center of the intersection. This propagation continues until the next Cell Density Packet-Multi-junction Connectivity (CDP-MC) is received. At that point, the process of creating a new M-JCP is repeated, and the updated packet replaces its predecessor. This ensures that the latest multi-junction connectivity information is continuously disseminated around the junction.

2.5.2. Junction selection mechanism

The junction selection mechanism is activated when a 'data' packet is generated and reaches an intersection. The process involves dynamically evaluating intersections one by one, considering real-time changes in vehicle traffic and aiming to evenly distribute the connectivity information of other intersections across the entire network map.

During the selection of the next intersection, the node (whether it is the source or an intermediate node) references a preloaded road map to locate neighboring intersections. Using previously collected statistics stored in the M-JCP packet and taking into account various curvometric distances leading to the final destination, a score is calculated for each candidate intersection. This score, determined by the formula (IV, 5), enables the choice of the next junction to which the 'data' packet will be transmitted.

$$\text{Score} = \alpha * (1 - D_p) + \beta * TC + \gamma * MMC \quad (\text{IV}, 5)$$

Where:

$$D_p = d_n / d_c;$$

d_n: Curve Metric between candidate junctions and destination;

d_c: Metric Curve distance between current junction and destination;

TC "Total Connectivity": Value of the total connectivity of road traffic between the current junction CJ and the next candidate NDJ junction recovered from the packet;

MMC: Multi-junction connectivityies that describe the mean connectivity of second-hop intersections;

α, γ and β: weight factors such as α + β + γ = 1.

The best destination intersection is selected based on the highest score assigned to each junction. Figure IV.4 illustrates the junction selection mechanism's process. This process begins with the generation of the first packet, CDP-MC1, at junction J3 and culminates with

the generation of packet M-JCP6 at junction J0. In addition to utilizing traffic statistics from the road segment (J3, J1) to generate CDP-MC1 (generated by every node arriving at the end junction J3), we also leverage packets M-JCP1, M-JCP2, and M-JCP3.

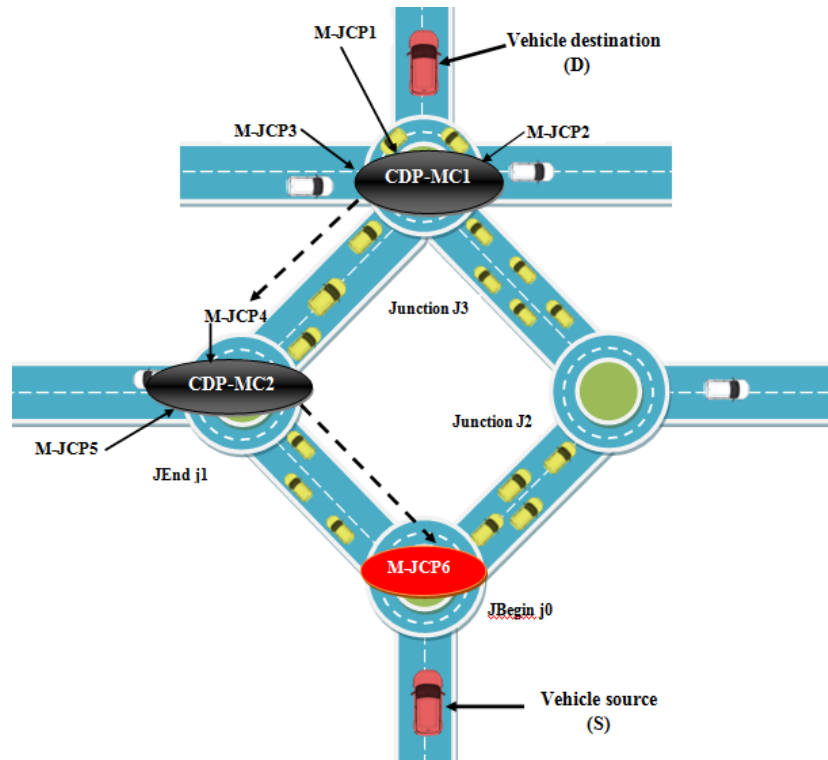


Fig IV.4-Example of routing between junctions.

Once CDP-MC1 is generated, it propagates from one Cluster Header (CH) to another within the road segment (J3, J1) until it reaches junction J1, where it transforms into M-JCP4. Through collaboration with packets M-JCP5 and the arrival of another vehicle at junction J1, CDP-MC2 is generated using the same algorithm and mathematical formulas (Formula (IV,1), Formula (IV,2), and Formula (IV,3)). Similarly, M-JCP6 is created following the same procedure as M-JCP4.

Using the curvetric distance connecting junctions J0 and J3, we calculate and assign scores to the candidate intersections, J1 and J2. The intersection with the highest score between J1 and J2 is selected as the next best intersection by the vehicle(s).

2.5.3. Routing between junctions

GRBRT-MI protocol leverages the two-hop neighborhood to transmit data packets between the two junctions. Each vehicle maintains a neighborhood table that includes both one-hop and two-hop neighbors. The position, speed, and direction of these neighbors are updated through periodic control messages called "Beacons" exchanged between vehicles. The neighbor's table is crucial for making routing decisions, particularly in this third routing step. It should be noted that optimizing the two-hop neighborhood, as defined in TFOR, is

necessary to reduce the control messages involved in constructing and updating this table. This optimization aspect will be addressed in future research.

3. Simulation

To evaluate the performance of GRBRT-MI, we use two types of simulators: a road traffic simulator and a network simulator. The road traffic simulator generates vehicle mobility patterns on a map, while the network simulator models the behavior of various network entities. We consistently chose OMNeT++ [85, 86], SUMO [87, 88], and VEINS simulator [89] to assess the performance of our newly proposed approach, GRBRT-MI.

Specifically, we utilize the VEINS simulator to simulate network traffic and evaluate the network-related aspects of our proposed approach. On the other hand, the SUMO simulator is employed to simulate road traffic and analyze the effects of traffic conditions on our routing protocol.

By employing these simulators in combination, we can comprehensively assess the performance and effectiveness of the GRBRT-MI protocol, taking into account both network and road traffic dynamics.

3.1. Simulation setting

In order to validate the proposed new routing approach presented in this research paper, it is crucial to utilize an urban simulation zone that closely resembles real-world conditions. This simulation zone should accurately represent the variations in vehicle speeds, directions, densities, and other relevant factors. It should also include obstacles, two-way bidirectional roads, and junctions, mirroring the complexities of an urban environment.

To assess the effectiveness of the proposed approach, it is important to use the same urban simulation zone and parameters that were employed in validating the LTD-FOR. The only difference is the addition of a new variable γ , as defined in Table IV.1, specific to the proposed approach. While the scenarios may not be identical, they were designed in a compatible manner to address the problem formulated in this research work.

By conducting simulations in this urban simulation zone and comparing the results with the existing protocols, we can evaluate the impact and effectiveness of the proposed routing approach in a realistic and representative environment.

Table IV.1-The Simulation parameters.

Simulation/Scenario	Mac/Routing
Simulation time	200 s
	Weight factors (α, β, γ)
	1/3

3.2. Simulation results

We compare the performances of GRBRT-MI three protocols: TFOR, GSR, and GPSR, using three network evaluation metrics: packet delivery ratio, end-to-end delay, and routing overhead. These metrics, which were previously defined in Chapter III, are essential for our simulation and provide valuable insights into the performance and efficiency of the routing protocols being evaluated. By comparing the results of these metrics, we can assess the effectiveness of GRBRT-MI in relation to the other protocols under consideration.

3.2.1. Packet delivery ratio

The packet delivery ratio, also known as the packet reception rate, represents the ratio of successfully received data packets at the destination.

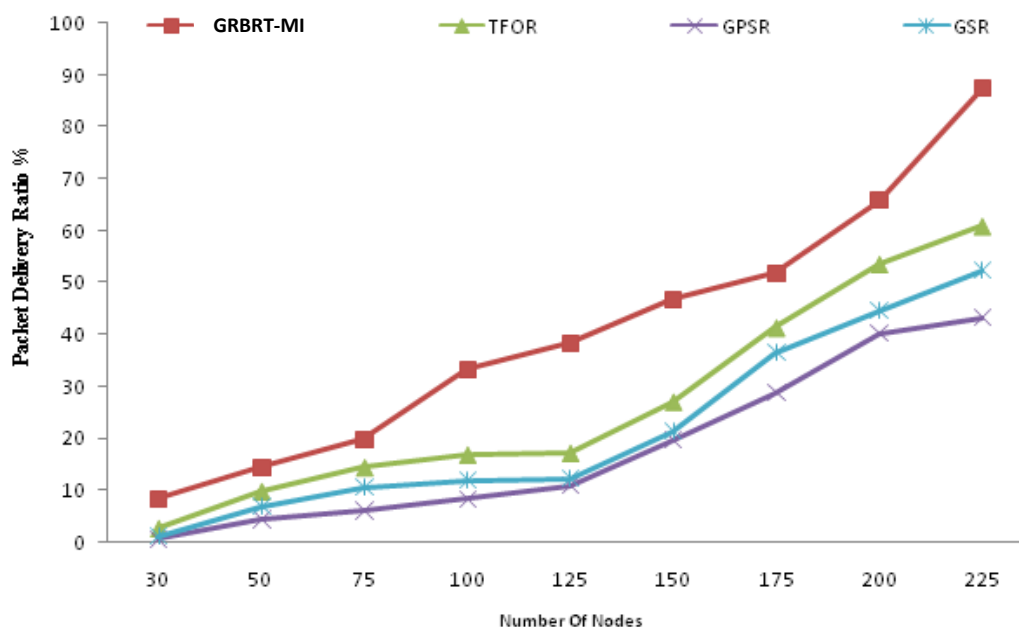


Fig IV.5-The packet delivery ratio according to the number of circulating vehicles (at 5 packets/s).

In Figure IV.5, we can observe the number of received packets in relation to the number of vehicles. It is evident that the packet delivery rate for all protocols steadily increases as the number of vehicles increases. This demonstrates the positive impact of higher vehicular density on the successful delivery of data packets across all protocol types.

However, the newly proposed routing approach, GRBRT-MI, exhibits a significantly higher packet delivery rate compared to TFOR, GSR, and GPSR protocols. It can achieve a delivery rate of up to 87.5% with a density of 225 vehicles. This impressive performance can be attributed to the utilization of the new technique in the collection of road traffic statistics, which extends to the exploitation of second-hop intersections, thereby enhancing the utilization of vehicle traffic information.

