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Carlos Renato Storck

A 5G VEHICLE-TO-EVERYTHING ECOSYSTEM WITH INTERNET OF VEHICLES BASED APPROACHES

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Carlos Renato Storck

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Thesis presented to the Graduate Program in Informatics of the Pontifical Catholic University of Minas Gerais in partial fulfillment of the requirements for the degree of Doctor in Informatics.

Advisor: Prof. Dr. Fátima de Lima Procópio Duarte Figueiredo

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Thesis presented to the Graduate Program in Informatics as a partial requirement for the degree of Doctor in Informatics from the Pontifical Catholic University of Minas Gerais.

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To my parents and siblings,
with my love and respect.
Also to my wife Kamila,
my son Carlos Augusto,
and the new baby Giovanni,
the reasons of my life.

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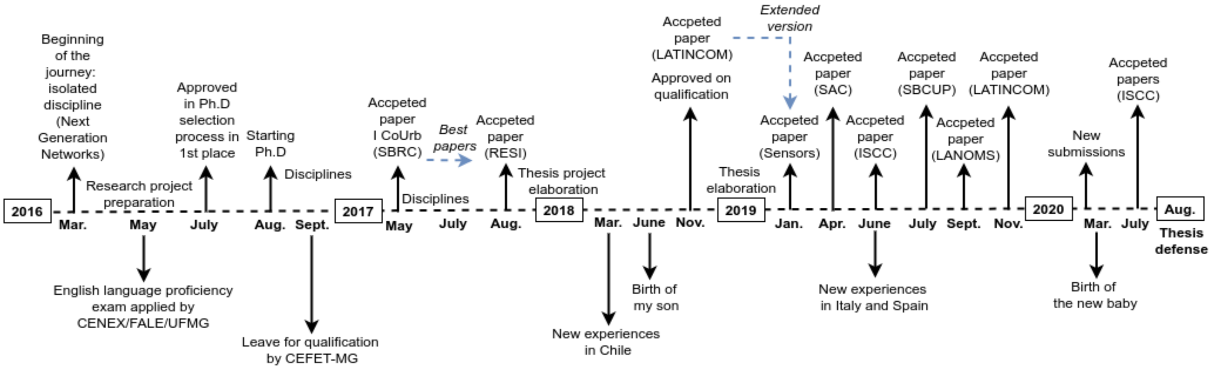
Figure 1: My Ph.D. time line



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“A good decision is based on knowledge and not on numbers.”

Plato

RESUMO

A visão de futuro, do século passado, costumava incluir telefones sem fio, pessoas falando através de telas, veículos inteligentes, tudo interconectado com tudo. O futuro chegou. Hoje em dia, a Internet conecta mais coisas que pessoas. Os veículos estão entre as muitas coisas conectadas à Internet. Eles estão cada vez mais inteligentes, automáticos e conectados. As redes de veículos podem ser úteis no controle, no alerta e na minimização de acidentes. Eles também podem monitorar o tráfego e fornecer aplicativos de entretenimento multimídia a bordo. Os veículos podem ser conectados, entre si, no modo "veículo a veículo" (V2V - *Vehicle-to-Vehicle*), ou podem ser conectados a outros elementos em um ambiente virtual denominado "veículo para tudo" (V2X - *Vehicle-to-Everything*). A "Internet de veículos" (IoV – *Internet of Vehicles*) é um sistema de rede aberto e integrado com vários componentes, incluindo veículos, pessoas e coisas que precisam de uma boa infraestrutura de rede para fazer parte de cidades inteligentes.

A rede celular de quinta geração (5G - *Fifth Generation*) é certamente a infraestrutura para conectar veículos. A tecnologia 5G influencia a IoV e o desenvolvimento de carros inteligentes. Criado pela tecnologia "celular baseado no V2X" (C-V2X - *Cellular-based V2X*), o ambiente virtual pode proporcionar maior conforto aos motoristas, mais segurança, nas estradas, por meio do "sistema avançado de assistência ao motorista" (ADAS - *Advanced Driver Assistance Systems*) e da direção autônoma para conexões mais confiáveis. As soluções devem ser compatíveis com a rede de comunicação 5G e além.

As redes 5G visam fornecer largura de banda ultra-alta para permitir capacidade de rede suficiente para muitas coisas conectadas. As interfaces aéreas em frequências de onda milimétrica (mmWave - *millimeter Wave*) e inovações em toda a tecnologia sem fio no ecossistema V2X são alguns recursos para fornecê-la. Novas tecnologias de rede são exigidas para suportar os novos modelos de serviços 5G que estão sendo projetados. Veículos, coisas e pessoas totalmente conectados representam o objetivo principal das tecnologias IoV e V2X. Mas há um conjunto de desafios relacionados ao V2X pela conectividade dos aplicativos IoV, tais como falta de infraestrutura e cobertura adequada, densidade de veículos conectados, integração de tecnologias, serviços e padrões distintos, instalação de serviços baseados no usuário e um número muito elevado de *handovers* em cenários de grande mobilidade.

Esta tese propõe abordagens estratégicas para a conexão IoV em um ecossistema 5G V2X, com a integração de tecnologias. A motivação para o desenvolvimento deste trabalho surgiu dos desafios para resolver problemas reais tais como densidade de veículos

conectados, integração de tecnologias, serviços e padrões distintos e mobilidade. Apesar do ganho de capacidade esperado, a densificação da rede celular causa dificuldades na seleção das células. Com isso, pode haver maior número de *handovers* falhos e desnecessários (efeito *ping-pong*), mais atrasos e consumo de energia e altas taxas de perdas de pacotes. Inovação é necessária em toda a tecnologia sem fio no ecossistema V2X, mas a falta de um padrão internacional comum é um grande problema. Além disso, a alta mobilidade veicular torna difícil a manutenção de conexão dos nós da rede.

Os objetivos deste trabalho foram a caracterização da arquitetura IoV suportada por uma rede 5G em comunicações C-V2X, a proposição de um ecossistema 5G V2X, a apresentação de uma abordagem probabilística sobre a seleção de células virtuais (V-Cells - *Virtual Cells*) centrada no usuário, a indicação de uma solução de decisões de *handover* para veículos conectados à uma rede 5G ultra-densa (UDN - *Ultra-Dense Network*) e a validação de um modelo de estrutura de tecnologia de rede 5G como facilitador para o fornecimento de novos serviços. A necessidade de soluções estratégicas para as conexões IoV em um ecossistema 5G V2X reside no problema que tal tecnologia não existe. A proposta e as contribuições desta tese incluem abordagens específicas para a instalação de células virtuais, para lidar com *handovers* frequentes, para fornecer entretenimento a bordo e serviços baseados em localização sob controle de “rede definida por software” (SDN - *Software-Defined Networking*) e para permitir o desempenho eficiente da comunicação C-V2X em aplicações suportadas pela rede 5G por meio de conexões IoV.

Esta tese tem cinco partes. Na primeira parte (capítulo 2), é apresentado o estudo sobre IoV por 5G destacando a rede integrada V2X, arquitetura, recursos, padrões, protocolos de comunicação, infraestrutura, modos, avaliação, avanços recentes, desafios tecnológicos e direções futuras. Na segunda parte (capítulo 3), um ecossistema 5G V2X para provimento de IoV é proposto indicando uma simulação de mobilidade veicular com DASH (*Dynamic Adaptive Streaming over HTTP*) como algoritmo adaptativo utilizado em cenários rurais e urbanos com diferentes densidades de veículos conectados ao 5G, considerando interrupções de reprodução, qualidade de vídeo, transições, nível de *buffer*, taxa de *bits* e frequência. Na terceira parte (capítulo 4), uma abordagem probabilística centrada no veículo é apresentada para tratar o problema de gerenciamento de V-Cells em uma rede ultra-densa com cenários de veículos em alta mobilidade, discutindo os resultados da avaliação do uso de redes complexas para a seleção de célula. Na quarta parte (capítulo 5), a principal contribuição da tese é apresentada pela solução FiVH (*5G Vehicular Handover*) como decisão de *handover* para veículos que estão conectados em 5G UDN, apontando na abordagem a relevância da *inter-v-cell*, o controle de congestionamento e balanceamento, mas também as regras de velocidade média e qualidade de serviço (QoS - *Quality of Service*). A tese usa uma combinação de métricas de rede complexas para escolher a melhor célula virtual para o veículo em movimento através de um caminho

ótimo. A tese considerou a integração com o controlador SDN, já que a rede celular 5G necessita de suporte de mobilidade de alta velocidade. Na quinta parte (capítulo 6), um modelo de tecnologia de rede 5G é proposto para serviços baseados em localização, para suportar aplicações V2X e outros serviços em cidade inteligente, considerando o *framework* de computação urbana em redes 5G (CoUrbF5G - *Urban Computing Framework in 5G Networks*). O simulador de eventos discretos ns-3 e o emulador de rede Mininet foram usados para simulações e emulações das soluções propostas. Os resultados obtidos mostraram o potencial das soluções propostas para garantir a qualidade dos serviços utilizando comunicações 5G V2X.

Palavras-chave: Conexões IoV. Comunicações 5G V2X. Veículos conectados. C-V2X. 5G UDN. FiVH.

ABSTRACT

The past century's future vision used to include wireless phones, people talking through screens, smart vehicles, everything interconnected with everything. The future has arrived. Nowadays, the Internet connects more things than people. The vehicles are among many things connected to the Internet. They are increasingly intelligent, automatic, and connected. The vehicle networks can be useful in the control, alert, and minimization of accidents. They can also monitor traffic, and provide multimedia entertainment applications on board. Vehicles can be connected among themselves in Vehicle-to-Vehicle (V2V) mode, or they can be connected to other elements in a virtual environment called Vehicle-to-Everything (V2X). The Internet of Vehicles (IoV) is an open and integrated network system with several components, including vehicles, people, and things that needs a good network infrastructure to be part of smart cities.

The Fifth Generation (5G) cellular network is the certainly infrastructure to connect vehicles. 5G technology influences IoV and the development of smart cars. Created by Cellular-based V2X (C-V2X) technology, the virtual environment can provide greater comfort to drivers, more safety on roads through the Advanced Driver Assistance Systems (ADAS) and autonomous steering for more reliable connections. The solutions must be compatible with 5G communication network and beyond.

5G aims to provide ultra-high bandwidth to allow enough network capacity to many connected things. The air interfaces at millimeter Wave (mmWave) frequencies and innovations across the wireless technology in the V2X ecosystem are some features to provide it. New network technologies are required to support the 5G new services models. Vehicles, things, and people fully connected are the main goal of the IoV and the V2X technologies. But there are a set of challenges related to the V2X by IoV applications connectivity such as lack of infrastructure and suitable coverage; connected vehicle density; integration of distinct technologies, services, and standards; user-based services installation; and a very high number of handovers in scenarios with great mobility.

This thesis proposes strategic approaches for the IoV connection over a 5G V2X ecosystem, with the technologies integration. The motivation for the development of this work has come from challenges to solve actual problems such as connected vehicle density; integration of distinct technologies, services, standards; and mobility. Despite the expected capacity gain, the densification of the cellular network causes difficulties in the cell selection. Thus, there may be a greater number of failed and unnecessary handovers (ping-pong effect), longer delays and energy consumption, and high packet losses. Innovation is needed across the wireless technology in the V2X ecosystem but the

lack of a common international standard is a big problem. In addition, the high vehicular mobility makes it difficult to maintain the connection of the network nodes.

The goals of this work were the characterization of the IoV architecture supported by a 5G network on C-V2X communications; the proposition of a 5G V2X ecosystem; the presentation of a probabilistic approach about user-centered Virtual Cells (V-Cells) selection; the indication of a handover decisions solution for 5G Ultra-Dense Network (UDN) connected vehicles; and the validation of a 5G network technology structure model as a new services provider facilitator. The need for strategic solutions for IoV connections in a 5G V2X ecosystem lays on the problem that such technology does not exist. This thesis proposal and contributions include specific approaches to the virtual cell installation, the deal with the frequent handovers, to provide the demanded onboard video entertainment, and location-based services under Software-Defined Networking (SDN) control to enable the efficient performance of C-V2X communication in applications supported by the 5G network through IoV connections.

This thesis has five parts. In the first part (chapter 2), the study about IoV by 5G is presented highlighting the V2X integrated network, architecture, features, standards, communications protocols, infrastructure, modes, evaluation, recent advances, technological challenges and future directions. In the second part (chapter 3), a 5G V2X ecosystem for providing IoV is proposed indicating a vehicular mobility simulation with Dynamic Adaptive Streaming over HTTP (DASH) as an adaptive algorithm used in rural and urban scenarios with different densities of vehicle that are connected to the 5G, considering playback interruptions, video quality, transitions, buffer level, bit-rate and frequency. In the third part (chapter 4), a vehicle-centric probabilistic approach is presented to address the problem of V-Cells management in an UDN with scenarios of vehicles in high mobility, discussing the evaluation results of the use of complex networks to the cell selection. In the fourth part (chapter 5), the main contribution of the thesis is finally presented by the 5G Vehicular Handover (FiVH) as handover decision for vehicles that are connected in 5G UDN, pointing out in the approach the inter-v-cell relevance, the congestion control and balancing, but also the average speed and Quality of Service (QoS) rules. The thesis uses a combination of complex network metrics to choose the best virtual cell for the vehicle in motion through an optimal path. The thesis considered the integration with SDN controller, since the 5G cellular network needs high-speed mobility support. In the fifth part (chapter 6), a 5G network technology model is proposed for location-based services to support V2X applications and other smart city services, considering the Urban Computing Framework in 5G Networks (CoUrbF5G). The ns-3 discrete event simulator and the Mininet network emulator were used for simulations and emulations of the proposed solutions. The obtained results have shown the potential of

the proposed solutions to guarantee quality of services using 5G V2X communications.

Keywords: IoV connections. 5G V2X communications. Connected vehicles. C-V2X. 5G UDN. FiVH.

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LIST OF ABBREVIATIONS AND ACRONYMS

3GPP – Third Generation Partnership Project

5G-AN – 5G Access Network

5G – Fifth Generation

5QI – 5G QoS Indicator

A-CPI – Application-Controller Plane Interface

ADAS – Advanced Driver Assistance Systems

C-V2X – Cellular-based V2X

CN – Core Network

D-CPI – Data-Controller Plane Interface

D2D – Device-to-Device

DASH – Dynamic Adaptive Streaming over HTTP

eMBB – enhanced Mobile Broadband

eV2X – enhancement Vehicle-to-Everything

IoT – Internet of Things

IoV – Internet of Vehicles

ITS – Intelligent Transport Systems

ITU – International Telecommunication Union

MEC – Mobile Edge Computing

mMTC – massive Machine-Type Communication

mmWave – millimeter Wave

NBI – Northbound Interface

NFV – Network Function Virtualization

NR – New Radio

PDCP – Packet Data Convergence Protocol

PDR – Packet Delivery Ratio

PNF – Physical Network Function

QCI – QoS Class Identifier

QoE – Quality of Experience

QoS – Quality of Service

RAN – Radio Access Network

SBI – Southbound Interface

SDIoV – Software Defined Internet of Vehicles

SDN – Software-Defined Networking

TR – Technical Recommendation

TS – Technical Specification

TTI – Transmission Time Interval

UDN – Ultra-Dense Network

UE – User Equipment

UPF – User Plane Function

URLLC – Ultra-Reliable and Low Latency Communication

V2I – Vehicle-to-Infrastructure

V2N – Vehicle-to-Network

V2P – Vehicle-to-Pedestrian

V2V – Vehicle-to-Vehicle

V2X – Vehicle-to-Everything

VANET – Vehicular Ad hoc Network

WAT – Wireless Access Technology

RAT – Radio Access Technology

V-Cells – Virtual Cells

LIST OF PUBLICATIONS

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1. C. R. Storck, E. E. O. Lousada, G. G. O. Silva, R. A. F. Mini, and F. Duarte-Figueiredo, (***In Portuguese***) "Uma Solução de Decisão de *Handover inter-V-Cell* para Veículos Conectados em Redes 5G Ultradensas," in *Proceedings of the 12th Brazilian Symposium on Ubiquitous and Pervasive Computing (SBCUP)*. Cuiabá, Brazil: SBC, Nov. 2020, pp. 1-10. *Accepted*.
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Collaboration with Mobile Computing and Wireless Networks Group Members

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2. (**Honorable mention**) E. E. O. Lousada, C. R. Storck, R. A. F. Mini, and F. Duarte-Figueiredo, (***In Portuguese***) “Protocolo Baseado em Métricas de Redes Complexas para Mitigação de Tempestade de *Broadcast*,” in *Proceedings of the 11th Brazilian Symposium on Ubiquitous and Pervasive Computing (SBCUP)*. Belém, Brazil: SBC, July 2019, pp. 1-10. [Online]. Available: `https://sol.sbc.org.br/index.php/sbcup/article/view/6591/6487`.

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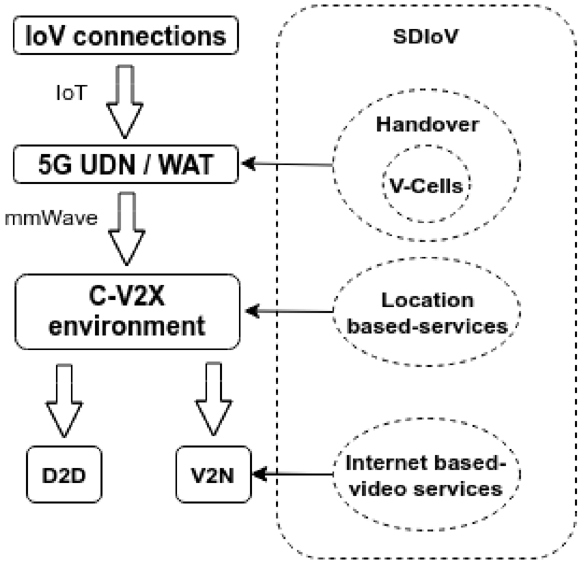
1 INTRODUCTION

This thesis main subject is the Internet of Vehicles (IoV) that is a domain in the Internet of Things (IoT) developed for the automotive industry as a platform to allow information interaction among vehicles, pedestrians, drivers, and city infrastructure. IoV can be considered part of intelligent cities and it is characterized as an open and integrated network system, composed by several components, including vehicles, people, and things (YANG et al., 2014). Through the 5G network, it is expected the IoV infrastructure allow cars to be connected to new radio technologies increasing the speed in the V2X communications ecosystem. The C-V2X (MANNONI et al., 2019) can offer enhanced road safety Advanced Driver Assistance Systems (ADAS) sensors, autonomous driving by longer interaction range and higher reliability connections. The V2X application types are divided into two basic operations: Device-to-Device (D2D) and Vehicle-to-Network (V2N). Supported by 5G, the IoV dynamic mobile communication systems are intra-vehicular or inter-vehicular. An overview of the proposed approaches to connected vehicles in a 5G V2X ecosystem that will be presented in this thesis is demonstrated by the scheme in Figure 2 adopting the Software Defined Internet of Vehicles (SDIoV) concept.

Figure 2: Proposed approaches to connected vehicles in a C-V2X ecosystem



Vehicular Ad hoc Network (VANET) has an architecture that supports specific applications of safety and traffic efficiency that is the main reason for its Internet access to be not fully available and non-collaborative. VANET has limited communication types, which is basically related among V2V, to roadsides, and partially to

Vehicle-to-Infrastructure (V2I). IoV, by its turn, promises advanced challenging features as business oriented architecture with high opportunities for various applications of safety, traffic optimization and efficiency, infotainment, and much more. The IoV capability is the collaboration between heterogeneous nets, reliable Internet service, and it includes different types of communications among V2V, to roadsides and partially to V2I but also to cellular networks and Internet, to personal devices and Vehicle-to-Pedestrian (V2P), and to sensors (BORCOCI, 2017; GASMI; ALIOUAT, 2019).

IoV is an evolution from the VANET through the IoT technology, and both of these technologies (VANET and IoV) are responsible for diverse networking scenarios in which devices and services aspects are also diverse. So, there is the modeling need of an IoV network architecture to understand how the IoV distributes network that supports the use of data created by connected cars and VANETs. This V2X architecture must include the 5G Wireless Access Technology (WAT) function into the vehicles. The 5G implementation faces specific challenges such as the ones related to the V2X by IoV applications connectivity about the lack of infrastructure and suitable coverage; connected vehicle density; integration of distinct technologies, services, and standards; user-based services installation; and a very high number of handovers in scenarios with great mobility.

