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Title

Robust Applications for Internet of Vehicles

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"If you don't climb the mountain

you can't see the view ".

Pablo Neruda

Declaration of Authorship

I, Rim Gasmi, declare that this thesis, \ Robust applications in Internet of Vehicles ", and the work presented in it are my own and has been generated by me as the result of my own original research. I confirm that:

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Acknowledgments

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Last and not least, I would like to thank my mother, my husband and all my family, friends and colleagues for their encouragement.

Dedication

This dissertation is dedicated

To my dear mother, at first and foremost

To my husband

To my brother and sister

To all my family and friends

For all their love, patience, kindness and support.

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Abbreviations

MANET	Mobile Ad hoc NETwork
VANET	Vehicular Ad hoc NETwork
ITS	Intelligent Transportation System
V2V	Vehicle to Vehicle
V2I	Vehicle to Internet
V2R	Vehicle to Road infrastructures
V2P	Vehicle to Personnel device
V2X	Vehicle to everything
IoT	Internet of Things
IoV	Internet of Vehicles
RSU	Road Side Unit
OBU	On Board Unit
GPS	Global Positioning System
CH	Cluster Head
CM	Cluster Member
WAVE	Wireless Access in Vehicular Environment
DSRC	Direct Short Range Communications
QoS	Quality of Service

Introduction

In this thesis, we are interested in proposing, designing, simulating and evaluating new protocols based on Quality of Service within the framework of the Internet of Vehicles. The research work was done in the LRSD Laboratory of Ferhat Abbas Sétif-1 University. In the introduction of this manuscript, we will introduce the concept and problematic of the research work, then we describe the goals and contributions of this thesis. Finally, we will describe the organization of this thesis.

Nowadays, the utilization of wireless communication technologies in the transportation field has augmented with the active growth of smart cars' development. It was announced that the number of vehicles in use grew up from about tens' million in 2006 to thousands' million in 2015 and this number is still increasing for the time being [1]. Thus, the demand for new methods to control the transportation systems is very needed. That is why Vehicular Ad hoc NETworks (VANETs) have been created. VANETs can be considered as the application of Mobile Ad hoc NETworks (MANETs) for road traffic information sharing. They offer vehicular communications via wireless and mobile networks with or without infrastructures. VANETs apply data exchanging and processing to transport means, infrastructures and users in the aim of increasing the efficiency, resilience, safety, robustness and environmental performance of the transportation systems. As a result, VANETs provide intelligent control and services to vehicular environments. The appearance of the new concepts of Internet of Things (IoTs), big data, cloud computing have encouraged the generalization of VANETs to the Internet of Vehicles (IoV), where vehicles act as active members and smart entities with new perception and communication capabilities [2], providing an omnipresent connectivity, a wide range of applications and services relating to the road safety, the intelligent transport and the comfort of users. Moreover, a vehicle in IoV are perceived as dynamic mobile communication system, that supports the following communication modes: intra-vehicle components mode and Vehicle-to-X (V2X) mode, where X take the role of: vehicle, road, infrastructure, human, cloud or Internet [3]. Compared to conventional VANETs, IoV have many specific advantages and characteristics, such as developing and extending the exploitation of the ITS in different fields of research and industry. As a main advantage, the ability to integrate multiple users, multiple vehicles and multiple networks using different communication technologies. Consequently, IoV enable reception, storage and processing of large number of data from different geographical areas through intelligent vehicles computing systems to offer several categories of services for road safety and other non-safety services to drivers and passengers. IoV support a large number of relevant applications and services, such as accident avoidance, collision warning, cooperative driving, wireless remote diagnosis, traffic flow regulation, route guidance, Internet access and infotainment applications like playing games and listening to music. Owed to this versatility of applications and services, IoV become a major research motivation of governments, car manufacturers and academic institutions, and attract more and more interests of them.

Research motivations and problem statements

Even though IoV have many advantages, they still suffer from a number of challenges such as rapid growing number of vehicles and other objects connected to the IoV system, the integration of all components and object communications in the IoV network, the big data that have to be processed and stored in IoV network [3]. Furthermore, IoV faces many implementation problems, such as the security and reliability of inter-vehicles communications and various simultaneous demands for assistance that cause a high number of collisions [4]. Otherwise, the challenges that already exist in classical VANETs also affect network system such as high mobility of vehicles, variable density, dynamic topology, network fragmentation and communication models. Considering all the above issues, the successful deployment of IoV consists of a number of important components, a key one of which is how to establish stable and efficient routing paths from sources to destinations in the complex and dense urban scenarios. The benefits of IoV will be limited without the available solution of this routing problem, the main challenges of IoV routing issue in urban scenarios are as follows:

Firstly, real-time and accurate QoS routing obtainment. Routing QoS can directly affect the efficiency and availability of several applications, for example, emergent accident warning is required to be shared with short delay and the communication of this routing path should be favorable, while reliable and robust routing paths with high packet delivery ratio are necessary to provide available E-payment service to customers. Routing QoS metrics, such as delay, packet delivery ratio, connectivity probability and network overhead play an essential role in establishing available routing paths, as they indicate the characterization of the routes quality which is highly relevant to instantaneous and precise operational traffic information (e.g., vehicle density, vehicle distribution and road segment length). Moreover, the spatial-temporal features of traffic conditions in IoV are dynamic, for example, the spatial vehicle density can change from very sparse to highly dense, and the temporal vehicle density in one area can be variant depending on the time of the day. As a result, real-time and accurate routing QoS is very difficult to be estimated in IoV scenarios.

Secondly, low QoS performance. In IoV environment, it is very hard to keep the best QoS for packets exchanging in vehicular scenarios for the following possible reasons: (1) the overall QoS of candidate routing paths are hard to be known by a sender vehicle, so routes discovery processes in large scale networks are always based on local traffic information with random characteristics, which may result in the end-to-end routes including network partitioned/congested road segments, (2) urban environments are usually large-scale scenarios and the communication distance from a source to its destination may be very great, (3) most traditional VANET routing protocols lack of self-adaptation features and cannot cope with topology changes availably, which can disturb the process of packets forwarding, and (4) different communication pairs are usually absent of cooperation and do not make use of explored routing paths, so more routing exploration processes are implemented, which may result in redundant overhead and higher transmission delay.

Thirdly, scalability and stability. Ensuring a stable and scalable routing mechanism over IoV is an essential and necessary phase toward the implementation of reliable vehicular communications. However, due to varying vehicle mobility and network topologies, routing paths are ruptured frequently, and it is very difficult to guarantee their stability.

Fourthly, network congestion. Large-scale vehicular structures are characterized by a high number of vehicles in IoV especially at rush hours, their connection exchange can easily charge the wireless channel with large traffic loads and may cause significant failure of packets delivery ratio and increase transmission delay. In fact, these traffic loads comprise not only data packets but also a number of Beacon packets, which are used to update road traffic information among neighbor nodes. Clearly, higher traffic loads and limited bandwidth can easily encourage network congestion and then decrease routing performance. Thus, alleviating network congestion and reducing overhead in IoV are very challenging issues that we want to address in this thesis.

Finally, heterogeneity conveyed data packets. IoV support a large variety of applications from safety to infotainment applications. Road safety applications usually demand low transmission delay and high reliability during resource utilization, packet loss and service availability are the common performance measures for infotainment applications. Moreover, some QoS metrics may give inverse results to each other in certain communication scenarios, for example, dense vehicles are helpful to the enhancement of connectivity but may augment packet loss ratio due to channel congestion and interference. To satisfy with heterogeneous applications, the best QoS routing selection with multiple QoS thresholds should be considered.

Goals and Contributions

To support a wide range of applications, routing protocols of IoV must be able to efficiently transmit packets to their destinations. In order to deal with the challenges, we propose in this thesis suitable for large-scale urban scenarios two routing protocols in which their roles are to search the best QoS routing path which satisfies with different applications requirements based on various QoS metrics namely speed, delay, direction, link lifetime, available bandwidth, and so on. Moreover, these routing protocols are adaptive and scalable, and can effectively increase communication stability and reduce network overhead to deal with network congestion and high mobility of vehicles in IoV. Otherwise, using efficient network structuring technique for the IoV paradigm in order to manage their challenges and provide suitable conditions to run the different applications is very required. Clustering structures have significantly improved network performances compared with classic flat structure in numerous applications [106], such as data dissemination and aggregation. In this concept, we propose a new clustering technique in the context of IoV to meet the requirements of such network. In order to realize our objectives, the main research contributions are conducted as follows:

Firstly, in our papers: "Vehicular Ad Hoc NETworks versus Internet of Vehicles - A Comparative View " [15], presented in the International Conference on Networking and Advanced Systems (ICNAS 2019), we compare between the two paradigms VANETs and

IoV under various aspects: network architecture, network characteristics, communication technologies, network platform.

Secondly, we propose a new routing protocol suitable for the IoV environment. The goal of this proposal is to find the stable links in network in order to ensure a good communication stability in such environment. In our paper entitled "A Stable Link Based Zone Routing Protocol (SL-ZRP) for Internet of Vehicles Environment " [86], accepted for publication at Wireless Personal Communications (Springer), we modify the well-known routing protocol named Zone based Routing Protocol (ZRP) by integrating QoS to its path's discovery process. This protocol aims to find the stable routes in network using geographic information, where each node can choose the stable route in its own zone by selecting its neighbor nodes that move to the same final region during its trajectory. Moreover, speed of vehicles and delay are also used as metrics in order to select the stable and fast routes in network.

In our paper entitled "A Weight-Based Clustering Algorithm for IoV", accepted for publication at Automatic Control & Computer Sciences (Springer), we present a new weight-based clustering algorithm for IoV, that aims to increase the stability of clusters and reduce communication overhead. The proposed algorithm uses three parameters namely: safety, mobility and density. For each group of nodes, a Cluster Head must be elected based on the three metrics previously cited. The variety of metrics used to select Cluster Heads may guarantee a high level of Quality of Service in IoV environment such as: high security, long connectivity, links stability and so on.

In our paper entitled "Reliable connectivity-based Clustering Algorithm for IoV", submitted at Future Generation Computer Systems journal (Elsevier), we introduce a new weight based clustering algorithm, where we will minimize the network overhead by using hierarchical architecture(clusters) and maximize the quality of service (short response time) by integrating selective parameters such as delay, density, speed and position to select the cluster heads in order to ensure some quality of service in IoV by guaranteeing a reliable connectivity and a low network overhead.

In our paper entitled "Unstable Connectivity Aware Protocol for Dependable Messages Delivery for Future Internet of Vehicles", submitted at International Journal of Wireless Information Networks journal (Springer), we propose to take advantage of the IoV features to choose appropriate metrics aiming to ensure route stability according to two levels. In the first one, best routes are discovered by using metrics such as signal strength, bandwidth, delay and node velocity. In the second level, an approach for estimating links life time has been used. The latter is based on speed and direction parameters in order to find the most durable route. To this end, Fuzzy Logic method has been used to reach our objective.

To sum up, the main contributions of this thesis can to be summarized as follows:

• Propose new routing protocols for the IoV network, which make it possible to improve its performances while guaranteeing a high level of service required by the function performed by the latter.

• Propose a new algorithm-based clustering architecture in order to minimize network overhead and guarantee high Quality of Service.

• Evaluate the performance of the proposed algorithms, compared with known upper bounds and best-known algorithms in recent literature.

Thesis organization

In this thesis, we opted for the \articles" format. Some chapters are therefore the transcription of articles published in, or submitted to, scientific journals or conferences. So, the thesis contains five chapters divided into two main parts: background and contributions, and it is organized as follows:

In the background part:

• Chapter 1 gives a background of knowledge about the Internet of Vehicle (IoV); their architecture, characteristics, challenges, communication technologies and applications; and all that belongs to this domain.

• Chapter 2 presents the state of the art on the routing algorithms for vehicular network in the literature. At this point, we attempt to detect certain problems still open or whose proposed solutions are still to improve, in order to propose new routing protocols suitable for IoV.

The contributions part of this thesis introduces the proposed clustering approaches:

• In Chapter 3, we present a new routing protocol suitable for the IoV environment, that aims to find the stable routes in network using geographic information, in such manner each node can choose the most stable route in its own zone by selecting its neighbor nodes that move to the same final region during its trajectory. Moreover, speed of vehicles and delay are also used as metrics in order to select the stable and fast routes in network.

• In Chapter 4, we introduce a new weight based clustering algorithm, where we will minimize the network overhead by using hierarchical architecture(clusters) and maximize the quality of service (short response time) by integrating selective parameters such as delay, density, speed and position to select the cluster heads in order to ensure some quality of service in IoV by guaranteeing reliable connectivity and low network overhead.

• In Chapter 5, we propose a new two-level routing protocol for IoV communication. The first level aims to find the best routes using several metrics such as signal strength, bandwidth, delay and node velocity. The second level aims to find the durable routes in term of link lifetime. The approach used to estimate link lifetime is based on speed and direction parameters.

• Finally, we conclude our thesis with a brief discussion and some future perspectives.

Background

Chapter 1

Internet of Vehicles: An overview

1.1 Introduction

In the recent decade, mobile communications have known a great development by enabling us to interchange data with anything, anywhere and at any time. The utilization of such kind of developed communications systems in vehicles is anticipated to be a reality in the next years. VANETs inherit the characteristics of Mobile Adhoc NETworks (MANETs) as free connected objects capable of moving randomly and communicate wirelessly. VANETs refers to the Intelligent Transportation System (ITS), where vehicles are intelligent objects communicating (send and receive data) between each other with a smart manner [4]. This new concept of exchanging data between vehicles, sensors, and infrastructures will provide a large variety of applications for driver such as: driver safety, driver assistance and infotainment. Internet of Things (IoTs) is a network of objects containing sensors in which they capture and gather data from their surroundings and distribute data through the internet [5]. Internet of Vehicles (IoV) allow data collecting and information sharing about vehicles, roads and their surroundings. Moreover, IoV include data treatment, data computing, and secure data sharing over network platforms. Through such data, network platform can manage and supervise vehicles with an efficient manner, and offer various services such as multimedia and Internet applications [6]. IoV are considered as integrated systems that supports intelligent road traffic management, intelligent dynamic information service and intelligent vehicle control, illustrating a typical application of IoTs technologies in Intelligent Transportation Systems (ITS). In this chapter we are going to introduce the fundamental concepts of IoV. Here, we point out on definitions, architecture, applications, communication technologies, characteristics, challenges that face IoV environment in different aspects, and the simulations and mobility models used to design such network IoV.

1.2 IoV’s definition

Alam et al. [7] defined IoV as an ITS integrated IoT from the perspective of intelligent transportation. Moreover, IoV is considered as the vehicular ITS, which regards the driving vehicle as the information sensing and intelligent mobile object.

Hartenstein et al. [8] consider that IoV is a global network that integrates three sub-networks: intra-vehicle network, inter-vehicles network, and vehicular mobile Internet.

Jiacheng et al. [9] present the definition of IoV from the perspective of integration of on-board sensors and communication technology. They consider IoV as a set of intelligent vehicles equipped with advanced sensors, controllers, actuators, and other devices, which uses modern communications and network technology for providing the vehicles complex environmental sensing, intelligence decision-making and control functions.

It can be concluded that there are differences in the definitions of IoV when researchers provide their definition in view of their own research areas

1.3 IoV's communication architecture

Vehicle: is an intelligent vehicle with complicated intra-vehicle systems as shown in Figure 1.1. Vehicle embeds various sensors in order to detect vehicle and driving status, and communication devices to communicate with other vehicles and/or Internet [10]. A software platform (a vehicular operating system) is necessary to process status information and controls all devices.

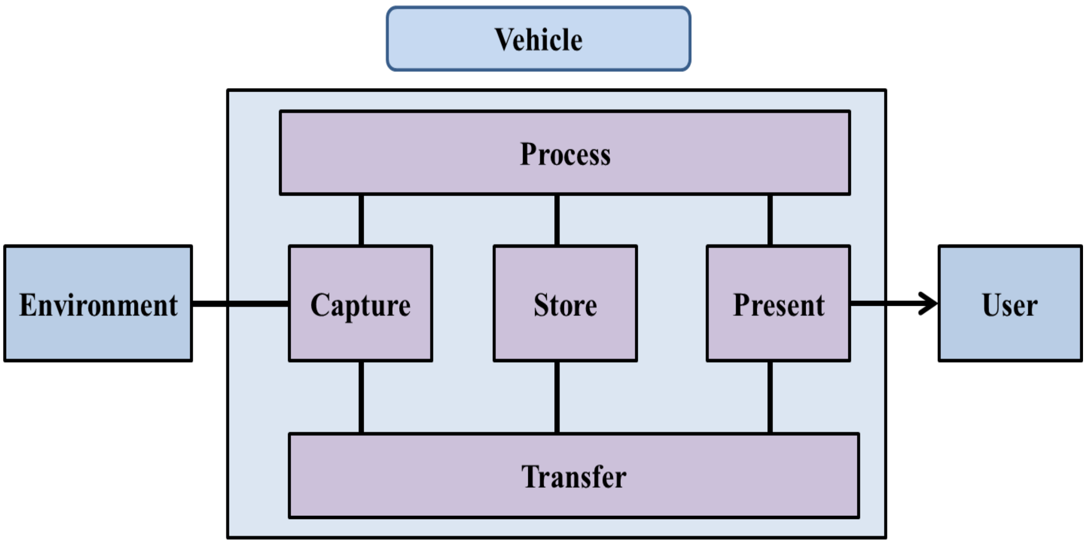


Fig.1.1 Intra-vehicle systems in IoV

On Board Unit (OBU): It is a terminal equipment mounted on-board of a vehicle to provide a mutual wireless communication between vehicle and surrounding vehicles and infrastructures. it uses Wireless Access in Vehicular Environment (WAVE) standard which is based on the emerging IEEE 802.11p specification [11]. It operates on the 5.9 GHz Direct Short Range Communications (DSRC) band.

Road Side Unit (RSU): It is a computing device installed on the roadside that provides communication services to vehicles. Like OBU, the RSU uses WAVE standard which is based on the emerging IEEE 802.11p specification. It also operates on the 5.9 GHz DSRC standard. They are controlled and managed by the Transportation Control Center (TCC) through wired communication channels. It acts as a gateway that allows vehicles to establish connection with Internet. The RSU provides different services to vehicles such as: communication services, security services, data dissemination and aggregation services, and Internet access. In addition, the RSU has a number of functionalities such as: extending the network coverage, traffic directories, data dissemination, security management, location servers and service proxies [3].

IoV supports various types of connection which are:

• Vehicle-to-Vehicle (V2V) ad hoc communication: by this type of communication each vehicle can contact its neighbor vehicles without passing by any fixed infrastructure support (direct communication) and can be mainly used for safety, security, and dissemination applications [10].

• Vehicle-to-Roadside unit (V2R) ad hoc communication: V2R refers to the information exchanged between vehicles and roadside units such as traffic lights or warning signs on roads, where roadside units are used as data storage servers. V2R communication can reach long distance unlike V2V. In addition, roadside units may play role of intermediate hops to increase range communication to destination [8].

• Vehicle-to-Infrastructure (V2I) ad hoc communication: through this kind of communication, vehicles can connect to internet and benefit from several internet services [11].

• Vehicle to Personal devices (V2P) or Vehicle to Human (V2H) refers to the interaction between vehicles and personnel devices that appertain to persons (drivers, passengers, pedestrians, cyclists) like tablets, smart phones, etc. Through this kind of connection vehicles can share with mobile devices different services (file sharing, music, video streaming) [14].

• Vehicle-to-Sensor (V2S) this type of communication is considered to enable vehicles to monitor their behavior during their movement by detecting their speed, their position, the tire pressure, the oil pressure [12], etc.

• Vehicle-to-everything (V2X) The appearance of IoT allows vehicles to be able to connect to everything that can share information about vehicle's surrounding [15]. Figure 1.2 illustrates IoV network communication

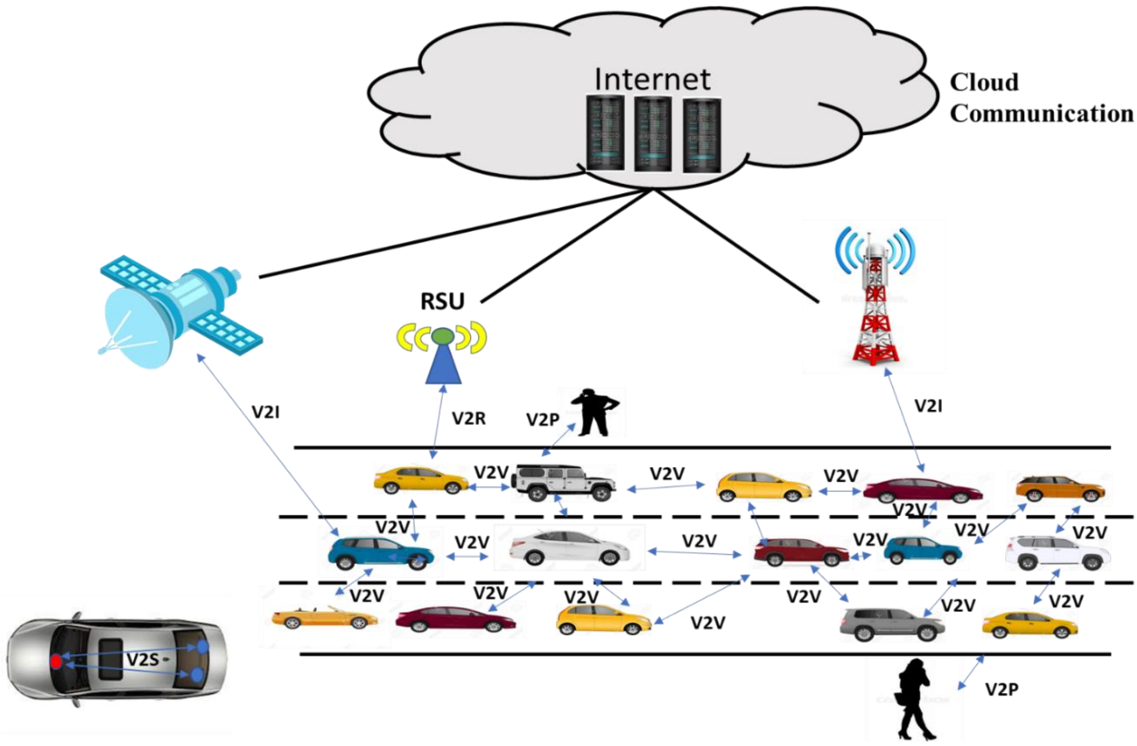


Fig.1.2 IoV network communication

1.4 Layered architecture of IoV

IoV model architecture is based on five layers [15] that allows interconnection of all network components and data dissemination in an IoV environment as shown in Figure 1.3.

• User Interaction Layer: This layer includes the different types of machines and devices that participate in communication process (sensors attached to vehicles, RSUs, cellular infrastructures, smart phones, etc). The goal of this layer is to collect data about vehicular network environment and devices. This layer is also responsible to transform data with electromagnetic and secure manner to the coordination layer.

• Coordination Layer: The second layer of the architecture is represented by the various universal heterogeneous networks including WAVE, Wi-Fi, 4G/LTE and satellite networks. This layer is responsible of data treatment where it processes all different data received from all heterogeneous networks and converts them into uniform structure in order to be known and treated in each candidate network.

• Processing and Analysis Layer: This layer is the core of IoV, it is responsible of storage, processing and analysis of received information from previous layer and making decision based on these analyses. This layer is known as data management center (cloud computing) where different computing, analysis and security techniques are used.

• Application Layer: The fourth layer is consisting on intelligent applications including: safety applications such as: congestion management, accident alert, etc, or no safety applications that include: parking and gas stations indication, file sharing, video streaming, etc. This layer is responsible of offering intelligent services to end users that are based on smart and high analysis of treated data arrived from the previous layer. It also offers to the business layer the data applications used by the end users of network.

• Business Layer: this layer is responsible to make strategies to develop new business models based on the data applications used by the end users of network and data statistical analysis. This layer is also responsible to make decision allied to economic investment and utilization of resources.

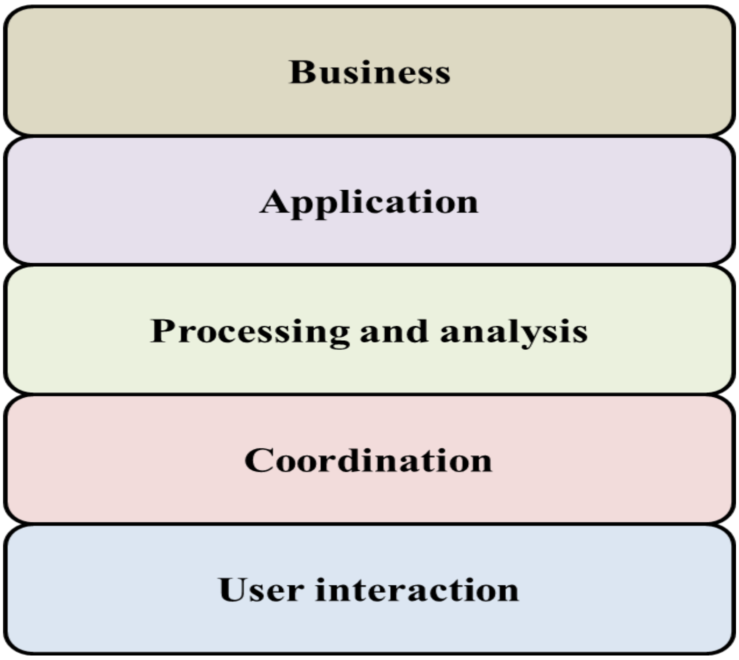


Fig.1.3 Layered architecture of IoV

1.5 Network technologies

Wireless LAN (WLANs) are a useful connectivity solution for different ad-hoc networks and environments. IEEE 802.11p is designed for wireless access in the vehicular environment to support intelligent transport system applications. Wireless access in vehicular environment is presented by two standards:

• Wireless Access in Vehicular Environment (WAVE)standard: includes the features of Dedicated Short-Range Communications (DSRC), the IEEE 802.11p for PHY and MAC layers and the IEEE 1609 family for upper layers. DSRC uses Dynamic Spectrum Access (DSA) as an additional technology. DSA allows vehicles to communicate through unused spectrum for different communication technologies such as TV spectrum [16]. DSRC/WAVE support the high mobility of vehicles, where vehicles move with speed of 10 up to 200Kmph, with a communication range of 300 m and reaching up to 1000 m and a data rate of more than 27Mbps.

• CALM (Continuous Air interface for Long and Medium range): combines a set of wireless technologies including GSM2G/GPRS-2.5G, UMTS-3G, Infrared communication and wireless systems in the 60 GHz band, adapted to IEEE 802.11p [18].

In addition of network technologies cited above, IoV supports other different network technologies (Figure 1.4) such as:

• Bluetooth: is a short-range wireless technology based on the IEEE 802.15.1 standard and operating in frequency band (2.4 GHz). It allows the communication between mobile devices at a data rate up to 3 Mbps [19], The Bluetooth devices are common in current automobiles, such as the Bluetooth headset and rearview mirror.

• ZigBee: is based on the IEEE 802.15.4 standard and operates on the ISM radio spectrum (868 MHz, 915MHz, and 2.4 GHz). ZigBee technology enables vehicles to connect with its internal sensors devices (V2S) [20], ZigBee is low-cost and can provide an acceptable data rate (250 Kbps in 2.4 GHz frequency band).

• 4G/LTE technology: it is a cellular system that uses radio waves to transmit data over long distance. it uses the 1700 and 2100 MHz frequency bands, and supports data transfer speed up to 129 Mbps and high mobility through soft handoff and seamless switching. LTE has been proposed as a practical technology for vehicular machine-to-machine communication [13].

• WiMAX (Worldwide Interoperability for Microwave Access): refers to a wireless communication standard defined by a family of standards IEEE 802.16 [14]. It is mainly used as a high-speed broadband internet access and transmission system. WiMAX covers a wide transmission range with robust communications and high Quality of Service (QoS), which make this technology suitable for multimedia applications.

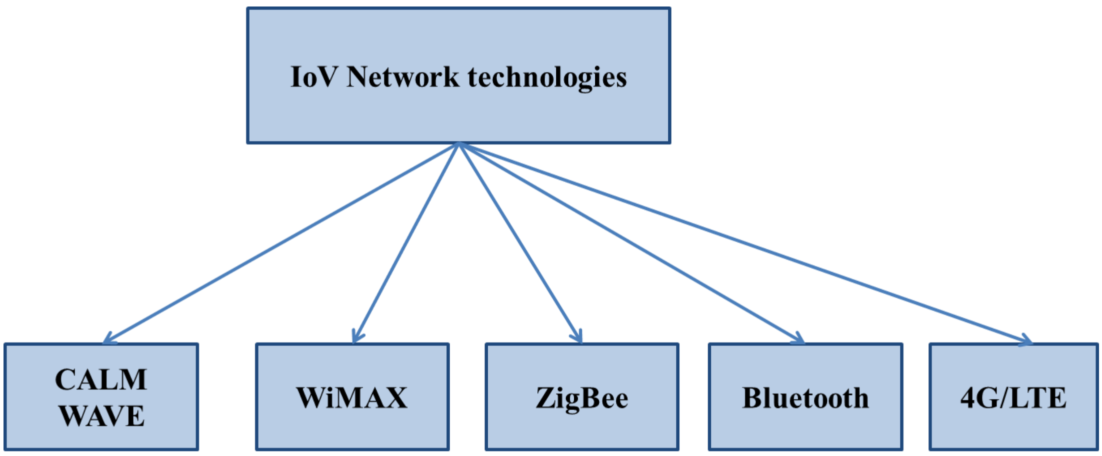


Fig.1.4 IoV Network technologies

1.6 Network platform

IoV system gives vehicles the ability to take different roles at the same time, where they benefit from several services through internet as consumers (clients) members, and at the same time they participate as producers (servers) to offer different services. Evidently, IoV is a mixed system with two kinds of computing models which are: client-server system and peer-2-peer system. With the client-server system, vehicles can demand services from servers such as: infrastructures, roadside units, vehicles, and so on [21]. A server can be a simple computing node or a cloud data platform. With peer-2-peer system, vehicles can help each other to execute distributed computing tasks, such as, videos streaming, files downloading, etc. With cloud data platform, IoV can execute various difficult tasks and can manage different complex applications with better manner. The primary goal of using cloud data platform in IoV is to enhance real time road data processing and to apply artificial intelligence to make intelligent decisions for smart client services. IoV cloud platform is divided into three layers [13]:

1) Basic Cloud Services: this layer includes all different cloud services given to intelligent data applications such as Data, Storage, Networking, Computing, Cooperation and Gateway.

2) Smart ITS Application Servers: IoV comprises various intelligent applications types such as: road safety applications, congestion management applications, entertainment applications and so on. Intelligent servers are composed of two processing engines: internal engine that includes: big data storage unit, big data processing unit and big data analyzing unit. The basic cloud services offered by the cloud platform are used in order to implement these tasks. The external engine includes two kinds of units: information gathering unit which is responsible of in-source data collecting and information diffusion unit which is responsible of final delivery of services to client's applications.

3) Information Consumer and Producer: IoV network supports various intelligent devices which are the end user of the smart information offered by intelligent servers such as: vehicles, roadside units, personal devices and so on. The major responsibilities of these devices are data collecting from vehicular network environment. Developing new business models for organizations related to automobile production and repair. Internet-based services development is also one of the primer usages of data gathered by intelligent devices.

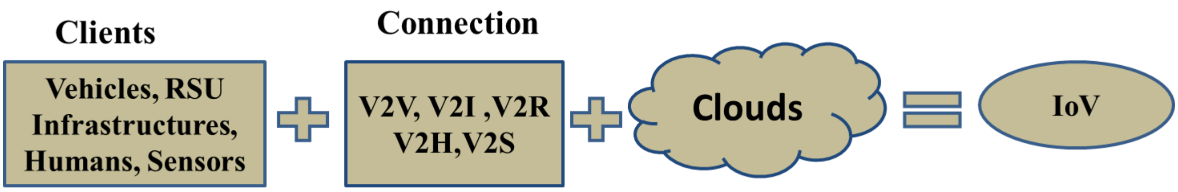


Fig.1.5 Network platform

1.7 IoVs' applications

With the emergence of IoV, the previous existing applications of VANETs have been enhanced and various new applications have designed as well. This new structure founds the fundamental network needed for many significant applications that demand smooth connectivity and addressability between their elements. However, the total of these applications can be divided into two major categories; safety-oriented applications and user-oriented applications.

1) Safety-oriented applications

Safety, management client traffic safety and management related ITS applications are broadly divided into four groups including safety, navigation, diagnostic and remote telematics [22].

- **Safety**

The traffic safety related ITS applications are V2V communication-based applications. The execution and quality of processes could be considerably improved by integrating cloud-based smart servers [21]. The servers use big traffic data to take smart decisions in IoV. These applications improve driver's performance and quality of driving. The applications integrate automatic operations on wheels, and thus, minimize the efforts required for qualitative driving. Some of the traffic safety applications are introduced below:

Accident Prevention- It is a V2V connection system for vehicles. It utilizes real time information exchanged between vehicles to prevent accidents. It provides different automatic processes including speed control, lane change, stoppage, steering control, etc.