In contrast, the GSR protocol relies on generating a series of intersections to determine the optimal path without considering road traffic statistics. Consequently, it fails to adapt effectively in scenarios with low vehicle density, resulting in lower packet delivery rates. The GPSR protocol exhibits the lowest delivery rate among all the routing protocols. This can be attributed to the frequent occurrence of local optima (lack of the next relay node) during intersection selection based solely on distance between the destination and source/relay node as a routing technique for data packets.

While the TFOR protocol achieves an acceptable delivery rate by utilizing directional and non-directional traffic flow information to select the next junction, it falls short in comparison to the GRBRT-MI protocol. This is primarily because TFOR solely relies on the first intersection for collecting road traffic statistics, ignoring the potential benefits of considering intersections beyond the first hop. This highlights the strength of the new technique proposed in inter-vehicle communication within the GRBRT-MI protocol.

3.2.2. The end-to-end delay

The end-to-end delay represents the average time it takes for a data packet to traverse the network from its source (sender) to its destination.

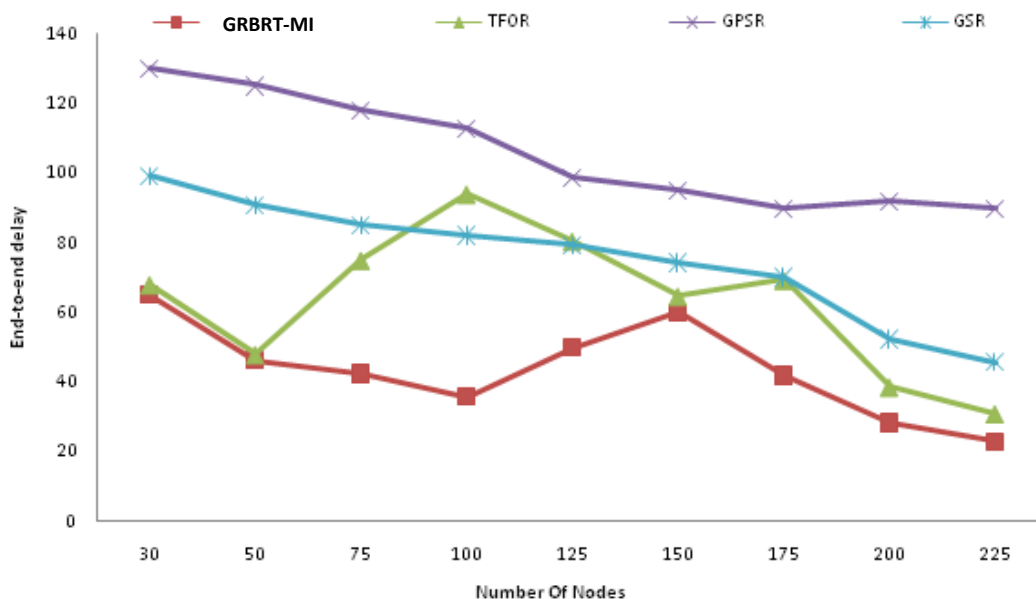


Fig IV.6-End-to-End delay according to the number of circulating vehicles (at 5 packets/s).

As depicted in Fig IV.6, an increase in vehicle density has a positive impact on reducing end-to-end delays for all the simulated protocols in this experiment. However, our proposed approach exhibits the lowest end-to-end delay compared to the other three protocols. This can be attributed to the successful implementation of our new intersection selection strategy, which considers both one-hop intersection statistics and the statistics of subsequent intersections (two-hop and beyond). Additionally, the use of a two-hop neighborhood table helps minimize the number of hops and consequently reduces the end-to-end delay.

TFOR also utilizes the two-hop neighborhood table information, resulting in a continuous reduction in delay compared to GSR and GPSR. However, TFOR still experiences higher transmission delays compared to the GRBRT-MI protocol. This is primarily due to TFOR's reliance solely on one-hop intersection statistics for routing decisions, which can lead to suboptimal intersection choices and longer transmission times.

On the other hand, the GPSR protocol's poor performance in the city environment is attributed to its inability to consider obstacles. As a result, it requires additional time to overcome local optimum phenomena and ensure successful packet transmission from source to destination. In contrast, the GSR protocol utilizes curvmetric distance for data routing, enabling quicker operations. However, this advantage is offset by longer transmission times compared to GRBRT-MI and TFOR, especially in scenarios with low traffic density along a pre-selected path. Furthermore, the GSR protocol lacks traffic-awareness, limiting its overall performance.

3.2.3. Overhead Routing

The routing overhead is a measure that evaluates the total number of control packets generated in relation to the number of data packets received at their respective destinations throughout the simulation.

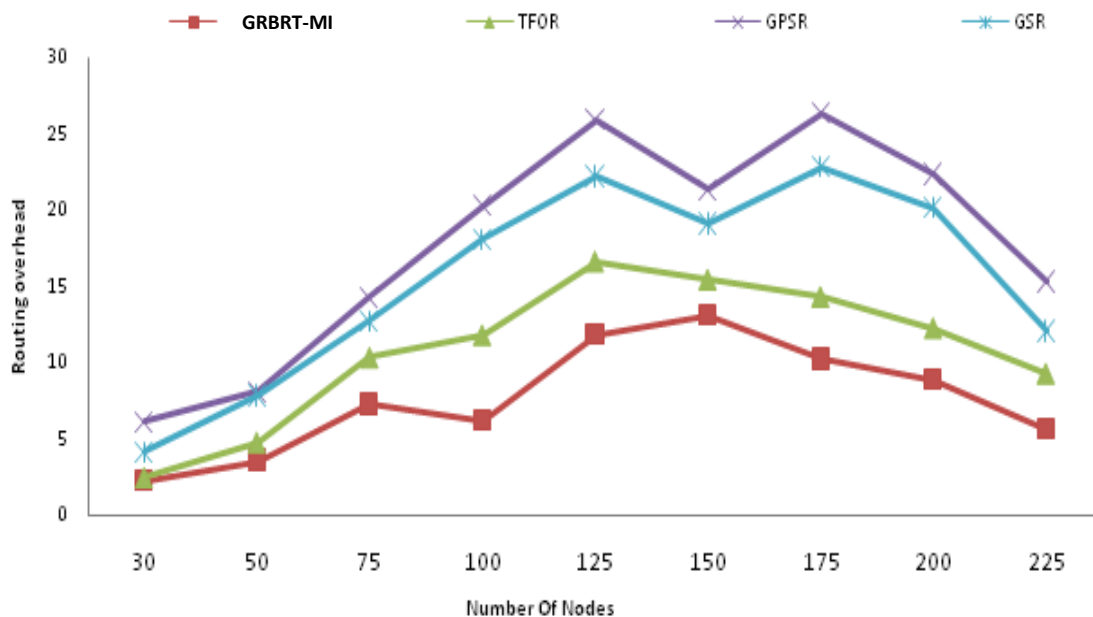


Fig IV.7-Routing overhead according to the number of circulating vehicles (at 5 packets/s).

The graph depicted in Fig IV.7 illustrates the trend of protocol routing overhead with increasing vehicle density for all the protocols evaluated in this study, including the GRBRT-MI protocol. It is observed that as the vehicular density increases, the routing overhead also tends to increase for all protocols. However, beyond a vehicular density of 150, there is a reduction in the overhead rate. This reduction is particularly significant for the GRBRT-MI

and TFOR protocols, which can be attributed to their improved packet delivery rates that positively impact the overheads generated by these protocols.

The graph demonstrates the effectiveness of the new strategy employed in the selection of the best next intersection, which plays a crucial role in determining optimal routing paths and minimizing resource utilization. The GRBRT-MI protocol exhibits superior performance in terms of efficient network resource utilization and successful routing decisions compared to TFOR, GSR, and GPSR. It achieves a high data packet delivery rate while maintaining lower routing overheads.

In the case of the GPSR protocol, it operates in two phases: the greedy phase and the perimeter phase. When the local optimum phenomenon occurs, the perimeter phase is activated, leading to an increased utilization of control messages to overcome this phenomenon. Consequently, the GPSR protocol exhibits the highest routing overhead among the evaluated protocols, including GRBRT-MI, TFOR, and GSR.

On the other hand, the GSR protocol demonstrates lower routing overhead compared to the GPSR protocol due to its limited reliance on control messages generated by the location neighbor's service.

Overall, the graph highlights the effectiveness of the GRBRT-MI protocol in achieving a balance between high data packet rates and efficient utilization of network resources, making it a favorable choice compared to TFOR, GSR, and GPSR protocols.

4. Conclusion

In this chapter, we have introduced a novel geographical routing protocol called GRBRT-MI. This protocol addresses the challenges of vehicular networks by leveraging road traffic statistics from both one-hop and two-hop junctions to make informed decisions in selecting the next junction for data routing.

The simulation results clearly demonstrate the effectiveness of GRBRT-MI in improving network performance across key metrics. It achieves a remarkable enhancement in packet delivery rates, significantly reduces end-to-end delays, and minimizes routing overheads. These outcomes validate that GRBRT-MI effectively meets the requirements of vehicular networks by excelling in the most critical network performance indicators.

By leveraging the road traffic statistics of both one-hop and two-hop junctions, GRBRT-MI optimizes the selection of next junctions, leading to improved routing efficiency and better utilization of network resources. The protocol's ability to strike a balance between

maximizing packet delivery rates and minimizing end-to-end delays demonstrates its superiority over existing solutions.

In conclusion, the GRBRT-MI protocol emerges as a compelling solution that effectively addresses the challenges of vehicular networks. Its ability to optimize packet delivery, reduce end-to-end delays, and minimize routing overheads makes it a promising choice for enhancing network performance in vehicular environments.

In the last chapter, we want enhance the ideas which have been proposed and discussed in the previous chapters IV to see the behavior of inter-vehicle routing with its different network metrics.

Chapter V:

A Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs for ITS in Smart Cities (GRBLTD-MI)

A Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs for ITS in Smart Cities (GRBLTD-MI)

1. Introduction

The selection of an optimal path in geographic routing heavily relies on the decision-making process at road intersections. Existing protocols employ a scoring mechanism to calculate the optimal intersection, which plays a crucial role in establishing the most efficient itinerary. However, relying solely on the determination of the first best intersection can sometimes lead to errors in calculating the optimal path, particularly in certain scenarios.

