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Presenated by:

**ZERROUKI HAYET**

Subject:

# *MAC protocol for vehicular adhoc*

Publicly defended on 06 March 2024, before the jury composed of

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# Résumé

Le protocole de contrôle d'accès au canal (MAC) pour les réseaux véhiculaires demeure un défi important pour la diffusion des messages de sécurité. En outre, les performances de réseau ne sont pas satisfaisantes en variant les conditions de traffic. Le groupement (clustering) est une technique efficace pour améliorer les performances du protocole MAC. Cependant, la latence et l'excédent générés par la formation et le maintient des groupes sont des obstacles courants à l'adoption massive de cette technique. À cette fin, nous proposons, comme première contribution, un système de regroupement des véhicules pour le reseau véhiculaire. En tirant parti de l'apprentissage par renforcement, notre système peut rapidement former des clusters conscients des conditions du réseau. En outre, notre système de regroupement basé sur l'apprentissage par renforcement assure une maintenance dynamique et coopérative pour les regroupements. L'efficacité de notre système est évaluée par des simulations approfondies, et les résultats de la simulation montrent l'efficacité de l'algorithme proposé. Les résultats de la simulation montrent que la proposition dépasse une approche précédemment développée et permet de séléctionner des chefs de cluster plus persistant avec des durées plus longues et des connexions plus stables avec leurs members.

Avec l'augmentation du nombre d'utilisateurs, l'attention est accordée à la qualité de l'expérience (QoE) et à l'allocation des ressources de canal dans IoV. C'est pourquoi nous proposons, comme deuxième contribution, un schema MAC basé sur la qualité de l'expérience et le clustering pour les reseaux véhiculaires. La proposition a pour objectif d'améliorer l'efficacité du réseau et la qualité du service qu'il fournit. Dans cette contribution, les véhicules sont organisés en groupes dans lesquels il y a un chef dans chaque groupe. Le chef de groupe est responsable de l'attribution des slots de temps, de la transmission des messages envoyés par les membres de leur cluster et de la planification des communications entre les clusters et à l'intérieur du cluster. L'efficacité du système est évaluée à travers diverses simulations. Les résultats de la simulation montrent que le protocole obtient un taux de collision plus faible et un débit plus élevé que le standard.

Le protocole MAC est souvent confronté au problème de la congestion du réseau. La congestion se produit généralement lorsque la capacité du réseau est inférieure à la charge du canal. Cela peut bloquer l'échange des messages et provoquer une latence supplémentaire. Pour atténuer cette situation, nous proposons comme troisième contribution un nouveau algorithm MAC d'évitement de congestion pour le reseau véhicullaire.  L'objectif de cette étude est de réduire la congestion des réseaux. Sur la base de la technique d'apprentissage du renforcement profond, nous proposons un nouveau schéma qui utilise plusieurs paramètres MAC pour éviter ou gérer la congestion de réseau détectée. Le schema proposé ajuste périodiquement les paramètres MAC en supervisant le comportement de la communication à proximité de chaque véhicule. De cette façon, il peut réduire les retards et le taux de collision d’une part, et augmenter le debit de l’échange de données d’autre part.

L’objectif principal de notre quatrième contribution est de minimizer la congestrion de reseau en minimisant la redundance des messages lors de la diffusion des messages d’accident. Nous avos utilize les message unicast au lieu des messages de diffusion (broadcast) permettant la communication multi-saut entre les véhicules et les serveurs. Les simulation de cette proposition ont montré l’éfficacité de cette contribution. Comme dernière contribution, nous avons propose un susteme de santé permettant de detecter des incidents relatifs aux état de santé des conducteur. Ce system permet la detection rapide des incident pour une prise en charge rapide. Il permet

également de gérer de manière efficace la recherche des ambulalnces et d’assurer les premiers soins tout en évitant des accidents de route.

# Abstract

The Medium Access Control (MAC) protocol in the vehicular networks is based on the standard 802.11p. It remains an important challenge for broadcasting safety messages. It gives unsatisfactory performance especially in various traffic conditions, and it is facing the problem of network congestion. Clustering is an efficient technique for achieving high scalability on Vehicular ad hoc networks. However, the latency and overhead generated from forming and maintaining clusters are common barriers to the mass adoption of this technique. To this end, we propose, at the first time, an efficient clustering scheme for Vehicular ad hoc networks. Leveraging reinforcement learning, our scheme can quickly form network condition-aware clusters. In addition, our Reinforcement Learning-Based Clustering scheme (RLBC) assures dynamic and cooperative maintenance for clusters. The effectiveness of our scheme is evaluated through extensive simulations, and the simulation results show the effectiveness of the proposed algorithm. The simulation results show that the RLBC outperforms a previously developed approach and allows for more persistent cluster heads with higher durations and stable connections with their members.

With the increase in users, attention is given to Quality of Experience and channel resource allocation in vehicular networks. This is why we propose, at the second time, an efficient aware Clustering MAC scheme. The purpose of is to improve the efficiency of the network and the quality of service it provides. In this contribution, vehicles are organized into clusters in which there is one cluster head in each group. The cluster head is responsible for attributing slots, forwarding the message sent by their cluster members and scheduling inter-cluster and intra-cluster communications. The efficiency of this scheme is evaluated through various simulations. The simulation results show that the proposed protocol achieves a lower collision ratio, higher throughput and lower delay.

Congestion usually occurs when network capacity is less than channel load. This can block the message exchange and cause additional latency and more collisions. To alleviate the situation, we propose at the third time an efficient congestion avoidance MAC scheme.  The aim of this study is to reduce network congestion and messaging overhead. Based on deep reinforcement learning technique, we propose a new scheme that uses several MAC parameters to avoid or manage detected network congestion. It adjusts the MAC parameters periodically by supervising the behavior of the communication in the vicinity of each vehicle. In this way, it can decrease delay and collision rate, and increase throughput.

The primary aim of our fourth contribution is to alleviate congestion by minimizing the redundancy of messages. This is accomplished through the utilization of unicast connections, enabling point-to-point communication between vehicles and nearby fog servers. Through simulations, this work demonstrates the significance of the proposed Vehicle Emergency Message Dissemination algorithm in enhancing safety applications. These simulation results show that the proposed algorithm outperforms an efficient work. At least, we propose a healthcare system which provides drivers with means to detect anomalies related to chronic diseases, as well as mechanisms to detect the occurrence of road accidents. Indeed, to offer drivers and pedestrians immediate emergency services, emergency messages are generated and sent to a remote server to request medical intervention from a nearby ambulance.

**Keywords**: MAC protocol; Clustering algorithms; Time division multiple access; Vehicular communication ; congestion control; QoE; Safety application; IoV;

# THESIS PUBLICATIONS

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Zerrouki, H., Moussaoui, S., Derder, A. et al. Reinforcement learning-based clustering scheme for the Internet of Vehicles. Ann. Telecommun. 76, 685–698 (2021).

## CONFERENCE PAPERS

Hayet. Zerrouki, Samira. Moussaoui and A. Boualouache, "Prediction-based Congestion Avoidance MAC Protocol for IoV (PCA-MAC)," 2022 First International Conference on Computer Communications and Intelligent Systems (I3CIS), Jijel, Algeria, 2022, pp. 123-127.

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# TABLE OF CONTENTS

# List of Figures

# List of Tables

# List of Abbreviations

VANETs: Vehicular ad hoc networks

IoV: the Internet of Vehicles

V2X: vehicle to everything

MANETs: mobile ad hoc networks

WAVE: Wireless Access in Vehicular Environments

RSUs: roadside units

QoS: quality of service

V2I: Vehicle-to-Infrastructure

V2V: vehicle to vehicle

MAC: Medium Access Control

PHY: physical layer

QoE: Quality of Experience

CCH: control channel

CSMA/CA: Carrier Sense Multiple Access with Collision Avoidance

TDMA: time division multiple access

CMs: cluster members

CH: Cluster head

RL: Reinforcement learning

DSRC: dedicated short-range communication

OBUs: onboard units

GAPC: global affinity propagation clustering

VEMD: an V2V-based emergency message dissemination scheme for internet of vehicles

SDSL: Safe drive safe live

# Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: ____ZERROUKI Hayet______

Date: ______16/10/2023_______________

# Chapter 1: Introduction

## 1.1 MOTIVATION

By collecting and sharing data, vehicular ad hoc networks aim to make roads safer and the driving experience more comfortable. They have advanced and developed significantly in the last few years by enabling communication between the vehicle and everything V2X. The Internet of Vehicles and V2X communication have the potential to revolutionize transportation by reducing congestion and improving the overall mobility experience. In this way, we can expect more innovations and applications that will shape the future of transportation. For example; fig. 1 illustrates the number of google researches including vehicle to everything given by google trends.

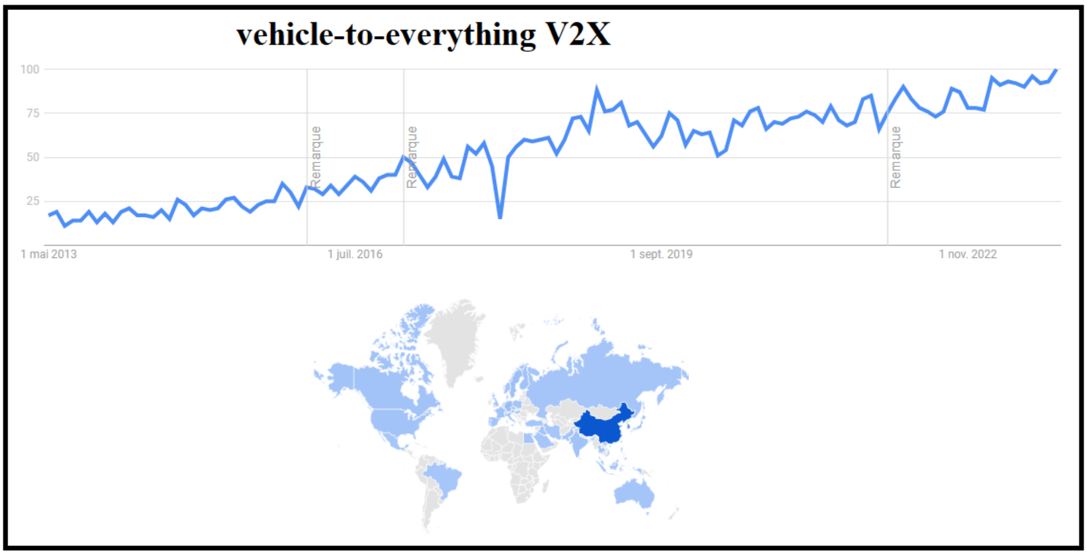


Figure 1 Number of google researches including Vehicle to everything as provided by Google Trends from 2013 to 2023.

In vehicular ad hoc networks, the number of vehicles can range from a low density of vehicles in rural zones to a very high density in urban networks. This large number of participating nodes creates a critical problem regarding the scalability of the proposed protocols. In addition, vehicles are not subject to power and storage limitations like in mobile ad hoc networks (MANETs) [1, 2]. However, these networks are very dynamic since vehicles change their positions constantly and rapidly. Consequently, network partitioning occurs very often. To address this problem, the Wireless Access in Vehicular Environments (WAVE) standard has been developed to provide wireless access for vehicles and deployed roadside units

(RSUs) [3,4]. Despite their demonstrated performance gains, the quality of service (QoS) of such networks significantly drops in high-density scenarios. This situation affects the functioning of IoV applications, especially critical safety applications. These applications have a set of minimum requirements related to the delay, communication range, and period of each message [5,6].

On the other hand, even though Vehicle-to-Infrastructure (V2I) networks allow highly stable communications in urban environments, they suffer from the high cost of infrastructure deployment and their unavailability on highways and in rural zones. In addition, vehicles on roads are not all connected to the Internet. As a result, the trend towards developing vehicle to vehicle (V2V) based protocols has become more popular [7-9].

Vehicles in IoV are communicating with each other through various technologies. The 802.11p and P1609 [3,4] are the major adopted technologies in IoV. These standards define the Medium Access Control (MAC) and physical layer (PHY) specifications. Similar to Vehicular Ad-hoc NETworks (VANETs), the Medium Access Control (MAC) is critical for IoV because it determines when the vehicle can transmit packets on the wireless channel. In addition, with the changing requirements of the MAC requests coming from IoVs in a highly dynamic topology, QoS management is lagging in achieving an acceptable level of satisfaction or Quality of Experience (QoE). Hence, a change in criterion from QoS to QoE based radio resource allocation has taken place in the vehicular network environment.

In view of the high rate of data transmission in this type of network, frequent disconnections, and high mobility of vehicles, IoV is facing the traffic congestion problem. This type of congestion leads to a significant loss of messages and causes transmission delays. Generally, congestion occurs when the density of vehicles is high or when the amount of exchanged data is very large. This appears when the network load becomes important especially in the control channel (CCH). A current contention-based MAC protocol which uses the standard 802.11p has drawback performance [10]. The CSMA/CA algorithm defined in 802.11p does not detect the congestion. It does not consider any method to manage congestion according to the network overload [11,4]. The problem in IoV networks is that the standard 802.11p [11] does not have an indication of heavy congestion. Vehicles are not informed of the state of network congestion. Therefore, it is important, before considering any congestion control mechanism, to correctly estimate the congestion level around a given vehicle. Furthermore, this will avoid a poor congestion control decision leading to degraded network performance. The current randomness when selecting the contention window in the 802.11p MAC protocol is not enough given the new constraints of applications in IoV, as well as the enormous amount of data to be shared on the network. Each vehicle reacts differently from the others, as the network load is not the same and depends on the position of each vehicle. The CSMA/CA algorithm ensures this constraint by enlarging the interval of the contention window, but this random method is not the optimal method to ensure QoS and acceptable latency for such network. Subsequently, a contention-based mechanism to access channels is not efficient in high-density traffic. A time division multiple access (TDMA) is highly used as a free-contention approach in VANETs. It has the advantages of bounded delay and high throughput, but it needs to assign time slots for each vehicle and it requires a long waiting delay before sending a long message. So, it is usually used with the standard 802.11p as a hybrid MAC protocol [12]. The hybrid MAC protocol combines the advantages of both 802.11p for slots allocation and TDMA for data transmission such as in [13] and [14]. It allows adaptive and efficient communication, making it well-suited for the challenging and rapidly changing vehicular environments. However, it is generally designed for small-scale networks with a limited number of vehicles. The hybrid MAC is facing different challenges: inefficiencies of bandwidth allocation, support of both safety and non-safety packet transmissions with high reliability at high traffic density, timeout of safety data delivery, and the need of a coordinator or a central entity to manage communication activities. In vehicular networks, the requirement for a coordinator without relying on infrastructure can be addressed through the use of Cluster-based Hybrid MAC protocols. These protocols utilize the concept of clustering, where vehicles are grouped into clusters, and each cluster has its cluster head as coordinator.

Clustering technique aims to form stable groups of communicating vehicles where the relative mobility is low. Although there are several clustering solutions in the literature, selecting cluster heads that allow for the establishment of reliable and stable cluster structures is still critical in the IoV. To achieve a stable clustering structure, certain aspects should be considered, such as high-density traffic [15], isolated vehicles at crossroads [16], and cluster head changes [17]. When the cluster head leaves its current cluster, it quits its CH role, and the cluster needs to be reformed. Due to the high mobility of vehicles, this situation can occur very frequently. This affects network performance in both highway and urban scenarios. For instance, during cluster maintenance process, much information sent by the cluster members to the previous CH can be lost. This can happen when a cluster member takes much time to join a new cluster or has considerably high overhead, large end-to-end delays, and low throughput. Hence, it is important to propose a method that avoids additional network overhead (control messages) and optimize opportunistic use of the radio resource allocation. In addition, the proposed method should take advantage of the existing standards instead of making full changes. Also, they should not focus on some limited network environment scenario and have to consider heavy traffic load.

## 1.2 KEY CONTRIBUTIONS

The main contributions of this thesis are summarized as follows:

- We propose an intelligent clustering scheme for vehicular ad hoc networks that aims to efficiently select cluster heads and avoid unnecessary cluster reformation to improve cluster stability. Our scheme leverages reinforcement learning (RL) to select the cluster head (CH) to ensure long-term cluster stability. Indeed, based only on received beacons, our scheme can learn a policy to select suitable CHs over time. In addition, the proposed reinforcement learning-based clustering scheme (RLBC) can efficiently predict the connectivity quality of cluster heads with their members and the link quality between each cluster member and its CH; this allows for dynamic and timely maintenance of the cluster structure with a low communication overhead.
- We introduce a new Clustering-based MAC protocol in which cluster heads may switch between 802.11p and TDMA to keep effective bandwidth exploitation. The proposed protocol called QoEC-based MAC improvises the QoE parameters in network on clustering approach.
- We propose an intelligent congestion control scheme for vehicular ad hoc networks that aims to efficiently select the appropriate handler to decrease network congestion level. This will avoid the extreme situation in which the network will be unable to broadcast the important messages. Our proposal is called prediction-based congestion avoidance MAC (PCA). It is easily integrated into the IEEE 802.11p standard without the need to change the standardized architecture of vehicular networks, while taking advantage of the internet servers available in the IoV. In addition, the PCA algorithm does not generate additional overhead for the operation of our scheme (control messages).
- We propose an V2V-based emergency message dissemination algorithm for internet of vehicles. The objective of this work is to enhance communication between vehicles by controlling network congestion. The proposed congestion control focusses on an improved management of the transmission mechanism for important messages, considering various data flow scenarios. This contribution is relied on the use of unicast messages and the proximity of vehicles to internet servers.
- We propose a health application for internet of vehicles. The objectives of this work are threefold. First, it aims to detect anomaly related to driver health, especially

cardiovascular diseases. Second, it resolves to save the driver's life by rapid searching an ambulance and primary health assistance. Third, it aims to reduce the risk of road accident due to the detected road anomaly.

## 1.3 ORGANIZATION OF THE THESIS

This thesis is structured into seven chapters.

- Chapter 1 introduces the whole thesis. It presents the motivation, the key contributions, and the organization of the thesis.
- Chapter 2 presents the MAC protocols for vehicular network. It provides an overview of vehicular networks. It gives an overview on the existing standards and related works.
- In Chapter 3, we propose the first contribution called reinforcement learning-based clustering scheme (RLBC).
- In Chapter 4, we propose the second contribution called QoE aware Clustering MAC protocol (QoEC-MAC).
- In Chapter 5, we present the third contribution called prediction-based congestion avoidance MAC (PCA).
- Chapter 6 presents both the fourth and the fifth contributions called VEMDS: An V2V-based emergency message dissemination scheme for internet of vehicles and SDSL: safe drive safe live respectively.
- In Chapter 7, we present conclusion, perspectives and future works.

# Chapter 2: Literature Review

## 2.1 INTRODUCTION

In this chapter, we will present the foundations of vehicular ad hoc networks, as well as its desired extensions known as Internet of Vehicles (IoV) networks. This chapter is divided into two distinct parts. In the part, we will focus on norms and standards. The second part will examine the MAC protocols, including their taxonomy and a short discussion.

## 2.2 VEHICULAR AD HOC NETWORKS

Vehicular ad hoc networks (VANETs) are becoming one of the most prominent and challenging area aiming to make roads safer and make driving more comfortable. They differ from other networks by their own characteristics in which vehicles change their positions constantly. In consequence, disconnect in networks occur very often. It is important to note that, vehicular networks have an important advantage over MANETs. Nodes in VANET are not subject to power and storage limitation as in mobile networks. They are designed for communication between vehicles and road-side units (RSUs) to improve road safety and traffic efficiency. In VANETs, communication between vehicles and RSUs is often established using wireless communication technologies, such as Wi-Fi, cellular networks, or dedicated short-range communication (DSRC) standards. Nowadays, the inclusion of vehicular Ad-hoc networks in the Internet of Things has received a significant interest. This combination introduces a new type of vehicular network called Internet of Vehicles [1]. IoV refers to intelligent communication between electronic devices, including vehicles, through the exchange of data stored in the cloud. It allows for optimal data processing thanks to permanent internet connectivity in vehicles and network devices.Each vehicle must enter the channel quickly and without interfering with any other vehicle. To ensure efficient and secure communication in VANETs, various MAC (Media Access Control) protocols have been proposed and developed. This chapter reviews the most used MAC protocols in VANETs.

## 2.3 STANDARDISATION IN VANET

Wireless Access in Vehicular Environments (WAVE) is a set of communication standards and protocols specifically designed for vehicular ad hoc networks (VANETs) and intelligent transportation systems (ITS). WAVE is standardized under the IEEE 802.11p and IEEE 1609 families of standards [3-4]. IEEE 802.11p defines the physical and MAC layer specifications, while IEEE 1609 encompasses the higher-layer protocols and messaging formats for vehicular communication (see Fig.2).

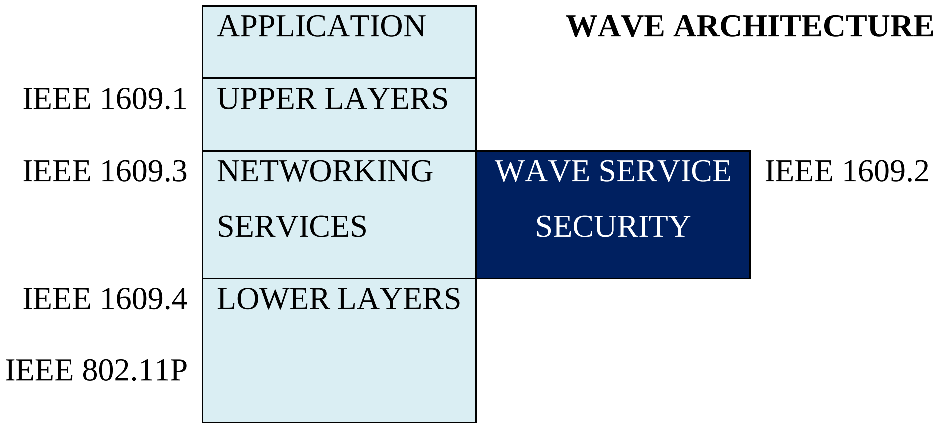


Figure 2 WAVE ARCHITECTURE.