The system would be very useful for highway and dense urban traffic environments, where automatic vehicle control has important impact on safety in case of emergency situations [23].

Emergency Call- It is an emergency call system for vehicles. It calls the emergency services such as police, fire and family or friends in case of emergency. It is both automatic and manual system. It can be considered as black-box information of the vehicle; it contains all the information related to the present and past situations of the vehicle. The information includes number of passengers, speed, direction, location, lane, cause of emergency, etc [10].

- **Navigation**

The navigation related ITS applications are location-based services. The execution of these applications is mainly based on the precision of location information. The information is obtained from the GPS receiver integrated in the vehicles. These applications are helpful to manage traffic, and thus, improves traffic efficiency. Some of these applications are presented below:

Real Time Traffic Information- It is a traffic information system. It offers live traffic information using video sensor of vehicles and heterogeneous communication networks. This could efficiently replace the current image analysis and radio broadcasting based non-real-time traffic information systems. The system is based on efficient online streaming of traffic information using heterogeneous vehicular networks [24].

Parking Helper- It is a parking system for vehicles. It used to help drivers to find the nearest available parking space by communicating with the parked vehicles. The system utilizes GPS receiver and cooperative positioning techniques. The system would minimize the waste of power and time in searching parking space, particularly in dense urban traffic environment [25].

Multi-modal Transportation- It is a transportation system for people. It enhances the resources including time, money, comfort, fuel, entertainment, etc., according to the choice of users. It offers route planning service including multiple means of transportation and optimizing user’s priority.

- **Diagnostic**

Vehicle diagnostic applications are considered as personal health consultant for vehicles [11]. In addition to real time monitoring total condition of vehicles, cloud-based data management of vehicle's condition is one of the key tasks of these applications. The cloud-based diagnostic data is utilized for online prediction and maintenance advisory to vehicles. One of the diagnostic clients is described below:

Self-Repair- It is a cloud-based step-by-step repair guidance system. The system is based on a cloud-based database. It is mainly helpful to fix hardware/software problems of the vehicle. The database develops automatically with the advancements in the technology. The guidance is available for all kinds of vehicles through audio and video technologies. The system would significantly minimize the amount of money spent in repairing.

- **Remote Telematics**

Distantly accessing some of non-driving processes of vehicles could be made possible by utilizing very secure remote telematics applications. The applications are based on precise remote tracking, authentication and authorization methods. These applications are actually the transformation of traditional physical entity-based processes into digital entity based operation. The applications improve the ease of usage and monitoring of vehicles. Some of the examples in this category include remote locking/un-locking, car surveillance.

2) **User-oriented applications**

The user-oriented ITS applications for IoV can be widely divided into four categories such as insurance, car sharing, infotainment and other applications.

- ***Insurance***

The insurance based ITS applications are based on some statistical analysis of information including usage of vehicles, driving behavior, place of usage and time duration of usage. These applications would reduce insurance cost, and thus, optimize vehicle ownership cost. One of the insurance-based applications is introduced below:

Insurance on Driving Statistics- It is an insurance system that calculates automatically the insurance fee using the driving statistics data. The data contain daily, monthly or yearly driving duration, it includes also daily/monthly/yearly infraction of traffic rules or the manner how you drive. The system is relied on the cloud-based vehicle usage statistics. The system could significantly optimize cost of insurance [13].

- ***Car Sharing***

The goal of car sharing applications is to improve the usage of resources while utilizing cars which in turn minimizes the cost incurred in transportation. This goal can be achieved by using one vehicle in group, one of these applications is presented below.

Car Pooling- It is a car sharing application based on cloud platform. It attributes car service seekers to car owner. The attribution is based on the optimization of similar criteria of passengers. The criteria include local address, work place, timing, gender, age, and employment position. The registration of car owners and car service seekers are verified by the service provider [8].

- ***Infotainment***

Infotainment applications are based on reliable Internet connectivity. The application would enhance productivity and travel experience by being online while driving. One of the infotainments applications is presented below:

Connected Driving- The system would enhance productivity in driving duration while avoiding on-road fatalities using automatic support applications for drivers in IoV. The system considered as a device synchronization system for vehicles, where it allows vehicles' units display to connect to home computers, smartphones or other online equipment. The system uses remote login in various kinds of online devices with security credentials [6].

- ***Others***

It exists some other applications which do not belong to the aforementioned categories. These applications are based on various business concepts and technologies. One of the applications in this category is presented below:

Cloud Service- In cloud system vehicles have two options to communicate based on cloud communication: either they form their autonomous cloud of group of vehicles or they connect to traditional cloud. In the two cases, the resources of connected vehicles are available for utilization as cloud service as well as the vehicles can use intelligent cloud services. The cloud system can remove computational and storage limitations at vehicles. It could open new business models in connected drive [9].

1.8 IoV's characteristics and challenges

IoV networks are characterized by numerous features comparing to other types of networks. As IoV is considered as the progress of the traditional VANETs, various IoV features are similar to VANETs features, like dynamic topology, different network density, high vehicles mobility, and network obstacles. Moreover, IoV networks support other characteristics such as:

- Scalability: IoV networks can integrate hundreds or even thousands of connected vehicles comparing to classical VANETs. Moreover, based on the application used, IoV can further increase the number of connected devices to millions.
- Different wireless access technologies: IoV platform supports numerous kinds of wireless access technologies such as WLANs, WiMAX, cellular wireless, and satellite communications [16].
- Extended network communication: IoV creates more types of communication comparing to conventional VANET, that is characterized by its limited communication types, IoV allows vehicle to communicate with every smart object such as smart-phone, tablet, and so on.
- Cloud Computing: Comparing to VANET, the operations in IoV are mainly based on cloud computing services.

Due to the high interaction of network components such as users, vehicles and things, IoV network is required to provide best communication capability that is manageable, controllable, operational, and credible [13]. IoV faces numerous challenges that need to be studied in order to provide more communication reliability, robustness and stability.

- Fault tolerance: Since IoV architecture is based on clouds communications some vehicles can break down; thus, this failure should not affect the rest of the network.
- Latency: it is defined as the period of time taken by a packet to be transmitted in the network., in some critical applications such as accident alert, latency must be minimized as much as possible in order to guarantee fast messages transfer.
- Networks compatibility: the different kinds of access technologies supported by IoV require researchers to take in consideration these multiple access technologies during the design of applications and protocols for IoV.

- Security: The information exchanged via IoV network are very important and confidential especially with access to the Internet. Therefore, the operation of securing these networks is a fundamental task and a prerequisite for the deployment of IoV [18].
- Connectivity: The high speed of the moving vehicles may drive to frequent change in the network topology. Therefore, a high rate of arrival and departure of nodes can be affected. Dealing with such a limitation drains an important communication overhead. That, nodes need frequently to choose a reliable route in order to ensure data deliverance to specific destinations. The vehicles must permanently be connected.
- Quality of services (QoS): IoV is considered as real-time distributed system that must satisfy timing, reliability and security constraints as well as application specific quality requirements to deal with scheduling of the integrated services in real time [25]. To address this diversified problem, QoS requirements have to manage the network resources to provide the QoS guarantees in IoV. The most robust IoV system provides better QoS.

1.9 Simulations and mobility models for IoV

Network simulation is the most helpful method used to evaluate the performance of networks theoretically before they are deployed physically. In fact, the network simulator has to take into account all specific characteristics of the moving vehicles i.e., the nodes mobility model in order to mimic the real IoV environment. In IoV, vehicles movement is limited to the roads and the interaction with other vehicles (acceleration, deceleration and lane change). Thus, utilizing random models where the change in speed and position of nodes is randomly does not give a real evaluation of the protocols designed to vehicular environments. Therefore, IoV networks simulation should be carried out by simulators designed especially to VANETs. Traffic simulation models are categorized into microscopic, mesoscopic and macroscopic mobility modeling. Microscopic mobility modeling considers flow of vehicle in detail, such as acceleration / deceleration, driver's behavior, car's length, car's speed. Macroscopic properties are general in nature. When large number of vehicles is in motion, global parameters can be represented as flow (mass and density). Mesoscopic modeling represents an intermediate modeling level of traffic flow. It may lead to efficient trade-off between modeling of individual vehicles and the modeling of large quantities of vehicles.

This model may take different forms such as the modeling headway distance as an average of large number of vehicles sometimes size or density of cluster of vehicles. This model includes dynamic behavior of vehicle and macroscopic properties such as density and velocity for large number of vehicles Among the mobility generator in VANETs, we have: VanetMobiSim, SUMO and RoadSim. The mobility models provide a precise description of vehicles mobility in the network. According to the available literature, there exist many mobility models, which are widely used for IoV networks. Compared to conventional VANET networks, IoV vehicles are much more restrictive in terms of traffic on the network and require more traffic applications and services. These scenarios cannot be therefore handled by conventional networking solutions. These mobility generators, called also vehicular traffic simulators, rely on a traffic flow theory. For instance, Simulation of Urban MObility "SUMO" [28] is an open source, microscopic, multi-modal traffic simulation. The simulation allows to address a large set of traffic management topics, where it permits to simulate how a given traffic demand which consists of single vehicles moves through a given road network. It is purely microscopic: each vehicle is modelled explicitly, where it has an own route, and moves individually through the network. MOVE [29] is built on top of an open source micro-traffic simulator SUMO. It allows users to rapidly generate realistic mobility models for VANETs simulations. The output of MOVE is a realistic mobility model and can be immediately used by popular network simulators such as NS3, NS2, OMNET, etc.

1.10 Conclusion

IoV is one of the emergent fields that attract growing interest from academia and industry areas in the last few years. This is due to the high important role that plays IoV in fundamentally increasing safety of the intelligent transportation systems (ITS). The IoV paradigm supports numerous communication types such as Vehicle-to-everything (V2X), Vehicle-to-Human (V2H), Vehicle-to-Sensors (V2S) besides the classical communication types inherited from the conventional VANETs communications (V2V, V2I and V2R). In this chapter we have presented an overview of the emergent IoV technology and a perspective for their future applications. In the introduction we introduced the development of VANET towards the new paradigm IoV. Next, related definitions of IoV, IoV’s protocol stack, IoV platform, IoV network technologies and IoV’s applications are presented. Since their special characteristics create new challenges and requirements, we discuss in general the IoV’s issues. Finally, simulations and mobility models for IoV networks are presented.

Chapter 2

State of the art: Routing protocols in VANETs

2.1 Introduction

The appearance of the new era of Internet of Things drove to the evolution of Vehicular Ad-hoc NETworks (VANETs) toward a new paradigm named the Internet of Vehicles (IoV). The difference of the vehicle concept in VANET and IoV makes these two paradigms different in the terms of devices, communications, services and applications. In VANET, the vehicle is considered as a smart mobile object used to forward messages among vehicles and infrastructures. However, each vehicle in IoV is considered as a smart object with a powerful multi-sensor system. Moreover, a vehicle in IoV is perceived as a dynamic mobile communication system, which allows the following communication modes: intra-vehicle components mode and Vehicle-to-X mode, where X can be vehicle, road, infrastructure, human or Internet. Therefore, IoV enables the acquisition and processing of large amount of data (big data) from different geographical areas via intelligent vehicles to offer various services for drivers and passengers [30].

IoV environment is characterized by special features and characteristics, that make the design and the implementation of robust application for such networks a very challenging task [31]. The high mobility of vehicles is the first factor that distinguish IoV network from other types of ad-hoc and wireless networks. The vehicles' speed changes according to the road conditions, it may be low or medium in urban areas and high on highways. The speed variation may affect the network stability and drives network topology to be very dynamic. The high mobility of nodes can cause frequent disconnections in the links of communications which causes a temporary stop of the service provided by the application of the network. It is therefore necessary to ensure and provide a high Quality of Service, even in the presence of breaks in communication links, to ensure the required service. The nodes density in IoV network is not stable during time and area variation. Where, the density in urban areas is higher than in rural areas, and it is different at what time of day is considered (night, morning and rush hours) [32].

Considering all the above issues, researchers have turned to the use of new techniques and mechanisms in order to guarantee some Quality of Service in its turn ensures a stable network connectivity and an effective data routing and dissemination in the network. Routing algorithms play a pivotal role in today's networks, and with the exponential increase in network density and distributed systems and applications it is obvious that the network traffic management and routing are the core issues [33]. The central job of the routing algorithm is to generate a path for the network packets. The routing protocol gives the overview of the topology of the entire network while the routing algorithm adds the power of intelligence to how one computes the path between multiple network nodes. Driving packets from source node to destination node in a network with an effective manner will ensure stable network connectivity and robust communication. A large number of routing protocols have been proposed for IoV and the main goal of these routing protocols is to provide the best path through multi-hops wireless communications. Number of properties in relation to routing algorithms need to be taken into consideration in order to reach a solution to the routing problem:

- Correctness: The property states that an algorithm should be able to accommodate itself within topological variation and network problematic conditions [34]. The algorithm should also be able to find the optimal path in any circumstances for the network.
- Simplicity: The property states that an algorithm needs to be simple, efficient and easy to implement.
- Robustness: It is crucial that the network should have the capability to work in a situation like node failure, path congestion, like failure and so forth.
- Stability: The property states that after specified runs of the time-frame window an algorithm needs to be in a stable position.
- Fairness: The property states that for the delivery of a packet, the packet delivery time schedule must be followed.
- Optimality: The property states that an optimal path should be found from a source to destination. The optimal path depends on the network parameter. It is not compulsory that an optimal must always be the shortest path, for instance a longest path can be considered an optimal path because of less buffer delay for example.
- Scalability: The property states that an algorithm needs to be capable of improving and giving its best performance as the network resources expand and traffic grows.

In this chapter, we provide most representative literature in vehicular routing area and present deeply the different protocols classified according to their core concepts, namely topology-based, geographic-based, QoS-based, packets forwarding based and clusters based.

Then, we classify the routing protocols and we highlight the common limitations for each type of communication.

2.2 Topology-based routing protocols

Topology-based routing protocols [36], this type of routing protocols typically take advantage of available link's information stored in node's routing table to send packets from source to destination. AOMDV (Ad hoc On-demand Multi-path Distance Vector) routing protocol [37] is a multi-path on-demand protocol which is an improvement of AODV routing protocol [38]. AOMDV makes use of same control messages used in AODV to maintain network connectivity. Moreover, AOMDV adds supplementary fields to minimize the overhead appearing during discovering multiple paths process, in which AOMDV saves all available paths in the routing table, then the source selects the first created route as the favorite one. Compared with single-path based routing protocols, the performance of AOMDV is better in minimizing route discovery retransmission, enhancing robustness and reducing transmission delay.

R-AOMDV [39] is an extension of AOMDV routing protocol. In R-AOMDV routing protocol, a source node sends a route request packet when it has not an available route to the destination. R-AOMDV is similar to AOMDV in term of route discovery process that is based on route request and route reply control packets. R-AOMDV is a cross-layer routing protocol, where it adds two fields to route replay message (maximum retransmission count at MAC layer and total hop count at network layer) in order to calculate the quality of the whole path. R-AOMDV protocol provides all good advantages of multi path routing protocols, such as minimizing rebroadcast route discovery and improving network robustness. Furthermore, R-AOMDV introduces good performance comparing to AOMDV in both rural and city vehicular networks [40], as well as enhances the routing processes based on the quality of routes. However, the routing protocols based on IP addresses are not suitable for VANETs because they must send the packets to nodes' IPs even though they change their locations, and in this situation the sender node must look for a new intermediate forwarding node, which may lead to increase the packet delay and packet loss.

ZRP (Zone Routing Protocol) [41,42] is a hybrid routing protocol, its concept focuses on dividing network into several zones in terms of many factors, namely transmission power, signal strength, speed and so on. ZRP takes advantage of both reactive and proactive routing schemes for outside and inside zone, respectively. On one hand, it reduces the extent of the proactive process only to the node's local neighborhood. As we will see, the local routing information is usually referred to in the procedure of ZRP, decreasing the waste related with the purely proactive schemes. On the other hand, the search over the whole network can be performed efficiently by reactively querying selected nodes in the network comparing to querying all the network nodes.

TORA (Temporally Ordered Routing Algorithm) [43] is a distributed routing protocol using multi hop routes. TORA is designed to minimize the communication overhead caused by the messages sent used to update the frequent network changes. TORA creates a directed graph which considers the source node as the tree root. Once a sending node broadcasts a packet to a particular destination, packets should be sent from higher nodes to lower nodes in the tree, the neighbor nodes need to broadcast a route reply to check if they have a downward link to the destination, if not, they just drop the packet. TORA guarantees multi path loop free routing since the packet always passes downward to the destination and don't go upward back to the source node. The major advantage of TORA is that it offers a route to every node in the network and decreases the control messages broadcast. However, it causes routing overhead in maintaining routes to all network nodes, especially in highly dynamic networks, such as VANETs and IoV.

2.3 Geographic-based routing protocols

Geographic-based routing protocols are based on the geographical information of network nodes, where the source sends a packet to the destination utilizing its position information rather than using its network address [36]. The protocols of this category require each node to be able to recover its location and the location of its neighbors using a location service such as the GPS (Geographic Position System). When the source node wants to send a packet, it usually inserts the position of the destination in the packet header that will help to forward the packet to the destination without route discovery and route maintenance process. Hence, geographic-based routing protocols are considered to be more stable and suitable for large scale networks such as VANETs and IoV, compared to topology-based routing protocols.

GPSR (Greedy Perimeter Stateless Routing) [44] is a reference geographic-based routing protocol, it utilizes two routing mechanisms to forward data packets to reach their destination including greedy forwarding and perimeter forwarding. Greedy forwarding algorithm is used if the forwarding vehicle has a neighbor of which the location is the closest to the destination.

While the current forwarding vehicle is the closest one to reach its destination, GPSR passes to perimeter forwarding applying the right-hand rule in order to select the next hop. The main advantage of GPSR lies in recovering the geographical information of its neighbors via Hello packets. A forwarding vehicle chooses next node based on local optimal which is geographically closest to the destination. However, the recovery strategy of GPSR is ineffective in term of time consumption especially in highly dynamic network environments. Additionally, GPSR is more suitable for open network environments with even distribution of nodes, but it suffers in a presence of obstacles. When it was applied in city environment, it shows poor performance [45, 46], establishing direct communication between two nodes with GPSR is difficult under the presence of obstacles such as buildings and trees.

GSR (Geographic Source Routing) [46] is a source routing protocol particularly designed for city environments to get over the drawbacks of GPSR. In GSR, the better routing path is the shortest one towards the destination, routing path selection process uses Dijkstra shortest path based on city digital map information. This shortest path consists on a sequence of intersections, each packet must follow the computed sequence of intersections to attain its destination. Greedy forwarding is utilized to transfer data packets between two participating intersections. When local maximum problem appears, packets will be forwarded through carry and forward strategy. The inconvenient of GSR is that the distance-based shortest path is not the best path since it does not consider vehicular traffic information along the path. In addition, GSR is a source-driven routing protocol that utilizes fixed intersection selection mechanism, which results in worse performance in highly dynamic networks.

GPCR (Greedy Perimeter Coordinator Routing) [45] is proposed to tackle the planarization problem in GPSR by considering urban streets as a planar graph. Here each road segment is regarded as an edge of the network topology graph, and each junction is defined as a vertex. Based on the distance towards destination, GPCR makes actual routing decisions at intersections to determine which next road segment is the best option for packet forwarding. Therefore, packets should be forwarded to a node on the junction, and this node is known as the coordinator node, and it is elected based on two methods. The first one is to make use of beaconing services so that each node is aware of position information of its neighbors, and a node can be considered a coordinator node when it has two neighbors that are within communication range of each other, but do not list each other as a neighbor. This indicates that the two neighbors are hidden to each other and the coordinator node is able to forward messages between them. The second method is derived by calculating the correlation coefficient that relates a node to its neighbors. A correlation coefficient close to zero indicates that there is no linear coherence between the positions of the neighbors which indicates that the node is located at a junction.

GpsrJ+ (Greedy Perimeter Stateless Routing Junction+) [47] is proposed to more improves the packet delivery ratio based on few modifications of GPCR. GpsrJ+ utilizes two-hop beaconing to guess the next road segment in which the packet should be transferred to reach a destination. If the current transferring node has the same direction as a coordinator node, the prediction mechanism avoids the intersection and sends the packet to the node forward of the junction node. However, if the coordinator node has a different direction from the current forwarding node, it chooses the coordinator node as a next relay hop. In comparison with GPCR and GPSR, GpsrJ+ enhances and increases packet delivery ratio and reduces the number of hops in the perimeter mode of packet forwarding.

A-STAR (Anchor-based street and traffic Aware Routing) [48] is a practicable routing protocol in city environments. A-STAR makes use of vehicular traffic on the street and then allocates weight to each street based on the number of bus lines that the road owns. The more bus lines a road possesses, the less weight it is allocated and vice versa. A digital map facilitates computation of intersections by using Dijkstra shortest path algorithm. Greedy forwarding algorithm is used to forward from packet form its source to destination. When packets fall in a local maximum, a new recovery strategy is presented. The road segment where the local maximum problem appears is marked as "out of service" for a short duration and this information is broadcasted through the network thus other data packets can avoid this "out of service" street. A-STAR routing protocol is traffic aware that takes in consideration the number of bus lines but it does not take into account vehicular traffic density. Furthermore, most of network traffic is oriented towards streets having many bus lines (which may induce bandwidth congestion) rather than secondary streets, even if these streets provide better connectivity and may supply best path.

LOUVRE (Landmark Overlays for Urban Vehicular Routing Environments) [49] builds an overlay on top of an urban topology. That is, the overlay is consist on the connected roads in the network, thereby a routing path from source to destination can be established based on the overlay. Additionally, LOUVRE utilizes a P2P (Peer-to-Peer) protocol to find and transfer traffic density information of each road, and each node shares density information with its neighbors using beacon messages. However, the scalability of the overlay is limited due to the P2P exchange delay in the whole network.

RBVT (Road-Based using Vehicular Traffic) [50] creates road-based paths based on successions of road intersections. RBVT consists of two routing protocols: a reactive protocol (RBVT-R) and a proactive protocol (RBVT-P). The route discovery process in RBVT-R is similar to source driven routing protocols [38], though the routing information saved in the packet' header is a succession of road intersections instead of nodes. RBVT-P is similar to LOUVRE where nodes periodically find and distribute the road-based network topology to keep a general view of the network connectivity. The performance of RBVT-R depends on the stability of road segments' connectivity, and the performance of RBVT-P depends on the efficiency of network connectivity information exchange. However, RBVT needs the exchange and maintenance of non-local information, which drives to high network overhead. Moreover, data packet headers save a list of intersections that the packets should pass by and it might lead to scalability issues. In addition, the direction of vehicles is not taken into consideration in the optimized geographical forwarding.

2.4 QoS-based routing protocols

VANETs support a number of applications for safety and comfortability, so efficient QoS-based (Quality of service) routing protocols [51-55] are necessary to forward packets within the required QoS constraints in the targeted regions so as to satisfy various applications.

RMRV (Road-based Multipath Routing protocol for urban VANETs) [56] is a road-based QoS-aware multipath routing protocol in urban scenarios. The main goal of the proposed routing protocol is to find multiple routes through the road plan and estimate paths' lifetime in order to choose the most stable path. A space-time planar graph approach is proposed to predict the connectivity of each road segment; therefore, the path's future lifetime and the life periods can be derived. However, the routing paths are discovered by flooding mechanism, which causes high network overhead and decreases exploration efficiency. Further, different communication pairs are missing of cooperation to adapt with dynamic vehicular environments.

CAR (Connectivity Aware Routing) [57] is a connectivity-aware routing protocol designed especially for inter-vehicle communications in the urban scenarios. CAR protocol launches its path discovery process when node demands a path to the destination, the source starts broadcasting exploring messages that record the speed vector of the mobile nodes through which they pass. If the speed vector direction of the current node is different from that of the previous forwarding node, these two nodes are considered as a broadcaster pair and are inserted to the header of the message. When a broadcast message arrives to the destination using the shortest delay, the path this message passing through is considered as the chosen routing path, which consists on a set of intermediate broadcaster pairs. Evidently, CAR is source-initiated routing that has to maintain a complete routing path, which cannot adapt with the fast topology changes of VANETs, especially in large-scale urban scenarios. Moreover, the broadcasting characteristic of routing discovery increases redundant overheads and exacerbates network congestions.

VADD (Vehicle-Assisted Data Delivery routing) [58] is a delay sensitive routing protocol. In this algorithm, a forwarding vehicle takes a routing decision at the intersection and sends the packet to the road which has minimum packet delivery delay. Based on some traffic parameters such as road length, average vehicle velocity and road traffic density, the estimation of roads delay is modeled and expressed using a set of linear system equations ($n \times n$) with Gaussian elimination method, where n is the number of intersections. Once the intersection is chosen, a forwarding node at the road tries to find the next relay node. On straight-aways, the priority is allocated to the closest node to the next intersection. In case where there are no direct neighbor nodes within the transmission range of the forwarding node, it transmits its packet until it finds an appropriate neighbor. However, VADD has some drawbacks like high complexity, especially when the number of intersections increases in the scoped area. Moreover, VADD does not take in consideration the distribution of vehicles that plays an important role in network connectivity and ignores the effects of the 1-hop delay being relevant to channel condition, channel transmission rate, traffic load and so on.

IGRP (Intersection-based Geographical Routing Protocol) [59] is a road-based QoS routing protocol. In IGRP, the routing path consists on a succession of intersections. IGRP selects the road intersections in such manner that the connectivity probability of the selected path maximizes and satisfies the QoS constraints in terms of end-to-end delay, hop count, and BER (Bit Error Rate). Geographical forwarding is still utilized to forward packets between any two intersections within the path, reducing the path’s sensitivity to individual node movements. However, IGRP requires additional traffic statistics service to obtain the demanded node density and average speed information for QoS metrics estimation. In addition, IGRP is a source-driven routing protocol and the header of each data packet adds a complete list of intersections, which is not helpful to adapt with topology changes and routing scalability. Moreover, the mathematical estimations of delay and hop count are not precise due to the absence of the partly connected road segments' case.

ARP-QD (Adaptive Routing Protocol based on QoS and vehicular Density) [60] is an intersection-based routing protocol to find the best path for data forwarding, which can ensure diverse QoS requirements based on hop count, link duration and connectivity in order to adapt with dynamic topology as well as discontinuous connectivity, and make the balance between stability and efficiency of the algorithm. In order to decrease the network overhead, an adaptive neighbor discovery algorithm is proposed to obtain neighbors' information based on local vehicular density. However, connectivity is estimated by broadcasting control packets which may drive to channel congestion in case where there is high traffic load, and this metric is an instant and not precise value in dynamic scenarios. Additionally, using only global distance is not enough to indicate the complete QoS of a routing path, and packets may suffer from network partitions/congestions in the future road segments.

MURU (MUlti-hop Routing protocol for Urban VANETs) [61] is a distributed routing protocol, does not required any pre-installed infrastructure and capable to find robust paths in urban VANETs in order to provide high packet delivery ratio with low overhead. To evaluate the level of stability of any available routing path, a specific metric called EDD (Expected Disconnection Degree) is proposed, that is defined as the probability of path disconnection in a predefined time interval. EDD is calculated based on the predicted speed and movement trajectory of each vehicle, then the route that has the smallest EDD is selected. Furthermore, MURU uses backoff mechanism based on road map geometry to delete unnecessary control messages in order to reduce network overhead. Otherwise, MURU is susceptible to local optimums which would considerably decrease the scalability of the routing protocol.

2.5 Packet forwarding algorithms

An appropriate packet forwarding algorithm plays a key role in designing available routing protocols for VANETs and some related works in this field are given in this section [63].

AODV [38] Ad hoc On-demand Distance Vector utilizes the routing table information to choose next hop, however the route discovery process of AODV causes high network overhead, which may become more vital when the wireless link is unstable. In [62], a data packet plainly selects the next hop according to its packet header in which the whole path list is saved. Though, the complete node-based path field drives to routing overhead and scalability issues. In order to adapt with the problems of scalability and reliability, geographical transferring method is used to forward data packets.

Greedy+AGF (Greedy perimeter stateless routing with Advanced Greedy Forwarding) [64], in this algorithm, the source and destination node have to denounce their velocity vectors to each other. Further, packet processing time and packet traveling time are inserted into each packet header. When transferring data packet to the next hop, the source firstly verifies whether the destination node is saved in its table of neighboring nodes and still available based on the packet traveling time and the velocity vectors of the source and the destination node. If the destination node exists in its neighbor table, but the new position prediction indicates that the destination node may be out of its communication range during data packet sending process, then the node closest to the new position of the destination is selected as the next hop. If the destination node does not exist in the neighbor table, the sending node checks the packet traveling time and approximates whether it may possibly attain the position of the destination node within one hop transmission. If yes, data packet is directly sent to the destination node. If no answer is received then the next closest to the destination node is selected, and the process repeats. However, the two geographic forwarding algorithms sometimes make data packets fall into local maximums and then initiate repair strategy, which does not perform well in city scenarios because they rely on a distributed algorithm to planar the graph [45]. [46] just makes use of a restricted greedy forwarding algorithm to overcome the local maximum problem.

GeOpps [65] uses a trajectory-based geographic method to select next hop. Upon the proposed routes to their own destination, neighboring nodes firstly calculate the nearest point that they will pass through to the data packet’s destination, then they use a function formula (based on the information of the nearest point and digital map) to estimate the minimum time that this data packet needs to attain its destination. Finally, the neighboring node that can transfer this data packet to its destination with shortest time will be selected as the next hop. However, these geographic forwarding algorithms demand proactive Hello message broadcast, which utilizes several resources and consumes more bandwidth in VANET environments. Thus, the performance of VANET routing protocols is affected, especially in rush hours in urban scenarios. In order to eliminate the impacts of Hello message broadcast, the distributed next-hop selection algorithms are proposed in ad hoc and sensor networks [66–68] based on the receiver-based concept. The sender broadcasts a control packet to its neighbors to inform it about an awaiting data packet transmission, then each neighboring node uses specific criteria to decide if it can be chosen as a next hop candidate, and if so, it calculates a waiting time, that is utilized to allow the better candidate to response first. If a neighbor does not hear a better candidate before its waiting time expires, it informs the sender that it is the best next hop.

2.6 Clusters based routing protocols

The main concept of routing protocols of this category is to divide network into groups and select a node to be chief of group based on various metrics such as node ID, position, density, speed, direction of nodes and so on, to take the role of group manager [69]. Clustering structures have several advantages comparing to flat structures, where by using clustering architectures networks may guarantee load balancing, high scalability and lowest overhead [70].

SCRP [71] Stable CDS-based Routing Protocol, is based on a distributed geographic location source forwarding technique that uses the vehicular network topology to choose the data routing routes with low delay. SCRP algorithm creates stable backbones throughout road segments using two major metrics which are: vehicles' velocity and their spatial distribution. These backbones are associated at intersections through special gateway nodes that keep an up-to-date vehicular network topology and follow the expected delay for data routing on the road segments. Upon this information, the SCRP allocates weights to the road segments. Thus, the road segments that have the lowest weights are chosen to form the routing paths. In this regard, the SCRP solution can avert the local maximum problem and guarantee load balancing on all possible routing paths.

A fuzzy-logic-based clustering algorithm for VANETs [72], CHs are elected in the basis of their relative speed and distance from vehicles within their neighborhood. Moreover, the proposed protocol strengths the clusters stability via the election of secondary CH (to be used as CH when the previous CH becomes unavailable). In addition, the maintenance phase is adaptable to driver's behavior on the road based on a fuzzy logic inference system. Hence, the algorithm is suitable to be applied in environments with high mobility.

AWCP [73] A multi-objective genetic-based algorithm Adaptive Weighted Clustering Protocol is designed for VANETs, it elects the CHs based on calculated weight value that is based on various parameters such as highway ID, vehicles direction, vehicle location, vehicle velocity and vehicles connectivity. The main goal of AWCP algorithm is to enhance network stability. by defining a genetic multi-objective method whose inputs are the metrics used to calculate the nodes weights. This method aims to provide a stable clusters structure as long as possible, improve the data delivery rate, and reduce the total clustering overhead.

PCTIC [74] Position Based Clustering Technique for Ad Hoc Inter-vehicle Communication, this algorithm is destined for large multi-hop VANET. The clusters are formed based on geographic position of vehicles. The algorithm selects one node of each group to take the role of CH based on the Minimal Dominating Set (MDS) problem. The size of cluster is defined according to the maximum distance between the CHs and their members. Thus, the clusters are independently monitored and dynamically re-configured each time vehicles move and change their directions.

2.7 Classification and comparison of routing protocols in VANETs

Based on our review, Figure 2.1 shows our classification for the presented routing protocols. In Table 2.1 we provide a general comparative of various routing algorithms in VANETs and IoV discussed above where we define the methods used, the advantages of these protocols, their limitations and our remarks upon each type.