In this chapter, we propose a new approach called GRBLTD-MI (A Geographic Routing Based on Local Traffic Density and Multi-Hop Intersections in VANETs) [102] specifically designed for city environments with multi-lane and bi-directional roads. Building upon our previous proposal presented in the previous chapter, we calculate the score of the best next intersection by considering the connectivity of multiple junctions (one or n-hop intersections). We incorporate factors such as local traffic density, vehicular speed, inter-vehicular distance, and vehicular direction to enhance the routing process in terms of packet delivery ratio, end-to-end delay, and packet overhead.

In this solution, we continue to calculate road traffic statistics as we did in the previous proposal. However, we further improve the second mechanism used for selecting the best next intersection. By considering multi-hop intersections and incorporating various factors, we aim to enhance the accuracy and effectiveness of the routing process, resulting in improved performance across key network metrics.

The GRBLTD-MI approach takes into account the complex dynamics of city environments with multi-lane and bi-directional roads, enabling better decision-making and selection of optimal paths. By leveraging local traffic density and multi-hop intersections, we aim to address the limitations of previous approaches and provide a more robust solution for geographic routing in vehicular ad hoc networks.

2. Related work

In this section, we review relevant related work that directly relates to our proposed solution in this chapter. Other related work is present in the second chapter.

The GPSR [31] protocol selects the closest one-hop neighbor to the destination as the next forwarding node for data packets. However, GPSR ignores the presence of intersections and considers only the shortest distance to the neighbor node. Consequently, it suffers from the local optimum problem, especially in urban scenarios.

The GSR [76] protocol determines the sequence of junctions based on the calculated shortest route using Dijkstra's algorithm. While it considers intersections for route determination, it neglects other factors such as traffic statistics, leading to suboptimal performance in scenarios with fluctuating traffic conditions. A-STAR [77] also uses an anchor-based routing approach with street knowledge but fails to consider non-directional density flows, affecting its routing decisions.

The GPCR [32] protocol always forwards data packets to a coordinator node located at the intersection instead of the node closest to the destination. This strategy helps to overcome the local optimum problem experienced by GPSR, enhancing important routing parameters. GpsrJ+ [33] combines the benefits of GPSR and GPCR, but the use of two-hop neighborhood tables introduces additional complexity and cost.

Protocols like GyTAR [78], E-GyTAR [79], and TFOR [80] consider the road network map and traffic statistics for routing decisions. They incorporate route structure and traffic density, with TFOR using two-hop neighbor information to improve efficiency. These protocols outperform GPSR and GPCR, but each has its limitations in terms of local optimum avoidance and traffic direction awareness.

The DGSR [81] protocol improves on GSR by using the Dijkstra algorithm to estimate alternative shortest paths to the destination. Each path is represented by a series of junctions, and directed gourmet transmission is employed for data packet forwarding. Simulation results demonstrate that DGSR achieves better routing performance than GSR but still faces the local optimum problem.

The RTAR protocol [82] makes routing decisions at intersections based on traffic and network conditions of adjacent routes. Control packets are transmitted to assess road conditions, and scores calculated from these assessments are used for route decisions.

Several other routing solutions have been proposed, including the CJBR [83] protocol that employs a multi-metric junction selection mechanism. The IGCR [84] protocol utilizes location information and a map for multi-hop routing, while SIGO (Shadowing-Fading-Based Intersection Geographic Opportunistic Routing Protocol) [99] addresses the effect of shadowing by actively selecting street intersection nodes as relay nodes. These recent routing protocols aim to improve inter-vehicular communication in VANETs by considering intersections as key points for path selection. Each protocol incorporates different factors and

mechanisms to enhance routing performance in terms of packet delivery ratio, end-to-end delay, and other important metrics.

3. System model and assumptions

Smart city technologies [94] and intelligent transport systems play a crucial role in helping cities to adapt: to population growth, reduce traffic congestion, and work towards a more sustainable future. Urban mobility, which involves the movement of people within a city, is a complex subject influenced by various factors such as infrastructure, technology, politics, and culture. The history of urban mobility is extensive, and its future is driven by increasingly sophisticated technologies.



Fig. V.1-Smart cities architecture

Figure V.1 provides an overview of the architecture of smart cities and the networks they comprise. To achieve maximum efficiency in intelligent transport, urban mobility, and energy usage, a range of technologies is required. The good news is that city modernization does not have to be an all-or-nothing approach. Many technologies are already in place, and others can be gradually upgraded over time. The most significant challenges in this context, including privacy, data security, and data ownership, lie at the intersection of technology and public policies. Nevertheless, the implementation of intelligent transportation systems, with their intricacies and challenges, remains a central obstacle for realizing smart cities, particularly the development of inter-vehicular routing protocols in this complex environment [13].

To implement our proposed solution, we define our system model as a VANET network consisting of N vehicles operating within a smart city environment with multi-lane and bidirectional roads, without the use of Roadside Units. It is assumed that each vehicle is equipped with an on-board navigation system that utilizes GPS to determine its geographical position. The proposed routing solution is designed to be used in various applications,

including convenience services and road safety applications such as internet access, collaborative driving, emergency calls, and accident alerting.

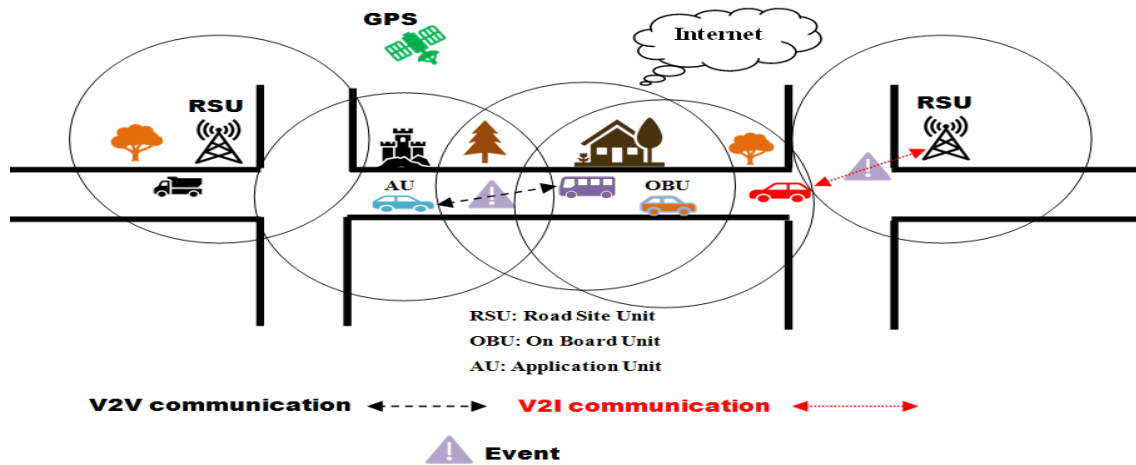


Fig. V.2-VANET model.

Figure V.2 illustrates the main components of our environment. It is important to note that the various problems and challenges discussed in Chapter IV regarding VANET routing serve as a foundational component for this chapter. However, in this solution, we will address these issues as a collective problem and use them as a basis to present and discuss our new routing approach.

3.1 Vehicle direction

As discussed previously in [100,101], connections between vehicles moving in opposite directions tend to have poor connectivity. Therefore, it is crucial to prioritize vehicles that are traveling in a similar direction to the destination vehicle. However, this does not mean that vehicles moving in the opposite direction should be completely disregarded.

3.2. Global traffic density

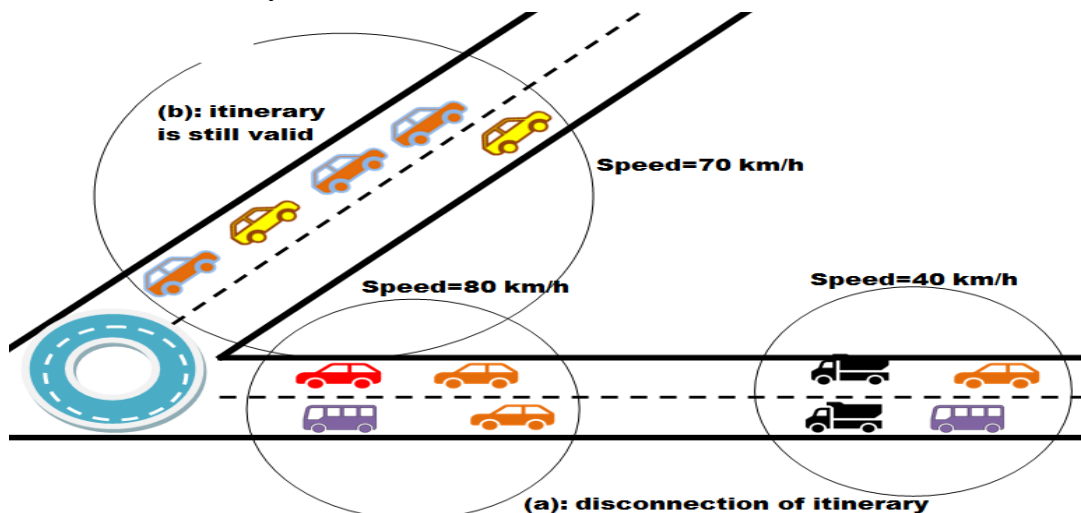


Fig.V.3-Durability of the optimal itinerary.

It is also **noticeable** in the **previous studies** [100,101], to better calculate connectivity, it is more advantageous to calculate local rather than the global traffic density. In fact, global traffic density does not give a good **estimation** of connectivity (see the example in fig.V.3).

3.3. Inter-vehicle distance

Previous studies [100,101] have highlighted the importance of calculating local traffic density rather than relying solely on global one when assessing connectivity. Local traffic density provides a more accurate estimation of connectivity compared to global traffic density, which may not accurately reflect the actual connectivity between vehicles (see the example in fig.V.4).

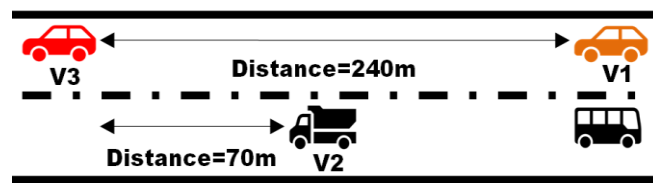


Fig. V.4-The effect of distance on the ideal itinerary

3.4. Vehicle speed

Previous study [101] has demonstrated that the traffic speed of vehicles becomes more consistent, then, the strength and stability of connectivity increase. In other words, when the vehicles in the traffic flow maintain similar speeds, it enhances the overall connectivity between them, leading to improved communication reliability and stability.