### 2.2.1. DEDICATED SHORT RANGE COMMUNICATION (DSRC)

Dedicated Short Range Communication (DSRC) refers to a specific communication technology used in vehicular networks. DSRC operates in the 5.9 GHz frequency band. It is allocated seven 10 MHz channels for communication. These channels are used for various applications in Intelligent Transportation Systems (ITS) and vehicular communication [3-4]. Here are the details of the seven DSRC channels:

- **Control Channel (CCH): (**Channel 178) This channel is used for safety-critical and time-sensitive communication. It's primarily reserved for applications like vehicle-to-vehicle (V2V) safety messages. It consists the frequency 5.865 GHz. [4]
- **Service Channels (SCH):** They are used to transmit non safety messages such as personal information and parking information [3-4]. The six service channels are:
    - Channel 172: Frequency: 5.850 GHz.
    - Channel 174: Frequency: 5.855 GHz.
    - Channel 176: Frequency: 5.860 GHz.
    - Channel 180: Frequency: 5.870 GHz.

- Channel 182: Frequency: 5.875 GHz.
- Channel 184: Frequency: 5.880 GHz

### 2.2.2. IEEE 1609 FAMILIES OF STANDARDS

The Institute of Electrical and Electronics Engineers (IEEE) created a group of standards known as the IEEE 1609 family for wireless communication in moving vehicles. Common names for these standards are "IEEE 1609" or "Wireless Access in Vehicular Environments (WAVE)" standards. They are created to make it easier for vehicles to communicate with one another and with infrastructure, thereby improving safety and enabling a variety of applications in the transportation industries, particularly in the context of Intelligent Transportation Systems (ITS).[3-4].

IEEE 1609.1: This standard specifies the architecture and requirements for wireless access in vehicular environments.

IEEE 1609.2 (WAVE Security): This standard defines security services and mechanisms to protect communication within the vehicular environment. It outlines methods for message authentication, privacy, and integrity in V2V and V2I communication.

IEEE 1609.3 (WAVE Networking Services): This standard defines the networking services required for vehicular communication, including data exchange formats, addressing, and routing.

IEEE 1609.4 (Multi-Channel Operations): This standard specifies the operation of multiple channels for wireless communication in vehicular environments. It includes both Control Channel (CCH) and Service Channel (SCH) communication. It helps ensure reliable communication by utilizing multiple frequency channels. The synchronization interval (Fig.3) is a fundamental concept in IEEE 1609.4 which represents a sequence of frames. Each frame is partitioned in control channel interval (CCI) and service channel interval (SCI).

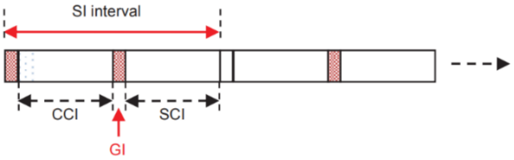


Figure 3  Synchronization interval (SI) format [2].

### 2.2.3. 802.11P MAC

This is a standardized MAC protocol for wireless communication in VANETs that is based on the IEEE 802.11 family of standards. It provides reliable communication between vehicles and RSUs in real-time, making it suitable for safety-critical applications [3-4]. More details about this standardization is given in sub section 2.2.1.

## 2.4 MAC PROTOCOLS FOR VANET

MAC protocols for VANETs can be divided into contention-based, contention-free and hybrid MACs protocols (see Fig.4). Many research studies have been proposed on the development of such protocols for cooperative diversity in IoV. This section presents an overview of recent MAC protocols for vehicular networks [12].

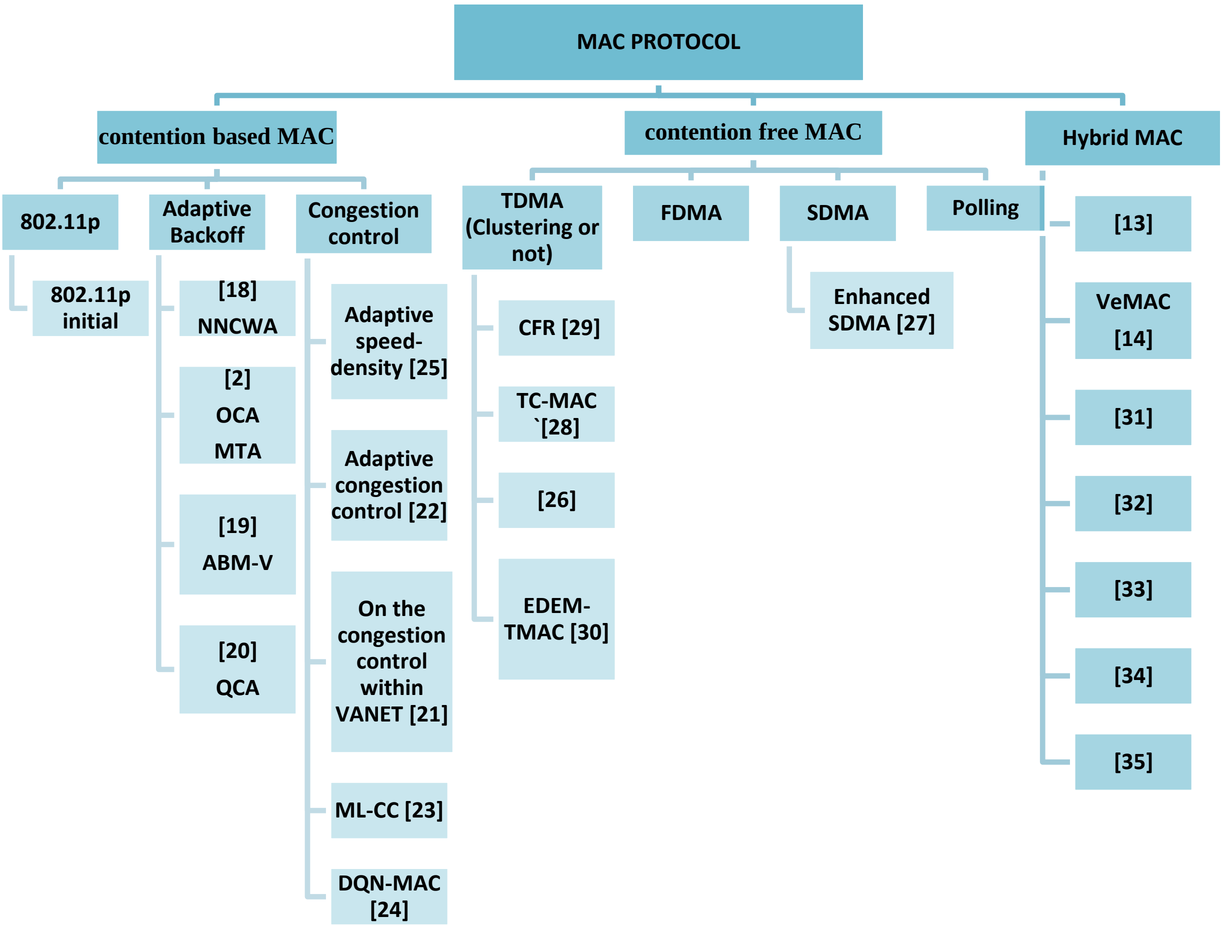


Figure 4 MAC protocols for VANETs.

### 2.3.1. MAC PROTOCOLS FOR VANET

Contention-based MAC (Medium Access Control) protocols are used in Vehicular Ad-hoc Networks (VANETs) to manage the communication between vehicles. The main aim of these protocols is to coordinate the access to the wireless medium in a decentralized manner, allowing multiple vehicles to communicate with each other in a fair and efficient way. In contention-based MAC protocols, multiple vehicles can simultaneously attempt to transmit data. The contention-based Medium Access Control (MAC) protocol in IEEE 802.11p is an integral component of the Wireless Access in Vehicular Environments (WAVE) standard. It is meticulously designed to address the unique challenges of communication in vehicular networks. Operating within the DSRC band, this MAC protocol relies on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to efficiently manage access to the shared wireless medium. It begins with Carrier Sense, wherein vehicles' onboard units (OBUs) continuously monitor the channel for activity. When the channel is deemed idle, a Distributed Inter-Frame Space (DIFS) is initiated to add a level of fairness, requiring a waiting period before transmission to reduce the risk of collisions. Subsequently, a randomized Backoff Procedure is employed, allowing OBUs to independently select a backoff timer value from a dynamically adjustable Contention Window (CW). This randomness in access times introduces an element of fairness while adapting to changing network conditions. Transmission begins when the backoff timer reaches zero and the channel remains free, ensuring that only one vehicle transmits at a time. Following data transmission, Acknowledgment (ACK) frames confirm successful data reception, and in the absence of ACKs, the protocol initiates a Backoff and Retry process to mitigate potential collisions.

- **Adaptive Backoff protocols**

Zerrouki et al. [18] present a simple algorithm for vehicular networks which tries to minimize the probability of collision, and to optimize the back-off distribution. They propose a dynamic adaptation of contention window (CW) size in order to achieve better throughput performance and lower average end-to-end delay. The CW is adapted according to the channel conditions by using the artificial neural network. Another work [2] focuses on the development of two algorithms to ensure equitable allocation of the Synchronization Interval (SI) for diverse applications. The first algorithm, named Optimal Channel Access (OCA), is designed to enable vehicles to access the channel with an optimal probability derived to maximize the successful transmission rate. The second algorithm, known as the Mobility and Topology Aware Algorithm (MTA), is an adaptive approach. It dynamically adjusts Dedicated Short-Range Communication (DSRC) parameters (contention window) based on the prevailing road and network conditions. Ma et al. [19] propose a novel approach called Adaptive Backoff Mechanism for Vehicular Ad Hoc Networks (ABM-V) to tackle the issue of broadcast storms in VANETs. In this work, The recipient evaluates the expected benefits and redundancies by analyzing the distribution of neighboring vehicles. Utilizing Dempster-Shafer evidence theory, the receiver dynamically adjusts the backoff time, ensuring more efficient use of network resources. Ultimately, the node with the shortest backoff time is chosen as the relay, responsible for retransmitting the packet to neighboring nodes. The authors in [20] introduce the Q-learning principle to the contention-based MAC protocol in VANETs. A proposed Q-learning-based collision avoidance (QCA) scheme uses a backoff reward model in Q-learning which resimes on inceasing and decreasing contention window value according to the reward and Q-learning policy. Also, this research leads to improved Quality of Service (QoS) performance by considering several factors such as traffic density, high mobility, service payload, and data rate.

- ***Congestion control in contention-based MAC protocols***

In the literature, there are several commonly used contention-based MAC protocols in VANETs, including congestion control strategies. Congestion control in Vehicular Ad Hoc Networks (VANETs) refers to the implementation of strategies and mechanisms to manage and mitigate network congestion [11]. Due to the rapidly changing topology and varying traffic patterns, vehicular networks are susceptible to congestion, which can lead to communication delays, packet loss, and reduced network efficiency. The goal of congestion control in VANETs is to prevent or alleviate congestion situations, ensuring that data packets are delivered reliably and within acceptable time frames.

Bouassida et al. [21] proposed a congestion control strategy by assigning message priorities. These are set based on message content and network status. Machine Learning Congestion Control (ML-CC), which is a centralized strategy that is based on congestion control management using the machine learning algorithm. It contains three units: the detection unit, the data control unit, and the congestion control unit.

The authors in [22] presented a dynamic adaption of the packet transmission rate that reduces collisions in the control channel CCH. In this work, the network congestion is detected using the occupation time channel CBT (Channel Busy Time). If the occupation time exceeds a predefined threshold, the channel is then considered congested. Thereafter, a signal will be sent by the MAC layer to the application layer to block all beacon messages. Although this proposal [22] is effective in terms of congestion control, stopping the sending of beacon messages can disrupt the progress of certain applications considerably.

The proposed approach [23] uses a learning method on the grouping of messages by RSUs. Although the simulation results have demonstrated the effectiveness of the solution proposed, the use of a single parameter and a single fixed threshold (equal to 70%) to detect congestion can degrade performance in some scenarios. In addition, the very high density as well as the dynamic mobility of vehicles can make the task of grouping messages in real time difficult for the RSU to handle. If the network is congested, the congestion also arises with the RSUs because the vehicles and the RSUs use the same channel to exchange data.

In [24], the authors proposed a Multiple Channel Access using Deep Reinforcement Learning for Congested Vehicular Networks. It uses a deep reinforcement learning model to adjust the value of the contention window according to the neighbor's rate and CW value. The authors of this work have shown the simulation results using 150 vehicles as the maximum value. This is not very realistic for congestion management. Moreover, we noticed that acting solely on the value of CW may prevent the proposed model from reaching its optimal performance.

Facchina et al. [25] proposed a strategy which consists in adjusting the transmission power based on network density through vehicle velocity. The main idea of this work is that the transmission power of each vehicle is calculated according to its speed. This approach has the advantage of being simple and easy to implement, but the congestion estimation is not reliable in all traffic scenarios. For example, in dangerous areas, vehicle velocity is low but does not necessarily reflect a high traffic density.

### 2.3.2. CONTENTION FREE MAC PROTOCOLS

Contention-free MAC (Medium Access Control) protocols are an alternative approach to manage the communication in Vehicular Ad-hoc Networks (VANETs) compared to the contention-based MAC protocols. In contention-free MAC protocols, there is no competition for channel access, and the transmission of data is generally scheduled and controlled by a centralized entity, such as a network coordinator or a cluster head [26].

The following are some contention-free MAC protocols studied in the literature: TDMA based protocols, FDMA based protocols, CDMA based, and Polling-based protocols. The most commonly used of them are TDMA based protocols. TDMA protocol divides the available bandwidth into time slots and assigns a specific slot to each vehicle for transmission. Vehicles can transmit data in their assigned slot without the risk of collisions.

The authors in [27] propose enhancements in the SDMA protocol for safety communication in VANETs. In this work, the road is divided into spatial slots. The TDMA time slots are assigned to each spatial location based on the traffic distribution. The slot allocation considers sparse traffic and the paucity of slots in congested traffic. The authors propose to use SINR (signal to noise and interference ratio) to maximize throughput. In [28], a new MAC algorithm for vehicular ad-hoc networks using a new method for TDMA slot reservation based on clustering of vehicles is presented. This paper integrates the centralization approach of cluster management and a new scheme for TDMA slot reservation. The idea of this work is to have vehicles listen to the control channel and the service channel during the same time cycle. Also, it is assumed that there are non-overlapping logical TDMA frames. The work presented in [29] proposes a novel near collision-free reservation (CFR) MAC that provides near collision-free scheduling in VANETs. In this scheme, each vehicle randomly reserves its time slots based on the traffic in its vicinity.

The authors in [ 26] propose a novel clustering-based contention-free MAC (CC-MAC) protocol to handle intra-cluster and inter-cluster transmission collision problems in VANETs. Depending on the position and mobility of the vehicles, different time division multiple access (TDMA) slots can be accessed by vehicles traveling in opposing directions. There is no consistent pattern used when assigning slots on CCH and SCHs. By reallocating the collided time slots in the same frame after monitoring the average number of vehicles depending on the projected cluster size, an effective control channel interval (CCHI) slot reallocation mechanism is used to reduce access collision. The authors in [30] propose a time division multiple access (TDMA) MAC protocol for efficient delivery of emergency messages (EDEM-TMAC) in VANETs. The idea of this work focuses toward the critical event which must be send by the node immediately when it occurs. They consider two types of emergency message (EM): Explicit EM and Implicit EM. The time slots were allocated dynamically using an even-odd scheme to address the issue of collisions between emergency messages and association request messages.

### 2.3.3. HYBRID MACS PROTOCOLS

Hybrid MAC protocols in vehicular networks integrate multiple access mechanisms to handle the diverse communication requirements and dynamic nature of the vehicular environment. These protocols aim to balance the trade-off between contention-based and contention-free access methods. The flexibility of Hybrid MAC protocols in VANETs allows for adaptive and efficient communication, making them well-suited for various applications, including traffic management, collision avoidance, and infotainment services.

Hang et al. [31] proposed a clustering-based MAC multichannel protocol (CMCP) using two transceivers, the first over TDMA and the second over EDCF 802.11, to support QoS for real-time safety messages and a variety of future multimedia. The MAC protocol within a cluster operates without contention, ensuring a seamless communication environment. Meanwhile, cluster-head vehicles use the contention-based IEEE 802.11 MAC protocol.

Borgonovo et al. [13] designed an ADHOC MAC protocol to prevent hidden and exposed terminal issues. The protocol is fully distributed and is based on TDMA, wherein each period of time is divided into different frames. Each frame is also portioned into several time slots for a vehicle to transmit its packets. The authors compared their protocol with IEEE 802.11p and claimed it is reliable. However, the ADHOC MAC protocol does not consider the seven DSRC channels in its scheme. Hassan et al. [14] resolved this issue by introducing a novel multichannel TDMA MAC protocol named VeMAC. To ensure that all vehicles have an equal chance of transmitting data, VeMAC requires that each vehicle access the control channel once for each frame. Every vehicle that successfully accesses a slot without colliding would periodically use the same slot in future frames. Subsequently, it has to broadcast its one-hop observed slot occupancy information. This is to inform all vehicles about the availability and occupancy of slots.

Chaurasia et al. [32] addressed the problem of cluster rupture and tried to solve it by introducing motion parameters in the MAC protocol. In addition, they use RSU, which handles the channel usage map to increase channel usage and prevent the hidden station issue. Singh et al. [33] proposed the dynamic control channel interval (DCI) MAC scheme to transport real-time safety messages by considering a multiple-channel contention-free technique and the dynamic interval of the CCH and SCHs. According to the current network traffic demand, this task breaks up the SCH's interval period into small time slots. The time division multiple access MAC protocol SCMAC, which is based on slotted competition, is introduced in [34]. Each time slot is divided into two segments by the protocol: the reserve period (RP) and the transmission period (TP). Prior to transmission in the TP, nodes compete in the RP to determine whether the channel can be used. The authors propose that nodes combine a black burst broadcast with a black burst experience. Therefore, nodes don't need to be given set times to access the channel; they just access the channel when necessary.

Yi Cao et al. [35] have proposed an adaptive high-throughput multi-channel MAC, AHT-MAC, to enable data transmissions over service channels (SCHs) in vehicular ad hoc networks. Therefore, the SCHs' transmission range is changed in accordance with the CCH's. The authors have developed a service resource block (SRB) management system that helps nodes locate the resources that are available to them and can be utilized to communicate with others. To fully utilize all SCHs, the authors proposed an SRB sharing mechanism in which nodes utilize all SCHs to achieve transmissions at a high data rate when the node density is low. On the other hand, nodes share their SCH resources when the density is high. In this way, rapid node density changes can be handled. Using two transceivers is proposed to use the CCH and SCHs at the same time, resulting in effective utilization of these channels.

### 2.4.1. SUMMARY AND DISCUSSION

In contention-based protocols, there is no requirement for a predefined schedule; instead, each node competes for channel access when it wants to transmit, with no assurance that it will be successful. This drawback is particularly significant in VANETs, which are created specifically to increase road safety. Therefore, it is particularly difficult to build an effective MAC protocol that complies with the QoS requirements of VANET applications. Contrarily, contention-free protocols can offer finite delays for real-time applications, but they also necessitate time synchronization between all of the network's nodes and the periodic exchange of control messages to keep the schedule table updated [26].

There have been numerous studies and surveys on contention-free MAC protocols for VANETs, and their effectiveness in different scenarios has been evaluated [29-26]. These studies have shown that contention-free MAC protocols can provide efficient and reliable communication in VANETs, especially in scenarios with high traffic density or strict delay constraints. However, they also have some disadvantages, such as increased overhead due to the centralized management and the need for a coordinator or a cluster head.

The hybrid MAC protocols utilize different combinations of channel access strategies to transmit both safety and non-safety messages. Generally, they combine TDMA with CSMA in two adjacent periods. This study [34] offers a survey on hybrid MAC protocols for VANETs. However, the authors agree that only a limited number of hybrid MAC protocols have tackled the important challenges as improving Quality of Service (QoS), enabling simultaneous multiple channel operation and merging collisions [34]. As illustrated in Table 1, most of existing MAC protocols for VANET focus on V2V communications because it represents the main communication type in vehicular networks. The authors in aforementioned protocols evaluate their scheme through simulation and few protocols uses analytical models to validate the proposal solution. In addition, safety Applications represent the most important interest on MAC protocols for VANETs. We can also see that there are many recent works on MAC protocols which means this area is still relevant and represents a vast research topic. However, limited protocols are interesting on QoS requirement as expected in table 1.

| **Parameters** | **Ref** | **Year** | **Channels** | **Density** | **Mobility** | **Application** | **Type** | **QoS** | **Simulator** | **Analytical Model** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Contention based Protocols**<br>*Backoff adaptation* | [18] | 2013 | Single | 150 vehicles | 80-108km/h | Safety Applications | V2V | / | NS2 | / |
| | [2] | 2015 | Multiple | 100 vehicles | 80-120km/h | Safety & non safety | V2V | / | NS2 | Back-off Markov chain |
| | [19] | 2023 | Single | 200 vehicles | 15-120km/h | safety | V2V | / | Python<br>SUMO | / |
| | [20] | 2023 | Single | 100 vehicles | 54-108km/h | safety | V2V | Yes | NS2 | Markov decision process |
| **Contention based Protocols**<br>*with*<br>*Congestion control* | [21] | 2008 | Multiple | 0 to 50 vehicles | Max 120km/h | Safety & non safety | V2V<br>V2I | / | not mentioned | / |
| | [22] | 2010 | Multiple | 70 Vehicles | / | safety Applications | V2V | Yes | a discrete-event driven simulator | / |
| | [23] | 2016 | Single | 50 to 500 vehicles | 0-40km/h | Safety & non safety | V2I<br>V2V | | NS2<br>MOVE<br>SUMO | / |
| | [24] | 2020 | Multiple | 50 to 150 vehicles | Max 57.6km/h | safety Applications | V2V | / | NS3<br>SUMO | Markov Decision Process MDP |
| | [25] | 2020 | Single | 309 vehicles | Max 50km/h | safety Applications | V2V | No | OMNet<br>VEINS<br>SUMO | / |
| **Contention free Protocols**<br>*TDMA*<br>*Or*<br>*SDMA* | [27] | 2012 | Multiple | 44-65 vehicles | 36-108km/h | Safety & non safety Applications | V2I<br>V2V | No | NCTUns<br>NGSIM | / |
| | [28] | 2012 | Multiple | 20-200 vehicles | Max 104km/h | Safety & non safety Applications | V2V | No | ns-3<br>IDM | / |
| | [29] | 2014 | Single CCH | 80-320 vehicles | Mean 100km/h | safety Applications | V2V | No | MATLAB | / |
| | [26] | 2022 | Multiple | 20-200 vehicles | Max 108km/h | Safety & non safety | V2V | No | OMNet<br>INET<br>SUMO | / |
| | [30] | 2020 | Single CCH | 4-188 vehicles | / | safety | V2V | No | OMNet | / |
| **Hybrid MAC protocols** | [13] | 2004 | Single | 50-100 vehicles | / | safety | V2V | No | / | / |
| | [14] | 2013 | Multiple | 80-600 Vehicles | 10-100km/h | Safety & non safety s | V2V<br>V2I | No | Matlab | Markov chain |
| | [31] | 2007 | Multiple | 72-240 vehicles | 72-180km/h | Safety & non safety | V2V | Yes | Matlab | delay and successful delivery rate |
| | [32] | 2019 | Multiple | 20-100 vehicles | 36-108km/h | Safety & non safety | V2V | No | MATLAB<br>NS2/Sumo | Stochastic Modeling |
| | [33] | 2019 | Multiple | 14-100 vehicles | / | Safety & non safety | V2V | No | / | optimum cchI /network traffic load |
| | [34] | 2020 | Single | 200-500 vehicles | / | Safety | V2V | / | / | / |
| | [35] | 2020 | Multiple | 87-378 vehicles | 50km/h | Safety & non safety Applications | V2V | No | NS3<br>SUMO | Yes |

Table 1 Comparison of various MAC protocols.