1.1 Problem and motivation

The 5G network is defined to support at least three emerging use cases: enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communication (URLLC), and massive Machine-Type Communication (mMTC). UDN is a promising technique to meet the requirements of explosive data traffic in 5G mobile communications. The Third Generation Partnership Project (3GPP) Release 15 (3GPP, 2019b) supports increased data throughput and greater capacity for eMBB, but also sets the foundation for support URLLC case of mission-critical uses such as autonomous vehicles, for example. The 5G New Radio (NR) (NAIK; CHOUDHURY; PARK, 2019) specifies new frequency ranges to enable higher data throughput for applications like streaming High Definition (HD) video that requires ultra-high bandwidth to allow better network capacity by implementing air interfaces at mmWave frequencies with up to 1 GHz bandwidth and by accelerating the innovation across the wireless technology in the V2X ecosystem (MOLINA-MASEGOSA; GOZALVEZ, 2017).

5G pushes the boundary of the wireless network and will drastically increase the network traffic. New network technologies are required to support the new use models and to minimize cost. 5G NR must coexist with several already existing services and with new services that will be introduced to support use cases. That´s why it is so important to simulate, design, validate, and optimize new products and services of voice, data, and

IoT/IoV traffic by 5G. Furthermore, the 5G network slicing (CARMO et al., 2019) makes it more dynamic, enabling operators to allocate speed, capacity, and coverage with better quality; even asking for more antennas, mmWave technology, higher speed, and additional costs (CHEN et al., 2016; YE et al., 2018; LIANG; YE; LI, 2019).

The current 5G solutions have problems related to the lack of a sophisticated infrastructure, related to the general associated cost, and also related to the ambiguity of the communication technologies which make harder the adoption of the V2X applications by IoV (SULLIVAN, 2017). The 5G cellular technology promises to provide connectivity and short-latency to enable high rate for data transmission with high communication costs. It lacks extensive network coverage being not suitable for multimedia features that require high bandwidth (SELVANESAN et al., 2018). Other issues about IoV are the big number of connected vehicles that create a large volume of data to be processed and storage (XU et al., 2018), the integration of distinct technologies, services, and standards that open the IoV to new use cases, the mobility that makes hard to keep the nodes connected and provide them with resources to transmit and receive in real-time (LAURIDSEN et al., 2017), and the lack of only one international standard makes hard the V2V communication (ZHAO et al., 2018).

The focused problem of this thesis is the search for strategic solutions to the IoV connections to be executed in a 5G V2X ecosystem, with the integration and the adoption of emerging technologies.

C-V2X is the main radio interface to support IoV connections by 5G network. The 5G has uplink/downlink connections that can improve coverage and throughput on the network and can reduce latency by fast radio access, handovers, and coordinated resource allocation. But the use of the IoV in 5G V2X ecosystem has communication limits, especially when there are many vehicles and frequent handovers. Handovers involve the transition of a great number of information between cells on the network. Subjects around handovers that matters are: congestion, coverage, mobility, network available resources, protocols and topology parameters. Consequently, the QoS delivered to the users is affected by the handover decisions (HUSAI et al., 2019).

5G will be everywhere and will be faster than the current technology, allowing IoV connections to provide easier communications among vehicles, drivers, traffic and city infrastructures or any other internet-connected item. In this evolution process of the communication system around the world, several companies, such as the Germany Bavarian Motor Works (BMW) among several others, are investing billions of Euros to develop a platform that will connect services like route management, booking transportation, electric car charging, parking, and ride-sharing, and will eventually pair with autonomous vehicles (CONDOLUCI et al., 2019). It means that the industries are offering opportunities for 5G network to support IoV to expand and realize its potential to relay information between vehicles, drivers and operations centers, to perform maintenance, to uptime routes, to reduce costs, and to increase efficiency across the traffic board. In urban scenarios, the IoV by 5G will act as city planners and logistics managers, and it will evolve for drivers and vehicles to safely interact.

The 5G cellular networks for vehicular applications can cover a wide range use cases, but have requirements that include very high data rates and timely service delivery, while also considering ultra-low communication latencies, for example. In this direction, the members of the project named 5G Communication Automotive Research and innovation (5GCAR) have defined enhancements in terms of system architecture, security, and privacy, specifically targeting automotive applications. This project considers five different classes of use cases: cooperative maneuver with lane merge, cooperative perception with see-through, cooperative safety with network-assisted vulnerable pedestrian protection, autonomous navigation with high definition local map acquisition, and remote driving for automated parking. In accordance with Condoluci et al. (2019), there are technical and non-technical issues that challenge the current network architectural conception. Among the technical challenges are the V2X main characteristics: mobility and simultaneous requirements for massive numbers of ultra-reliable, low latency, high bandwidth communications. Among the non-technical challenges are the multiple access network connectivity (including the management of multiple network slices); the resilience requirements, security, and data privacy; and the roaming between operators. To face these challenges, the 5GCAR has proposed improvements on the 3GPP to develop the 5G Service-Based Architecture (SBA) to support the requirements of V2X applications. The introduced 5GCAR enhancements focus on optimized End-to-End (E2E) V2X network connectivity for highly reliable and low-latency V2X services, security and privacy, QoS and traffic flow management in a multi-Radio Access Technology (RAT) and multi-link V2X communication system (CONDOLUCI et al., 2019).

The motivation for the development of this work has come facing all these 5G network challenges which are associated with problems such as the mentioned before (connected vehicle density; integration of distinct technologies, services, standards; and high mobility). Furthermore, nowadays, with the accelerating and fostering 5G development goals all around the world, new architecture design, testing, and evaluation are real and urgent needs. And the high complexity expected from a 5G V2X network architecture together with the imposed challenges for its development and evaluation motivates, even more, this thesis production.

Previous works have just considered isolated aspects or a few components that are relevant to the handover decision. This present thesis contribution to the scientific academic study is the presentation of a solution for 5G UDN connected vehicles, by the integration of the handover with an SDN controller. In reason to make this proposed solution available, the work has characterized the IoV architecture supported by a 5G network on C-V2X communications; has proposed a 5G V2X ecosystem; has presented a probabilistic approach about user-centered Virtual Cells (V-Cells) selection; has indicated a handover decisions solution for 5G Ultra-Dense Network (UDN) connected vehicles; and the validation of a 5G network technology structure model as a new services provider facilitator. In this proposal, several components were adopted such as, among others, double connectivity, cells identification for V-Cells selection; V-Cells installation by SDN and functions virtualization; and average speed rules considering QoS by QoS Class Identifier (QCI) and 5G QoS Indicator (5QI) which is the first time used on handover decision process.

1.2 Statement and goals

Some approaches which were developed for 5G connected vehicles are presented in this thesis' statements, considering the integration of services that were developed with the SDN controller, such as video services based on the Internet and services based on localization, virtual cells, and handover decisions. This thesis is organized in the following goal-modules (GM):

- **GM1** Characterization of the IoV architecture supported by a 5G network on C-V2X communications considering standards and technological challenges. This bibliographic review is important to present the 5G features and the evolution of communications and applications that this network supports. The objective is to show all the main aspects that evolve the 5G V2X.

- **GM2** Proposition of a 5G V2X ecosystem based on SDN controller to provide IoV connections among vehicles as entertainment consumer points, evaluating vehicular Internet-based video services traffic by mmWave communications in urban and rural scenarios through the Network Simulator ns-3.

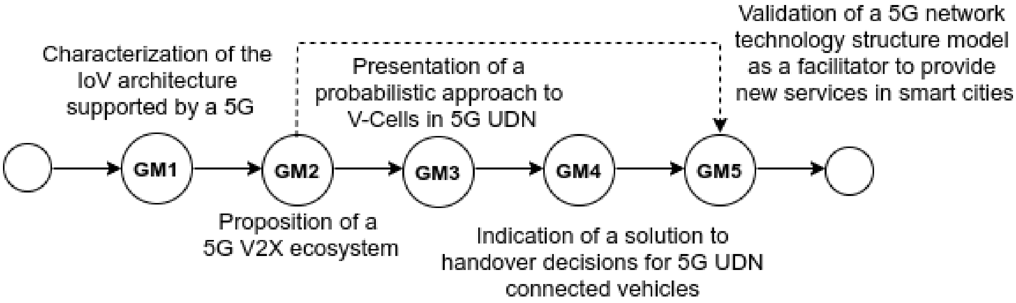
- **GM3** Presentation of a probabilistic approach about the user-centered V-Cells selection as the biggest 5G UDN challenge on the IoV connections, especially on V2N services.

- **GM4** Indication of a handover decision solution for 5G UDN connected vehicles.

- **GM5** Validation of a 5G network technology structure model as a facilitator to provide new services for several segments in smart cities. This is the last step that connect all the previous GMs once the IoV architecture characterization on GM1 was used as collected data to evaluate a 5G network technology structure mode, the 5G V2X ecosystem analyzed was proposed on GM2, the probabilistic approach model evaluated was presented on GM3, and the handover decision solution demonstrated as applicable to support and provide new services was indicated on GM4.

The goal modules interaction can be better understood by the scheme shown in the Figure 3. In GM1, the characterization of the IoV supported by a 5G network on C-V2X communications and the architecture were described. This module was used to present the 5G on C-V2X features, the evolution from RAT to C-V2X communications, and the evolution from VANET to IoV applications. On the development of this module, the work had the intention to show the 5G V2X standards, the protocols for communications, the ecosystem infrastructure, modes, evaluation, recent advances, studies, projects, supports and technological challenges.

Figure 3: Scheme of goals interaction



In GM2, to overcome the technological challenges presented on module 2, part of the collected data was employed to propose a 5G V2X ecosystem based on SDN controller to provide IoV connections among vehicles as entertainment consumer points. Vehicular Internet-based video services traffic by mmWave communications in urban and rural scenarios were evaluated through the Network Simulator ns-3. This module has been used to describe the IoV as open and integrated network system used in V2X applications. At this point, the work was dedicated to propose a 5G V2X ecosystem model, presenting the adopted methodology, pointing the simulations materials and the methods, the parameters of 5G V2X scenarios, the fog cell network topology simulated, the logical view of SDIoV entertainment services, and the operation of the proposed architecture. Finally, the following results were shown and discussed: throughput, average delay in a fog cell 5G V2X, and packet delivery ratio in 5G V2V communications. Also were evaluated metrics the vehicular Internet-based video services traffic in urban scenarios with different vehicle densities.

In GM3, part of the collected data was used as the base to build the presentation of a 5G UDN user-centered V-Cells selection probabilistic approach. It has considered the movements adaptation as transmission points in scenarios involving high mobility such as V2N communications. The study in this module has pointed the need for dynamic V-Cells management by the network slicing according to specific service requirements. This work has also introduced cell selection rules for vehicle-centric V-Cells formation using the 5G UDN. The proposed approach evaluation methodology was conducted by the ns-3 network simulator in different scenarios. Simulation results were shown and analyzed. They have lighted the active V-Cells in common, the total radiated power, and throughput. In the end, it brought the conclusions about the guarantee of the network new services offer.

In GM4, in order to answer the new requirements to support the 5G cellular network needs that were pointed on module 4, part of the collected data was used to present a solution of inter-V-Cell handover decisions for 5G UDN connected vehicles, considering the integration among the handover with an SDN controller. In this module, the proposed solution has also been tested using the ns-3 network discrete event simulator, and the obtained results showed with evaluation in the face with other studies about SDN-based mobility management. This module was used to present the proposed solution under the 3GPP standards for the V-Cells adoption to allow user-centered approaches, considering bandwidth and throughput as an ascending criteria. The average speed and the QoS rules guided the handover decision process. The proposed solution was evaluated through the ns-3 network discrete event simulator. The results have shown that this new mechanism has achieved its main goal by reaching assertiveness levels in the handover decision process. The executed handover numbers and the packet loss rate were presented and discussed.

At this point, it is important to light up that open-source simulators normally are very complex and do not have a Graphical User Interface (GUI). They are not easy to use, require the knowledge of various scripting with programming languages, and also come with no support. Other link-level simulators, such as the NetSim, due to the computational complexity, are limited (can scale up to 100's of User Equipment (UEs) and 5G base stations (gNBs)) and it is difficult to model the radio interface at a granularity of one symbol (TECTOS, 2019).

In GM5, to validate the presented module 5 solution, part of the collected data was used to evaluate a 5G network technology structure mode, incorporated with SDN and virtualized controllers, as a facilitator to provide new services in smart cities. The proposal analysis was done by applying data mining techniques along with ancillary methods in the Data Science processes, such as Knowledge Discovery in Databases (KDD) and big data. This module has brought the model evaluation through emulations on Mininet and POX controllers, adopting Urban Computing Framework in 5G Networks (CoUrbF5G) as a system service, and also brought results that were analyzed using the Gephi tool to demonstrated how the proposed model is applicable to support and provide new services such as intelligent transportation, road monitoring, energy consumption, public safety, among others. So, this module was used to present how the 5G networks are going to integrate people and vehicles in several environments by IoT.

1.3 Origins of the material

This thesis all chapters have been published and they are organized as it follows.

- **Chapter 2 (about IoV by 5G):** The work “A Survey of 5G Technology Evolution, Standards, and Infrastructure Associated with Vehicle-to-Everything Communications by the Internet of Vehicles”, published on IEEE Access on 2020, with Qualis A1, was used as the base structure for this chapter.
- **Chapter 3 (about 5G V2X ecosystem providing IoV):** The work “A 5G V2X Ecosystem Providing Internet of Vehicles”, published on Sensors on 2019, with Qualis A1, was used as a reference on the chapter 2 and to structure the chapter 3. It is an extended version of the “5G V2X Ecosystem Providing Entertainment on Board using mmWave Communications”, published on the proceedings of the 10th IEEE Latin-American Conference on Communications (LATINCOM), in Guadalajara, Mexico, 2018, with Qualis B2. Finally, new results were evaluated through work “A Performance Analysis of Adaptive Streaming Algorithms in 5G Vehicular Communications in Urban Scenarios,” published on the proceedings of the 25th IEEE Symposium on Computers and Communications (ISCC), in France, 2020.
- **Chapter 4 (about the vehicle-centric probabilistic approach to virtual cell management in ultra-dense 5G networks):** The work “A Vehicle-Centric Probabilistic Approach to Virtual Cell Management in Ultra-Dense 5G Networks”, published on the proceedings of the 25th IEEE Symposium on Computers and Communications (ISCC) in France, 2020, with Qualis A3, was used as the base for the chapter 4. This work has adopted complex network metrics inspired by the works: “Using Complex Networks Metrics to Mitigate the Broadcast Storm Problem” produced by Lousada, Storck, Mini, and Duarte-Figueiredo, published on the proceedings of the 24th IEEE Symposium on Computers and Communications (ISCC), in Spain, 2019, with Qualis A3; and “Protocol Based on Complex Network Metrics for Broadcast Storm Mitigation” also produced by the same authors in Portuguese, published on the proceedings of the 11th Brazilian Symposium on Ubiquitous and Pervasive Computing (SBCUP), in Brazil, 2019, with Honorable mention Qualis B4.

- **Chapter 5 (about a solution of handover decisions for 5G UDN connected vehicles):** The work "FiVH: A solution of inter-V-Cell handover decision for connected vehicles in ultra-dense 5G networks", accepted in Vehicular Communications, with Qualis A1, along with the work "An inter-V-Cell Handover Decision Solution for Vehicles Connected in Ultra-dense 5G Networks" produced in Portuguese, accepted in proceedings of the 12th Brazilian Symposium on Ubiquitous and Pervasive Computing (SBCUP), in Brazil, 2020, with Qualis B4, was the base-structure for chapter 5. It is an advanced work, an evolution from the "SoftH: Soft Handover Multicriteria Mechanism" produced by Oliveira, Storck, and Duarte-Figueiredo, which was published in proceedings of the 34th ACM/SIGAPP - SAC, in Cyprus, 2019, with Qualis A2.

- **Chapter 6 (about location-based services):** The work "A 5G Urban Computing Framework Service Model" published on Brazilian Journal of Development on 2020, with Qualis B2, along with the work "A 5G New Smart City Services Facilitator Model" published on the proceedings of the 11th IEEE LATINCOM, in Brazil, 2019, with Qualis B3, was used on the approach of the location-based services that present a 5G new smart city services facilitator model. The work "Proposal for a Data Mining for 5G Networks-based Framework" produced in Portuguese, published on RESI, in 2017, with Qualis B3, was also used as the base to structure the chapter 6. It is an extended version of the work "CoUrbD2M: Data Mining Oriented to Urban Computing in Big Data scenarios and 5G Networks" published on the proceedings of the 1st Workshop on Urban Computing (CoUrb) for the 35th Brazilian Symposium on Computer Networks and Distributed Systems (SBRC), in Brazil, 2017.

These contributions from the author´s works for the present thesis are listed in Table 1, which is in descending order based on the Qualis score (A1 is the biggest concept, and B5 is the lowest score).

Table 1: Author´s contributions

Chapter	**Work**	**Local**	**Year**	**Qualis**
Chapter 2	A Survey of 5G Technology Evolution, Standards, and Infrastructure Associated with Vehicle-to-Everything Communications by Internet of Vehicles	IEEE Access	2020	A1
Chapter 3	A 5G V2X Ecosystem Providing Internet of Vehicles	Sensors	2019	A1
	A Performance Analysis of Adaptive Streaming Algorithms in 5G Vehicular Communications in Urban Scenarios	ISCC	2020	A3
	5G V2X Ecosystem Providing Entertainment on Board using mmWave Communications	LATINCOM	2018	B2
Chapter 4	A Vehicle-Centric Probabilistic Approach to Virtual Cell Management in Ultra-Dense 5G Networks	ISCC	2020	A3
Chapter 5	FiVH: A solution of inter-V-Cell handover decision for connected vehicles in ultra-dense 5G networks	VEHCOM	2020	A1
	SoftH: Soft Handover Multicriteria Mechanism	SAC	2019	A2
	Uma Solução de Decisão de *Handover inter-V-Cell* para Veículos Conectados em Redes 5G Ultradensas	SBCUP	2020	B4
Chapter 6	A 5G Urban Computing Framework Service Model	BJD	2020	B2
	A 5G New Smart City Services Facilitator Model	LATINCOM	2019	B3
	Proposta de um Framework Baseado em Mineração de Dados para Redes 5G	RESI	2017	B3
	CoUrbD2M: Mineração de Dados Orientada à Computação Urbana em cenários de *Big Data* e Redes 5G	I CoUrb	2017	-

1.4 Thesis outline

The remaining of this thesis is organized as follows. Chapter 2 presents a study about IoV through 5G. In the chapter 3, a 5G V2X ecosystem for IoV provision is proposed. In the chapter 4, a vehicle-centric probabilistic approach is presented to address the problem of virtual cells management in an ultra dense network with scenarios of vehicles traffic in high mobility. In the chapter 5, based on the presented approach, a handover decision solution for 5G UDN connected vehicles is proposed, considering the integration between delivery with the SDN controller, since the 5G cellular network needs, for example, high-speed mobility support as solution and advancement to new network requirements. Finally, in the chapter 6, a 5G network technology model is proposed for location-based services to support V2X applications and other services to be made available in smart cities. The proposed strategies were tested using the ns-3 network discrete event simulator or the Mininet network emulator. Chapter 7 presents the conclusion of this thesis. The obtained results that were discussed in this thesis conclusion show the potential of the proposed solutions to get better QoS using 5G V2X communications.

2 INTERNET OF VEHICLES BY 5G

The very last wireless network technology created to increase the speed and the connections responsiveness, the fifth-generation network can transmit a great volume of data. It uses wireless broadband connections to support specific end-users and businesses services. It is specifically useful for the IoV, guaranteeing fast connections and security. The 5G network technology can be used to support V2X communications and applications on autonomous vehicles. It can enable information exchanges between vehicles and other infrastructures and people. It can also provide a more comfortable and safer environment and accurate traffic knowledge. The traffic flow can be improved, reducing pollution and accident rates. The cellular network can be associated with V2X as a communicating base to offer enhanced road safety and autonomous driving, and also to offer the IoV connections.

This chapter 2 presents the 5G technology evolution, the standards, and the infrastructure associated with the V2X ecosystem by IoV. In other words, it presents the IoV supported by 5G V2X communications, and describes on the section 2.1 the IoV integrated network and how it is used on C-V2X. Section 2.2 presents the IoV architecture that is going to be supported by C-V2X communications; Section 2.3 describes the standards associated to the 5G on V2X; Section 2.4 considers the challenges involved on the 5G V2X and discusses future directions; and Section 2.5 presents the final remarks.