3.5. The connectivity of one-hop intersection

Relying solely on road traffic statistics collected from the first intersection (one-hop intersection) to determine the best next one while disregarding other subsequent ones (two-hop, three-hop, etc.) can result in communication interruptions. This approach overlooks alternative routes that may offer better data transmission opportunities. It is important to consider all available intersections along the route to ensure uninterrupted vehicular communication and avoid disregarding potential paths that could lead to improved data transmission.

4. A Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs (GRBLTD-MI)

The objective of GRBLTD-MI [102] is to enhance the performance of routing processes in VANETs, specifically in terms of end-to-end latency, routing overhead, and successful packet delivery rates when compared to recent protocols such as LTD-FOR , GRBRT-MI, BTA-GRP, TFOR, GyTAR, E-GyTAR, and others. GRBLTD-MI routes data incrementally, considering the unique factors of this environment and network. The selection of the next

junction is dynamically performed in real-time, taking into account the variation of vehicular traffic based on the selected metrics.

GRBLTD-MI consists of three steps: road traffic statistics collection, junction selection mechanism, and routing between junctions.

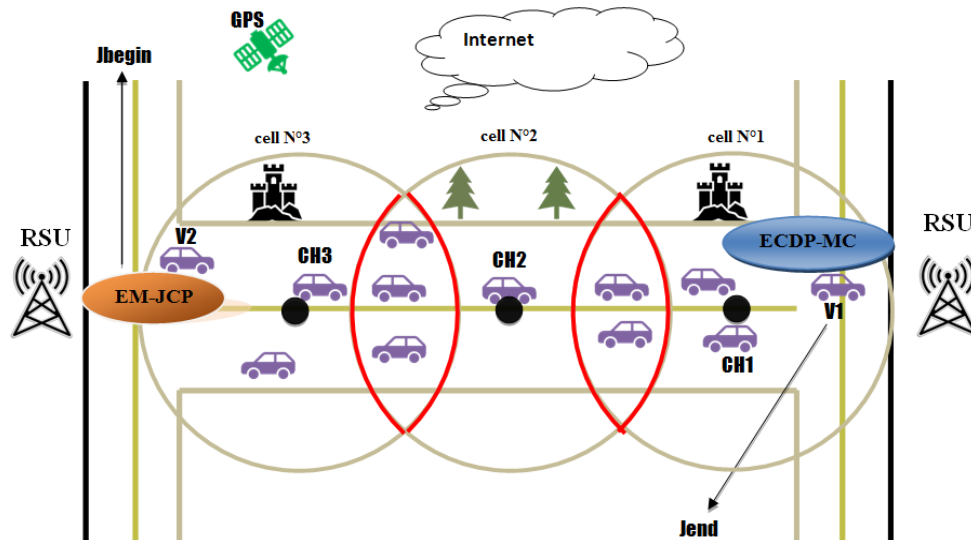


Fig.V.5-GRBLTD-MI process.

4.1. Road traffic statistics collection

We adopt the same configuration as the GyTAR, E-GyTAR, TFOR, LTD-FOR, and GRBLTD-MI protocols regarding the division of roads into cells between junctions and the assignment of a Cluster Header (CH) responsible for the internal and external administration of control messages from vehicles within and outside the group. (For example, CH1, CH2, and CH3 shown in Fig.V.5). To facilitate the collection of inter-junction statistics, we introduce a new message called Enhanced Cell Density Packet and Multi-Junction Connectivity (ECDP-MC), which has the format shown in Fig.V.6.

Road Id		Cell Id	
Direction	Cell's centre position	Multi-Junction Connectivities	
Time	Local Cell Connectivities		

Fig.V.6-the composition of the ECDP-MC packet.

The ECDP-MC [102] includes the road ID, cell ID, transmission time, location list of the cell-center (route anchors), packet direction, and local cellular connectivity (LCC). The LCC represents the combined values of connectivity strength for all cells between the CHs or forwarder nodes and their neighbors in front of it towards the JStart intersection, based on predefined parameters such as direction, speed, and inter-vehicle distance. The calculation follows the formula (V, 9).

It is important to note that the "Multi-junction connectivity" field in the ECDP-MC consists of concatenated values that describe the connectivity of the two-hop intersections in each route fragment associated with a candidate intersection.

We summarize the general algorithm of the collection mechanism as follows:

- ✓ Every node (e.g., vehicle V1 in Fig.V.5) initiates the ECDP-MC packet when it reaches the JEnd junction or when the vehicle leaves the road.
- ✓ The Forwarding Vehicle node (FV) (e.g., vehicle CH1 in Fig.V.5) transmits the ECDP-MC packet between the JEnd and JBegin junctions in the road section. It forwards the packet from JEnd to the beginning of JBegin.
- ✓ FV may or may not be the cluster head (CH node). If it is so, it consults its neighbor table (considering only the neighbors in front of the node towards the JStart intersection) and updates the ECDP-MC packet by calculating the "Local Cell Connectivity" of each cell using the formula (V,9). The current connectivity value is added to the calculated connectivity value for the current cell. FV then forwards the ECDP-MC packet to the closest vehicular node of the nearest anchor until it traverses the entire route segment and reaches the next junction (JStart) as shown in Fig.V.5.
- ✓ If FV does not have a suitable neighboring vehicle closer to the closest anchor point (in a local optimal situation) while the packet is moving between the two junctions, the "Local Cell Connectivity" is set to 0. At this point, the ECDP-MC packet returns to the JEND junction to inform nearby vehicles of this temporary connection interruption.
- ✓ Once the ECDP-MC packet reaches the cluster head of the final anchor, it is transformed into an Enhanced Multi-Junction Connectivity Packet (EM-JCP) as depicted in Fig.V.5. The EM-JCP spreads in the intersection region (e.g., by vehicle V2 in this example) and is used for routing decisions. The format of EM-JCP is shown in Fig.V.7.

Road Id	Time
Total Connectivity	Nhop-Connectivity

Fig.V.7-EM-JCP packet.

The EM-JCP contains the route identifier, the propagation time, the road id, The combined value of second-junction connectivity (Nhop-Con) and total connectivity(TC).

The mathematical formulas used to calculate Nhop-Connectivity (Nhop-Con) are:

$$\text{mean} = \left(\frac{\sum_{i=1}^{l=n} \text{LCC}(i)}{n} \right) \quad (\text{V.1})$$

$$\text{variance} = \left(\frac{\sum_{i=1}^{l=n} (\text{LCC}(i) - \text{mean})^2}{n} \right) \quad (\text{V.2})$$

n-hop connectivity (Nhop-Con) is calculated as follows:

$$TC = \frac{1}{\text{variance} + 1} * \text{mean} \tag{V, 3}$$

$$\text{Nhop-Con} = \frac{1}{\text{variance} + 1} * \text{mean} + \text{min (Multi-Junction Connectivities)} \tag{V.4}$$

Where,

n: is the number of cells in the road segment candidate in question;

n-hop connectivity: is the total connectivity of 2-hop intersections of the road segment in question;

min (Multi-Junction connectivities): represents the smallest connectivity among the concatenated values of Multi-Junction connectivity. This measure allows for an equal comparison between the different 2-hop junction candidates in terms of connectivity, the minimum connectivity value of the selected road segment indicates that this choice has the best 2-hop junction connectivity and therefore this path should be favored in the improved junction selection mechanism.

Once the creation of the EM-JCP packet is completed, it is distributed within the junction area by transmitting it from one node to another one (neighbor), or to itself, that is closer to the center of the intersection. This propagation continues until the next ECDP-MC packet arrives. At that point, the process of creating a new EM-JCP packet is repeated, and it is propagated again around the same junction. The new EM-JCP packet replaces the value of its predecessor, ensuring the updated and relevant information that is propagated throughout the junction area.

4.1.1. Connectivity

A) Connectivity modeling

To evaluate the connections which relate a Cluster Head (CH) vehicle and a forwarding vehicle with its neighbors, we define connectivity by three components (inter-vehicular distance, the speed difference internally, and the relative speed externally) as illustrated in Fig.V.8.

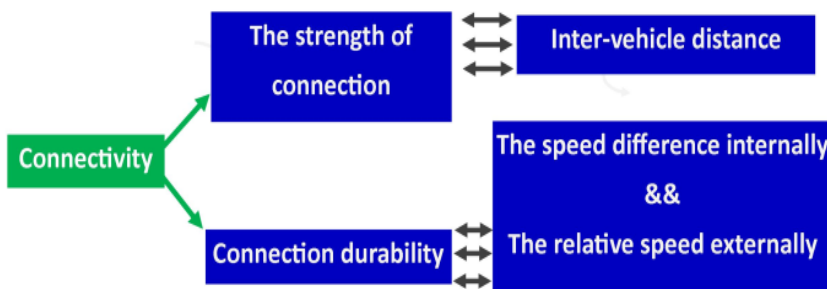


Fig.V.8-Connectivity modeling

To refer to this defined model, a shorter distance between two vehicles results in stronger connectivity, while a greater distance weakens it. Additionally, when vehicles travel at similar speeds, the connectivity becomes stronger, leading to enhanced durability. Similarly, transporting vehicles on low-speed routes contributes to strong and sustainable connectivity. The connectivity model is summarized by Formula (V.5).

$$\text{Connectivity} = \text{LS} * \text{ILD} * \text{ELD} \tag{V. 5}$$

LS: Link Strength presents the distance between two vehicles;

ILD: Internal Link Durability presents the validity duration of the link between two neighbor's vehicles;

ELD: External Link Durability reflects the validity duration of the itinerary on a road.

B) The mathematical system

Let R be a two-way road delimited by two intersections I and J. let N be the number of vehicles traveling in the road R in both directions. Let V₁ be any vehicle traveling in the road R with the speed S₁ in the direction D₁. Let be V₂, V₃... V_M the neighboring vehicles of V₁ which are positioned in its front towards the intersection JStart and which circulate in the road R with the speeds S₂, S₃, ... S_n respectively in the directions D₂, D₃, ... D_n respectively. It is assumed that in time t, the vehicle V₁ receives the ECDP-MC packet from a neighboring vehicle which is behind V₁ towards the intersection JEnd. The following formulas are valid:

$$\checkmark \text{Connectivity}(R,t)_{\text{total}} = \sum_{i=1}^N \text{connectivity}(V_i) \dots \tag{V, 6}$$

$$\checkmark \text{Connectivity}(I,J) \neq \text{Connectivity}(J,I) \dots \tag{V, 7}$$

(Equality exists only in some cases).

$$\checkmark \text{Connectivity}(V_1)_{R(t)} = \frac{\sum_{i=1}^M \text{LCC}(V_1, V_i)_{R(t)}}{M} \dots \tag{V, 8}$$

(LCC(V₁, V₂)_{R(t)} is the formula V.9).