### 2.4.2. FUTURE RESEARCH DIRECTIONS

The MAC protocols employed in VANETs must be flexible enough to accommodate the frequent topology changes, high bandwidth requirements, high-speed vehicle mobility, and diverse quality-of-service (QoS) requirements. One of the most important goals is to develop an appropriate MAC protocol that allows for high throughput for applications other than safety while maintaining low latency and low collision.

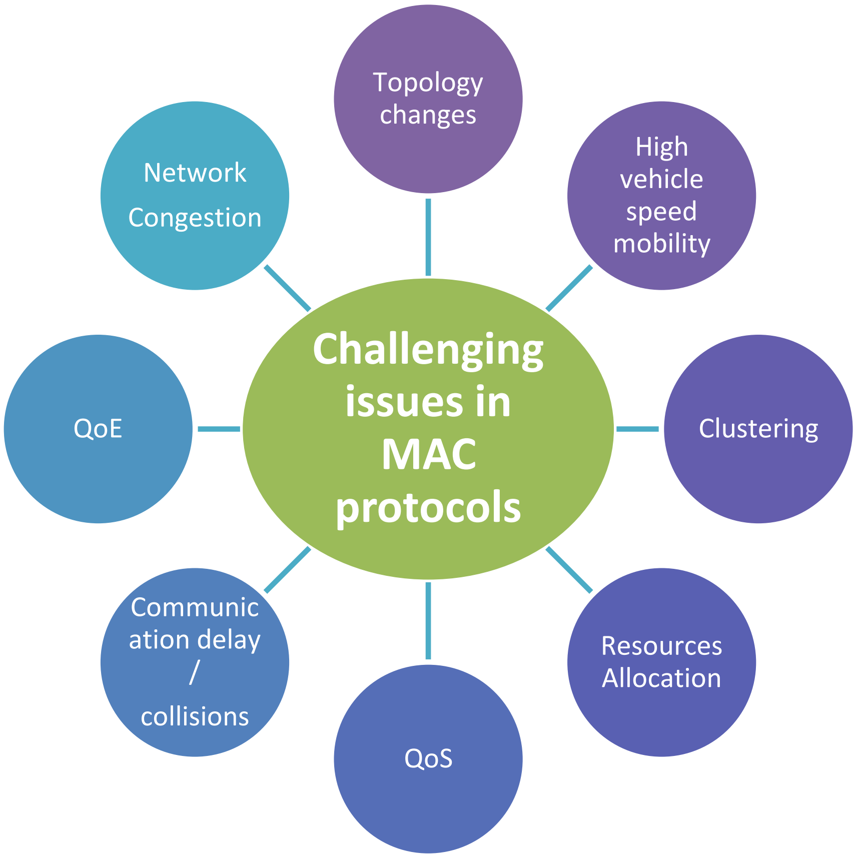


Figure 5 Challenging issues in MAC protocols for vehicular networks.

Recent developments in computer technology opened up vast possibilities of intelligent solutions for traffic safety, accessibility, and efficiency. Artificial

Intelligence (AI) is currently being used in various application domains because of its strong potential to enhance conventional data-traffic methods. In the area of Vehicular Ad hoc NETworks (VANETs), huge data is regularly collected from various sources. This data could be used for various purposes which include MAC parameters optimization, predicting and managing network congestion, predicting mobility and network topology, thereby improving safety, and quality of road experience (see Fig.5). Future VANET research opportunities may influence the full potential of Artificial Intelligence.

Although research has been done to enhance the performance of cluster-based TDMA in VANETs, there are still certain unresolved problems as a result of the quick changes in network topology that need more investigation. Despite the research efforts to improve the performance of cluster-based TDMA in VANETs, there remain some issues due to the rapid changes in network topology that require further study. First, cluster stability is a significant problem because MAC protocol performance decreases with cluster instability. In addition, each vehicle can join or leave a cluster at any time. The channel access schedule is lost if the vehicle is the cluster head, and message collisions will result. So, predicting which vehicle will replace the current cluster head should be investigated, especially given that it is possible to forecast a vehicle's path within a VANET. For this reason, we investigate in developing mechanisms for cluster formation and maintenance with more stability and less overhead. Our proposal study on that will be presented in chapter 3.

A time division multiple access (TDMA) is highly used as a free-contention approach in VANETs. TDMA has the advantages of bounded delay and high throughput, but it needs to assign time slots for each vehicle and it requires a long waiting delay before sending a message. So, it is usually used with the standard 802.11p as a hybrid MAC protocol. The hybrid MAC protocol combines the advantages of both 802.11p for slots allocation and TDMA. Two periods make up a frame in hybrid protocols, especially those that mix TDMA and CSMA. In order to reserve a time slot during the second period, vehicles communicate with one another or with a coordinator during the random-access period (first period), which is generally based on CSMA/CA. However, the behavior of the hybrid MAC protocols is significantly impacted by the fluctuating vehicle density brought on by high node mobility. This is due to the fact that these protocols' performance would suffer when there is a high vehicle density. In addition, several aforementioned works can improve the network performance to some extent. However, opportunities for further research and improvements still exist, particularly in achieving efficient and reliable communication in dense and dynamic vehicular networks. In fact, the packet transmission with stricter QoE requirements would be allocated with the bandwidth resources to improve service rate. For this reason, we investigate developing a new MAC hybrid protocol called QoE Clustering MAC protocol, which will be presented in chapter 4.

In summary, the choice of MAC protocol in VANETs depends on various factors, including the traffic characteristics, network size, communication requirements, and the trade-off between efficiency and overhead. Due to the new QoS requirements of internet of vehicles and the limitation of existing MAC protocols for VANETs, either new mechanisms must be developed, or these MAC protocols must be improved.

## 2.5 CONCLUSION

In this chapter, an overview of the existing MAC protocols in VANET are explained and discussed. Those protocols are presented based on their classification to provide some insights. The purpose of the MAC protocols in VANET is to enhance network performance in terms of delay, throughput and packet delivery ratio. The future research efforts need to consider traffic conditions to guarantee a reliable MAC protocol in VANET environment.

# Chapter 3: Reinforcement Learning-based Clustering Scheme for the Internet of Vehicles

## 3.1 INTRODUCTION

In general, vehicles move in linear flows and trend to form group structures on highways and congested urban roads. Each group (cluster) has its cluster head (CH) as coordinator and some CH' neighbours as cluster members (CM). Clustering creates small independent clusters with some similar properties which can ensure scalability and supports QoS. So, vehicles may be in CH or CM states. The ultimate purpose of any clustering scheme is to increase clusters' stability despite frequent changes in topology. Moreover, it should function in different density scenarios. A clustering process is generally composed of two steps: (a) the cluster formation procedure and (b) the cluster maintenance procedure. First, the vehicles are grouped based on some predefined rules using traffic mobility metrics, for instance, the direction of vehicle flow [15] or various network metrics, such as the antenna's power and the received signal strength indicator (RSSI) [36]. Subsequently, to ensure cluster maintenance, the cluster members periodically check their connectivity with the cluster head (CH). To avoid frequent cluster restructuring, prediction methods can be used. The main contributions of this chapter can be summarized as follows:

1- We propose a novel cooperative algorithm to improve the efficiency of cluster head decisions. To do so, we propose a "substates" attribute that allows each vehicle to switch between the cluster head and cluster member states without losing the role of its primary state. This aims to maintain a stable cluster structure and avoid unnecessary re-clustering.

2- We propose an algorithm using reinforcement learning to select the cluster head (CH) with the purpose of ensuring long-term cluster stability for vehicular ad hoc networks with a low communication overhead.

3- We introduce a new cluster connectivity prediction algorithm to enhance system performance using reinforcement learning.

The rest of this chapter is organized as follows: Related works are presented in section (3.2). The RLBC protocol is explained in section (3.3). The proposed protocol is presented in section (3.4). Simulation results are discussed in section (3.5). Finally, section (3.6) concludes the chapter.

## 3.2 AN OVERVIEW OF CLUSTERING METHODS IN VEHICULAR NETWORKS

Clustering approaches consist of making topology smaller and more hierarchical [7-9]. However, clustering remains a challenging issue for vehicular ad hoc networks due to congested traffic, which causes/leads to channel overhead [8]. Various clustering algorithms have been proposed in the literature, and most of these protocols use information related to the current position, future position, node velocity, variance of the node velocity relative to that of each of its neighbors, and vehicle direction [31,8,9]. The differences between these protocols are based on how the position information is used. The main idea behind these works is to only group vehicles with similar moving speeds in the same cluster. Lin et al. [45] proposed a clustering algorithm for MANETs based on node IDs to support multimedia traffic. Similarly, the authors in [46] extended the lowest ID algorithm by introducing the relative mobility between each pair of nodes using the signal power level mobility metric. This study has served as a referential algorithm for comparisons with many other solutions [47,48,9]. Hang et al. [31] proposed a clustering-based MAC multichannel protocol (CMCP). The selection of the cluster head is determined by sending ITJ (Invite to Join) messages, and vehicles that receive ITJ messages join the cluster. The scheme considers the WAVE 802.11p standard of VANETs. However, the main shortcoming of this technique is the cluster lifetime, which is not enhanced due to the randomness of the cluster head selection process. The authors in [49] presented a state-based clustering algorithm (SBCA) for VANETs to increase the lifetime of the clustering architecture. They considered the selection of the second cluster head (SCH) for each cluster as a reserve for the primary cluster head (PCH). This formalism is similar to that proposed in [31], except for the case when the CH is in the transmission range of another CH; moreover, a weighted factor based on velocity differences between the CH and its members was added to the neighboring nodes to determine which one was selected. In [8], the authors proposed a distributed and mobility-aware cluster based on the MAC protocol (DMMAC) for driver behavior that estimates the future positions and velocities of vehicles. To preserve the cluster topology for as long as possible, the authors extended the MAC clustering protocol by adding a learning mechanism, where a fuzzy logic inference system (FIS) was applied to predict the future positions and speeds of nodes. In [9], the authors proposed a modified version of mobility-based MAC clustering called APROVE. This protocol relies on the affinity propagation algorithm, which is considered a fast clustering algorithm. In this protocol, availability and responsibility information is used, where each vehicle can choose a vehicle among its adjacent nodes as its exemplar [49]. The similarity function used in [9] contains the inter-distance and speed variations. Even if this protocol permits an increased lifetime, the overhead remains important when considering the VANET environment. Furthermore, the convergence time is very long due to the exchange of affinity messages, and the CH selection procedure is frequently called. In [16], Huo et al. proposed a novel clustering scheme called enhanced low overhead and stable clustering (EnLOSC) for crossroads in VANETs by combining two nearby clusters with a small cluster size metric. To improve communication quality, the authors considered both vehicle transmission power loss and mobility in the clustering maintenance phase. An extended cluster formation procedure was proposed in [17] by introducing a "temporary cluster head", with the aim of increasing cluster stability. They also designed a cluster merging procedure. When two CHs hear each other based on the distance between them, a predefined threshold is defined to avoid frequent re-clustering. In [7], the authors proposed an adaptive mobility, and range-based clustering (AMRBC) protocol using velocity, position and transmission range in the cluster head selection process. In this work, the number of vehicles in a cluster was computed and maximized to improve network reliability. Xiang et al. [50] proposed the global affinity propagation clustering (GAPC) algorithm by considering the future position, velocity, current communication rate, and required communication rate of each vehicle in the similarity function. They adopted the concept of normal neighbors to represent vehicles within the defined communication range instead of abnormal neighbors. In addition, vehicle members in this work chose to join the cluster with the lowest compound estimation value to improve cluster stability.

The aforementioned works improve the cluster stability to some extent. Several methods are based on predicting the future positions and destinations of vehicles during cluster formation. Thus, vehicle re-clustering due to mobility changes cannot be detected and handled by such methods. In [16], the authors addressed this problem by considering the predicted "stay time" of a cluster member (CM) after it joins the cluster. Therefore, the cluster head can recommend some candidate members to become cluster heads based on the future cluster size and the density of the nodes. However, detecting future disconnections with the CH in advance has not yet been considered.

## 3.3 REINFORCEMENT LEARNING

In the literature, there are various algorithms for learning problems that can broadly be divided into three classes: supervised learning, unsupervised learning, and reinforcement learning algorithms. We choose reinforcement learning (RL) in this work for two reasons. First, RL is an artificial intelligence approach [39] that is often applied to dynamic environments. Therefore, it allows us to determine an optimal decision without using a predefined set of training data, unlike in deep learning, neural networks, and other learning algorithms. Second, it is difficult to select the cluster head using supervised learning due to topological changes in IoV networks. Hence, RL is the most suitable prediction model that will enable the accurate selection of cluster heads.

The agent observes and learns about the environment and makes decisions that are represented as actions. The idea behind the RL algorithm is that the agent observes its delayed reward and estimates its long-term reward. The RL algorithm includes a state S, an action A and a reward R. The state is the decision-making factor observed by the agent in the environment. The action is a choice that an agent makes to learn and thus improve its reward. The reward is the positive or the negative result of the decision made in the previous time instant. It is the variable to be maximized. Considering each vehicle as an agent that interacts with the network environment is consistent with the theory of reinforcement learning. Each vehicle becomes CH or selects the best CH from among its neighbors. It aims to maximize its reward to increase its stable connectivity with each neighbor. To do so, it observes the network environment in its area, learns its reward, and performs an action to improve the reward in the next time instant. In this contribution, we consider each vehicle as an agent. The action $A_t$ is the vehicle identity to be chosen from the neighbor vehicles as a cluster head candidate. The agent can choose itself as a cluster head candidate. The reward $R_t$ represents the cluster stability metric to be maximized (fig.6). The state St represents the vehicle substates (Undecided, Temporary-CH, and Temporary-CM). If the agent vehicle selects one neighbor to be CH candidate as the action, the state $S_{t+1}$ becomes Temporary-CM. Otherwise, if it selects itself as a cluster head candidate (as the action), the state St+1 turns to Temporary-CH. The Q-table contains all Q-values $Q(S_t, A_t)$ that represent the impact of choosing the action $A_t$ while the vehicle is in the state $S_t$. Furthermore, the Q-table enables a vehicle to choose its next optimal action by considering the maximal value in the Q-table when the vehicle is in the state $S_t$. In this work, the future value $Q(S_{t+1}, A_{t+1})$ of an action $A_{t+1}$ given the state $S_{t+1}$ at the current time t+1 is updated based on the value of the previous state Q(St, At) and a learning rate. The updated Q-value is based on the epsilon greedy strategy that is used in the reinforcement learning concept. We note that the first action is obtained through computing two factors before running the Q-learning algorithm. This allows accelerating the exploitation of the environment rather than the exploration, and so, avoiding that the vehicle randomly choose actions, since it is not aware of its environment. Further details can be found in section 3.5.1. $Q(S_{t+1}, A_t)$ can be given as:

$$Q(S_{t+1}, A_{t+1}) \leftarrow Q(S_t, A_t) + \alpha R_{t+1} \tag{1}$$

where α is the learning rate at which the Q values can change with a dynamic network topology. It determines the impact of the received reward from the environment (feedback) on the current Q-value. The parameter α value selection is explained in section 3.6. "$R_{t+1}$" represents the expected immediate reward of executing action $A_{t+1}$ at state $S_{t+1}$. The learning process is improved by each agent until an optimal policy is established. More details will be presented in section 3.5.

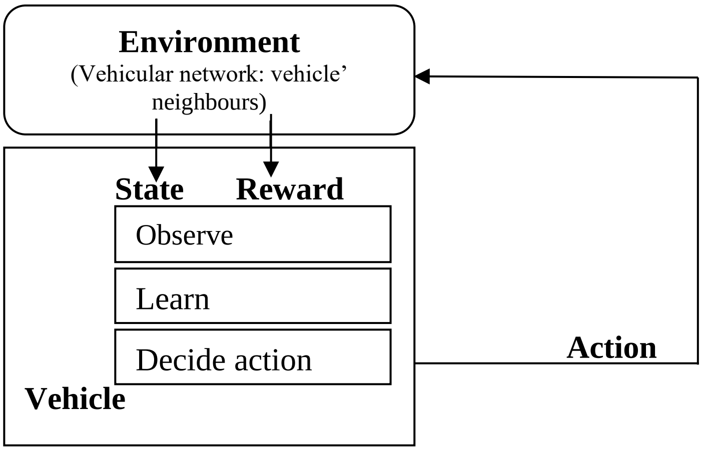


Figure 6 Reinforcement learning and its representation in the RLBC algorithm.

## 3.4 SYSTEM MODEL

Each vehicle in the network is equipped with an IEEE 802.11p on-board unit (OBU) device, which allows inter-vehicular communications. It implements the WAVE 1609.4 protocol for multichannel operations. Therefore, CCH and SCH channel switching are enabled for all vehicles. We assume that a vehicle knows its location using GPS. The time clock is obtained through Coordinated Universal Time (UTC). We also assume that each vehicle is assigned a distinct ID. During the CCH interval, each vehicle is tuned to the control channel, so it can discover the neighboring vehicles in its vicinity through periodic beacon messages. We exploit optional fields of standardized beacons (WAVE short message (WSM)) [51] to send two extra parameters: the sub-state (SS) and complementary information (CI). These two additional fields are coded in 2 bytes and used for the cluster management procedures (see Fig. 7). They will be explained further in the following sections. The occurrence of the beacon message is assumed to be a uniform distribution. The vehicles send packets with a unified transmission power Pt. The following fields represent the notations used in this work (Table 2).

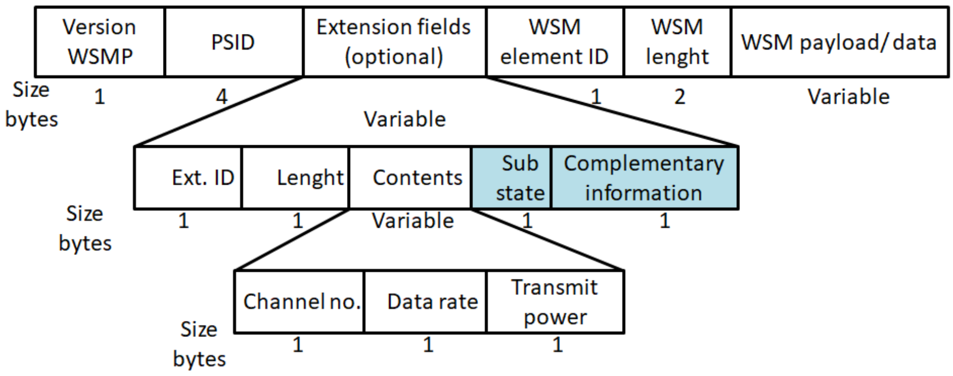


Figure 7 WAVE short message (WSM) with the extra parameters SS and CI [27].

Table 2 Notations used in RLBC protocol.

| Notation | Description |
|---|---|
| Vi: | Vehicle identifier |
| $N_i$: | Number of neighbors of Vi |
| $N_{rb}^{j}$: | Number of received beacon messages by vehicle i from vehicle j |
| $T_{rb}(k)$: | Time reception of the kth beacon message. |

## 3.5 REINFORCEMENT LEARNING-BASED CLUSTERING SCHEME

The main goal of our clustering scheme is to avoid frequent vehicle re-clustering caused by the unpredictable behaviors of the member vehicles. Communication channels become quickly congested in high-density scenarios. Therefore, our protocol aims to establish highly stable clusters with long lifetimes and minimum overhead.

In what follows, we present the RLBC scheme. RLBC is based on dividing vehicles into clusters. Each cluster has one cluster head (CH) and a number of ordinary vehicles as their members (CM). The proposed scheme is composed of three procedures:

(i) Reinforcement learning-based cluster formation procedure.

(ii) Inter-cluster connectivity prediction procedure.

(iii) Real-time cluster maintenance procedure.