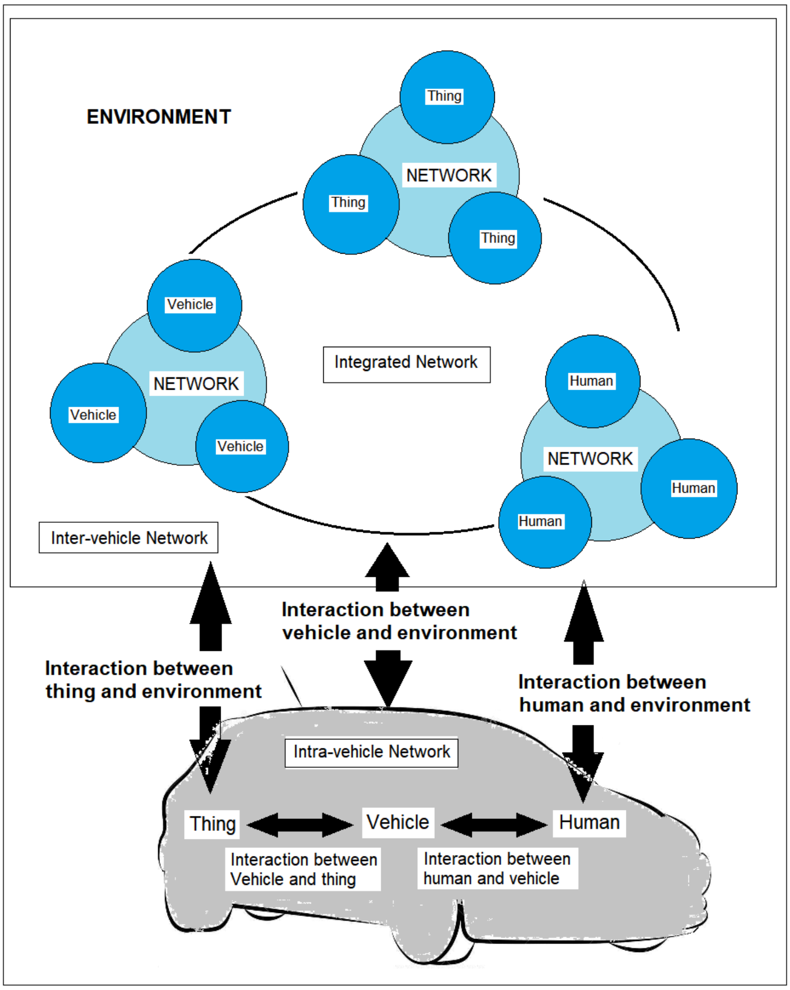
2.1 IoV integrated network

The comfort of having vehicles, things, and people fully connected is the main goal of the IoV and the V2X technologies. The current VANET uses each vehicle that is connected to the Internet as a node (CUNHA et al., 2016), and its evolution through the IoV which makes the IoT available in the cars, allows the data integration, helping to keep the traffic flow, to manage fleets, to avoid accidents, and to entertain or localize the users everywhere and whenever. By distance, speed-reducing, and acceleration sensors, the IoV enhances driving aids with, for example, the adaptive cruise control that through the vehicle Artificial Intelligence's (AI) can understand other cars' maneuvers (CHEN et al., 2018; YE et al., 2018; LIANG; YE; LI, 2019).

With technological development, IoT is guiding the IoV evolution. It includes the performance to change the vehicle's trajectory by the road distributions in the city and the traffic flow, the performance to integrate humans and vehicles as extensions to each other what makes the combination among human's abilities and vehicle's intelligence, and the performance to interconnect humans, vehicles and multi-level collaboration systems by sensors and mobile devices into a global network. This integration aims to enable several services on board and around vehicles that work as manned computers or large cell-phones (YANG et al., 2014).

An IoV network is composed of an environment integrated by "human", "vehicle" and "thing", which are the terminology referred to specific network groups that collaborate to each other. "Human" holds people in "vehicle" or in the environment and "thing" is any kind of element that is not "human" or "vehicle". Both can consume and/or provide services and applications to/from the environment. IoV provides such services and applications by internet through the interaction between environment and "vehicle", environment and "human", environment and "thing". IoV also provides services and applications inside a "vehicle" by an intra-vehicle network to allow the interaction between "vehicle" and "thing", and "vehicle" and "human" (YANG et al., 2014), as shown in Figure 4.

Figure 4: IoV network model



The IoV platform supports all these interactions through the technologies that were developed by several academic and industrial types of researches focused especially on layers, models, security, privacy, quality of service and wireless access. These technologies shall be understood as the Information and Communications Technology (ICT) that enable modern computing by its infrastructure and components present in devices such as cell-phones, wireless networks, service applications and other systems that connect people and things "in" or "to" intelligent environments.

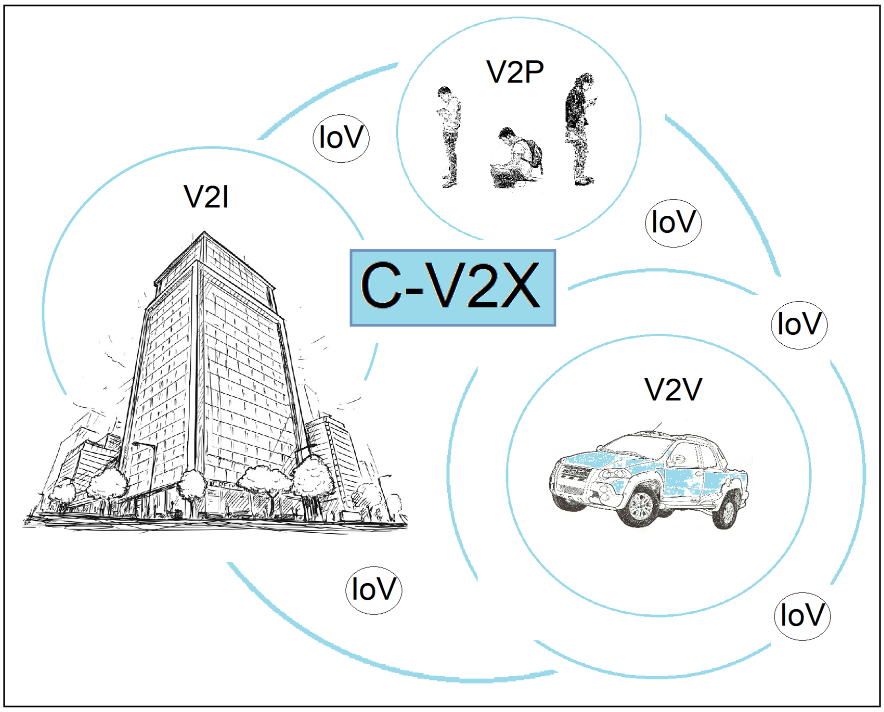
Created to increase the speed and the responsiveness of the connections, 5G can transmit a great volume of data by wireless broadband connections and 360^o antennas. 5G networks support specific services in vehicles, allowing the IoV to use secure and fast connections (KOMBATE; WANGLINA, 2016). 5G cellular services provide everywhere user access to 5G cellular networks. 5G is a hundred times faster than Forth-Generation (4G) that already speeds up to 500 times faster than Third-Generation (3G). 5G has going to have a much lower level of latency, and requires larger blocks of airwaves than 4G.

The 3GPP Release 15 supports V2X communications and applications on autonomous vehicles by the evolution from the Multiple-Input and Multiple-Output (MIMO) antenna and millimeter Waves (mmWave) (MARTIN-VEGA et al., 2018; COLL-PERALES; GOZALVEZ; GRUTESER, 2019). V2X communications enable the information exchanges between vehicles and other infrastructures and people (thing and/or human), providing vehicles accurate knowledge about the environment. The development of V2X communications must ensure reliability levels and network' scalability as the data load increases (5G-PPP, 2018).

V2X creates a more comfortable and safer environment, improving traffic flow, reducing pollution and accident rates. It is up to be applied in the short term into safety, efficiency and information services applications about collisions or hazards on the roads, speed guidance, and congestion warnings. It provides improved driving experiences with route recommendations and automatic parking, but different applications require for different communication performance requirements (WANG et al., 2019).

The C-V2X is a communicating base that offers enhanced road safety and autonomous driving (KUTILA et al., 2019). It uses a transmission mode called direct C-V2X, which provides longer communication range and higher reliability to connect 'vehicles", "things" and "human'. The C-V2X chipset solution is going to be compatible with 5G and with the Advanced Driver Assistance Systems (ADAS) sensors as part of a specific platform for the C-V2X direct communication mode. It was designed to offer IoV connections with or without cellular network for V2I, V2V and V2P (QUALCOMM, 2019), as shown in Figure 5.

Figure 5: IoV on C-V2X



A review over the Physical Layer (PHY) changes introduced under Release 14 for Long-Term Evolution-Vehicle (LTE-V), and its evolutions under discussion in Release 15 to support 5G V2X communications and autonomous vehicles' applications are provided in (MOLINA-MASEGOSA; GOZALVEZ, 2017). The communication modes 3 and 4 support direct V2V communications, being the radio resources allocated by the cellular network under mode 3. As mode 4 does not require cellular coverage, and as vehicles autonomously select their radio resources using a distributed scheduling scheme supported by congestion control mechanisms, it is considered the baseline mode for C-V2X as an alternative to Institute of Electrical and Electronic Engineers (IEEE) 802.11 protocol, the Dedicated Short-Range Communications (DSRC) developed in the United States or Intelligent Transportation System (ITS)-G5 developed in the European (MANNONI et al., 2019).

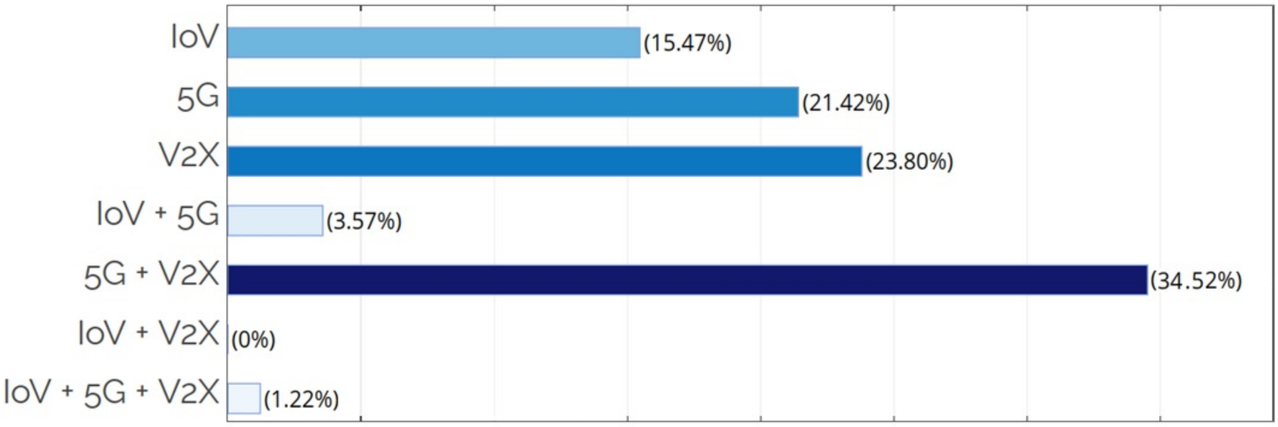
Naik et al. (NAIK; CHOUDHURY; PARK, 2019) presented the C-V2X as an important evolution of Radio Access Technologies (RAT) to enable reliable vehicular communications since C-V2X is going to support advanced vehicular applications that are characterized by low latency, high data throughput requirements, and supplemental sensors for vehicles with autonomy.

The present chapter is about IoV supported by 5G V2X communications. The adopted methodology in this study was the literature research about the 5G technology evolution and standards, about the infrastructure associated with the V2X ecosystem by IoV, considering its architecture, the possible applications and also the V2X features and protocols presented in the existing studies and projects on 5G V2X. This chapter is especially interested in the 5G challenges in the technologies developed for vehicular communications.

Some key-words especially used to search about the proposed context for this chapter were: IoV architecture, model, challenges and technologies; vehicular networks; cellular V2X communication systems; requirements of autonomous driving; VANET applications and challenges; connected cars in cellular network; 5G infrastructure for V2X ecosystem; and others. The most consulted digital library were IEEE. Also were consulted material on ACM, Elsevier, MDPI, Springer, Wiley, and others in the period from 2009 to 2020.

In this chapter were selected 109 references and, from those, 84 are studies about the three specific contents (IoV, 5G and V2X) evolved on the present study. 13 works talk about IoV only (15.47%), 18 about 5G only (21.42%), and 20 about V2X only (23.80%). 3 works have associated IoV with 5G (3.57%), 29 have associated 5G with V2X (34.52%), neither one work has associated IoV with V2X (0%), and 1 work (prepared by the same authors of this survey) has associated IoV with 5G and V2X (1.22%) as shown in the Figure 6.

Figure 6: Percentage of studies about IoV, 5G, and V2X



This chapter is written in reason to study exactly the interaction among these three contents (IoV, 5G, and V2X) as the contribution for the knowledge of the 5G development and use in several scenarios. So, the main aim of this study is to research about the 5G technological evolution, standards, and infrastructure in association with V2X communication by IoV. From those 84 works, 6 are also surveys: 2 about IoV only, 3 about V2X only, and 1 about 5G with V2X as shown in Table 2.

Table 2: Surveys about the proposed contents

Reference	**IoV**	**5G**	**V2X**	**Year**	**Remarks**
(YANG et al., 2017)	✓	✗	✗	2017	The survey reviews the different perspectives to provide a new notion from a network point of view, and to propose a new architecture with four layers. The work summarizes the key technologies, providing traffic service and sharing sensing data coordinately, which can solve the communication.
(HAMID; ZAMZURI; LIMBU, 2019)	✓	✗	✗	2019	The survey brings an overview of the importance to vehicle connectivity as well as the current application of IoV in the autonomous vehicle. The work highlights several issues of the IoV involving connectivity between the environment, the requirement of the wide coverage of 5G Internet as well as security concerns.
(MACHARDY et al., 2018)	✗	✗	✓	2018	The survey has collated searches about the need to extend the perceptual bounds of sensor-equipped vehicles beyond the individual vehicle to the broad implementation of intelligent transportation systems. It has also searched for new directions and standardization efforts toward V2X technology.
(MUHAMMAD; SAFDAR, 2018)	✗	✗	✓	2018	The survey presents an introduction to V2X services alongside the corresponding requirements, describing the potential benefits of using cellular infrastructure for such services and the reference architectures for cellular-based V2X systems. The work focuses on the security issues of V2X in the cellular networks.
(WANG et al., 2019)	✗	✗	✓	2019	The survey cares about an innovative paradigm called Cognitive Internet of Vehicles (CIoV) proposed to help address the aforementioned challenge. The work presents an evolution, related technologies, and architecture overview of CIoV including cognitive design issues and simulations.
(BAZZI et al., 2019)	✗	✓	✓	2019	The survey provides an insight in the comparison between IEEE 802.11p and short range C-V2X technologies for connected and automated vehicles, also trying to isolate the contribution of the physical and medium access control layers.
This Survey	✓	✓	✓	2020	The present survey presents a embracing research about 5G technology evolution and standards, and also the infrastructure associated with V2X communications by IoV.

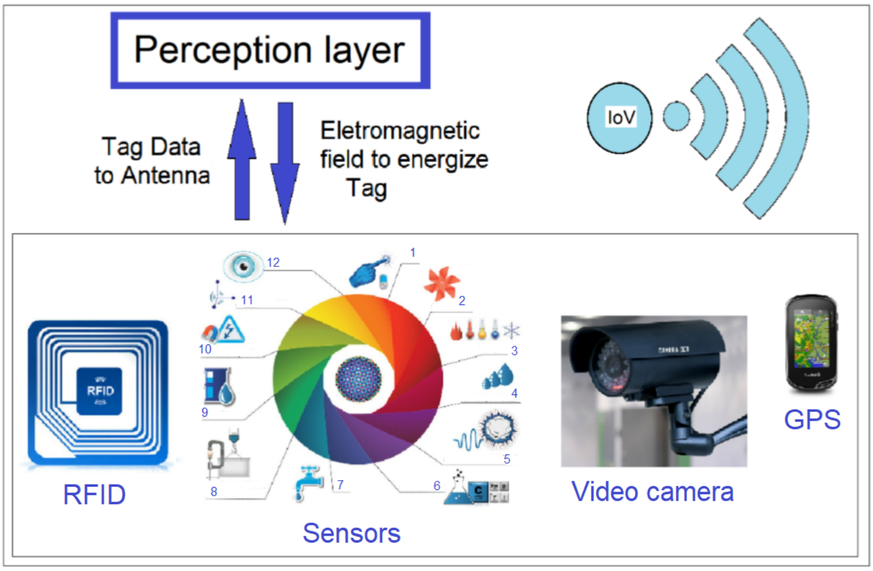
2.2 Internet of Vehicles by C-V2X

This section presents the IoV architecture with the types of V2X interactions, the 5G technology and its features on C-V2X, and the evolution from the RAT to C-V2X communications and also from VANET to IoV applications.

2.2.1 IoV architecture

Typically, to support wireless modes as V2V, V2I, and V2P, the IoV architecture has three layers: perception, network, and applications. The perception layer keeps all the sensors that mine the environmental data inside/outside the vehicles to detect any specific interesting event or change anytime, anywhere. It includes video cameras, radar, Global Positioning System (GPS) receiver, and others such as the Radio Frequency Identification (RFID) that allows the perception of human, vehicles, and things, as shown in Figure 7.

Figure 7: IoV perception layer



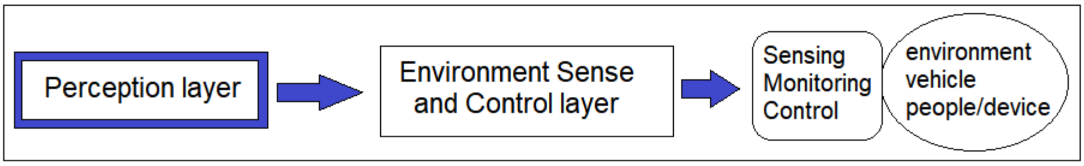
1 Position/Presence/Proximity; 2 Motion/Velocity/Displacement; 3 Temperature; 4 Humidity/Moisture; 5 Accustic/Sound/Vibration; 6 Chemical/Gas; 7 Flow; 8 Force/Load/Torque/Strain/Pressure; 9 Leaks/Levels; 10 Electric/Magnetic; 11 Acceleration/Tile; 12 Machine Vision/Optical/Ambiente light

The network layer makes the IoV applications transmission through network communications for smart devices inside/outside the vehicles. The application layer is the processing infrastructure that uses statistics tools to support data storage, analysis, decision making about the situation of risks such as traffic congestion, bad weather, and much more used in smart applications for safety and efficiency on several online services.

Besides being an IoV service network for V2X communications, C-V2X is a complex system with coordinative interaction and dynamic evolution that requires pervasive and cognitive support computing. In this direction, another proposal (YANG et al., 2017) has presented an IoV architecture divided into four layers: vehicle Network Environment Sensing and Control (NESC) layer; network access and transport layer; coordinative computing control layer; and application layer.

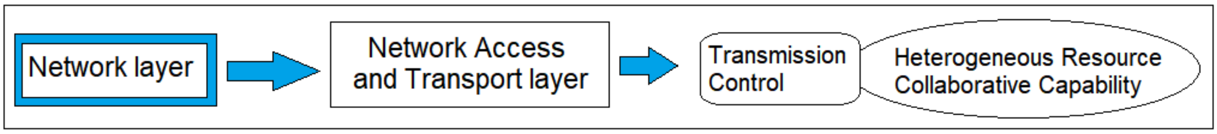
The NESC layer can be associated to the perception layer, because it is the IoV services recognition basis, by which the vehicles sense environment information around them. This layer technology receives and executes coordinative control instructions for cooperative control (YANG et al., 2017), as shown in the Figure 8.