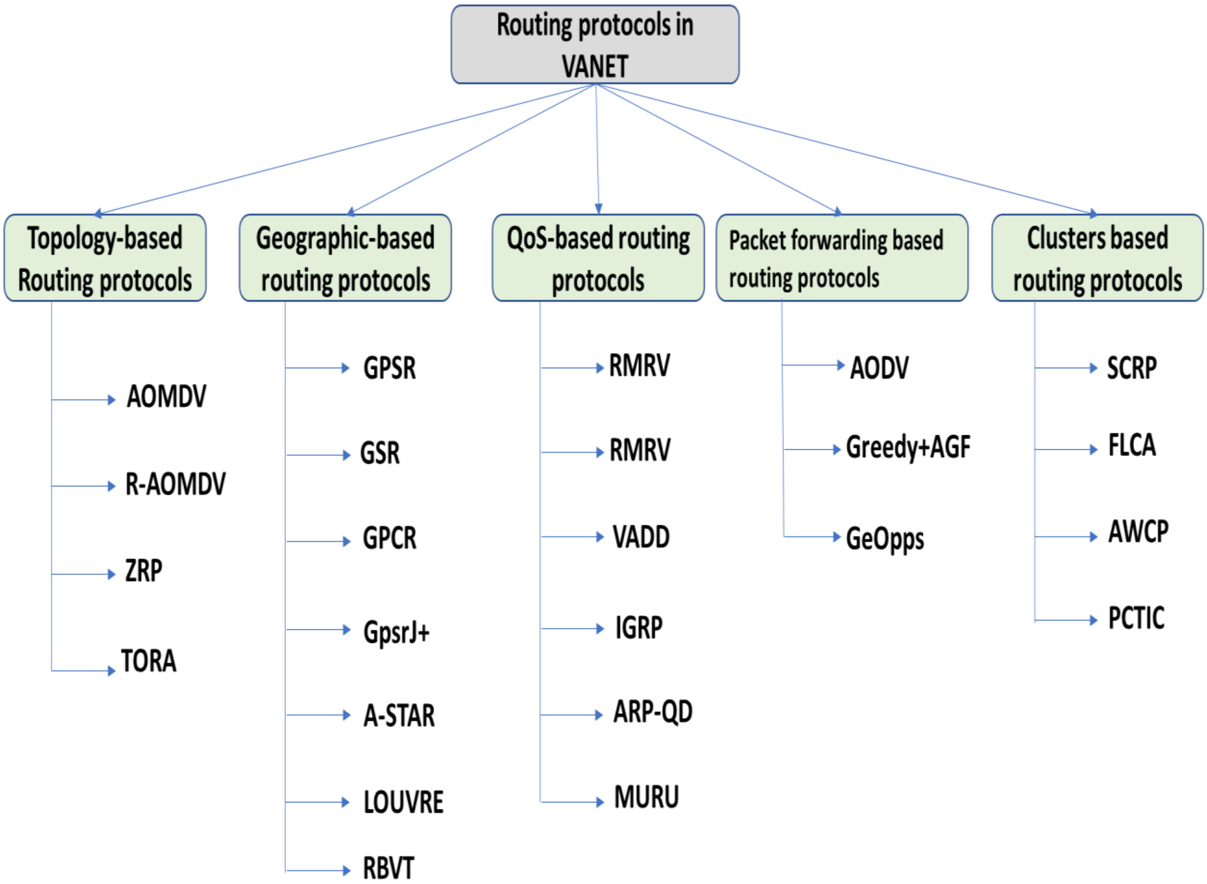


Fig.2.1 Classification of routing protocols in VANET

Table 2.1 Comparison of routing protocols in VANET

Routing Protocols	**Methods Used**	**Strengths**	**Limitations**	**Comments**
Topology-based Routing	Network topology information saved in the routing table as a basis on sending packets	• Network topology initially known • The shortest time to find	• Fail to discover a complete path (frequent network changes)	The most of these protocols are proposed for MANETs. These protocols

		route to destination. • Less resource consumption. • Support of messages unicast, multicast and Broadcast.	• Unnecessary flooding. • More overhead • Routes discover and maintaining delays.	can be helpful for small networks (less overhead).
Geographic-based routing protocols	Sharing Vehicles Geographic Information based on Global positioning service	• No need to create and maintain global routes. • More stable in high mobility environment. • More fitting for network distributed nodes. • Lowest overhead. • More scalable	• Obstacles in highway scenario • Deadlock problem in location server • Position services may fail in tunnel or obstacles (missing satellite signal)	More suitable for VANETs; but need more researches for small networks and control congestion
QoS-based routing protocols	Selecting some network parameters to use to estimate the quality of service of links	• More Quality of Service. • Minimum packet delay. • Less links disconnections.	• More messages sent to update the parameters values. • Consumes more resources.	Need more researches to improve reliability, packet retransmission, scalability and avoid collision

Packet forwarding algorithms	Packets broadcasting to all network nodes inside the broadcast domain.	• Less packet loss. • More reliable data transmission	• Consumes bandwidth • Routes loop • Network congestion • Less network throughput • More packet delay. • Packet collisions	These protocols are useful for alert messages. Need some packets flooding constraints.
Clusters based routing protocols	Network is divided into Clusters, each cluster has a cluster head to manage communication inside and outside the cluster	• Efficient routing by sending one copy to multiple nodes • Minimum network consumption • Minimum packet delivery delay • Easy to implement.	• Consumes resources by electing each time CHs. • Frequent changing in cluster heads.	The proposed protocols of this category are very useful for scalable networks. control for dynamic groups.

2.8 Conclusion

In this chapter, we did review existing literature for five types of communications that this thesis did consider: topology-based routing algorithms, geographic-based routing algorithms, QoS-based routing algorithms, packets forwarding based routing algorithms and clusters-based routing algorithms. Then, we classified the routing protocols and we highlighted the common limitations for each type of communication. These limitations did motivate the contributions we made in this thesis.

Contributions

Chapter 3

A Stable Link based Zone Routing Protocol (SL-ZRP) for Internet of Vehicles environment

3.1 Introduction

These last years, IoV domain has attracted the attention of researchers and has become one of the most addressed research fields in networking systems according to their impact on human life. IoV presents the notion of encapsulation of communications, that enables vehicles to communicate with various networks, adapt to them and utilize the services they offered. Due to numerous factors, such as the huge number of vehicles connected (scalability problem), the large volume of data (big data) to process and store, road conditions and traffic flows, and communication heterogeneity [30, 75], the design of robust applications becomes a challenge in IoV. Routing protocols are becoming the most treated issue in IoV because of their important role to set a robust interaction between vehicles. Proposing a robust routing protocol plays an essential role in resolving several driving and traffic problems. To fitly support multimedia applications and efficiently update road information, it would be important that a network can provide a convenient Quality of Service (QoS). Therefore, a robust IoV routing protocol should supply the best response time to the requested vehicles without causing extra load in the network as this may drive to harmful results, especially in emergency circumstances. Routing protocols are basically divided into proactive, reactive and hybrid protocols based on routing information updating mechanism. Proactive routing protocols achieve their goal by keeping consistent and updated routing information between each pair of nodes in the network by proactively distributing routing updates at fixed time intervals. Proactive routing protocols examine the network topology before a request comes in via broadcasting mechanism. Since the proactive routing algorithms safeguard routing tables for all nodes in the network, a route is found as soon as it is requested. These protocols have several advantages. They guarantee a low latency and a minimum end-to-end delay in route discovering process. Destination-Sequenced Distance Vector (DSDV) [62] and Optimized Link-State Routing (OLSR) [76] are examples of this category. Reactive (on-demand) routing algorithms establish a route to a given destination only when a node requests it by launching a route discovery process. Once a path has been established, the node keeps the connection until the destination becomes inaccessible, or the route has expired. These routing algorithms are more effective on control overhead and power consumption because routes are created only when needed. Examples of this class are: Dynamic Source Routing Protocol (DSR) [77] and Ad Hoc On-Demand Distance-Vector Routing Protocol (AODV) [38]. Despite the advantages of reactive protocols (guaranteeing low network overhead by reducing the number of control message), they have higher latency in routes discovering. This is due to flooding route request packets issued in order to find the route based on the received replies. On another side, proactive protocols require periodic route updates in order to maintain information in routing tables; also, many determined routes might never be needed. All these efforts will increase the routing overhead and uselessly consume bandwidth. Hybrid routing protocols integrate proactive and reactive routing algorithms features. Hybrid protocols come to minimize the overhead cost caused by periodic exchanging messages process in proactive protocols. In the other hand, hybrid protocols minimize the high delay caused by the new establishment of routes each time a node needs communication in reactive protocols. Among the known hybrid protocols, we can cite Zone Routing Protocol (ZRP) [41]. However, hybrid protocols still need a high Quality of Service to support networking applications. IoV refers to the real time data interaction between vehicles and sensors, vehicles and vehicles, vehicles and roads, as well as vehicles and personal devices using different wireless communication technologies [78]. Applications in IoV include accident prevention, emergency call, online streaming, music downloading, etc [13]. In IoV, it is desirable to take into account the speed and direction of vehicles in order to overcome the frequent disconnection of links caused by these parameters. Moreover, multimedia applications and road information exchange are very sensitive in term of delay.

Zone Routing Protocol (ZRP) is a hybrid routing protocol in which each node updates routing information about its routing area proactively, while it uses a reactive method in order to get routes to destination outside its routing zone. In this work, we propose a Stable Link based Zone Routing Protocol (SL-ZRP), which is an enhancement of Zone Routing Protocol in order to ensure link stability in IoV applications using QoS function based on speed, destination and delay to find the stable routes which in turn reduce the response time and network overhead. We evaluate the performance of SL-ZRP with various appropriate performance metrics. Furthermore, SL-ZRP and ZRP performances are compared regarding Packets Delivery Ratio, Network Overhead and End-to-End Delay metrics. The rest of this chapter is organized as follows: Section 3.2 introduce the Zone Routing Protocol with its routing protocols. Section 3.3 presents motivation and proposition goal. Section 3.4 gives details of the proposed work. Section 3.5 introduce the proposed QoS based IARP. Section 3.6 presents the proposed IERP used for ZRP. Section 3.7 provides the performance evaluation of the proposed algorithm. Finally, a conclusion is presented in Section 3.8

3.2 Zone Routing Protocol (ZRP)

ZRP [41] as suggested by the protocol name uses the notion of zones that defines the routing area for every participating node. ZRP is the most appropriate hybrid routing protocol for wide-scale networks because of its network structure. The ZRP structure is designed to combine between the contrasting proactive and reactive approaches. ZRP uses a proactive mechanism for node discovery within direct neighborhood nodes, while inter-zone communication is performed using reactive approaches. ZRP uses the fact that node communication in network is mostly localized, thus changes in node structure within the neighborhood of a node have high importance. The size of a zone (area) is characterized by the number K of hops necessary to reach the zone perimeter. The routing zone of each node is a section of the network, where all nodes within a distance less than or equal to K hops are reachable. ZRP provides two routing protocols: Intra-zone Routing Protocol (IARP) and Inter-zone Routing Protocol (IERP).

- **IntrA-zone Routing Protocol (IARP)**

IARP is a proactive approach based on periodic maintenance and updating of routing tables.

Route queries outside the node area are distributed by route requests through the zone border nodes (i.e., those with hop counts equal to K), instead of flooding the network. Each node gathers information about all the neighbors in its routing zone periodically using Hello messages that die after one hop, i.e., after reaching nodes neighbors. Then each node manages a routing table for its routing zone, so that it can find a route to any node in the routing zone from this table. Each node sends proactively a message called Zone Notification Message (ZNM). A ZNM dies after K hops, i.e. after reaching node neighbors at a distance of K hops (peripheral nodes). Each node receiving this message decreases the hop count of the message by 1 and forwards the message to its neighbors until K=0. Figure 3.1 shows an example of intra-zone routing of a node, i.e, node 1.

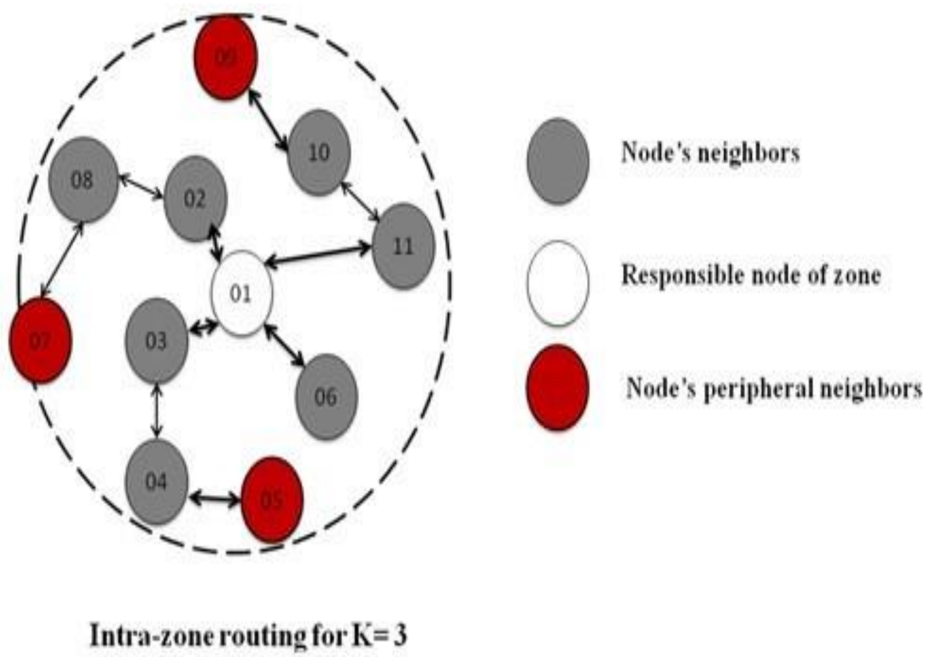


Fig.3.1. Intra-zone Routing Protocol (IARP) for K=3

- **The IntEr-zone Routing Protocol (IERP)**

IERP is responsible of finding routes between nodes located at distances greater than the zone radius. IERP relies on bordercasting which consists to send a request message to border nodes each time no route is found in the current zone. It is possible to any node that knows the identity and the distance to all the nodes in its routing zone to use the Bordercasting method and this is by the virtue of the IARP protocol. The IERP operates as follows: The source node first verifies whether the destination is within its routing zone. If so, the route to the destination is known and the node stops its route discovering process. On the other side, if the destination node is not in the same routing zone of the source node, the source forwards a route request to all its peripheral nodes. All the peripheral (border) nodes apply the same method: check if the destination is within their area. If so, a route reply is sent to the source to show the route to the destination. If not, the peripheral node redistributes the route request to its peripheral nodes, which, in turn, apply the same procedure. An example of this route discovery procedure is showed in Figure 3.2 where node 01 requests a communication with node 19. Thus, a route within a network is defined as a succession of nodes, separated by approximately the zone radius. We note that in the case where several route replies are received, ZRP selects the route with the lowest number of hops between the source and the destination.

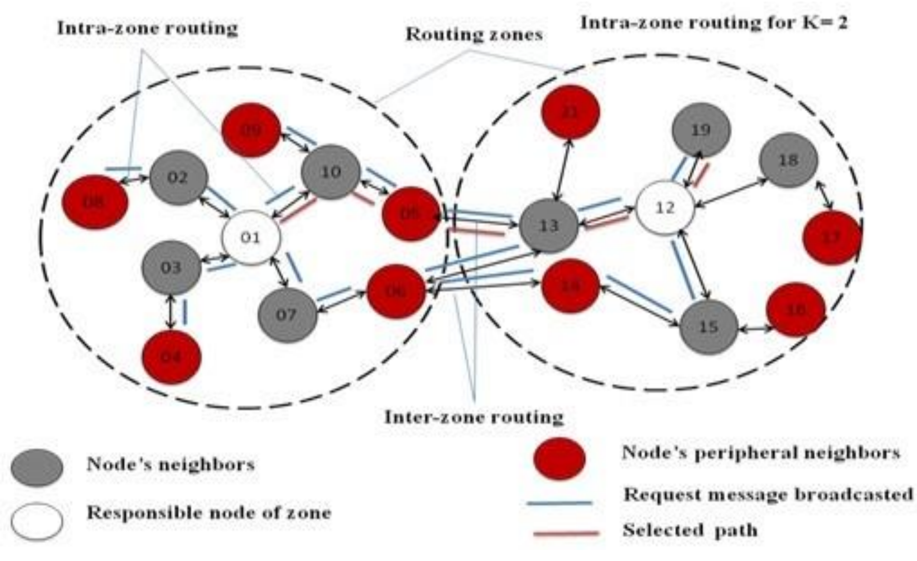


Fig.3.2 ZRP Inter-zone Routing Protocol (IERP) for K=2

3.3 Motivation and proposal goals

Applications and road exchanging information in IoV need a high QoS. The dynamic nature of vehicles in IoV leads to frequent changes in network topology which affects the QoS of these applications. Consequently, routing is one of the most complex and challengeable issues in IoV [69]. A robust routing protocol in IoV must provide the best response time to the requested vehicle without incurring any excessive extra load in the network [79,80]. ZRP uses a hybrid routing mechanism where a reactive mechanism is used in inter-zone and proactive mechanism for intra-zone. The hybrid protocol in turn reduces network overhead and delay, and is the most suitable for large-scale networks. In IoV, the routing function is particularly challenging due to the rapid change in network topology which requires fast and efficient reaction from routing protocols in case of links failure to find an alternative path [36],[69]. Although ZRP offers several advantages but it still has some drawbacks such as not supporting QoS in its routing protocols. In IARP, when a node needs connection outside its routing zone, it must request all its peripheral nodes that consume a large number of packets in network. Otherwise, the method used in IERP to choose the best route is based on short paths i.e., the lowest number of hops between the source and the destination which is not a good indicator of QoS. IARP as well as IERP do not take into account the quality of links in the route computation process. That is not admissible in QoS context and we believe that bad links cause long delays and low Packet Delivery Ratio (PDR). Several works have been suggested in order to ameliorate the QoS in ZRP. In [81] the authors proposed a Binary Error Rate (BER) based approach of ZRP (BER-ZRP) which adds quality control to all the phases of route selection decisions. In order to find routes where packets have better chance to reach their destination without needing several retransmissions; the nodes with bad links (in terms of BER) are ignored from the route request process. Effectively taking into account BER to select the best route is a good choice to avoid resending packets, but it is desirable to take into account the mobility factor. The frequent disconnection of links caused by the high mobility can also affect the communication between two vehicles which may lead to rebroadcasting of packets again. In [82], the authors propose a Zone-based Greedy Routing Protocol (ZGRP) where they combine between ZRP [41] and GPSR

[44] routing protocols. They mark the packets with their destination locations. A greedy method is used in choosing a packet next hop. Under ZRP, nodes maintain a routing table for their intra-zone nodes. This zone may be much larger (depending on the hops of radius) than the signal channel range. The authors apply the GPSR function just on ZRP border nodes, not for all their neighbors. Through this way, the forwarding nodes only search their border nodes from the direction to destination. Choosing neighbors with same direction can extend the time of connection. However, selecting best neighbors in term of same direction may not ensure that these selected neighbors have a low speed which in turn may lead to high packets loss. With ZRP, each time a node needs inter-zone communication it requests all its border nodes which will consequently request all nodes zone. With a large number of Intra-zone nodes, the network overhead will be affected by the high number of exchanged request messages. Authors in [83] take fewer nodes for routing and forwarding packets. For selecting nodes, they pick up 1 or 2 border nodes that connect neighbor zones, named as" key nodes". Such key nodes should connect together as a proactive routing relay-chain to forward packets between zones. The authors did not show the parameters used to select these key nodes and the major problem of this solution is that the selected key nodes may not reach node destination in all the times. Authors in [84], integrate a system traffic flow observer in ZRP protocol in order to find the node most sensitive to congestion and averts data drops by re-routing the video streams nearby the overfilled node. After identifying the congested node, a new flow will be selected for sending the packet to a receiver in the safest manner. The sender node chooses the lowest loaded node by which the packets will be sent; the new path will be monitored for determining either the previous path is affected by congestion or not. If so, the new path should be selected. The idea behind the proposal seems to be good, in term of minimizing the packet loss and delay, but it was suggested to be used in mesh networks. Therefore, each new selected node will reach the destination, but this idea is not adaptive to vehicular networks.

In this work, we take the advantages of ZRP as a hybrid protocol where the IARP is suitable for real time applications and all applications that need cooperation and fast distribution of information. IERP is suitable for client-server applications and so on. We extend ZRP with functionalities aiming to find the stable routes during vehicle trajectory in order to share data (route information, download cooperation, video streaming, etc.), minimizing network overhead and frequent link disconnection. We use QoS function based on speed, final region and delay of neighbors to find the stable nodes in each node zone and select some peripheral nodes to be responsible to share request message outside the zone.

3.4 Proposed Protocol

In this section, we propose a Stable Link based Zone Routing Protocol (SL- ZRP) that aims to find the stable routes in a zone-structured network in order to ensure a robust cooperation exchanging data process. SL-ZRP with its hybrid nature minimizes the number of control packets needed to search a new valid path between a source node and its destination. We suppose that each node is equipped with a GPS and digital map and can locate its position in the map. We suppose that the digital map is divided into several regions, and each node knows the organization of the city map. Therefore, by knowing the final destination (i.e., region) of each node, we can minimize the number of nodes concerned to broadcast the route queries by giving the priority to the nodes that share the same final region as the source node, and thus minimizing the number of packets exchanged in the network. In the other hand, each node can select the stable routes in its own zone by finding its neighbor nodes that reach the same final region during its movement and avoid links disconnection caused by neighbor nodes that will change their regions latter. Moreover, the high difference between the speeds of nodes may lead to frequent links disconnection in network which in turn augments the number of packets lost. Taking in consideration the difference between the speeds of nodes to calculate the quality of links between nodes is very important to select the stable links in each node zone and ignore links that are not stable. Furthermore, the time taken by a message sent from a source node to arrive to its destination node has a relationship with different factors namely bandwidth, queue occupancy, throughput, etc. The best quality of these factors means a short transmission delay of packet between a source node and a destination node. Using the period of time taken by a packet to arrive to its destination to measure the quality of links has a significant role to reduce the response time between nodes. Based on precedent reasons cited above, in the following we describe the SL-ZRP concept.

In SL-ZRP, each node computes and maintains the following variables: where (a) is the receiver node and (x) is the sender node.

- **Node priority**: the priority (P) of a neighbor "x" of node "a" is determined by its final destination. This parameter is a fixed value priority that we give it for each node according to its final destination.

$$\boldsymbol{P_a(x)} = \begin{cases} 0.5, & \text{"}x\text{" has the same destination region or the same futur passed region as "}a\text{"} \\ 1.5, & \text{otherwise} \end{cases} \quad \textbf{(1)}$$

The values used are determined and validated during simulation phase.

- **Node speed (S)**: Node speed (S) is the difference between the current node speed (node a) and the neighbor node speed (x).

$$\boldsymbol{S_a(x)} = \frac{|\boldsymbol{V_a - V_x}|}{\boldsymbol{10}} \quad \textbf{(2)}$$

Where V_a is the speed of node a and V_x is the speed of its neighbor x. We note that if $V_a = V_x$ we will take $S_a(x) = 10^{-4}$ which means long connectivity.

- **Delay (D)**: is the time taken by a message sent (beacon message) from a neighbor x to arrive to the current node a.

$$\mathbf{D}_{\boldsymbol{a}}(\boldsymbol{x}) = \boldsymbol{t_a - t_x} \quad \textbf{(3)}$$

Where t_a is the time of reception of beacon message by current node "a", t_x is the sending time of message by node "x".

To select neighbors with higher quality of service in an urban environment, an urban-based QoS metric is introduced. SL-ZRP focuses on the cooperation of neighbors; a vehicle is capable of reaching its destination using stable routes. Our proposed urban based QoS metric incorporates node priority, node speed and delay parameters mentioned above. The QoS value is calculated as follows:

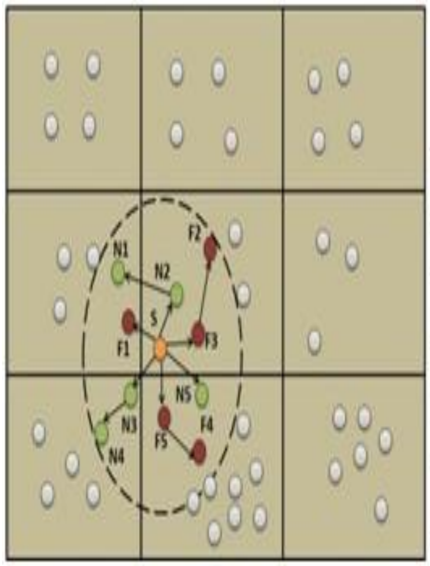
$$\boldsymbol{QoS_a(x)} = \boldsymbol{P_a(x)} * \boldsymbol{S_a(x)} * \boldsymbol{D_a(x)} \quad \textbf{(4)}$$

At first, each node in the network discovers and forms its group of neighbors with K hops through beacon messages exchanging process. A beacon message contains the current region of the source message, destination region of source message, time of sending the message and node speed. After receiving these parameters, the receiver node calculates the QoS value of the sender node and updates its routing table, we note that all parameters used have to be the lowest as possible in order to ensure a best quality of service. Each node in the network has three categories of neighbors:

Friend neighbors: denote the priority nodes that have lowest QoS value, that will be used mainly to share traffic information or data that need robust connection and link stability (file downloading).

Normal neighbors: are the rest of nodes that have medium to highest QoS value. These nodes are used to help the source node to find a route to its destination in case where no friend node has a route to this destination.

Peripheral neighbors: are the bordercaster nodes having distance equal to k hops. These nodes are used to broadcast route requests in order to find the destination node out of its own zone. The set of Peripheral neighbors may contain only Friend neighbors or only Normal neighbors or both of them. Figure 3.3 illustrates an example of categories of neighbors, where initially, the node S discovers its neighbors and calculates the QoS value for each neighbor. Then node S classifies all its neighbors from the smallest to the biggest based on QoS value. After that node S takes 50% of its nodes neighbors that have the smallest QoS value as a Friend neighbors set (F1,F2,F3,F4,F5) and the rest is considered as a Normal neighbors set (N1,N2,N3,N4,N5). The Peripheral neighbors set include all neighbors that have distance equal to K hops (F2,F4,N1,N4). Each time node S discovers a new neighbor it updates its routing table.



Friend Neighbors		Normal Neighbors		Peripheral neighbors
F5	QoS=0.010	N2	QoS=0.19	F2
F3	QoS=0.019	N3	QoS=0.27	F4
F1	QoS=0.022	N5	QoS=0.76	N1
F2	QoS=0.050	N1	QoS=0.83	N4
F4	QoS=0.086	N4	QoS=0.88	

Fig.3.3 Intra-zone neighbors' classification for vehicle S

Similarly to ZRP, SL-ZRP relies on two protocols: an intra-zone communication protocol and an inter-zone communication protocol. We describe, in the following, the both of them.

3.5 QoS based IARP

In SL-ZRP each node has to know the following information:

- The organization of the city map
- Its final destination region.
- All its zone neighbor nodes.
- The intermediate regions that will pass them to attain its final region.
- The final destination region, the speed and time response of all its neighbors.
- The QoS value of all its zone neighbors.
- Its friend neighbors.

- Its normal neighbors.
- Its peripheral neighbors.

We note that all nodes inside or outside the region that share the same final region, will pass by the same intermediate regions in order to arrive at the final region.

Communications in SL-ZRP are based on beacon messages exchange process. Each node N periodically collects information about all nodes in its routing zone. N_i maintains a routing table for its routing zone, so it can find a route to any node N_j in the routing zone from this table. Each node, after reaching its neighbors at different distance of hops (up to K hops); it classifies these nodes according to QoS value from the lowest to the highest into three categories: Friend neighbors, Normal neighbors and Peripheral neighbors. When a node needs communication with another node, it checks its routing table for route. Three cases are possible: if it has a direct route (1 hop) to destination it sends route request directly. In the contrary case (more than 1 hop), it checks its Friend neighbors for route to destination, and then it selects the path that has lowest QoS value. In the case of no route is found through its Friend neighbors, the vehicle verifies the Normal neighbors with the same way. A final case appears when no route is found, in this situation we apply the IERP protocol. Figure 3.4 shows an example of SL-ZRP intra-zone routing protocol where vehicle 01 wants to send a data packet to node 06. In this case, two paths are available: the first path is by node 03 and the second path by node 05. Based on QoS function, node 03 and node 04 are Friend neighbors of vehicle 01, which means that this path is the more stable path to communicate with node 06, thus this path will be selected by vehicle 01.

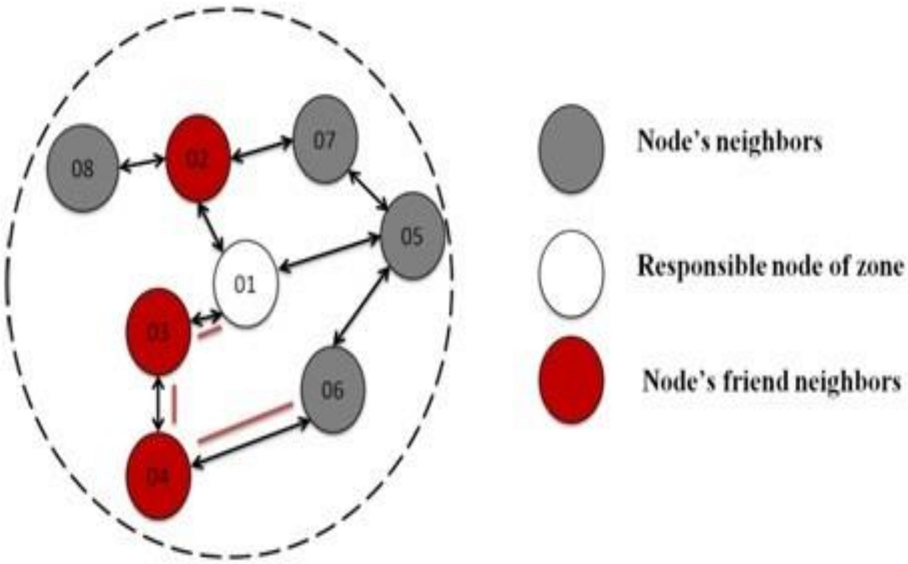


Fig.3.4. SL-ZRP Intra-zone Routing Protocol

3.6 IERP protocol of SL-ZRP

Consider a situation where vehicle 01 wants to send a packet to node 19. Here the source vehicle is vehicle 01 and the destination node is node 19 as shown in Figure 3.5. To send the packet to the destination node, it has to find the path first. Vehicle 01 goes through its routing table for node 19 utilizing the IARP Protocol. Since node 19 is not in its own routing zone, it initiates the route requests using Inter-Zone Routing protocol. The requests are bordercasted to the peripheral neighbors. Here, the peripheral neighbors of vehicle 01 are: nodes 04, 05, 06, 08 and node 09. Now node 05 and node 06 go through their own routing table for node 19. Since the vehicles cannot find the destination node 19 in their routing tables, they need to send a request to their peripheral neighbors utilizing bordercasting method. The peripheral neighbors for node 05 are node 12 and for node 06 are node 12 and node 15. Now the nodes examine their routing tables for node 19. Since node 19 is in the zone of node 12 and node 15, they add the path from themselves to vehicle 01 using the route request path. Finally, they send the generated route reply back to vehicle 01. Now vehicle 01 gets multiple route replies. Among the replies, it uses the path containing more friend neighbors to node 19 and sends the data packet. In this way, the route discovery process is done and it reduces the delay for vehicle 01 and node 19 to communicate.

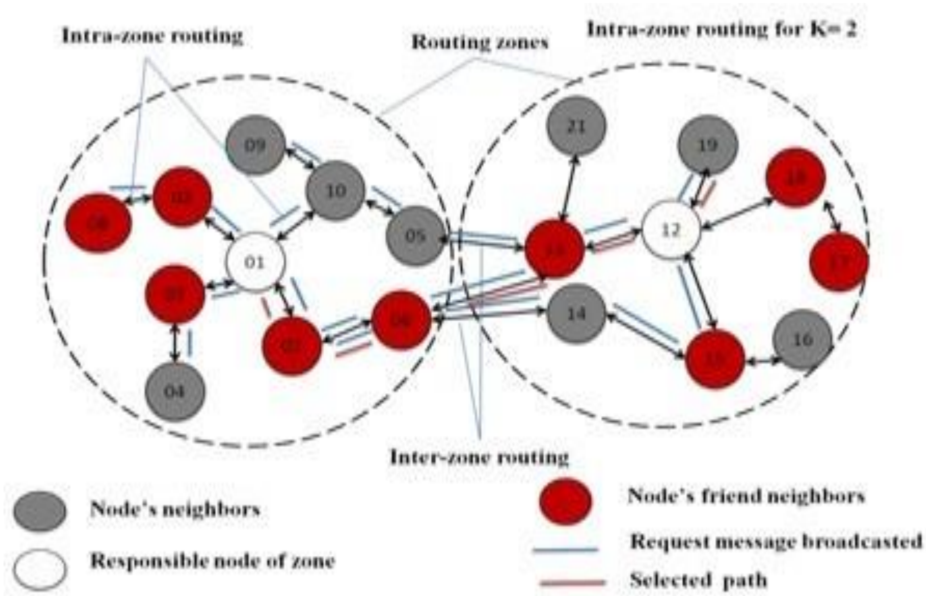


Fig.3.5 SL-ZRP Inter-zone Routing Protocol

Algorithm1 SL-ZRP

1: **while** node is ON **do**
2: beacon message received from neighbor node
3: calculate QoS value and update routing table
4: **if** *Vehicle needs connection* **then**
5: **if** *the destination node is in my own zone* **then**
6: **if** *I have a direct route* **or** *I have a route by friend neighbors* **then**
7: send route request directly
8: **else**
9: choose a Normal neighbor that has lowest QoS value and send route request
10: **endif**
11: **else**
12: send route request to peripheral nodes
13: **endif**
14: route request received
15: **if** *I am the destination* **then**
16: send route reply
17: **else**
18: **goto** *5*.
19: **endif**
20: **endif**
21: **endwhile**

3.7 Simulation and Results

To evaluate the performance and efficiency of our proposal, we use Network Simulator 3 (NS-3) as a network simulator [85]. For vehicles, we have used the software Simulation of Urban MObility (SUMO) [28] to generate realistic mobility traces of vehicles and road traffic scenarios to imitate a real road network. We have generated a realistic mobility model using the tool Mobility Model Generator for Vehicular Networks (MOVE) introduced in [29]. For Media Access Control (MAC) layer we used IEEE802.11p. For other adhoc nodes we utilized random waypoint model for mobility model and IEEE802.11 for MAC layer. We consider the channel bandwidth as 10 MHz , this protocol is proposed to be used in urban where the speed is randomly and its maximum value is fixed as 60km/h.