To calculate the connectivity of the vehicle V₁ (cluster head or forwarding node) with its neighbors, there are four cases (see formula (V.9)) related to the speed of the vehicle V₁ and its neighbors as well as to the direction of each. We set the following connectivity formula (V,9) "LCC(V₁, V₂)_{R(t)}" (local cellular connectivity) in proportion to one vehicle V₁ with another neighboring vehicle V₂ according to four cases:

$$\text{LCC}(V_1, V_2)_{R(t)} = \begin{cases} \left(1 - \frac{\text{dist}}{\text{CR}}\right) * (S_1 + S_2 + 1)^{-1} & \text{if } S_1 = S_2, D_1 = D_2 \\ \left(1 - \frac{\text{dist}}{\text{CR}}\right) * \frac{(S_2 - S_1)}{(S_2 + S_1 + 1)} * (S_1 + S_2 + 1)^{-1} & \text{if } S_2 > S_1, D_1 = D_2 \\ \frac{\text{dist}}{\text{CR}} * \left(1 - \frac{(S_1 - S_2)}{(S_2 + S_1 + 1)}\right) * (S_1 + S_2 + 1)^{-1} & \text{if } S_1 > S_2, D_1 = D_2 \\ \frac{\text{dist}}{\text{CR}} * \left(1 - \frac{|S_2|}{(|S_2| + |S_1| + 1)}\right) * (S_1 + S_2 + 1)^{-1} * DC & \text{if } D_1 \neq D_2 \end{cases} \tag{V, 9}$$

Where:

Dist: the distance between the forwarding vehicle *V1* and a neighboring vehicle *V2* from which we want to calculate the force that binds them together;

CR: It is the communication range; it is around 250 m;

S1: It is the instantaneous speed of forwarding vehicle *V1*;

S2: The instantaneous speed of neighboring vehicle *V2*;

D1: The direction of forwarding vehicle *V1*;

D2: The direction of neighboring vehicle *V2*;

t: Time;

R: Route;

DC: The direction coefficient and $0 \leq DC \leq 0.5$.

Based on formula (V.9), an optimal link exists between two vehicles that are in close proximity, moving at a converging speed, and traveling in the same direction as the destination node. Additionally, these vehicles should possess multiple connections with neighboring vehicles. This combination of factors indicates a strong and reliable link within the network.

4.2. Junction selection mechanism

Following the creation of a 'data' packet, the third phase of the mechanism is initiated when the packet reaches an intersection. In this phase, the junctions are dynamically selected in a sequential manner to incorporate the newly collected real-time road traffic statistics and distribute the varied connectivity of other junctions (n-hop junctions) across the entire network map to the possible maximum extent. Once the next best intersection is identified, the node (whether it is the source or an intermediate node) explores the map to locate neighboring junctions. Utilizing the previously gathered statistics stored in the M-JCP packet, along with considering the distinct curvometric distances leading to the final target node, a score is computed and assigned to each potential junction. This scoring, performed according to formula (V.10), facilitates the selection of the subsequent junction to which the 'data' packet will be transmitted.

$$\text{Score} = \alpha * (1 - D_p) + \beta * TC + \gamma * N_{\text{hop-Con}} \quad (\text{V.10})$$

Where:

$$D_p = d_n / d_c;$$

d_n: Curve Metric between candidate junctions and destination;

d_c: Metric Curve distance between current junction and destination;

TC "Total Connectivity": Value of the total connectivity of road traffic between the current junction *CJ* and the next candidate *NDJ* junction recovered from the packet;

N_{hop-Con}: Multi-junction connectivities that describe the connectivity of second-hop intersections;

α, γ and β : weight factors such as $\alpha + \beta + \gamma = 1$.

The destination junction chosen as the best intersection is determined based on its high score. This indicates that the connectivity of this path, as well as the subsequent path, is superior to all other possible paths. By selecting the junction with the highest score, we ensure that the chosen route offers the best connectivity compared to alternative routes.

4.3. Routing between junctions

The GRBLTD-MI [102] protocol utilizes the two-hop neighborhood to facilitate the transmission of data packets between two junction points. Each vehicle maintains a neighborhood table that includes both one-hop and potential two-hop neighbors. This table is constantly updated through the exchange of periodic control messages called « Beacons » and « Neighbors » between vehicles. The neighborhood table plays a crucial role in making routing decisions, particularly in the third step of the routing process. However, it is important to optimize the two-hop neighborhood to minimize the number of control messages and ensure the table remains up-to-date.

In the upcoming section, we will demonstrate the efficiency and contributions of our proposed solution by presenting the results obtained from extensive simulations. This process will be discussed in the subsequent simulation section, providing valuable insights into the performance and effectiveness of the GRBLTD-MI protocol.

5. Simulation

To evaluate the performance of GRBLTD-MI, we use e OMNeT++ [85, 86], SUMO [87, 88], and VEINS simulator [89].

We conducted a performance comparison between the GRBLTD-MI protocol and several existing protocols, namely TFOR, GSR, and GPSR, to validate the efficiency of our novel proposal. To ensure a fair comparison, we utilized the same urban simulation zone and parameters that were previously used for validating these protocols. However, there was one difference in our setup, which involved the introduction of a new variable γ , as defined in Table V.1. It is important to note that although the scenarios were not identical, they were carefully designed to address the specific challenges revealed by the GRBLTD-MI protocol in the context of the proposed routing solution.

Table V.1-The Simulation Parameters.

Simulation/Scenario	Mac/Routing		
Simulation time	200 s	Weight factors (α, β, γ)	1/3

5.1. Simulation results

We use key performance metrics such as packet delivery ratio, end-to-end delay, and overhead routing as defined in Chapter III. This comparative analysis allows us to evaluate and identify the best-performing protocol among the considered options. By examining the results of this comparison, valuable insights can be gained regarding the suitability of each protocol for specific network scenarios, as well as their respective strengths and weaknesses. These findings will serve as a valuable guide for selecting the most appropriate protocol based on the specific requirements and characteristics of the network environment.

5.1.1. Packet delivery ratio

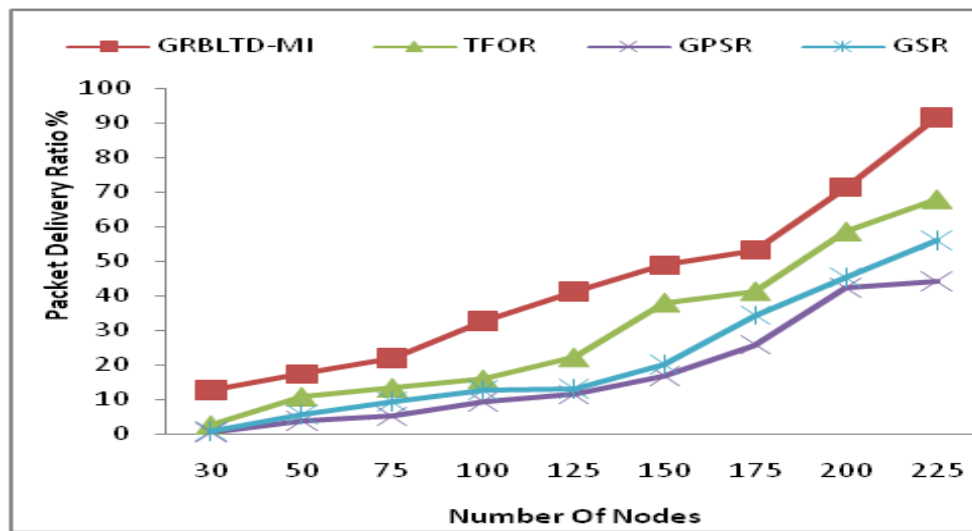


Fig. V.9 (a)-The packet delivery ratio according to the number of circulating vehicles (at 5 packets/s).

Figure V.9 (a) illustrates the relationship between the number of received packets and the number of vehicles in the network. It is evident that the packet delivery rate increases consistently for all tested protocols as the number of vehicles increases. This indicates that higher vehicular density positively impacts the overall packet delivery performance.

Notably, the proposed GRBLTD-MI protocol exhibits a significantly higher packet delivery rate compared to the TFOR, GSR, and GPSR protocols. In certain scenarios, the delivery rate reaches as high as 91% with a vehicle density of 225. This exceptional performance can be attributed to the novel approach employed in the road traffic collection mechanism, which leverages the statistics of second-hop intersections and employs various metrics (such as local density, distance, speed, and inter-vehicle direction) to gather information. By considering these parameters and the 2-hop junction collection strategy, GRBLTD-MI effectively selects the most efficient route between source and destination vehicles, resulting in superior packet delivery rates. On the other hand, the GSR protocol relies on generating a sequence of intersections to determine optimal routes based solely on curvetric distance, disregarding

road traffic statistics. Consequently, in scenarios with low vehicle density, data packets may not be transmitted efficiently.

The GPSR protocol exhibits the lowest delivery rate compared to other routing protocols. This is primarily due to the local optimum phenomenon, where the selection of intersections based solely on the distance between the destination node and the source/relay node leads to repetitive occurrences of suboptimal routing decisions.

While the TFOR protocol achieves an acceptable delivery rate by utilizing directional and non-directional traffic flow information for next junction decisions (e.g., overall traffic density), it cannot match the performance of the GRBLTD-MI protocol. TFOR reliance solely on the road traffic statistics of the first intersection, while ignoring subsequent intersections, limits its effectiveness in inter-vehicle communication.

The results demonstrate that the GRBLTD-MI protocol outperforms TFOR, GSR, and GPSR in terms of packet delivery rate. The incorporation of second-hop intersection statistics and the careful consideration of various metrics in the routing decision-making process significantly enhance the efficiency and effectiveness of inter-vehicle communication.