Figure 8: NESC layer



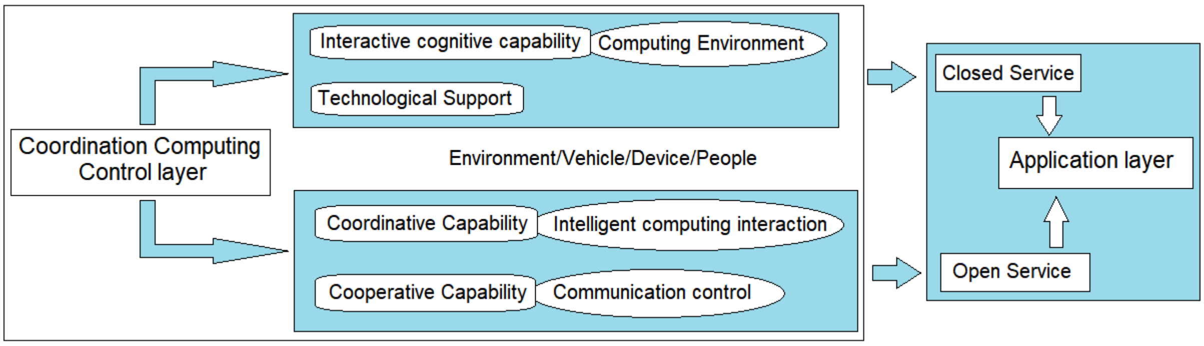
Network Access and Transport (NAT) layer realizes besides the network access, data processing, data analysis, and data transmission, also realizes the remote monitoring and nodes management within the IoV. This layer can be associated to the network layer, because it makes the inter-connection and the information exchange, providing real-time, three-dimensional, and seamless heterogeneous network access. It also dispatches access resources and balances the information load (YANG et al., 2017), as shown in the Figure 9.

Figure 9: NAT layer



The Coordination Computing Control (CCC) layer provides IoV applications with the cooperative capability for communication control and coordinative capability for intelligence computing interaction. It involves the environment, vehicles, devices and people with open services. This layer also provides technological support and interactive cognitive capability for the computing environment, involving vehicles, devices and people with closed services. The application layer of IoV provides various types of opened and closed services, while the opened ones share information to support the business operating model, the closed one is related to the specific industry applications, such as intelligent traffic command and control platform (YANG et al., 2017), as shown in the Figure 10.

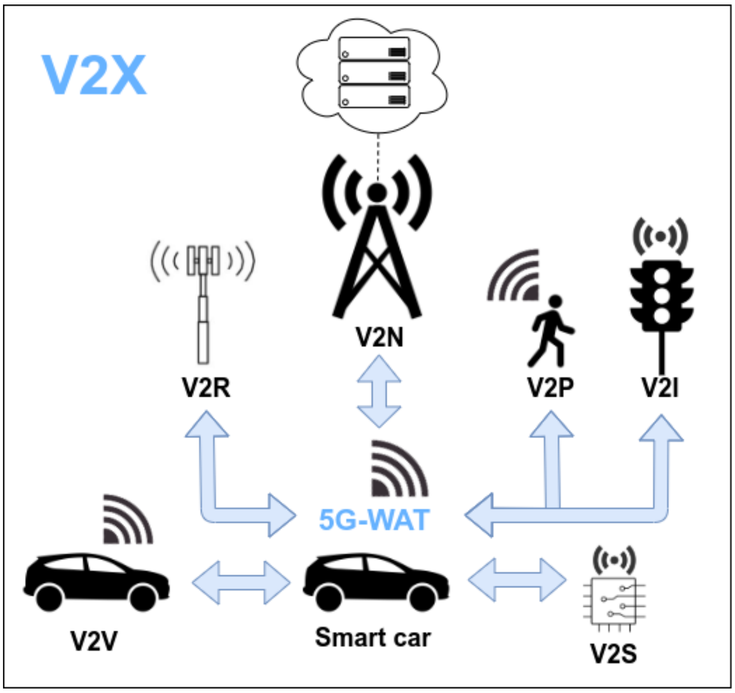
Figure 10: Application layer



To better understand the IoV function on V2X, besides the V2I interaction representation, the vehicle to the Road Side Units (RSU) or better V2R and the Vehicle-to-Sensor (V2S) shall be represented when the 5G Wireless Access Technology (WAT) be incorporated into the vehicles (DOMINGUEZ; SANGUINO, 2019). For while, VANET still enhances safety and efficiency of the traffic, using real-time communication between the advanced WAT, with or without the RSU help, because it can be divided into three ranges (long, medium and short) with modes such as Wireless Access in Vehicular Environments (WAVE), Wi-Fi, ad-hoc, or hybrid mode which associate cellular to ad-hoc.

It is important that for the online vehicle presence in the environment, each smart car must have an Internet identifiable number or a "cyber license" that is controlled in the Vehicular Global Identification (GID) terminal. Due to this internetworking environment in IoV, different WATs are utilized to establish connections among smart cars to the network services by V2N, to other vehicles by V2V, to RSU by V2R, to personal devices by V2P, to the traffic control center (eg. traffic light) by V2I, and to the environmental sensors by V2S (KAIWARTYA et al., 2016), as presented in Figure 11.

Figure 11: Types of V2X interactions by IoV



There are also other ways to describe the V2X application types divided into two basic operations: Device-to-Device (D2D) involving V2V, V2I, and V2P; and V2N with evolved packet-switching communications (STORCK; DUARTE-FIGUEIREDO, 2018). But what matters in fact is that the IoT technology drives the VANET evolution into the IoV that is going to have large applications on transportation and communication fields (YANG et al., 2017). These two different IoT technologies (VANET and IoV) are responsible by two different networking scenarios in which devices and services aspects are also different. While a vehicle in VANET is used to form just an inter-vehicle communication network, IoV is used to create dynamic intra-vehicular mobile communication systems (WAN et al., 2019) which include V2X supported by 5G. Finally, for IoV communications by 5G, user-centric network conception is required to include full V2X connections (CHEN et al., 2016).

2.2.2 5G on C-V2X features

The 5G can be classified as an UDN and as a Heterogeneous Network (HetNets) (BOBAN et al., 2016; FALLGREN et al., 2018). The cell densification is an expected technique in 5G in order to improve the network capacity, especially in terms of connection speeds. In this way, users are connected to Base Stations (BSs) through a virtual cell known as V-Cell (RIGGIO et al., 2014; BEHNAD; WANG, 2017). However, the virtual cells based on user needs formation is a still underutilized area and it lacks new mechanisms for an improvement of the services offered by the 5G network, benefiting, for example, services offered by IoV through 5G V2X communications.

The 5G network is expected to be reliable and fast. The services and applications are going to be accessed by a single Internet Protocol (IP) or identification on the wireless and mobile networks interoperability. The actual system consists of an user-terminal and a number of autonomous RATs linked to the Internet, but in the mobile terminal for C-V2X a different radio interface for each RAT is going to be a need and must provide access to the Internet with Quality of Service (QoS) in its support mechanisms. In today's communication world, the 4 and 6 IP versions (IPv4 and IPv6) ensure enough control data for proper routing of packets that belong to specific connections in accordance with established user-policies.

The main point is the expectation that the C-V2X is can be able to support safety applications that demand an End-to-End (E2E) latency of around 100 milliseconds (ms) (NAIK; CHOUDHURY; PARK, 2019). The C-V2X basic time-frequency resource structure is similar to LTE's one. The smallest allocation unit in time is one sub-frame that is 1 ms composed of 14 Orthogonal Frequency Division Multiplexing (OFDM) subcarriers, and the smallest frequency-granularity is 12 subcarriers of 15 kilohertz (kHz) each (MA et al., 2016). C-V2X devices can transmit using Quadrature Phase Shift Keying (QPSK) or 16-Quadrature Amplitude Modulation (QAM) schemes with turbo coding in each OFDM subcarrier. So, in addition to data symbols, C-V2X users also transmit control information and reference signals (MOLINA-MASEGOSA; GOZALVEZ, 2017).

For this proposal, the technological advances in mobile communications allow different deployment architectures for vehicular networks to support many applications with different QoS requirements in several environments. The VANET is one of these architectures that allow communication among nearby vehicles and/or among vehicles and fixed roadside equipment by IoV (CUNHA et al., 2016).

V2X is a critical component of 5G networks. While the 5G aims to satisfy requirements such as reduced latency, increased reliability, and higher throughput under bigger mobility and connectivity density, the key features of V2X focus on ultra-reliable and low latency communication for safety-critical use cases (DI et al., 2017; KOUSARIDAS et al., 2018; HUSAIN et al., 2018; HUSAI et al., 2019; NAIK; CHOUDHURY; PARK, 2019). 5G V2X is very important for the automotive industry because of its infrastructure and a great capacity to support communication services because 5G networks shall enable vehicles to accommodate different types of V2X message deliveries to support intelligent transportation systems, where all vehicles and infrastructure systems are interconnected with each other. That is why connected vehicles are the next frontier for IoT, while the continuous 5G V2X technology evolution is required to support high-reliability and low-latency radio access for critical messages even in the high-density IoV systems (YANG et al., 2019).

2.2.3 From RAT to C-V2X communications

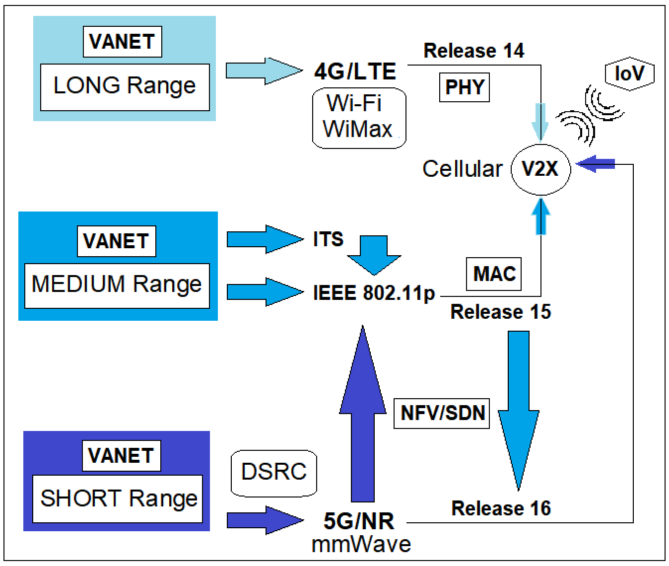
VANET is a special Mobile Ad Hoc Network (MANET) which also presents low bandwidth, short transmission range, and omnidirectional broadcast (CUNHA et al., 2016). Some other VANET characteristics that may represent problems where vehicles are connected are: 1st) it has high dynamic topology due to the vehicles speed and the radio propagation in different directions; 2nd) it has a very short time-period of connectivity, leading to frequent and fast topology changes that make the links between vehicles quickly disappear while they are transmitting information; 3rd) it has geographical localization by targets defined by Cyber-Identity (Cyber ID); 4th) it has mobility and prediction constrained to roads, streets and highways, traffic lights, speed limit, traffic conditions, and driving behaviors; and 5th) it has a propagation model which operates on free-space with reflexive signal interference in highways, or on topographic complex with reflexive and attenuation interference in rural environments, or also on variable density of vehicle numbers and the presence of obstacles causing shadows, multi-path, and/or fading effects in the cities (CUNHA et al., 2016).

In the way to solve all these VANET's problems before the C-V2X evolution, RAT, by its time, is able to support existing multicast, broadcast and unicast services such as download, streaming, group communication, TV reception, and others but some new ones as V2X. RAT is also able to support those services by dynamic adjustment based on user distribution and service requirements in large geographical areas. The Radio Access Network (RAN) through co-operation in the same spectrum is able to support the flexible allocation of resources considering high mobility and data flow aggregation. So, RAN architecture is able to support connectivity through multiple transmission points, and also to enable the separation of control plane signaling and user plane data from different sites. This RAN architecture is able as well to allow Network Function Virtualization (NFV) deployments and network slicing (3GPP TR 23.799) for the multiple operations. RATs enable RAN-internal localization as cell-ID and especially RAN-external operation as Global Navigation Satellite System (GNSS), Bluetooth, Wireless Local Area Network (WLAN), Terrestrial Beacon Systems (TBS) and sensors on the network layer of IoV architecture. By hybrid methods, RAT is able to exploit high bandwidth, massive antenna systems, network functionalities and the massive number of devices to deploy indoors and outdoors supporting and regulatory requirements, offering positioning services and high security on efficient connections (WYMEERSCH et al., 2017, 2018). RAN design for 4G supports D2D interactions, Mission Critical Communications (MCC) for diverse types of services and efficient group or isolated communications, but also provide mechanisms to enable emergency calls including positioning/location, multimedia priority services, and public warning services. In time, RAN design for 5G/mmWave shall provide infrastructure for communication to support V2X services by cell (3GPP, 2018a, 2018b).

Higher levels of processing are going to be available by 5G to free the multicarrier systems to be orthogonal as OFDM what is going to provide considerably more flexibility. The 5G technology opens up the possibility of using several antennas on single equipment by their sizes and by the shorter wavelengths which allow dense networks to reduce the size of the cells providing a much more overall effective use of the available spectrum. 5G requires smart antennas to support radio positioning (switched beam), and/or to improve the capacity of wireless systems (adaptive array). In the 5G software, a single unified IP standard of different wireless networks and a broadband combination with wireless technologies such as WAT (and others) are used to enable service implementations, encryptions, flexibility, and much more.

Representing the context of IoV architecture, 5G and the features of its application on V2X communications, the scheme in Figure 12 shows the VANET ranges and each component that allows the IoV on C-V2X.

Figure 12: VANET ranges for C-V2X



On VANET long range there is 4G working in combination with Wireless Fidelity (Wi-Fi) and/or Worldwide Interoperability for Microwave Access (WiMax) on the physical layer system under Release 14; on the VANET medium range, the ITS and the proposed developments by IEEE 802.11p and Release 15 to allow Medium Access Control (MAC) system works in the direction to support C-V2X by NFV and SDN; on VANET short-range, DSRC is being introduced by the perspectives of 5G/New Radio (NR) using mmWave under Release 16 to support C-V2X.

2.2.4 From VANET to IoV applications

In the IoV heterogeneous network environment, a WAT range is going to be available for connections with several applications on smart devices and the cloud based servers. The WAT is divided into vehicular, cellular mobile and small range static communications; and since these technologies have been developed for different types of communication networks, their characteristics are different. To select appropriate WAT for a specific client application and for the QoS maintaining, there is a prioritized preference of wireless technologies based on data rate, communication range, mobility support, communication delay, security support and scalability, as shown in (KAIWARTYA et al., 2016).

As the VANET still perform the communication up to the transition to the advanced WAT applications on IoV (KAIWARTYA et al., 2016), VANET supports vehicle performance monitoring and analysis applications which include remote vehicle diagnostics by long-term and large-scale collection and proper mining of in-vehicle sensor data. Nowadays, the solutions to support such applications rely on cellular communications 4G adapted for data transmission but also impose severe privacy risks to vehicle drivers (LI; LIU; CHIGAN, 2012). VANET potential applications are targeted to on-road safety, transport efficiency and information/entertainment (infotainment). The safety-related applications have real-time constraints that rely on one-hop broadcasting and multi-hop V2V and V2I communications as cooperative driving (platooning) (NARDINI et al., 2018); the transport efficiency is pursued by traffic management that focuses on optimizing vehicles' flows by reducing travel time as avoiding jam situations (BRITO; DUARTE-FIGUEIREDO, 2017); and the comfort applications aim to provide the road traveler with infotainment to make more pleasant the journey (AMADEO; CAMPOLO; MOLINARO, 2012).

As in a typical VANET, each vehicle has an On-Board Unit (OBU) but it is expected to exist RSUs installed along the roads as well it makes possible the communication among OBUs and RSUs by DSRC over the wireless channel. It allows arbitrary vehicles to broadcast safety messages to other nearby vehicles by V2V communications and to other RSUs by V2I communications. It makes the VANET a sensor network because it helps the traffic control center and other central servers to collect useful information about the road conditions, to offer mobility and security support in real-time (CHIM et al., 2014). For efficient VANET safety applications, a significant number of RSUs must be deployed to quantify the connectivity by the routing performance improvement in the broadcast environment to ensure scalability and mobility support (SOU; TONGUZ, 2011). Since the reliability and timeliness are two critical requirements of vehicle safety-related communication services in VANETs, the WAT is expected to play a key role in the intelligent transportation system by the DSRC, that was projected to support low-latency wireless data V2V and V2I communications, in order to work with sensors in the vehicles for safety on the road (ZHANG; MA; WU, 2014). 5G-WAT applying in vehicular environments is going to lead the IoV to improve the road safety applications and is going to reduce the fatalities number that is caused by road accidents, through the development of the information sharing between moving vehicles regarding in the road. That's why safety applications are already attracting more consideration since the drivers' behavior monitoring is being used to alert the drivers about abnormal driving behaviors of other drivers on the road (AL-SULTAN; AL-BAYATTI; ZEDAN, 2013; ANDRADE et al., 2017).

Besides all these VANET applications, IoV is going several others applications which is bringing fundamental changes to urban management about transport, logistics, and the collective lifestyle, such as safe driving, traffic control, crash response, convenience services, social behaviors (ALAM; SAINI; SADDIK, 2015; NING et al., 2018), and many others. IoV is so the important evolution from VANET that is going to bring by the WAT the support for 5G network development to be employed on C-V2X communications which had its beginning on RAT.

2.3 5G V2X standards

The steps towards 5G implementation standardization has been done in the Release 15 until March 2019. But, since then, the international scientific community has decided that while 5G is not ready to provide enhancements to support advanced services, LTE standardized by the Release 14 is going to be the only safety core for V2X communications. This decision is about the 5G V2X changes designed to enhance the carrier aggregation with support of up to eight bands, the use of frequencies above 6 Gigahertz (GHz), the flexible numerology, with the possibility of subcarrier spacing of 30 kHz and 60 kHz at 5.9 GHz, the possibility to transmit over single slots and even portions of slots, the addition of a feedback channel to allow higher reliability and lower latency, and the use of MIMO receiving antennas to enable spatial diversity especially useful to mitigate multipath in urban scenarios (BAZZI et al., 2019).

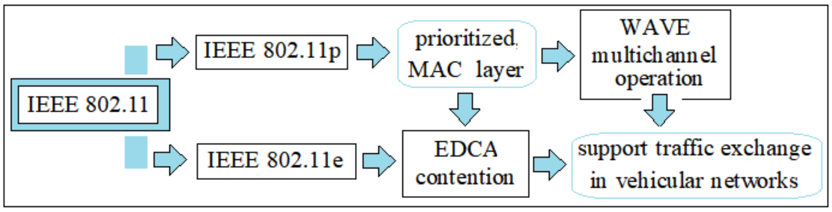
Nowadays, new solutions with high reliability and low latency are required to reduce congestion and the negative transportation impact on the environment and on people's quality of life. But these solutions must use the technological resources currently available and in an efficient way. V2X communication is a solution that is associated with the set of standards that will enable the vehicles to interact with the current infrastructure including roads and road users, and it can be available both by some of the major standardized technologies (DSRC/IEEE 802.11p, and its extension IEEE 802.11px) or C-V2X (ULLAH et al., 2019).

2.3.1 V2X communications protocols

The IEEE specifies the 802.11 protocol to provide the MAC for WLAN communication in different frequencies. IEEE 802.11 enables easy Internet connections allowing the WLAN benefits such as the easier wireless stations deployment. Due to the wireless medium nature, radio signals are hackers vulnerable, by this kind of security problems, information such as MAC address helps adversaries to identify network devices since each MAC address has one unique assignment to network interface cards (NIC) given by the manufacturer and cleared during the data communication. It is hard to keep consistent, robust and secure communications in an IEEE 802.11 WLAN because of the connectivity, performance and security problems in the network. In fact, Wi-Fi is not going to provide consistent access to the Internet if "dead spots" are created on the physical spaces where the radio signals are hidden by network obstacles. Since some radio signals cannot head directly to the destination by obstacles or get delayed to reach there, the IEEE 802.11 increase retransmissions degrading the communication performance. The IEEE 802.11 traffic may suffer plenty of retransmissions especially in a hotspot setting, what can be used as a metric to distinguish among the wireless from the wired network, once Wi-Fi suffers a high rate of retransmissions by channel contention, interferences, or extra MAC overhead. That´s why just 40% of the time is available for data packets transmitting because most part of it is used on radio signals retransmission, acknowledgment and management (TAKAHASHI et al., 2010).