Parameters	Value
Bandwidth	10 MHz
Data rate	6 Mbits/s
MAC layer	IEEE802.11p/IEEE802.11
Transmission range	300 m
Traffic type	CBR
Data packets size	1024 byte
Network size	400 .. 1200
Road network map	3000m 3000m
Number of regions in the map	4, 8,10
Simulation time	150 seconds

Table.3.1 simulation parameters

We tested several scenarios during our simulation. The parameters used in our simulation and their values are shown in Table 3.1. We compared SL-ZRP with ZRP in terms of the following metrics:

- **Generated overhead:** measured by the number of request packets (RREQs) sent in the network.

- **Packet Delivery Ratio (PDR):** Defined as the ratio between the number of packets successfully received at destination and the total number of packets sent by the source node for a given traffic flow.
- **End to End (E2E) delay:** This metric refers to the average time separating the transmission of a data packet by a source node and its reception at the final destination.

Figure 3.6 illustrates the variation of the achieved packet delivery ratio during simulation time in network with 800 nodes. The plotted results are divided into three phases:

At 30 second: we observe that PDR records its minimal value for both ZRP and SL-ZRP because the simulation is in its first phase, so the communication links are not all discovered yet and the available communication links are unreliable. From 30(s) to 120(s): in this phase, the PDR increases rapidly. At this time, the road network becomes more interactive which creates more stable links among nodes. The results show that our protocol achieves higher PDR comparing to ZRP and this is due to the method used to divide the city map that increases the number of stable routes in SL-ZRP.

After 120 (s): At this time, the PDR is stable and this is due to the end of different started communications.

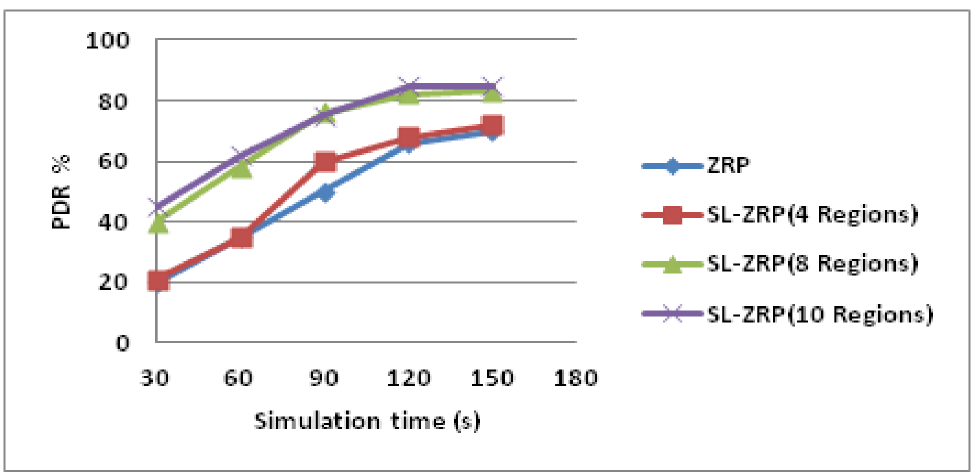


Fig.3.6 Packet delivery ratio during simulation time

Figure 3.7 shows the variation of number of RREQs sent in the network versus simulation time. The plotted results between 30(s) and 60(s) show high and similar value of REEQ for ZRP and SL-ZRP. In this period, all nodes are requesting for communication, therefore nodes are required to send more REEQ messages. After the 90th second, SL-ZRP (4 Regions), SL-ZRP (8 Regions) and SL-ZRP (10 Regions) achieve a significant reduction of the generated overhead compared to ZRP. SL-ZRP proves its performance by choosing stable routes based on QoS comparing to the standard ZRP.

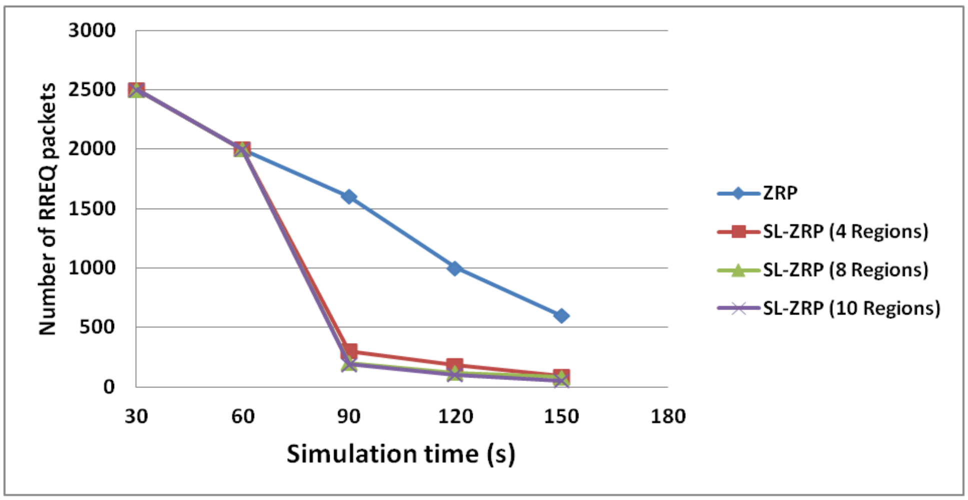


Fig.3.7 Number of RREQ sent during simulation time

Figure 3.8 illustrates the variation of the average End to End delay during simulation time. SL-ZRP shows a good minimization of delay during simulation time and this is due to the best routes selected by our protocol. delay (D) parameter used to calculate QoS value helps us to find the nodes that replay in short time according to their best features such as large bandwidth, low queue occupancy and low handoff time which in turn minimize delay metric in our proposed algorithm.

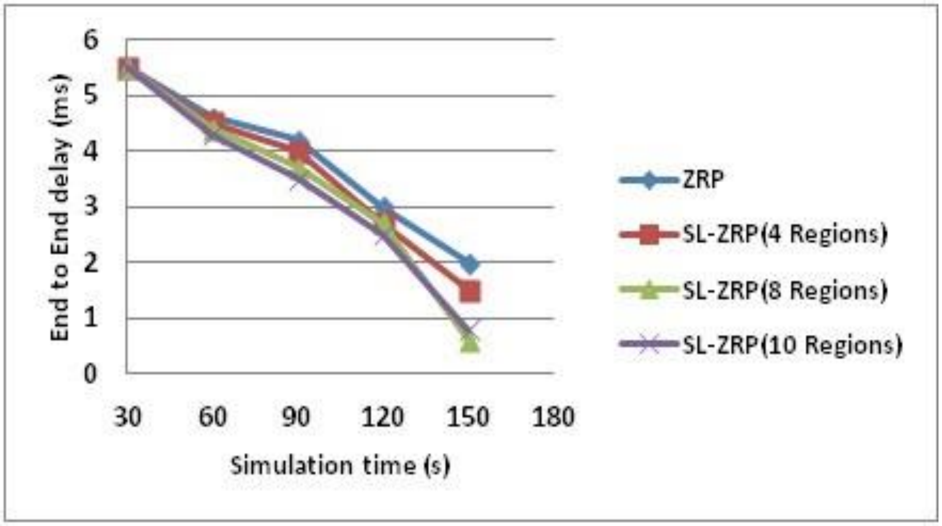


Fig.3.8 Average End to End delay during simulation time

To evaluate the impact of network density on SL-ZRP performance, we vary the number of nodes in the network from 400 to 1200 nodes. The speed of nodes is randomly determined with maximum value of 60 km/h.

The results plotted in Figure 3.9 illustrate the evolution of the average packets delivery ratio comparing to the variation of the network size. The results show that more we increase the number of nodes more the PDR increases for the four protocols. The large number of available links in network helps nodes to choose the best links in term of QoS, which in turn increases the PDR. Moreover, choosing the best route by a node means that will have long connectivity with its destination during its trajectory.

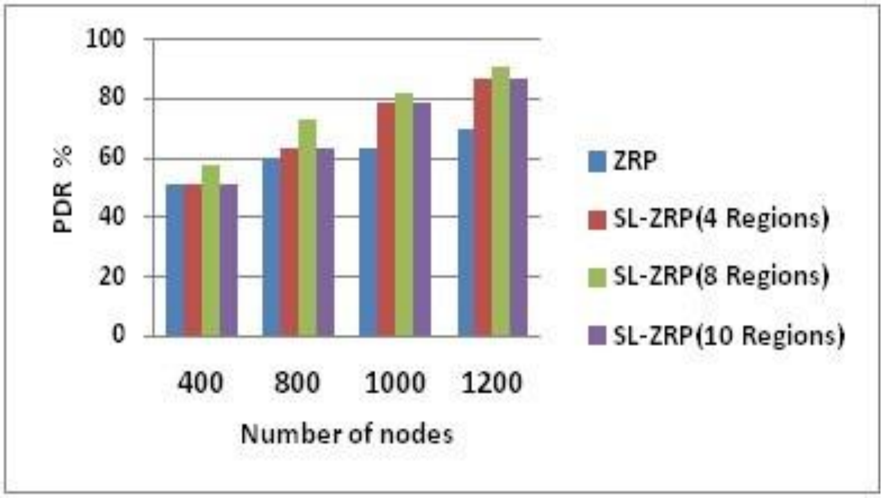


Fig.3.9 Packet delivery ratio versus Number of nodes

The results depicted in Figure 3.10 illustrate the variation of average End to End delay versus number of nodes, the results show that our protocol is more efficient than ZRP in high network density. With 400 nodes, the four protocols take the same delay and this is due to the few available links in term of small response time. However, from 800 to 1200 nodes SL-ZRP performs more conveniently than ZRP which means that besides of achieving optimization aspects, the proposal is also complying with the scalability issue.

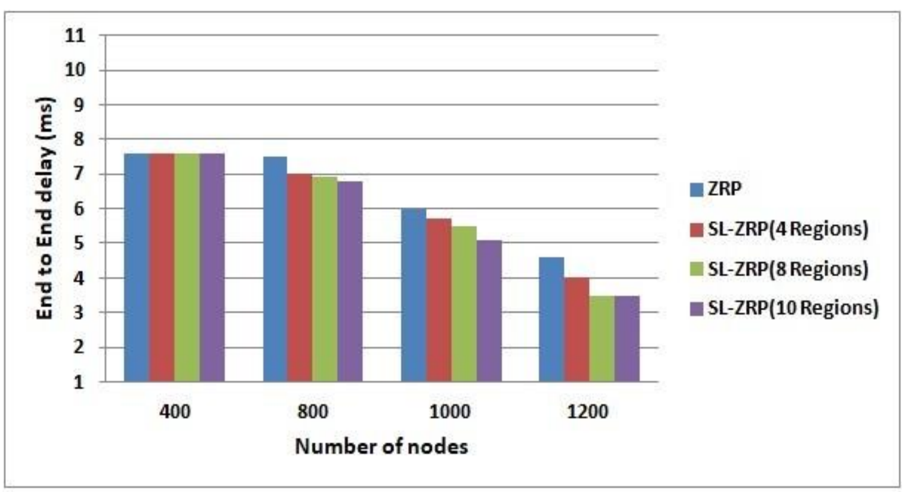


Fig.3.10 Average End to End delay versus Number of nodes

Figure 3.11 shows the number of RREQ sent versus the number of nodes; the results illustrate that the number of RREQs sent in the network increases with the increase in the number of nodes for all protocols. The high number of RREQ in scalable network is logical, and it is referred to the high number of nodes requesting connections. As we can observe, SL-ZRP confirms its performance comparing to ZRP, this is related to the strategy of routes selecting process used in SL-ZRP. Reducing the number of regions in network drives SL-ZRP to work similar as ZRP. SL-ZRP with small number of regions drives nodes to broadcast more RREQs in order to establish routes, because the priority parameter (P) used to calculate QoS value will not be significant. However, in dense network a higher number of regions is more suitable because in this case, establishing routes is less challenging and more regions will reduce the RREQs overhead (Scalability).

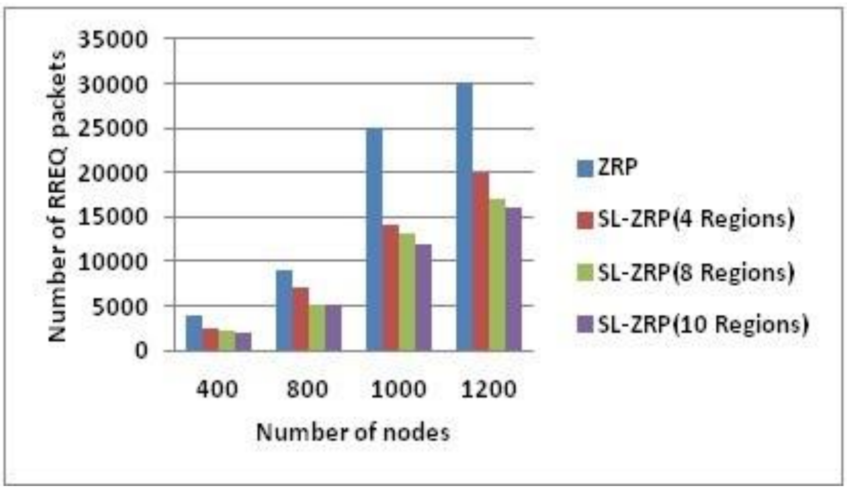


Fig.3.11 Number of RREQ sent versus Number of nodes

3.8 Conclusion

The recent advances in communication network technologies have led to the emergence of Vehicular Ad hoc Network which paved the way to Intelligent Transport System paradigm. The latter in turn, gives the opportunity to vehicles to communicate and interact in a larger environment such as VANETS in a more global context like Internet of Vehicles. In order to provide efficient communication to vehicles and to effectively use different applications with high quality of service, we have proposed Stable Link based Zone Routing Protocol (SL-ZRP). To achieve the expected QoS, SL-ZRP uses three parameters namely: node priority, node speed and delay. The performances of the proposal are evaluated via multiple simulated scenarios regarding relevant metrics like: network latency, packets delivery ratio, network overhead and scalability. Simulations, carried out via a combination of NS-3, SUMO and MOVE simulators, showed for our proposal, convincing results outperforming those of classical ZRP and complying with application requirements in Internet of Vehicles environment.

Chapter 4

Reliable connectivity-based Clustering Algorithm for IoV

4.1 Introduction

Vehicular Adhoc Networks (VANETs) is known as a part of Mobile Adhoc Networks (MANETs), where vehicles play the role of mobile nodes, VANETs communications are defined by the interaction and data sharing between vehicles, Infrastructures and Roadside Units (RSU). Internet of Things (IoT) is a novel field that appeared recently, IoT brings a new concept called smart object (smart house, smart corps, smart animal …) [15]. IoT network allows various smart objects to communicate and exchange information among each other in order to accomplish a specific task. In the last few years, Internet of vehicles appeared as a new sub-class of IoT. The emergence of the new domain of IoT drives the classical VANETs, the core of Intelligent Transport Systems (ITS) to be an autonomous field named by IoV. A vehicle, in IoV, is considered as a smart machine, that offers different services to the end users through Internet connection such as safety applications (accident alert, traffic alert…), and entertainment applications (games, videos streaming, music downloading…). IoV is considered as the extension of the classical VANETs in different aspects (nodes communications, network technologies, network scalability, …..). IoV network communications provide various connection types such as Vehicle-to-Vehicle connection (V2V), Vehicle-to-Infrastructure connection (V2I), Vehicle-to-Person connection (V2P), Vehicle-to-RSU (V2R) and Vehicle-to-X connection (V2X). V2X means that a vehicle can communicate with any smart objects in its surroundings. IoV has several specific characteristics: high speed vehicles which represent nodes with high mobility, vehicles are the dominants nodes in the network, where the number of vehicles is very high compared to other smart objects, the network scalability, the number of interacting connected nodes in IoV is very high, the support of heterogeneous networks such as 4G, Bluetooth, Zigbee and so on , and IoV network architecture is based on clouds. IoV provides divers advantages like: sharing traffic information, sharing alert event, driver assistance, infotainment system, intra-vehicle control, … [10]. However, it has some drawbacks such as the high dynamicity of network caused by the high speed of vehicles, which in turn increases the topology change rate that effects packets delivery ratio [86]. The high number of vehicles connected to IoV in intelligent city, causes a high growth in network overhead which results in packets loss. The shared information of connected vehicles in network make vehicles susceptible to hackers to control their movements where they can force them to accelerate, brake or steer. IoV faces different challenges such as: improving network Quality of Service (QoS) by minimizing the time of packets broadcasting especially alert messages, minimizing network overhead to avoid the loss of packets, augmenting the level of security to protect users from hackers,… . Clustering is one of the best methods used to minimize network overhead and increase network reliability. In this chapter, we introduce a new weight-based clustering algorithm using delay, density, speed and position metrics in order to ensure some quality of service in IoV by guaranteeing reliable connectivity and low network overhead. We compare the performance of the proposed algorithm using network simulator NS-3, SUMO and MOVE to show the performances of the proposed clustering approach.

The rest of this chapter is organized as follows: Section 4.2 presents the classification of clusters algorithms and their limits. Section 4.3 introduces our motivation and clustering approach. Section 4.4 shows the parameters used. Section 4.5 describes the proposed approach in details. Section 4.6 shows the clustering properties. Section 4.7 presents the experimental results. Finally, conclusion is presented in section 4.8.

4.2 Classification of clustering algorithms

Choosing an efficient network structuring technique for IoV paradigm is a challenging topic. Clustering has significantly improved network performances compared with classic flat structure in numerous applications [87],[88]. Several works have been proposed in order to provide reliable network structure. Various methods have been designed specifically for vehicular networks based on different parameters and concepts. In this section we will present the most well-known and recent clustering protocols proposed for vehicular networks. Then we summarize their characteristics and limits in Table 4.1.

4.2.1 Classical MANET based clustering algorithms

Lowest Relative Mobility Clustering Algorithm (MOBIC) [89], is a very popular clustering algorithm in MANET. The criteria of selection of cluster head nodes is based on the relative mobility of nodes. The main idea of this algorithm is to select the nodes that move with low mobility as cluster heads, where the authors suppose that these nodes provide more stability. MOBIC utilizes a time interval called Cluster Contention Interval (CCI) to eliminate unnecessary cluster heads, in case where two CHs are neighbors after period expiration of CCI, the CH that has the highest ID gives up the role of CH. This mechanism is used to minimize the CHs maintenance redundancy.

Highest Degree (HD) algorithm [90], is based on node density factor, the nodes that have more neighbor nodes will be selected as CHs. In order to know the node that has more neighbors, each node broadcasts periodically a hello message to its direct neighbors, that includes the degree value of this node. After receiving the beacon messages by neighborhood nodes, each node compares its degree value with the received value. The node that has the highest degree becomes the CH and the rest of neighbor nodes become cluster members.

A Flexible Weighted Clustering Algorithm based on Battery Power (FWCABP) for MANETs [91]. The main idea of this proposed work is to avoid the nodes that have low battery power to be elected as a cluster head. With the same mechanism of HDC algorithm [90], each node broadcasts a hello message that contains a weight value of the node, which is computed based on node degree, sum of distance to neighbor nodes, node mobility and remaining battery power. The node that has the smallest value is elected as CH. FWCABA calls the maintenance process in two cases: if a node moves outside its cluster and/or the battery power of the CH decreases to a predefined threshold value.

Score Based Clustering Algorithm (SBCA) [92] for MANETs. This algorithm shares the same idea of FWCABA [91] in term of weight value but with different factors: remaining battery power, degree value of node, number of members and node stability. The goal of this technique is to create minimum number of clusters and maximize the lifetime of mobile nodes. To initiate the cluster formation phase, each node broadcasts a beacon message to its neighbors including its calculated score. The node that has the highest score is selected as CH.

4.2.2 Neighborhood based clustering algorithms

- One-hop clustering algorithms

A Self-Organized Clustering Architecture for Vehicular Ad Hoc Networks (SOCV) [93], is a one- hop clustering scheme based on combination of public-key with secret-key cryptography. The main goal of this work is to propose a new system that reduces the number of communications in dense road traffic and ensure safe network communications in VANET. The authors create a dynamic virtual backbone in the network that includes Cluster-Heads and cluster-gateways nodes, the main responsibility of these nodes is guarantying efficient message propagation in the network.

Stochastic Modeling of Single-Hop Cluster Stability in Vehicular Ad Hoc Networks [94], in this work clusters formation phase is based on stochastic mobility model. A stochastic mobility model is used to measure the time variations of intervehicle distances. At the first a discrete-time lumped Markov chain is used to model the time variations of the system of distance headways, then to measure cluster stability the authors use the analysis of the first passage time to derive probability distributions of the time periods of invariant cluster overlap state and cluster-membership. Finally, queueing theory is utilized to model the behavior of the number of nodes that do not belong to any cluster and common nodes between neighboring clusters

- k-hops clustering algorithms

A distributed D-hop cluster formation for VANET(DHCV) [95], creates clusters in such manner that the distance between each node in the cluster and the Cluster Head of the same cluster is at most D-hops. The main purpose of this proposed scheme is to divide vehicles into non-overlapping clusters, which have adaptative sizes in accordance with their mobility. To create D-hop clusters, each vehicle chooses its Cluster Head based on relative mobility calculations within its D-hop neighbors.

Multi hop-cluster based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination (VMaSC-LTE) is proposed in [96]. In this proposed scheme, the authors suppose that the high number of broadcasted messages and disconnected network problems will reduce the messages delivery ratio and latency performance in network that is based only on LTE technology. The authors suppose also that network that is based on pure cellular communication is not feasible according to the high cost of communication between vehicles and infrastructures. In order to enhance network performance, authors propose to use a hybrid architecture based on IEEE 802.11p based multi-hop clustering and LTE. Cluster Heads selection process is based on the average relative speed of vehicles.

4.2.3 Geographic information-based clustering algorithms

- Position based clustering algorithms

A Position Sensitive Clustering Algorithm (PSCA) [97], is designed for vehicular networks with high density. Cluster Head selection process is based on broadcasted position information, where all cluster members have to broadcast their expected status messages using multi-hops routing. The initial CHs selection process is performed by the principle of "Randomly Competition, First Declare Win". After a series of received information and calculation work, the CH broadcasts a message of control at a specific time by direction-based broadcasting. Each cluster member has to send its position information to the CH before the next specific time, so that the CH updates this information and uses it in the next iteration of the clustering process.

A new Position Based Clustering Technique for Ad Hoc Inter-vehicle Communication (PCTIC) [74], is a new clustering algorithm for large multi-hop VANET. Clustering formation process is performed using geographic position information of vehicles, vehicles priorities and traffic information. The Cluster Heads are selected based on the Minimal Dominating Set (MDS). The maximum K- hops distance between CHs and their cluster members defines the size of each cluster. Each Cluster Head controls and monitors its cluster independently and re-configures it dynamically during vehicles movement.

- Destination based clustering algorithms

A Destination Based Routing (DBR) algorithm for context-based clusters in VANETs [98] presents two mechanisms to minimize data traffic and end-to-end delay in VANETs. The First mechanism is a context-based clustering algorithm that is based on different metrics such as direction, relative velocity, interest list and final destination. The second mechanism is a destination-based routing protocol proposed for the context-based clusters in order to enhance the inter-cluster communication. Using the context-based clustering that includes interest list of vehicles, the overall end-to-end communication is significantly improved.

A Destination-Aware Context-based Routing (DACR) scheme using a soft computing clustering algorithm for VANET [99], in this work the authors present two soft computing approaches. The first is a hybrid clustering method that combines the geographic and the context clustering in order to improve network performance by minimizing network control overhead and traffic. The second is a destination-aware routing protocol designed for inter-clusters communication in order to enhance message transmission process by augmenting packet delivery ratio and reducing the end-to-end delay.

4.2.4 Mobility based clustering algorithms

A new Aggregate Local Mobility (ALM) clustering algorithm is proposed in [100]. The main purpose of this work is to prolong the network connectivity lifetime in VANETs. This proposed algorithm introduces an aggregate local mobility mechanism to control and monitor the existing CHs. To select the CHs, each node calculates its mobility variance over all its neighbors. The authors suppose that the vehicle that has lower variance is more stable. As a result, the vehicle that has less mobility variance relative to its neighbors is the most suitable to be selected as CH.

Mobility adaptive density connected clustering algorithm (MADCCA) [80], constructed for cluster stability only in different scenarios. On the basis of traffic density cluster head, switching is done maintaining average node density for each CH. Key parameters used in MADCCA are vehicle's velocity and node density in a different environment. MADCCA is compared with a mobility-based metric for clustering in MANET (MOBIC) [89] and aggregated local mobility (ALM) [100]. MADCCA performed better than MOBIC and ALM in experimentation with the use of static transmission range value for all nodes.

An efficient Dynamic Mobility-based Clustering (DMC) algorithm for forming a stable core network for future data aggregation and dissemination [101] performs the cluster formation process based on the vehicles' mobility patterns. Moreover, the authors add a number of metrics such as direction, relative speed, relative average distance and link stability. The proposed algorithm used a new dynamic cluster formation mechanism, where vehicles are assumed to be static during the formation phase. In order to improve the cluster formation phase a "temporary cluster head" method is proposed. Moreover, in order to monitor the cluster size, the algorithm presents a "safe distance threshold" method.

4.2.5 Weight based clustering algorithms

Efficient Weight-based Clustering Algorithm using a Mobility Report (WECA-MR) [102] is a new algorithm designed for IoV environment. The main goal of this proposed method is to guarantee efficient clusters stability with minimum number of CHs. The cluster formation process is based on nodes weight values. The calculated weight values are based on three parameters: number of neighbors, average distance and Mobility Report (MR). The latter uses two other mobility metrics: velocity and acceleration in order to increase clusters stability.

A multi-objective genetic-based algorithm Adaptive Weighted Clustering Protocol (AWCP) [103] introduces a genetic multi-objective method that uses different metrics inputs such as highway ID, vehicles direction, vehicle location, vehicle's velocity and vehicles connectivity in order to calculate the nodes weights. CHs selection process is based on weight values that combine different parameters. Its main goal is to enhance network stability, improve data delivery rate, and reduce network overhead.

QoS Based Clustering for Vehicular Networks (QoSCluster) [104] is a multi-metric clustering algorithm. The authors proposed two kind of metrics to calculate the weight value: QoS Metrics that include average link expiration time, average link bandwidth and average time to completion, and stability metrics that include the level of connectivity, relative mobility and the average relative distance. The authors compared the proposed scheme to DMCNF [105], the obtained results show the effectiveness and robustness of QoSCluster.

4.2.6 Bio-inspired clustering algorithms

Clustering algorithm for Internet of Vehicles (IoV) based on dragonfly optimizer (CAVDO) [106] is a metaheuristic approach based on Dragonflies Algorithm (DA). DA is characterized by two swarming behaviors 'Dynamic Swarming' which is used for food search, and 'Static Swarming' which is used for local movement or hunt. This algorithm uses dynamic weights during its working process, in CAVDO authors used direction and velocity of participating nodes to generate the weights. To evaluate the fitness of dragonflies the authors used a multi-objective function. The proposed work is compared to ACO [107] and CLPSO [108], CAVDO performed equally or better than ACO and CLPSO.

Another recent bio-inspired algorithm for VANETs clustering technique is proposed. It is called Binary artificial bee colony (BABC) algorithm [109]. The main goal of this method is guarantying robust communication by using minimum spanning tree to connect nodes without loops. The maximum number of nodes considered for simulation is 16 using only one parameter 'maximum hit prediction'. The proposed work is compared to Kruskal algorithm using only vehicle to roadside scenario. BABC outperformed Kruskal algorithm due to its advanced capabilities to connect nodes to each other.

A metaheuristic clustering algorithm based on the enhancement of Ant Colony Optimization (CACOIOV) [110] is proposed. It stabilizes the network topology by using two distinct stages for packet route optimization. Another algorithm, called mobility Dynamic Aware Transmission Range on Local traffic Density (DA-TRLD) [111], is employed together with CACOIOV for the adaptation of transmission range regarding density in local traffic

Intelligent Clustering using Gray Wolf Optimization (ICGWO) [112] is a novel proposed algorithm for clustering. It is based on the social behavior of Gray Wolf Optimization (GWO). The social behavior of GWO is based on three steps: searching, encircling and hunting. In nature, the GWO divides the wolves pack into four categories: alpha (α) which is the strongest candidate in the pack that gives the orders to all other wolves. Beta (β) take the second position after alpha wolves, they support alpha to make decisions. Delta(δ) these wolves help to protect all the group. Omega (ω) are the weakest wolves in the pack. Authors used fitness function to divide the nodes into three categories and give them their positions.

Based on our review, we propose new classification for clustering algorithms in IoV as illustrates Figure 4.1, as well as we provide in Table 4.1 a general comparative analysis of various clustering algorithms in IoV discussed above based upon various key parameters. The parameters selected for the comparison are: Density, QoS, Total Overhead, Overlapping Clusters and Stability.

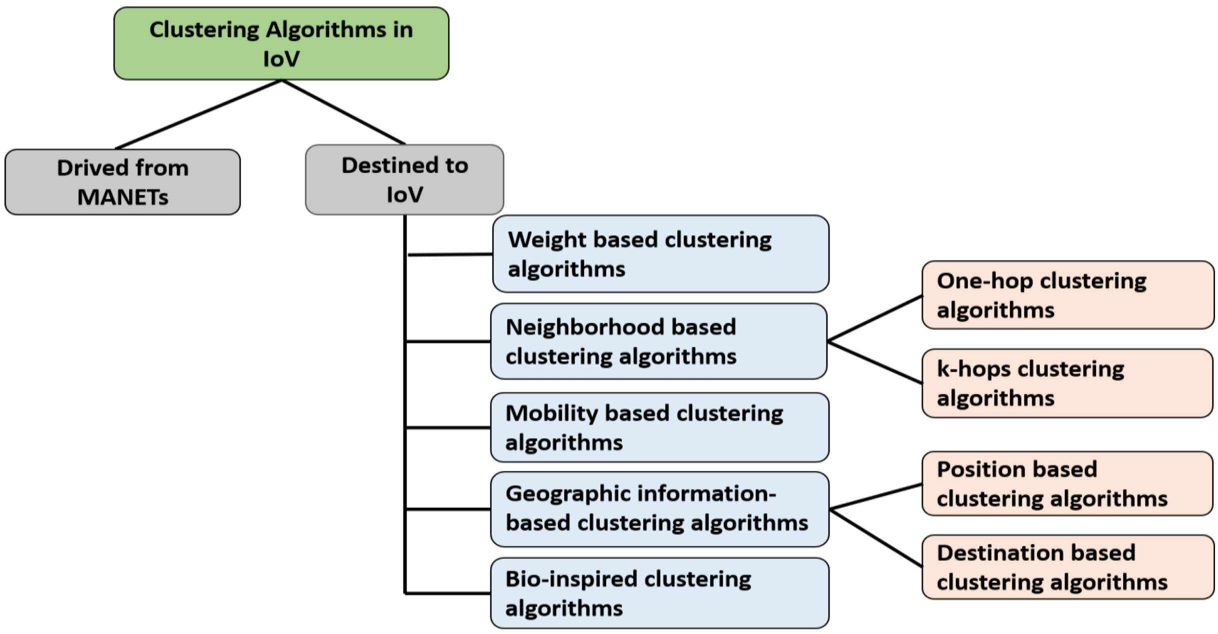


Fig.4.1 Routing protocols Classification in IoV.