In Figure V.9 (b), we present the packet delivery rate versus traffic rate using CBR (constant bit rate) traffic. Generally, as the traffic rate increases, the packet delivery ratio tends to decrease. This decrease can be attributed to congestions and collisions that occur as a result of increased network traffic. When the packet sending rate exceeds a certain threshold, the

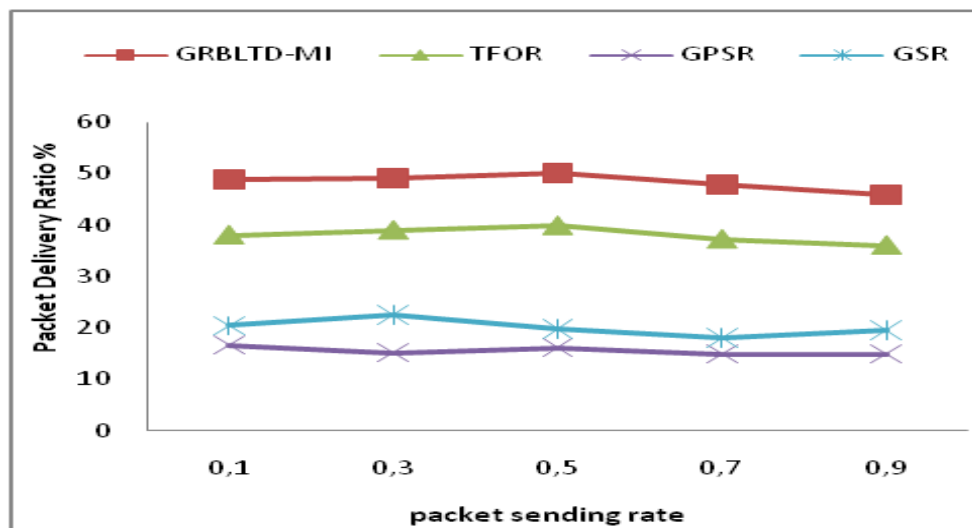


Fig. V.9 (b)-The packet delivery ratio according to the packet sending rate (150 nodes).

transport layer reacts by potentially dropping some data packets, resulting in a decrease in the overall packet delivery rate.

Furthermore, we observe that the packet delivery ratio decreases as the packet delivery rate increases for all four protocols under consideration. This trend is consistent across all

protocols. In the case of GPSR, it employs a recovery mechanism to address the local optimum problem. However, the execution of this mechanism, along with any associated rules such as Planarization Graphs or Random elimination of crossed links, requires additional control messages. As a consequence, the increased number of control messages contributes to collisions and congestions, negatively impacting the packet delivery ratio.

Similarly, GSR utilizes Reactive Location Services (RLS), preselected routes, and carry-and-forward techniques to make routing decisions. These approaches also require additional control messages, leading to a reduction in the packet delivery ratio when congestions and collisions occur.

The observed decrease in packet delivery ratio with increasing traffic rate is attributed to congestions and collisions. Additionally, the use of recovery mechanisms, such as in GPSR, and the reliance on control messages in protocols like GSR contribute to the reduction in packet delivery efficiency.

5.1.2. The end-to-end delay

In Figure V.10 (a), it is evident that an increase in vehicle density positively contributes to the reduction of end-to-end delays for all simulated and tested protocols in these experiments. Furthermore, our proposed GRBLTD-MI protocol demonstrates the lowest end-to-end delay compared to the other three protocols.

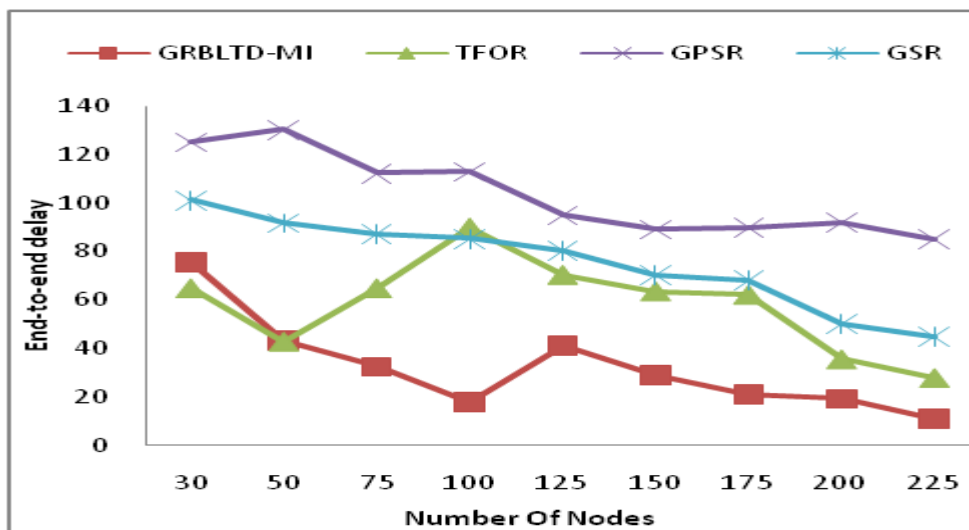


Fig.V.10 (a)-End-to-end delay according to the number of circulating vehicles (at 5 packets/s).

This superiority in end-to-end delay can be attributed to the successful implementation of our new strategy for selecting the next best intersection, which takes into account the statistics collected from both one-hop intersections and the subsequent two-hop intersections. The utilization of the two-hop neighborhood table also plays a crucial role in minimizing the number of hops and, consequently, reducing the end-to-end delay. Additionally, our protocol

effectively incorporates various statistical criteria such as local traffic density, distance, speed, and inter-vehicular direction through a new mathematical equation proposed in this study. This comprehensive approach ensures the selection of the most suitable itinerary, setting it apart from other protocols.

TFOR, in a similar manner, utilizes the information from the two-hop neighborhood table to continuously minimize delay compared to GSR and GPSR. However, TFOR still registers a higher transmission delay compared to the GRBLTD-MI protocol. In certain scenarios, this can lead to the GRBLTD-MI protocol outperforming TFOR, as the latter solely relies on the statistics of one-hop intersections for routing decisions.

On the other hand, the GPSR protocol exhibits poor performance in urban environments due to its inability to account for obstacles. This limitation results in increased end-to-end delay as the protocol requires additional time to overcome local optimum phenomena and successfully broadcast packets from the source node to the destination node. Similarly, GSR protocol relies solely on curvmetric distance for data routing decisions, resulting in longer transmission times compared to GRBLTD-MI and TFOR, especially in scenarios with low traffic density along pre-selected itineraries. It should be noted that the GSR protocol is not a traffic-aware routing protocol.

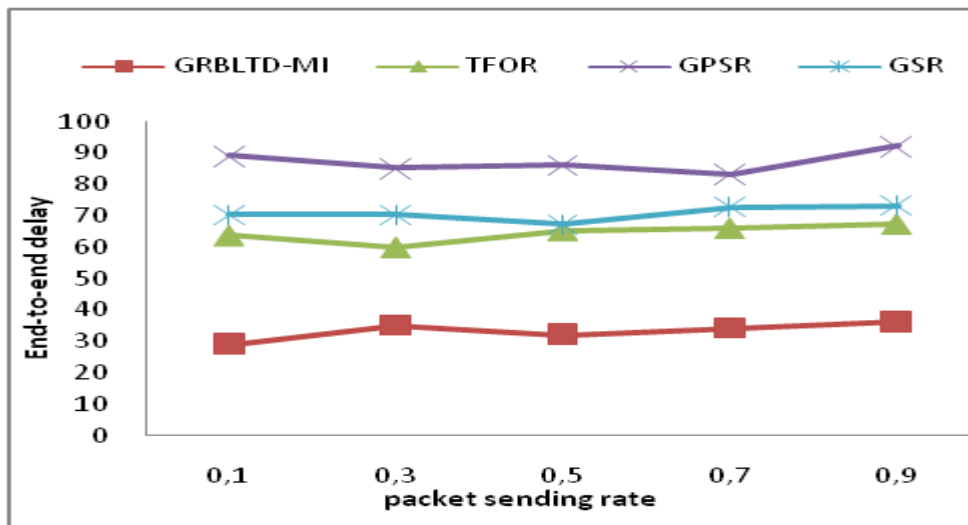


Fig. V.10 (b)-End-to-end delays according to the packet sending rate (150 nodes).

Next, we examine the influence of packet sending rate on end-to-end delay through the graph presented in Figure V.10 (b). In general, increasing the packet sending rate does not have a significant impact on end-to-end delay for the four protocols examined in this study. However, when the packet sending rate becomes very high, a slight negative effect on end-to-end delay is observed. In this context, our GRBLTD-MI solution stands out with the best end-to-end delay performance, as it is not affected by traffic and does not require a large number of control messages. Conversely, TFOR is also relatively unaffected, albeit with slightly

lower throughput. Both protocols demonstrate efficient performance without being burdened by excessive control message processing, which can contribute to congestions and collisions.

In contrast, the GPSR protocol exhibits the highest delay compared to the other protocols. Its recovery system generates a significant number of control messages and requires additional time to execute when encountering a local optimum. This contributes to an increase in end-to-end delay. The GSR protocol shows lower end-to-end delay compared to GPSR but still exhibits higher delay compared to TFOR and GRBLTD-MI. GSR calculates the most favorable itinerary (as a sequence of junctions) without considering road traffic statistics, and the storage technique it employs to address local optimum problems introduces additional delay and negatively impacts the overall end-to-end delay.

5.1.3. Overhead routing

The graph in Figure V.11 (a) illustrates an increase in protocol routing overhead as vehicle density increases for all tested protocols, including the GRBLTD-MI protocol (which utilizes frequent « beacon » and « neighbor » messages). This increase continues until the vehicle density reaches 175, after which the routing overhead experiences a reduction rate. Specifically, for the GRBLTD-MI and TFOR protocols, the routing overhead follows the increase in packet delivery rate, indicating a positive impact on the overhead costs generated by these protocols.