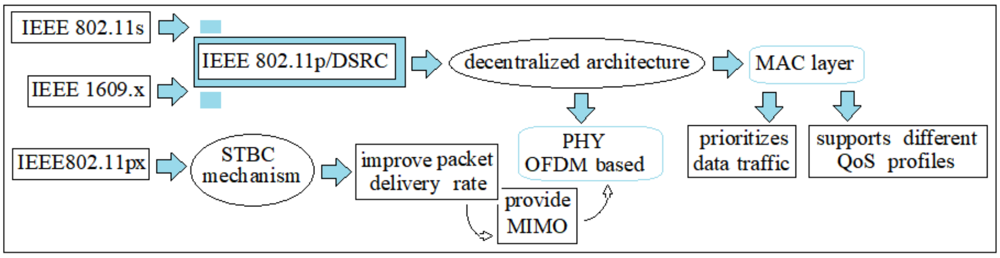
The IEEE 802.11p has been proposed as an amendment to IEEE 802.11. It supports traffic exchange in vehicular networks with the core mechanism of its MAC layer based on the prioritized, and with the contention based on the Enhanced Distributed Channel Access (EDCA) scheme of 802.11e and on the multichannel operation of the WAVE system (AMADEO; CAMPOLO; MOLINARO, 2012; MOLINARO; CAMPOLO, 2019), as shown in Figure 13.

Figure 13: IEEE 802.11p and IEEE 802.11e



The IEEE 802.11p/DSRC standard incorporates the suite of IEEE 802.11s and IEEE 1609.x. It has modifications, and with decentralized architecture for which PHY protocol is OFDM based, while the MAC layer supports different QoS profiles and prioritizes data traffic. This protocol operates without network coverage in a fully distributed manner, because of the direct communication among the source and the destination endpoints that allows effective and immediate data transmission in/out the vehicles. However, the throughput and the end-to-end delay performance degrade quickly as the network load increases, and by this, the protocol is only suitable for transferring low bit rate data streams in vehicular environments and cannot be applicable to some V2X applications where transmission is not reliable beyond the communication range that typically extends to several 100s of meters. To overcome the IEEE 802.11p/DSRC deficiencies, IEEE 802.11px is the enhanced version of the protocol that brings the Space-Time Block Coding (STBC) mechanism to increase the performance under noisy channel transmissions, to improve around 40% the packet delivery rate, and to provide MIMO antenna capabilities with better OFDM layouts, as well very high throughput frame by enhancing the channel capacity (ULLAH et al., 2019), as shown in Figure 14.

Figure 14: IEEE 802.11p/DSRC



V2X communications are going to bring unlimited applications alone. In vehicles they are going to assist in better traffic management leading to several other benefits by intelligent transportation system (ITS). Nowadays, the two RATs that enable V2X communications are DSRC and C-V2X. Both of them operate in the 5.9 GHz band but C-V2X also in the cellular operators' licensed carrier. DSRC relies on the IEEE 802.11p standard and uses a MAC protocol because it is simple, well-characterized and able to realize distributed operations. While DSRC in vehicles has poor scalability and communication challenges by high-mobility environments, the 3GPP has developed C-V2X-LTE based on RAT. It enables the vehicles to operate in the lack of cellular infrastructure. To minimize the performance gap among DSRC and C-V2X and to support additional operation modes and to increase the offered throughput, the NR is being developed in Release 16 to associate the 5G NR, that was standardized in Release 15, as advanced support for V2X applications. C-V2X operates in or out of coverage scenarios and defines data transmission modes that enable direct V2X communications using the basic time-frequency resource structure similar to that of LTE. C-V2X users also transmit control information and reference signals such as the Demodulation Reference Signal (DMRS) which is used for channel estimation in LTE, inserted in two of the fourteen OFDM symbols or in a C-V2X sub-frame designed for high-mobility environments (NAIK; CHOUDHURY; PARK, 2019).

2.3.2 5G infrastructure for V2X ecosystem

The 5G cellular systems are going to have the mmWave technology that operates in the spectrum between 30 GHz and 300 GHz, while the carrier frequencies are spread around 60 GHz with a 2.16 GHz channelization. Through beamforming, this technology is going to achieve high array gains by implementing large antennas which are going to get higher data rates up to several gigabits-per-second. Under ideal propagation conditions, mmWave systems outperform the IEEE 802.11p/DSRC standards for V2X communication.

To understand how 5G applications can be available, it is important to understand that a network slice is a combination of a Core Network (CN) and RAN functions. It has several functional requirements such as security and mobility support, and delivery performance such as latency, reliability, and throughput. An operator can compose different network slices in parallel. The data communication in one slice must not negatively affect services in other slices. Network slicing isolates functions and resources that are specifically tailored to the market needs. Slicing the CN segment affects Control Plane (CP) functionalities, such as mobility management, session management and authentication. It also affects User Plane (UP) functionalities, which become programmable and auto-configurable. By the shared nature of wireless resources, slicing the RAN is a less mature and challenging practice and encompasses various RATs. In order to offer strict latency and scalability of some applications, an E2E slice can be composed of different slice instances in the RAN and in the CN segments with a proper binding mechanism among them to support the targeted service.

To enable this technology of network slicing, the control (C) and the user (U) planes (P) functionalities shall be decoupled, but also the open Application Programming

Interface (API) principles and the programmability of NFV and SDN shall be leveraged. With this CP and UP functionalities decoupling it is going to be possible to displace them in convenient locations: UP functions can be distributed close to the user to reduce service access latency, while CP functions can be placed in a central site which makes management and operation less complex. In the V2X ecosystem, the NFV can be dynamically instantiated, relocated, and horizontally/vertically scaled in accordance with the requirements of the services supported by a given slice, also with the network demands and to underlying infrastructure dynamics. A SDN controller can configure NFV chains in a given slice, and can flexibly interconnect UP/CP functionalities running over distributed hardware through the setup of paths that can be automatically reconfigured either to handle traffic engineering requirements or to react to possible network failures. In the V2X ecosystem, network slicing can effectively cope with a wide variety of use cases with divergent demands provided over the 5G infrastructure by multiple tenants (CAMPOLO et al., 2017, 2018; SANCHEZ-IBORRA et al., 2019).

The V2X is going to offer increased environmental perception to enable sensor-data sharing among vehicles and infrastructures. It will enhance the automated driving control, allowing the cooperation between the vehicles by the perception and the control subsystems of 5G (CAO et al., 2016).

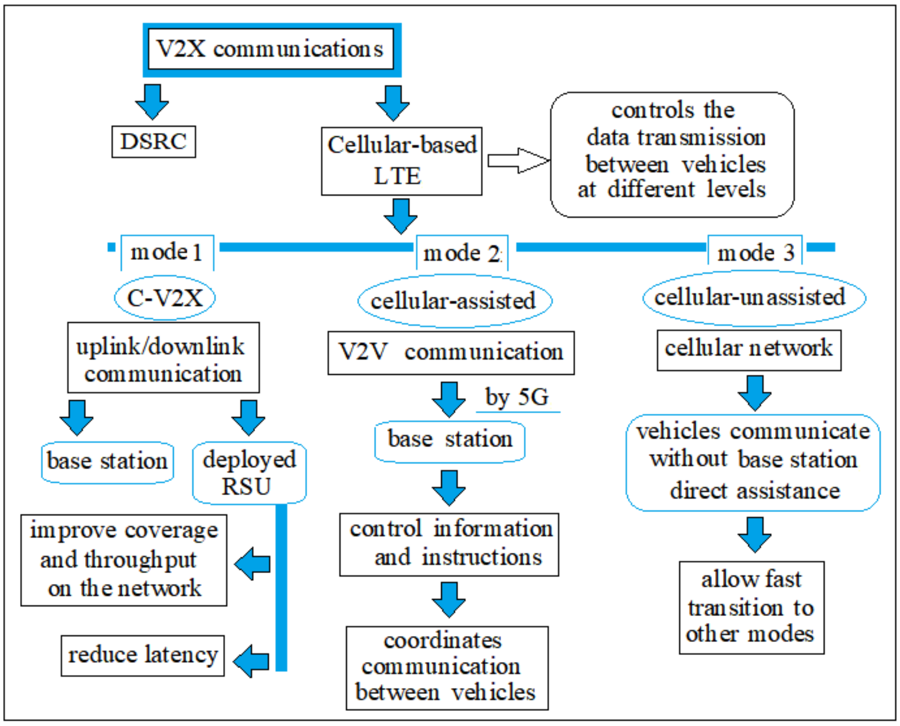
The virtual cell allows approaches to be created centered on the user. It basically consists of several transmission points with an association pattern for each user and his/her respective mobility (SAHIN et al., 2017, 2018). The virtual cells are formed by the association of a user with several Transmission Points (TPs) around him/her. It is highlighted that TPs should act in a cooperative way and can adapt themselves to user mobility. With this, the V-Cell moves because of the user. For this, a controller is required to dynamically configure and manage virtual cells, which can be instantiated by network slice according to specific service requirements. Sahin et al. (SAHIN et al., 2018) present a V-Cell concept, that can be applied in several V2X use cases where broadcast communications for a group of vehicles occur, for example, in Cooperative Awareness Messages (CAM) and Decentralized Environment Notification Messages (DENMs). For this, the authors have adopted the steps of intra-VC optimization (transmission weight selection), power control and admission control. The authors assume that through co-operative beamforming all the TPs in a V-Cell are transmitting the same data in parallel to a vehicle so there is no intra-VC (V-Cell) interference. However, inter-V interference needs to be considered. A "s" data symbol of a data flow in a V-Cell is transmitted with a "p" transmission power and distributed throughout all TPs of the V-Cell according to the "w" weighting factors. This proposal was evaluated by the interactive software called MATrix LABoratory (MATLAB) used on simulations considering LTE systems channel parameters.

2.3.3 5G V2X modes, evaluation and recent advances

Cellular-based V2X is the main radio interface to support V2V 5G communication. It is realized in three distinct modes: I) C-V2X refers to the uplink/downlink communication. It takes place within a base station. It can happen within RSUs too, that are going to be deployed to improve coverage and throughput, but also to reduce latency by fast radio access, handover, and coordinated resource allocation. II) Cellular assisted by V2V is a scheme where the base station coordinates the communication between vehicles by providing control information and instructions to vehicles, being well-suited for extremely low latency and high reliability V2V communication, as the network infrastructure ensures resource availability when requested, and time-consuming data transmission over the cellular network is avoided. III) Cellular unassisted by V2V is a mode where vehicles communicate without direct assistance from the base station. The resources are under control of the cellular network and the out-of-coverage users further remain synchronized to the cellular network and follow a common time reference because they are part of the cellular network.

The transition to one of the other modes can be very fast. In these three modes, the cellular network controls the data transmission between vehicles at different levels and ensures that their data rate, reliability, and latency needs are satisfied, as shown on Figure 15.

Figure 15: V2X modes



One of the most challenging requirements of cellular-based V2X is the time and the frequency synchronization. C-V2X-LTE based and 5G V2X are going to require users to be synchronized among each other in order to avoid inter-symbol and inter-carrier interference, which are caused by the misalignment of multi-carrier signals transmitted over the air. The problem is the V2V and C-V2X coexistence in only one frequency band further that needs BSs and RSUs synchronization, which is in contradiction with the unsynchronized base stations typical scenario on the same or different network operators. That is why the common time reference distribution and the agreement among all involved network entities must be achieved before any data communication can be established (FALLGREN et al., 2018).

To evaluate the V2X implementation, the 5G-DRIVE is a study-project that is going on in the European Union (EU) and in China to harmonize researches and trials on interoperability of the 5G networks in both areas and the evolution of the services that are operating at 3.5 GHz bands for Enhanced Mobile Broadband (eMBB) and at 3.5 and 5.9 GHz bands for V2X scenarios. In this direction, three levels of V2X testing were realized: 1st) in the laboratory, by conducted/wired mode or no over-the-air transmissions, to evaluate ITS-G5 and LTE-V2X (PC5) devices against the European Telecommunications Standards Institute (ETSI) harmonized standard for the 5.9 GHz band on the European Norm 302-571. 2nd) in large and small anechoic chambers, by a radiated mode that is only over-the-air transmissions, to measure harmful interference between ITS-G5 and PC5 devices in the 5.9 GHz band on co-channel and split band scenarios. 3rd) in outdoors, also by radiated mode to deploy ITS-G5 and PC5 devices, to compare and to contrast both technologies from a user experience point of view (CHEN, 2019).

The goals of this harmonization are structured into the technical area to build pre-commercial E2E testbeds in two cities with sufficient coverage to perform extensive eMBB and IoV trials; to develop and trial key 5G technologies and services, including (but not limited to) MIMO at 3.5 GHz, E2E network slicing, Mobile Edge Computing (MEC) for low latency services and V2X, SDN for transport and CN, and network and terminal security; to develop and trial cross-domain network slicing techniques across the two regions for new services; to demonstrate IoV services using V2N and V2V communications operating at 3.5 GHz and 5.9 GHz, respectively; to analyze potential system interoperability issues identified during the trials in both regions; and to submit joint contributions to 3GPP and other 5G standardization bodies regarding the key 5G technologies developed and evaluated in the project. The spectrum usage at 3.5GHz for indoor and outdoor environments in selected trial sites is also a subject of interest of the project. It aims to joint evaluation reports and recommendations on 5G key spectrum bands in Europe and China; and to investigate regulatory issues regarding the deployment of V2X technologies, such as the V2V and C-V2X coexistence in the 5.9 GHz band

(KOSTOPOULOS et al., 2019).

A 5G V2X framework for social-enhanced communications is built upon the cellular V2X architecture specified by 3GPP considering the MEC and SDN technologies as expected in 5G systems. The SDN controller manages switches and other network elements, including the social V2X network application which is going to be augmented with the capability to configure social routing paths at different priorities. This controller can create social paths to connect friends, by injecting proper rules in the flow table of traversed switches through the OF southbound interface. So, it can enforce algorithms that prioritize the data delivery to a given set of friends, because by having a topology global view it can define rules to configure a path towards among the access routers to which the intended destinations, avoiding packets duplication. While including the SDN in the CP, separated by the data plane, all the forwarding data is under CP commands which decisions trigger the establishment of direct communications among vehicles. In this way, the SDN potentials in the framework are empowered with MEC to clearly identify specific modules and their roles in the established communication, managing and exploiting the social relationships (CAMPOLO; MOLINARO; IERA, 2018).

Besides SDN can realize the network transmission and control, it can also control network traffic flexibly by separating the control and the data planes, as allowing a dynamic load balancing for data plane traffic (SILVA; STORCK; DUARTE-FIGUEIREDO, 2019). Vehicle communication architecture based on SDN was proposed to shield the heterogeneous access technologies differences produced in processing the vehicular data using different communication technologies such as cellular network and DSRC. It also can eliminate the differences among cellular and broadcast network by a multi-RAT integration based on a content distribution network which is able to satisfy audio and video services. By its turn, MEC integrates the Internet and the wireless network effectively. It adds the functions of computing, storage, and data processing in the wireless network, while builds an open platform for applications implant, and opens the information interaction between wireless networks and service servers by wireless application interface (DATTA et al., 2017; LI; LI; HOU, 2017; FRASCOLLA et al., 2017, 2018). It upgrades the traditional base station to an intelligent base station. For the 5G network transmission and control, it is going to reduce the communication delay to help the road information be promptly transmitted to the data platform which accurately controls the traffic and implements V2X communication applications (YANG et al., 2017).

2.3.4 5G V2X studies and projects

Several 5G studies and specification projects are taking place in many countries. Some of them are about the International Mobile Telecommunications for 2020 (IMT-2020) and beyond, targeting: radio regulations, operational aspects, protocols, test specifications, performance, QoS, Quality of Experience (QoE), and security; the 5G specifications, targeting: RAN, service and systems aspects, CN and terminals; the 5G technologies, targeting: mmWave transmission, 5G protocols, MEC and NFV; the 5G initiative, targeting: technology evolution towards 5G; the 5G Public-Private Partnership (5G-PPP) projects, targeting: 5G infrastructure and 5G architecture; the technical community, targeting: 5G development and deployment; the 5G network development on Americas, targeting: support and promotion for the full development of wireless technology capabilities; the 5G research and development by the industry, targeting: 5G RAT and network technologies; and much more (STORCK; DUARTE-FIGUEIREDO, 2019).

The 5G development is going to benefit IoV. The RAT needs new networking schemes to assure the QoS demanded by the users and, for that, network slicing techniques are going to enable traffic differentiation to ensure flow isolation, resource assignment, and network scalability. To guide the 5G network slicing for IoV, an accurate bandwidth control with a full flow-isolation which is essential for vehicular critical systems was developed based on a MEC architecture. The MEC provides flexibility for the dynamic placement of the VNFs in charge of managing network traffic. This solution is able to integrate heterogeneous radio technologies such as cellular networks and specific IoT communications with potential in the vehicular sector, creating isolated network slices without risking the CN scalability (SANCHEZ-IBORRA et al., 2019).

Since the WAT is not able to answer all the vehicular network requirements, 5G is going to enable super-fast, reliable, and low latency connections. In fact, a 5G system is not just able to overcome previous generations in requirements such as capacity and latency, but it is also going to allow new applications and usage scenarios with very different requirements on capacity, reliability, and latency such as scenarios with autonomous vehicles. In this direction, it was proposed that the 5G vehicular network is going to be based on the integration of flexible and reconfigurable on-the-fly radio interfaces, so that the provided performance is going to include higher throughput, the possibility of sharing the same radio resources among users communicating through the infrastructure and V2V users, and the improvement of the spectrum usage and the overall system capacity. It is also going to offer lower latency in V2V communications, ultra-high reliability through V2V extended network coverage and through the exploitation of V2V network as fall back solution in the absence of the infrastructure, higher connectivity density, higher mobility and full coverage (MASINI; BAZZI; NATALIZIO, 2017).

5G is going to develop the best technological solution to enable V2X improvements like road safety, traffic efficiency, and the availability of infotainment services, to provide V2V, V2P, V2I, V2N communications (FESTAG, 2015; CHEN et al., 2017). Many groups are working on the integration of RAT into the cellular system architecture as a key concept in 5G mainly meant for Wi-Fi and/or ITS, as presented in Table 3.

Table 3: 5G V2X supports

Support	**Specifications**	**Location**	**Responsible Group**	**Use Cases**
ITS	Traffic message channel (TMC) and electronic fee collection (EFC) developed in the context of real-time traffic information (RTTI).	Europe	International telecommunication union (ITU), 3GPP, standards development organization (SDO), ETSI, national standardization organizations (NSO), and commission for European normalization (CEN) by technical committees (TCs) and European norms (ENs).	Department for Transport of London, United Kingdom.
Wi-Fi	DSRC with allocation of 5.9 GHz frequency band, spectrum subdivided into 10 MHz channels, using OFDM, a widely used multi-carrier transmission.	USA	ITU, 3GPP international organization for standardization (ISO), SDO, society of automotive engineers (SAE) and IEEE 802.11 by categorizing and learning modules (CALMs), PHY, MAC and WLAN.	Federal Communications Commission (FCC) drives 5.9 GHz proposal for C-V2X, Wi-Fi use forward in the USA.

Some studies have been carried out in various countries on the best ways of applying and using V2X, which have evolved chronologically in convergent directions, as shown in Table 4.

The LTE-V2X standards or PC5 (also known as LTE side-link) and IEEE 802.11p (also known as DSRC or ITS-G5), both operating in the 5.9 GHz band provide direct communications between road users. 3GPP has covered, in 2016, the LTE by the Release 14 encompassing two interfaces: 1st) Uu interface connects end-user devices and vehicles to mobile network base stations and mobile core networks, for provision of Internet and V2N services; and 2nd) the PC5 that connects V2V to V2I and to V2P, providing low-latency and high-reliability for vehicular services, but not necessarily requiring assistance from a mobile network. The Protocol 802.11p/2012 is an extension of 802.11a/2010 (about Wi-Fi), and was standardized by the IEEE in 2009 including the multiple access mechanism on Carrier Sense Multiple Access (CSMA) protocols with Collision Avoidance (CA) as a protocol of statistical for direct communications (AMADEO; CAMPOLO; MOLINARO, 2012; 5GAA, 2017; MOLINA-MASEGOSA; GOZALVEZ, 2017; 5G-PPP, 2018; WANG et al., 2019; NAIK; CHOUDHURY; PARK, 2019; ULLAH et al., 2019).