The CH should be selected as the vehicle having the highest communication stability with its neighbors. In the literature, this is achieved by computing a predefined factor using one or multiple metrics, such as position and velocity. The problem with such a method is that before running a cluster formation procedure, it is not possible to obtain an overview of the cluster connectivity and its future behavior. It is clear that a particular condition for a vehicle to be selected as a cluster head may not be satisfied over time. Therefore, a suitable cluster head may become unsuitable. To address this issue, each vehicle in the proposed algorithm estimates its ability to be a CH. It proposes a suitable neighbor to be the CH if it is not able to be one itself. Subsequently, we propose a new cooperative algorithm based on reinforcement learning able to select suitable cluster heads in a short period of time.

We propose using the notion of “sub-states”. To do so, we distinguish between two kinds of node states: “primary” states and “sub”-states. Each “primary” state includes several “sub”-states. There are three “primary” states: cluster head, cluster member and undecided. Fig. 8 describes these states and their transitions. Sub-states describe the predicted future primary states. A vehicle can switch from one sub-state to another without losing the role of its primary state (cluster head or cluster member). By using this strategy, we aim to maintain a stable cluster structure by avoiding unnecessary re-clustering. In fact, many existing strategies in the literature suggest that the cluster head selection process starts when the cluster head becomes unreachable or when there is a different member that has the best connectivity with its neighbors. In the RLBC algorithm, each cluster head periodically evaluates the connectivity with its members. The cluster members also evaluate their connectivity with their cluster head. The connectivity evaluation is carried out in each vehicle. It is based only on auto-acquired or received data. Each vehicle updates its sub-state according to its connectivity with its fellow cluster members and its CH.

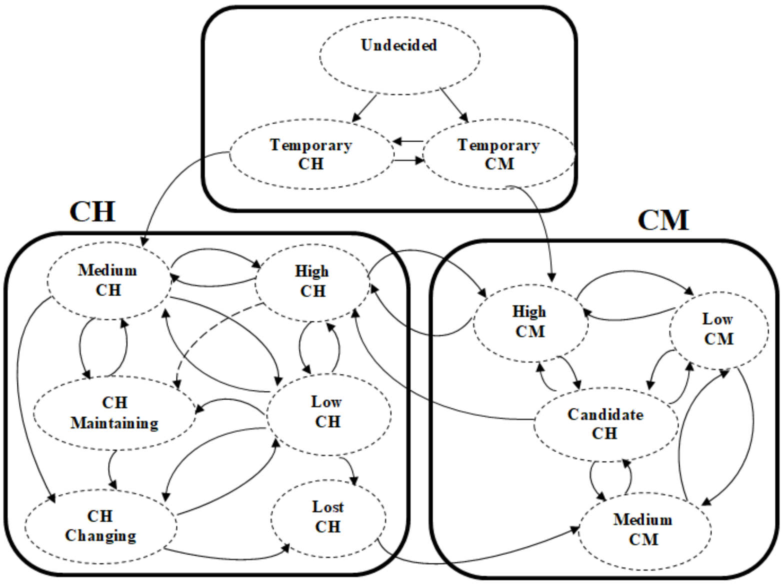


Figure 8 State transitions the in RLBC algorithm.

Our proposal offers three advantages:

(i) It provides information about the future changes in the network topology.

(ii) It proposes real-time interactions between CHs and their members (CMs) regarding the future behaviors of clusters. A CM may confirm or deny its connection with its CH or may recommend some neighbors as CH candidates. Therefore, the protocol is highly suitable for VANET environments.

(iii) It reduces the amount of network overhead. The “sub”-state attribute is used by each vehicle to periodically announce its current and future states to its neighbors. This reduces message collisions because the cluster member can be informed about the behavior of its cluster head in advance. More details will be presented in the following subsections.

### 3.5.1. Cluster Formation procedure

Initially, all vehicles are in the “undecided” state. Before running the cluster formation procedure, each vehicle performs a preliminary test to check whether it is able to become a cluster head or select one of its neighbors as a cluster head candidate. To do so, each vehicle “i”, after receiving a sufficient number of beacon messages Tcollect, computes clustering factor CFij for every neighbor j as well as its own self-clustering factor CFii. The CFij and CFii factors reflect the communication stability between Vi and Vj and between Vi and its neighbors, respectively. To calculate these factors, we use two metrics: the number of received beacon messages from a neighbor j ($N_{rb}^{j}$) and the average time period between the reception of two consecutive beacon messages from the same neighbor $T_{rb}(k) - T_{rb}(k-1)$. These factors are initially used to select a suitable vehicle among the neighbors to be the cluster head for vehicle i. Thus, vehicle Vi selects the identity of a neighbor Vj having the lowerst CFij as the cluster head candidate and sets its sub-state as “temporary CM”. Otherwise, if vehicle “i” finds that its CFii is lower than all CFij values, it considers itself the CH and sets its sub-state as “temporary CH”. The obtained vehicle identity is set in the CI attribute. The sub-state and CI attributes are broadcast in the next beacon messages. Subsequently, vehicle “i” computes its Q-value and periodically updates the Q-table to optimize its future actions.

$$CF_{ij} = \sum_{k=1}^{N_{rb}^{j}} \left( \frac{\left| T_{rb}(k) - T_{rb}(k-1) \right|}{N_{rb}^{j}} \right) \tag{2}$$

$$CF_{ii} = \frac{1}{N_i} \sum_{j=0}^{N_i} \sum_{k=1}^{N_{rb}^{j}} \left( \frac{\left| T_{rb}(k) - T_{rb}(k-1) \right|}{N_{rb}^{j}} \right) \tag{3}$$

The temporary CH turns into a cluster head if the reward is higher than a threshold Thf. Otherwise, it must wait until it finds a more suitable cluster head. In this case, it changes its state to “cluster member” and terminates the cluster formation procedure. The selection of a cluster head is guaranteed by the convergence of the Q-learning algorithm due to the following three situations. First, a temporary CH can select itself as a cluster head if it is approved by the majority of neighbors. Second, if more than one cluster head is selected simultaneously, they execute the cluster merging algorithm, and one of them is maintained in the next period. Third, if no cluster head is selected, vehicles continue to run the Q-learning cluster formation procedure until the algorithm converges. The probability of selecting one cluster head in a short time period is high due to the deterministic nature of the Q-learning algorithm. In addition, the two metrics used in the cluster formation procedure aim to distinguish a suitable vehicle from the others. However, in the worst situation, each vehicle with the “temporary CH” sub-state turns into a CH after a long training period Tfe. The utility of using the threshold value Thf is in maintaining stable clusters and accelerating the cluster formation procedure. The value of the threshold is selected to semantically discern clusters with good connectivity from others (see Fig. 9).

```
Algorithm 1. Cluster formation algorithm
Each vehicle $V_i$,
Computes CFij and CFii using equations (2) and (3)
Selects action i //vehicle identity
loop  // Every CIf (cluster interval formation), vehicle i will:
Compute reward $R_{t+1}$ using equation (4)
Update Q-value $Q_{t+1}(a_i)$ using equation (1)
Select action a
$V\pi^*(S_t) = \max a \in A\, Q_t(S_t, a)$
if ($R_{t+1}$ > Thf and sub-state = temporary-CH)   sub-state = CH and exit
      else   if (current_time> Tfe   and sub-state = temporary-CH)
                                    sub-state = CH and exit
             else
                    if (sub-state = temporary-CM and neighbor in
                                       CH  sub-state exists)
                         sub-state = CH and exit
                     End if
             End if
End if
end loop
end
```

Figure 9 Pseudocode of the cluster formation algorithm.

A cluster head does not send an ACK to any vehicle member to reduce overhead. However, the algorithm selects a suitable CH, and its identity is periodically broadcast in beacon messages. Subsequently, a selected CH is joined by all vehicle members having this CH's identity in their CI attributes. Therefore, a CM confirms its membership once its CH changes its primary state to "cluster head". Similarly, the temporary CM updates its primary state to "cluster member". Therefore, we consider that both the CM and CH states are the final states of cluster formation. The reward and the Q-value are calculated using equations (1) and (4).

$$R_{t+1} = \frac{\text{Number of neigbors selecting vehicle "i" in their CI attributes}}{\text{the neighborhood table size}} \qquad (4)$$

### 3.5.2. Cluster Connectivity prediction algorithm

In most clustering schemes, when a cluster member determines that it has better connectivity than its current cluster head, it starts forming its own cluster. Consequently, the old cluster head gives up its role and becomes a normal cluster member. Therefore, cluster head changes become very frequent, especially in highly dynamic network topologies. Our goal is to detect these small changes to avoid unnecessary cluster reformation and help the cluster head make appropriate decisions about the cluster structure. Hence, we adopt the notion of "sub-state" described above, which indicates the connectivity quality inside each cluster. The substate value is an approximation of the future topology changes and the future quality of communication between the CH and its members. As mentioned below, the sub-state values for the CH primary state are high CH, medium CH and low CH. Transitions between these values are based on a factor called the connectivity level (CL). The connectivity level is computed constantly by each CH to predict the stability of the cluster observed in its vicinity. By taking advantage of the principle of reinforcement learning, the CH computes its CL value according to the last value of CL, the new received feedback from its members (CMsReward) and its self-reward (CHreward). The parameter β represents the impact of the CH self-evaluation connectivity with its members. The parameter 1- β represents the impact of the previous CL value on the new one. The parameter γ represents the impact of the received feedback from cluster members on the new CL value. (see Fig. 10). The motivation of selecting these parameters values is explained in section 3.6. A CH with the minimum communication instabilities with its members is most suitable for continuing the coordination of the cluster. When the CH detects the presence of non-member vehicles in its communication range, it has additional difficulties managing its cluster and becomes an unsatisfactory CH.

```
Algorithm 2. Cluster Connectivity prediction algorithm
loop  // Every CPI (cluster prediction interval), cluster head i will verify:
CHreward = 0
For every neighbor vehicle Vj, do

    if Vj = member of Vi and current_time>Texpire, j
        then CHreward = CHreward -2

    if Vj = member of Vi and current_time<Texpire, j
        then CHreward = CHreward + 1

    if Vj ≠ member of Vi
        then CHreward = CHreward -1
end for
CHreward= CHreward/ Ni
end loop

CMsReward = number of cluster members in substate “high CM” / Ni
CL = (1 – β) CL + β * CHreward + γ * CMsReward
End
```

Figure 10 Pseudocode of the cluster connectivity prediction algorithm.

The cluster head changes its sub-state according to its connectivity level (CL) value. The higher the CL value is, the more stable the cluster is. Some empirical thresholds are used, and the possible CH sub-state changes are as follows:

$$\text{CH Sub-State} = \begin{cases} \text{High CH} \qquad \text{CL} > \text{Th}_\text{b} \\ \text{Medium CH} \qquad \text{Th}_\text{a} < CL < \text{Th}_\text{b} \\ \text{Low CHCL} < \text{Th}_\text{a} \end{cases} \tag{5}$$

Similarly, each cluster member Vi computes its CL value whenever possible. This CL is computed through the average rate of received messages over time as follows:

$$\mathrm{CL(CM)_i} = \left(\frac{\mathrm{N_{rb}^{j}} * \mathrm{I_{beacon}^{\square}}}{\mathrm{T_{ij}^{com}}}\right) \tag{6}$$

Sub-state transitions are also based on the computed CL values and some thresholds, as illustrated below:

$$\text{CM Sub-State} = \begin{cases} \text{High CM} & \mathrm{CL} > \mathrm{Th_d} \\ \text{Average CM} & \mathrm{Th_c} < CL < \mathrm{Th_d} \\ \text{Low CM} & \mathrm{CL} < \mathrm{Th_c} \end{cases} \tag{7}$$

### 3.5.3. Real-Time Cluster Maintenance procedure

This section describes how network clustering is maintained, and the primary state of each vehicle is changed according to the interactions between the CH and its CMs using their sub-state and CI attributes. The sub-state attribute allows the cluster head to be informed about its communication quality with its members. Complementary information (CI) allows the CH to glean additional information about the structure of its cluster. CI is also helpful for CMs in various situations. The proposed real-time cluster maintenance algorithm is triggered periodically by each vehicle in the cluster. The cluster maintenance procedure is described as follows.

a. cluster merging

At any stage, if a CH finds that there is another CH in its transmission range and observes that it is not selected by the majority of its members, it waits for a determined period of time. In parallel, it adds the identity of the vehicle selected by most members as an alternative CH candidate in its CI attribute. It also sets its sub-state to “CH-changing” and broadcasts its CI and sub-state in the next beacon messages. In contrast, if it is still selected as the CH by the majority of its members, it temporarily sets its sub-state to “CH-maintaining” to inform the other CHs and members that it is keeping its role. A CH in the “CH-changing” sub-state must change its state to “cluster member” if the other CHs in its vicinity are in the “CH-maintaining” sub-state. After that, the CH in the “CH-maintaining” sub-state changes its sub-state to “high-CH”. Otherwise, it runs the cluster formation procedure again because a non-CH is selected by the majority of CMs, and forming new clusters is most suitable to guarantee cluster stability.

b. cluster polling

When a CH is in the “low” sub-state, we can distinguish two situations: congested situation and non-congested situation.

- The congested situation:
  This situation occurs when the cluster members confirm their membership with this cluster head but the network is congested. In this case, using our cluster maintenance procedure, it is not necessary to change the cluster head because doing so probably would not optimize the performance of the network.
- The non-congested situation:
  In this situation, when the connectivity levels between the CH and its members are low; hence, changing the CH is inevitable. To address both situations, the cluster head waits for a short period of time "Twait", enabling the cluster members to approve their membership with the cluster head.

In both situations, each cluster member finds its CH is in the "low" sub-state. So, it considers that the CH is about to leave its cluster or that the cluster connectivity is poor. Therefore, the cluster poling procedure is executed according to the following steps:

1. Each cluster member recalculates its connectivity level according to equation (6) and updates its sub state (if necessary), as described in equation (7).
2. If a CM's updated sub-state is "medium" or "high", then this CM maintains its membership with its CH by broadcasting the "high CM" sub-state in the next beacon messages. Otherwise, if the CM's updated sub-state is "low", it recomputes its $\mathrm{CF_{ij}}$. and its $\mathrm{CF_{ii}}$ and chooses itself or one vehicle among its neighbors as a CH candidate (similar to the cluster formation procedure). Subsequently, it broadcasts the identity of the selected vehicle in its CI attribute and sets its sub-state to "Candidate-CH" or "low CM" according to the selected vehicle's ID.
3. When the waiting time period Twait expires, a cluster head in the "low" sub-state enables CMs to confirm their membership, and it analyze its neighborhood list to confirm its primary state as "CH". Thus, it resets its sub-state to "high CH" if the majority of members confirm good connectivity levels. If the majority of members have low connectivity with the CH, three situations can occur.
   a. The first is when there is a vehicle candidate to be CH that is selected by more than Nprop% of neighbors; then, this vehicle ID is broadcast in the CI attribute in the next beacon messages. The old CH changes its role from "CH" (low CH) to "cluster member" and set its sub-state according to its connectivity level (see equation 7).

b. In the second situation, the old CH does not find any candidate among its neighbors to be CH. In this case, the cluster formation procedure is necessary. Therefore, the CH instructs its neighbors to execute the cluster formation procedure by setting its sub state to an intermediate value ("lost CH").

c. The last situation occurs when the whole network is congested. In this case, all CHs in the "low" sub-state do not find any better candidates. Therefore, cluster reformation is unnecessary and is delayed. Thus, these CHs wait for the Twait period to expire without changing their sub-states. Subsequently, they decide to keep their roles as CHs if the majority of members (Nprop%) confirm a good connectivity level. Otherwise, they set their sub-states to "fail CH", and the cluster formation procedure is run again.

4. Leaving cluster

At any time, if a cluster member finds that its CH is in the "lost CH" substate, it runs the cluster formation procedure.

A CH omits a CM from its neighbor list if it does not receive beacon messages during three consecutive beacon intervals from this CM.

### 3.6 Simulation Results

We conduct a simulation study using the discrete event simulation environment OMNeT++5.6 [41], the Veins framework veins-5.0 [43], and Simulation of Urban Mobility SUMO 1.12.0[42]. IEEE 802.11p DSRC, IEEE 1609.4, and the WAVE environment are configured for use in the Veins simulator. We use an imported road map from OpenStreetMap. It consists of a 5x3 km2 road portion of Cheraga, Algiers (see Fig. 11). The total number of vehicles encountered over the duration of the simulation varies from 50 to 400 vehicles.

Table 3 summarizes the considered parameters in our simulations. We simulate and evaluate various metrics: CH lifetime, CM lifetime, CH change rate, CM change rate, total overhead and percentage of CHs leaving detection. The results are compared with a recent algorithm called GAPC [50]. The GAPC algorithm is the closest procedure to the proposed scheme since it uses the affinity propagation model in the clustering formation procedure. This means that each vehicle contributes to selecting the best exemplar to be the cluster head and does not only evaluate its ability to become a cluster head like the majority of the existing approaches. The comparison is performed using the same simulation parameters.

| Parameters | Value | Parameters | Value |
|---|---|---|---|
| Simulation time | 1000 s | β | 0.8 |
| Simulation area | 5000m x3000 m | Γ | 0.5 |
| Communication rate | 250 m | Thb | 0, 7 |
| Beacon message interval | 1 s | Thc | 0, 3 |
| Maximum velocity | 30 m/s | Thd | 0,7 |
| Tcollect | 10 s | CPI | 2 s |
| Learning rate parameter, α | 0, 2 | Twait | 3 s |
| Tfe | 60 s | Thf | 0,8 |
| Tha | 0, 3 | CIf | 1 s |

Table 3 Simulation parameters in RLBC algorithm.

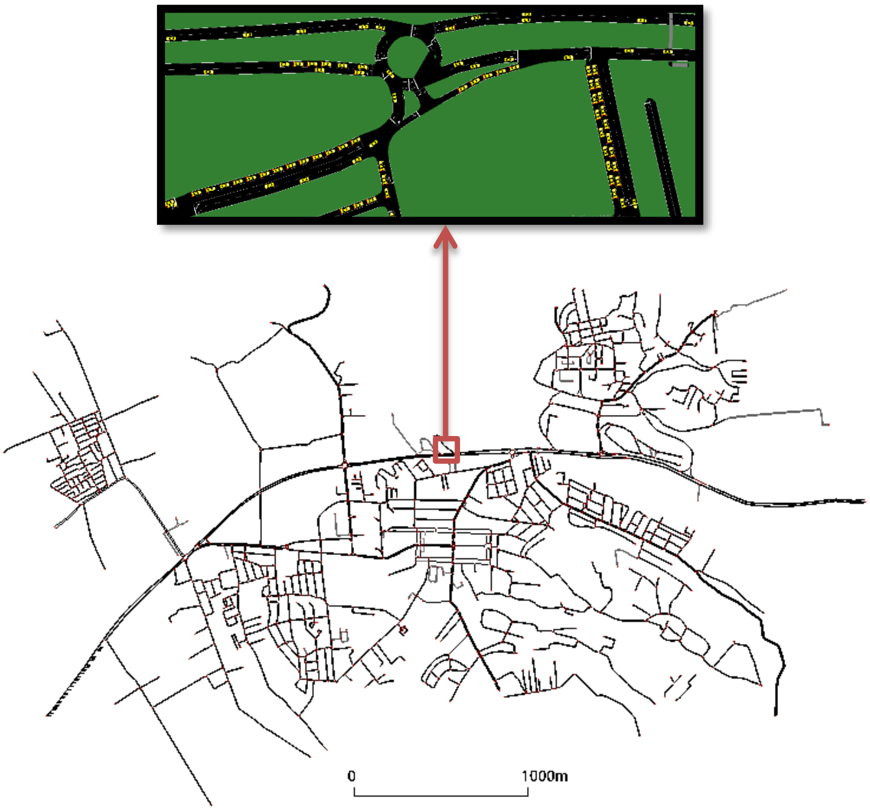
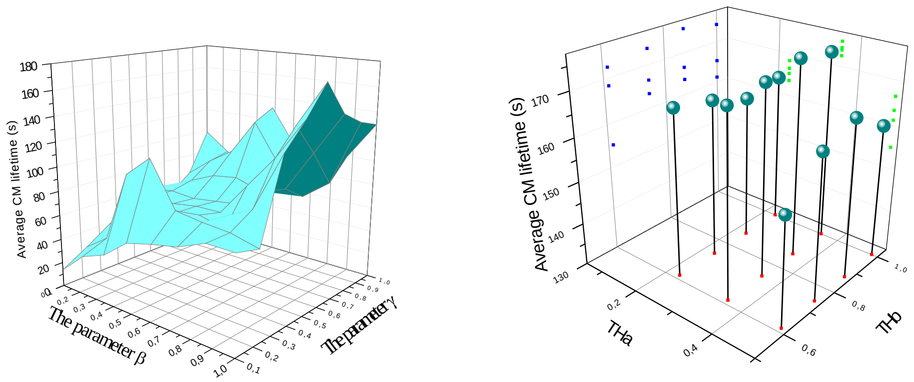


Figure 11 Road map used in the RLBC algorithm, selected from the city of Algiers.

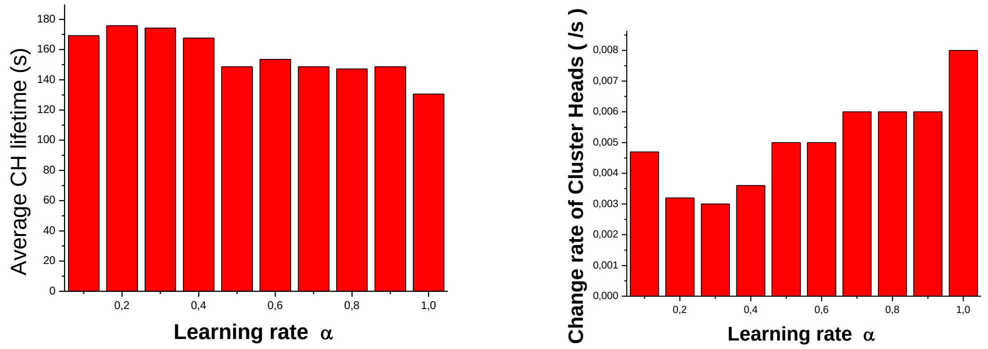
### 3.6.1. Performance for varying the empirical parameters and used thresholds

Our RLBC protocol makes use of various empirical parameters, namely: the learning rate α, Tha, Thb, Thc, Thd, the parameters β and γ. In this section, we evaluate the performance sensitivity of these parameters to obtain a good trade-off between them. To do so, we vary their values from 0.1 to 1 and conduct several empirical simulations (at least five simulations for each scenario with the same parameter value) considering different metrics. We also vary the number of vehicles (from 50 to 400 vehicles) and vehicles velocity from 11.1 m/s to 44.4 m/s. Fig. 12 (a) and (b) shows the impact of the parameters β and γ on the average cluster head lifetime and the influence of the Tha and Thb combination on the average cluster duration. Fig. 13 illustrates the performance of the learning rate α on the average cluster duration and the average rate of cluster head changes. These evaluations have allowed us to select the appropriate values of these thresholds and parameters.