Clustering Schemes	Based on	Density	QoS	Total Overhead	Overlapping Clusters	Stability
MOBIC [89]	MANET	Low	No	High	Possible	High
HD [90]	MANET	Low	Yes	High	No	Moderate
FWCABP [91]	MANET	Low	No	High	No	Medium
SBCA [92]	MANET	Moderate	No	Low	No	High
SOCV [93]	One-hop	Low	No	Low	Possible	Medium
Single-Hop [94]	One-hop	Medium	Yes	Low	Possible	Medium
DHCV [95]	k-hops	Medium	No	High	No	Medium
VMaSC-LTE [96]	k-hops	High	Yes	High	No	High
PSCA [97]	Position	Moderate	No	High	Possible	High
PCTIC [74]	Position	High	No	Medium	Possible	High
DACR [98]	Destination	Medium	No	Medium	Possible	Low
DBR [99]	Destination	Low	No	Medium	Possible	Medium
ALM [100]	Mobility	Medium	No	Medium	No	High
MADCCA [80]	Mobility	High	Yes	Medium	No	High
DMC [101]	Mobility	Medium	No	High	Possible	High
WECA-MR [102]	Weight	Medium	Yes	Medium	No	High
AWCP [103]	Weight	High	Yes	Medium	Possible	High
QoSCluster [104]	Weight	Medium	Yes	Low	Possible	High
CAVDO [106]	Bio-inspired	High	Yes	Medium	Possible	High
BABC [109]	Bio-inspired	Medium	Yes	Low	No	Medium
CACOIOV [110]	Bio-inspired	High	Yes	High	No	High
ICGWO [112]	Bio-inspired	Medium	No	Medium	Possible	High

Table 4.1 Routing protocols comparison.

4.3 Motivation and Clustering approach

Network congestion is one of the major problems that appears when there is a large number of connected nodes in network. The different types of connections in IoV increase the number of interacting nodes which in turn increases the number of exchanged packets. The high number of packets sent and received in network causes various issues such as packet loss, queueing delay and blocked connections. In order to solve the problem of network congestion clustering algorithms have been used in several existing proposed solution in literature as introduced in section 4.2. Clustering is a mechanism of gathering of vehicles and other nodes based on some metrics such as node ID, position, density, speed, direction of nodes and so on [87]. Clustering structures have several advantages by comparison to flat structure such as guarantying network load balancing, increasing network connectivity stability and minimizing network overhead [88],[113]. According to the available literature, most of the proposed clustering algorithms [104],[102] are focused only on one-hop clustering, which only allows communication between a Cluster Member and its Cluster Head with one-hop distance at most. Consequently, the coverage area is very small, and many clusters are formed, which affects the network performance and increases the rate of overlapping between clusters. Moreover, as VANET is a subclass of MANETs, several proposed protocols are derived from MANET clustering schemes [87]. As a result, these schemes do not take in consideration IoV characteristics such as the high nodes mobility, the high dynamic topology and the limited driving directions of nodes. Furthermore, most of the proposed clustering protocols do not use various combined parameters which in turn decreases network Quality of Service. Other proposed clustering approaches are based on high number of control messages [114-115], which causes overloading of the networks and leads to many collisions. In emergency situation with people lives at stake, time is a critical factor on network where alerts messages must to be broadcasted as quickly as possible to prevent injuries and damage from happening. Only if we ensure a low network overhead, a reliable connectivity and an updated network communication, the goal of short response time can be achieved. In this work we introduce a new weight-based clustering algorithm (WBCA), where we will minimize the network overhead by using hierarchical architecture (clusters) and maximize the quality of service (short response time) by integrating selective parameters such as delay, density, speed and position to select the cluster heads. Figure 4.2 shows IoV Network based Clusters structure.

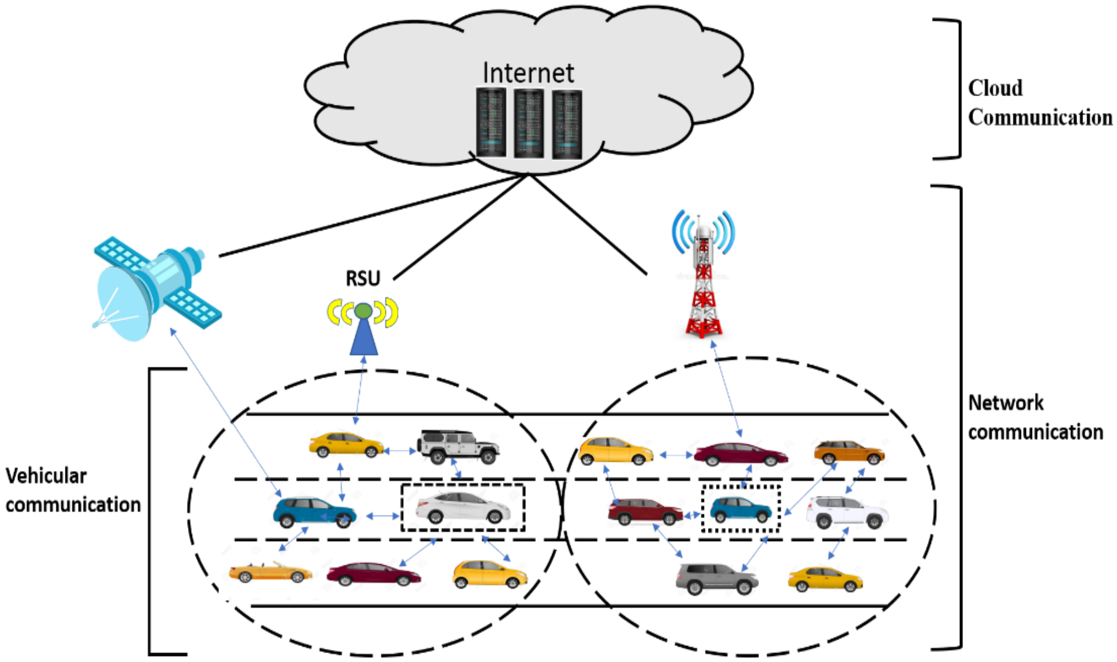


Fig.4.2. IoV Network based Clusters structure

4.4 Parameters used

In order to ensure a robust connectivity in IoV environment, we use four metrics that have relationship with nodes connectivity in IoV, each parameter is defined below:

Node density (D): Node density or node degree ($\boldsymbol{D_{v_i}}$) of node v_i is defined by the number of links between node v_i and its neighbors with k distance, where it is calculated by the ratio between the number of links and the number of nodes in a k-neighborhood.

$$\boldsymbol{D_{v_i}} = \frac{|\boldsymbol{e=(a,b)\in E, a\in\{v, C(v_i)\}\ b\in C(v_i)}|}{\boldsymbol{dv_i}} \qquad \textbf{(1)}$$

Where, e represents a link between two nodes *a* and *b* at time *t*, *E* represents the set of links between nodes, $\boldsymbol{C(v_i)}$ represents the set of k-neighborhood of node v_i and dv_i is the degree of node v_i (the number of nodes in its k-neighborhood).

Node Mobility (M): Speed of vehicles is an important factor that indicates the stability of cluster to guarantee a stable connectivity between cluster head and cluster members. We assume that the vehicle that has closer speed to its neighbors is the vehicle that must have a high priority to be selected as cluster head. For that, we used the exponential-weighted average of speed over a period T, instead of the instant value.

$$\boldsymbol{S_{v_i}^{n} = (1-\alpha)S_{v_i}^{n-1} + \alpha\, V_{v_i}^{n}} \qquad \textbf{(2)}$$

where $S_{v_i}^{n}$ denote the exponential-weighted average speed for node v , $V_{v_i}^{n}$ denote the new value of velocity and $S_{v_i}^{n-1}$ the previous exponential-weighted average speed of node $\boldsymbol{v_i}$, $\boldsymbol{\alpha}$ is the smoothing factor $0 \leq \boldsymbol{\alpha} \leq \boldsymbol{1}$.

Each node needs to know how close its speed to the average speeds of its neighbors. Each node v calculates its effective average relative speed based on the average speeds of its neighbors. For node v_i we denote u_{v_i} the average speed of its neighbors. Then, $\boldsymbol{u_{v_i}}$ is calculated as

$$\boldsymbol{u_{v_i} = \frac{\sum_{j=1}^{N} S_{v_j}}{N}} \qquad \textbf{(3)}$$

Where $\boldsymbol{S_{v_j}}$ is the speed of each neighbor of node v_i, N is the number of the neighbors of node v_i. Then, the speed difference between node v_i and the average speed of its neighbors can be calculated as

$$\boldsymbol{M_{v_i} = \left| \frac{S_{v_i} - u_{s_{v_i}}}{S_{max_{v_i}} - u_{s_{v_i}}} \right|} \qquad \textbf{(4)}$$

where $\boldsymbol{S_{max_{v_i}}}$ denote the maximum speed of its neighbors.

Node Position (P): Node position is another factor that determines the stability of a cluster. The node with the closest distance to its neighbors should be given the high priority to be selected as a cluster head, because its probability to leave the cluster is small. Let $(x_i\ , y_i\ )$

denote the position coordinate of node v_i , (x_j ,y_j) the position coordinate of any neighbor v_j of node v_i . Then, the mean position of the neighbors of node v_i is $x_i^u = \frac{\sum_{j=1}^{N} x_j}{N}$, $y_i^u = \frac{\sum_{j=1}^{N} y_j}{N}$. Let (x_i^{max}, y_i^{max}) denote the node position that has the longest distance to the mean position of the neighbors of node v_i. Then, the normalized distance P_{v_i} of node v_i with the mean position of its neighbors is

$$\boldsymbol{P_{v_i}} = \frac{\sqrt{(x_i - x_i^u)^2 + (y_i - y_i^u)^2}}{\sqrt{(x_i^{max} - x_i^u)^2 + (y_i^{max} - y_i^u)^2}} \quad \textbf{(5)}$$

Node Delay (DE): The delay (($\boldsymbol{DE_{v_i}}$) of node v_i *is* defined as the average time taken by a node v_i to response to the requests of its neighbors. Here we distinguish four different delays that have relationship with the total transmission delay and can affect it which are:

Transmission Delay (Td): Which is the amount of time required to transmit all of the packet's bits into the link. In other words, it is simply time taken to put data bits on communication medium. This parameter depends on two factors which are length of packet (PL) and bandwidth of network (B).

$$\mathbf{Td} = \mathbf{PL}/\boldsymbol{B} \quad \textbf{(6)}$$

Queuing Delay (Qd): Queuing delay is the time a request waits in a queue until it can be executed. It depends on congestion. It is the time difference between when the packet arrived destination and when the packet data was processed or executed. It may be caused by mainly three reasons i.e. originating switches, intermediate switches or call receiver servicing switches.

$$\mathbf{Qd} = (\mathbf{N} - \mathbf{1})\ \mathbf{L}/(\mathbf{2} * \mathbf{R}) \quad \textbf{(7)}$$

where N is the number of packets, L is the size of packet and R is the bandwidth.

Propagation Delay (Pd): is defined as the time taken by the first bit to travel from the sender node to the receiver node of the link. In other words, it is simply the time required for bits to reach the destination from the start point. propagation delay depends on two factors which are distance (Ds) and transmission speed (Ts).

$$\mathbf{Pd = Ds/Ts} \tag{8}$$

Processing delay (Prd): is the time it takes node to process the packet header. Processing of packets helps in detecting bit-level errors that occur during transmission of a packet to the destination.

The Total Delay (TD) is calculated as :

$$\mathbf{TD = Td + Qd + Pd + Prd} \tag{9}$$

But in reality, Processing delay and Propagation delay are negligible where in high-speed, nodes are typically on the order of microseconds or less. So, the new formula of total delay will be calculated as:

$$\mathbf{TD = Td + Qd} \tag{10}$$

After the calculation of four metrics (D,M,P,DE), the weight value W_v of a node v is calculated as:

$$\boldsymbol{W_v = \omega_1 \frac{1}{D_v} + \omega_2 M_v + \omega_3 P_v + \omega_4 DE_v} \tag{11}$$

where $\boldsymbol{\omega_i}$ are the weighting factors for the corresponding metrics and $\sum \boldsymbol{\omega_i} = 1$.

4.4 Network Architecture

In this part, we introduce our proposed clustering algorithm based on several metrics that respond to service quality requirements and guarantee a stable and efficient network connectivity. IoV is considered as a high scale and complex network where it is hard for a vehicle to gather precise details on multi-hop nodes and decide which CH will choose among the multi-hop neighbors. A vehicle can treat the collected information and determine which vehicle among its neighbor nodes is the most stable. In literature, in most existing clustering protocols [102], [104],[93],[94] the CH is elected based on weight values at 1-hop distance and after the process will be extended to attend 2-hop or k-hop neighbors. The use of such method to form clusters may not guarantee a best selection of Cluster Heads. This election process is done locally (1-hop) which do not ensure that the rest of nodes at k-hop are excellent in term of metrics used. The main idea of this work is to collect nodes information at k-hop distance in a first step, clusters formation is based on weight values calculated based on position, density, mobility and delay that provide stability and quality of service. The node with the lowest weight value selects itself as CH, then it sends CH_elect message to inform its neighbors. Each node has to send a Join Request message in order to join a cluster. We consider that all nodes have a same synchronized timer and a geolocation system that allows to know the position of the vehicle. We also assume that the network deployment environment represents a highway environment consisting of (3) three lanes on each side and characterized by high density, absence of obstacles and high-speed vehicle traffic. We use three types of messages: information messages, control messages used for cluster formation and cluster maintenance (Hello, CH_elect, JOIN, ...) and alert messages. Table 4.2 summaries the types of messages used in our proposal.

Our network topology is organized in clusters. Each node can take one of the following states: Not-Decided, Cluster Head, Gateway, Core Member Node or Margin Member Node. Initially all nodes are in the Not-Decided state, as time progress each node tries to join a cluster by being in one of the four states Cluster Head, Gateway, Core Member Node or Margin Member Node.

- **Not-Decided (ND):** is the status taken by a node in its initial phase or when it gives up its role as cluster head.
- ***Cluster Head (CH):*** it is the coordinator of the group (cluster), its role is communicating information between nodes in the same cluster (intra-cluster communications), between different clusters (inter-cluster communications).
- ***Gateway:*** is a relay node, it is the common access point for two or more cluster heads, when a node belongs to the transmission ranges of two or more cluster heads.
- ***Core Member Node (CMN)*:** it is an ordinary node (not a gateway or CH). All CMN are connected to their CH with a 1-hop distance or more.
- ***Margin Member Node (MMN):*** it is a core member node with a k-hop distance to the cluster-head.

Messages types	Description
Hello message	Update network information
weight-val	share the calculated weight value
CH_elect( )	Share the elected CH
Join Request message	Join a cluster
Join Accept message	Acceptation of a node to be member of the cluster

Table 4.2 Messages types

(1) **Initial Phase:** This phase presents the first step when no clusters have been set up in the network. Initially, each node gets the initial Not-Decided (ND) status. All the network nodes exchange periodically (each Time Interval (TI)) HELLO messages with their neighbors in order to inform them of their presence and exchange with them the necessary information such as id, speed, x and y coordinates as shown in Figure 4.3. This information allows them to calculate the four parameters values. After receiving a Hello message that includes the node ID, current status, speed, position, each node updates all necessary information of its neighbors in its neighborhood table and recalculates its weight value (W) using the updated four parameters (density, mobility, position, delay). The receiver node adds new nodes to its neighborhood table and eliminates the nodes that exist in its neighborhood table but it does not receive any message from them.

Algorithm 1: Node_initial_status (v_i)

state (v_i) $\leftarrow$ ND

Wait for a Hello message

Receive(Hello)

Get position (Pv)

Get speed (Sv)

While (TI not expired) do

Calculate_ Density_value(vi)

Calculate_ Mobility_value(vi)

Calculate_ Position_value(vi)

Calculate_ Delay_value(v_i *)*

Calculate Weight value W(v_i)

Update neighborhood table

End

Send (weight-val) message to its k-neighbors

End.

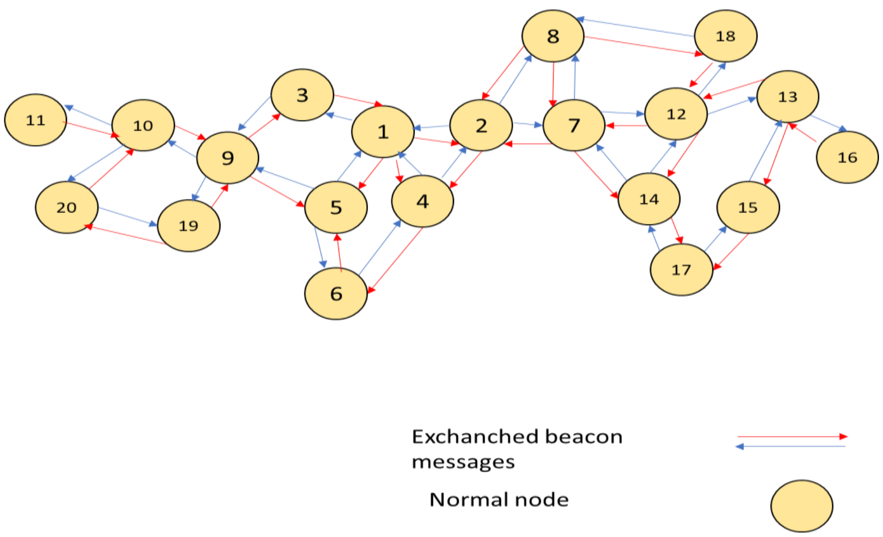


Fig.4.3 Beacon exchanging process

(2) **Cluster heads selection process.** Once all network nodes are detected and the Time Interval (TI) expires, each node calculates its weight value using equation (11) and shares it by broadcasting a weight-val message to its k-neighbors. After receiving (weight-val) message the cluster head election process is invoked. Each node compares its weight value (W) to the weight values of all its neighbor nodes. The node with the lowest weight value refers to itself as CH and sends a message CH_elect to its neighbors. If there is more than one node that has the same lowest (W) value, in this case the node that has the lowest mobility value is selected as cluster head. In the case where the problem is not solved the node with lowest DE is elected. In the case where there is more than one node that share the same DE value, the CH will be selected based on the lowest P value. If there are more than one node that has the same P value, we select the node that has the highest D value as CH. The node that has the lowest ID is selected as CH if the problem still not resolved. After selecting the Cluster Head, the elected CH shares its status to its k-neighbors by sending a CH_elect message to all network nodes as shown in Figure 4.4.

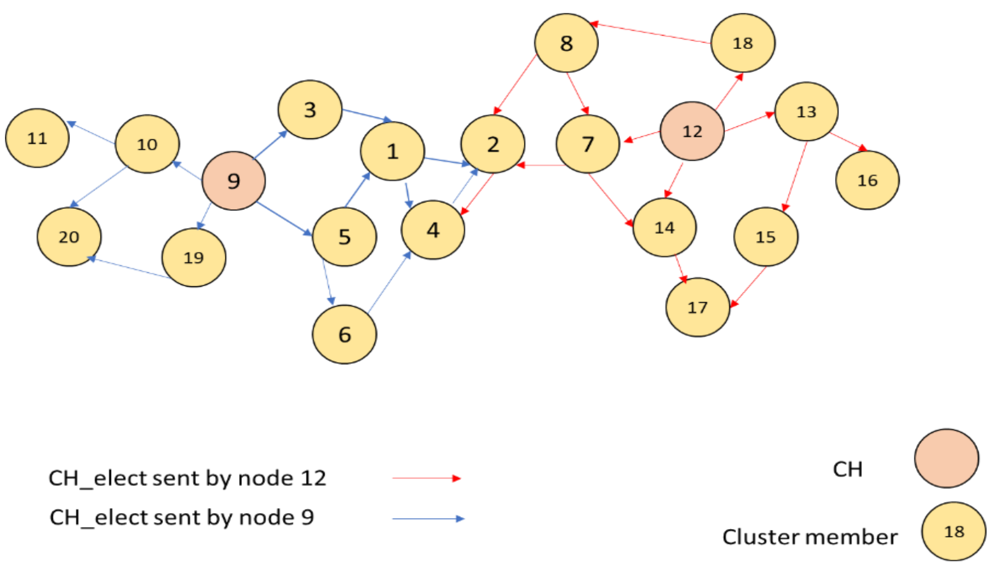


Fig.4.4 Cluster Head election process

Algorithm 2 *Cluster Heads Election (v_i)*

Receive(weight-val)

For *((All $v_j \in \mathcal{N}(v_i)$)) **And** ($v_i \neq v_j$)) **Do***

- *Extract and Store the information received from the weight-val messages in its neighbors table.*
- *Compares the received weights of all its K-hop neighbors with its own weight value.*

If *($W(v_i)$ is the maximum)* ***then***

7: ***If*** *($W(v_i) == W(v_j)$)* ***then***

If *($M_{v_i} > M_{v_j}$)* ***then***

v_j is elected as CH

Status (v_j) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_j*)*)*

Else

If *($M_{v_i} == M_{v_j}$)* ***then***

If *($DE_{v_i} > DE_{v_j}$)* ***then***

v_j is elected as CH

Status (v_j) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_j*)*)*

Else

If *($DE_{v_i} == DE_{v_j}$)* ***then***

If *($P_{v_i} > P_{v_j}$)* ***then***

v_j is elected as CH

Status (v_j) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_j*)*)*

Else

If *($P_{v_i} == P_{v_j}$)* ***then***

If *($D_{v_i} < D_{v_j}$)* ***then***

v_j is elected as CH

Status (v_j) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_j*)*)*

Else

If *($D_{v_i} == D_{v_j}$)* ***then***

If *($Id_{v_i} > Id_{v_j}$)* ***then***

v_j is elected as CH

Status (v_j) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_j*)*)*

End If

v_i is elected as CH

Status (v_i) = Cluster Head

*Broadcast_K-Neighbors (*CH_elect(*v_i*)*)*

Else

v_i waits reception of CH_elect messages sent by different elected CHs and choose the CH that has the lowest weight value among them, if there are more than one CH have the same value, go to 7 .

End If

End For

End For

(3) **Gateway election**. Each Cluster Head is responsible to select its gateway nodes. The nodes that have margin member states and they belong to different clusters are candidates to be gateway nodes. The selection of gateway node process is based on the mobility value received in Join Request message. The node that has the lowest mobility value M is selected as gateway node. If there are several nodes that have the same lowest mobility value M the gateway candidate with the lowest weight (W) value will be selected. If the problem is not solved the node that has the lowest ID value is elected. Then each CH forms its own cluster as illustrated in Figure 4.5.

```
Algorithm 3 Gateways Election Algorithm
For (each cluster) Do
   For ((All v_i ∈ C(CH v_i ))And (status( v_i )=margin member)) Do
        If (M_{v_i} is the Minimum) Then
            g_i = v_i
            Status ( v_i ) = Gateway.
            Send (Gateway-select) message to the selected node
            For (((All v_j ∈ C(CH v_i ))And ( Status ( v_j ) = margin member)And( v_i ≠ v_j)) Do
                If (M_{v_i} = M_{v_j} ) Then
                    CH v_i chooses the node with the lowest weight.
                    If (W_{v_i} = W_{v_j} ) Then
                    CH v_i chooses the node with the lowest ID.
                    End If
                EndIf
            End For
        End If
   End For
End For
```

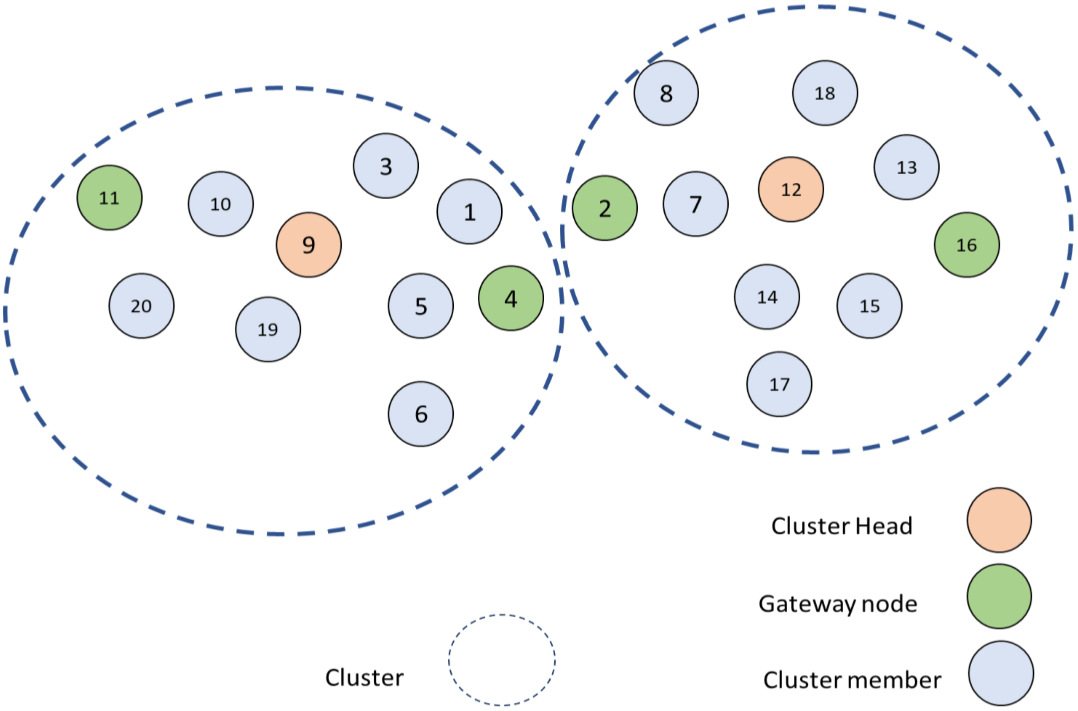


Fig.4.5 Clustering scheme

(4) **Cluster node join process.** At the reception of the CH_elect messages from different CHs, each node sends a Join Request message to the different Cluster Heads. The corresponding Cluster Head responds with an acceptance message, the node updates its status to either core member or margin member in order to assume its role as a member of the cluster and updates the ID of its CH. If the node receives several Accept messages from its neighbor CH, it chooses the CH with the lowest weight and it saves all the IDs of the CHs according to the order of their weight values in order to contact them after in case where the CH abandons its role.

Algorithm 4 *Node Join Cluster Algorithm*
For *(All moving $v_i \in V$)* ***And*** *(status (v_i) = not-decided)* ***Do***
- *v_i sends a request message to the corresponding Cluster Head to join the cluster and waits a* ***T*** *period for response.*
If *(no response arrives after time T)* ***Then***
- *v_i increases its transmission power to reach more CHs.*
- *v_i sends a request message to other Cluster Heads*
Else
If *(v_i receives one Join Accept message)* ***Then***
- *v_i joins the corresponding Cluster and updates its status to member node (Core or Margin) and all important information.*
Else
If *(v_i receives more than one Join Accept message)* ***Then***
If *(there is more than one CH with same lowest weight (W) value)* ***Then***
- v_i joins the CH with the lowest ID and updates its status to member node (Core or Margin) and all important information.
Else
- v_i joins the CH with the lowest weight value (W) and updates its status to member node (Core or Margin) and all important information.
End If
End If
EndIf
EndIf
End For

(5) Local **Cluster Maintenance Phase**. The clusters maintenance phase attempts to update and adapt to the topology changes that can be caused by different movements of nodes. In our proposed solution there are two distinct kinds of events when cluster maintenance algorithm is applied: the node movement and the weight value change in the cluster head. In each event, each node updates the information required.

- Node Movement

  A node in the network has two types of movement. The first one when it enters a range of a new cluster, in this case the new node sends Join Request message to the corresponding cluster head based on CH_elect messages received and waits for the response. The second type when a node gets out of the communication range of its CH, in this case, the concerned node modifies its state to not-decided and tries to find another cluster to join. In both cases, the status of the node is updated.

- Weight Value Change

  The nodes' movement might change the weight value of nodes by changing their own (mobility, density, position). In our proposed solution, the weight value of each node is verified periodically. In the case where the weight value of a member node becomes lower than the weight value of its cluster head then the re-election process of a new cluster head is applied locally. The precedent CH becomes a member node and the member node that has the lowest weight value becomes a CH.

Algorithm 5 *Local Cluster Maintenance Algorithm*

For *(All active* $v_i \in V$*)* ***Do***
 If *(status(* v_i *) = CH)* ***Then***
  - v_i *distributes an abandon role message to its cluster members.*
  - v_i *changes its status to not-decided and looks for a new cluster to join it.*
 For *(All* $v_j \in \mathcal{N}(v_i)$*))****Do***
  - v_j *changes its cluster information.*
  - v_j *calls the CH election algorithm to re-select a new CH.*
 End For
 Else
  If *(status (* v_i *) = core member* ***Or*** *status (* v_i *) = margin member* ***Or*** *status (* v_i *) = gateway)* ***Then***
   - v_i *sends (move- message)to its CH.*
   - v_i *changes its status to not-decided and looks for a new cluster to join it.*
  For *(All* $v_j \in \boldsymbol{C}(v_i)$*))****Do***
   If *(status(* v_j*) = Cluster Head)****Then***
    - *changes information about the moving node.*
    - *informing member nodes of the moving node by sending an information message to them.*
    If *(status (* v_i *) = gateways)* ***Then***
     - *CH node calls the gateway election Algorithm to re-elect a new gateway.*
    End If
   Else
    - *Updates information related to the moving node.*
   End If
  End For
End if
End if
End For

4.6 Clustering properties

In order for the proposed algorithm can work correctly, some clustering properties must be satisfied.

Definition 1 *Clarity property*: this property avoids the ambiguity in CH selection process and eliminates clusters overlapping problem, which means that each cluster has to have one and just one CH and each node has to join one and only one cluster.

Lemma 1 The Clarity property is satisfied.

Proof

Part 1: each cluster has one and just one CH

Based on Algorithm 1, v_i is selected as CH, if it meets to following conditions:

1. It has the minimum weight value among its neighbors.
   $Status(v_i)=CH \rightarrow \min(W(v_i))$.
2. It has the minimum mobility, if two or more nodes have the same weight value
   $W(v_k)= W(v_j)= \ldots\ldots\ldots =W(v_i)$, $Status(v_i)=CH \rightarrow \min(M_{v_i}, M_{v_k}, M_{v_j}, \ldots)$.
3. It has the minimum delay, if two or more nodes have the same weight value and same mobility.
   $W(v_k)= W(v_j)= \ldots\ldots\ldots =W(v_i)\&(M_{v_k} = M_{v_j}=\ldots\ldots\ldots= M_{v_i})$, $Status(v_i)=CH \rightarrow \min(DE_{v_i}, DE_{v_k}, DE_{v_j}, \ldots)$.
4. It has the minimum position, if two or more nodes have the same weight value, same mobility, and same delay.
   $W(v_k)= W(v_j)= \ldots\ldots\ldots =W(v_i)\&(M_{v_k} = M_{v_j}=\ldots\ldots\ldots= M_{v_i})\&(DE_{v_j} = DE_{v_k}=\ldots\ldots\ldots= DE_{v_i})$
   $Status(v_i)=CH \rightarrow \min(P_{v_k} = P_{v_j}=\ldots\ldots\ldots= P_{v_i})$.
5. It has the maximum density, if two or more nodes have the same weight value, the same mobility, the same delay, the same position.

$W(v_k) = W(v_j) = \ldots\ldots\ldots = W(v_i)$&($M_{v_k} = M_{v_j} = \ldots\ldots\ldots = M_{v_i}$)&($DE_{v_j} = DE_{v_k} = \ldots\ldots\ldots = DE_{v_i}$)& ($P_{v_k} = P_{v_j} = \ldots\ldots\ldots = P_{v_i}$), *Status* $(v_i) = CH \rightarrow \max(D_{v_k}, D_{v_j}, \ldots\ldots\ldots, D_{v_i})$.

6. It has the minimum Id, if two or more nodes have the same weight value, the same mobility, the same delay, the same position and the same density.
   $W(v_k) = W(v_j) = \ldots\ldots\ldots = W(v_i)$&($M_{v_k} = M_{v_j} = \ldots\ldots\ldots = M_{v_i}$)&($DE_{v_j} = DE_{v_k} = \ldots\ldots\ldots = DE_{v_i}$), ($P_{v_k} = P_{v_j} = \ldots\ldots\ldots = P_{v_i}$)&($D_{v_k} = D_{v_j} = \ldots\ldots\ldots = D_{v_i}$),
   $Status(v_i) = CH \rightarrow \min(Id_{v_k}, Id_{v_j}, \ldots\ldots, Id_{v_i})$.

This implies a unique choice of CH for each cluster and the first part of the property is verified.

Part 2: each node joins one and only one cluster

In this case we have two possibilities:

possibility 1: if node v_j knows already the CH, which means that v_j has a neighborhood relationship with the CH. In this case, node v_j will receive a CH_elect(v_i) message sent by the elected CH. According to algorithm 1 node v_j accepts the invitation to join of the CH that has the minimum weight value W. Otherwise, if there are more than one CH that have the same W value, v_j applies the same instructions used in algorithm 1 to elect a CH until it arrives to a one solution(node ID).

possibility 2: if v_j arrives as a new node and wants to join a new cluster, in this case v_j applies algorithm 3. According to algorithm 3, if v_j gets just one acceptation during a defined period it joins directly the cluster . Otherwise, it joins the cluster that is headed by CH that has the lowest W value.

