# How to tackle bandwidth scarcity in vehicular communication

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# Abstract

The following report is discussing the Master of Science dissertation of the author that is concerned about the bandwidth scarcity problem in the vehicular ad-hoc networks. The discussion is focusing on introducing the reader to the vehicular network, its benefits and issues, followed by analysing the bandwidth problem through multiple protocols that were designed by different researchers to fulfil this issue. The author then proposes an alternative solution that would better suit the subject and address the issue of scarcity in the network. A conclusion is overviewing the vehicular network regarding this issue followed by possible future improvements that would bring more benefits than drawbacks to every person using this type of network.

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# List of Abbreviations

| | |
|---|---|
| **AC** | Access Categories |
| **AODV** | Ad-Hoc On-Demand Distance Vector |
| **A-STAR** | Anchor-Based Connectivity Aware Routing |
| **BBUC** | Base Band Unit Controllers |
| **BS** | Base Station |
| **BSM** | Basic Safety Message |
| **CAM** | Context Awareness Messages |
| **CBR** | Cluster Based Routing |
| **CBR** | Channel Busy Ratio |
| **CCA** | Clear Channel Assessment |
| **CCH** | Control Channel |
| **CCHI** | Control Channel Interval |
| **CR** | Cognitive Radio |
| **C-RAN** | Cloud Radio Access Network |
| **CSMA/CA** | Carrier Sense Multiple Access/Collision Avoidance |
| **CW** | Content Window |
| **DBRA** | Distributed Beacon Rate Adaption |
| **DCC** | Decentralised Congestion Control |
| **D-FPAV** | Distributed Fair-Transmit Power Control |
| **DP** | Dynamic Programming |
| **DSA** | Dynamic Spectrum Access |
| **EDD** | Expected Disconnection Degree |
| **ETSI** | European Telecommunications Standards Institute |
| **FC** | Fog Computing |
| **FC-CH** | Fog Computing Cluster Heads |
| **FC-ZC** | Fog Computing Zone Controlled |
| **FPAV** | Fair-Transmit Power Control |
| **GEM** | Geocast Message Forwarding |
| **GNSS** | Global Navigation Satellite System |
| **GPCR** | The Greedy Perimeter Coordinator Routing |
| **GPRS** | Global Positioning System |
| **GPSR** | Greedy Perimeter Stateless Routing |
| **GPSR-AGF** | Advanced Greedy Forwarding |
| **GSR** | Geographic Source Routing |
| **ITS** | Intelligent Transport System |
| **LAR** | Location Assisted Routing |
| **LTE** | Long Term Evolution |
| **MAC** | Media Access Layer |
| **MANET** | Mobile Ad Hoc Network |
| **MCKP** | Multiple-Choice Knapsack Problem |
| **NP** | Nondeterministic Polynomial Time |
| **NPPB** | Nth-Powered P-perimeter Broadcasting |
| **OBU** | On-Board Unit |
| **OTN** | Optical Transmission Network |
| **PU** | Primary User |

| | |
|---|---|
| **P2P** | Peer-To-Peer |
| **RC** | Radio Cognition |
| **ROVER** | Robust Vehicular Routing |
| **RREQ** | Route Requesting Messages |
| **RREP** | Route Reply Message |
| **RSU** | Roadside Deployment Units |
| **SDN** | Software Defined Networking |
| **TDMA** | Time-Division Multiple Access |
| **TP** | Transmit Power |
| **TR** | Transmit Rate |
| **VANET** | Vehicle Ad Hoc Network |
| **VCARP** | Vehicular Context Aware Routing |
| **VLC** | Visible Light Communication |
| **V2I/I2V** | Vehicle-To-Infrastructure/Infrastructure-To-Vehicle |
| **V2V** | Vehicle-To-Vehicle |
| **V2X** | Vehicle-To-Everything |
| **WLAN** | Wireless Local Area Network |
| **ZOI** | Zone of Interest |
| **ZOR** | Zone of Relevance |

# Declaration

No part of this project has been submitted in support of an application for any other degree or qualification at this or any other institute of learning. Apart from those parts of the project containing citations to the work of others, this project is my own unaided work.

Signed,

Alex-Radu Malan

## Chapter 1
# Introduction

Humans have always created and engineered new things to have an easier life. Transportation is one of the core elements in our everyday life actions, moving from one place to another, reaching new places and having new experiences. Cars and vehicles, in general, gave us the ability to reach these places way faster than before which is why over the last 200 years this industry has been found in a never-ending development. Different types of roads were created through the years, our settlements are also designed around these paths which served billions of people into reaching their destination. Nowadays the thing that we are most concerned about is the traffic accidents and deaths increasing each year since the number of participants in traffic is growing. The autonomous cars were proposed as a way to reduce the issues mentioned above, by having a software system trained using artificial intelligence and different models regarding this subject, which will eventually reach a level of reliability and safety. If this type of vehicles will be introduced on the road, first and foremost we have to create a system that can deal with the current vehicles and provide the basic information bits that will inform the driver in the circumstance of an accident or traffic-related problem. The data that has to be sent from car-to-car is making use of the available bandwidth, but the number of vehicles that access the network is constantly growing which pose problems like network congestion. To reduce congestion, there are multiple procedures and algorithms currently developing and improving. The paper will discuss the vehicle network, its needs and applications, but also on how solutions can be created in a new or hybrid way.

## Chapter 2
# An overview on vehicular networks

### 2.1 Vehicular Networks: Main Characteristics
In today's society, the need for transport increases so the number of vehicles on the road. There are more and more vehicles everywhere which also lead to more and more transport-related issues such as accidents, congestions, factors that slow down the process of transportation. To create a solution for this problem, we have taken the mobile network and use its principles in the making of a vehicular network that would give possibilities to prevent these traffic and vehicle-related problems and also have multiple features that will make the process of transportation easier for every participant in the traffic. The vehicular network is also called 'VANET' which stands for Vehicular Ad Hoc Network. This network not only covers the car-to-car communication and interaction but also the way cars communicate and exchange information with the other elements in the process, such as the road and infrastructure. All of these elements connected are related to a new concept known as the Intelligent Transportation Systems (ITS) which is considered to be a framework on which multiple features can be implemented to help the participants. The main idea of the VANET is not to replicate the mobile network that makes use of a cellular network, but to have spontaneous networking, since the traffic is constantly changing, therefore the location and the environment in which the information is exchanged has high mobility. A core part of the whole process of VANET is the decentralization in such a way that vehicles would communicate without a base station

### 2.2 Potential Applications and Impact
Along with its creation, the VANET also comes with multiple features and applications that will benefit the people that make use of it. Though these features are in the early stages, the future will bring us the ITS, which will be a complex system that will not only have resources for the traffic participants, but it will use the data from them to improve itself. One of the functionalities would be the predictable mobility pattern system which will allow the network to model itself after recognised patterns in vehicle movement along the road. Mobility models have to be implemented so that the network will keep up with the high mobility of the vehicles and the way they connect and disconnect from road links in a dynamic way. In terms of traffic and road, there should be better engineering of the traffic to reduce the time it takes to get to a destination and decrease the congestion along the path. In the driver's perspective, multiple chunks can be added to the system, such as better road traffic safety functionality that will inform people about accidents or dangers in advance. The quality of the road-travel would increase as well since numerous elements can be added. Examples of these applications are Electronic Brake Lights that can be used by the driver or by the autonomous cars to break even though their visibility might be obscure. Another feature would allow the vehicles to follow each other very closely without bumping into each other by simply taking the parameters from the front vehicle and adjusting the speed and location so that our vehicle can drive in an organised way. Features are also related to the road services that will provide information about the closest gas stations, shopping malls, grocery stores, restaurants, hotels, and more elements that everybody makes use of in the process of transportation. All of the above have a big advantage over the mobile ad-hoc network (MANET) since the battery life is longer for each node. The goal is to have fewer accidents, more control over the issues that might end up on the road and give people infotainment and ease-of-use of the services and resources they seek.

## 2.3 Quality of Services Challenges

The Quality of Service can be defined as being the measurement of the overall performance of a system or service. In this paper, we are using this measurement for the VANET performance and assurance of working communication between the vehicles. To provide an overall result, the quality of service has multiple parameters that are taken into consideration, such as bandwidth, packet delivery ratio, data latency, delay variance and other. It is of great importance to create a model that make use of these parameters in the best way possible so that the VANET will provide the resources fast and reliable to the participants (Kumar, 2010).
An important parameter to start with is data latency. It represents the time duration from issuing a message until it is received by the receiver vehicle. In the equation, there is an important parameter in the process of sending and receiving packets, the time delay. By having the time delay we can calculate the throughput, but in the routing path, the most important part is the reliability of the link rather than the delay. In. order to minimise the data latency there are two approaches: either limiting the number of transmissions while forwarding a message or using data mulling strategy. The second approach is using vehicles with computers on board in such a way that they create communication links that will load and unload the data once the message has reached the terminal location.

Another element in the quality of service, of high importance, is the bandwidth and its efficient utilisation. Most of the time the bandwidth utilisation can be under or more estimated depending on the situation. In the first scenario, the bandwidth estimation is lower than the network capacity, while in the second scenario it is higher; either case will lead to performance decrease. An important factor in designing the VANET is the ability to have vehicles with equipment of different network characteristics. If two vehicles want to communicate without congestion, they have to be into an interference range which can vary from each one depending on the bandwidth they have. A solution that would provide interference range when the message has to be sent is the bandwidth sharing; the car with the highest bandwidth will share more of its own to get to the other car that has to receive the message. The available bandwidth is depending on the transmitted traffic. Another approach would be the use of AODV (Ad-Hoc On-Demand Distance Vector) which is a base station that builds routes between nodes. The networks in AODV are silent until the connections are established based on the request of network nodes that need broadcast from them. When a connection is established, the rest of the AODV nodes record the node that made a request for broadcasting and forward the message, basically creating temporary routes back to the requesting node. The node that initiated this request is using the route that contains the least number of hops through other nodes. The entries that are not used in the table are recycled after time pass. In the case of a link failure, the error is passed back to the transmitting node and the process is repeated. The overall problem with the AODV is the fact that they are using more bandwidth since it has more overhead. If one base station is having scarce bandwidth it is unable to receive routing information from others.