(a) (b)

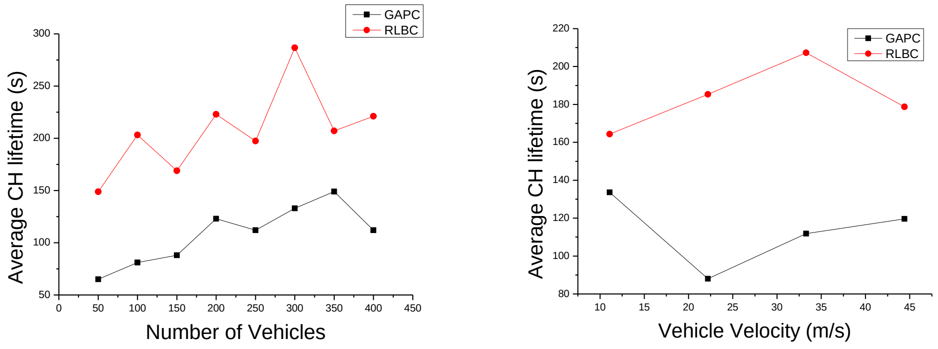
Figure 12 The impact of thresholds on the performance of RLBC (a) the impact of β and γ on the average CH duration, (b) the impact of Tha and Thb on the average CH duration.



(a) (b)

Figure 13 The impact of the learning rate  on the performance of RLBC, (a) Average CH duration, (b) Average rate of cluster head changes.

### 3.6.2. CH lifetime

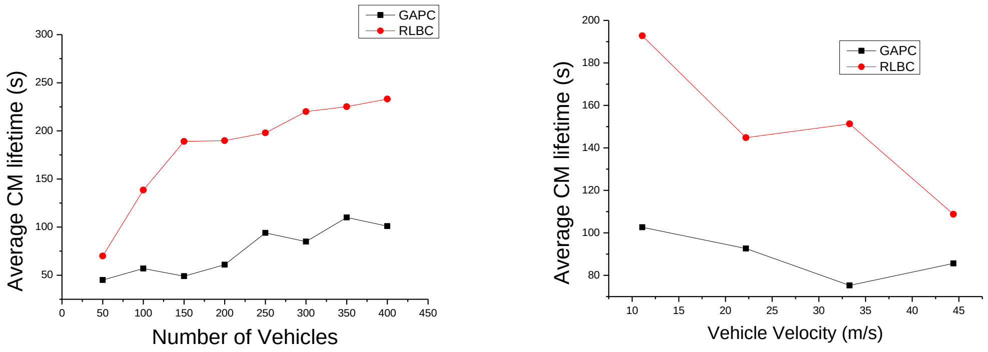


(a) (b)

Figure 14 The average cluster head lifetime: according to the number of vehicles (a), according to the vehicle velocity (b).

Fig. 14 (a) shows the average cluster lifetime according to the number of vehicles. Compared with GAPC [50], RLBC improves the cluster stability by approximately 52%. This can be explained by the fact that the cluster members contribute to CH decisions about leaving clusters and thus decrease unnecessary re-clustering. This is because the proposed algorithm takes the average cluster lifetime as the optimization goal in both the formation procedure and the maintenance procedure. Fig. 9 (b) shows that the average cluster lifetime is not significantly affected by the variation of vehicle velocity.

### 3.6.3. CM lifetime

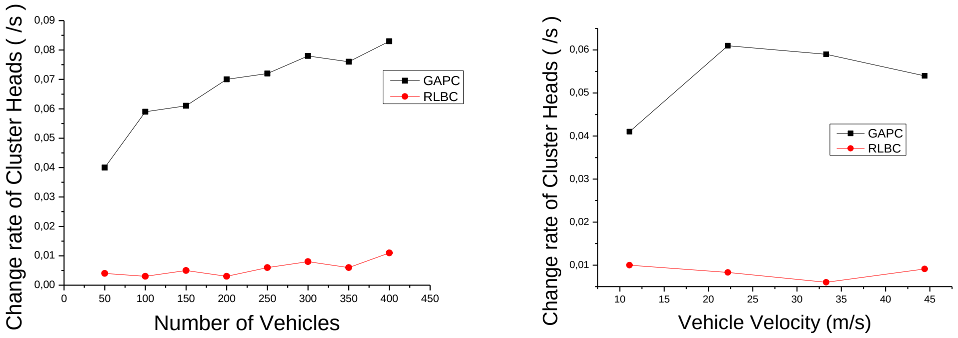


(a) (b)

Figure 15 The average cluster member lifetime: according to the number of vehicles (a), according to the vehicle velocity (b).

The results shown in Fig. 15 (a) prove that the average cluster member lifetime obtained using RNBC increases as the number of vehicles increases. This is because the cluster size is larger in denser scenarios. Hence, there are more CMs in a cluster in such a case. Therefore, the probability that a CH stays connected with a CM is higher. When the number of vehicles is 50, the average cluster member lifetime is 60% higher than that of GAPC [50]. Contrary to that of the CH lifetime (see Fig. 14), the average CM lifetime deviation rate is relatively low. This is due to the very dynamic nature of the Internet of Vehicles. Thus, the connectivity quality between cluster heads and cluster members is very changeable. As expected, in Fig. 10 (b), the average CM lifetime of the RLBC algorithm increases by approximately 40% compared to that of the GAPC algorithm. In contrast to CH lifetime metric, the average CM lifetime decrease significantly according to high vehicle velocity.

### 3.6.4. The average rate of CH changes

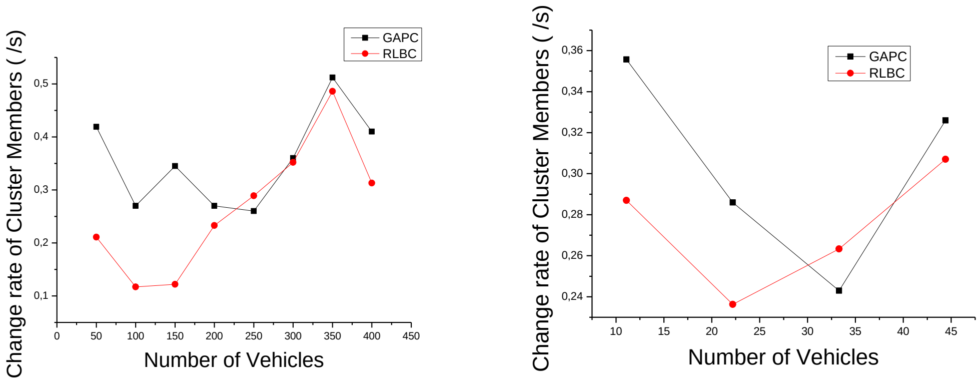


(a) (b)

Figure 16 The average rate of cluster head changes: according to the number of vehicles (a), according to the vehicle velocity (b).

According to Fig. 16 (a), the average rate of cluster head changes increases when the number of vehicles increases. It is also proportional to the cluster head lifetime. Fig. 16 (b) shows the average rate of cluster head changes as the vehicle velocity increases. We can clearly observe that the RLBC algorithm reduces the average rate of cluster head changes by approximately 82% compared to the GAPC algorithm. The RLBC algorithm improves both the cluster head lifetime and the average rate of cluster head changes over those of the GAPC algorithm. In fact, in GAPC, CHs are changed according to affinity propagation. Subsequently, the cluster formation procedure is run more frequently. However, we notice that both the GAPC and RLBC algorithms maintain durable clusters at different road densities.

### 3.6.5. The average rate of CM changes

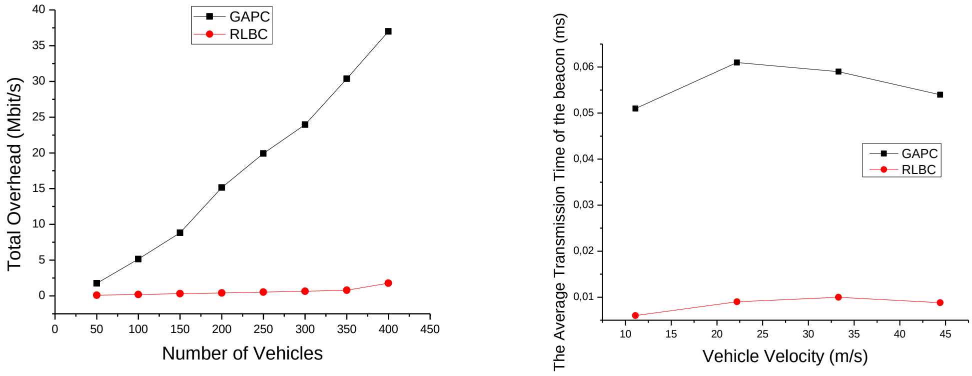


(a) (b)

Figure 17 The average rate of cluster member changes: according to the number of vehicles (a), according to the vehicle velocity (b).

Fig. 17 (a) illustrates the average rate of cluster member changes as the number of vehicles increases. The RLBC algorithm reduces the average rate of CM changes by approximately 43% compared to the GAPC algorithm when the number of vehicles is less than 200 vehicles. The average rate of CM changes is high when the number of vehicles is large in both the GAPC and RLBC algorithms. This is because of the frequent topology changes of vehicles in urban scenarios. The results shown in Fig. 17 (b) show that the average rate of cluster member changes are affected by the vehicle mobility metric.

### 3.6.6. The total overhead and the average transmission time

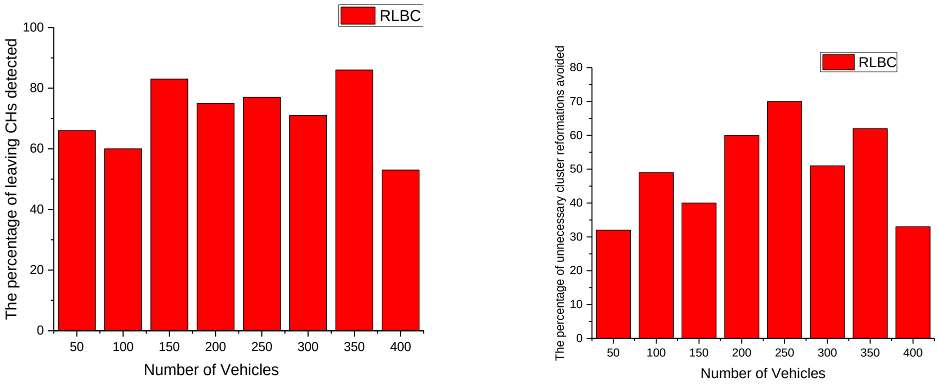


(a) (b)

Figure 18 Comparison of the total overhead (a) and the average transmission time of beacon message of the RLBC and the GAPC algorithm.

The total overhead is an important metric for providing an indication of the extra bandwidth consumed by the cluster formation and cluster maintenance process. As expected, in Fig. 18 (a), the total overhead of the RLBC algorithm decreases by approximately 73% compared to that of the GAPC algorithm. This is achieved by eliminating the three tables (I, Ri, Ai) that are used in the affinity propagation procedure. The size of each table is equal to the number of neighbor vehicles. In RLBC, only two parameters are added to beacon messages for cluster management. These two parameters are coded in 2 bytes and are diffused by each vehicle every 1 s (beacon interval). This means that only partial topological information from the network is diffused by any vehicle. Furthermore, we cannot consider this addition as cost because we used fields already included in the beacon message. The overhead is reasonably low in the RLBC algorithm, which significantly optimizes bandwidth usage. Fig. 18 (b) shows the impact of adding these attributes on the transmission time of beacon messages. Compared with GAPC, RLBC decreases the transmission time by approximately 80%. This can be explained by the fact that we have used the optional fields of the standard format of the beacon (WSM (WAVE Short Message). Consequently, there is no impact of this addition in the opposite of GAPC which broadcasts the three tables (I, Ri, Ai) in each beacon message.

### 3.6.7. The percentage of leaving CHs detected in advance and unnecessary cluster formations avoided



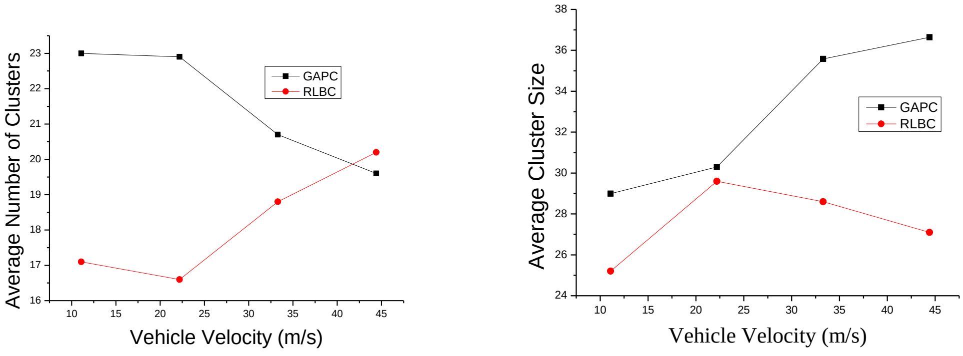
(a) (b)

Figure 19 The percentage of leaving CHs detected in advance (a) and the percentage of unnecessary cluster reformations avoided (b) vs. the number of vehicles.

Fig. 19 (a) demonstrates the advantage of using prediction in terms of the percentage of leaving CHs detected in advance. This metric represents the number of confirmed leaving CHs for which their sub-states were set to “low CH” before leaving out of the total number of leaving CHs. The results show that more than 71% of leaving cluster heads are detected in advance. This is explained by the fact that cluster structures are stable during short periods of time when the network topology is often changing. The RLBC algorithm detects potential changes in advance based on the sub-state attributes and cluster connectivity predictions to avoid unnecessary cluster reformation and help each cluster head make an appropriate decision about its cluster structure.

Fig. 19 (b) shows another advantage of using prediction in terms of the percentage of cluster reformations avoided. This evaluation metric represents the number of maintained cluster heads after running the polling procedure out of the number of CHs in the “low CH” sub-state. The results show that the percentage of cluster reformations avoided varies from 32% to 70%. This means that the cluster member’s confirmation of the cluster head is independent of the number of vehicles. Each cluster member confirms whether to maintain its CH based on its observed connectivity level with this node. This metric also determines when cluster reformation may be necessary to enhance the communication reliability among the various clusters. In particular, cluster reformation occurs when the percentage of cluster reformations avoided is low (approximately 40%).

### 3.6.8. The size and the number of the clusters



(b)

Figure 20 The average number of clusters (a) and the average cluster size (b) vs. the vehicle velocity.

Fig. 20 (a) shows the impact of vehicle velocity on the clustering performance considering the average cluster size and average number of clusters metrics. As expected, in Fig. 20 (b), the average cluster size in the RLBC algorithm decreases by approximately 26% with high vehicle velocity and by 13% with low velocity compared to that of the GAPC algorithm.

Globally, the network mobility represented as vehicle velocity metric does not have significant impact on the average cluster size. However, the mobility metric affects the number of clusters. This is explained by the fact that the number of clusters is dependent on the neighborhoods of each vehicle. With varying vehicle velocity, the vehicle connectivity highly varies. Thus, new clusters have to be created or reformed in order to assure the clustering maintenance.

Globally, considering the feedback sent from its members, the cluster head decides whether to maintain its cluster. The accuracy of the prediction is derived from the fact that all CHs and all CMs continuously analyze their communication link quality and act together in a constructive and cooperative fashion. In this way, the clustering performance of the RLBC algorithm is improved in terms of the CH lifetime, the number of CH changes, the CM lifetime and the number of CM changes, as verified via the conducted simulations.

### 3.7. Conclusion

In this chapter, we presented a new reinforcement learning-based clustering (RLBC) algorithm for the Internet of Vehicles that aims to maintain stable cluster structures. This enables the maximization of the network lifetime and the minimization of the communication overhead. To implement RLBC, we have proposed the concepts of sub-states and connectivity levels, which are continuously computed by each CH and each CM to predict the stability of their clusters. This approach allows us to avoid unnecessary re-clustering, and hence maintains more stable cluster formations than those obtained with other approaches. To demonstrate the feasibility and RLBC and evaluate the algorithm, we conducted a simulative study considering various metrics and compared our results to a recent clustering protocol (GAPC). The results show that the RLBC algorithm enhances network reliability and outperforms GAPC in terms of cluster stability, CH lifetime, CM lifetime, message overhead and clustering accuracy.

# Chapter 4: A QoE aware Clustering MAC protocol for Internet of Vehicles (QoEC-MAC)

## 4.1 INTRODUCTION

In Internet of vehicles, vehicles often need to transmit, collect, and share various types of messages with different QoS requirements such as transmission rate, throughput, and delay. Therefore, it is essential to explore V2V communications, as not every vehicle is linked to the Internet, particularly in locations like rural areas, tunnels, and certain highways. Vehicle-to-Vehicle communication remains an alternative that can be used to overcome this issue in IoV[52,53].

As previously mentioned, the hybrid MAC protocol combines the advantages of both 802.11p for slot allocation and TDMA for data transmission, such as in [8] and [9].

This chapter describes our second contribution by introducing a new clustering-based MAC protocol in which cluster heads may switch between 802.11p and TDMA to keep the effective exploitation of bandwidth. The proposed protocol, called QoE aware clustering MAC (QoEC-MAC), improvises the QoE parameters in the network on the clustering approach. The remainder of this chapter is organized as follows: Section (4.2) introduces the system model. The proposal QoEC-MAC protocol is presented in Section (4.3). The performance evaluations of QoEC-MAC against the standard are shown in Section (4.4). Section (4.5) provides a conclusion to this chapter.

## 4.2 SYSTEM MODEL

This chapter focuses on the Internet of Vehicles network, where each vehicle has an IEEE 802.11p on-board unit (OBU) device that operates using the WAVE 1609.4 protocol [4] and TDMA for inter-vehicular communications. Every vehicle has two transceivers: one operating on the Common Control Channel (CCH) and the other capable of switching to any Service Channel (SCH). The time clock for synchronization is obtained through Coordinated Universal Time (UTC), and GPS is used by each vehicle to determine its location.

This contribution is a continuity of our previous work [54] presented in chapter 3. We assume that vehicles are grouped at the initial stage, as illustrated in Fig. 21.

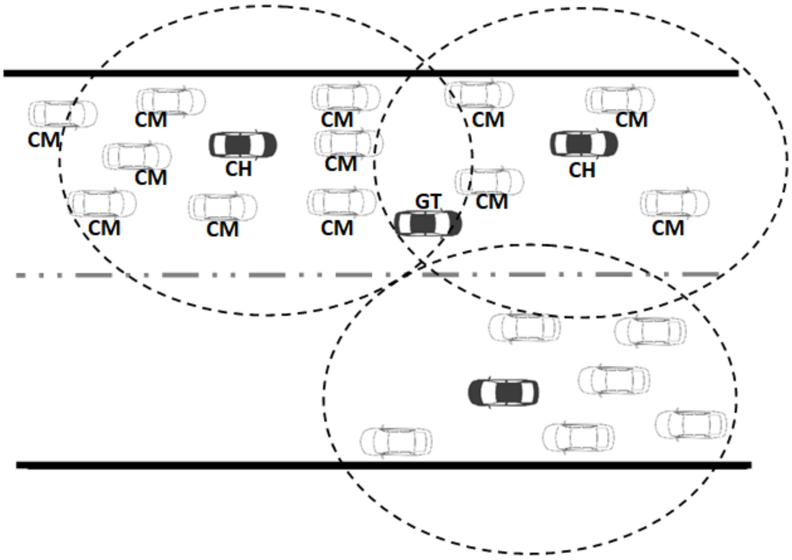


Figure 21 Network topology.

Vehicles communicate by exchanging several kinds of messages. They use periodic beacon messages to determine the neighbouring vehicles, manage the clustering process, and indicate their existence in the network. We added to the beacon message two fields: Sub-Stage (SS) and Complementary Information (CI) for the cluster management procedures. We extend the sub-state attribute by considering other values used for communication purposes. There are four states: Cluster Head (CH), Cluster Member (CM), Undecided (U), and GaTeway (GT). Each state includes several sub-states, as described in [54].

We also define some rules for communications between vehicles in the network:

1. Cluster members' vehicles in the same cluster can directly communicate with each other and use their available time slots.
2. Cluster Heads vehicles and Gateway vehicles relay traffic between clusters and connect all clusters.

We have to notice that only CH and GT are responsible for coordination in the cluster. If one CH loses its role as coordinator, cluster formation will be run and the coordination will be achieved by the new elected CH.

## 4.3 QOE AWARE CLUSTERING MAC SCHEME

We propose a new MAC protocol called QoEC-MAC. It consists of forwarding data through effective bandwidth exploitation while considering communications that are both intra- and inter-cluster. The QoEC MAC employs CSMA/CA and TDMA mechanisms for accessing the CCH. As described in Fig. 22, channel access time is divided into a sequence of frames. Each frame consists of two intervals: CCH and SCH intervals. The CCH interval, which is 50 ms, is divided into three parts: fixed-CCH, safety-CCH, and critical-CCH intervals. The SCH interval is portioned over several service slots that provide non-safety packet transmissions without collisions. Fig. 22 depicts the frame's structural layout.