This implies that each node can belong to only one cluster and the second part of the property is verified.

Definition 2 Dominance property: In a cluster, every member node can reach the cluster head.

Lemma 2 The dominance property is satisfied.

Proof

For each cluster member, it exists two methods to reach CH depending on node type (*CMN*, *MMN*, Gateway).

Method 1: if it has a direct link (one-hop) to a CH, this method is used by CMN with K=1:

Thus, the node v_j can reach CH directly.

Method 2: if it has indirect link (K-hops) to a CH, this method is used by *MMN* and Gateway with K≥2.

v_j neighborhood table records and updates all necessary information using received CH-elect message.

Thus, the node v_j can reach its CH in k-hops via its neighborhood table.

This implies that each node in cluster can reach its CH, the property is verified.

Definition 3 Independence property: No two cluster heads can be neighbors.

Lemma 3 The independence property is satisfied.

Proof

We assume that we have two neighboring cluster heads, CH_1 and CH_2 of clusters C1and C2, respectively. The following condition is satisfied:

Since every node can belong to only one cluster (Lemma 1), the conditions above present a contradiction.

The independence property ensures an efficient clustering method with a few clusters.

Lemma 4 Cluster formation algorithm terminates.

Proof

for each phase of clusters formation we used period intervals namely: Beacon interval (BI), Collection duration (TI) in order to terminate each phase and move to another.

4.7 Performance Evaluation

In this section, we evaluate the proposed work performances using network simulator NS-3 [85], SUMO [28]. To simulate vehicles mobility, the realistic scenarios are generated for IoV using MOVE [29]. The simulation is performed on a machine with Intel i7 processor and 8 GB of RAM. The scenarios are simulated on a one-directional highway of 10 km length with three lanes. For vehicles physical and MAC layers are configured according to the 802.11p standard, for other nodes we used 802.11 standard. The speed of vehicles varies between (40 km/h – 120 km/h). Moreover, the transmission range of vehicles is fixed to 300 m. The simulation period in this work is 300 s. The different simulation parameters are presented in Table 3. We compare the results of our proposed work to QoS-cluster [104] and MADCCA [89].

Parameter	**Value**
Simulation Time	300 s
speed (velocity)	40 km/h – 120 km/h
Scenario	Highway
Highway length	10 km
Packets size	512 bits
Max hop	3
Beacon interval (BI)	1 s
Collection duration (TI)	10 s

Table.4.3 simulation parameters.

The comparison is based on various metrics:

• **Average Rate of CH Change:** The total number of status changes from CH to another status per second. Low Average Rate of CH Change determines the level of cluster's stability.

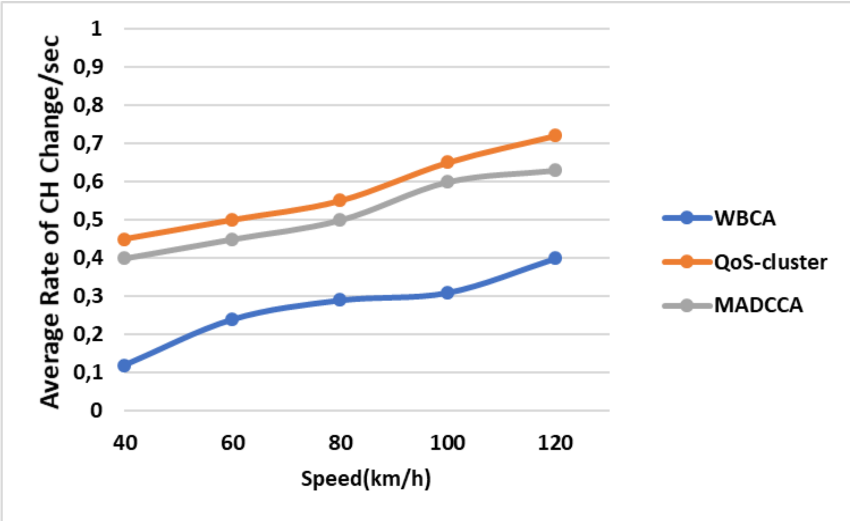


Fig.4.6 Average rate of CH change Vs Speed

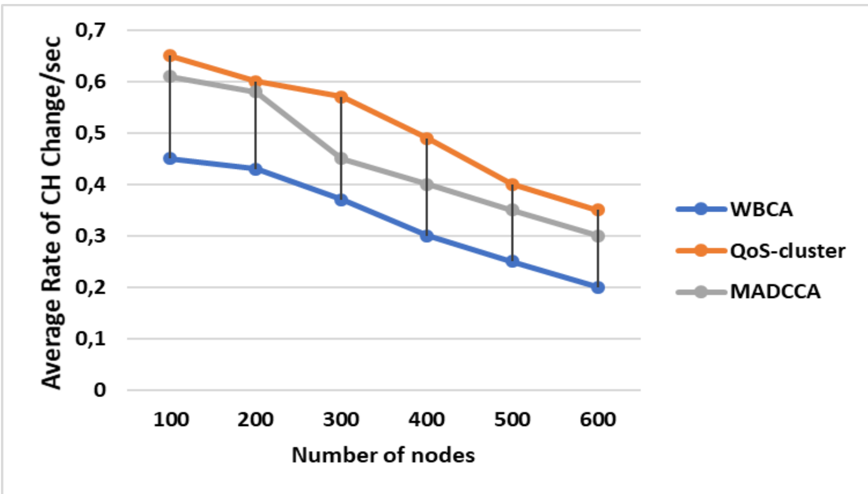


Fig.4.7 Average rate of CH change Vs number of nodes

Figure 4.6 shows the average rate of CH change of WBCA versus QoS-cluster and MADCCA under various speeds. Figure 4.6 demonstrates that Average Rate of CH Change when using QoS-cluster and MADCCA is higher than when WBCA is used. WBCA outperforms QoS-cluster and MADCCA schemes by 61% and 55% respectively. This amelioration is due to the effective CH election process that uses mobility and position metrics, which ensures stable connections between CHs and their CMNs as long as possible.

Figure 4.7 shows the average rate of CH change of WBCA versus QoS-cluster and MADCCA under different number of nodes. Figure 4.7 demonstrates that the average rate of CH change when using WBCA is lower than when QoS-cluster and MADCCA are used. WBCA performs better in dense network, the high number of nodes in network gives more choices to WBCA in term of stable nodes that have lowest weight values (W) to be selected as stable CHs. Mobility metric used in second round of the CH selection process (when there are several nodes with same W value) allows CHs to keep stable connections with their CMNs as long as possible and decreases the average rate of CH change by 37% and 29% when compared to QoS-cluster and MADCCA, respectively.

• **Average Cluster Head Lifetime:** is the ratio between the sum of time duration from the time a vehicle becomes a CH and the moment it charges to another status. A longer Cluster Head Lifetime leads to more robust communication with lower overhead.

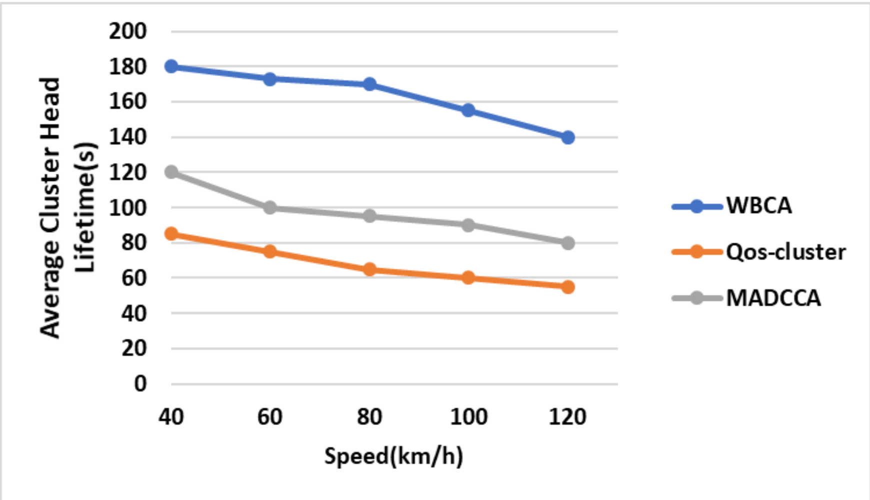


Fig.4.8 Average cluster head lifetime Vs speed.

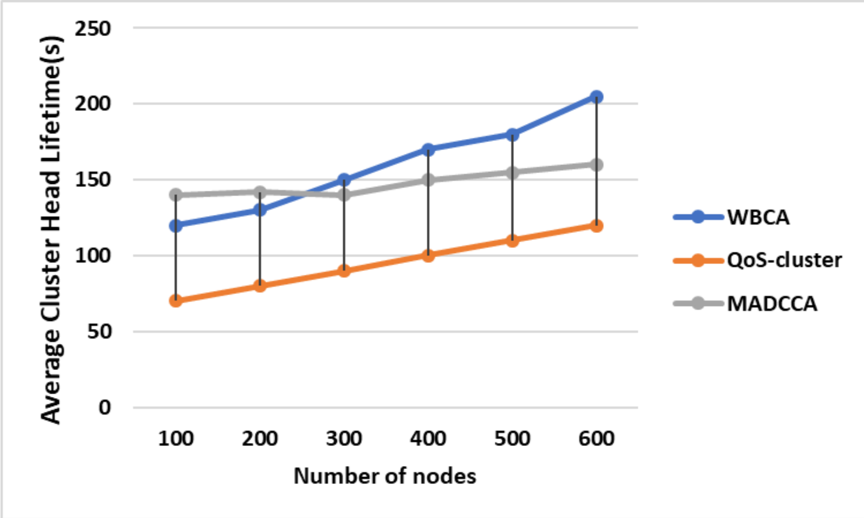


Fig.4.9 Average cluster head lifetime Vs number of nodes

Figure 4.8 presents Average Cluster Head Lifetime of the proposed WBCA protocol versus QoS-cluster and MADCCA approaches under different speeds. As shown in Figure 4.8 WBCA outperforms both QoS-cluster and MADCCA in term of Average Cluster Head Lifetime. We observe that when a vehicle's speed increases, the Average Cluster Head Lifetime of the three simulated protocols decreases relatively. The high dynamism of vehicles makes it difficult for the cluster's heads to keep stable connections with their CMNs. However, WBCA shows a significant improvement in lifetime duration by 56% and 38% by comparison to QoS-cluster and MADCCA approaches, respectively. The weight value (W) used to elect CHs in our proposed work is calculated using mobility metric that is based on average speed between CHs and their CMNs. Therefore, this metric selects CHs that have speeds close to their CMNs speeds which in turn augments the lifetime of cluster connectivity. So, it results in more stable clusters, while other two approaches QoS-cluster and MADCCA generate less stable clusters.

Figure 4.9 illustrates Average Cluster Head Lifetime of the proposed WBCA protocol versus QoS-cluster and MADCCA approaches under different speeds. As depicted in Figure 4.9 from 100 nodes to around 250 nodes WBCA has lower Average Cluster Head Lifetime compared to MADCCA, this is may be due to the limited choices in nodes to be selected as CHs. However, when the number of nodes becomes more that 250 nodes WBCA performs very well by 45% and 4% by comparison to other simulated approaches QoS-cluster and MADCCA. This mean that our approach is suitable large scale IoV.

• **Cluster Number:** The number of clusters formed during the simulation period. In general, fewer clusters could indicate the efficiency of the clustering algorithm.

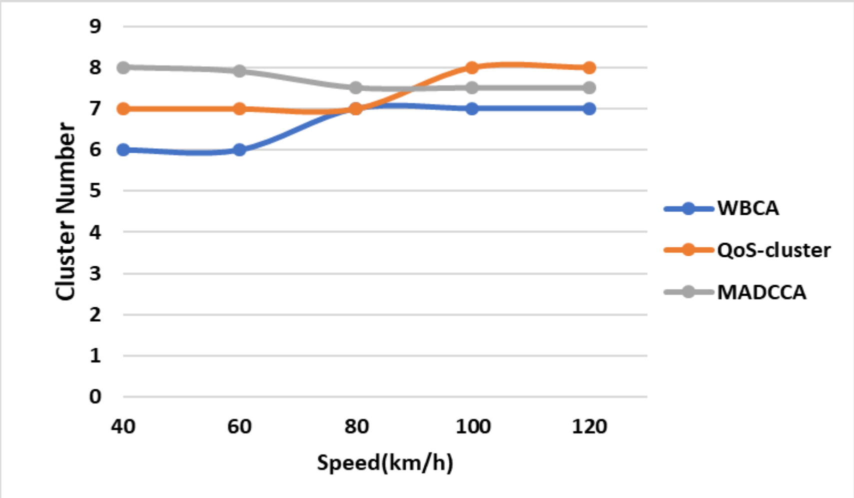


Fig.4.10 Number of clusters Vs Speed

Figure 4.10 illustrates the number of clusters of the WCBA approach versus QoS-cluster and MADCCA approaches under different speeds. The proposed approach forms fewer clusters compared to both QoS-cluster and MADCCA, where it reduces number of clusters by 13% and 32%, respectively. This is due to the effective K-hops clustering process that is based on average K-hops metrics used in calculating the weight value(W) compared to 1- hop clustering protocols.

Figure 4.11 shows the number of clusters of the WCBA approach versus QoS-cluster and MADCCA approaches for different number of nodes. As shown in Figure 4.11 the number of clusters increases each time the number of nodes increases as expected. The high number of nodes results in the network being divided into higher number of clusters. Moreover, the WCBA protocol performs better and creates few numbers of clusters compared to other protocols QoS-cluster and MADCCA that show less performance ratio of 29 % and 32%, respectively. This is because of the use of the density metric when calculating the weight value (W). So, the nodes that have higher number of neighbors are most probable to be chosen as CHs.

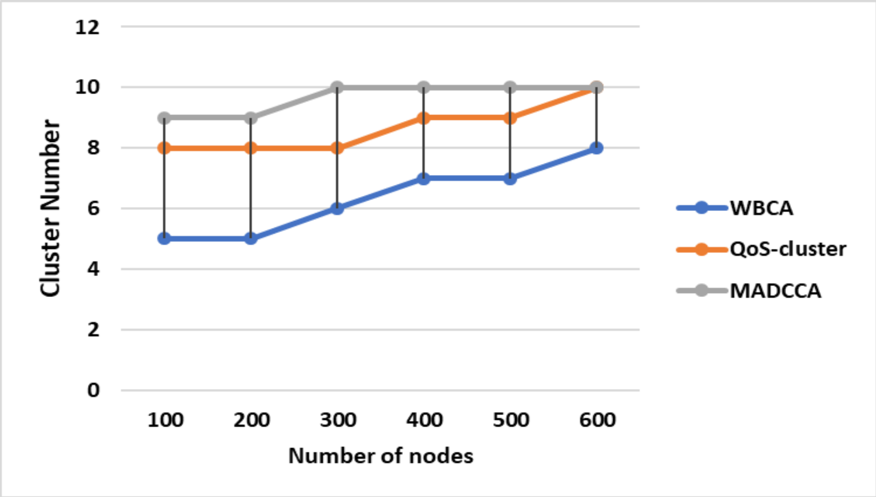


Fig.4.11 Number of clusters Vs number of nodes

• **Clustering Overhead:** The total number of control messages received by each vehicle in the network during the cluster's formation phase.

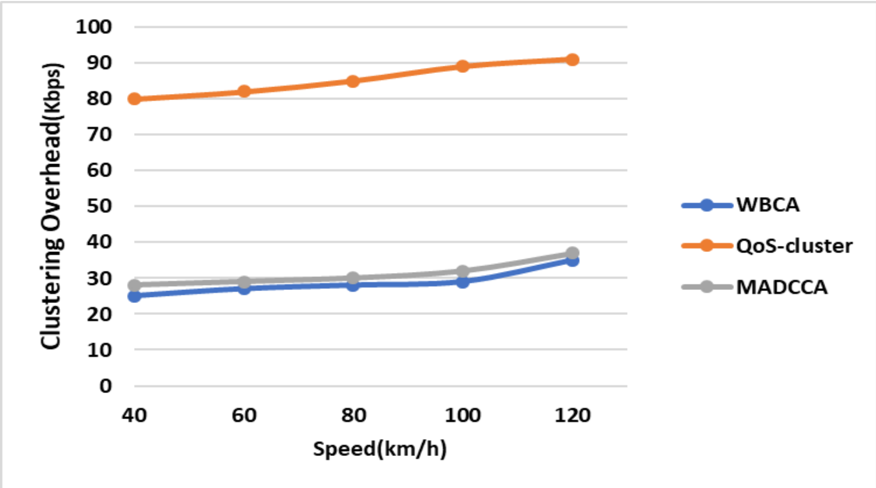


Fig.4.12 Clustering Overhead Vs speed.

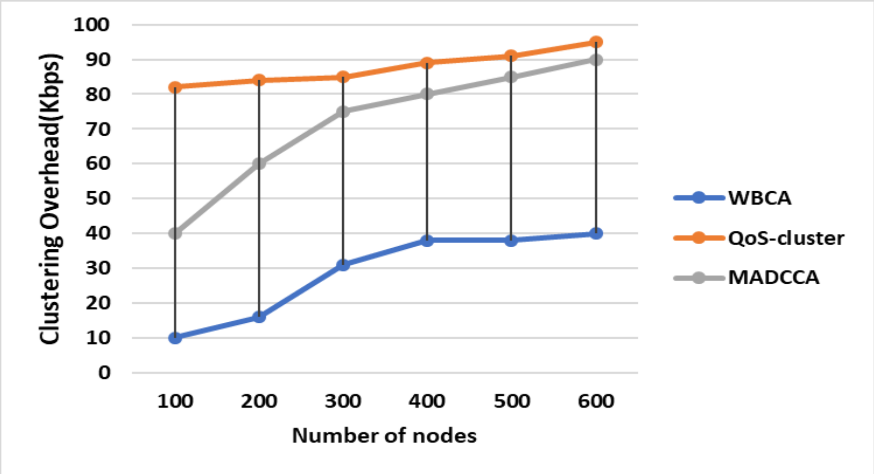


Fig.4.13 Clustering Overhead Vs number of nodes.

Figure 4.12 presents the clustering overhead of WBCA, QoS-cluster and MADCCA under different speed values. The clustering overhead increases slowly as the nodes' speed increases. This is expected because nodes with high mobility exchange more messages to maintain the clusters and to keep stable connection between the CHs and their CNM. The clustering overhead in our proposed work is lowest compared with QoS-cluster and MADCCA, where the network overhead recorded by WBCA is reduced by 65% compared to QoS-cluster and by 9%. Compared to MADCCA. This is due to the high cluster stability proved by our protocol in term of Average CH lifetime and Average Rate of CH Change showed before.

Figure 4.13 shows the clustering overhead of WCBA approach versus QoS-cluster and MADCCA approaches under different number of nodes. The clustering overhead increases as the number of nodes increase for the three simulated protocols as expected. However, WBCA outperforms QoS-cluster and MADCCA schemes by 73% and 66% respectively. This improvement is the result of combining metrics (mobility, position, density, delay) in our protocol when calculating weight values. This ensures robust connectivity and minimizes network overhead.

• **Message Delivery Ratio:** The average number of messages that have been successfully received by the destination divided by the average number of messages sent by the source.

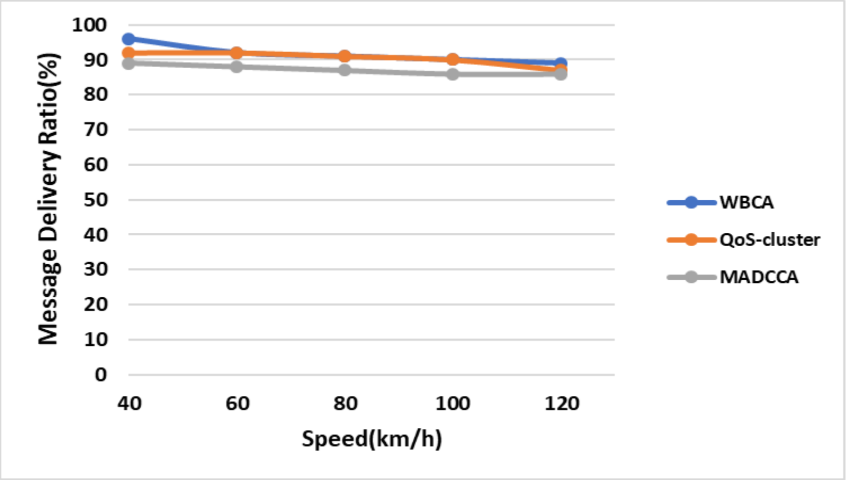


Fig.4.14 Message Delivery Ratio Vs speed

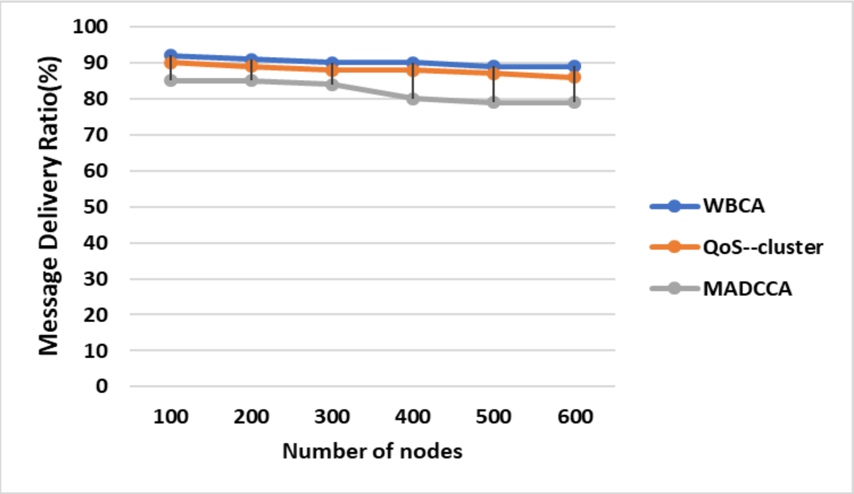


Fig.4.15 Message Delivery Ratio Vs number of nodes

Figure 4.14 illustrates the message delivery ratio of WBCA, QoS-cluster and MADCCA under different speed values. We observe that message delivery ratio decreases slowly with the increase in speed. This is due to the high mobility of nodes that causes frequent links disconnection and therefore less chances to deliver the message successfully. In general, there is a very small difference in the message deliver between the three protocols. However, WBCA still records the high performance among them with 97% of total messages delivered compared to QoS-cluster and MADCCA that recode 90% and 89% respectively.

Figure 4.15 depicts the message delivery ratio of WBCA, QoS-cluster and MADCCA under different numbers of nodes. As expected, the message delivery ratio decreases as the number of nodes increases. Our proposed scheme WBCA shows a slightly higher message delivery ratio for all the scenarios considered. The high number of exchanged messages in dense networks makes nodes queues overloaded, which leads to the loss of new received messages. The results show that our scheme deals very good with this problem and increases the message delivery ratio by 3% and 11% compared to QoS-cluster and MADCCA, respectively.

- **Delay**: it is defined as the average time taken by message to be transmitted from a source to a destination.

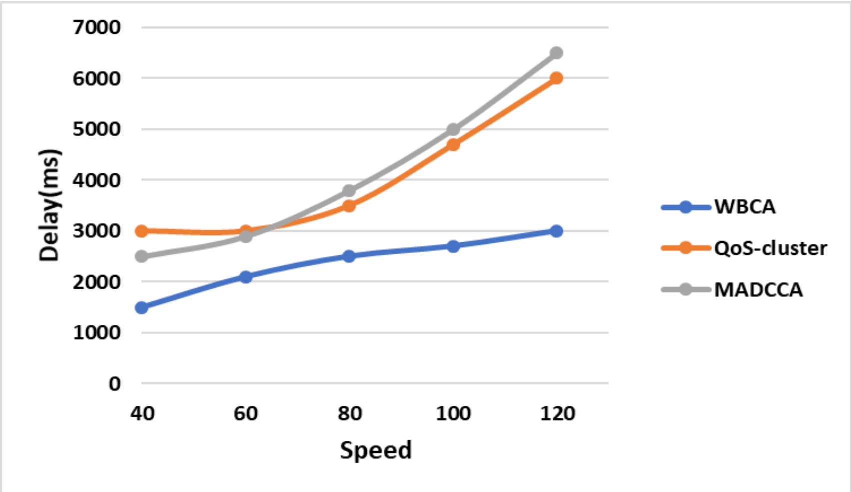


Fig.4.15 Delay Vs speed.

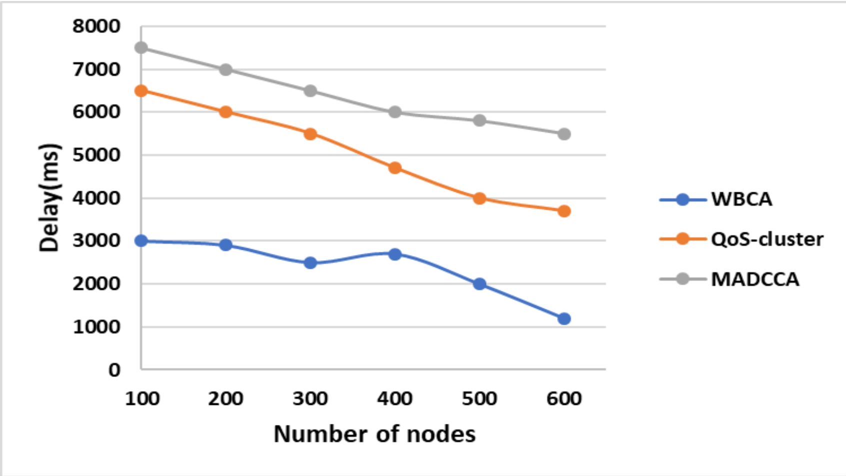


Fig.4.16 Delay Vs number of nodes.

Figure 4.16 shows the result of delay of WBCA, QoS-cluster and MADCCA under different speed values. According to Figure18 WBCA gave consistently lowest delay each time the speed value increased comparing to QoS-cluster and MADCCA protocols. The high mobility of vehicles makes it hard for network members to keep stable connections with their neighbors which in turn drives vehicles to reestablish new connection. However, WBCA generates more stable clusters, while other two protocols QoS-cluster and MADCCA give moderate performances. Although the high augmentation in speed values, WBCA reduces the delay by 50% and 47 % compared to QoS-cluster and MADCCA, respectively. WBCA uses the weight value (W) to elect CHs that helps CHs to form cluster with homogeneous parameters like speed in which it ensures a long connection lifetime.

Figure 4.17 presents the delay of WCBA approach versus QoS-cluster and MADCCA approaches under different number of nodes. As depicted in Figure 4.17, the delay decreases continuously each time the number of nodes augments, this is logical because the high number of nodes provides more route options to network members, thus it augments the chance to select the stable route among all available paths. The delay recorded by our proposed work is the lowest compared to other simulated protocols, this is due to the high stability of clusters formed by our proposed algorithm that showed a good minimization of 65% and 72% compared to QoS-cluster and MADCCA, respectively.

4.8 Conclusion

In this work, we proposed a new weight-based clustering algorithm (WBCA). The Cluster Heads (CHs) are selected based on calculated weight value (W), which is based on four metrics: mobility, density, position and delay. The calculated weight values can determine the vehicles that have more homogeneous environments with their neighbor nodes. These vehicles are selected as CHs and the rest of nodes in their communication range will be cluster node members. Our proposed approach shows significant improvement in term of connection stability, network overhead, messages delivery ratio by comparison to QoS-cluster [104] and MADCCA [89]. The proposed scheme WBCA reduced the average rate of CH change by 76% compared to QoS-cluster and MADCCA. For the average cluster head lifetime our proposal records the longest duration (180 s under different speed values and 200 s under different numbers of nodes) among all the simulated protocols. WBCA minimizes the number of clusters and network overhead by 44% and 88% respectively compared to the values recorded by QoS-cluster and MADCCA. Moreover, our proposed algorithm increases the message delivery ratio by 11% compared to the other simulated protocol. WBCA shows fast messages delivery by recording the shortest delay of 1000 ms while MADCCA's delay is 5500 ms which indicate that our scheme reduced the delay by 82%. The results of simulation demonstrate the resistance of our algorithm under different speeds and numbers of nodes, WBCA reaches our predefined achievements by 90% for all metrics used.

As future perspectives to improve our solution in the short and long term, we expect:

– Integrating a reliable mechanism that take into account highways with two directions.

– Analyzing the proposed approach with analytical manner.

– Adding more parameters to support other applications that required other measurement (bandwidth) like multimedia applications.

- Testing the performance of the proposed work in very dense network where the number of nodes is up to 2000 nodes.

Chapter 5

Unstable Connectivity Aware Protocol for Dependable Messages Delivery for Future Internet of Vehicles

5.1 Introduction

Internet of vehicles (IoV) technology is an extended and promising emergent field of well-known Vehicular Ad hoc NETwork (VANET) paradigm. This extension is the expected consequence of the transition of the traditional Internet network to the Internet of Things (IoT). IoV is dedicated to constitute a platform enabling primarily tasks managing vehicles security in roads and secondly offering passengers to get access to objects located via IoT network. IoV network is essentially formed by vehicles as nodes [10]. In the near future, IoV enabling the Intelligent Transportation System paradigm (ITS) will undergo a significant change when integrating autonomous vehicles as intelligent and powerfully platform systems. All this would generate a huge traffic messages that should be rigorously taken into account in order to ensure dependable message delivery in real time manner. Therefore, Timely useful information acquisition in an unstable connectivity environment like IoV is of paramount importance when making decision is related to critical events. For instance, saving lives in accident occurrences greatly depend on the urgent messages sent out and received by rescue services [13]. Furthermore, preventing accidents by alerting obstacles impeding road circulation requires stable link communications conveying surely emergency messages to their appropriate destinations. Therefore, high velocity of vehicles affects negatively node communication links leading to frequent link disconnections. Packets routing process is one of the most challenging issues in networking field. Several methods have been used in order to improve the QoS in routing protocols. The authors in [116] proposed A Cluster-Based Directional Routing Protocol (CBDRP) in VANET, the network is divided into various clusters based on direction parameter, where vehicles that share the same direction are gathered in one group, and each group elects its Cluster Head (CH). During data transmission, the source node sends packet to the CH of its own cluster, and the CH forwards the packet to the CH of the destination cluster. Finally, the destination CH sends out the data packet to the destination node. The algorithm selects the best path based on the transmission direction vector of data packets and speed vector. However, the proposed protocol did not consider any factor of quality of service in term of data transmission like bandwidth or delay which confirms that it is not adaptive with multimedia applications. The work presented in [117] proposes a heuristic clustering algorithm based on Road Side Unit RSU) for IoV. The authors of this proposal suggest to centralize the clustering algorithm at the distributed RSUs and give them the responsibility of performing the cluster formation phase using graph theory concepts (node degree and adjacency matrix). The proposed algorithm does not improve the quality of links between CHs and their cluster members and does not show any factor used to find the best route to a CH. In [118] authors suggest to use Bus Node (BN) routes as a reference to collect the moving tracks of nodes (buses, vehicles...) and select the suitable CHs. These tracks are used in order to calculate the contact time between a node and a BN based on time of entering to BN zone radius (meet time) and time of departure of BN. The contact time represents spatial and time dependence within the region and it used to increase cluster stability. The authors have proposed a new idea by using BN routes and they assume that cluster stability depends on contact time calculated. However, the cluster head election process is based only on meet time and departure time and no other parameters are used. These two parameters are not enough to guarantee a stable clustering schema especially in vehicles network. The authors in [119] proposed an optimization scheme based on Particle Swarm Optimization (PSO) algorithm to set the transmission parameters according to vehicular network conditions such as: concurrent transmission collisions, hidden terminals and so on. The proposed work gives a solution to neighbor vehicles where they have a direct communication route and does not take into account the case when two vehicles are not in the same communication area. The protocol cited in [120] “A Street-Centric QoS-OLSR protocol” modifies the classical Optimized Link State Routing (OLSR) protocol to support the quality of service attribute. The authors use two approaches namely: link centric and street centric to select Multi Point Relays (MPRs) in the network. Link centric approach is defined by the available bandwidth, and street centric approach is defined by the weight of node and the percentage of its neighbors in the same street. The problem of this protocol is that the authors passed over the most important factor of network dysconnectivity such as nodes velocity to select the MPRs which will lead to the frequent link disconnections. Dividing the network into clusters or zones is one of the methods used to make network more stable and more manageable.

Based on the weak points cited above, the main challenges we face are given as follows:

1. No algorithm is proposed in literature to find the best routes between CHs and their cluster members or between the members of a cluster.

2. The methods of QoS estimation are not efficient and not adaptive to comply with high traffic load. The high exchange of periodic messages may cause channel congestions and increases the network overhead.

3. The route selection implemented by means of poor QoS capacity, as we cited above like in [116], [117], [118], [119] uses insufficient parameters to select the attended best route. The latter has to significantly improve the network routing service especially in an unstable environment like in the targeted IoV network.