Packet Delivery Ratio (PDR) is part of the QoS representing the number of packets received by the destinations and the packets sent from the sender. It is also considered the most important metric in packet forwarding, being affected by different parameters, such as packet size, group size, node mobility and action range. It usually chooses reliable routes which require fewer hops and longer predictable lifetime; so instead of using the shortest path, it will use the ‘safest’ path. To have the link availability prediction, there is a need for two nodes that maintain their movement patterns during prediction time. A packet that is forwarded is counted as one transmission which is correlated with the number of route changes in the simulation. It is not only important for the prediction, but also for the routing and the vehicles in a way that VANET protocols will provide the best route decisions for the driver. It was also introduced a metric that would estimate the quality of a certain route based on different factors, such as speed, the position of the vehicle, trajectory, etc. which is called expected disconnection degree (EDD). The route with the lowest EDD will be chosen. Overall, the nodes are dynamic by nature, so the packet delivery relies on the connection between two nodes, so by using clustering, location-aware broadcasting and aggregation, the performance of the packet delivery ratio will increase.

### 2.4 Network Modelling and Architecture of VANET

To communicate vehicles, need a model. When talking about vehicle ad-hoc networks there are different possibilities to get to the right model. First of all, vehicles can make use of RSU (Roadside Unit Deployment) which would be antennas that act as the third party for them. Second of all, there is the idea of vehicles communicating between each other directly without the need of any antenna or middle, which is also referred as being an ad hoc architecture which lead us to the third option that is a hybrid architecture in which some vehicles make use of the RSU while other communicate through antennas, but the issue here is that they have to cover the whole vehicle environment. To get this design pattern done we have to look and research into different components of driving, from acceleration, deceleration, changing lanes, human behaviour etc. if we want an error-free packet transmission model. The hardest part in using a wireless network is the actual transmission and reception of the signal since the channel it propagates is very dynamic in nature, by having lots of factors, objects and elements that absorb it or moves its path, which it is important to recover the transmitted signal. Some models have been proposed as a solution for the signal issue.

#### 2.4.1 Free Space Radio Propagation Model

This model aims to transmit the signal in an open space without any environmental effects acting on it.

$$P(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}$$

*Figure 1. Free Space Radio Formula (Poonia, 2012)*

In the above equation, P(d) is the received signal in Watt. Pt is the transmitted signal power, followed by Gt and Gr which are the gains of transmitting and receiving antennas. The λ represents the wavelength, d is the distance between the transmitter and receiving antennas and L refers to the system loss. The big problem with the above model is the fact that cars move through highways and roads with obstacles that affect the signal, technically being opposite to the model's idea of a free of environmental effects (Poonia, 2012).

#### 2.4.2 Two Ray Ground Radio Propagation Model

Being popular in the MANET research it is useful in predicting the received signal over large distances from the transmitter. In the equation below we can observe Pr(d) which refers to the received power at distances followed by elements found in the Free Space Radio Model alongside ht and hr which are the heights of the transmitting and receiving antennas and also L being the parameter that shows the faster power loss as the distance increase. Although better than the free model it is not advised to be used in VANET since there are oscillations caused by the constructive and destructive combinations of the two rays.

$$\mathrm{Pr}(d) = \frac{P_t\, G_t\, G_r\, h_t^2\, h_r^2}{d^4\, L}$$

*Figure 2. Two Ray Formula (Poonia, 2012)*

**2.4.3 Shadowing Radio Propagation Model**

The following model is consisting of two parts. The first part, path loss model, focus on measuring the mean received power at a distance *d*. β is the path loss exponent which can take certain values and also it can be expressed in dB via equation Figure 3.

| Environment | | B |
|---|---|---|
| Outdoor | Free Space | 2 |
| | Shadowing Urban Area | 2.7 to 5 |
| In building | Line-of-Sight | 1.6 to 1.8 |
| | Obstructed | 4 to 6 |

$$\left[\frac{\mathrm{Pr}(d)}{\mathrm{Pr}(d_0)}\right]_{dB} = -10\,\beta \log(d/d_0)$$

*Figure 3. Shadowing Formula (Poonia, 2012)*

The second part of the model aims to show the variation of the received power at an assured distance. Its lognormal random variable that has the Gaussian distribution if it expressed in dB. The equation below represents the overall shadowing model in which XdB is the Gaussian Random variable with 0 mean and standard deviation σdB also known as the shadowing deviation.

$$\left[\frac{\mathrm{Pr}(d)}{\mathrm{Pr}(d_0)}\right]_{dB} = -10\,\beta \log(d/d_0) + X_{dB}$$

*Figure 4. Shadow Deviation (Poonia, 2012)*

The values that can result in the shadowing deviation can be observed in the table below. It can be used in the VANET by having a variation in either β or σdB for different environmental conditions or obstacles.

| Environment | σdB (dB) |
|---|---|
| Outdoor | 4 to 12 |
| Office, Hard Partition | 7 |
| Office, Soft Partition | 9.6 |
| Factory, Line-of-Sight | 3 to 6 |
| Factory, Obstructed | 6.7 |

*Figure 5. Different output based on environment (Poonia, 2012)*

### 2.4.4 Nakagami Radio Propagation Model

It is a mathematical modelling of a radio channel by using fading with the benefit of having multiple parameters which will allow us to look closer and adjust it even for the free space model. The figure below represents the probability density function that is followed by the gamma distribution form.

$$f(x) = \frac{2m^{m}\, x^{2m-1}}{\Gamma(m)\Omega^{m}}\, exp\left[\frac{-mx^{2}}{\Omega}\right], x \geq 0, \Omega > 0, m \geq \frac{1}{2} \qquad P(x) = \left(\frac{m}{\Omega}\right)^{m} \frac{x^{m-1}}{\Gamma(m)}\, exp\left[-\frac{mx}{\Omega}\right], -x \geq 0$$

*Figure 6. The formulas for the Nakagami Model (Poonia, 2012)*

Here the Ω is the value of the distribution, or also known as the average received power., followed by the fading parameter *m* that together with Ω represent functions of distance. The model can be applied to VANET for the performance protocol since varying the *m* parameter we can get a fading scenario like a city or highway.

## 2.5 VANET Communication Challenges

In terms of communication, multiple parts represent the security as a whole that has to be reviewed. First of all, the security of messages is a big issue since the content has to be secure and checked in a short time since it has to be used as soon as possible. We continue with the authentication service which has to assure that the communication is authentic alongside its entities. The vehicle should only act based on messages generated from a legal sender which lead us to authenticate the message senders. Another issue is the integrity of messages which plays an important role in the process since we have to receive an unaltered message, being the same with the one that has been sent. Therefore, we have to prevent modifications, insertions, reordering or replays. Besides these elements, the message content has to be confidential which provides drivers privacy against unauthorised entities. Accessibility plays a key role in the process since there are attackers that will make you lose access to the information (Deny of Service Attack). In VANET security we have a digital signature as building block since validating the participants that send the messages is a requirement to any security system. When the system has more users coming in, it has to be scalable, which means expansion with little performance decrease or network outage. Another aspect is reliability since it is difficult to acknowledge the received message in the opposite direction. In the VANET the vehicles the majority of the messages will be transmitted through a periodic broadcast that announces the state of the vehicle to the neighbours, but it needs to be reliable. Last but not least we have the Media Access Control (MAC) layer that has to access the shared medium which is the wireless channel. In this process, we have to coordinate the transmission of data since there is the possibility to lose data or have a large number of collisions.

## 2.6 VANET Routing

One of the biggest challenges when it comes to designing a vehicle ad hoc network is the creation of a dynamic routing protocol that can distribute the information from one node to another. As mentioned before, it is harder than a mobile network since there is a high dynamic changing topology, which leads us to the main idea of VANET routing: finding and maintaining an optimal path of communication in any environment. There are five categories in which the VANET routing can be classified (Khan, 2013).

### 2.6.1 AD-Hoc/Topology Driven Routing

VANET is an infrastructure-less network similar to MANET, but with slight differences in the topology implementation. In the ad-hoc routing, there are three subcategories: proactive, reactive and hybrid which have elements for design implementation. The proactive part is constantly updating the table with new routes within the network, which is sent to all the other nodes via HELLO packets messages in periods. The drawback of this approach is the control overhead which restricts the use of resources such as bandwidth. The second approach only sends messages when there is a need which reduces the overheads and delivers the information faster, but it puts overheads on the routes maintenance part. The overhead in the reactive category are linked to finding new paths to send the information and the process works via sending Route Requesting Messages (RREQ). If a node wants to transmit information to another node, first thing first it will send a RREQ to its neighbours. When the neighbour node receives the message request, it compares the destination in the message with its identifier. If the identifiers do not correspond with the message, then it will rebroadcast the message to its other neighbours. When the RREQ reaches the destination, it uses a Backward Learning Method to announce the source of its findings through RREP (Route Reply Message) message. The third idea would be to implement the protocol using both proactive and reactive routing which would send a message request to a small number of nodes rather than to all.