Table 4: Studies about V2X

Project	**Location/Year**	**Main Contributions**
(DI et al., 2017)	China, Australia and USA/2017	This paper considers the V2X communication network where each vehicle broadcasts its safety information to its neighborhood in each transmission period.
(5GAA, 2017)	European Union/2017	This report presents a quantitative analysis about the ability of cooperative intelligent transport systems (C-ITS) using short-range ad-hoc on direct communications to reduce the number of fatalities and serious injuries caused by motoring accidents.
(SULLIVAN, 2017)	Canada/2017	This work presents DSRC and cellular technologies for V2X communication which keys are: 1st) VANET, developed specifically for the purpose of vehicular communication, and MANET.
(HUSAI et al., 2019)	USA, Germany, Finland, France and South Korea/2018	In this paper it is explained that for real-time V2X communications success, it is paramount that 5G mobile networks be resilient, highly reliable, and secure in the delivery and reception of information to and from the vehicle.
(LIANGHAI et al., 2018)	Germany/2018	This reference shows that in reason to provide QoS to the wireless system, new applications are going to be enabled by the 5G network which includes V2X communication that requires low E2E latency and ultra-high reliability.
(JACOB; FRANCHI; FETTWEIS, 2018)	Germany/2018	This work presents how hybrid V2X communications enables multiple communication technologies coordination to efficiently adapt to the time-varying channel and road traffic conditions and also to increase the reliability and throughput of transmissions by combining multiple RATs in parallel.
(MACHARDY et al., 2018)	Japan/2018	In the research and standardization efforts toward the V2X, the technology is intended to enable the communication among vehicles and supporting road infrastructure.
(SNSTELECOM, 2017)	USA and Japan/2019	This work presents V2X as the technology able to allow vehicles to directly communicate with each other, with the roadside infrastructure, and with other road users to deliver an array of benefits in the form of road safety, traffic efficiency, smart mobility, environmental sustainability, and driver convenience.

On the V2X communication network, as each vehicle broadcasts safe information by low latency and high reliability, the Non-Orthogonal Multiple Access (NOMA) is used to reduce the access latency and to improve the packet reception probability. In this context, there are centralized scheduling and resource allocation in which the users and time/frequency elements are considered as disjoint sets of objects to be matched with each other (CAO et al., 2016; MOLINA-MASEGOSA; GOZALVEZ, 2017; YANG et al., 2017; DI et al., 2017; CAMPOLO et al., 2017; CHEN et al., 2017; 5G-PPP, 2018; CAMPOLO; MOLINARO; IERA, 2018; ULLAH et al., 2019). Since the legacy from the cellular networks is not going to meet the service requirements for QoS to the wireless system, new applications that require low E2E latency and ultra-high reliability are going to be enabled by the 5G network, such as V2X communication. In addition, as due to the high-reliability requirement that avoids a single V2X transmission technology application to meet the targets in some scenarios, the multi-RATs scheme where the data packet travels through both the LTE-Uu and PC5 interfaces to obtain a diversity gain is an interesting proposal (MASINI; BAZZI; NATALIZIO, 2017; 5G-PPP, 2018; CAMPOLO; MOLINARO; IERA, 2018; LIANGHAI et al., 2018; WANG et al., 2019; BAZZI et al., 2019; SANCHEZ-IBORRA et al., 2019).

On the RAN, besides the Uu interface enhancements used for unicast and multi-/broadcast between network and vehicles, the most prominent feature is the D2D extension of the communication over PC5 interface to better support V2X communication. It is because, different from 802.11 protocol, PC5 does not implement carrier sensing to defer from channel access in case the channel is detected to be busy. The 5G-V2X 3GPP standards, from Release 14 to 16, consider the 5G splitting up in two tracks: the enhanced LTE that on V2X supports only fixed Transmission Time Intervals (TTI) of 1 ms, and the NR that is new spectrum and waveform, whose access design is going to enable a flexible and scalable TTI structure with intervals below 1 ms (500 μs is expected) in order to reduce air interface latencies, especially for time-critical V2X applications (LI; LIU; CHIGAN, 2012; AL-SULTAN; AL-BAYATTI; ZEDAN, 2013; CAO et al., 2016; MASINI; BAZZI; NATALIZIO, 2017; CHEN et al., 2017; FALLGREN et al., 2018; JACOB; FRANCHI; FETTWEIS, 2018; BAZZI et al., 2019; SANCHEZ-IBORRA et al., 2019).

For V2X communication, DSRC and cellular technologies are keys, first because VANET was developed specifically for the purpose of vehicular communication, and MANET plays an important role in the development of ITS; then, cellular systems, WiMAX, microwave, Wi-Fi, DSRC, ZigBee (that is a specification for a suite of high level communication protocols used to create personal area networks built from small, and low-power digital radios, based on an IEEE 802 standard), Bluetooth, and mmWave are in some way already being used for wireless communication; and at the end, cellular (based on 3GPP-Release 14) and DSRC (based on IEEE 802.11p) have proved to be potential communication technologies enabling connected cars (SULLIVAN, 2017). The researches in the field of MANET and VANET have shown that the use of DSRC supported by the IEEE 802.11p standard was supplemented by IEEE 1609 about wireless communication, including definitions of the architecture, management structure, security, and physical access for WAVE. Considering the communication between OBUs and RSUs infrastructures, DSRC-based communication provides a number of benefits for V2X applications, including low end-to-end latency, flexible organization due to a lack of centralized control, and relatively low cost. DSRC is the longest considered candidate for V2X applications and has been proposed as a mandated standard by the United States Department of Transportation (USDOT), as well as the ETSI and the Commission for European Normalization (CEN) among others. But another candidate access technology for V2X is the C-V2X based on LTE technology and the potential future 5G developments, which advantages include a much larger coverage area, pre-existing infrastructure, deterministic security, and QoS guarantees, as well more robust scalability. V2X is a specific case of ITS, dealing with wireless communication and coordination between vehicles and their environment. V2X communication occurs in the context of a dynamically changing VANET and, leveraging low-latency communications and information sharing, V2X technologies aim to help drivers of today and the autonomous systems of tomorrow coordinate more economically, efficiently, and safely (CHIM et al., 2014; FESTAG, 2015; CHEN et al., 2017; MACHARDY et al., 2018; CHEN, 2019).

The efforts to get 5G for V2X communications are being considered by 3GPP with the C-V2X designed to operate in two modes: I) D2D for V2V, V2I, and V2P direct communication without necessarily relying on the network involvement for scheduling. That is going to help in providing ultra-low latency communication and in transferring large amounts of data reliably among neighboring vehicles; and II) Device-to-Network (D2N) for V2N communication, which uses the traditional cellular links to enable cloud services to be part of the E2E solution by means of 5G network slicing architecture for vertical industries. In this PHY design, 5G NR is used as a key technology enabler to channel modeling aspects for V2X services (HUSAIN et al., 2018; HUSAI et al., 2019). V2X is being considered essential for the autonomous driving ability development. Its features are non-line-of-sight sensing capability which allows vehicles to detect potential hazards, traffic, and road conditions from longer distances and sooner than other in-vehicle sensors such as cameras, radar, and Light Detection and Ranging (LiDAR). Although the legacy V2I technologies are currently in operational use worldwide for Electronic Toll Collection (ETC), advanced V2X systems are beginning to gain broad commercial acceptance with two competing technologies: IEEE 802.11p/DSRC standard, and the relatively new 3GPP-defined C-V2X which has a forward evolutionary path towards 5G. With an initial focus on road safety and traffic efficiency applications, Toyota and General Motors have already equipped some of their vehicle models with IEEE 802.11p-based V2X technology in Japan and North America (SNSTELECOM, 2017).

Most of these studies converge to the fact that any 5G V2X access technology must be able to realize the transmission of basic safety and service messages between vehicular and infrastructural nodes. The most frequently studied WAT used in conjunction with V2X is based on IEEE 802.11p/DSRC and/or cellular/LTE. Besides much of the data passed to and from the connected car can also make use of the cellular, there is a great collection of requirements and new technology challenges which the overcoming is seen as the next step for 5G cellular networks.

2.4 Challenges and future directions

The current cellular technology provides connectivity up to 2 km with latency between 1.5 and 3.5 seconds. It enables a high rate for data transmission to support U/L up to 75 Mbps and D/L up to 300 Mbps. It is also moderately suitable for V2V applications, more suitable for V2I but it has high communication costs. The DSRC technology provides 300 to 1000 meters medium range connectivity. It provides around 200 μs of ultra low latency, and it enables adequate rate up to 27 Mbps for data transmission. It is highly suitable for V2V applications and moderately suitable for V2I applications but it requires visibility and it is not suitable for multimedia features requiring high bandwidth. It also lacks extensive network coverage (SULLIVAN, 2017; SELVANESAN et al., 2018). These analyses can be better observed on Table 5.

Table 5: Uses and challengers of the existing technology

Technology	**Use**	**Challenger**
Current Cellular	It provides connectivity up to 2 km with latency between 1.5 and 3.5 seconds.	It enables a high rate for data transmission to support U/L up to 75 Mbps and D/L up to 300 Mbps.
	It is also moderately suitable for V2V applications, and more suitable for V2I.	It has high communication costs.
DSRC	It provides 300 to 1000 m medium range connectivity.	It requires visibility.
	It provides around 200 μs of ultra low latency.	It is not suitable for multimedia features requiring high bandwidth.
	It enables adequate rate up to 27 Mbps for data transmission.	It also lacks extensive network coverage.
	It is highly suitable for V2V applications and moderately suitable for V2I applications.	

Among the IoV issues and their respective solutions the following ones can be cited:

- *Big Data*: great number of connected vehicles creates a large volume of data to be processed and storage, such as driverless cars that are expected to process 1 GB of data per second. So, the mobile cloud computing and the big data analytics will play an important role in handling big data (XU et al., 2018).

- *Security and Privacy*: as an open public network which involves many different integrating technologies, services and standards, IoV is a target for intrusions and cyber-attacks that may lead to physical damage and privacy leakages. So, it is going to need an efficient data security and privacy system (MUHAMMAD; SAFDAR, 2018; SHARMA; LEE; YOU, 2019).

- *Reliability*: as cars, sensors, and network hardware can have bad function, the system has to deal with incorrect data, as well as faulty communications such as service denial attacks. For that the technology shall offer safety to the vehicle before entertainment (ORSINO et al., 2018).

- *Mobility*: It is difficult to keep the nodes connected and provide them with resources to transmit and receive in real-time when vehicles are moving fast and the network topology keeps changing continuously. To solve that, the system shall offer network stability for no-stop connections (LAURIDSEN et al., 2017).

- *Standards*: the lack of one international standard makes difficult the effective V2V communication. That is why governments shall participate and encourage industries to collaborate in the technological development of the best practices and to accelerate adoption, standardization, and network interoperability by open standards to enable smooth sharing of information (FESTAG, 2015; WANG; MAO; GONG, 2017; ZHAO et al., 2018).

The summary of the issues and solutions of IoV technology can be observed on Table 6.

Table 6: Issues and solutions of IoV technology

Technological Aspects	**Issues**	**Solutions**
Big Data	Great number of connected vehicles creates a large volume of data to be processed and storage.	Mobile cloud computing will handle the big data.
Security and Privacy	IoV is a target for intrusions and cyber-attacks that may lead to physical damage and privacy leakages.	Efficient data security and privacy system are needed.
Reliability	The system has to deal with incorrect data, as well as faulty communications.	Vehicle safety shall to be offered before entertainment.
Mobility	When vehicles are moving fast and the network topology changes continuously, it is difficult to keep nodes connected and to transmit and receive in real-time.	Stability for no-stop connections shall to be offered to the network.
Standards	One international standard for effective V2V communication is lacked.	Governments shall participate and encourage industries to collaborate in the technological development.

2.4.1 Technological challenges

The specific challenges that are being faced by the 5G implementation are: 1st) standards integration is a great challenge because there are multiple groups working around of the interoperability and the backward compatibility with older technologies such as 3G and 4G. 2nd) there is no common architecture for the engineering interconnection that would allow the technological knowledge to be shared and regularized for international use. 3rd) the infrastructure installation is a huge task that deals with the spectrum and installing new antennas, because 5G network is going to rely, at least in part, on higher-frequency bands where is going to exist more space in the available airwaves, but signals cannot nearly travel as far as they could over the frequencies used for 4G. 4th) obstacles like buildings, trees, and even bad weather can also cause interference on the communications requiring more BBs using MIMO antennas to ensure better coverage.

There are several challenges for 5G V2X wireless accesses but the greatest is related to the mmWave technology. It is referred to a communication pattern that uses Extremely High Frequency (EHF), between 30 and 300 GHz band of the radio frequency spectrum. Before the 5G application, mmWave had a historical use on the automotive industry when the 77 GHz band has already been used in the context of Long Range Radar (LRR) in automatic cruise control and other car sensor applications.

As mmWave technology has very strong directional high radio frequencies characteristics, it requires Line-Of-Sight (LOS) connection between a transmitting and a receiving car, or an infrastructure element. It is difficult to achieve in mobile scenarios across different road infrastructure and geographic settings. This means that pre-sense crash warning systems that rely on wireless communication occurring in conditions, when LOS is not available, will not be an easy task. There is also the issue about the car roof that is unsuitable for 360^o antenna coverage which is necessary for V2X applications. The low antenna height, the strong directional properties of the band and the cars themselves blocking the transmissions on de road are other significant issues for the 5G use (MACHARDY et al., 2018). The summary of the challengers for 5G implementation can be observed on Table 7.

Table 7: Challenges for 5G implementation

Technology	**Challenges**	**Specification**
5G	Standards integration	There are multiple groups working around of the interoperability.
	Architecture	There is no common technology to be shared and regularized for international use.
	Infrastructure installation	The 5G network requires spectrum and installing new antennas to rely on higher-frequency bands.
	Obstacles	Whatever those cause interference on the communications make the connections ask for better coverage by MIMO BBs.
	Device support	It is an already overcome challenge because there are available 5G-enabled smart-phones for ubiquitous network and autonomous vehicle technology is in the market even still in limited forms.
	Cost	The new great challenge is to make such an expensive network become available in remote and rural areas.
5G V2X	mmWave technology	It has EHF that requires LOS connections.
	Other significant issues	Car roof is unsuitable for antenna escapable of the 360^o coverage which is necessary for V2X applications. Low antenna height, strong directional properties of the band, and cars themselves block the transmissions on de road.
	Security and privacy	It is also an already overcome challenge because the 5G has standards and sophisticated cyber-security warnings designed to establish trust between networks.
	Transfer data increase	The great new challenge is the ability to let multiple cars negotiate the best way to traverse an intersection or share sensor data like video cameras and radar by a device for unifying all vehicles in the road together.
6G and beyond	Connection in remote areas	Updates on 5G deployment experiences, further technology development, and new business models are expected to guide the telecoms industry on the super-efficient connectivity.

In this context, it is also important to realize that DSRC is a mature technology that has been widely tested and commercialized in many countries. But it still has some coexistence troubles with LTE-V2X (PC5) which has only started to be standardized in 2015, and therefore it is not yet present in commercial services (ZHAO et al., 2018). Since these two technologies have to coexist in the future generation wireless network to provide V2X communications on IoV, they shall be compared to allow a better overview on their challenges (ZHAO et al., 2018), as shown in Table 8.

Table 8: Technical Aspects

Technical Aspects	**DSRC**	**LTE-V2X**	**4G**	**5G V2X**
Theoretical bit rate	3-27 Mb/s	20 Mb/s (uplink) 80 Mb/s (downlink)	75 Mb/s (uplink) 300 Mb/s (downlink)	10 Gb/s (uplink) 20 Gb/s (downlink)
Practice bit rate	3.5 Mb/s	-	20 Mb/s	1 Gb/s
Theoretical coverage	500 m	More than 1 km	5 km	1732 m (rural) 500 m (urban macro) 200 m (urban micro)
Practice coverage	Less than 500 m	Up to 150 m (urban) Up to 320 m (highway)	Up to 2 km	-
Theoretical mobility support	More than 250 km/h	Less than 140 km/h	Between 120 and 350 km/h	Up to 500 km/h
Theoretical latency	Less than 50 ms	Less than 100 ms or less than 20 ms in emergency situations	Less than 10 ms	Less than 4 ms
Frequency band	5.9 GHz	5.9 GHz	0.45-3.8 GHz Unlic. band (5 GHz)	0.45-6 GHz (FR1) 24 - 52.6 GHz (FR2)
System bandwidth	10 MHz	10 MHz	20 MHz	50, 100, 200, 400 MHz
Subcarrier spacing	156.25kHz	15kHz	15kHz	15, 30, 60 kHz (FR1) 60-120 kHz (FR2)
Subcarriers	52	600	1200	3300
Power limits [EIRP]	33 dBm (Private RSUs and mobile OBUs); 40 dBm (Public safety mobile OBUs); 44.8 dBm (Public safety RSUs)	23 dBm (OBU); 33 dBm (RSU)	23 dBm (OBU); 33 dBm (RSU)	33 dBm (OBU and RSU); 46 dBm (BSs)

LTE-V2X provides much better performance with regard to data transmission rate supporting high bandwidth demand for applications. In 5G V2X, data rate and reliability are going to be even higher than the current values of LTE-V2X which enhance cellular base stations to cover larger areas. Compared to DSRC, the mobility support of LTE-V2X is worse. But even if terminals and base stations have to be upgraded, LTE-V2X can be associated to cellular infrastructure and be largely reused. The existing facility can allow telecommunication operators to expand in the IoV market.

By its turn, DSRC is more cost-effective than LTE-V2X, as the latter leans on a worked-on version of cellular networks, which usually offer more services, and therefore is more complex and expensive. It provides smaller coverage due to its intrinsic short-range characteristic and, consequently, high-speed vehicles can only connect to RSUs for short periods of time. Even if multi-hop communication is employed to extend the coverage, a route to an RSU cannot always be guaranteed, especially in networks with low vehicle density. DSRC supports more robust dissemination of safety messages than LTE-V2X. DSRC presents good performance as mobility support, but the lack of perspective in the standard evolution can be a serious limitation for its future development. Even though its technology has over 15 years offering products available on the market and already currently deployed on the road in the United States, Europe, Japan, Australia, and Korea (ZHAO et al., 2018), the DSRC future perspective is not promising.

Despite the differences among both technologies, some challenges are common for them:

- *Low data rates*: to achieve fully automated safety-critical functions, the autonomous vehicles constantly exchange raw sensor data by different V2X modes. This can create a huge amount of data transmission. Neither DSRC nor LTE-V2X can currently support the required data rate for real autonomous vehicles.
- *Low PDR and high latency*: due to the IEEE 802.11 standards design, in highly dense networks, CSMA can cause high channel contention among vehicles and it may further degrade the performance of a network, causing low PDR and increased latency. In LTE-V2X, instead, data packets are required to be sent to the base station before being forwarded to the destination vehicle. It is mainly because of the centralized control nature of the cellular network. Even if the cellular D2D feature can provide direct communication between two vehicles, such connections are not going to be authenticated. Therefore the authentication capability provided by the base station will be needed.
- *Lack of multi-hop routing*: the technique of multi-hop packet relaying has not been widely standardized neither by DSRC nor LTE-V2X. Also, the ETSI/TC-ITS architecture is the only one that involves geographical routing functionality to support road transport and telematics. The heavyweight design of LTE-V2X translates into a higher overhead, and without multi-hop routing, in a high dense network, base stations could be overloaded, causing high latency. Therefore, there is the need to avoid all packets being sent to base stations for either authentication or reaching other vehicles.
- *Lack of ad hoc networking*: under severe natural disasters like flooding and earthquakes, traditional infrastructure communication networks can be damaged and cause communication paralysis. This creates big problems for firefighters and emergency rescue teams (even though usually they might use their low-frequency emergency communication capabilities). Therefore, it is necessary to involve ad hoc communications among vehicles, and vehicles and RSUs to handle the growing vehicle generated data traffic (ZHAO et al., 2018).

One of the V2X communication problems, associated with DSRC, is related to the vehicles high-speed mobility, to the currently incomplete infrastructure, and to the vulnerable reliability of service connection. It means that, V2X with DSRC alone cannot meet requirements for future autonomous driving scenarios. Under agreed communication protocol and data interaction standard, wireless communication and information exchange may be conducted on IoV by V2X. With the evolution of mobile communication industry, 5G network service is closer to answer the user requirements by its enhanced customization capability, deep integration among network and business, and more friendly services.

Due to its elasticity and expandability, 5G network slicing may explore and release the telecommunication technology potentiality, enhancing efficiency and reducing cost. It can easily attempt the potential market demand in fields such as vehicles, smart city, and industrial manufacturing. Moreover, with the network slice broker introduction, the 5G network slicing technology may realize network resources sharing, integration and allocation. These tasks were mutually independent originally. They may be realized in real-time including special requirements network resources dynamical scheduling. The DSRC and the C-V2X technologies combination shall be a good solution for connected vehicles, because it does not just enable the safe driving but it can supply high-quality telematics services to the drivers (XU et al., 2017). With the availability increasing of vehicles which are able to support higher automation levels, the need for coordination among vehicles becomes even more important. Safety requirements and automated driving are defined as the most stringent tasks (CAO et al., 2016).