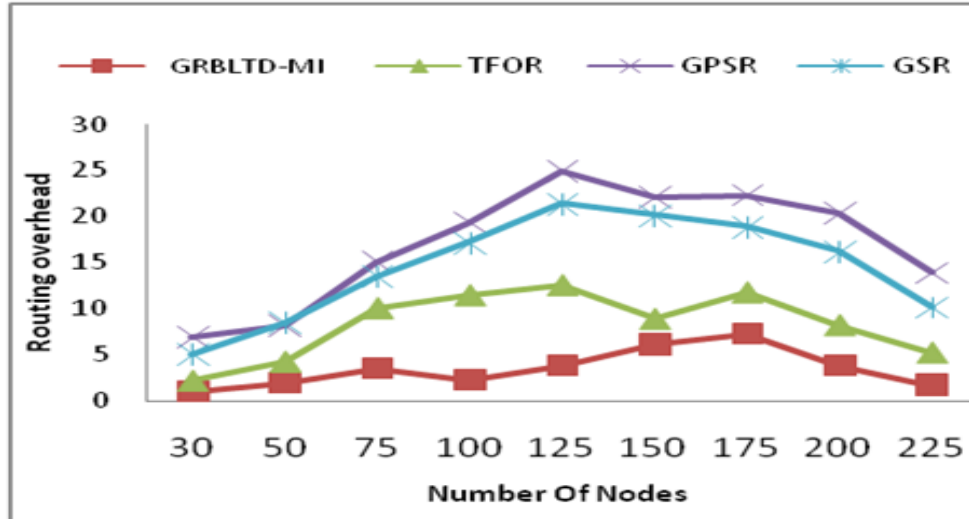


Fig.V.11 (a)-Routing overhead according to the number of circulating vehicles (at 5 packets/s).

The graph of Fig.V.11 (a) demonstrates the effectiveness of the new strategy employed in GRBLTD-MI, which takes into consideration vehicle speed, local vehicle density, inter-vehicle distance, and vehicle direction parameters in the intersection selection mechanism. This approach plays a crucial role in choosing a better route for successful data routing and leads to superior utilization of network resources compared to TFOR, GSR, and GPSR. As a result, GRBLTD-MI achieves a higher packet delivery rate and lower routing overhead.

In the case of the GPSR protocol, it operates in two phases: the greedy phase and the perimeter phase. When the local optimum phenomenon occurs, the second phase is initiated, resulting in a significant increase in control message usage to overcome this phenomenon. This is why GPSR exhibits the highest routing overhead compared to GRBLTD-MI, TFOR, and GSR. On the other hand, the GSR protocol generates less routing overhead than GPSR due to its lower reliance on control messages resulting from the use of location neighbor service.

Furthermore, Figure V.11 (b) depicts the ratio of routing overhead in relation to the packet sending rate. In general, routing overhead increases proportionally with the packet sending rate for all protocols, except for the new routing solution (GRBLTD-MI), which demonstrates the best protocol overhead even with an increase in the packet sending rate. This can be attributed to the efficient routing mechanism of GRBLTD-MI, which does not heavily rely on control messages.

Additionally, as the packet sending rate increases and reaches a certain level, there is a possibility of data packet discards, resulting in a decrease in packet delivery ratio. However, this is mitigated by the parameters (local traffic density, distance, speed, and inter-vehicular direction) used in the selection mechanism and the application of the new tactic of selecting the next intersection based on the collected statistics from both one-hop and second-hop intersections. These factors significantly contribute to establishing reliable unicast routing decisions and aid in maintaining a lower routing overhead.

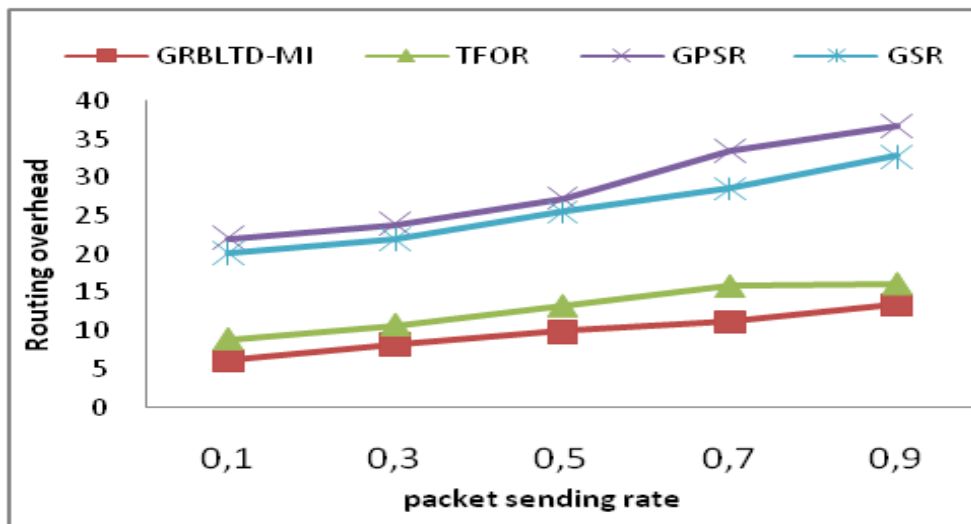


Fig.V.11 (b)-Routing overhead according to the packet sending rate (150 nodes).

6. Conclusion

In this chapter, we have addressed the limitations and shortcomings of existing intersection-based geographic routing protocols, such as TFOR, E-GyTAR, GyTAR, and A-STAR, as discussed in Chapter II of this research thesis. We have observed that relying solely on road

traffic statistics at one-hop candidate intersections can result in inaccuracies in establishing and maintaining optimal routes in certain scenarios. To overcome these limitations, we have developed a novel multi-metric approach, named GRBLTD-MI, which extends the utilization of road traffic statistics from both one-hop and two-hop candidate intersections. By incorporating these extended statistics, we aim to effectively distribute as much as possible and utilize network information across the global map.

To evaluate the effectiveness of our proposed approach, we conducted simulations using carefully defined parameters and compared the performance of GRBLTD-MI against TFOR, E-GyTAR, and GSR in a controlled test environment. The simulation results clearly demonstrate that GRBLTD-MI achieves significant improvements in various key network metrics, including packet delivery rate, end-to-end delay, and routing overhead. These improvements indicate that GRBLTD-MI outperforms the other protocols considered in this study.

Based on these findings, we confidently conclude that GRBLTD-MI is the most suitable and effective protocol for vehicular networks, considering its superior performance in optimizing network metrics. The incorporation of extended road traffic statistics and the multi-metric approach of GRBLTD-MI have proven to be effective in enhancing packet delivery, reducing end-to-end delay, and minimizing routing overhead.

Chapter VI:

Conclusion and perspectives

1. Conclusion

Ad hoc vehicle networks (VANETs) have been developed to facilitate communication between vehicles themselves or between vehicles and other networks through Roadside Units (RSUs). VANETs, which are an advanced form of mobile ad hoc networks (MANETs), aim to improve road safety in a coordinated and sustainable manner.

To fulfill this objective, efficient and reliable routing communication protocols are crucial for VANETs. These protocols need to ensure high data delivery rates, minimal transfer times, and cost optimization. However, the existing routing protocols designed for MANETs cannot be directly applied to VANETs due to the unique characteristics of VANETs. Factors such as high vehicle speeds and dynamic information exchange pose challenges and result in suboptimal routing performance. For example, the dynamic topology of VANETs makes the process of searching and maintaining routes complex. As a result, researchers have focused on developing routing solutions specifically tailored to VANETs.

Numerous routing protocols exist for VANETs, and they are classified using different methods and criterias. Geographic position routing protocols have been identified as the most suitable for reliable routing in VANETs. These protocols leverage geographic data of nodes without relying on route discovery processes or link status information. By adopting the geographic approach, these protocols offer advantages in terms of simplicity and independence from dynamic network conditions.

Overall, the research problem addressed in this thesis is to explore and propose routing solutions that address the specific challenges of VANETs. The focus is on developing efficient and reliable protocols that leverage the geographic characteristics of the network. These efforts are aimed at improving road safety and optimizing communication within VANETs.

In this comprehensive study, we extensively explored the routing challenges in VANETs and focused specifically on geographic routing protocols based on intersections. Our goal was to develop a new routing solution tailored to VANETs by leveraging various metrics such as road traffic statistics, local density, vehicular speed, vehicular direction, inter-vehicular distance, and curvometric distance.

To begin, we conducted an extensive literature search to gain insights into vehicular routing and define the problem more precisely. We thoroughly analyzed the existing publications on the topic, identifying critical issues that hinder the successful deployment of VANETs and require attention from the research community.

Based on our findings, we proposed our initial routing solution called LTD-FOR (« Local Traffic Density of Flow-oriented Routing Protocol for VANETs », an improved version of the TFOR protocol. TFOR is a geographic protocol based on intersections and known for its reliability. However, our study revealed several limitations in TFOR, such as the reliance on global density instead of local density and the lack of consideration for vehicles moving in the opposite direction of the recipient vehicle. In LTD-FOR, we introduced two new formulas to estimate local traffic density and vehicular direction, significantly enhancing the performance of the protocol. Simulation results comparing LTD-FOR with witness protocols like TFOR, GSR, and GPSR demonstrated the superiority of our approach in terms of packet delivery ratio, end-to-end delay, and packet overhead.

During our extensive study, we also identified other scenarios that can affect data routing decisions. Specifically, relying solely on traffic statistics at the first-hop intersections may lead to errors if subsequent intersections have poor vehicle density. To address this issue, we proposed a new inter-vehicular routing solution called GRBRT-MI (Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs). GRBRT-MI considers junction connectivity in multi-hop scenarios, resulting in improved routing decisions. Simulation comparisons against TFOR, GSR, and GPSR further validated the superiority of GRBRT-MI in terms of packet delivery ratio, end-to-end delay, and packet overhead.

Building on our previous contributions, we proposed another VANET routing protocol intitled GRBLTD-MI (Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs) that combines the road connectivity of the first candidate intersection with that of the second intersection (multi-hop intersection). This protocol incorporates metrics such as vehicles' local traffic density, speed, distance, and direction. By integrating several equations proposed in this study, our routing protocol enables precise selection among multiple multi-hop intersection candidates, leading to reliable delivery of data packets. Through extensive simulations, we demonstrated significant improvements in routing performance compared to prominent routing protocols.

Overall, our research efforts have resulted in the development of novel routing solutions specifically designed for VANETs. These solutions address the unique challenges of VANETs and outperform existing protocols in terms of packet delivery ratio, end-to-end delay, and packet overhead.

2. Future research directions

Throughout this thesis, our focus has been on enhancing our understanding of inter-vehicle communication, a crucial element of intelligent transportation systems. We embarked on an extensive study to identify and tackle the gaps and limitations present in current routing protocols. As a result, we proposed and validated our contributions to address these issues.