**2.6.2 Location Based Routing Protocols**

In this routing protocol, the information regarding a vehicle's location is retrieved using different map systems, such as the Global Positioning System (GPRS) or traces of the traffic models to retrieve information. Unlike topology protocols, the location-based does not need maintenance at the route since it can be established when there is the need for it, which also reduces the constraint on bandwidth. There are algorithms such as Greedy Perimeter Stateless Routing (GPSR) that use the nearest neighbour to get the location, which makes it suitable for dynamic networks since each node knows about its neighbours. Face routing is used in the case of no neighbours by using a perimeter mode. In the urban areas, it is not recommended to be used since there are delays in the PDR, so the researchers created a modified algorithm called Advanced Greedy Forwarding (GPSR-AGF). The difference between the two versions is the fact that the second one includes the speed and direction of the destination node in the HELLO packets that are being sent. Besides these two approaches, there is a third one which makes use of the road layout to discover the destination. Geographic Source Routing (GSR) is making use of this scheme relying on the maps available and the algorithms for the shortest path. A reactive type of protocol has been introduced as well to decrease the overhead which is called Location Assisted Routing (LAR) that is using the window size or the distance variation to determine the next hop. In the simulation of high traffic, it showed the fact that LAR has high connectivity between nodes which results in fewer packets being lost in the process, but on the other side, it has a decrease in the throughput when the number of nodes jumps over 50 since there are high interferences among the transmitted signals.

If we want to focus on an approach that is not relying on external resources but uses the understanding of street paths in urban areas to create a planner graph. The Greedy Perimeter Coordinator Routing (GPCR) make use of this mechanism and the packets are forwarded to a node (coordinator) found on the junction edge and all the decisions on routing are made by this coordinator. Related to this protocol we find a similar one called Anchor-Based Connectivity Aware Routing (A-STAR) which is position based, used in urban environments that uses the information for a particular route to determine the number of junctions for maximum connectivity. This particular approach has been better than GSR or GPSR in terms of performance.

### 2.6.3 Cluster Based Protocols

A protocol known as Cluster-Based Routing (CBR) has been introduced, that creates small groups of vehicles called clusters, each of them having a vehicle with the role of cluster-head. The concept is used in rigid networks when the first thing to do is to establish a mechanism that will create the cluster range and then finding the optimal routes to communicate.

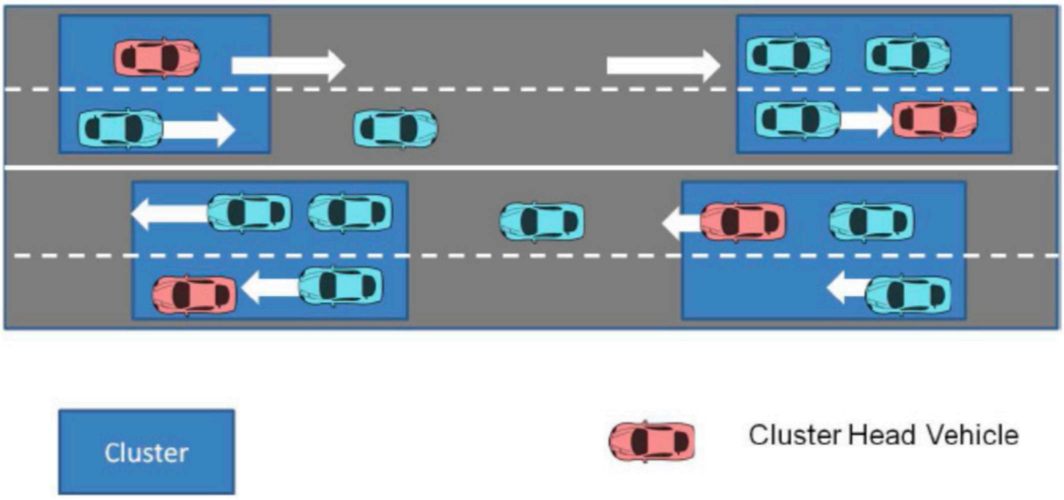


*Figure 7. Vechicle Clustering*

An updated version of the CBR is the LORA-CBR that uses the cluster-head followed by zero or more vehicles and a gateway to communicate with other cluster-heads. The routes are only updated when they need to (reactive approach) and the cluster-heads update the rest of the cluster vehicles with beacon messages to update its parameters. Compared to the AODV and DSR, LORA-CBR showed better performance since we update the cluster-head rather than each vehicle individually and in the case of sending information to other vehicles outside the cluster, the cluster-head will forward the message to the neighbour cluster-head which will continue the process until the message reaches the destination vehicle(that being a cluster-head or in the group of a certain cluster-head that received the message).

### 2.6.4 Broadcast Protocols

Being one of the traditional approaches, the broadcasting protocols use flooding as a method of sending packets to the vehicles outside of the range. Flooding technique refers to the action of sending the packets to every attached node of the source until it reaches the destination. There are two main algorithms related to this subject: BROADCOMM and Nth-Powered P-persistent Broadcast Protocol (NPPB). First of them will take the highway structure, for example, and then simulating the region it will divide it into virtual cells. There is a hierarchy of Cell Reflector (CR) established by the cell members which acts as a base station by gathering messages for the particular cells and their neighbours. Besides that, the CR also takes decisions on forwarding messages to individual vehicles. The NPPB algorithm is designed to mitigate the broadcasting storms in dense VANET situations in such a way that the emergency messages can be transmitted effectively. It mainly focuses on a weighted p-persistent routing scheme which allows further nodes to be accessed easier.

### 2.6.5 Geocast Protocol

The main purpose of the geocast routing is to disseminate the information for a specific area and also narrow down the search for the next hop to a Zone of Relevance (ZOR). A simple scenario for this would be when a vehicle has an accident; it is relevant to report it to the vehicles within that zone rather than the ones located further. There has been a design architecture submitted called Robust Vehicular Routing (ROVER) which floods only the control packets while the data is disseminated in a unicasting way which improves the efficiency and reliability of the scheme. The ZOR is rectangular with width and length which covers all the lanes on the current road. Vehicle node accepts the message if it is in the ZOR and rejects it otherwise which is why the scheme is useful in low-density environments. Another routing scheme that is presented is GROOV for both cities and highways which aims to find the best relay node than using a greedy selection approach. The greedy selection has a focus on reducing the delay but compromises the PDR. To make optimal routing decisions there is a context-based protocol that is introduced, VCARP (Vehicular Context-Aware Routing) that make use of vehicle destination, location, packet cache state for picking the best routing decision. We store the packets in a cache to avoid retransmission which leads to reducing the number of routing overheads in VANET.

## 2.7 Summary

The chapter aims to introduce the concept of Vehicular Ad-Hoc Networks alongside its use in real-world scenarios. We focus on presenting how it will change the way vehicle and their owners will engage with each other in traffic, but also the network is going to reduce congestions, improve the emergency system and provide multiple applications for the participants to make their life easier. Another section is talking about the quality of service and the way algorithms are going to maintain the network performance, even though there are factors that act as obstacles in their way. To create and have these algorithms we take important parameters belonging to the network, such as data latency, bandwidth, PDR, etc. and analyse how we can manage each of them and get to a solution. The last section is providing a brief overview of multiple protocols that can help the inter-vehicular communication to withstand the outside factors and create a reliable way to share information. Some of the categories include Ad-Hoc Protocols that are constantly updating each vehicle with the right information, Location-Based which make use of the car's location in order to create connections, Cluster Protocols and how they create groups of cars that will communicate with each other, Geocast that disseminate the intel for a certain area and Broadcast Protocols which are flooding the nodes with information. Overall, the components, applications and their impact, challenges and routing protocols were discussed in the above chapter.

## Chapter 3
# Bandwidth scarcity in vehicular networks

### 3.1 Bandwidth Scarcity Overview

Vehicle Ad-Hoc Network is aiming to provide communication ways without needing centralised systems or infrastructure. The purpose is to have traffic monitoring, but also to maintain the network efficient and reliable while data is being exchanged. The second idea related to this subject is focusing on providing multiple features for the traffic participants to make their trip easier. By trying to achieve these goals there are obstacles along the way which creates congestion on the network in different scenarios for which we have to find the most suitable solution. The main two problems for this subject is when the traffic is dense and sparse. For dense situations, in which there is a large number of vehicles using the network, the pie everyone has to share it is called bandwidth. Bandwidth is always limited, which is why having a lot of traffic will make it hard for the data to be exchanged in a fast and reliable way between the participants which we so call congestion. The other type of issue is in the sparse situations where vehicles are far from each other, so if one vehicle would like to send data to another one, the problem would be the 'middle' node that might not be reached because of the bandwidth limitations and the long distance that cannot be achieved by the sender. Most of the time we face congestion-related problems in cities, where on a given range there is a large number of vehicles. In the accident scenario, there are traffic congestions as well, which is why the other participants have to be informed about it and also provide alternative routes for better traffic management. The focus of this chapter is to approach different ideas on how to handle the network in case of congestions. The first part will aim to prevent and/or control the congestion by adapting the vehicles based on the available bandwidth. On the other side, the second approach will aim to find better alternatives on how to use different channels to enhance traffic congestions or nearly congested situations.

In terms of information exchange, there are two categories of data: event-driven and traffic management messages. The traffic management messages are the actual beacons (hello messages) that are broadcasted within the network which also contains information about the vehicle node position, speed, direction. The first category, event-driven safety messages, are broadcasted in the event of an accident or emergency. If these types of messages are not delivered on time on the network so that they can inform the vehicles, there can be serious issues, accidents and congestion in the traffic, which is why we have to provide suitable solutions that will lead us to safe driving.