4. The proposed solution is not efficient in term of long distance as explained above.

The main purpose of this work is to find and select the best routes between the Cluster Heads, between CHs and cluster members, and between the members of a cluster. To deal with the weak points cited above and in order to minimize the network overhead, we propose a new communication protocol named: Routing Protocol based Quality of Service and Links Stability (RPQLS). The proposal is specifically adapted to IoV architecture with hierarchical communication management enabling smart connectivity. Therefore, the network is organized in clusters. A cluster includes a set of nodes (vehicles) as cluster members and each cluster is managed by a Cluster Head (CH) elected by its peers [70],[101],[106],[121]. The First Hierarchical Level (FHL) concerns the inter-cluster head communications and the Second Hierarchical Level (SHL) is dedicated to the inter cluster member communications. FHL uses Fuzzy Logic method through two fuzzy systems. One system combines between signal strength and bandwidth and another between velocity and delay. SHL is based on links estimation lifetime which we consider as a good indicator of links stability.

The rest of chapter is organized as follows: Section 2 describes our proposal with its two levels modeling. Section 3 deals with carried out simulations to evaluate performance of the proposal. The final section concludes this work.

5.2 Proposed framework

Cluster-based routing protocols are showed to be more advantageous than flat routing protocols since they guarantee lower overhead, higher scalability and throughput, and better usage of the system capacity because of better performance in MAC layer context [122]. At the network layer, clustering reduces the size of routing table and decreases transmission overhead resulting from updating routing tables following frequent topological changes comparing to proactive protocols [70]. Although each node stores only a fraction of the total network routing information, clustering is able to achieve topology information by aggregating current nodes information. Consequently, clustering may be considered to create more scalable and stable communication schemes [123]. Through IoV architecture, each vehicle can be connected with: an existing infrastructure, a sensor, another vehicle, a personnel device, etc. The different connection types in IoV let the network to be very interactive and scalable and need a stable structure to manage it. In our proposed framework, nodes are organized into clusters. Each cluster is controlled by a Cluster Head (CH) in charge of: offering services to its cluster members, gathering information from network (mobile servers), sharing information with others servers and so on. Cluster members can also exchange route information between them. In this proposal, we are interested to ensure a robust connection and high quality of service for network users by finding stable routes between cluster members and between clusters. So, we suppose that the clustering is already done by any clustering algorithm adaptive with IoV environment [118],[106],[121],[124]. To form the clusters on the road we used the algorithm introduced in [97] where vehicles and personnel devices that share the same moving direction are divided into many clusters; each vehicle and every personnel device (smart phone, tablet, etc) of passengers is considered as a node. Each ordinary node can communicate with its Cluster Head, its neighbors in the same cluster and with any close infrastructure with radio communication. The responsibility of cluster head is assigned only to vehicles in order to avoid the constraint of energy lack being caused by battery depletion. Figure 5.1 shows the architecture of our framework called Routing Protocol based on Quality of service and Link Stability (RPQLS).

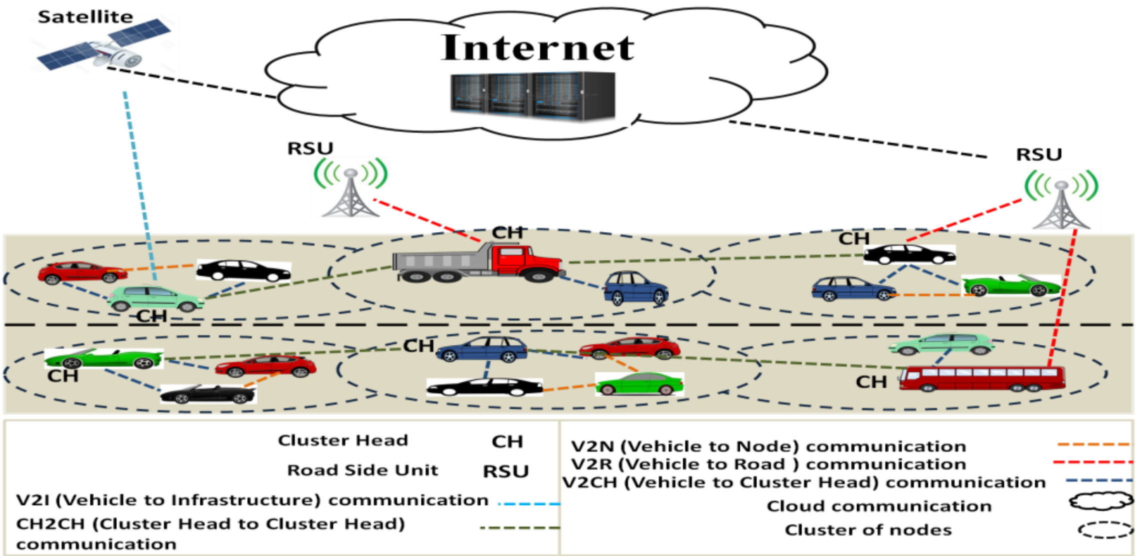


Fig.5.1. Clustering based RPQLS Architecture

5.2.1 First Routing Level (inter-clusters)

This level aims to obtain high cluster stability for guaranteeing a long duration of contact and short response time between the cluster head source and destination. In this level, we suggest to combine between four parameters to ensure more quality of service in Internet of Vehicles communication. The first one consists in Signal strength used in the transmission power when broadcasting messages; it is expressed by dBm. This parameter indicates if the source and destination nodes are close to one another or not. The second metric is the Bandwidth defined as the amount of data that can be transmitted in a fixed amount of time and measured by (b/s); a high value of Bandwidth leads to fast data transmission. The third parameter represents the Delay which indicates the time taken by a packet from the source node to the destination. It is measured in second, and a low delay means a low response time. The last one is the node velocity (Speed) measured in km/h; node velocity is the main factor that causes frequent link disconnection, especially in IoV environment. To reach the attended quality of service, we need to find the route having maximum Signal strength and Bandwidth and minimum Speed and Delay. Excellent Signal strength and low speed mean a long connectivity; large Bandwidth and low Delay imply fast transmission. Nodes in IoV lack of intelligence, they are unable to act according to their own initiative to decide if the route is best or not. Therefore, they need to be assisted by an intelligent system to decide in their place. Such a system may be built from Fuzzy Logic approach.

Fuzzy logic is an extension of the classical logic that allows modeling of data imperfections (Incomplete or ambiguous data) and to a certain extent, approaches the flexibility of human reasoning. Thus, in the present concept, we use Fuzzy logic in order to give vehicular nodes the ability to decide and choose the best route based on received information. Fuzzy Logic has been advantageously used in many research and development fields, particularly in wireless networks like VANETs and IoV which concern us [125-129].

In our proposal, the important parameters used are divided into two categories: the first one contains parameters that need maximization and the second one includes parameters that need minimization. We utilize two fuzzy systems using Fuzzy Logic method: the first Fuzzy System is used to combine between the Signal strength and Bandwidth and the second Fuzzy System is used to bring together nodes Velocity and Delay. Before starting details of each Fuzzy System, we begin by defining Fuzzy Logic method.

5.2.1.1 Fuzzy Logic Approach

The concept of Fuzzy Logic (FL) [130-132] is a control system methodology implemented in systems in order to solve various problems related to an environment of imperfect information without any measurements and any computations. It includes different systems starting from small, simple, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. Our problem in this proposal and especially in this level is to find best servers in IoV according to some suitable criteria. The main reason motivating the use of Fuzzy Logic in our protocol is the large advantages provided by FL along cited previously such as: the ease to model human reasoning, its simplicity and flexibility of calculation, it covers a wider range of operating condition and so on. It is hard, in our context, to establish an accurate analytical model because of unavailable precise numerical values for certain metrics. For example, values related to: Signal strength, Bandwidth, node density and mainly connectivity.

5.2.1.2 First Fuzzy System

As mentioned above, to have more link quality, we need to select links that have more Signal strength and Bandwidth. The first Fuzzy System describes the three phases of Fuzzy Logic applied on both metrics namely Signal strength and Bandwidth.

Fuzzification

Firstly, a set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as Fuzzification. Signal strength and Bandwidth membership functions and output membership function are shown in Figures 5.2, 5.3, and 5.4, respectively. Membership functions can be classified into three variables as Low, Medium and High. To facilitate the calculation of membership degrees, we have transformed the real values (x-axis) of input variables to [0, 1]. The membership degrees are calculated through Table 5.1**.** Trapezoidal membership function is used to define each input membership function. We have chosen Trapezoidal function for its greater precision in the calculation. The fuzzy output value determines the probability of link QoS. In Figure 5.4, five output functions have been calculated as fuzzy output.

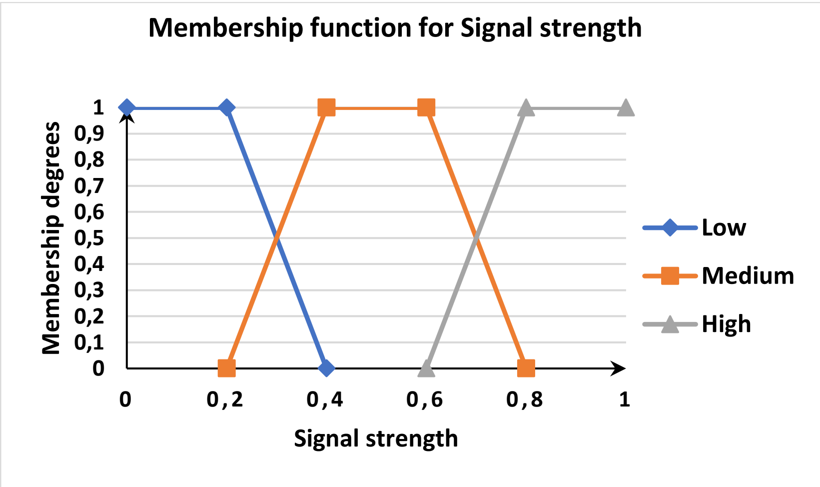


Fig.5.2 Membership function for Signal strength

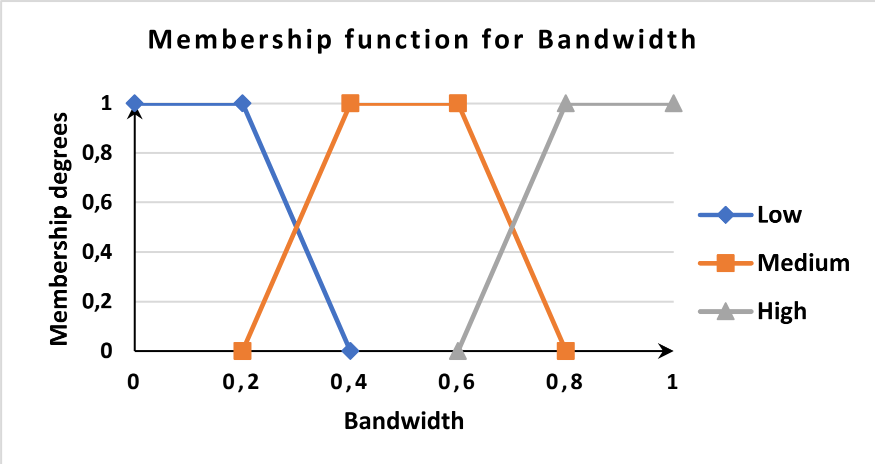


Fig.5.3 Membership function for Bandwidth

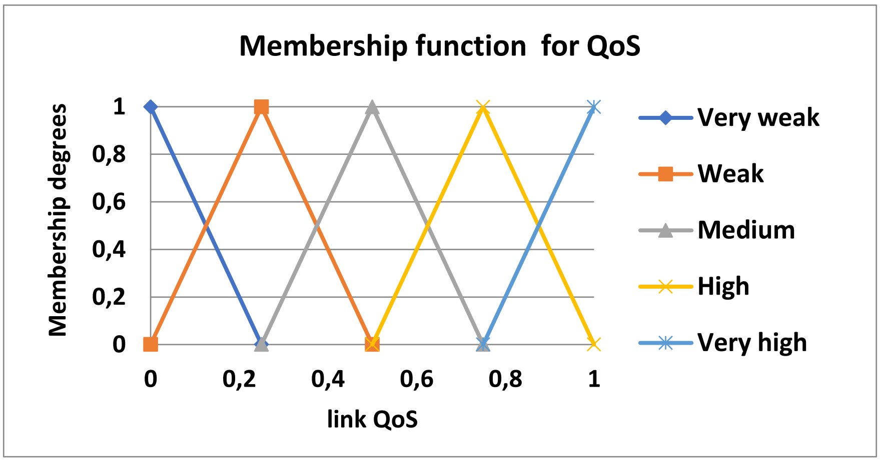


Fig.5.4 Membership function for link QoS of First Fuzzy System

Interval	Membership degrees		
	Low	Medium	High
$0 \leq x \geq 0.2$	1	0	0
$0.2 < x > 0.4$	$u = -\frac{x-0.4}{0.2}$	$u = \frac{x-0.2}{0.2}$	0
$0.4 \leq x \geq 0.6$	0	1	0
$0.6 < x > 0.8$	0	$u = -\frac{x-0.8}{0.2}$	$u = \frac{x-0.6}{0.2}$
$0.8 \leq x \geq 1$	0	0	1

Table.5.1 Membership degrees Calculation Method

Fuzzy rules for first Fuzzy System

In fuzzy logic, the fuzzy rules are written based on IF-THEN rules. Each rule has two parts: part antecedent premise (condition), expressed by IF…, substantial part (conclusion) expressed by THEN. These rules are used for mapping fuzzy values and pre-defined rules, and combinations of rules are used in order to calculate link fuzzy values. These rules as shown in Table 5.2 are used in each node in order to calculate the link state between the sender and the receiver of message.

Rule number	Signal strength	Bandwidth	Quality of service
1	Low	Low	Very weak
2	Low	Medium	Weak
3	Low	High	Medium
4	Medium	Low	Weak
5	Medium	Medium	Medium
6	Medium	High	High
7	High	Low	Medium
8	High	Medium	High
9	High	High	Very high

Table.5.2 IF-THEN rules for the first fuzzy system

Defuzzification

With defuzzification process, we will be able to convert membership degrees of output linguistic variables into numerical. A Centre Of Area (COA) method is used in our proposition for defuzzification phase; this method provides a crisp value based on the center of gravity of the fuzzy set. The total area of the membership function distribution used to represent the combined control action that is divided into a number of sub-areas. The area and the center of gravity of each sub-area are calculated and then the summation of all these sub-areas is taken to find the defuzzified value for a discrete fuzzy set. For discrete membership function, the defuzzified value is denoted by Equation 1 below.

$$FL1 = \sum_{i=1}^{n}[\,x_i * \mu(x_i)]/[\mu(x_i)] \qquad (1)$$

Where x_i is the sample element, $\mu(x_i)$ is the membership function and n represents the number of elements in the sample.

5.2.2 Second Fuzzy System

Fuzzification

As the first fuzzy system, we classified the input membership functions into three variables. Choosing a bigger number than three for membership functions variables is not a good solution. A high number of variables leads to high number of IF-THEN rules which can hamper the system work. Unlike using a lower number than three cannot satisfies all variable situations. Figure 5.5 illustrates the membership function for speed. Figure 5.6 represents the membership function for Delay. Figure 5.7 shows the membership function for QoS. The membership degrees are calculated with the same method as mentioned above in Table 1.

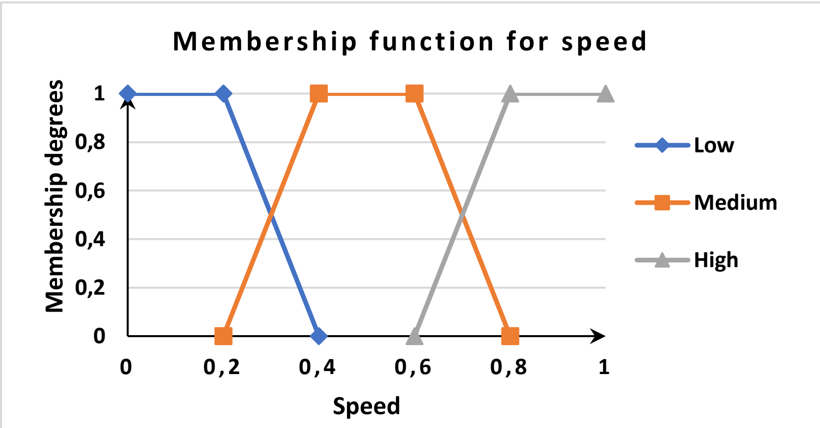


Fig.5.5 Membership Function for Speed

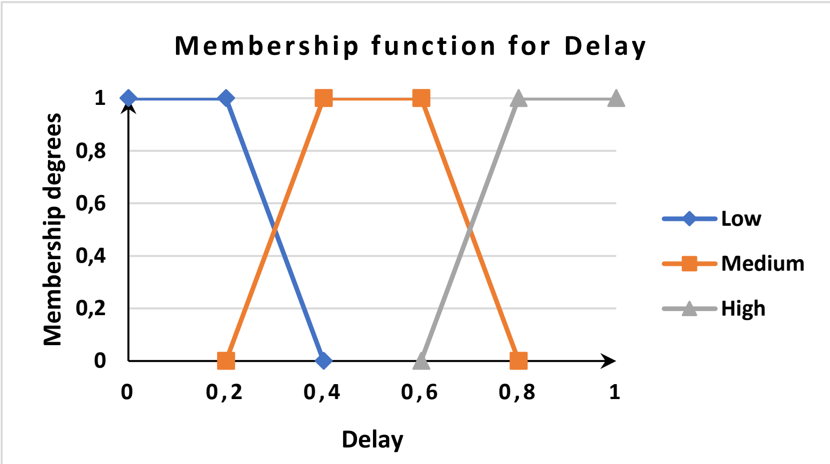


Fig.5.6 Membership Function for Delay

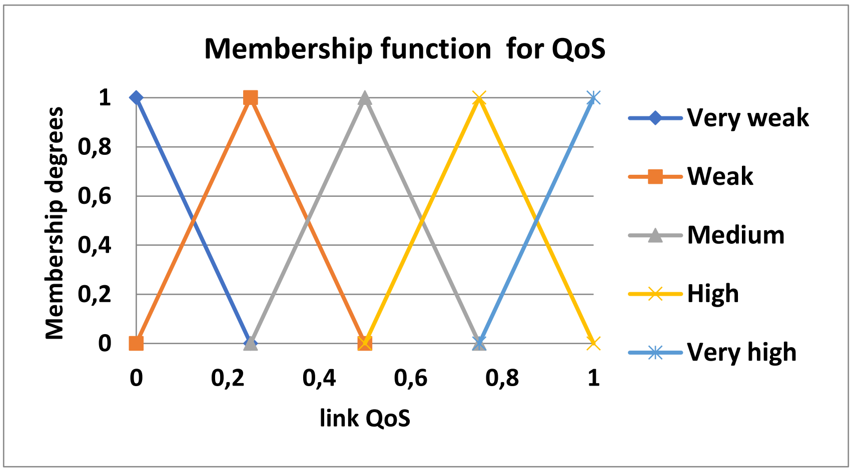


Fig.5.7 Membership function for link QoS of second Fuzzy System

Fuzzy rules

Rule number	Speed	Delay	Quality of service
1	Low	Low	Very high
2	Low	Medium	High
3	Low	High	Weak
4	Medium	Low	High
5	Medium	Medium	Medium
6	Medium	High	Weak
7	High	Low	Medium
8	High	Medium	Weak
9	High	High	Very weak

Table.5.3 IF-THEN rules for second fuzzy system

Deffuzification

The second Fuzzy System defuzzification phase utilizes Equation.2 to calculate output cost value.

$$FL2 = [\sum_{all\ rules} x_i * \mu(x_i)]/[\mu(x_i)] \qquad (2)$$

5.2.3 Routing mechanism for the first proposition

In the first level of our proposal, the establishment of route is done by a request as shown in Figure 5.10. Each cluster head requestor initiates its route searching by broadcasting a REQuest Message (REQM). A REQM message illustrated in Figure 5.8 contains: IP_source (IP address of source cluster head), ID_Msg (Identification of Message), IP_Dest (IP address of destination cluster head), S (Speed of source cluster head), and T (time of sending message) in order to calculate the Delay by the receiver node. MFV (Minimum Fuzzy Value) that takes the minimum value of all fuzzy values of previous neighbors participating in route discovery process. It is obtained from the combination of Signal strength and Bandwidth. MXFV (Maximum Fuzzy Value) takes the maximum value of all fuzzy values of all previous nodes participating in route discovery process. MXFV is a result of combination of delay and speed parameters. The pair (IP_source, ID_Msg) identifies REQM message, the ID_Msg is incremented each time the cluster head source broadcasts a new packet of REQM. Thus, if a vehicle has received a REQM duplicate message, the second will be dropped. The QoS of each link is represented by both MFV (min FL1) and MXFV (max FL2) values of Fuzzy System illustrated above.

IP_source	ID_Msg	IP_Dest	S	T	MFV	MXFV	Seq_Id

Fig.5.8 REQM (Request Message) Format

IP_source	ID_Msg	IP_Dest	Max_value	Seq_Id	Data

Fig.5.9 REPM (Reply Message) Format

Each node receiving the packet REQM compares the address of destination with its address. Two possible cases can occur: if the two addresses are similar, the receiver node is the destination. Otherwise, the node checks if it has already received a REQM with the same ID (ID_Msg) and the same source cluster head address. If it is the case, the node must ignore the packet REQM. In the contrary case, the node becomes an intermediate node. Then, it saves the pair (IP_source, ID_Msg) in its cache to reject the future duplicates REQM. The receiver node calculates the delay and estimates Signal strength and Bandwidth and recovers speed from the received packet. Once all parameters are available, the receiver node calculates the FL1 and FL2 values and compares between the calculated and the received ones. The lowest between FL1 and MFV and the highest between FL2 and MXFV will be inserted in REQM. The key idea of taking the minimum value of FL1 during the route discovering process is to avoid the route that have weak nodes and find the best of the worst. For example, all nodes of route have high values of FL1 except one node has low value. This means that: this node can leave the route in few times because it has a low signal or can delay the time transmission because it has a low Bandwidth. As a result, the source will loss the communication with its destination as fast as possible. The same case for FL2 applies, the route that has maximum value means high speed which causes frequent link broken or high Delay that leads to long transmission time. When the destination receives all packets REQM from the different routes, it calculates the ratio between MFV and MXFV using **eq.3** for each REQM packet received. The aim of the ratio value is to have a harmonization between the two FL values; then the route having the maximum value is selected. The destination inserts the max value of ratio value in the packet REPM (replay message) shown in **Figure 5.9** (We note that REPM is unicast) and send it to the cluster head source.

$$\text{ratio\_value} = MFV / MXFV \qquad (3)$$

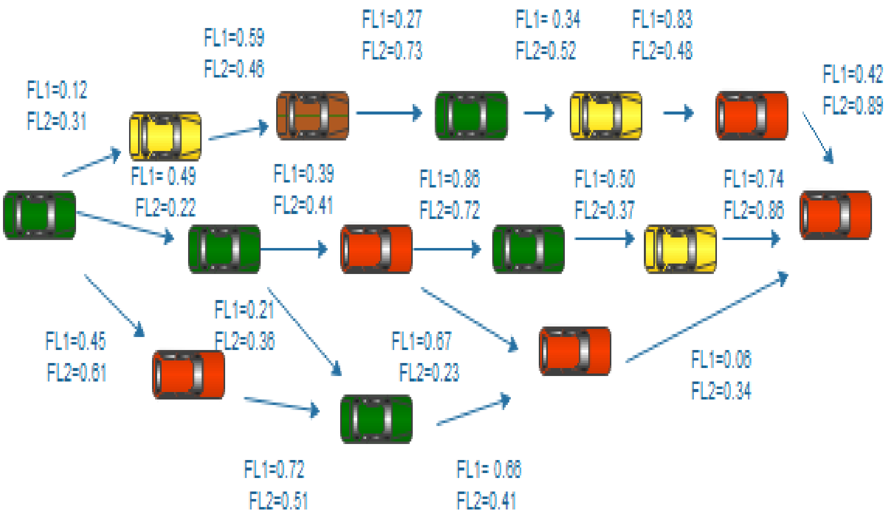


Fig.5.10 REQM Broadcasting Process

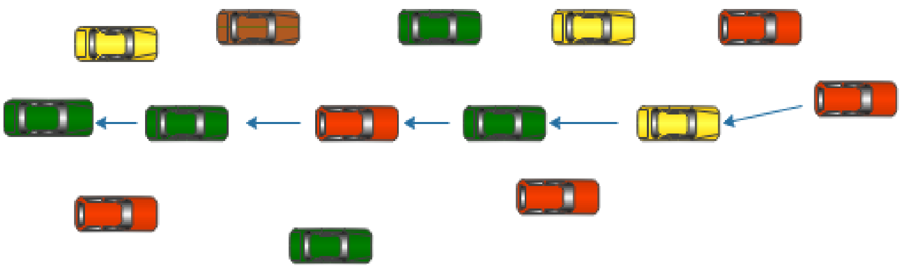
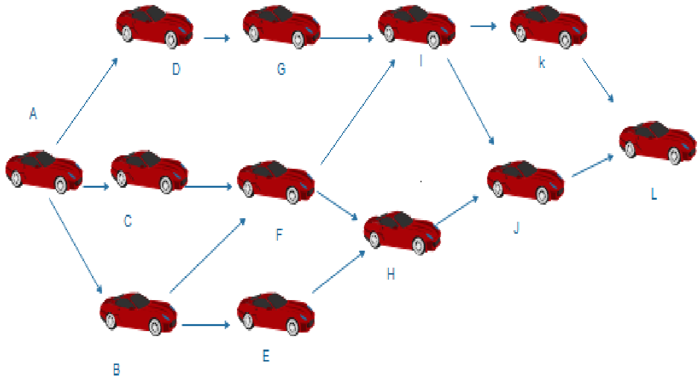


Fig.5.11 REPM Sending Process

5.2.4 Routing mechanism for the second proposition

During simulation phase, we observed that the average Delay is a little bit high and the first proposition needs to be improved to comply with our needs. We suspected that the time taken, in destination cluster head to choose the best route between all the routes received, has a relationship with this Delay. To deal with this, we proposed another solution dedicated to improve the average Delay in the first level of the first proposition. The same concept of FL1 and FL2 calculation is used. In this second proposal, we give each intermediate node the possibility to take the decision on which route will be selected. The cluster head requestor broadcasts a REQM (Request Message) to all its neighbors. The criteria of node selection are based on FL1 and FL2 values discussed above and based on previous information in route establishment process. Each node receiving the REQM, calculates FL1, FL2 values based on received and available parameters; then it takes the ratio between FL1 and FL2.Two possibilities can happen: if the receiver node has just one neighbor sender, it calculates its FL1 and FL2 values; then it compares them with MFV and MXFV, respectively. If FL1 is the lowest, it will be inserted or/and if FL2 is the highest it will be inserted. The node receiver saves the previous path in its routing table and forwards the packet to its neighbors. In the case where the receiver has more than one sender in this time, the receiver node will compare between all ratio values of packets received. The receiver chooses the path that has the maximum value; it saves it in its routing table and ignores the other received paths. Finally, when the REQM arrives to the destination cluster head, the latter resends a REPM (Reply Message) to the original cluster head sender by the best route selected. Figure 5.12 shows the routing mechanism of the second proposition where: SN (source node), D (destination that receives the packet), FL1, FL2 (FL1, FL2 values between SN and D), MFV (Min FL1in REQM message), MXFV (Max FL2 in REQM message), and SP (Selected Path).



SN	D	FL1	FL2	MFV	MXFV	SP
A	B	0.71	0.38	0.71	0.38	A
A	C	0.51	0.07	0.51	0.07	A
A	D	0.44	0.51	0.44	0.51	A
B	E	0.61	0.39	0.61	0.39	AB
B	F	0.15	0.46	0.15	0.46	AC
C	F	0.65	0.13	0.51	0.13	AC
D	G	0.44	0.51	0.32	0.51	AD
E	H	0.42	0.64	0.42	0.64	ABE
F	I	0.57	0.81	0.51	0.81	ACF
F	H	0.21	0.91	0.21	0.91	ABE
G	I	0.25	0.68	0.25	0.68	ACF
H	J	0.31	0.83	0.31	0.83	ACFI
I	J	0.61	0.11	0.51	0.81	ACFI
I	K	0.73	0.17	0.51	0.81	ACFI
J	L	0.49	0.52	0.49	0.81	ACFIK
K	L	0.56	0.67	0.51	0.81	ACFIK

Fig.5.12 Path Selecting Process of Second Proposal

5.3 Second routing level (Intra-cluster)

In the second level of our proposed protocol, we suppose that each vehicle has at least one route to its cluster head by which it sends its service request. The goal of this level is to find the best path in term of stability. In order to ensure robust connectivity, we use the estimation link lifetime as an indicator of link stability which leads to the QoS in routes. Many works have been proposed to estimate the link lifetime based on different metrics [133 -136]. These works have been dedicated to VANETs and very few works have addressed the issue in IoV environment. In our present work, the estimation of link lifetime is based on nodes speed and direction. We chose this approach because it is based on the main factors generator of frequent links disconnection like velocity and direction. The same direction and close velocities mean unlimited connectivity. As a cluster head is a gateway or access point for vehicles in cluster to have access to different services, utilization of stable route is required. Link expiration time *LET* is shown in Figure 5.13 and it has been calculated based on velocity and direction parameters and the angle between two vehicles based on the Eq.4.

$$LTE_{ij} = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \qquad (4)$$

Where,$a = v_i cos\theta_i - v_i cos\theta_j$, $b = x_i - x_j$, $c = v_i sin\theta_i - v_i sin\theta_j$, $d = y_i - y_j$. Vehicle velocity (v_i) and coordinates (x, y) parameters are available via GPS.

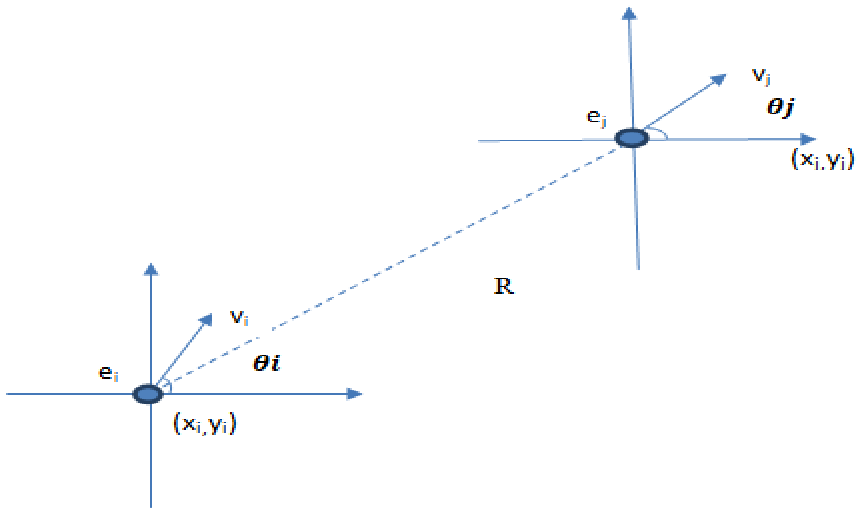


Fig.5.13 Parameters used to calculate *LET*

5.3.1 Routing mechanism of second level

Each node in a cluster exchanges its parameters (position, velocity) with its neighbor nodes using periodic *Hello* messages as shown in Figure 5.14**.** Each vehicle receives Hello message estimates the link lifetime based on received parameters and saves link lifetime value and source address in its route table. Each cluster member node, in each cluster, has to discover all possible routes to all its cluster vehicles including its cluster head using Hello messages. After receiving Hello messages from neighbor nodes, the source node classifies all available routes in its routing table according to the long route lifetime. If a node does not receive a Hello message from its neighbor during an interval of time t, it marks the routes using by this neighbor as disabled. Then it sends an error message ERRM to neighbors upstream of the route. In the case where node needs a communication, the node requestor checks if the destination is in its cluster. If so, it chooses the longest link lifetime in its routing table according to the destination address and it sends a unicast request. In the contrary case, the node requests or sends a request message through the longest link life time path saved in its routing table to the cluster head. In turn, the cluster head sends a reply message to node requestor via the same path. The example represented in Figure 5.15 and Figure 5.16 illustrates node exchanges, mechanism parameters and the links establishment process with their cluster head, respectively. Flowchart of first proposition and second proposition are shown in figure 5.17 and figure 5.18, respectively.