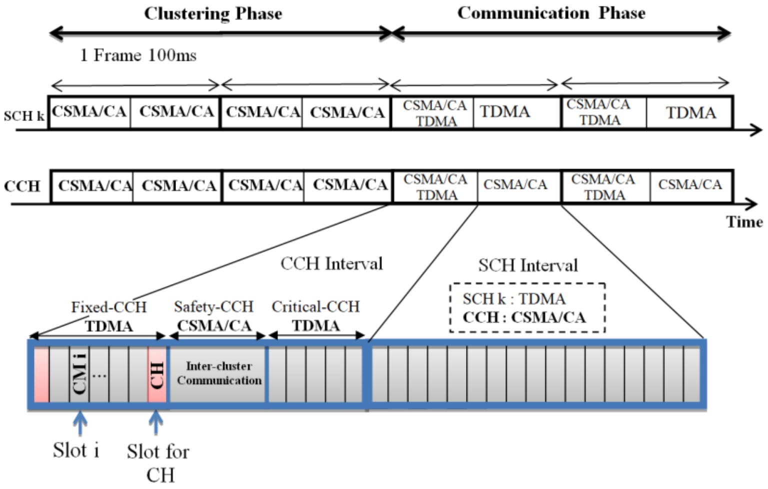


Figure 22 Time frame structure.

Fixed CCH and Critical CCH are designed for intra-cluster communications, while Safety CCH is designed for inter-cluster communication. The idea is to enable as many delay-critical packets as possible to be forwarded from one cluster to another on the same CCH interval. The cluster head is designed to have two transmission powers as a coordinator. It uses short-range transmission power when it needs to communicate with its CMs, and long-range transmission power when it needs to exchange messages with its neighbouring CHs.

### 4.3.1. INTRA CLUSTER COMMUNICATION

At the beginning of the clustering communication process, the CH sends an announcement message (AnnouncementMsg) using CSMA/CA on the CCH to inform each member about its time slot immediately after being selected as CH. This message includes the gateway table and the time slot table considering all its neighbours as cluster members and it represents the beginning of the communication protocol. Upon receiving the slot allocation table, each CM uses its designated time slot as a unique identification number within the cluster. It respects the frame structure rules in the next CCH switching interval. In Fixed-CCH, the CM uses that time slot during all the next periods until it leaves the cluster or switches to a new time slot. It uses its appropriate time slot to send safety, beacon, and request messages (ReqMessage). When the CM considers that one service from any provider (CH, GT or CM) cannot guarantee QoE in its vicinity, it sends a ReqMessage to the CH in which it specifies the computed QoE value and the ID of the service. The CH computes the QoE for each service (or provider) to enhance QoS. More details about computing QoE by CH and CM are described in Section (5.3.2). If the CH does not receive the beacon from any CM during a pre-defined amount of time τc-min, the corresponding identification number will tune to free, and its time slot can be utilized by a more recent CM or by the CH. This is why the CH manages the reservation time slot without any additional control message. This mechanism enables the cluster to maintain its normal operations while reducing interference with other clusters inside the same cluster.

### 4.3.2. QOE MAPPING TECHNIQUE

Quality of Experience (QoE) is a measure of how well a member perceives the quality of a safety service or application. During critical intervals, the packets are forwarded to maximize the QoE of all users and ensure that users with safety-critical applications are prioritized over those with non-critical applications. The mean opinion score (MOS), which has a range of 0.0 to 5.0, is used to record the user-perceived QoE in terms of the data transmission delay. A greater MOS indicates an improved user experience, whilst the worst quality is indicated by a MOS of 0.0. In this paper, we consider the registration of the service providers and the QoS requirements identification followed by the data transfer phase in its control plane only at the beginning of the communication protocol. Letting d1 and d2 be the satisfied delay and the maximal tolerable delay, respectively. Their values are obtained through the QoS requirements of two safety applications by inspiration from [55] and [56]. The values are empirically adjusted. Each cluster member estimates the QoE value of each service k according to equation (1),

where D is the transmission delay of the last received packet from the service k. The parameters k, α, β, and λ are the constants.

$$QoE_k = \begin{cases} 0, & D \le d1 \\ \alpha(1-\left(\frac{D-d1}{d2}\right)^2)^{\lambda \mathrm{B}(\frac{D-d1}{d2})^{\lambda}} & d1 < D < d2 \\ 5, & D \ge d2 \end{cases} \tag{1}$$

The distribution of equation (1) is presented in Fig.23. From equation (1), we notice that as the transmission delay increases, the QoE of the CM decreases. Therefore, the lower the QoE value for each service, the less the user satisfaction. If the cluster member estimates that QoE is not convenient, meaning QoEk < Thk, it sends a ReqMessage in which it specifies the QoE value and the identity of the corresponding service k.

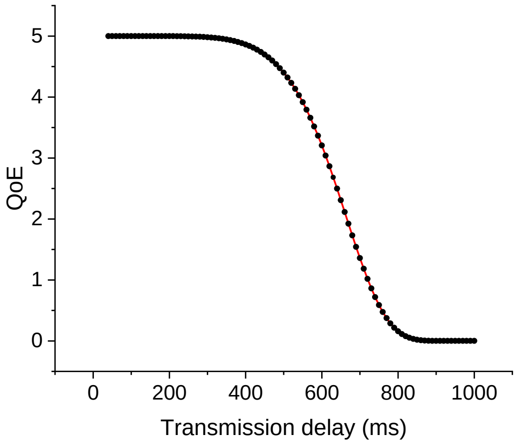


Figure 23 QoE values.

Furthermore, the CH identifies the vehicles that require network resources to transmit the data based on received ReqMessages by its cluster members. It estimates the mean QoE value through the received QoE values over time by equation (2) for each safety service k, where N is the number of CMs using the service k and sending ReqMessages.

$$\overline{QoE_k} = \frac{1}{N}\sum_{i=1}^{N} QoE_i \qquad (2)$$

When a CH has to send packets to another CH, it first evaluates all mean QoE values using the equation (2), and then it selects one packet from the service which has the lowest value and sends it. After reception of the packet by the adjacent CH, it uses the same process until reaching the destination. In this way, each CH controls the packet transmission delay. It can be informed about the degradation of each service and can thus handle the situation.

### 4.3.3. INTER CLUSTER COMMUNICATION

The CHs transmit data if the destination is not in its cluster. In the Safety-CCH interval, each CH communicates with the adjacent CHs using long-range transmission power. The CHs can be so far that direct communication cannot be established. Therefore, we propose to use gateways to interconnect CHs. The gateway represents a CM vehicle which can be connected to more than one CH. The CH selects the gateway as a member that can reach other CHs. It can select more than one gateway to optimize inter-cluster communication. Each CM that can establish connections with more than one CH must specify in the CI attribute of its beacon message its candidacy to become a gateway. The CH selects the CM candidate with the highest connectivity level to serve as the gateway. It chooses the first received candidacy if the CM is in a high CM sub-state. Following that, it informs its members to become gateways by sending gateways tables and slot tables in the AnnouncementMsg. The corresponding CMs change their sub-state to Gates and inform their vicinity through beacon messages. This cannot increase the overhead because it's sent only at the beginning of the clustering communication protocol, as shown in Fig.22.

After a packet sent by a certain CM reaches its CH during the Fixed-CCH interval, and if the destination is not in its cluster, the packet will be forwarded to the adjacent CHs in the Safety-CCH interval using CSMA/CA. The CH reorganizes packet priority based on the QoE of each provider k. Then, it sends packets from low QoE to other CHs during the Safety-CCH interval. The other packets are sent to adjacent CHs or GTs during SCH intervals using CSMA/CA under the CCH. In this way, the CH can forward those packets during the next frame and decrease any additional delay. Also, low priority class is prioritized at high load to enhance the QoS for the corresponding safety service or application. The main idea behind the proposed policy is to give more priority to degraded services while ensuring fairness. As already mentioned, using two transceivers allows CHs to use SCHI on the CCH for inter-cluster communication. They forward packets based on their arrival time without considering any prioritization.

### 4.4. SIMILATION RESULS AND DISCUSSION

In order to evaluate the performance of the QoEC-MAC algorithm, we use the simulator OMNET++ 5.6.2 [41], Simulation of Urban Mobility SUMO-1.2.0 [42] and the Veins framework Veins-5.0 [43]. The total number of vehicles varies from 30 to 180. A variety of highway scenarios with vehicle numbers ranging from 30 to 180 is included in our simulation. IEEE1609.4 is selected as a baseline in order to evaluate the network performance of QoEC-MAC and the clustering efficiency of our previous reinforcement learning based clustering scheme [54] presented in chapter 3. Various empirical parameters are used in QoEC-MAC, including the threshold $\alpha$, $\beta$, $\lambda$, and Thk. Table 4 summarizes the parameters considered in our simulations.

Table 4 Simulation parameters.

| Parameters | Value | Parameters | Value |
|---|---|---|---|
| Simulation time | 330 s | SafetyCCH | 0.01s |
| Simulation area | 5000m x3000m | $\tau$c-min | 3s |
| Short communication range | 300 m | d1 | 42ms |
| Long communication range | 1000 m | d2 | 1s |
| Beacon interval | 0.1 s | $\alpha$ | 5 |
| Data rate | 100-1000 pkt/s | $\beta$ | 3 |
| Velocity | 16-33.3 m/s | $\lambda$ | 5 |
| FixedCCH, CriticalCCH | 0.02s | $Th_k$ | 4 |

Fig. 24 (a) and (b) represent the average collision rate and the total number of backoff time slots according to the number of vehicles, respectively. Compared with IEEE1609.4, QoEC-MAC increases the collision rate by approximately 56%. This is because only CHs and GTs are contending for channel access during Safety-CCH and SCH intervals in QoEC-MAC. Therefore, a small number of contending vehicles results in the collision domain being considerably smaller. This is confirmed by the very low values of backoffs shown in Fig. 24 (b). Besides, in IEEE1609.4, all vehicles contend for channel access, resulting in very high values in the backoff. Furthermore, as the communication load increases, vehicles have more packets to send. Therefore, the vehicles contend very frequently, increasing the collision ratio. In addition, the IoV is quite dynamic, which leads to greater contention and more collisions. That is because the connectivity quality between cluster heads and cluster members is very variable. However, as expected in Fig. 24 (a), it does not have significant impact on the network performance in terms of average collision rate. This is explained by the fact that the formation procedure is run less frequently compared to that of another clustering approach, as explained in [54].

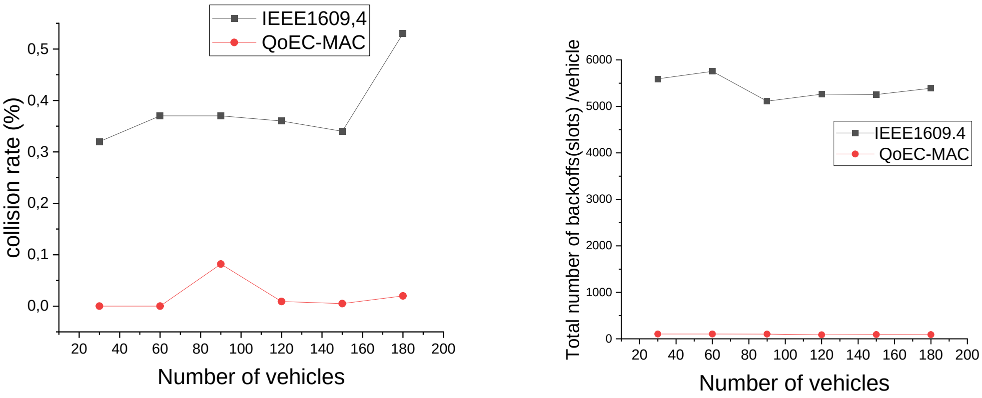


Figure 24 (a) Average collision ratio; (b) Total number of backoffs (slots time).

According to the number of vehicles, Fig. 25 (a) displays the channel transmission delay. As the number of vehicles rises, so does the transmission delay in QoEC-MAC. The findings indicate that QoEC-MAC reduces delay by about 57% when compared to IEEE1609.4. This is due to the slot reservation mechanism's ability to reduce the access delay in each frame on the basis of QoE information and the stability of clusters in the network. In fact, QoEC-MAC allows as many delay-critical packets to be transmitted between clusters on the same CCH interval as possible, which results in decreasing packets transmission delay.

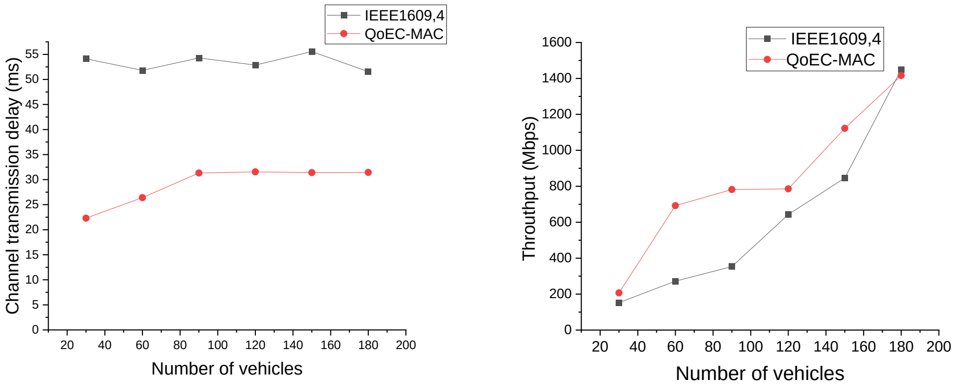


Figure 25 (a) Channel transmission delay; (b) Total throuthput.

Fig. 25 (b) shows the total throughput as the number of vehicles increases. The total throughput of QoEC-MAC is higher than that of IEEE 1609.4. This is due to the high collision rate of IEEE 1609.4, which is in turn due to the vehicle's mobility and the amount of exchanged data, which keeps rising along with the rise in vehicle density. In addition, the QoEC-MAC allows cluster heads and gateways to use the CCH during the SCHI for inter-cluster communications at the price of using two transceivers. This enhances wireless channel exploitation. We can also notice that when the number of vehicles exceeds 120, the total throughput becomes more important for both QoEC-MAC and IEEE 1609.4 under heavy network load.

## 4.5. CONCLUSION

In this chapter, we proposed a new QoE-aware clustering MAC scheme for the IoV that aims to handle channel allocation resources. For this purpose, the QoEC-MAC considered that the vehicles are arranged in groups. Each group has one cluster head that is in charge of assigning slots, transmitting messages delivered by the cluster members, and scheduling communications between and within the cluster. Furthermore, QoE-oriented MAC is used to improve the efficiency of the network by reducing transmission delay and packet loss. The simulation results show that the QoEC-MAC outperforms the IEEE 1609.4 in channel transmission delay, collision ratio and total throughput.

# Chapter 5 Prediction based congestion avoidance MAC scheme

## 5.1. INTRODUCTION

The main goal of MAC protocol is to avoid frequent message collisions caused by the mobility of the vehicles in IoV networks, especially in high-density scenarios. Communication between vehicles quickly becomes congested in such a situation. As is the case with any solution for managing congestion, we can distinguish two main steps: (i) the congestion detection and (ii) the congestion control. The congestion detection phase allows each vehicle to know if the network is congested within its scope. Given the highly dynamic nature of vehicular networks, vehicles cannot rely solely on network observations of their vicinity to decide about the state of congestion. This is because the vehicle observations are not sufficient to get a correct estimate of the congestion level, thus leading to inadequate congestion control. To address this issue, in this chapter, we use the capacity of cloud computing, which are obviously part of the Internet of Vehicles networks. We propose a new learning model located at the internet server called Prediction based Congestion Avoidance MAC scheme (PCA). Consequently, each vehicle will be relieved of the enormous processing task due to the learning mechanism. The vehicles exploit the learning model implemented in the servers and benefit from the estimation model to dynamically manage the congestion, if any, using only vehicle-to-internet communication.

The rest of this chapter is organized as follows: an overview is presented in section (5.2). The deep reinforcement learning method is explained in section (5.3). The proposed protocol is presented in section (5.4). Simulation results are discussed in section (5.5). Finally, section (5.6) concludes the chapter.

## 5.2.OVERVIEW

In what follows, we present the PCA scheme, which is based on adapting several MAC parameters to manage congestion using a deep reinforcement learning model. We chose to act on several parameters instead of choosing only one in order to increase the efficiency of our model. In fact, several studies [21,23,25] have demonstrated that the adaptation of the contention window, transmission power and beacon interval contributes significantly to the reduction of network congestion. In this work, we employ these three factors to reduce vehicular network congestion in particular.

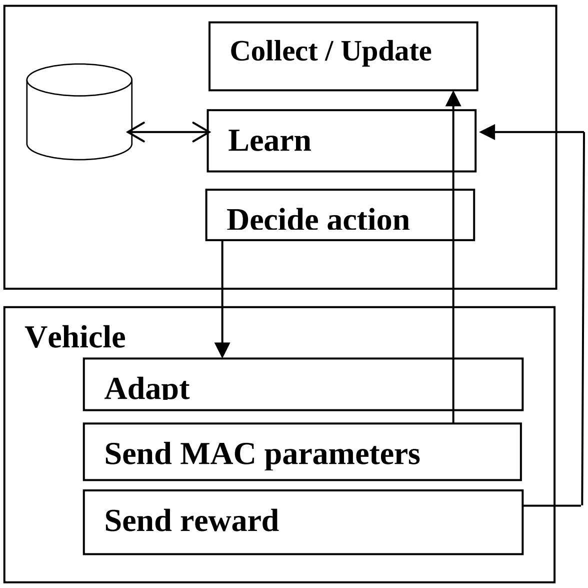


Figure 26 The global flowchart of the proposed PCA.

The proposed learning model uses continuously received parameters from all vehicles using internet communication in order to increase the learning accuracy of the model, and thus the efficacy of vehicle-to-vehicle communication. Each vehicle interacts with an internet server to take the appropriate congestion control action. The vehicle communicates with the server using LTE network. The global flowchart of the proposed PCA is illustrated in Fig. 26.

## 5.3.DEEP REINFORCEMENT LEARNING METHOD

There are several machine learning algorithms [35]. We can cite SVM, random walkthrough or random forest, neural networks and reinforcement learning. Learning can be used to solve congestion problems in IoV. The use of a simple neural network is not possible in our work because we do not have an initial dataset that we can use to predict the level of congestion and thus choose the appropriate action to take in order to control the congestion. In addition, using a simple reinforcement learning model allows the system to hear and act through its interactions with the environment by producing actions and receiving appropriate rewards. However, it takes a lot of time for the model to correctly estimate the level of congestion. To enhance the backoff algorithm implemented in 802.11p, we propose the use of deep reinforcement learning (DRL).

The proposed DRL is adapted to 802.11p CSMA/CA actions taken in consideration of network conditions. The choice of the DRL was motivated by its capacity to exploit the variability and the availability of huge amounts of data and communication parameters in real time, which can be very beneficial to the management of network congestion. To do so, each vehicle observes the network environment in its area using the collection of several MAC parameters. These parameters represent the state of vehicle i at time t. They are sent to server, and, through the DRL model, the server informs vehicles about the appropriate congestion avoidance action by sending the output value. The output of the proposed RDN corresponds to action that could decrease network congestion. After that, the vehicle applies the selection action and computes the corresponding reward, which is also sent to the server. The server learns and performs an action to improve the reward in the next time instant through the deep learning model.  Our model uses one input layer, one hidden layer and one output layer. The number of neurons in the hidden layer was set to 10 after several tests and simulations.

### 5.4.PCA ALGORIHM

Algorithms 1, 2 and 3 represent the PCA scheme. The deep reinforcement learning process is being undertaken on the web server. It is invoked periodically Tcollect by each vehicle by sending the input parameters (the current state at time t) to the web server using the internet. When the Internet server retrieves the state of vehicle i, it runs epsilon greedy algorithm [40] to provide the action to be done by this vehicle at time t according to the current vehicle state. The server returns the congestion control action number num_action to this vehicle so that it can in turn do the appropriate handling. This action consists of adaptation by increasing or decreasing one parameter factor among CW, transmission power and beacon interval as described in Algorithm 2. Despite the fact that the congestion actions have been characterized as static adjustments, congestion control is not carried out in a static manner since it runs each action using the deep reinforcement learning model. Then, the web server saves the state set at time t (the neural network inputs), the returned action number num_action at time t, and Q(state,a). The desired output will be retrieved at time t+1 by the vehicle in order to measure the reward after processing the selected action. This value (reward) is sent from the vehicle i to the server in order to compute the error. The line [Input: (S,at), computed output: ei = Q(a,t), desired Output : Rewardi (t+1)] is inserted into the learning base at time t+1 by the web server. The reward (desired output) is calculated using equation (1) where Ni denotes the number of the neighbors of vehicle i (Vi), Ib is the beacon interval, $N_{rb}^{j}$ denotes the number of received beacon from the neighbor j during the whole communication time between Vi and Vj. $T_{rb}^{j}$ is the time of the first reception of beacon message from the vehicle Vj.

$$\mathrm{Re}\,ward_i = \frac{1}{N_i}\sum_{i=1}^{n}\frac{\left|Ib * N_{rb}^{j}\right|}{Current_{Time} - T_{rb}^{j}} \qquad (1)$$

This reward is computed through the average rate of received beacon messages over time. It can indicate the state of the network in the vicinity of the corresponding vehicle. Therefore, the higher the reward value, the less congestion there is. The Mean Squared Error loss (MSE) in this model is estimated by equation (2), where n denotes the number of samples from data set and ei represents the predicted value from RND. Therefore, the weights can be adjusted and updated based on the back propagation algorithm [39].

$$MSE(e_i, \mathrm{Re}\,ward_i) = \frac{1}{n}\sum_{i=1}^{n}(\mathrm{Re}\,ward_i - e_i)^2 \tag{2}$$

```
Algorithm 1. Information Collection Algorithm
loop  // Every CI ( Collect interval),  At time t, vehicle i:

    Collect Inputt information from MAC,

    $Input_t$ ={ The contention window CW, the number of neighbors of the vehicle VI_neighbour, the SNR collision count, TXRX collision count, BusyTime channel parameter, txPower,  the number of sent messages NBsent, number of received messages Nbrec, the beacon interval Ib }

    Send $Input_t$ information to Server Internet;

    Compute Rewardi using equation (4) corresponding to the
    Previous state $S(Input_{t-1}, num\_action_{t-1})$

    Send reward and $S( Input_{t-1}, num\_action_{t-1})$ to Internet server to
    run learning

End Loop
```

**Algorithm 2.** Congestion Control Action Algorithm

*At the reception of num_action from Internet Server, the vehicle i does*

```
Switch num_action do

Case 1 :    Action =" Cw = Cw + cw_a1";

Case 2 :    Action =" Cw = Cw - cw_a2";

Case 3 :    Action =" Transmission_Power =
             Transmission_Power +  TPower_a1";

Case 4 :    Action =" Transmission_Power =
             Transmission_Power - TPower_a2";

Case 5 :   Action =" Beacon_interval = Beacon_interval  + BI_a1";

Case 6 :   Action =" Beacon_interval = Beacon_interval  - BI_a2";
End Case
```

**Algorithm 3.** Learning Algorithm

*At the reception of Input parameters from vehicle i, the Internet server:*

**Input**: N : random value between 0 and 1,  S  is the current state, Q : the Q values

```
// Call the epsilon greedy algorithm, and retrieve the number of the action to be done l
vehicle i
if  (N  < $\varepsilon$ )  then
                  num_action = random[1 : 6]
    else
          for j from 1 to 6  do
                   Q(S, actionj)=RND(Input)   /* action j as
                             described in    Algorithm 2*/

                   ei = Q(S, actionj) // computed RND output;
                   num_action = indice_max(Q_values);
          end  for
end  if
   Save [ S  ( $Input_t$) , ei= (S, actionj), num_action ];
   Send num_action to vehicle i;
```

***At the reception of Reward (desired output yi) from vehicle i, the server will:***

*Insert [ S , ei= (s, actionj), num_action, Reward ] in the data set*
*Compute the error using equation (2)*

*Update the weights of the RND using computed error.*

Figure 27 Pseudocodes of the congestion control action algorithm.