Cooperative lane change, collision avoidance, and convoy management are typical examples of V2X use cases that are eventually expected to lead to fully connected automated vehicles. There is also a list of functional requirements that should be supported by communication technologies also for other V2X use cases implementation. They are different modes of dissemination, single-hop or multi-hop V2X communication ranges, connection management, V2X message prioritization and capability for congestion control and data retransmission (BOBAN et al., 2018; SHAH et al., 2018).

In fact, communication technologies such as DSRC can help to provide greater benefits to drivers, as automotive industry increases the number of vehicles with additional sensors, including radars and cameras. In the USA, DSRC currently communicates using seven channels in the 5.9-GHz spectrum. The basic safety message (BSM) use as a V2V base that is extended to the roadway infrastructure and users establishes a V2X ecosystem. As this technology does not require a cellular or a data network, vehicles equipped with DSRC do not require coverage or infrastructure costs, nor incur in any cellular network carrier charges. DSRC provides a foundation key for interoperability of messages by V2X and a pathway for the deployment of other radio frequency technologies, such as long-term evolution LTE-V2X and 5G V2X. With the superior performance and the evolutionary path to 5G, C-V2X is the communication technology that is better to be the global solution for V2X communications. C-V2X supports the wireless communication advances and new automotive applications that are needed for enhancements in safety and autonomous driving, and traffic efficiency (PAPATHANASSIOU; KHORYAEV, 2017).

The C-V2X direct communications integrated into an LTE-based telematics unit, this technology is also cost-effective in the broader transportation ecosystem (UHLEMANN, 2018). Although DSRC can provide reliable V2I and V2V communications, the achievable data rate may not satisfy many emerging vehicular applications such as video/image transmission and autonomous driving. In this case, 5G V2X combine the advantages of both cellular and ad hoc connectivity among vehicles to the vehicular communications development. Compared with DSRC, 5G employs more advanced techniques, such as MIMO that can significantly improve the reliability and efficiency of vehicular communications, leading to high data rate and low latency (CHENG; ZHANG; YANG, 2019).

2.4.2 Future directions

The summary of the futures directions can be observed in Table 9. To generate a more promising solution for vehicular communications, 5GAA suggests allocating separate 10 Megahertz (MHz) channels to both technologies to avoid any interference between them. These communications can make the combination with the advantages of both technologies DSRC and C-V2X, creating a hybrid approach. It is working in Europe but in the massive V2X communications scenarios, the traffic load produced by several automotive devices is difficult to handle with the conventional cellular and DSRC solutions. In this context, the use of SDN for vehicle (SDN-V) or Software-Defined for IoV (SDIoV) presents a promising architecture which can enable the DSRC and C-V2X coexistence, because it is going to allow the management and the centralized control of the heterogeneous 5G (GE; LI; LI, 2017; HAN et al., 2017; ZHAO et al., 2018; STORCK; DUARTE-FIGUEIREDO, 2019; PENG et al., 2019; GHAFOOR et al., 2019).

With a global view, SDIoV is going to provide distinguishing features such as intelligent multi-hop routing, dynamic resource allocation, and advanced mobility support. It is also going to allow the creation of an ad hoc network to guarantee robustness and seamless communication. Through SDIoV, artificial intelligence mechanisms can be deployed on the control plane in vehicles as part of the V2X technology. It can provide traffic control, intelligent routing strategies, and joint scheduling in real-time (CHEN et al., 2018).

Table 9: The expectatives of future 5G aspects

Aspect for search	**Expectative**
Vehicular communications associating the advantages of DSRC and C-V2X technologies.	It allocates separate channels to both technologies to avoid any interference between them, creating a hybrid approach. The traffic load produced by several automotive devices in the massive V2X communications scenarios is difficult to handle with the conventional cellular and DSRC solutions.
Use of SDN-V or SDIoV architecture.	It enables DSRC and C-V2X coexistence to allow management and centralized control of heterogeneous 5G network.
SDIoV provide features such as intelligent multi-hop routing, dynamic resource allocation, and advanced mobility support.	It allows the creation of an ad hoc network to guarantee robustness and seamless communication.
SDIoV artificial intelligence mechanisms are deployed on the control plane in vehicles as part of the V2X technology.	It provides traffic control, intelligent routing strategies, and joint scheduling in real-time.
SDIoV architecture involves multiple communication technologies to support fully autonomous driving by allowing a network with the DSRC and the C-V2X coexistence.	It presents enough scalability to upgrade the current network to 5G and beyond features, to enhance the communication quality.
5G technology offers significant benefits from a range of mechanisms and capabilities to the future automotive systems, especially on the V2X context.	It improves the driving experience with safety and infotainment applications.
5G requires mmWave as EFH to achieve the requirements for better reliability, lower latency, and higher data rate.	It provides Gbit/s throughputs required for raw sensor data exchange among vehicles with applications on V2X communications. The very high the numbers of sensors, that are going to be deployed on vehicles, the very hard is the initial access procedure due to massive connection attempts.
5G promotes great model business change enabling new services and improving the existing ones, due to the technology enablers in RAT areas for V2X communications and network virtualization.	These enablers are already bringing new components and affecting business relationships. V2X communications and the technologies associated with 5G are going to disrupt current business relationships and create more collaborative business environments.
V2X technology demands a reliable Internet connection and the IoV feature helps autonomous vehicles use in smart cities and highways.	It asks for reliable and fast Internet connection to be developed by the 5G network. It demands cooperation among governmental sectors and industries.
5G V2X development involves the IoV technological needs for commercial business, with the improvement of vehicle surveillance and real-time tracking, with monitoring and analysis of traffic data, and logistic movement, and also with centralized storage and management of massive data in the data center.	It indicates that future business growth depends on the establishment of an agile 5G V2X data center architecture, which includes efficient storage, network, and computing performance to support the IoV demands and growth.
Modern vehicles connected through multi-RAT exchange massive information with their surrounding environment.	It needs VANET evolves to support V2X on the IoV architecture for an efficient and intelligent prospect for future communications and transportation systems.
Technological advances in communications and control systems have changed the cars into formidable sensor platforms.	These absorb information from the environment and from other cars to feed themselves back, assisting in safe navigation, pollution control, and traffic management.
5G V2X solutions ready for deployment by hardware/software are commercially available.	5G V2X communication allows the autonomous driving by perceptions, path planning, real-time local updates, and coordinated driving.
With CARMEN, cars with different levels of autonomy are 5G connected anyway.	It provides a platform that leverages the most recent advances of this technology to support safer and intelligent transportation by communications. 5G promotes awareness about the extended road situations, enabling vehicles and infrastructure to share information, exploring different network architectures and configurations to guarantee the coverage at all times.

The SDIoV architecture involves multiple communication technologies that can be used to support fully autonomous driving by allowing a network with the DSRC and the C-V2X coexistence. The SDIoV also presents enough scalability to upgrade the current network to 5G and beyond features, to enhance the communication quality.

The 5G technology is going to offer significant benefits from a range of mechanisms and capabilities to the future automotive systems, especially on the V2X context. It is going to improve the driving experience with safety and infotainment applications. 5G requires the mmWave that is an EHF used to achieve the requirements for better reliability, lower latency, and higher data rate (CHOI et al., 2016). Such 5G cellular systems employing mmWave at EHF provide Gigabit-per-second (Gbit/s) throughputs (ORSINO et al., 2018; HE et al., 2020). So, the connection among 5G wireless standards and vehicular communication systems is made by mmWaves transmissions because they are able to provide Gbit/s data rates, required for raw sensor data exchange among vehicles with applications on V2X communications (ANTONESCU; MOAYYED; BASAGNI, 2017). The very high the numbers of sensors, that are going to be deployed on vehicles, the very hard is the initial access procedure due to massive connection attempts (CHOI et al., 2016).

In short time, 5G is going to promote great model business change enabling new services and improving the existing ones, due to the technology enablers in RAT areas for V2X communications and network virtualization. These enablers are already bringing components such as network slicing (MOLINA-MASEGOSA; GOZALVEZ, 2017; CAMPOLO et al., 2017; KOUSARIDAS et al., 2018; FALLGRAN et al., 2018; BAZZI et al., 2019). But the way they affect business relationships is also changing.

The automotive sector that has typically been a well-defined and specialized “value chain”, due to connectivity guided by the new 5G technologies, now is being transformed into a “value network” in reference to economic ecosystems where every market “node” relies on others to create a common value proposition (ARAGON; ZARATE; LAYA, 2018).

In this context, V2X communications and the technologies associated with 5G are going to disrupt current business relationships and create more collaborative business environments. It is almost impossible that only one company can have the competence to create all solutions for the increasing industrial and commercial demands in this new universe of possibilities. The universe will be a place where cooperation among different sectors is essential (UHLEMANN, 2017).

V2X is a technology that demands a reliable Internet connection. The IoV feature can help autonomous vehicles use in smart cities and highways, where the reliable and fast Internet connection shall be developed by 5G network (HAMID; ZAMZURI; LIMBU, 2019). This demands cooperation among governmental sectors and industries, also because IoV can be easily manipulated by irresponsible sides, which creates security concerns about the network connectivity, the user privacy, and autonomous vehicles’ effective control (CHIM et al., 2014; MUHAMMAD; SAFDAR,

2018; CONTRERAS-CASTILLO; ZEADALLY; GUERRERO-IBANEZ, 2018; SHARMA; LEE; YOU, 2019). On another side, 3GPP has developed some functions to provide cellular standards enhancements specifically for V2V. Concentrated on V2X standards, direct V2V communications can be allowed by the distributed scheduling, which uses a mechanism based on sensing with the semi-persistent transmission, without introducing a detour through the BS.

Some tests, realized in South Korea and German, have already shown that 5G performance is going to support V2X services. They also have shown implemented new key 5G capabilities with multiple devices operating in the mmWave and multiple connected-car-use cases. V2V communication represents the very first step toward achieving fully autonomous driving in the 5G era (UHLEMANN, 2017). Other tests have been reported by (VUKADINOVIC et al., 2018; TOGHI et al., 2018; QUALCOMM, 2018; TOGHI et al., 2019; CHEN, 2019; KOSTOPOULOS et al., 2019; HETZER, 2019). These tests have accelerated 5G research and development and have the intention to facilitate the integration of the technical requirements of various industries into upcoming international 5G-standardization activities.

Some perspectives for the 5G V2X development involve the IoV technological needs for the commercial business, with the improvement of vehicle surveillance and real-time tracking, with monitoring and analysis of traffic data, and logistic movement, and also with centralized storage and management of massive data in the data center. It indicates that future business growth depends on the establishment of an agile 5G V2X data center architecture, which includes efficient storage, network, and computing performance to support the IoV demands and growth (YINGWEI, 2017).

Modern vehicles are going to be connected through heterogeneous RAT (multi-RAT) and they are going to exchange massive information with their surrounding environment as the automotive telematics are being developed. As the network scale is expanding both the real-time and the long-term information processing, the traditional VANET shall evolve to support V2X on the IoV architecture. It is a promise for an efficient and intelligent prospect for future communications and transportation systems (XU et al., 2018).

Traditionally, the vehicle has been the extension of the man, obeying the driver's commands, but the technological advances in communications and control systems have changed the cars into formidable sensor platforms. These platforms absorb information from the environment and from other cars to feed themselves back, assisting in safe navigation, pollution control, and traffic management. The next step in this evolution is the autonomous vehicles as an important instance of the IoT, where the IoV is going to have communications, storage, intelligence, and learning capabilities to anticipate the customers' intentions (GERLA et al., 2014).

Finally, with the commercial availability of the 5G V2X solutions ready for deployment by hardware/software, the expectative for 5G V2X communication is on the autonomous driving by perceptions, path planning, real-time local updates, and coordinated driving (FLAMENT, 2019).

With the Connected and Automated Road Mobility in the European Union (CARMEN), the cars with different levels of autonomy are going to be 5G connected anyway. It provides a platform that leverages the most recent advances of this technology to support safer and intelligent transportation by communications about speed, position, intended trajectories and much more. 5G is going to promote awareness about the extended road situations, enabling vehicles and infrastructure to share information, exploring different network architectures and configurations to guarantee the coverage at all times (RIGGIO, 2019).

That is why public authorities, groups of Original Equipment Manufacturer (OEM) and road operators have worked together to create an economic low-latency communication system which can improve road safety, traffic management, and road transport performance. In this context, V2X provides direct connections within a C-ITS also called ITS-G5 technology that is associated with WAVE and/or DSRC, which is based on the IEEE 802.11 standard (WiFi) or ETSI EN 302 663. Nowadays, there is already, in several countries, a great number of manufacturers able to provide ITS-G5 technological solutions.

2.5 Final remarks

This chapter presents a 5G technology overview with its evolution, standards and the infrastructure associated with the V2X ecosystem by IoV. The 5G vehicular communications challenges were especially considered. Initially, the chapter describes the IoV architecture with the V2X interactions types, the 5G technology with its features on C-V2X, the evolution from the RAT to C-V2X communications, and also from VANET to IoV applications. Then, the chapter introduces the steps towards the 5G implementation standardization by Release 15. It also points that only the LTE standardized by the Release 14 is still the safety core for V2X communications. There are challenges such as low data rates, low PDR and high latency, lack of multi-hop routing, and lack of ad hoc networking, noticed as also compared to DSRC and 4G. After the analysis of 84 literature works, the present chapter has identified the connectivity between vehicles and cellular networks as a big research challenge because of the fast vehicular mobility and the legacy networks signaling patterns. As a secular technology, vehicular upgrades tend to take a long time to change, consuming all types of used features that can be controlled by software. Besides that, there will still be millions of cars connected by 5G networks, behaving like cell phones for communication, identification, and network services. With superior performance and evolutionary path already crossed, 5G technology is well-positioned to be the global solution for V2X communications. It supports advancements in wireless connections and in new automotive applications that are expected for enhancements in safety, autonomous driving, and traffic efficiency. Therefore, wireless communications become paramount and are the pillars of vehicular systems. New network requirements, such as high data transmission rates (between 1 to 20 Gbps), massive connections (estimated at 1 million connected devices and cars), low latency ultra-low communications (1ms), and high-speed mobility support (up to 500 km/h), are still awaited. The great identified IoV technology issues were the ones about big data, security, privacy, reliability, mobility, and also standards. In the end, it is expected that the vehicular communications will associate the advantages of DSRC and C-V2X technologies, the use of SDIoV architecture, and other interesting aspects that are pointed to be considered in future works.

As this thesis brings many proposals around a 5G ecosystem, each of them will be compared with the literature in the respective description chapter.

Chapter 3 describes a 5G V2X ecosystem providing IoV and the 5G standards and features, the integration with a SDN. It also points out materials and methods for modeling and simulation, to present results and discussions about the proposed ecosystem.

3 A 5G V2X ECOSYSTEM PROVIDING INTERNET OF VEHICLES

The 5G cellular network is presented as the way to the ubiquitous Internet and its pervasive paradigm. It is expected to be the IoV network infrastructure, allowing cars to be connected to new radio technologies. This chapter presents a 5G V2X ecosystem to provide IoV motivated by a vehicular mobility simulation with DASH as adaptive algorithm performed in urban and rural scenarios with different vehicle densities. The idea of this proposal as strategic solutions is the integration and the adoption of emerging technologies. The proposed ecosystem is based on the SDN concept, considering vehicles as entertainment consumer points. The network infrastructure must be big enough to guarantee delivery and quality. For this purpose, vehicular Internet-based video services traffic and V2V communications in urban and rural scenarios were evaluated, and simulations were performed through the Network Simulator ns-3, employing millimeter Wave (mmWave) communications. Data transfer rate, transmission delay, and Packet Delivery Ratio (PDR) were analyzed and compared on rural and urban IoV scenarios. Adaptive streaming algorithms (FESTIVE, PANDA, and TOBASCO2) using the 5G ecosystem were analyzed of in the urban simulated scenarios with different vehicle densities. The results have shown satisfactory performance to the IoV connectivity requirements when adopting the 5G network with the V2X ecosystem for vehicle communications. For example, the throughput on urban micro scenario presented higher performance than the rural scenario. The difference between the urban micro scenario and the urban macro scenario is 21.5% for the density of ten active vehicles, and the percentage differences decrease between the simulated scenarios while the densities increase. PANDA is the best DASH algorithm to be used in multimedia, as an adaptive method of video streaming.

Section 3.1 presents an overview of some connected cars through the 5G V2X ecosystem and describes the IoV as part of intelligent cities characterized as an open and integrated network system, composed of several components through the cellular network that can be used in four V2X application types. Section 3.2 presents the related work, and section 3.3 describes relevant definitions and explanations about the 5G ecosystem but also presents the 5G standards, features, development, and integration with SDN. Section 3.4 describes the proposed 5G V2X ecosystem, and section 3.5 presents the adopted methodology, the materials and the methods used to model and the 5G ecosystem. The simulation, the parameters of 5G V2X scenarios, the fog cell network topology, the SDIoV entertainment services logical view, and the operation of the proposed architecture were also explained. In section 3.6 the network throughput, the average delay in a fog cell 5G V2X, and the packet delivery ratio in 5G V2V communications results are discussed. Section 3.7 presents the obtained results in urban scenarios with different vehicle densities. The studied metrics were the number of playback interruptions, video quality, quality of transitions, average buffer level, average bit-rate and bit-rate switching frequency, throughput, unfairness, instability, and inefficiency. In section 3.8, the final remarks are shown.

3.1 Connected cars through 5G V2X ecosystem

Vehicular communications require some wireless communication infrastructure to always have signal coverage. The 5G cellular network emerges as a new strong alternative to allow such connections, in a reliable, secure, and fast way, providing the IoV, as well as the V2X scenarios integration. It is expected that the 5G network can be able to attend the requirements for the future IoV applications and to offer Intelligent Transport Systems (ITS) in several scenarios involving high mobility, dynamic network topology, and high data volume (GE; LI; LI, 2017).

IoV can be considered part of intelligent cities and it is characterized as an open and integrated network system, composed by several components, including vehicles, people, and things (YANG et al., 2014), as Figure 16 illustrates. It shows that there are four V2X application types divided into this two basic operations: D2D involving V2V, V2I, and V2P; and V2N with evolved packet switching communications (WANG; MAO; GONG, 2017). In this ecosystem, safety enhancement Vehicle-to-Everything (eV2X) services or scenarios include automated driving, vehicle platooning, extended sensors, and remote driving. However, mobile entertainment with high data rate is an example of non-safety eV2X scenarios.

Figure 16: IoV through cellular network

Among the IoV promises, there is a need for efficient management, control, and operation, besides high capacity and assurance. In the literature, the OpenFlow (OF) protocol was indicated for the Software-Defined Internet of Vehicles (SDIoV) architecture as the communication protocol between the control plane and the data plane (JIACHENG et al., 2016).

The remainder of this chapter presents an SDN-based 5G ecosystem to support IoV communications. Nowadays, with the accelerating and fostering goals of the 5G development all around the world, new architecture design, testing, and evaluation are real and urgent needs. The high complexity expected from a 5G V2X network architecture together with the imposed challenges for its development and evaluation is this work motivation. The multimedia service delivery, that is a typical non-safety eV2X application, is analyzed. The onboard entertainment services can be managed through an SDN controller and the processing can be performed on a V2X-Server. Then, an evaluation is performed of the packages' delivery rate based on 5G V2V communication scenarios regarding the safety eV2X applications; for example, a collision avoidance system through IoV. A set of vehicle communication simulations with the 5G network, using millimeter wave links, is performed using the ns-3 simulator.

3.2 Related work

IoV provides all Internet services to drivers, passengers and vehicles, and the SDIoV is nothing else than the integration of SDN with IoV. This brings the need for innovation to support IoV communications, services, and applications. In this proposal, challenges are pointed out, such as high efficiency in resources use, capacity increase, management, and control in a scalable and flexible way, as well the QoS (Quality of Service) in vehicular communication networks (JIACHENG et al., 2016).

When SDN is applied in IoV by disassociating the control and data planes, the controller manages the network and can shape the data traffic for the specific application. In SDIoV, the packet routing can make IoV applications feasible while connected vehicles rely on the messages received from other vehicles and/or Road Side Unit (RSU) and, in such way, as the centralized controller has a global view of the whole network (GHAFOOR et al., 2019).