### 3.2 Approaching Beacon Congestion

The vehicles are always on the move, making VANET a dynamic network, each node being closer or further from the other ones, depending on time and location. Most of the time we will want to design protocols that will prevent congestion, rather than dealing with it. The big issue in such a network is the fact that being dynamic is leading to Control Channel (CCH) congestion that will decrease the performance since it is hard to predict how vehicles will move and also when a problem will arise. The protocols that are preventing the congestion are usually analysing the channel, so when there is overload, it will start some procedures/protocols that are trying to solve the issue.

#### 3.2.1 Dynamic Congestion Control Scheme

The following protocol has two components when talking about detecting congestions: self-originated event-based detection and neighbour-originated event-based detection. First of the elements is monitoring the safety messages and applies congestion control when necessary even though the messages are created by themselves. A relatable example would be the application layer of a vehicle that launches the safety message (a car that had an accident) that should be sent to other vehicles to be informed about its status; so, the congestion control mechanism is automatically deployed due to predictable congestion. The neighbour-originated detection is monitoring the safety messages received from neighbour nodes rather than itself, so when the message is received by a surrounding node the congestion control will launch through timestamp values of the messages. Based on the methods described above the channel usage is measured and compared to a predefined threshold to know when to increase the traffic or to launch the congestion control protocol (Qureshi, 2018).

$$\text{Channel usage} = \frac{\sum (wt_{busy} \times D_{busy} + wt_{backoff} \times D_{backoff} + wt_{AIFS} \times D_{AIFS})}{D_{CCH}} \times 100\%$$

**Algorithm 1** Weighting factors assignment.

if $(D^{max}_{backoff} - D_{backoff} > (\frac{D^{max}_{backoff}}{2}))$ *then*
  $wt_{busy} = 0.5$
  $wt_{backoff} = 0.35$
  $wt_{AIFS} = 0.15$
*else*
  $wt_{busy} = 0.5$
  $wt_{backoff} = 0.25$
  $wt_{AIFS} = 0.25$

*Figure 8. Weight algorithm (Qureshi, 2018)*

In Figure 8. we can observe the algorithm that is measuring the usage of the channel. The first element in the equation is Σ which denotes the overall busy time of n messages on the channel, followed by the weighting factor (*wtbusy*) and duration (*Dbusy*) the channel business for the sensed messages. There are the mean back-off weighting factor(*wtbackoff*) and duration(*Dbackoff*) of the safety messages but also the weighting factor(*wtAIFS*) and duration(*DAIFS*) of the safety message length. The last parameter is representing the duration of one control channel interval (DCCH). All the weighting factors have the sum equal to 1, but each of them gets assigned a value in the (0,1) interval. After the channel usage is calculated, the usual threshold that is being compared to is 70%. If the channel usage is equal or less than 70%, the usage is in its normal levels, but for values exceeding 70%, we are talking about a congested channel state. For the second part of the protocol, we will be discussing the congestion control mechanism, now that an overview of the detection has been provided. To have congestion-free channels, we are using two methods for managing overload: queue freezing and adaptive congestion control.

**Algorithm 2** Queue Freezing.

```
if      (A safety message is self-generated)
    Freeze all MAC queues immediately for all other messages except for the safety queue;
else if      (Safety message received from neighbours)
    If (message-time stamp > threshold – time stamp)
    Continue; || message is old therefore no need queue freezing
    else
    freeze all MAC queues immediately for all other messages except for safety messages;
    end if
End if
```

*Figure 9. Queue Freezing Algorithm (Qureshi, 2018)*

For a message originated queue freezing, the MAC queues are frozen based on the origin point of the message which is either itself or generated by a neighbour node. To launch and act it also checking the timestamp of the message (Figure 9.). On the other side, the adaptive congestion control is reserving a portion of the bandwidth for safety applications by using two strategies. The level-based strategy is having three levels (30%, 70% and 90%) that are using the channel usage and a calculation conducted over some time to determine if the channel may fall. For a given time duration, if the traffic is higher than 5% then it is considered to be increasing; on the other side of the traffic is reduced by 5% then the channel is decreasing (Figure 10).

**Algorithm 3** Adaptive congestion control.

```
Notations:
Increasing state: ± 5%
Decreasing state: −5%
Th^q:   Threshold queue freezing (90%)
Th^c:   Threshold congestion (70%)
Th^s:   Threshold sparse (30%)
CW:   Contention window
AC:   Access category
if      (channel state > Th^q)
    If (Channel state = = increasing)
    Freeze all;
    else if (Channel usage > Th^c)
     If (Channel state = = decreasing)
     if (CW(AC) < CW_max (AC)
     (CW(AC) = CW(AC) × 2
     end if
    end if
    else if (Channel usage > Th^s)
     If (Channel state = = decreasing)
     if (CW(AC) > CW_min (AC)
     (CW(AC) = CW(AC)/2
       end if
    end if
  end if
end
If
```

*Figure 10. Adaptive Congestion Control Algorithm (Qureshi, 2018)*

### 3.2.2 Non-Cooperative Power Control Game

In VANET, most of the beacon congestion control processes are represented by the Channel Busy Ratio (CBR) which is usually used in the detection mechanism. CBR can be defined by the ratio between the time a channel is busy to the sampling time, all being measured based on the Clear Channel Assessment (CCA) function according to the IEEE 802.11 standard. CBR is also used in most of the protocols and mechanisms since it is also an indicator of beacon message dissemination. The CBR can have a centralised approach, under the name FPAV (Fair-Transmit Power Control) that is using synchronisation between vehicles. First, there is a power level that is computed which is later compared to a certain level, like a threshold, and once the power is under that threshold, all the vehicles increase their power in the same manner (synchronised) by the same amount. The formula used in this algorithm is knowing about the vehicle density and also the packet size that is being transmitted by the vehicles. Another approach of the FPAV is D-FPAV which is the distributed version of it, that to calculate the channel load for every vehicle, the excess information will be sent on the back of beacons which is a problem since there are multiple neighbours. The best solution to save time is to allocate the information to each tenth beacon message rather than for each one of them (Goudarzi, 2019).

### 3.2.3 Local Map

Automated driving systems have to share information to have enough data to drive along the path in a reliable way. Instead of only sending beacon messages, we can use a locally created map data that can be accessed by the cars in a certain range of it which will lead to optimal use of the communication channel. There has been introduced an algorithm called Dedicated Short Range Communication (DSRC) that facilitates the above needs of intel exchange alongside traffic control systems, devices linked to the network carried by pedestrians that will enrich the map and how the automated systems drive on the road, but also how they perceive the surroundings by making a combination between locally sensed data into a map of situations. This map can be improved with multiple features once it has enough information, such as crash avoidance in different dangerous regions, long-range trajectory planning, re-routing of vehicles and so on so forth. The data in the exchanged messages is called the Basic Safety Message (BSM) in the USA and Context Awareness Messages (CAM) in Europe. The information collected in the beacon messages is recorded using the Global Navigation Satellite System (GNSS) receiver from the vehicle, alongside data provided by the local sensing systems like radars, cameras, LIDAR which shared with other vehicles will create benefit for everyone. The problem here is the huge data load that is on the network which is the main cause of congestions. A proposed solution for this issue is the LIMERIC (Linear Message Rate Integrated Control) algorithm which selects the transmit power based on the awareness distance and the rate is adapted based on the channel load (Bansal, 2013). Another idea to improve the scheme is to have a mechanism that will limit the wireless bandwidth that is allocated to the objects that provide information based on the number of requests that we receive from them by manipulating the MAC. The congestion control algorithm here is proposed by ETSI (European Telecommunications Standards Institute) which is a Decentralised Congestion Control (DCC) type. It takes the channel load and uses its feedback to regulate the message rate with three options to choose from: relaxed, active and restrictive. In a comparison between LIMERIC and DCC, LIMERIC is achieving lower reception intervals and tracking errors than DCC, which is one of the features of LIMERIC, to drive the load on the channel to a certain target to achieve maximum throughput even though in dense situations. Also, DCC shows the fact that it is unstable when it controls the gatekeeping and message generation. Even if the DCC would be improved there is no chance it can achieve stability and convergence.

### 3.2.4 Distributed Congestion Control

In the IEEE 802.11, the congestion control is classified into 4 categories, based on the mechanism used. First of them would be the Rate Adaption Based Approach in which the packets transmission rate is reduced to ease the channel competition among vehicles based on the network density. The second approach has the focus on a modified CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) protocols that are located in the MAC layer and also has control over the channel access for each vehicle. The solution is to weaken the channel access ability by modifying some parameters of the CSMA/CA protocol. The third approach is related to power adaption which is aiming to reduce or increase the power for each vehicle based on the channel load. If the transmission power decrease, the channel load decreases as well and the same applies in the opposite direction. The last idea is to have a hybrid approach in which we take the rate adaption, power adaption and also the modified CSMA/CA to solve the congestion, by taking each of them as parameters and adjust according to the environment conditions of the network (Shen, 2012).