## 5.5.SIMILAION RESULS AND DISCUSSION

In order to evaluate the performance of the PCA algorithm, we use the simulator OMNET++ 5.6.2 [41], Simulation of Urban Mobility SUMO-1.2.0 [42] and the Veins framework Veins-5.0 [43]. We conduct simulation study using an Algerian road map that we used in our previous work [54]. The total number of vehicles varies from 50 to 500. In our project we chose the protocol presented in [24] as a comparison solution. This choice is justified on the one hand by the novelty and effectiveness of this proposal; on the other hand, it uses a learning method and not a method based on the static adaptation of certain parameters. Table 5 summarizes the parameters considered in our simulations.

Table 5 Simulation and deep learning parameters.

| ***Parameters*** | ***Value*** | ***Parameters*** | ***Value*** |
|---|---|---|---|
| Simulation time | 300 s | Initial exploration | 1 |
| Simulation area | 5000m x3000m | Final exploration | 0.01 |
| Communication rate | 250 m | Loss | MSE |
| MAC | 802.11P | cw_a1 | 5 |
| Beacon interval | 1 s | cw_a2 | 5 |
| Data rate | 100-1000 pkt/s | TPower_a1 | 5 |
| Velocity | 16-33.3 m/s | TPower_a2 | 5 |
| Collection Interval | 20 s | BI_a1 | 0.2 |
| Learning rate α | 0, 0001 | BI_a2 | 0.2 |
| Discount Factor | 0.995 | Tcollect | 20 s |

Fig. 28 represents the average delays according to the number of vehicles. As expected, the transmission delay in DC-DQN increases when the number of vehicles increases. This finding is not valid for PCA because of the content of the messages exchanged that has not been modified in PCA. In other words, PCA does not add any information to packages. The vehicles don’t broadcast additional information using 801.11p network. They send only safety and non-safety messages as described by applications of IoV. In addition, this delay represents the end-to-end times (by considering one hop) because our work is not concerned with routing. As a result, the values obtained from the delays are close in PCA. The results also show that PCA improves delay compared to DC-DQN.

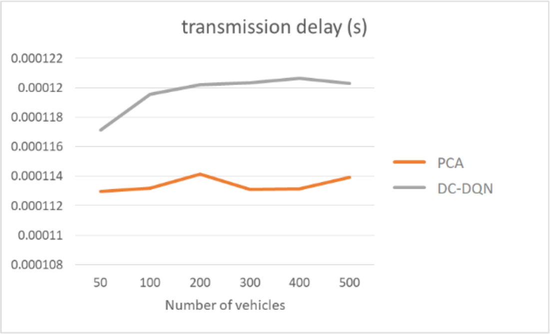


Figure 28 Average end to end delay.

Fig. 29 shows the average collision rate according to the number of vehicles. Compared with DC-DQN [24], PCA improves the collision rate by approximately 42%. This can be explained by the fact that DC-DQN uses ack packets for each message received (broadcast and unicast) in order to calculate the gain parameter used to adjust the value of the contention window. In addition, DC-DQN uses several additional parameters that are sent permanently (overhead), which further burdens the network. We can also notice that the collision rate, in our proposal as well as in DC-DQN, increases when the number of vehicles in the network is increased. This is due to frequent disconnections well known in vehicular networks, which are themselves due to the mobility of the vehicles as well as the amount of data exchanged, which continues to increase with the increase in vehicle density.

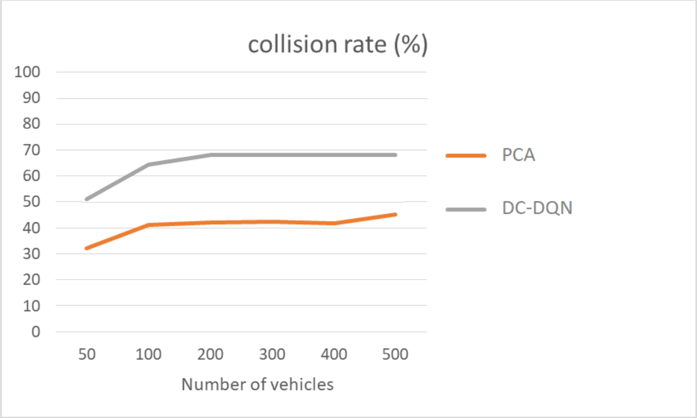


Figure 29 Average collision ratio.

The data collection between each vehicle and the server is used to enhance MAC parameters for V2V communication, which uses DSRC bandwidth. In this work, the period Tcollect is empirical and has been determined after several simulations. The information to be exchanged between the vehicle and the server is summarized with nine input parameters, one output parameter and the computed reward parameter as described previously. As a result, 64 bytes must be sent and received every 20 seconds via V2I communication between a given vehicle and the internet. Therefore, the bit rate of this exchange will be 3.2 bytes/s. When compared to the volume of data transferred via V2V communication, this rate is incredibly low. The generated overhead is thereby reasonably low in the proposed algorithm and concerns only V2I communication using internet (LTE network). As a result, no additional information is sent to the vehicular networks using V2V communications. In addition, since the data network speed of LTE is around 80Mbit/s, the communication delay between the server and the vehicle is 0.7 microseconds, and the algorithm further optimizes the DSRC bandwidth usage. However, if one vehicle fails to connect to the server, it can use the current MAC parameters until the next data exchange period. This will not affect the dissemination of safety messages and comfort messages because these messages are sent from the vehicles using only V2V communications. The V2I depends on internet connectivity in each vehicle. Furthermore, in Internet of Vehicles networks, we consider that most vehicles are connected to the internet.

## 5.6.CONCLUSION

In this chapter, we proposed a new deep reinforcement learning-based congestion control scheme for the Internet of Vehicles that aims to detect and correctly handle congestion situations. Furthermore, we use the availability of the internet in the vehicles in order to allow each vehicle to optimize the MAC parameters which are used in congestion control. We employ the dynamic adaptation of contention window, transmission power and beacon interval to reduce network congestion.

In order to concretely show the effectiveness of our proposal, we compared our approach with another recent solution published in [24]. Our solution gave improved performance compared to [24] in terms of delay and the collision ratio. This is due to the implementation of the deep reinforcement learning model on the internet server (clouds), the use of a large number of congestion indicators, and the diversity in the treatment of congestion, which translates into the set of actions.

# Chapter6: Safety applications in the Internet of Vehicles (IoV)

## 6.1. INTRODUCTION

As previously mentioned, the safety applications in the Internet of Vehicles (IoV) encompass a wide range of features and functionalities designed to enhance road safety. They highlight the potential of IoV in creating a safer and more efficient transportation ecosystem. In this chapter, we are interesting on two real-world systems that utilize MAC (Medium Access Control) protocol for channel access, highlighting their utility in safety applications:

*(i)* *Automated Emergency Event*: In the event of an accident, IoV systems can automatically generate emergency events, providing accurate location information and crucial details to emergency services for a rapid response.

*(ii)* *Health Monitoring for Drivers.* IoV can include systems that monitor the health of drivers in real-time, detecting signs of fatigue or impairment and providing alerts to ensure safe driving conditions.

The rest of this chapter is structured as follows: Section (6.2) describes an V2V based emergency message dissemination scheme for internet of vehicles, including its description and simulation results. Section (6.3) presents a new health application in internet of vehicles called safe drive safe live (SDSL). Finally, Section (6.4) concludes the chapter.

## 6.2.VEMD: AN V2V-BASED EMERGENCY MESSAGE DISSEMINATION SCHEME FOR INTERNET OF VEHICLES

In the Internet of Vehicles (IoV), congestion during message delivery is a major challenge during communication [24,57]. So, this proposition called an V2V based emergency message dissemination scheme for internet of vehicles aims to enhance the algorithm which is presented in [57], while leveraging the advantages of Fog computing available in Internet of Vehicles (IoV) networks.

In the algorithm proposed in [57], vehicles are distinguished based on their internet connectivity capabilities and are assigned different functions; each type of vehicle reacts differently from other types. In fact; this approach involves a congestion control algorithm considering an optimized approach to disseminating accident messages. The server organizes quick responses and alerts to inform incoming traffic to slow down at necessary locations. Although this work reduced congestion constraints for vehicles that can connect directly to the server and termed smart vehicles, but it is not optimal for reducing the number of transmissions and retransmissions. These messages are repeatedly transmitted to the central server simultaneously from various vehicles through broadcast communications. They are used in the case of a non-connected vehicle that lacks intelligent neighbors nearby. Therefore, the risk of congestion is not eliminated; in fact, this not only overloads the server, but also creates a message storm, leading to congestion in the IoV. So, we observed the need to propose a new proposition to enhance the algorithm presented in [57]. In this work, we drew inspiration from [57], focusing on optimizing the mechanism for routing accident messages to their final destination (in this case, the central server).

### 6.2.1. SYSTEM MODEL IN VEMDS SCHEME

In this work, we consider a vehicular network consisting of moving vehicles connected to each other using simple bidirectional V2V communication. The V2V communication operates in WAVE mode based on the IEEE 802.11p wireless network and the IEEE 1609.4 standard. It is facilitated through On-Board Units (OBUs) embedded in vehicles without the need for any specific roadside installations. In our solution, access control to the medium is managed using the CSMA/CA protocol, and message exchange at the MAC level is based on the Clear To Send / Ready To Send (CTS/RTS) technique to address the issues of hidden nodes and exposed nodes (to avoid collisions). The vehicles are equipped with internet connections using 4G LTE wireless technology, enabling data rates between 75 to 150 Mbit/s on average. This internet connection is primarily used for communications with servers (V2S vehicle-to-server mode). To design our proposal, we made the following assumptions:

Some vehicles are equipped with sensors. All vehicles are equipped with GPS positioning systems. All communications are assumed to be bidirectional. All vehicles maintain a list of one-hop neighbors based on their communication range. We focus on V2V communication in which the RSUs are not mandatory. However, if RSUs exists; they can contribute on the scheme as the OBUs.

We considers three types of vehicles as expected in Fig.30 :

- Intelligent vehicle (Iv): represents vehicles that meet both criteria internet connection and sensor (InternetVehFlag = true and sensorVehFlag = true).

- Smart vehicle (Sv): represents vehicles connected only to the internet (InternetVehFlag = true and sensorVehFlag = false).
- Basic vehicle (Bv): denotes regular vehicles that do not have either of the above-mentioned criteria (InternetVehFlag = false and sensorVehFlag = false).

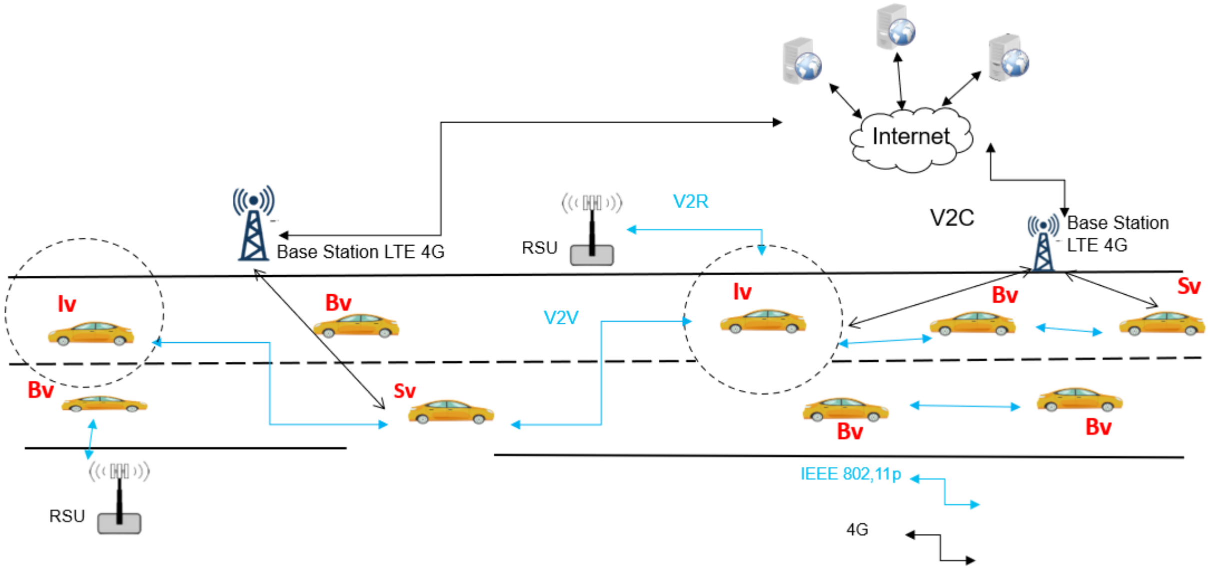


Figure 30 Network architecture of VEMDS.

- All vehicles must send beacon messages and emergency messages in the event of an incident (e.g., road accidents, roadblocks, foggy weather, or an upcoming storm, etc.) to a central Fog-type server.

### 6.2.2. DESCRIPTION OF VEMD SCHEME

A vehicle that possesses information, instead of sending it to all its Internet-connected neighbors, determines the next relay among its neighbors to transmit the information, favoring by this way unicast communications over broadcast. This relay can be either an Internet-connected Road Side Unit (RSU), an intelligent vehicle, or a smart vehicle (connected to the Internet).

Vehicles maintain neighbor lists that can consist of other vehicles or RSUs. Each vehicle knows the position, speed, and direction of all its follower neighbors through periodic exchange of beacon messages, allowing it to calculate distances.

Distances between the vehicle holding the message and its connected neighbors are calculated at regular intervals, ideally just after receiving a beacon message. Therefore, it is the responsibility of the vehicle to make the decision and choose its next relay by selecting the neighbor with whom it has the shortest distance. It will be able to directly transmit the message to the server using unicast communications, rather than blindly broadcasting repeated messages. This minimizes the number of messages and ensures, with a high probability, their timely arrival.

If a vehicle of type Bv faces an abnormal situation (incident), it cannot transfer this information directly to the server without the intermediary of another connected vehicle (either Iv or Sv). However, the presence of connected vehicles around a non-connected vehicle is not always guaranteed. Moreover, using indiscriminate broadcasting to convey emergency information to the server increases the network load. To address this issue, we considered adding an attribute named "Proxy server" to the Beacon Message. This information represents the number of hops to reach the server if a neighbor chooses this vehicle as the next destination. It is equal to 1 if the vehicle or RSU is directly connected to the server. In other words, it is one hop to reach the server. Therefore, it is equal to two if there are neighbors with a Proxy server equal to 1, and so on. It is essential that all vehicles determine the value of their local Proxy server beforehand and fill the neighbor table with this information before any communication in the network. The Proxy server value will then be integrated into the beacon message. The neighbor table will be updated with the new Proxy server values upon receiving each beacon message. When a vehicle has an emergency message, it begins to traverse the neighbor table to select the next transmission relay with the smallest Proxy server value. We can select multiple vehicles with the same Proxy server value (the smallest proxy value). In this particular case, we choose the vehicle closest to the vehicle. The Message Dissemination Algorithm is described in Fig.31.

```
Algorithm 1. Message Dissemination Algorithm
 // at  Initialization step
if ( InternetVehFlag = true AND SensorVehFlag = true) Then
   Vehicle type = Iv;
     else     if (InternetVehFlag = true) Then
                  Vehicle type = Sv;
                   else    Vehicle type = Bv;
              end if
end if

// If an accident has occurred
if (Vehicle type = Iv or Sv and InternetVehFlag = true Then
          Send the message to the Fog server;
         else
              for i from 0 to Total neighbor count
                   if ( Neighbor table[i] = Iv or Sv ) then
                             if ( Neighbor table[i].Proxy server < Min proxy ) then
                                  Min proxy = Neighbor table[i].Proxy server;
                                  Next hop = Neighbor table[i];
                             endif
               end for
end if
if  ( there are several  Neighbors with the same same Min  proxy ) then
                     for i from 0 to Number of neighbord (same proxy value)
                                  if ( Neighbor table[i].distance < Min distance) Then
                                           Next hop = Neighbor table[i];
                                          Min distance = Neighbor table[i].distance;
                                  end if
                      end for
end if
   Send the message to the next hop using unicast;
END
```

Figure 31Message Dissemination Algorithm.

### 6.2.3. SIMULATION RESULTS

In order to evaluate VEMD scheme, we conduct a simulation study using the discrete event simulation environment OMNeT++5.6 [41], the Veins framework veins-5.0 [43], and Simulation of Urban Mobility SUMO 1.12.0[42]. The results are compared with VEMS algorithm [57]. Table 6 summarizes the considered parameters in our simulations.

| **Parameters** | **Value** |
|---|---|
| Simulation time | 300 s |
| Simulation area | Highway, 3 Km |
| Communication rate | 300 m |
| MAC | 802.11P |
| Beacon interval | 1 s |
| Accident message interval | 15 s |
| Number of vehicles | 20 – 40- 70 – 100 vehicles |
| Number of RSU | 19 |
| Velocity | 11-22-33.3-44 m/s |
| Collection Interval | 20 s |
| Learning rate α | 0, 0001 |
| Discount Factor | 0.995 |

Table 6  The considered parameters in VEMD scheme.

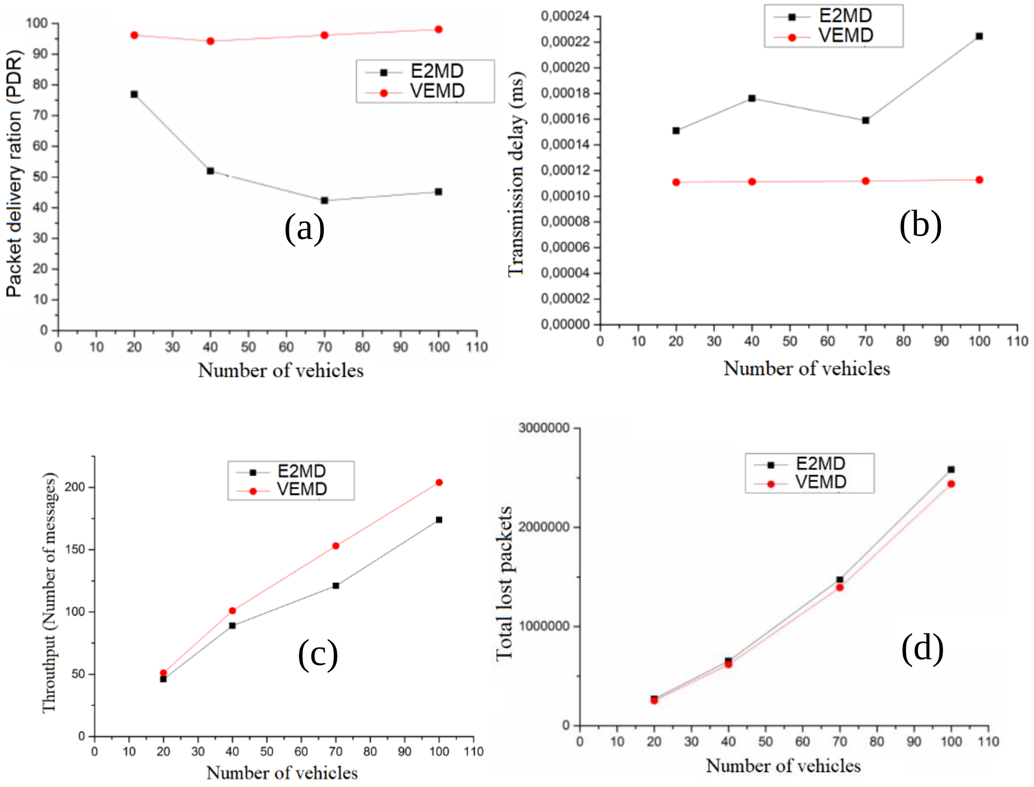


Figure 32Simulation results of VEMD compared to E2MD.

Fig. 32 (a), (b), (c) and (d) illustrates packets delivery ration, transmission delay, throughput and total lost packets respectively. As expected in Fig.31 (a), VEMD achieves a commendable packet delivery rate, outperforming E2MD across various vehicle density values. This is due to our strategy for handling redundant messages and the use of unicast messages guided by information from the Proxy.