Nevertheless, there remain specific challenges within vehicular networks that demand further exploration, and it is essential to reassess and modify existing solutions designed for ad hoc networks. Hence, we present several perspectives and new directions that warrant attention in the near future to complement and expand upon this study:

- Building upon our current work, we can extend our project to improve the achieved results. This could involve exploring additional parameters for collecting statistics, such as the direction coefficient (DC) and acceleration. We can also focus on optimizing the two-hop neighborhood table used in our new routing solution GRP GRBLTD-MI and refine the algorithm for collecting road traffic statistics to distribute the junction scores throughout the network (n-hop). Additionally, studying the impact of varying communication ranges on routing decisions would be valuable.
- The accuracy of density estimation in protocols based on road traffic density has not been precisely evaluated. It is crucial to independently assess the performance of these algorithms and conduct simulation comparisons to determine the best algorithm for each simulation environment.
- In the future, we also intend to explore new performance-based routing solutions using analytical methods such as Markov chains, queues, Petri networks, probabilistic techniques, or reinforcement learning.
- The next inter-vehicular routing solution should be studied in the context of a green environment, incorporating smart city models with infrastructure (including RSUs) and leveraging 5G/6G communication modes.

This thesis has enriched our knowledge on various fronts. We hope that this research will serve as a foundation for future works, fostering improvements and applications. Adapting and implementing these findings can contribute significantly to enhancing human lifestyles.

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❖ ملخص الأطروحة

في الشبكات المخصصة للمركبة (VANETs)، يلعب توجيه البيانات دورًا حيويًا في ضمان نقل البيانات بكفاءة. تعتبر بروتوكولات التوجيه الجغرافي القائمة على الموقع هي الأنسب لشبكات VANET لأنها تستخدم المعلومات الجغرافية للعقد دون الحاجة إلى اكتشاف المسار أو حالة الارتباط. في هذه الدراسة، نقدم مسحةً لبروتوكولات التوجيه في VANETs، وتصنيف الحلول الحالية المختلفة إلى أربع فئات رئيسية: القائمة على الطوبولوجيا، والقائمة على الكتلة، والقائمة على السحابة، والقائمة على الموقع، والبيث الجغرافي. ندرس أيضًا قيود البروتوكولات الحالية ونقترح ثلاثة حلول جديدة للتوجيه. الحل الأول يسمى "التوجيه المعزز لتدفق حركة المرور (LTD-FOR) وهو تحسين بروتوكول التوجيه الموجه لتدفق حركة المرور (TFOR). يستخدم LTD-FOR الكثافة المحلية واتجاه المركبات لتحديد التقاطع التالي، وبالتالي تحسين أداء التوجيه مقارنةً بـ TFOR.

من جهة أخرى، لاحظنا أن بروتوكولات التوجيه الجغرافي القائم على تقاطع يعاني من ضعف آخر يتعلق بجمع إحصاءات المرور حول الطرق. حيث أن هذه العملية يتم إجراؤها فقط على التقاطعات المرشحة الأولى، في حين يتم تجاهل إحصائيات تقاطعات الدرجة 'ن' بالكامل، وهذا ما يمكن أن يسبب في حدوث خطأ في حساب المسار الأمثل في بعض السيناريوهات المحددة. على هذا الأساس، تم تقديم ورقة بحثية جديدة تحتوي على حل توجيه جغرافي جديد يستند إلى تقاطعات يسمى GRBRT-MI وهو أكثر تكيفًا وملائمة بشبكة VANETs. يناقش هذا النهج الجديد اختيار التقاطع التالي مع الأخذ بعين الاعتبار شدة الاتصال بين العربات في التقاطعات المرشحة المختلفة على مستوى عدة خطوات (ن-خطوة). لتنفيذ هذا الحل؛ اخترنا استعمال الإحصائيات المرورية التي تم جمعها في تقاطعات الدرجة الأولى والثانية فقط. أظهرت المقارنة التي تم إجراؤها باستعمال المحاكاة على البروتوكول GRBRT-MI مقابل بعض بروتوكولات التوجيه القوية تفوق الحل التوجيهي الجديد من حيث: نسبة تسليم الحزم، مدة نهاية إلى نهاية وتكاليف البروتوكول.

أخيرًا، تأسست مقالتنا الأخيرة على مبدأ الاستفادة من مزايا الفكرة التي تم معالجتها في GRBRT-MI، حيث تم تطوير نهج جديد باسم GRBLTD-MI. يستخدم هذا النهج كثافة حركة المرور المحلية وسرعة السيارة والمسافة بين المركبات واتجاه السيارة لحساب درجة أفضل تقاطع تالي مع مراعاة الاتصال متعدد الوصلات. تأخذ هذه الطريقة في الاعتبار توصيل متعدد التقاطعات، مما يعني أنه يمكن استخدام توصيل تقاطع واحد أو عدة تقاطعات لحساب التوصيل المتعدد للتقاطعات.

تُظهر عمليات المحاكاة أن الأساليب الجديدة المقترحة (LTD-FOR، GRBRT-MI و GRBLTD-MI) تتفوق في الأداء على البروتوكولات الحالية من حيث معدل تسليم الحزم والتأخير من طرف إلى طرف وحمل الحزمة.

تساهم هذه النتائج في تحسين التوجيه في VANETs، بهدف تحقيق اتصال موثوق وفعال بين المركبات، مع مراعاة خصائص شبكات VANET واستغلال المزايا التي توفرها التقنيات الناشئة.

الكلمات الدالة

نظام النقل الذكي (ITS)، المدن الذكية، اتصالات VANET، V2V و V2I، التوجيه الجغرافي، التقاطعات، كثافة حركة المرور، جودة الارتباط.

❖ Résumé

Dans les réseaux de véhicules ad hoc (VANETs), le routage joue un rôle essentiel pour assurer une transmission efficace des données. Les protocoles de routage géographique basés sur la position sont considérés comme les plus appropriés pour les VANETs, car ils utilisent les informations géographiques des nœuds sans nécessiter de découverte de route ni d'état des liens.

Dans cette étude, nous présentons une enquête sur les protocoles de routage dans les VANETs, en classant les différentes solutions existantes en quatre catégories principales : les protocoles de

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routing basés sur : la topologie, les clusters, cloud computing, la position et les protocoles de routage Geocast. Nous examinons également les limites des protocoles existants et proposons trois nouvelles solutions de routage.

La première solution est appelée " Local Traffic Density of Flow-oriented Routing Protocol for VANETs " (LTD-FOR) et améliore le protocole "traffic flow-oriented routing" (TFOR). LTD-FOR utilise la densité locale et la direction véhiculaire pour sélectionner la prochaine intersection, améliorant ainsi les performances de routage par rapport à TFOR.

Etant donné que le protocole de routage géographique basé sur l'intersection souffre d'une autre lacune liée à la collecte de statistiques du trafic routier, cette opération n'est effectuée que sur les premières intersections candidates de premier pas, tandis que les statistiques des intersections de n-pas sont complètement ignorées et cela peut provoquer une erreur dans le calcul de l'itinéraire optimal dans certains scénarios. Pour cela, nous proposons une deuxième approche appelée "A Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs (GRBRT-MI)". Cette approche utilise la connectivité du trafic collecté dans les intersections d'un et de deux-pas pour sélectionner la prochaine jonction, améliorant ainsi les performances de routage.

Enfin, pour bénéficier des avantages fournis par l'idée proposée dans la solution GRBRT-MI, notre dernier document propose une approche nommée "A Geographic Routing Based on Local Traffic Density and Multi-Hop Intersections in VANETs" (GRBLTD-MI). Cette approche utilise la densité de trafic local, la vitesse des véhicules, la distance inter-véhiculaire et la direction des véhicules pour calculer le score de la meilleure intersection suivante, en prenant en compte la connectivité multi-jonction.

Les simulations montrent que les nouvelles approches proposées (LTD-FOR, GRBRT-MI et GRBLTD-MI) surpassent les protocoles existants en termes de taux de livraison de paquets, de retard de bout en bout et de surcharge de paquets.

Ces résultats contribuent à améliorer le routage dans les VANETs, en visant à réaliser une communication inter-véhiculaire fiable et efficace, tout en prenant en compte les spécificités des réseaux VANETs et en exploitant les avantages offerts par les technologies émergentes.

Mots clés

Système de transport intelligent (ITS), villes intelligentes, VANET, communications V2V et V2I, routage géographique, intersections, densité de trafic, qualité des liaisons.

❖ Abstract

In vehicle ad hoc networks (VANETs), routing is crucial for efficient data transmission. Geographic routing protocols based on location information are particularly suitable for VANETs as they do not require route discovery or link state information.

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This study provides a comprehensive survey of routing protocols in VANETs, classifying existing solutions into four main categories: topology-based, cluster-based, cloud-based, position-based, and geocast. The limitations of current protocols are examined, and three new routing solutions are proposed.

The first solution, Local Traffic Density of Flow-oriented Routing Protocol for VANETs (LTD-FOR), enhances the Traffic Flow-Oriented Routing (TFOR) protocol. LTD-FOR incorporates local density and vehicular direction to select the next intersection, resulting in improved routing performance compared to TFOR.

Given that the intersection-based geographic routing protocol suffers from another shortcoming related to collecting road traffic statistics that is only done on the first hop candidate intersection, while the statistics of n-hop candidate intersections are completely ignored and this can cause an error in the calculation of the optimal itinerary in some city scenarios. To address this, a second approach called A Geographic Routing Based on Road Traffic and Multi-hop Intersections in VANETs (GRBRT-MI) is proposed. GRBRT-MI utilizes traffic connectivity data collected from one- and two-step intersections to determine the next junction, thereby enhancing routing performance.

Finally, in order to enhance the proposed solution GRBRT-MI. our last paper has been proposed as an approach named A Geographic Routing Based on Local Traffic Density and Multi-hop Intersections in VANETs (GRBLTD-MI). GRBLTD-MI takes into account local traffic density, vehicle speed, inter-vehicle distance, and vehicle direction to calculate the score of the best next intersection, considering multi-junction connectivity.

Simulation results demonstrate that the proposed approaches (LTD-FOR, GRBRT-MI, and GRBLTD-MI) outperform existing protocols in terms of packet delivery rate, end-to-end delay, and packet overhead.

These findings contribute to the improvement of routing in VANETs, with the aim of achieving reliable and efficient inter-vehicular communication. The specific characteristics of VANET networks are considered, and the advantages offered by emerging technologies are leveraged to optimize routing performance.

Keywords

Intelligent Transportation System (ITS), Smart Cities, VANET, V2V and V2I communications, Geographic Routing, Intersection-Based, Traffic Density, Link Quality.