When the channel gets congested there are two consequences: some cars are going to be on the queue for way too long and since there is higher collision probability, the transmission failure can occur as well. The first thing we have to do is to measure the congestion by having an AC, v, with traffic priority m and apply them in the formula below (Figure 11).

$$C_m(v) = \frac{N_{\text{queue}}(v) + N_{\text{fail}}(v)}{N_{\text{total}}(v)},$$

*Figure 11. DCC Formula (Shen, 2012)*

Here we have the number of packets on the queue (N*queue*), followed by the number of failed to send packets (N*fail*) and the total number of packets (N*total*) that were generated by AC *v*. Basically if the Cm becomes larger than the congestion problem of the channel is getting more and more serious and in the case of transmission failure it can be also substituted by the number of packet that were send unsuccessfully. To address the issue, there has been an algorithm proposed in which there are multiple priority levels involved. In the traffic we have M that represents multiple priority levels, then there is the AC *v* with *m* = 1, 2, …., M in a vehicle which is measuring the congestion condition, then there is *T*, the time interval predefined. During the time interval, AC *v* is counting the above parameters (Ntotal, Nqueue, N*fail*) and always update the Cm(*v*) at the end of each T (time interval). Based on the priority level, there is a threshold assigned and denoted by Cth(*m*). If Cm(*v*) is greater than the threshold Cth(*m*) then the radio channel is getting more and more congested so the AC should increase the CW (Content Window) by multiplying a scaling factor *a* (usually a=2) until it reaches the initial value and also divide by *a* for the opposite scenario. The three parameters used in measuring the congestion condition are always assigned 0 at the start of each time interval *T*. The priority level will also have an impact on the threshold since a lower priority will also mean a lower threshold value, so when the density of the network is low, there will be low throughput as well since the CW will be increased by the AC. On the other hand, if the density is higher, there will be more collisions because AC would not increase the CW accordingly which is why the threshold should be dynamically adjusted based on the network density.

-

Table 2. Existing congestion control approaches for the IEEE 802.11p vehicular network summary table.

| Categories | Approaches | Communication Scenario | Measurements | Performance Improvements | System Overhead Request | Priority Consideration |
|---|---|---|---|---|---|---|
| Rate adaption based approach | UBPFCC [10] | V2V | Number of neighbor nodes; effective data rate | Fairness; channel utility; drop rate | ✓ | ✓ |
| | ODRC [11] | V2V broadcasting | Packet erasure rate; channel utilization | Tracking error | × | × |
| | F. Ye, et al. [12] | V2V broadcasting on 1-D spatial network | Vehicle density | Broadcasting efficiency | ✓ | × |
| | C. Chuang, et al. [13] | V2I | Queue length | Packet dropping probability | × | ✓ |
| | J. He, et al. [14] | V2V | MAC blocking event | MAC blocking time; packet reception ratio | – | × |
| Modified CSMA/CA protocol based approach | AoS [15] | V2V broadcasting on high way | Number of neighbor nodes | Throughput; packet loss probability | ✓ | × |
| | H. Jang, et al. [16] | V2V | Number of competing nodes | Throughput; collision rate; delay | ✓ | × |
| | Y. Zang, et al. [17] | V2V | Channel usage | Warning delay | ✓ | ✓ |
| | M. Barradi, et al. [18] | – | – | Collision rate | × | ✓ |
| | M. S. Bouassida, et al. [19] | V2V | Message priority | Warning delay | ✓ | ✓ |
| | SR-CSMA [20] | V2V | Location and power | Beaconing delivery ratio | ✓ | × |
| Power adaption based approach | D-FPAV [21] | V2V | Beacon load | Probability of message reception; channel access time | ✓ | ✓ |
| | Y. P. Fallah, et al. [22] | V2V broadcasting on high way | Channel occupancy | Tracking error | × | × |
| | L. Wei, et al. [23] | V2V multi-hop broadcasting | Distance; channel occupancy | Delay; packet delivery ratio | ✓ | × |
| | MUDDS [24] | V2V unicasting | Distance; vehicle density; packet reception rate; link availability rate | Delay; packet reception rate | ✓ | × |
| Hybrid approach | C. Huang, et al. [25] | V2V broadcasting | Packet erasure rate; channel occupancy | Tracking error; packet loss ratio | × | × |
| | W. Guan, et al. [26] | V2V in the intersections | Number of vehicles | Message success probability; average message delay | ✓ | × |
| | M. Sepulcre, et al. [27] | V2V for lane change assistance application | Distance; position | Channel busy time | ✓ | × |
| | S. Djahel, et al. [28] | V2V | Average waiting time; collision rate; beacon reception rate | Delay; beacon delivery ratio; emergency messages reception ratio | ✓ | ✓ |

*Figure 12. Congestion Control Approaches (Shen, 2012)*

### 3.2.5 Mobility Prediction-Based Beacon Rate Adaption

The main idea is to have vehicles use their neighbours to know what to do and when to do it in different situations. They make use of predicted moving states from the other vehicles if the prediction error of their own is less than a certain threshold. An example would be when there is a traffic jam in certain regions, so the velocity will be low as well, making it easier to predict the way vehicle move. The moving state can be in a vector representation X = [X, Y, V, D] where [X, Y] represents the vehicle coordinate and [V, D] is linked to its velocity and direction (Li, 2018). The algorithm has four parts: detector module, prediction module, Kalman Filter and a beacon generator. The first element has to provide the position of the vehicle (latitude and longitude) through the GPS and the speed, based on the vehicle speed sensor. Based on this, it is possible to predict the direction and acceleration which will be used in the predictor module and Kalman Filter at a certain time *k*. The prediction phase uses the classic kinematics laws to predict the vehicle movement at moment k based on moment *k-1* if there is no beacon broadcasting triggered. The moving state at that time is estimated by the Kalman Filter that is estimating a joint probability distribution over some noisy measurements on a given timeframe. The last part of the algorithm, the beacon generator is comparing both results from the Kalman and the prediction phase over a threshold and decides if there is going to be a beacon broadcast triggered.

### 3.2.6 Geocast Message Forwarding

In VANET the ideal would be that the message exchange would happen in a fast and reliable way. In a dissemination mechanism, a node is broadcasting a message to its neighbours within the transmission range. The data is retransmitted by the neighbours in their transmission range limit as well with the process keep on being the same for the other neighbours until the message arrives in all the nodes on the network. This type of broadcasting mechanism is known as geocast. There is a ZoI which is a geographic area where the messages will be broadcasted through this protocol which implies having a dynamic decision making at each hop since vehicles can enter or leave the ZoI at any time. Problems like increased collision probability, longer waiting times between nodes and lack of coordination of the messages, also known as broadcast storm, can happen at any time which is why a new protocol called Geocast Message Forwarding (GEM) has been introduced. Its main purpose is to minimize the number of transmissions that are being made in the ZoI by identifying the next hop before sending the message. Figure 13. is showing the execution of the algorithm by firstly deciding on which is going to be the next hop, by creating a table with possible candidates based on the congestion messages received over a while (Lima, 2018). The most important part is to select candidates that will have less hops to send the information further (in a way that it covers the ZoI), but also to have quality channels in order to ensure proper communication. There is also the possibility to choose more than one neighbour, so after the program decides which node(s) to send the information, their "name" is recorded in the message header which is then sent by geocast. The message arrives at the first chosen node since it has a higher priority than the second which acts like a plan B, and in the case of failing to forward the message, then the second node will check if it is in the ZoI first, and then it will try to send it. When the last step is achieved, the node that is located at the border of ZoI will transmit an empty list to the other's which will indicate that there are no more hops to transmit the message to, but also the end of the protocol as well.

**Algorithm 1** Geocast Message Forwarding Protocol

- **Step 1:** The source node $v_i$ triggers a geocast message $m$ and broadcasts it. Message $m$ includes, among other information, the ZoI, the location where the message was triggered and a list $L$ of relay nodes that, upon receiving the message, shall relay it.
- **Step 2:** On receiving message $m$, node $v_j$ checks whether its ID is included in the list $L$. The priority to relay the message is given the order of the nodes ID in the list.
- **Step 3:** When a node $v_j$ is at the edge of the ZoI, such that relaying the message $m$ is not necessary, it sends the message with an empty list $L$.

*Figure 13. Geocast Protocol (Lima, 2018)*

**3.2.7 Rate/Power Adaption Protocol**

The following protocol is aiming to find and update the optimal channel utilization rate which would also minimise the probability of collisions. The idea is focusing on using the binary search algorithm to find the optimal channel load value and apply it to the other vehicles by adapting the beacon TR (Transmit Rate) and TP (transmit Power). An iteration is related to one CCHI (Control Channel Interval) and the main parameters used here are the collision rate and the busy ratio. First and foremost, we will check the collision and busy ratio in order to determine if we should increase the TP/TR values or decrease them. If the collision rate is higher than normal, we will decrease the TP or the TR. On the other side if the collision rate is below then we will check the busy ratio and increase the *Tx* parameter in order for it to increase. After adapting the TP and TR we will increase the *Tx* or decrease it at each CCHI by using the Euclidian distance between the channel parameters (collision rate and busy ratio). After each CCHI the bounds are going to be updated with the TR*min*/TR*max* and TP*min*/TP*max*.