According to Fig 31. (b), we observe that the transmission delays in E2MD are variable and reach very high values with a high vehicle density. This observation does not hold for VEMD, where the delays are close when there are many connected vehicles.

The throughput in E2MD is low compared VEMD as illustrated in Fig.31 (c). This is because E2MD employs broadcast for message dissemination due to the elevated probability of locating a connected neighbor capable of directly transmitting the message to the server. As we can see from Fig.31. (d), congestion is indeed present in both algorithms. The elimination of congestion is impossible, but VEMD provides lower total lost packets values than those in the E2MD.

## 6.3. SDSL: SAFE DRIVE SAFE LIVE

The objective of this contribution is to reduce the risk of death on the road by rapidly accessing emergency medical services and so preventing road accidents. We have observed that early detection of an anomaly in the driver can significantly help avoid an accident, especially if nearby vehicles are alerted in time. Timely detection allows for prevention, which aligns precisely with our goal. We focused on cardiovascular diseases as they have unfortunately become the leading cause of mortality worldwide [58]. Cardiovascular pathologies or conditions can lead to a sudden impairment of cardiovascular functions. The driver may experience discomfort at the wheel with light-headedness, fainting, or sudden death [59]. This poses a danger to road safety. In some situations, driving may be possible after the pathology has been successfully treated, taking into account the assessment conducted by a cardiologist.

In this context, we need to manage ambulances and the health of the drivers as follows: we start by assessing the driver's health using a smartwatch or by detecting rapid health changes, especially concerning cardiovascular diseases, before the driver loses control. If necessary, the vehicle must be stopped to prevent an accident, and the search for a health vehicle must be initiated to transport the patient. We have named this application SDSL: safe drive safe live.

### 6.3.1. SYSTEM MODEL

Our study focuses on a system of connected vehicles moving in groups on our roads. We assume that each vehicle is capable of communicating with various objects using different types of networks. Each vehicle is equipped with an On-Board Unit (OBU) that employs three network models to communicate and exchange information:

The IEEE 802.11p standard for wireless communication is used to enable communication between V2V OBUs. We assume that each vehicle has an OBU, which is a small onboard computer capable of executing algorithms.

Wireless LTE 4G technology ensures internet connectivity for communication with servers. We assume that a set of vehicles is connected to the internet to facilitate communication with the server. For emergency phone calls, 4G technology is also utilized. The OBU is additionally equipped with Bluetooth for communication with a smart medical watch. All vehicles are equipped with a GPS positioning system. All vehicles have an automatic steering system that uses lidar, 360° camera, radars, and wheel sensors to ensure automatic parking in case of anomalies. Automatic stopping should be triggered without the driver's involvement in the event of a serious incident. V2V communications using the IEEE 802.11p standard are bidirectional. Vehicles maintain a list of neighbors within communication range through the exchange of periodic beacon messages using V2V communication. Beacon message includes several information such as position, speed, vehicle identity and the availability of an internet connection in the OBU. Vehicles can be divided into three distinct categories:

***OV***: for Ordinary passenger Vehicles.

***EV***: for Emergency Vehicles, such as ambulances.

***HV:*** Healthcare Vehicles,

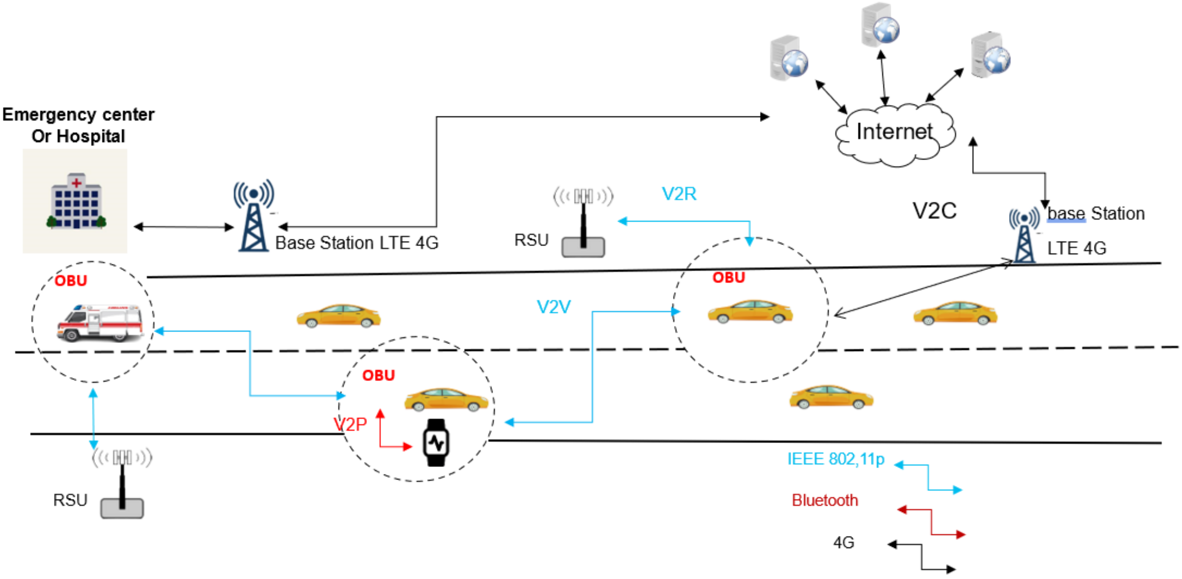


Figure 33 Network architecture of SDSL system.

Emergency vehicles are connected to the internet, while ordinary vehicles may be either connected or not connected. Healthcare professional vehicle is an ordinary vehicle driven/used by voluntary doctor. HV has a specific account in the system, allowing them to connect online via a mobile application at any time. They can activate their availability through their account to inform the system that a healthcare professional is nearby. A notification is sent to the On-Board Unit (OBU) on the vehicle to inform about the presence of an available doctor in this healthcare vehicles.

Each On-Board Unit (OBU) communicates with only one smartwatch at a given time since there is only one driver, and the watch is intended for use with a single patient. The emergency center is always connected to the internet, representing a hospital or clinic.

### 6.3.2. ANOMALY DETECTION IN SDSL

Our work focuses primarily on the detection of cardiac anomalies among various medical irregularities. To achieve this goal, we have chosen to use smartwatches equipped with heart rate and blood pressure sensors. These smartwatches play a crucial role in the accurate collection of data needed for the analysis and detection of cardiac anomalies. The smartwatch takes regular measurements of heart rate and blood pressure, and these measurements are linked to the age of the driver. Subsequently, this information is transmitted to On-Board Units (OBU) at the vehicle level. We have taken into account the specific characteristics of each health parameter in our decision-making process.

In the first step, we focus on data analysis and the detection of potential anomalies by the On-Board Unit (OBU). The OBU executes specific algorithms to process the received data and compares it with predefined reference ranges. We take age into account when considering heart rate. The average maximum heart rate is calculated as 220 minus the patient's age, and the target heart rate depends on the patient's age. Information on the average and maximum heart rate in beats per minute, as well as blood pressure categories, is from this work [60]. If the measurements of heart rate or blood pressure fall outside the previously defined reference ranges, the OBU detects an anomaly.

### 6.3.3. SEARCHING FOR A HEALTH PROFESSIONAL VEHICLE AND AN EMERGENCY VEHICLE (AMBULANCE)

#### ***a. Request creation***

In the second step of our anomaly detection process, the search for a Health Vehicle (RVS - ambulance) and the search for a Health Professional (RPS - volunteer doctor to try to save the patient while waiting for the ambulance to arrive). Consequently, the state of the request is composed of two sub-states: search for a health vehicle (SHV) and search for an emergency vehicle (SEV). There are three values for SHV and SEV: “pending”, “in progress” and “Terminated”.

The vehicle $V_i$ who detects the anomaly create an emergency message including vehicle position, SHV and SEV states, time of the incident, vehicle identity and the identity of a patient (if there is a medical file for this patient). This message represents the beginning of the request in which SHV and SEV are set to “pending”. The request is identified by time of the incident (with date) and the vehicle identity.

After the detection of the incident, the vehicle $V_i$ undertakes various actions, taking into account its internet connectivity. Firstly, If the vehicle is connected to internet, it sends an emergency message to the server to search for a nearby ambulance and health vehicle. If the server finds an ambulance, it changes the state of the search request SEV to "in progress" and informs the vehicle of this state change with an ACK. The vehicle then sends an emergency message to its neighbors with the new state "in progress" and continues to search for a healthcare professional. At the same time of the anomaly detection, the vehicle $V_i$ periodically sends a warning message to its neighbors, containing the vehicle's position, to inform them of the incident and attempt to avoid an accident as soon as possible. However, if the vehicle is not connected to the internet, it simply sends the emergency message only to its neighbors with the SEV state in "pending" and SHV state in "pending" too.

#### ***b. Actions to take when receiving an emergency message.***

When the vehicle Vj receives an emergency message, it first checks if this message does not already exist in its request list. If it doesn't find it, it records it with the identification of the request and its state, as well as the identifier of the source vehicle to facilitate the later dissemination of the ACK. There are four situations:

- **Vi is an emergency vehicle**

If Vj is an emergency vehicle and it is available, and the state of the message relates to the search for an emergency vehicle SEV is still “pending”, then it takes charge of this request and modifies the sub state SEV to "in progress". So, it will head towards the patient. At the same time, Vj informs the server of the state change, and the server grants access, sending the corresponding medical record to Vj based on the patient's ID. If the source vehicle is not connected, it sends an ACK to inform it of the update to its request by sending it to its neighbors. When the emergency vehicle arrives at the incident vehicle, it takes charge of the patient. The OBU of the patient's vehicle will automatically stop sending investment messages to its neighbors upon receiving the message from the emergency vehicle. In parallel, it also informs the server to set the search state to 'completed' and cancel the search for the health professional if it is in progress or pending. If the vehicle Vi is not connected internet, it sends the emergency message to its neighbors with the updated state of REV “ in progress” in order to inform the server about the changed state; and stop so searching for emergency vehicle.

- **Vi is a health vehicle**

When vehicle Vj receives a message, and it is a healthcare professional; it checks if the state of the search for a healthcare professional is pending. If this condition is satisfied, and the professional agrees to help, Vj updates the state of the healthcare professional search to “in progress” and heads towards the patient. If this health vehicle is out of service, then it operates like an ordinary vehicle.

- **Vi is an ordinary vehicle with connection to internet**

Next, if Vj is an ordinary vehicle and is connected, whether with an ordinary driver or a healthcare professional driver, it checks the state of the SEV search for a health vehicle. If it is pending, Vj broadcasts the emergency message to the server and waits for a certain period to receive an ACK indicating the state change. If an ACK is received, Vj updates its state accordingly. In case of a state change, Vj also informs the source vehicle of the message of this update. However, if it founds SHV on “pendig”, Vj broadcasts the emergency message to its neighbours if SEV is “pendig” or “in progress” and only if the distance between Vi and the source vehicle (detecting anomaly) is lower than k*R where k is a constant and R is the transmission range. This is to search for a health vehicle only on local region. The constant k determines the perimeter of search area.

- **Vi is an ordinary vehicle without connection to internet**

Next, if Vj is an ordinary vehicle and is not connected, it checks the state of the request. Vj broadcasts the emergency message to its neighbors if (SEV is “pendig”) or (SHV is “pending” while SEV is “pendig” or “in progress”). The Ack is broadcasted if the request in question has passed through this vehicle Vj.

### *c.* ***Actions to take when receiving a warning message.***

When vehicle Vj receives a warning message, it reduces its speed and takes preventive measures to avoid an accident. It decides to change routes if possible to bypass the risk zone. This quick reaction allows Vj to guard against the incident and ensure its safety as well as that of other road users. In other words, Vj sends the warning to its neighbors within a predefined perimeter. This sending is done only once to avoid network overload. It also serves to alert other drivers and maintain a safer road environment.

### *d.* ***Actions to take when receiving an ACK message.***

When a vehicle receives an ACK message containing the ID of the message and the state of the request, it checks its local list to see if the emergency message corresponding to this ID has already been recorded or not. If so, it updates the state of this request in its list with the new value. Then, the vehicle extracts the identifier of the source from which it received the emergency message for the first time and broadcasts an ACK to this source. To achieve this, it relies on the broadcast of messages to send the ACK messages to the initial destination.

### *e.* ***Actions to take by the server.***

Server-Level Processing When a vehicle connected to the Internet sends an emergency message to the server, an emergency request must be processed. The server first performs a check to determine if the emergency request is already recorded and if there are health vehicles available. If the request does not exist, and there are health vehicles available, the server starts by assigning the appropriate ambulance for the intervention. The selection of the ambulance is based on the closest and fastest availability. The server changes the state of the request to “in progress”. Then, it sends a message to the selected ambulance, including the location of the emergency request. It also broadcasts a notification to the vehicle that informed it to update the state of the request.

### *f.* ***Actions to take by emergency vehicle once arrived to destination.***

If the ambulance arrives at the patient's position and takes charge of the patient, it informs the server, the server updates the search state of the health vehicle to 'completed'. If a search for a healthcare professional is still in progress or pending, it will be canceled by the server. A thank-you and cancellation message will be sent to the healthcare professional's vehicle if the SHV state is “in progress” to inform them that the ambulance has arrived, so there is no need for their movement. Then, the server notifies all connected vehicles that received the emergency message and recorded it in their list of this update. If no health vehicle is available according to the server, the emergency request is put on hold in a queue until an appropriate vehicle becomes available. The server continues to monitor the queue and makes the selection as soon as an emergency vehicle becomes available. Furthermore, the broadcasting of the emergency message to find an ambulance remains active until an ambulance is found.

### 6.3.4. SIMULATION RESULTS OF SDSL

In order to concretely show the effectiveness and the feasibility of SDSL, we conduct a simulation scenario using the discrete event simulation environment OMNeT++5.6 [41], the Veins framework veins-5.0 [43], and Simulation of Urban Mobility SUMO 1.12.0 [42]. Table 7 summarizes the considered parameters in our simulations.

| **Parameters** | **Value** |
|---|---|
| Simulation time | 400 s |
| Simulation area | 5km x 3 Km |
| Communication rate | 600 m |
| MAC | 802.11P |
| Beacon interval | 2 s |
| Number of vehicles | 30,60,90,120,150 vehicles |
| Velocity | 11-22-33.3-44 m/s |
| Bitrate (IEEE 802.11p) | 6 Mbps |
| LTE download speed | 67.41 Mbps |
| LTE upload speed | 10.10 Mbps |
| Vehicle connectivity rate | 0%-100% |
| Period of sending positions to the server | 10s |

Table 7 The considered parameters in SDSL scheme.

Figure 34 (b) illustrates the variation in the arrival time of healthcare professional vehicles based on their speed, compared to that of emergency vehicles. An important observation is that healthcare professional vehicles have shorter arrival times than emergency vehicles. The incorporation of health vehicle into SDSL facilitates a prompt and efficient response for delivering on-the-spot medical care. This capability has the potential to significantly enhance patient outcomes and expedite the recovery process.

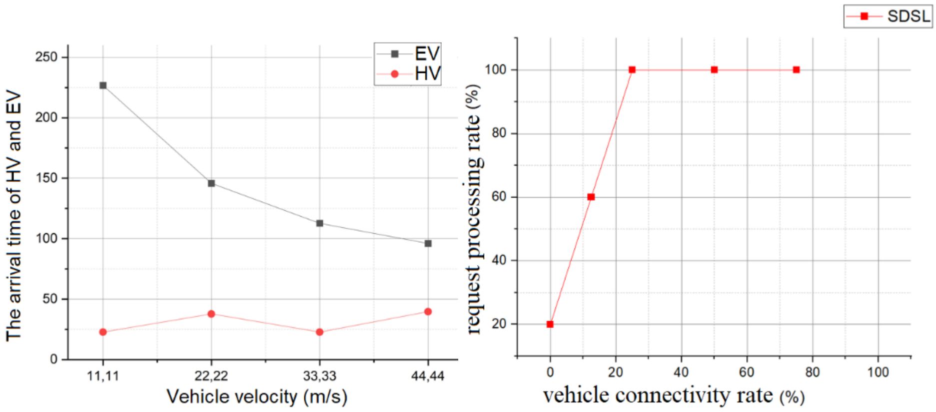


Figure 34 Simulation results of SDSL: (a) the arrival time of HV and EV, (b) request processing rate.

Figure 34 (b) depicts the request processing rate as a function of the vehicle connectivity rate. As shown, with a lower connectivity rate, there are still processed requests due to the utilization of 802.11p networks. However, with higher connectivity, all requests will be processed. This analysis emphasizes the importance of a minimum percentage of 25% connected vehicles in the network for system efficiency and to ensure a prompt and effective selection of healthcare vehicles.

## 6.4. CONCLUSION

In this chapter, we proposed two efficient systems that Emphasize the capability of vehicular ad hoc networks to contribute to the establishment of a transportation ecosystem that is both safer and more optimized. We emphasized their relevance in safety applications through various simulations. The first contribution of this chapter focused on the use of unicast communications and the proximity of vehicles to servers in order to develop an efficient emergency message dissemination scheme. Motivated by existing research in the field of health within the context of the Internet of Vehicles, we have developed the second contribution called SDSL to reduce the risks of accidents through a monitoring and health management system for drivers.

# Chapter 7: Conclusion, perspectives and future works

The inclusion of vehicular networks in the Internet of Things has received a significant interest. This combination introduces a new type of vehicular network called Internet of Vehicles. IoV refers to intelligent communication between electronic devices, including vehicles, through the exchange of data stored in the cloud. IoV encapsulates the concept of intelligent communication among electronic devices, with a particular emphasis on vehicles, facilitated through the seamless exchange of data stored in the cloud. This framework not only harnesses the benefits of continuous internet connectivity within vehicles and network devices but also enables optimal data processing. The Medium Access Control (MAC) protocol plays a pivotal role in the effective functioning of vehicular communication systems within the Internet of Vehicles (IoV). An efficient MAC protocol is essential for overcoming the challenges posed by the dynamic and high-mobility nature of vehicular networks. Such a protocol contributes significantly to the reliable, low-latency communication necessary for the success of IoV applications and services.

In this research study, we first introduced a new clustering method using Reinforcement Learning (RL) for Internet of Vehicles. We advised the use of RL to elect the cluster head (CH) using reward formalism which resumes on the number of received beacons. This approach permits to elect the suitable CHs for each cluster of vehicles and predict the connectivity quality between each cluster head and their members to allow a dynamic and timely maintenance of the cluster structure with a low communication overhead. Therefore, the introduced key elements that make the novelty of this contribution are threefold. First, we have used and adapt Q-learning algorithm in the proposed scheme in order to elect an optimal Cluster Head with large cluster lifetime and low changes rate in the cluster. Second, we proposed a novel cooperative algorithm to improve the efficiency of cluster head decisions. Third, we propose the usage of a basic beacon message with two extra parameters named: the Sub-State (SS) and Complementary Information (CI) which are coded in 2 bytes and used for the cluster management procedures. Thereby, the generated overhead is reasonably low in the proposed algorithm which significantly optimizes the bandwidth usage. We evaluate the proposed methodology through extensive simulations and demonstrated its effectiveness by the comparison with some recent state-of-the-art approach.

After that, we propose an efficient QoEC-based MAC scheme for Internet of Vehicles (IoV) by introducing a new Clustering-based MAC protocol in which cluster heads may switch between 802.11p and TDMA to keep effective bandwidth exploitation. The QoEC-MAC considered that the vehicles are arranged in groups. Each group has one cluster head that is in charge of assigning slots, transmitting messages delivered by the cluster members, and scheduling communications between and within the cluster. Furthermore, QoE-oriented MAC is used to improve the efficiency of the network by reducing transmission delay and packet loss. The simulation results show that the QoEC-MAC outperforms the IEEE 1609.4 in channel transmission delay, collision ratio and total throughput.

Then, we introduced a new deep reinforcement learning-based congestion control scheme for the dynamic environment of the Internet of Vehicles (IoV). Our approach not only detects but also effectively handles congestion situations, thereby ensuring seamless and efficient data transmission within vehicular networks. Leveraging the internet connectivity available in vehicles, we empowered each vehicle to optimize crucial Medium Access Control (MAC) parameters, such as contention window, transmission power, and beacon interval, instrumental in congestion control. To validate the efficacy of our proposal, we conducted several simulations, comparing our approach with a recent solution. The results demonstrated the superior performance of our scheme in terms of reduced delay and collision ratio.

Finaly, we introduce two safety systems (i) SDSL and (ii) VEMD, that underscore the potential of the Internet of Vehicles (IoV) in shaping a transportation ecosystem. Using detailed simulations, we demonstrate their importance in improving safety applications. VEMD focuses on taking use of unicast connections and vehicle' close proximity to servers. The goal of this strategy is to create a reliable emergency message distribution system. SDSL is based on existing health-related research by rapidly accessing emergency medical services, including ambulances, and tries to reduce accident risks. By detecting driver anomaly, SDSL strengthens safety measures on the road. The objective of SDSL is to save the driver's life while simultaneously preventing an accident.

Looking ahead, our research opens avenues for multifaceted exploration and advancement in IoV communication protocols. Firstly, we will compare QoEC-MAC with recent hybrid MAC protocols for IoV. We will also refine the implementation of the protocol by considering an efficient broadcasting scheme and enhancing the gateway selection mechanism. Future research will expand upon performance analysis within congested network environments and explore various scenarios involving node density. Conducting extensive field tests will provide invaluable insights into its adaptability and performance under diverse conditions, ensuring its robustness in real-time IoV scenarios.

Additionally, further research efforts should focus on enhancing the scalability and real-time responsiveness of our deep reinforcement learning model used on PCA MAC Protocol. As IoV networks continue to grow in complexity and scale, optimizing PCA scheme for large-scale deployments will be essential.

In summary, the ongoing research on MAC protocols for vehicular networks is poised to revolutionize IoV communication. By continuously refining technical aspects, considering user experiences, and adapting to evolving network challenges, the future of IoV holds the promise of unprecedented connectivity, efficiency, and user satisfaction. This journey represents a collective effort towards a smarter, safer, and more connected vehicular future.

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