<table>
<tr><td colspan="2">Source IP Address</td></tr>
<tr><td colspan="2">Destination IP Address</td></tr>
<tr><td colspan="2">Sequence Number</td></tr>
<tr><td>V</td><td>(x,y)</td></tr>
</table>

Fig.5.14 Hello Message Format

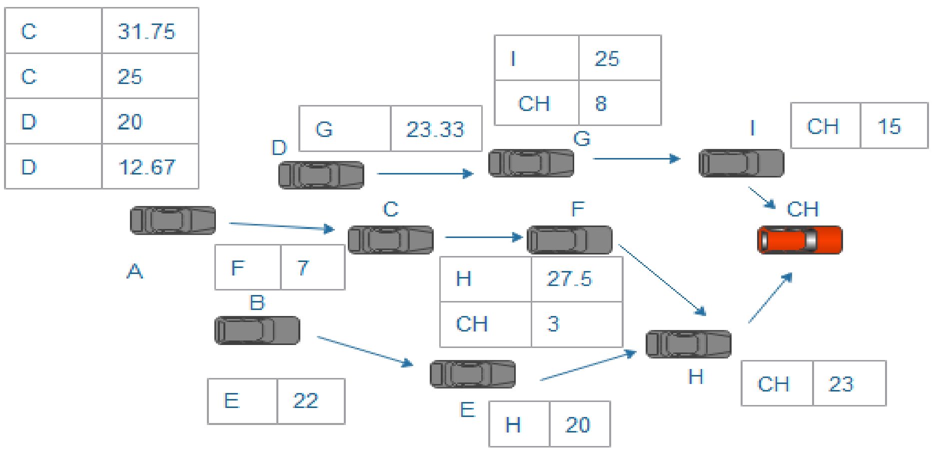


Fig.5.15 Vehicle Exchanges and Mechanism Parameters

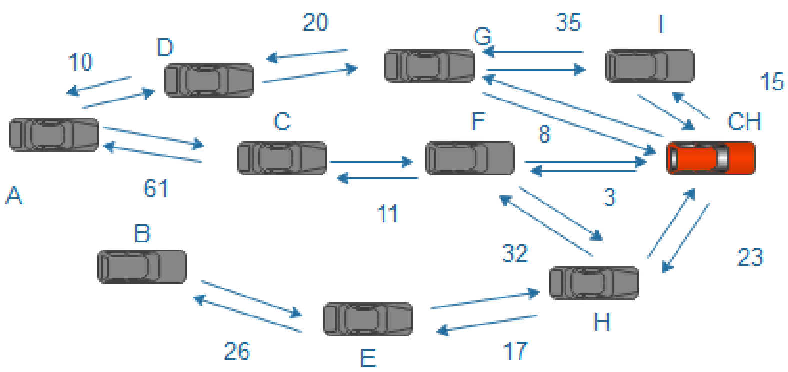


Fig.5.16 REQM Broadcasting Process

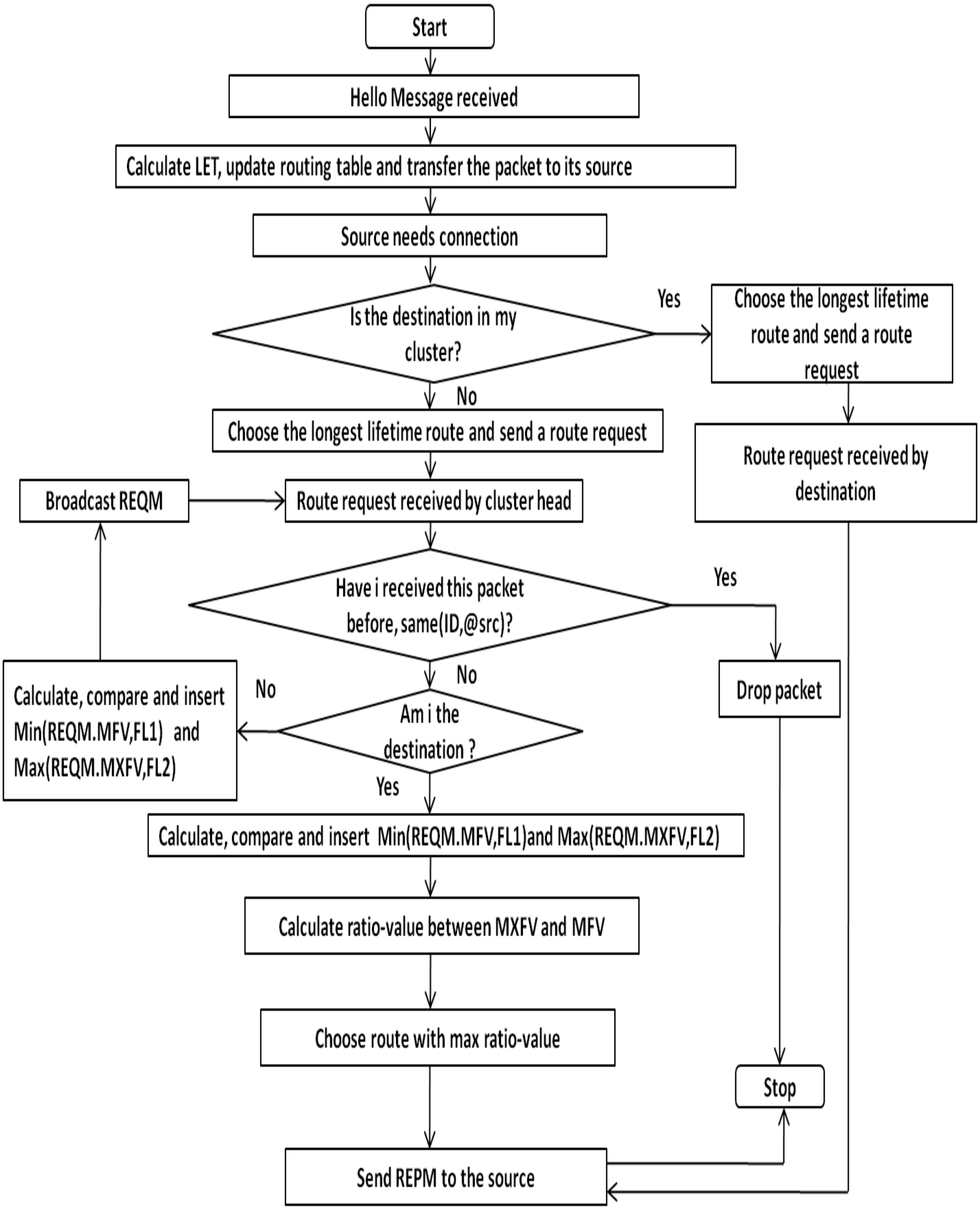


Fig.5.16 Flowchart for the First Proposition

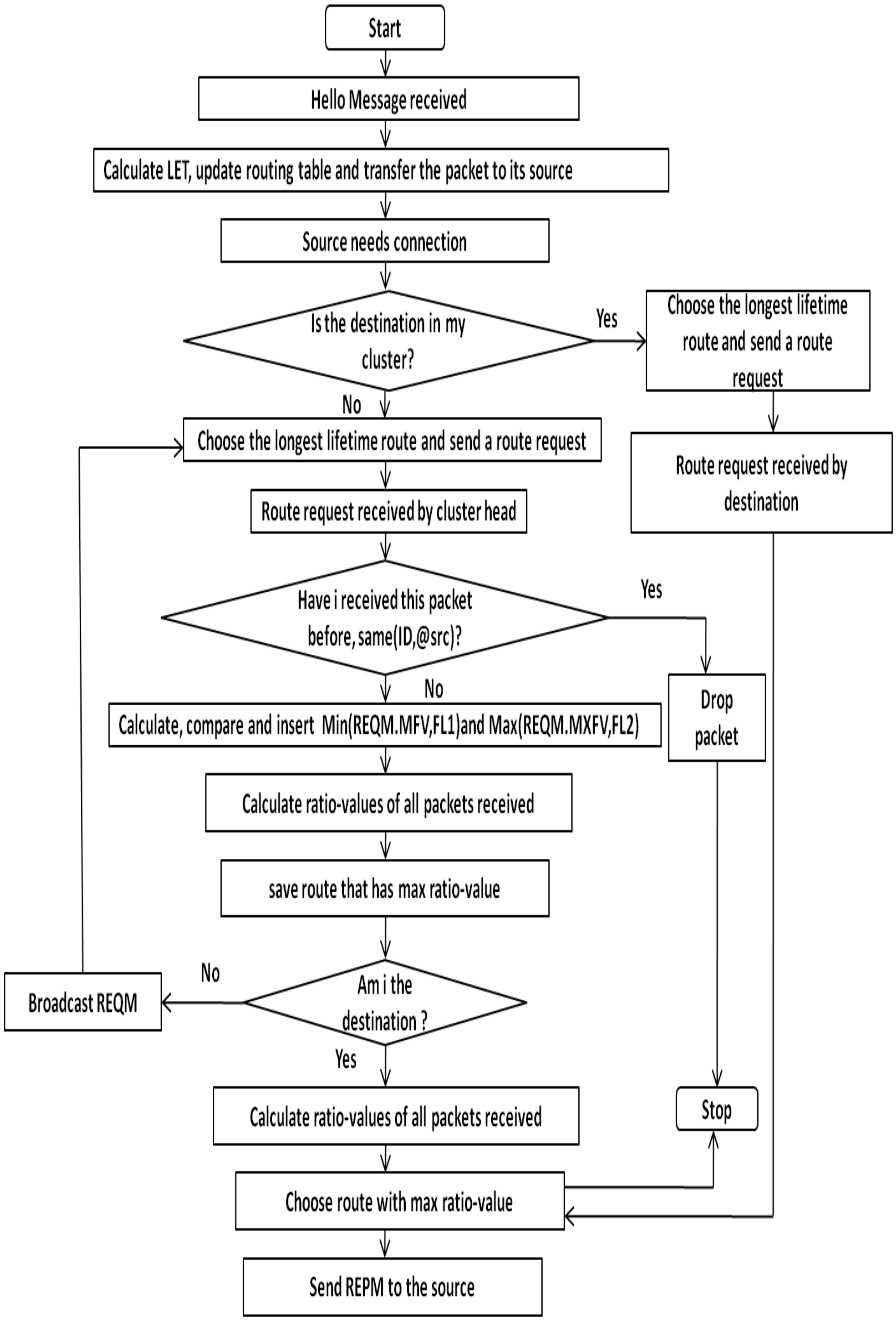


Fig.5.17 Second Proposition Flowchart

5.3 Results and Discussion

In this section, we report results generated from different simulation scenarios carried out and comparison between our proposal and referenced protocols ZRP, QoS-OLSR and CBDRP. To this end, we used the well-known NS3 network simulator [85] and we generated a realistic mobility model using the tool "Mobility Model Generator for Vehicular Networks" (MOVE) [28-29]. Vehicles are able to communicate with each other using the IEEE 802.11p MAC layer and 10 MHz of channel Bandwidth, other nodes like smart phones, tablets, etc. use the IEEE 802.11 MAC layer protocol. Due to unpredictability of node velocities and network density, the vehicles are predisposed to rapid information loss. In fact, these two factors play an important role on communication link lifetime and quality of routing between vehicles. We compared the routing protocols under various node speeds and various network sizes in order to evaluate the impact of these factors on the performance of our protocol. We have generated a highway vehicular environment where we considered 60 km/h as a minimum speed and 120 Km/h as a maximum one. **Table.5.4** shows the parameters used in the simulation process. Detailed analysis of the simulation results are given in the following.

Parameters	Value
Ns-3	version NS-3.26
Simulation time	300 s
Velocity	60–120 Km/h
Data packet size	500–3000 bytes
Source/destination	Random
Channel type	Wireless channel
MAC type communication protocol	IEEE 802.11p / IEEE 802.11
Simulation network area	3000m*3000 m

Table.5.4 Simulation Parameters

Average packet delivery ratio (PDR)

PDR metric represents the percentage of data packets that reach destination compared to the total number of packets sent to the same destination. Different events may lead to loss of data packets such as: network collision, link failure, insufficient bandwidth, overhead of buffering and nodes mobility. Speeds of vehicular nodes and network density have direct impact on various performance metrics like: PDR, Delay and link disconnections (Network overhead) in IoV networks. For this reason and in order to study the effect of varying speed on routing protocols in the first scenario, speed changes from 60 km/h to 120 km/h with 1500 as number of nodes. In second scenario, the number of nodes varies from 500 to 2000 nodes in the network with speed of 70 km/h. The results depicted in Figure 5.19.a show the variation of Packet Delivery Ratio versus the variation of nodes speed, where the PDR decreases as speed of nodes increases. With low mobility, proposition 1 and proposition 2 behave almost in the same manner and they exhibit better output with an average PDR of 85% and 89% respectively. As speed increases, degradation in the performance of ZRP is greater and PDR is reduced to 51%. CBDRP has not a stable variation compared to other protocols. QoS-OLSR has relatively high PDR than ZRP. As shown in Figure 5.19.b, PDR variation in different nodes number represents the dependence of routing protocols on diverse network densities. In protocols QoS-OLSR and ZRP, an increased number of nodes leads to a decreased packet delivery rate. ZRP has lower PDR compared with other protocols and this is due to high number of zone control messages, buffer overflow and increased packet loss rate. In the proposed protocol, the PDR rate is improved according different number of nodes as compared to other protocols, because the basic idea of PDR is the choice of stable routes. The stable route needs longer link lifetime, appropriate mobility, higher bandwidth and closer distance.

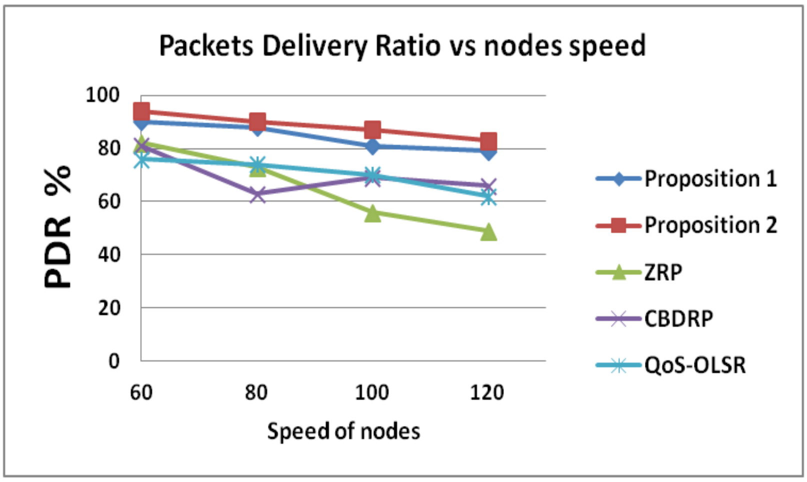


Fig.5.19.a Packets Delivery Ratio vs Node Velocities

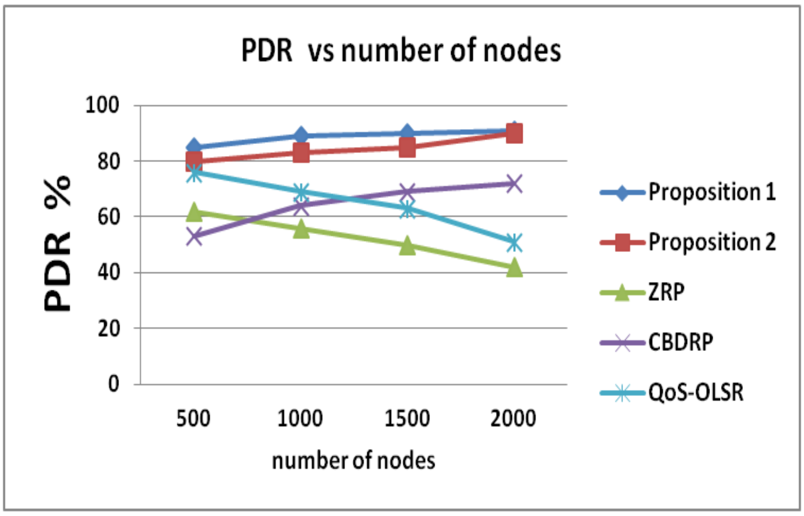


Fig.5.19.b Packets Delivery Ratio vs Number of Nodes

End to End Delay (EED) Metric

EED metric is the average time taken by a data packet sent from its source to arrive to its destination. In IoV networks, decreased link bandwidth and frequent link disconnections lead to increased probability of packet delay. Since the proposed approach selects stable routes for communication, there are lesser broken links during data transmission; this reduces the End to End delay. As shown in Figure 5.20.a, QoS-OLSR protocol at high speeds exhibits greater delays, because the link between two nodes is likely to be broken at high speeds. The absence of speed factor to select the MPRs in QoS-OLSR increases the probability of links disconnection. The CBDRP protocol delay is the lowest comparing to

QoS-OLSR and ZRP, particularly at high speeds. The reason of this performance is that route selection process between nodes in CBDRP is based on speed and direction vectors which minimize the probability of frequent links disconnection; this reduces the new link establishment which in turn decreases packets delay. The proposed protocols showed high performance in terms of delays comparing to other protocols. This is due to taking into account multiple parameters like: speed, signal strength, bandwidth and delay when selecting route to destination. The probability of failure and End to End packet delay will be reduced at different speeds. As shown in Figure 5.20.b, when network density increases, End to End delay also increases for ZRP, CBDRP, QoS-OLSR protocols. In the ZRP protocol, the End to End delay is the highest. The main reason for this delay is that in ZRP protocol for neighboring nodes only one parameter is selected (short path), which will invariably be its closest neighbor. This problem faced in the proposed protocol was resolved using fuzzy logic and taking into account various parameters. As shown in the diagram, the average End to End delay of proposed protocols decreases in different densities.

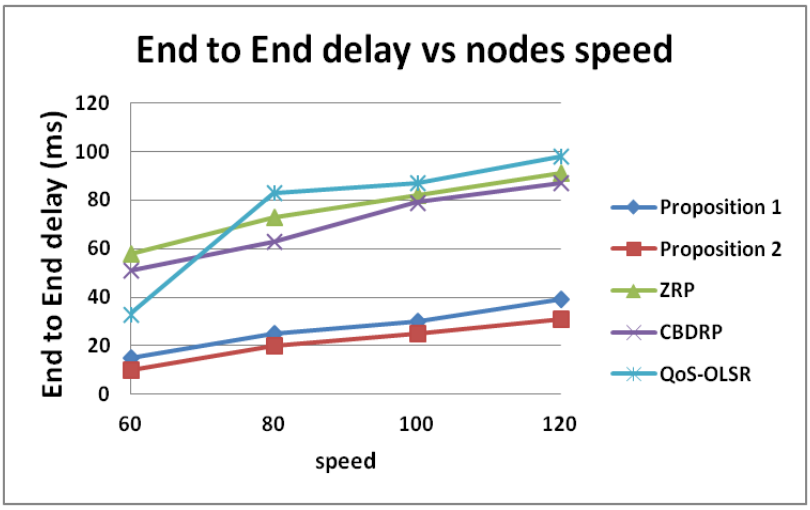


Fig.5.20.a End to End Delay vs Speed of Nodes

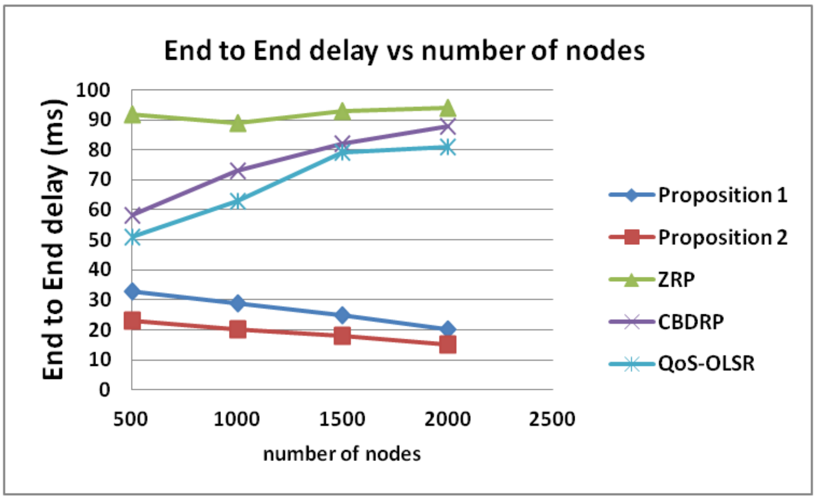


Fig.5.20.b End to End Delay vs Number of Nodes

Generated Overhead

This metric is measured in term of number of packets (Beacon messages) sent in the network. Frequent link disconnections lead nodes to resend a route request which in turn augment network overhead, beacon messages sent to update network and may also congest the network. Link stability could be affected by different crucial factors such as distance, direction, and speed; also decreasing the signal strength parameter leads to increased probability of link disconnection. As shown in Figure 5.21.a, the number of packets sent was greater in ZRP protocol compared with other protocols. In QoS-OLSR, increased speed of nodes leads to more link failure. In proposed protocols, the most stable link was selected using the longest link lifetime variable and the use of fuzzy logic (With appropriate velocity, higher signal strength (closer distance)) between cluster heads make link failure probability reduced and number of RREQ packets decreased at destination. As shown in Figure 5.21.b, in different network densities, the number of packets sent in CBDRP protocol had an upward trend and was higher than that of ZRP and QoS-OLSR protocols. In CBDRP protocol, increase of network density leads to increased network congestion and hence, the probability of link failure was very high. The number of packets sent by proposed protocols was fixed and less than that of the ZRP, QoS-OLSR and CBDRP protocols.

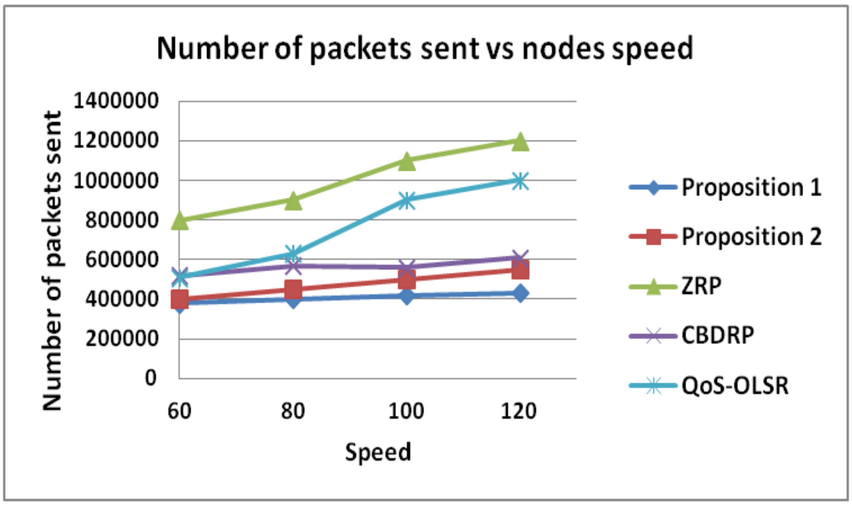


Fig.5.21.a Number of Packets Sent vs Node Velocities

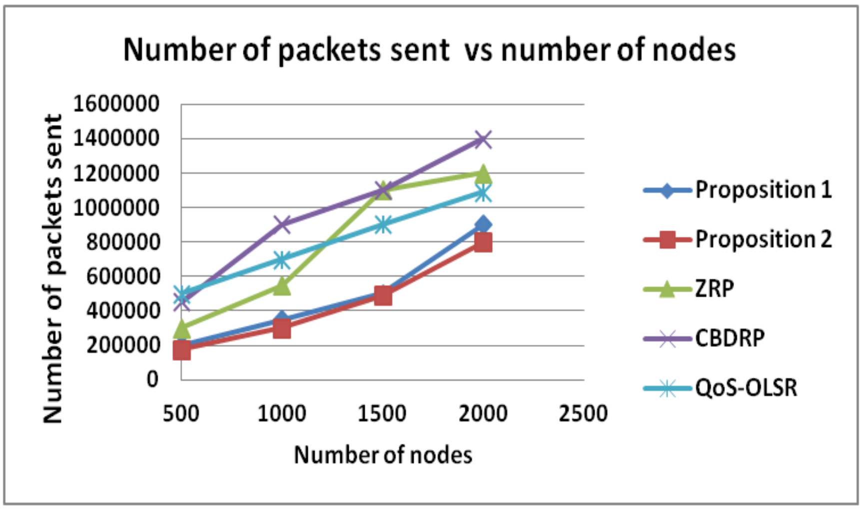


Fig.5.21.b Number of Packets Sent vs Number of Nodes

5.5 Conclusion

In an IoV environment, several types of messages are being transmitted, in particular urgent and non-urgent messages. Urgent messages convey key events which have to dependably reach their destinations in real time way. To achieve this objective, long-lasting communication links, stable and dependable must be available. This is what is devoted to our present work. Therefore, we proposed RPQLS: an efficient bi-level Routing Protocol based on Quality of service and Links Stability for internet of vehicles. In the first level, we selected essential parameters like Signal strength, Bandwidth, Velocity and Delay as Fuzzy

Logic inputs in order to determine the best routes between cluster heads. In the second level, we considered the estimation link lifetime as criterion of link durability in order to select stable routes between the cluster members. The performance evaluation of our proposal has been carried out through NS3 simulator using different relevant scenarios and metrics. The results provided by our proposition outperform those of the well-known protocols namely: CBDRP, ZRP and QoS-OLSR.

As a future work, we envision to enhance our proposal by suggesting a new cluster formation algorithm based on node capacities such as: computing ability, waiting queue size and delivery service time, all according to velocity variations.

Conclusion and Future works

As a new ITS paradigm, IoV becomes one of the most active research fields and plays an important role in solving various driving and traffic problems by advanced information and communication technologies. Despite these benefits, IoV have many design challenges and limitations that must be considered by researchers to suggest new solutions for these networks and improve the existing ones. In this regard, the choice of an efficient network structuring technique for the IoV paradigm is a topic that is still relevant, especially since this type of network is expanding, because of its huge potential for beneficial contributions, especially for security in which the lives of individuals are at stake. Many challenges characterize the IoV routing research field, such as scalability, redundant overhead, inadaptation to rapid topology changes, high exploration delay and so on. This thesis was divided on five chapters where:

In Chapter 1, we gave a background of knowledge about the Internet of Vehicle (IoV); their architecture, characteristics, challenges, communication technologies and applications; and all that belongs to this domain.

In Chapter 2, we presented the state of the art on the routing algorithms for vehicular network in the literature. At this point, we attempt to detect certain problems still open or whose proposed solutions are still to improve, in order to propose new routing protocols suitable for IoV.

In chapter 3, we proposed a new routing protocol suitable for the IoV environment. The goal of this proposal is to find the stable links in network in order to ensure the communication stability in such environment. Where, we modified the well-known routing protocol named: Zone based Routing Protocol (ZRP) by integrating QoS to its path's discovery process. This protocol aims to find the stable routes in network using geographic information, where each node can choose the stable route in its own zone by selecting its neighbor nodes that move to the same final region during its trajectory. Moreover, speed of vehicles and delay are also used as metrics in order to select the stable and fast routes in network.

In chapter 4, we presented a new weight-based clustering algorithm for IoV, that aims to increase the stability of clusters and reduce communication overhead using integrating selective parameters such as delay, density, speed and position to select the cluster heads in order to ensure some quality of service in IoV by guaranteeing a reliable connectivity and a low network overhead.

In chapter 5, we proposed to take advantage of the IoV features to choose appropriate metrics aiming to ensure route stability according to two levels. In the first one, best routes are discovered by using metrics such as signal strength, bandwidth, delay and node velocity. In the second level, an approach for estimating links life time has been used. The latter is based on speed and direction parameters in order to find the most durable route. To this end, Fuzzy Logic method has been used to reach our objective.

Future work and perspectives Although the proposed clustering approaches for IoV are very promising and can provide very acceptable performance, there are other significant topics that we plan to carry out and study further in the research and applications of clustering approach in IoV. We summarize them as follows:

• Investigate the use of the proposed algorithms in urban areas by designing effective corresponding algorithms and comparing its performance to existing clustering protocols.

• Improve the proposed solutions by integrating/proposing a mechanism to improve the consensus rate between the vehicles during the CHs selection phase, especially in the distributed approaches.

• Consider the impact of collisions and hidden terminals, that have an impact on the delivery ratio when the number of connected vehicles increase.

List of included publications

The thesis is based on the following papers:

A) Rim Gasmi, Ali Moussaoui, Chafia Chetebani " Routing based on link stability using fuzzy logic case (AODV), COSI 2017, Bouira, Algeria.
B) Rim Gasmi, Makhlouf Aliouat " Vehicular Ad Hoc NETworks versus Internet of Vehicles - A Comparative View ", the International Conference on Networking and Advanced Systems (ICNAS 2019), pp. 1-6, Annaba, Algeria.
C) Rim Gasmi, Makhlouf Aliouat, Hamida Seba "A Stable Link Based Zone Routing Protocol (SL-ZRP) for Internet of Vehicles Environment", wireless personnel communications journal (springer), No.112, pp 1045–1060 (2020).
D) Rim Gasmi, Makhlouf Aliouat "A Weight-Based Clustering Algorithm for IoV ", accepted for publication at Automatic Control & Computer Sciences (Springer).
E) Rim Gasmi, Makhlouf Aliouat, Hamida Seba "Geographical Information based Clustering Algorithm “GICA” destined to Internet of Vehicles“ accepted to the 3rd International Conference on Machine Learning for Networking (MLN'2020), Paris, France.
F) Rim Gasmi, Saad Harous, Makhlouf Aliouat " A reliable connectivity-based Clustering Algorithm for IoV ", submitted to Future Generation Computer Systems journal (Elsevier).
G) Rim Gasmi, Makhlouf Aliouat, Hamida Seba, Zibouda Aliouat " Unstable Connectivity Aware Protocol for Dependable Messages Delivery for Future Internet of Vehicles", submitted to International Journal of Wireless Information Networks journal (Springer).

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ملخص:

تتناول أطروحة الدكتوراه هذه بشكل أساسي مشكلات تحسين قوة اتصال الشبكة وتحسين استقرار الشبكة وتحسين النفقات العامة للشبكات في بيئة إنترنت السيارات. في هذا السياق، نحن مهتمون بخوارزميات التوجيه لتلبية متطلبات هذه البيئة. وبالتالي، فإن الهدف العام من هذا العمل البحثي يركز على تصميم ونمذجة ومحاكاة خوارزميات توجيه وتجميع جديدة لشبكات انترنت السيارات. في هذا الصدد، نقترح خوارزميتين توجيه جديدة تعتمد على جودة الخدمة لشبكات انترنت السيارات وخوارزمية تجميع جديدة مما يجعل من الممكن تحسين أدائها، مع ضمان مستوى عال من الخدمة التي تتطلبها الوظيفة التي تؤديها هذه الشبكات. تتمثل أهداف الخوارزميات المقترحة في**:** زيادة نسبة التسليم بين عدد كبير من المركبات المتصلة التي تسير بسرعة عالية، التقليل إلى حد كبير من النفقات العامة للشبكة وتقليل زمن التأخير في الشبكة. لقد أسفرت الدراسة التحليلية والمحاكاة لتقييم الخوارزميات المقترحة، والتي تم إجراؤها بواسطة مجموعة من محاكي الشبكة ومولد الحركة، عن نتائج مقنعة، تفوقت على تلك التي عرضته الخوارزميات الأساسية المقترحة في الأدبيات.

مفاتيح : شبكات المركبات، انترنت المركبات، التوجيه، جودة الخدمة، التجميع.

Abstract

This PhD thesis deals mainly with the problems of improving network stability, ensuring robust network connectivity and optimizing network overhead in the Internet of Vehicles (IoV) environment. In this context, we are interested in the routing algorithms to meet the requirements of such environment. Therefore, the general goal of this research work focuses on the design, modeling and simulation of new routing and clustering algorithms for the IoV network. In this respect, we propose two new routing algorithms based Quality of service for IoV networks, and a new clustering algorithm which make it possible to improve their performances, while guaranteeing a high level of service required by the function performed by these networks. The main goals of the proposed algorithms are: increasing the delivery ratio between a large number of connected vehicles traveling at high speed, minimizing significantly the network overhead and decreasing the network Delay. The analytical study and the simulation for evaluating the proposed algorithms, carried out by a combination of simulators NS3, SUMO and MOVE, have yielded convincing results, outperforming those exhibited by the basic referred algorithms.

Keywords: VANET, Internet of Vehicles, Routing, Quality of service, Clustering.

Résumé:

Cette thèse de doctorat porte principalement sur les problèmes de l'amélioration de la robustesse de connectivité du réseau, de l'amélioration de la stabilité du réseau et de l'optimisation de la charge dans un environnement Internet des Véhicules (IoV). Dans ce contexte, nous sommes intéressés par les protocoles de routage pour répondre aux exigences d'un tel environnement. Par conséquent, l'objectif général de ces travaux de recherche est de concevoir, modéliser et simuler de nouveaux algorithmes de routage et de regroupement pour le réseau IoV. À cet égard, nous proposons deux nouveaux algorithmes de routage basés sur la qualité de service et un nouvel algorithme de regroupement pour les réseaux IoV, qui permettent d'améliorer leurs performances, tout en garantissant un haut niveau de service requis par la fonction réalisée par ces réseaux. Les algorithmes proposés ont pour objectif : d'augmenter le rapport de transmission entre un grand nombre de véhicules connectés se déplaçant à grande vitesse, réduire de manière significative les frais généraux du réseau et de réduire le retard dans le réseau. L'étude analytique et la simulation d'évaluation des algorithmes proposés, réalisées à l'aide d'une combinaison des simulateurs simulators NS3, SUMO and MOVE, ont donné des résultats convaincants, supérieurs à ceux des algorithmes de base cités.

Mots clés: VANET, Internet des Véhicules, Routage, Qualité de service, Regroupement.