**Algorithm 1** Successive TR and TP adaptation SuRPA

**Input:**

$GI$: gradual_increase_rate
$CL$: confidence_level
$C_{ac}$: acceptable_collision_rate
$B_{op}$: optimal_busy_ratio
$C_c$: current_collision_rate
$B_c$: current_busy_ratio

At the end of each CCHI do:
**if** ($|C_c$ - $C_{ac}| < CL$) **then**
  *Reinitialise* $TR_{max}$ *and* $TP_{max}$
  *Reinitialise* $TR_{min}$ *and* $TP_{min}$
  Exit
**end if**
**if** ($C_c < C_{ac}$ && $B_c < B_{op}$) **then**
  **if** ($TP$ == $TP_{max}$ && $TR \leq TR_{max}$) **then**
    $TR_{min}$ = $TR$
    $TR$ = $Min$ ($TR$ * [$Min$ (1 + ($B_{op}$ - $B_c$), $GI$)], $TR_{max}$)
  **end if**
  **if** ($TR$ == $TR_{min}$ && $TP \leq TP_{max}$) **then**
    $TP_{min}$ = $TP$
    $TP$ = $Min$ ($TP$ * [$Min$ (1 + ($B_{op}$ - $B_c$), $GI$)], $TP_{max}$)
  **end if**
**end if**
**if** ($C_c > C_{ac}$) **then**
  **if** ($TP$ == $TP_{max}$ && $TR > TR_{min}$) **then**
    $TR_{max}$ = $TR$
    $TR$ = $Max$ ($TR$ * [1 - ($C_c$ - $C_{ac}$)], $TR_{min}$)
    Exit
  **end if**
  **if** ($TR$ == $TR_{min}$ && $TP > TP_{min}$) **then**
    $TP_{max}$ = $TP$
    $TP$ = $Max$ ($TP$ * [1 - ($C_c$ - $C_{ac}$)], $TP_{min}$)
    Exit
  **end if**
**end if**

*Figure 14. Rate/Power Algorithm*

### 3.2.8 ABC Protocol

The ABC mechanism, also known as Adaptive Beacon Control for Rear-End Collision Avoidance is designed to solve the congestion through multiple processes. As in any protocol related to VANET, we have to check the congestion level, so the algorithm is exchanging beacons amongst neighbours and then it detects congested channel conditions online. Once we detect congestion, the nodes within its THS will adapt the beacon rate to suppress it. The third step is to implement an algorithm known as DBRA (Distributed Beacon Rate Adaption) in a TDMA (Time-Division Multiple Access) broadcast contexts which have an NP

(Nondeterministic Polynomial-Time) – Hard of execution. A greedy heuristic algorithm is then used to solve the problem which at the end of the protocol will inform the other vehicles on how to adapt their transmission rate accordingly (Lyu, 2018).

### 3.2.8.1 Online Congestion Detection

To detect the congestion, the mechanism starts by exchanging beacons. Each vehicle broadcasts intel about itself and the other one-hop neighbours while the beacon status is having the information for the beacon rate $\alpha$ and the danger coefficient $\rho$. So, a vehicle $x$ will update its danger coefficient according to the kinematic information received by its sensors and the one-hop neighbours (collected in the previous slots) which will lead to a beacon status of each neighbour. After the vehicles know this information, they will be able to detect the congestion.

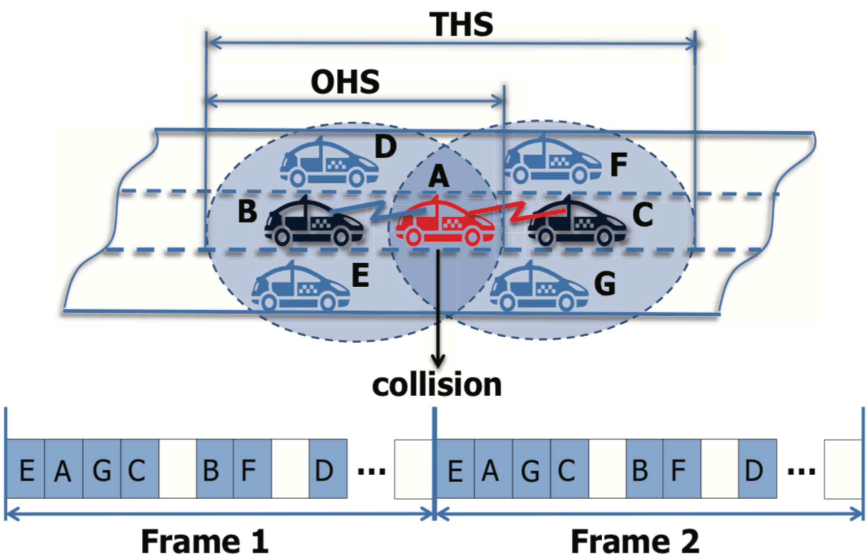


*Figure 15. ABC Protocol range (Lyu, 2018)*

### 3.2.8.2 Distributed Beacon Rate Adaption

If there is congestion detected, each node has to adapt its beacon rate transmission to stop the ongoing congestion. Two constraints have to be taken into consideration: the periodical beacon rate which refers to the beacon broadcast at a certain time slot every t frames and being silent at t-1 frames. The second constraint is the bandwidth limitation, which has a limit and the beacon bandwidth should not exceed it if we do not want to have congestions. The DBRA is NP-Hard since we can devise the polynomial reduction from a classic NP problem which leads to MCKP (Multiple-Choice Knapsack Problem) that is a variant from the original Knapsack problem. We have also the heuristic algorithm (greedy heuristic) that is used to assign a beacon rate for each node. MCKP can be implemented through DP (Dynamic Programming), but it is not acceptable for online decision making because of its pseudo-polynomial time complexity. First of all, each node is assigned with the minimum beacon rate and then the rest of the resources are ranked based on the danger coefficient and the vehicle with the largest ρ will get more resources until it reaches the maximum beacon rate ($\alpha max$). The procedure is looping until there is no medium resource available, but the algorithm might be unfair in assigning the danger coefficient since vehicles are constantly moving and the ρ is varying dynamically.

### 3.2.8.3 Adapting Results

When the DBRA phase is finished, we have to inform the other vehicles about the rate they have to adapt. The DBRA will compare the results from nodes then it will send them to the cars which will receive and compare the rate to their current rate, first, and then the rate will be changed accordingly.

### 3.3 Cognitive Radio Technology

The nodes that exchange information in VANET are making use of a spectrum that is being licensed and approved for this purpose, but there is an unlicensed part of it that is unused, which presents an opportunity for accessing more resources for the network. CR (Cognitive Radio) is using an opportunistic spectrum access procedure to exploit these resources and the Tv broadcasting spectrum that is being wasted. The DSA (Dynamic Spectrum Access) alongside RC (Radio Cognition) have been able to take the unlicensed users and capture the spatial-temporary licensed spectrum holes that were available, as long as the PU (Primary User) is not perturbed. In the CR-VANET (Cognitive Radio Vehicle Ad-Hoc Network) we have two features that are important: cognitive capability and reconfigurability. The components of CR in a vehicle are represented by learning engine, radio, reasoning engine, optimization tools, sensors, knowledge database, etc. which gives CR the possibility of gathering information in different ways from the environment. By saying that it is reconfigurable, we refer to the fact that it can adapt the operational parameters to the results gathered through its components. When the PU is idle, the SU (Secondary Users) can use the spectrum through CR. To work as it should be in the process of finding available spectrum, CR is using more phases like observing, analysing, reasoning and acting. We want to find and select an available spectrum, then choose the best operational parameters and coordinate the access with the other members/users and afterwards we reconfigure the operational parameters using the CR feature, then vacate the frequency when a PU is not idle anymore.

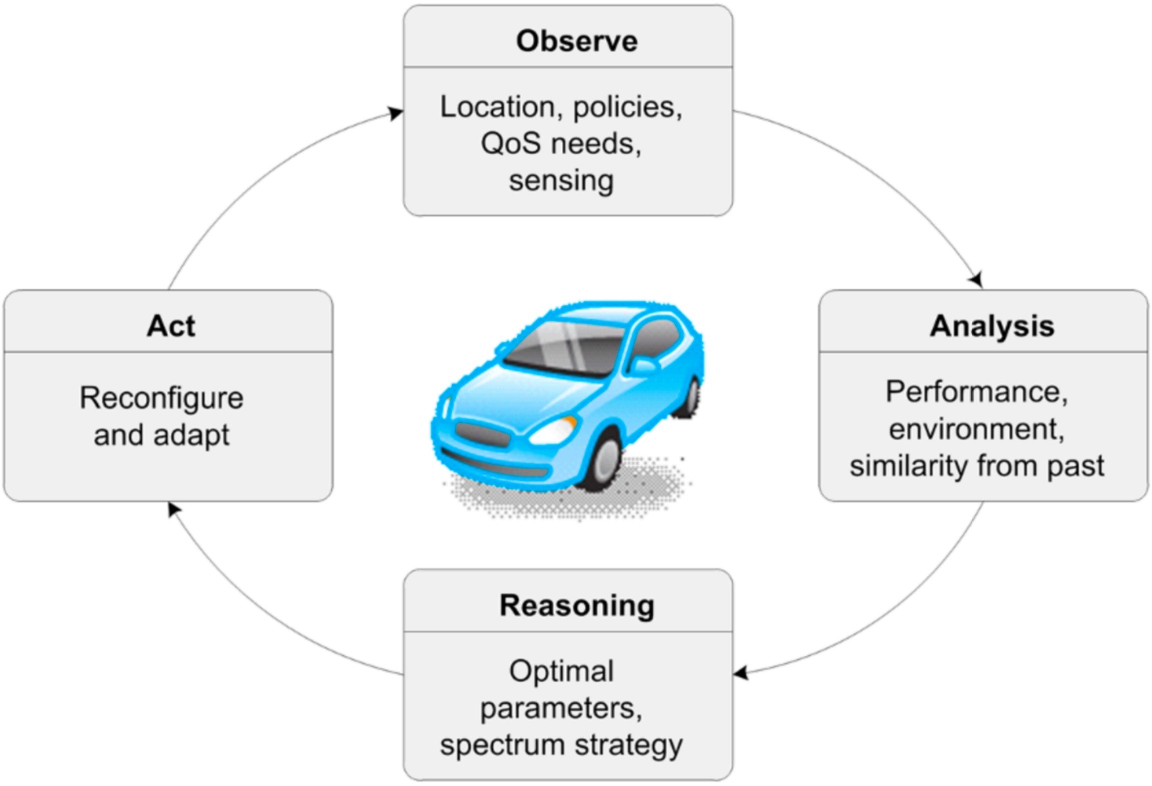


*Figure 16. Cognitive Radio technology Process (Singh, 2014)*

So far, this topic is in the research stage rather than in the implementation one since there are multiple elements from architecture to protocols and policies that have to be adopted first (Singh, 2014). First and foremost, the architecture for such system is costly since it has to have base stations (RSU) as infrastructure (on the road) and OBU (On-Board Units) being implemented on each vehicle along different sensors as well since the mechanism needs knowledge databases, spectrum information, radio maps, etc. The core part of the system is represented by the cognitive engine which drives its functionalities and takes as input the data recorded via the sensors mentioned above with the information from the knowledge database about what these sensors recorded in the past. By combining the past information with the present/real-time data we have a machine learning mechanism that is going to perform different actions based on them, from transmission optimization to spectrum management. There are multiple ideas for machine learning models that can be implemented or designed for the CR-VANET, such as Case-Based Reasoning, support for Neural Networks which can be useful in finding the spectrum holes and predicting the channel, Reinforcement Learning that can be used in real-time learning alongside selecting the proper channel fast, Genetic Algorithm that can optimize the transceiver parameters.

### 3.4 Summary

In the above chapter, there has been a brief presentation of the network scarcity problem regarding the bandwidth followed by different approaches in terms of protocols. There are two main types of approaches, the beacon and the cognitive radio technology that is currently newly introduced in the context of VANET. The beacon approach has covered ways of exchanging data in-between the nodes of the network, by focusing on location, transmission rate/power, prediction-based and so on so forth, while the cognitive radio technology has been focusing on introducing machine learning and AI in the context of VANET by equipping vehicles with different type of sensors that would collect information from the surrounding environment. Next section of the report will aim to overview these protocols and based on this; a new algorithm will be introduced.

Chapter 4
# Proposed Solution

## 4.1 Key Principle

VANET is an important technology for the future of transportation, making it easier and safer for drivers to get to a certain destination, avoiding any unwanted events and also having entertainment while being on the road. If we want to succeed in creating this system, we have to design and implement algorithms that would provide reliability first, since safety is one of the most important elements in the equation, speed, because every incident or new information might help the participants to choose a better way of driving to the destination and also an optimised use of resources. In the chapters presented above, we have seen how researchers created multiple protocols and algorithms to address these issues, but each of them has benefits and drawbacks, depending on the execution and idea brought for each of them. The most suitable solution would be to incorporate small elements from each of the best protocols/algorithms while focusing on technology created for the future. In the process of designing an algorithm, the first thing to do was to classify the details and pieces that represent the VANET. First of all, we are on planet Earth, which has multiple types of landforms, such as mountains, valleys, hills, islands, etc. where the network behaves differently based on the region. Next thing would be the human settlements, like urban, rural, isolated which will predict the number of vehicles/nodes the network will have to deal with. The third element would take the road and vehicle types, since a car, a bus or a truck behaves differently in traffic and also on certain street categories which affect the traffic flow. These vehicles have to communicate through the available technology, that would be WLAN (Wireless Local Area Network), LTE (Long Term Evolution)/5G, VLC (Visible Light Communication), etc. and there is some infrastructure that can be involved as well, such as RSU, OBU (On-Board Unit), Servers, Cloud Infrastructure, but also dissemination techniques as well, from V2V (Vehicle-To-Vehicle), V2X (Vehicle-To-Everything), V2I/I2V (Vehicle-To-Infrastructure/Infrastructure-To-Vehicle) to Opportunistic, Geographical, P2P (Peer-To-Peer) or Cluster-based. Besides the technical part, the protocol has to adapt rapidly in the case of disconnections or in the case of dynamic mobility of the vehicles which are constantly exchanging data through mesh nodes and through different structures that might affect the network signal. Overall, the algorithm is going to be represented by a combination between the emerging 5G technology and its features, such as C-RAN and Fog Computing with previously discussed protocol elements, like cluster-based, cognitive radio and geocast. The idea is focusing on a big abstraction picture in which vehicles from areas are clustered, followed by a cluster based on areas and regions and then a broader cluster over the network and map. The use of machine learning would benefit the knowledge database with information regarding traffic since it will be updated from each vehicle data. The bandwidth will be assigned according to each region; an area with more crashes and accidents will have more bandwidth since the probability is higher than for its neighbouring regions. In the following section of the chapter, there will be a step by step explanation of the algorithm alongside its elements and how they help it in the process, the benefits that will be provided to the public and the VANET and also the drawbacks since nothing is ever perfect.

## 4.2 Main Steps

### 4.2.1 Vehicle Communication

Some multiple ways and protocols allow a vehicle to exchange data, but one of the most effective, so far, is the use of 5G technology. Currently being implemented in MANET among most of the developed countries, like the USA, UK, Germany, France, etc. represents an advancement in terms of features and speed. Bandwidth is getting an upgrade compared to the 4G-LTE network, even though there are LTE bands that excel the 5G speed since it is still in development, which is a core element in the VANET that is avoiding congestion on the network. The number of devices supported by 5G is at around 1 million/km^2, that is ten times more than the previous generation of the cellular network was able to cover. In our situation bandwidth and coverage is very important since the number of vehicles on the road increase each year which lead to more bandwidth usage. The proposed solution is making use of fog computing and C-RAN (Cloud Radio Access Network) for the whole system to be able to send and receive information as fast as possible by making use of 5G and also to avoid the congestion of any kind on the network.

The whole system is made up of different components with a certain hierarchy (Figure …..). First of all, there are the SDN (Software Defined Networking) controllers that represent the core elements that are managing the network and its operations, such as resource allocation, mobility management and rule generation. They can also use some functionalities like learning, analysing the network and pre-process the data, but also, they manage the fog and its resources. Under the SDN Controllers, there are the FC-ZC (Fog Computing Zone Controlled) that are the computing enhancements in terms of CPU and storage that have access to VANET infrastructures like RSU and BS (Base Stations) that are connected further with BBUC (Base Band Unit Controllers). The role of the BBUC is to link the FC-ZC in-between that act as a digital unit responsible for implementing the base station functionalities from baseband to packet processing. The fourth element in the scheme is the FC-CH (Fog Computing Cluster Heads) that are under the FC-ZC management directly. They are equipped with SDN-enabled OBU. The end-users in the scheme are the FC-Vehicles that have the same equipment as FC-ZC, but they also have different functionalities like GPS sensor system, packet forwarding, interface selection and different transmission modes, such as V2V or V2I. The transmissions in-between these components are being made through the optical fibre and by the use of OTN (Optical Transmission Network).

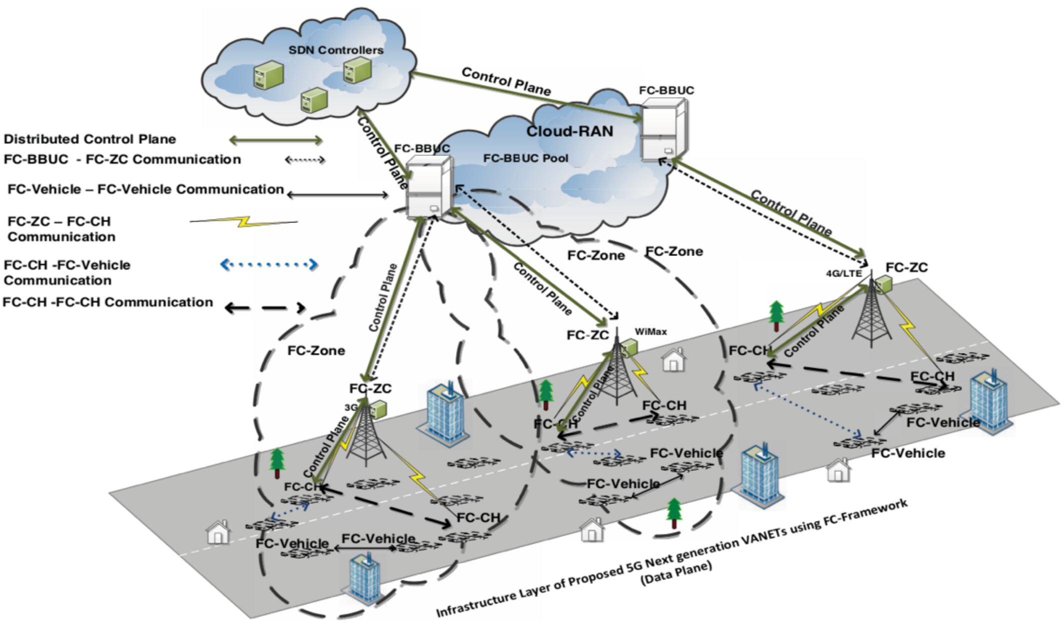


*Figure 17. Fog Computing and C-RAN illustrated(Khan, 2018)*

There are three parts of the logical structure for this architecture: data plane, control plane and application plane. First of them has two functions: the information gathering that is making use of different sensors in order to gather intel like position, speed, CCTV footage, network cameras, lane check camera, etc and the communication module which is connecting vehicles or FC-ZH in-between, but also include the communication modules like FC-BBUC and FC-ZC. The control plane is having SDN that decides the rules and policies. Although being the highest in the hierarchy, it will not control the whole network, but instead, there will be abstract policies sent to the FC-ZC, FC-BBUC and FC-CH which will interpret them and act as well (it depends on their local intelligence). The modules related to the control level are: information gathering that will help in the drawing of a global network map based on the intel received from the data plane, computing and storage modules, which are deployed in these types of systems, network status and monitoring, which is responsible for monitoring the links of SDN-based VANET architecture, inter-FC-zone communication, refers to FC-ZC to provide communication between components, inter-BBUC communication and intra-FC-zone communication, that is configured in FC-CH to provide communication between FC-CH and FC-Zone. Lastly, the application plane is most of the time responsible for generating strategies and rules based on requirements of the vehicles and then forward them to the control plane (Khan, 2018).

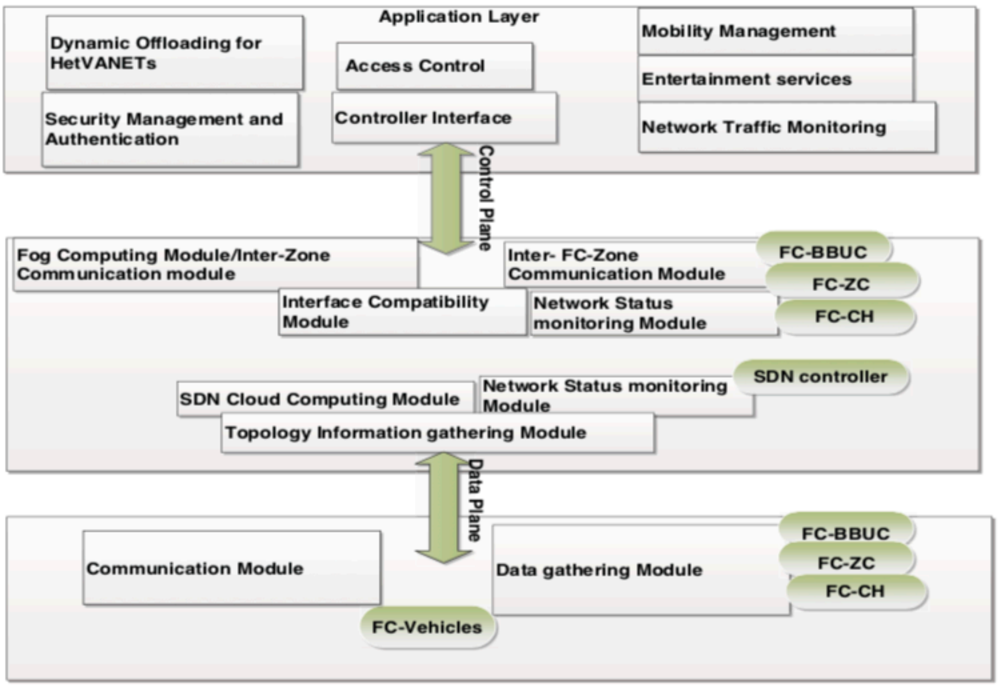


*Figure 18. The three planes (Khan, 2018)*

Simulation has shown the fact that implementing the SDN, fog computing system with 5G is having a good impact on the throughput and the delay of the transmissions. In Figure 19. you can observe the results of the proposed architecture compared to the traditional one and the normal 5G SD VANET alongside the decrease in delay.

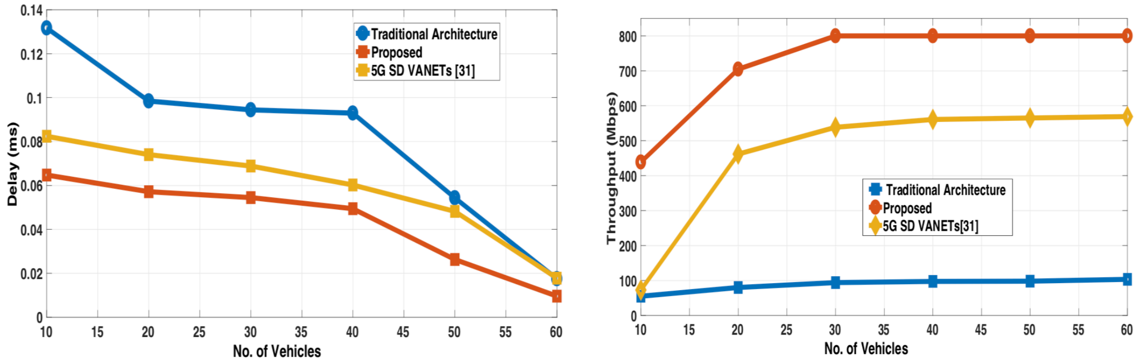


*Figure 19. Simulation Results (Khan, 2018)*

### 4.2.2 Clustering

After explaining the way vehicles will communicate, the next section is about clustering. The above idea is the best working when combined with a cluster-based approach (Altayeb, 2013). First of all, the vehicles on the street will use the cluster-based protocol to create small groups of cars that will communicate using the above protocol. After these small clusters are being created, we will continue to cluster small areas (for example, city areas within a given range, approximately 150-200m). The abstraction continues by clustering these areas into regions (cities, towns, villages) that are going to belong to the network. The purpose of this classification is simply to know how to allocate the bandwidth. The network is having a certain bandwidth over the highest hierarchy member of this scheme which will be allocated for the regions and areas, then to vehicles based on the priority of these. By using machine learning we can predict and classify the regions and areas that are most likely to possess a higher probability of congestion, so there will be different priorities based on the importance of the zones. For example, if an area, belonging to a city, is complicated in terms of streets, road signs and the number of car accidents is higher than the neighbouring areas, then it will get more bandwidth rather than the neighbours since the probability for another accident/congestion/traffic jam is higher.

### 4.2.3 Markov Chain

In the above chapter we have talked about cognitive radio technology and how vehicles are getting equipped with different types of sensors that will retain information, share it and use this data to predict scenarios and patterns. So far, the algorithm is using clustering to assign bandwidth to regions and vehicles, while 5G and its functionalities are playing the big part in the data exchange. We want vehicles to collect data from the environment they pass through, create a chronological line of events, then use it in a Markov Chain Model to predict possible accidents, traffic jams, congestions, etc. A Markov Chain is one derivation from the Markov Model, that is using the previous events to predict future events that might happen. A simple example to illustrate the model would be a street X that is having a traffic jam every single day when people go home after work (around 17:00 – 18:00). If today the vehicle is registering the traffic jam for the first time, the probability that tomorrow this event would happen is really low, but if our vehicle is passing through the same street 100 days in a row and the traffic jam is still here in that time interval, the probability will be increased in a radical way. The purpose of the Markov Chain (Benatia, 2013) in the algorithm is to have the cloud stacked with intel from multiple vehicles that pass through different regions and based on this data we can predict the traffic conditions in the future. We can imagine these clustered regions and areas as products, while the cars passing through them are customers and the collected data is representing the customer's reviews on the region.

### 4.3 Main Benefits

One of the most important parts of this solution would be the reduced delay, overhead and optimal utilization of bandwidth, based on priority geographic regions. This model would provide a better beacon exchange in-between the nodes and also there will be a big database with all the events recorded by vehicles, everything being classified and sorted on categories. This can be used in the autonomous car software development as well since we need data to provide to the model for it to learn patterns and actions. Since 5G can handle so many nodes per square kilometre, there should not be problems when talking about congestion on the network in most of the cases, but in very crowded cities there is still a possibility of having so much data to exchange between vehicles that they might occur.

### 4.4 Drawbacks

Although the idea would suit the VANET goal, multiple variables were not taken into account, such as the different regions in which signal and bandwidth are low or perturbed by different objects or outside forces. The cost of the infrastructure is high which can lead to problems in underdeveloped countries or in different places that would not benefit from having such a system, for example, the isolated human settlements. Overall, we have to think about alternatives in cases of a breakdown since there are cases in which the system might not work; these would be in the surroundings of the worst-case scenario, of course. The autonomous vehicles will have the software trained by the time they will become mainstream, rather than a minority, like in present. This would be beneficial not to be truly dependent on the network data all the time, so in the case of not reaching the cloud (eg. isolated zone with little to no signal), there will still be a possibility for them to drive in offline mode.

### 4.5 Summary

The proposed solution overall aims to have three components that will drive it. The first element is the 5G network packed with functionalities such as fog computing and C-RAN which would act as a protocol for message exchange and storage using the cloud technology. Secondly, there is the clustering mechanism, that is grouping cars, areas and zones in which these vehicles travel and provide priority levels based on the number of issues existed in each part of them. The mechanism will then allocate enough bandwidth for these groups that are in need, by having the third element in the equation: the Markov chain model. Lastly, the model will use different sensors attached to vehicles to collect and use the node surrounding data to predict future traffic-related problems that will eventually be reduced. As in any algorithm, there are benefits and drawbacks, most of them providing value to the traffic participants by having a smart, safe and reliable system which would find the best path for each of them. There might be errors and congestions happening as well, but in a way more limited amount than in the case of using traditional network strategies.

## Chapter 5
# Conclusion and future works

Overall, vehicle ad-hoc networks are part of the evolution of transportation in today's society. The paper has introduced the notion of VANET and its components, applications, issues, challenges but also the advancement in this field. Researchers contributed with multiple protocols and algorithms that are making use of the technologies available but also looking forward to enabling new ideas to be designed and implemented with the emerging ones. The bandwidth scarcity problem is an important subject that has to be considered in any of these future improvements, but with the 5G it will be under more control rather than now. The proposed algorithm can be implemented once the cognitive radio technology is not considered novelty anymore and its features will be available and of course when 5G is going to have broader coverage. The goal of the paper has been achieved by reviewing multiple protocols that stand out and have an important message to send to the VANET research community. They have inspired a new idea to combine artificial intelligence and the vehicle network in such a way that cars can make use of the cloud computing to gain huge amounts of data that can improve and perfect the autonomous cars driving and behaviour in any type of environment. An important factor in having a faster development of such a system is the way governments will create the policies about data protection and collection from the society, but also how it will react to these new ideas. By having an interconnected network which received data from mobile phones, vehicles, road infrastructure and so on so forth, will increase the risk of having security breaches and data leaks. Security has to play an important role in the design of any system that will serve society in the future.

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