IoV needs non-stop technology evolution to answer all the new safety requirements and use cases that come with the C-V2X development, in reason to provide a higher performance radio, while reusing upper layers defined by the automotive industry. The Third Generation Partnership Project (3GPP) defines C-V2X and to specify service requirements for V2X systems, with an expectation to support several advanced scenarios (PAPATHANASSIOU; KHORYAEV, 2017; 3GPP, 2019c).

In this direction, ITS and future vehicular networks require stringent requirements, and as already noted, these are hardly met through the IEEE 802.11p technology (ATALLAH; KHABBAZ; ASSI, 2015), that has 27 Mbps maximum throughput with V2X applications. As an alternative, the Long-Term Evolution (LTE) technology has been employed to support vehicle applications (3GPP, 2016; CHEN et al., 2017), however the performance is affected by interference as shown by (TALEB; KSENTINI, 2015).

The first V2X specifications involving cellular networks was provided in Release 14 of Long-Term Evolution-Advanced (LTE-A), focusing mainly on the aspects of vehicular safety applications, where was defined that vehicles should use a new PC5 interface for communication. It is because the LTE for vehicle standard supports side link or V2V communications using a direct interface on modes 3 and 4 which got physical layer changes introduced by Release 14, and its evolutions are being discussed on Release 15 to support 5G-V2X autonomous vehicles' applications (MOLINA-MASEGOSA; GOZALVEZ, 2017).

The 5G network integrated with SDN and Mobile Edge Computing (MEC) (BLANCO et al., 2017) is as a good candidate technology for VANETs' operational improvement, in terms of data rate, coverage, and QoS. There are other works that present interesting points to be considered for the 5G development common work, such as the four-tier architecture for urban traffic management (LIU et al., 2017). Even SDN has already been used for VANETs and has limitations in RSU when there is a high density of vehicles by it presents frequent handovers, what degrades its performance (LIU et al., 2016).

In (GE; LI; LI, 2017), the authors found that there is a minimum transmission delay, in accordance with different densities of vehicles. With the fog cell use, the authors were able to demonstrate an improvement on the transport management system performance. However, problems on the multi-hop routing retransmission and gateway vehicle selection on the proposed structure persist, which directly affects the system performance. Finally, a next generation 5G topology structure, using SDN controllers and a fog computing framework with zones and clusters to avoid frequent handovers between vehicles and RSUs is presented in (KHAN; ABOLHASAN; NI, 2018). The difference from these works to the present one lays on the fact that, in this thesis, communication occurs directly with the proposed 5G V2X ecosystem regardless of the vehicular density.

3.3 5G standards and features

This section presents the 5G standardization and the development efforts (Subsection 3.3.1), and the features of 5G mobile communications systems (Subsection 3.3.2).

3.3.1 5G standardization and development

The 5G networks specifications are being discussed and analyzed by the academy, by Standard Development Organizations (SDOs), by some consortia, by government and by industry. A panorama of institutions that contribute to the development and standardization of 5G networks is presented on Table 10, as well as the main contributions.

Table 10: Panorama of 5G networks development and standardization

Institution	Projects and Initiatives	Target	Main contributions
ITU (ITU, 2019)	International Mobile Telecommunications for 2020 and Beyond (IMT-2020)	Radio regulations; Operational aspects; Protocols and test specifications; Performance, QoS and QoE; Security	Recommendations (standards)
3GPP (3GPP, 2019e)	5G specifications	Radio access network; Service and systems aspects; Core network and terminals	Releases; Technical specifications
ETSI (ETSI, 2019)	5G technologies	mmWave transmission; Next generation protocols; MEC; NFV	Technical specifications
NGMN (NGMN, 2019)	Next Generation Mobile Networks (NGMN) 5G Initiative	Technology evolution towards 5G	White Papers
ATIS (ATIS, 2019)	Technical forum	Incubator of new business models	White Papers
5G-PPP (5G-PPP, 2019)	Working groups and various 5G Public Private Partnership (5G-PPP) projects	5G infrastructure; 5G architecture	White Papers
IEEE Future Networks (IEEE, 2019)	Technical community	Providing practical, timely technical and theoretical content; Development and deployment of 5G	Research publications
5G Americas (5G-AMERICAS, 2019)	5G network development on Americas	Support and promote the full development of wireless technology capabilities	White Papers
5GMF (5GMF, 2019)	5G research and development by industry	5G radio access technologies; Network technologies for 5G	5GMF White Paper
Verizon 5G TF (VERIZON, 2019)	Forum and technical specifications	Specifications for physical layer, MAC, RLC, PDCP, and RRC	5G specifications
5TONIC (5TONIC, 2019)	Open research laboratory	SDN; NFV; Physical and MAC layer	5G technologies
5GAA (5GAA, 2019)	Mobility and transportation services	Use cases and technical requirements; System architecture; Standards and spectrum; Business models	White Papers

Among the most recent, 5G Automotive Association (5GAA) consists of automotive and telecommunications companies, among them Audi, BMW, Daimler, Ericsson, Huawei, Intel, Nokia, and Qualcomm. This organization aims to deliver mobility and transportation solutions through technical studies, testing, analysis and deployment of the C-V2X (5GAA, 2019).

Some researches are being developed by the academy, all over the world. An example in Europe is the University of Surrey. It has the largest center of 5G technology research of the United Kingdom, called 5G Innovation Centre (5GIC), with the financing of £ 16 million from the Higher Education for England, also counting on more £ 68 million from the industry and partners (SURREY, 2019).

In the United States, the University of New York is an example and it has an academic research center for investigation about new technologies of wireless communication, involving devices, networks and applications. The main focus is the use of mmWave over 10 GHz. With the higher frequencies through mmWave and, consequently, greater propagation and penetration losses, researchers have studied beam formation techniques in order to improve the signal level (NYU, 2019).

In South America, the 4th Coordinated Call among European Union–Brazil (EU-BR) was launched in Brazil, on February 2017, through the Brazilian National Research and Educational Network (RNP) and Brazilian Ministry of Science, Technology and Innovation (MCTI). It predicted one project with the 5G theme and investment of R$3.248 million (Reais), amount that proves and emphasizes the importance of this new network development. Also, MCTI and National Telecommunications Agency (ANATEL) created the 5G Brazil Project to foment the 5G ecosystem creation in Brazil (TELEBRASIL, 2019).

All over the Asia continent, there are some 5G researches. For example, in the Malaysia Technology University, they created the Ericsson 5GIC that has signed a partnership with local and global businesses to support more 5G technology investigations (UTM, 2019).

3.3.2 5G features

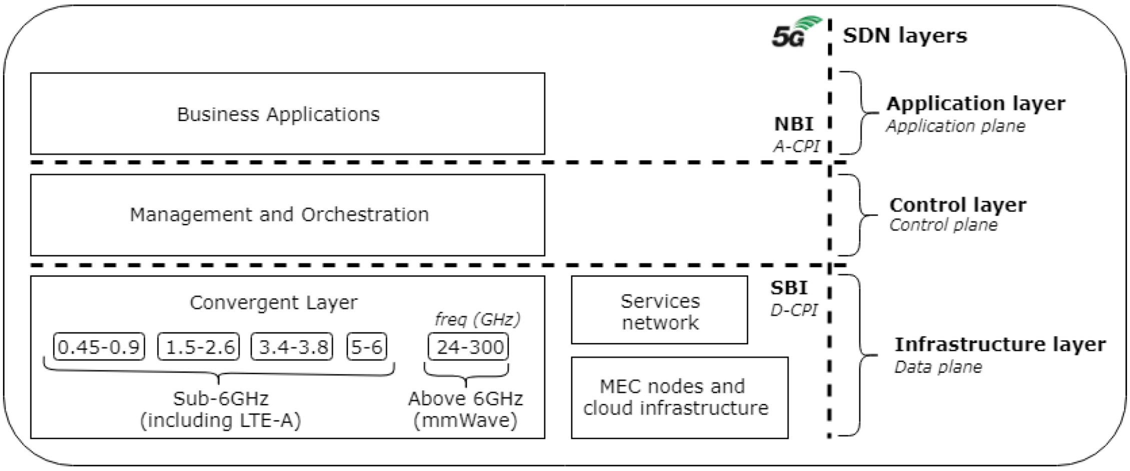
The 5G mobile communications systems are considered as new disruptive technology and can be an end-to-end ecosystem that will allow a fully mobile and connected society. Examples of design aspects for 5G architectures were presented by (AGYAPONG et al., 2014; KOSTOPOULOS et al., 2017). The 5G networks will account on the new radio, supporting technologies such as LTE-A, mmWave, Wi-Fi and Wireless Gigabit (WiGig), serving from cells with ultra-density to D2D (MA et al., 2015; PANWAR; SHARMA; SINGH, 2016). The set of required resources and functionalities to develop the 5G network is provided through reference architectures found at the 3GPP Release 15 (3GPP, 2019b) and Technical Specification (TS) 23.501 (3GPP, 2019d).

The 5G network use cases are typed by eMBB, mMTC and URLLC (ITU, 2015). Access to multimedia content, services and data such as virtual reality and augmented reality are typical applications of eMBB use case, providing a perfect user experience. mMTC use case is characterized by the IoT and D2D applications use with large number of connected devices and typical transmission of low volume data and non-delay-sensitive, with low-cost devices and long battery life. Wireless control of industrial manufacturing or production processes, IoT applications, remote medical surgery, delivery automation in a smart grid and transportation safety are examples of URLLC use case, demanding stringent requirements for reliability, latency, and network availability.

The 5G Access Network (5G-AN) can be designed in the 5G network considering the following aspects: outdoor or indoor, wide area macro or micro coverage. The types of 5G deployment scenarios are rural, suburban, urban, dense urban and indoor. The Rural Macro (RMa) environment focuses on larger and continuous coverage, supporting high-speed vehicles. The Suburban Macro (SMa) focuses on residential areas coverage as well as on rural towns with low-rise buildings. The Urban Macro (UMa) usually has on large cells and continuous and ubiquitous coverage. Dense Urban or Urban Micro (UMi) has high traffic loads, outdoor and outdoor-to-indoor coverage. Finally, Indoor Hotspot (InH) is characterized by small coverage and high capacity.

Considering 5G a heterogeneous high-speed network, several advanced features are expected and its development is a rather complex process. The operational network efficiency improvement will occur through technologies integration and use, such as cloud, fog, VANETs, Network Function Virtualization (NFV) and SDN (WANG et al., 2014; YOUSAF et al., 2017). Figure 17 shows a 5G system integration view and its relationship with SDN. The services offered on the 5G network are the application layer. The SDN paradigm allows a network to be directly programmable by decoupling the control plane and the data plane. It puts the network intelligence on SDN controllers enabling the network dynamic management (WICKBOLDT et al., 2015).

Figure 17: 5G integration with SDN



As Figure 17 shows, the business applications layer has the services and it communicates with the management and orchestration layer. Technologies such as LTE-A and mmWave with high frequencies, are part of the physical system, called convergent layer. The SDN functional architecture is composed by the Infrastructure layer represented by the data plane with the network elements, the Control layer represented by the SDN controller and, finally, the Application layer represented by the service plane with the services and the applications. Between the layers, there are the Southbound Interface (SBI) and Northbound Interface (NBI) that are communication interfaces which, respectively, pass along the characteristics of the network elements to the controller via the Data-Controller Plane Interface (D-CPI), and via the Application-Controller Plane Interface (A-CPI) connect it to the SDN application. The coordinators are responsible by the resources installation and by specific policies passed from the management layer through the Operations Support System (OSS) or Business Support System (BSS). The isolation of the user plane from the control plane by SDN is adequate to the 5G-IoV complex and heavy traffic, enabling secure and direct communication through the OpenFlow protocol.

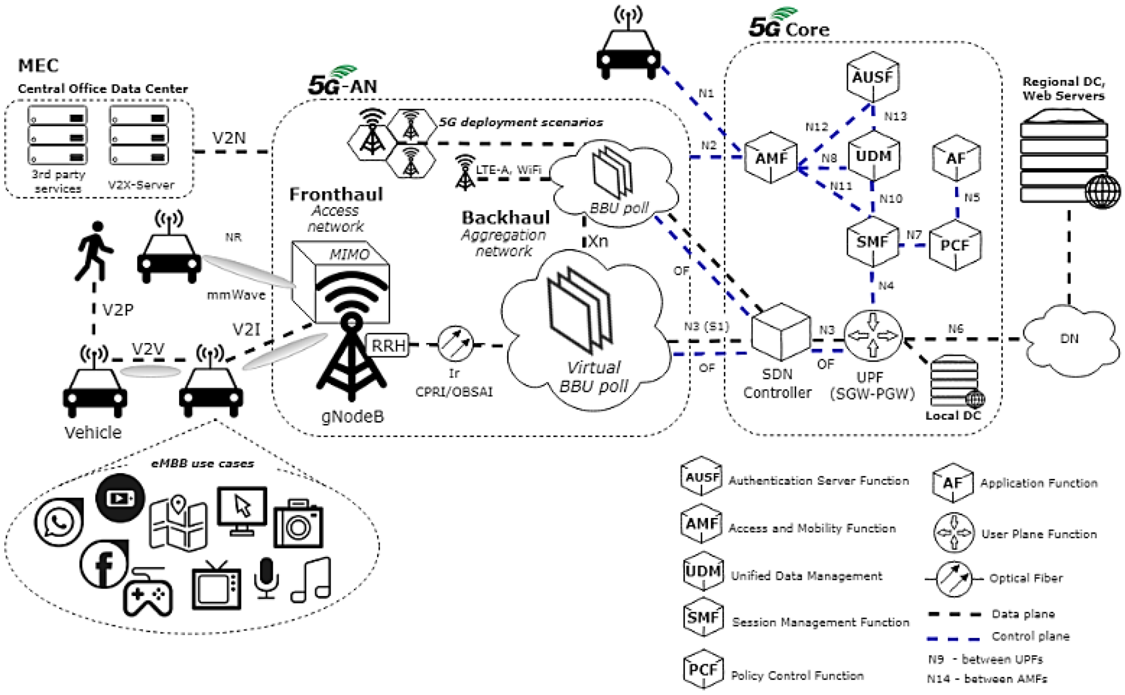
3.4 Proposed 5G V2X ecosystem

This section describes the proposed 5G V2X ecosystem's architecture. The fast mobility and the intense traffic in a next-generation vehicular network have motivated this work because it is one of the 5G network great challenges. The proposed 5G ecosystem puts the network intelligence on the SDN controller enabling the network dynamic management. Figure 18 shows the 5G V2X ecosystem proposed, which has as differences to other architectures that were proposed on the literature, a connection between the virtual Baseband Unit (BBU) polls and an SDN controller. It communicates through the backhaul with the Core Network (CN) called 5G Core Network (5GC) with the separation of the control plane from the data plane. At the CN, the Serving Gateway (S-GW) and Packet data network Gateway (P-GW) elements are unified as User Plane Function (UPF). Servers such as the V2X-Server can be enabled in the Central Office Data Center to support new services.

At the CN, the SDN controller is inserted and the OpenFlow (OF) protocol is adopted (TRIVISONNO et al., 2015; ONF, 2019). The OF has usually been employed and becomes a suitable alternative for 5G V2X scenarios since it enables secure and direct communication with the SDN controller. When the control plane and the data plane are separated, IP streams are routed from 5G next generation network Node Base Station (gNodeB) to UPF using the SDN controller.

On the control plane there are the reference points N1 between the vehicle and the Access and Mobility Management Function (AMF), N2 between 5G-AN and the AMF, N4 between the Session Management Function (SMF), and the UPF, N5 between the Policy Control Function (PCF) and an Application Function (AF), N7 between the SMF and the PCF, N8 between the Unified Data Management (UDM) and AMF, N10 between the UDM and the SMF, N11 between the AMF and the SMF, N12 between the AMF and the Authentication Server Function (AUSF) and N13 between the AUSF and the UDM. On the data plane are the reference points N3 between 5G-AN and the UPF, N6 between the UPF and a Data Network (DN) at the cloud and N9 between two UPFs.

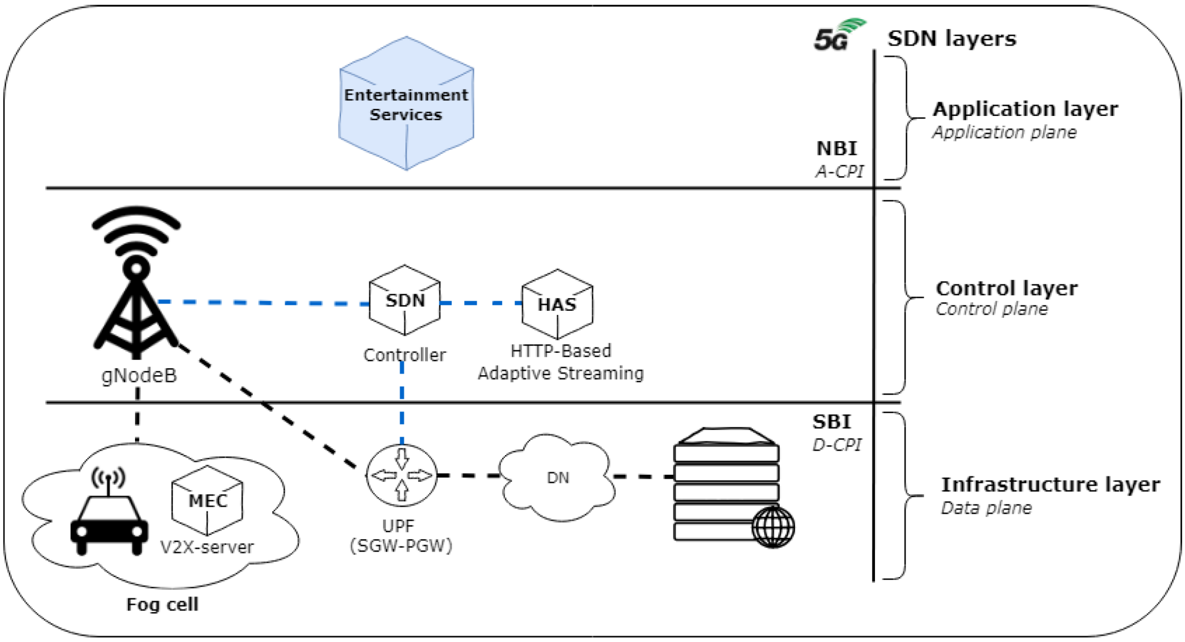
Figure 18: 5G V2X ecosystem



To support 5G V2X, the providing dedicated logical networks (i.e., slices) with virtualized functionalities over a common 5G physical infrastructure is presented in (CAMPOLO et al., 2018). The 5G V2X network slicing view can logically isolate control plane and user plane. Such as in our work, the 5G architecture presented follows 3GPP specifications composed by network functions and reference connection points, as well the four types of V2X communication modes identified as V2V, V2P, V2I and V2N. In the work, the authors report that in the CN domain, the AMF, UDM, and the AUSF can be shared among multiple slices. The UPF and SMF network functions can be dedicated per each slice. The SDN function is the remote configuration of the physical network, ensuring the resources reservation for the various slices which are being demanded by different types of V2X services. Each vehicle may require separate slices, one for each type of service, such as one slice for autonomous driving and another for entertainment on board. The vision of a preliminary 5G network slicing architecture is presented in a three-layer model (Business layer, Service layer and Infrastructure layer) with also an additional layer for management and orchestration. In our proposal, three layers are presented based on the Figure 18, with the management and orchestration functions embedded in the control layer. The practical validation through implementation is a future work.

The entertainment services delivery to people on board is one of applications of the IoV. One of the problems to be treated is how to make vehicles viable as entertainment centers, ensuring high Quality of Experience (QoE). The QoE that is perceived by the user while using the multimedia services depends significantly on the network QoS (MUSHTAQ et al., 2016). Therefore, there is a need of an architecture that supports IoV, with well-established standards and also extensible to new ones (KOMBATE; WANGLINA, 2016). In this direction, 5G infrastructure based on software defined concepts can support IoV applications (JIACHENG et al., 2016). For this purpose, Figure 19 shows the logical structure for entertainment services in 5G V2X ecosystem, divided into three layers, following the concept of SDN. The infrastructure layer consists of the vehicles, UPF and other service provider elements to the users. In the control layer, the SDN controller manages gNodeB and Hypertext Transfer Protocol based (HTTP) Adaptive Streaming (HAS). The application layer represents the abstraction provided by the controller through the entertainment services delivery.

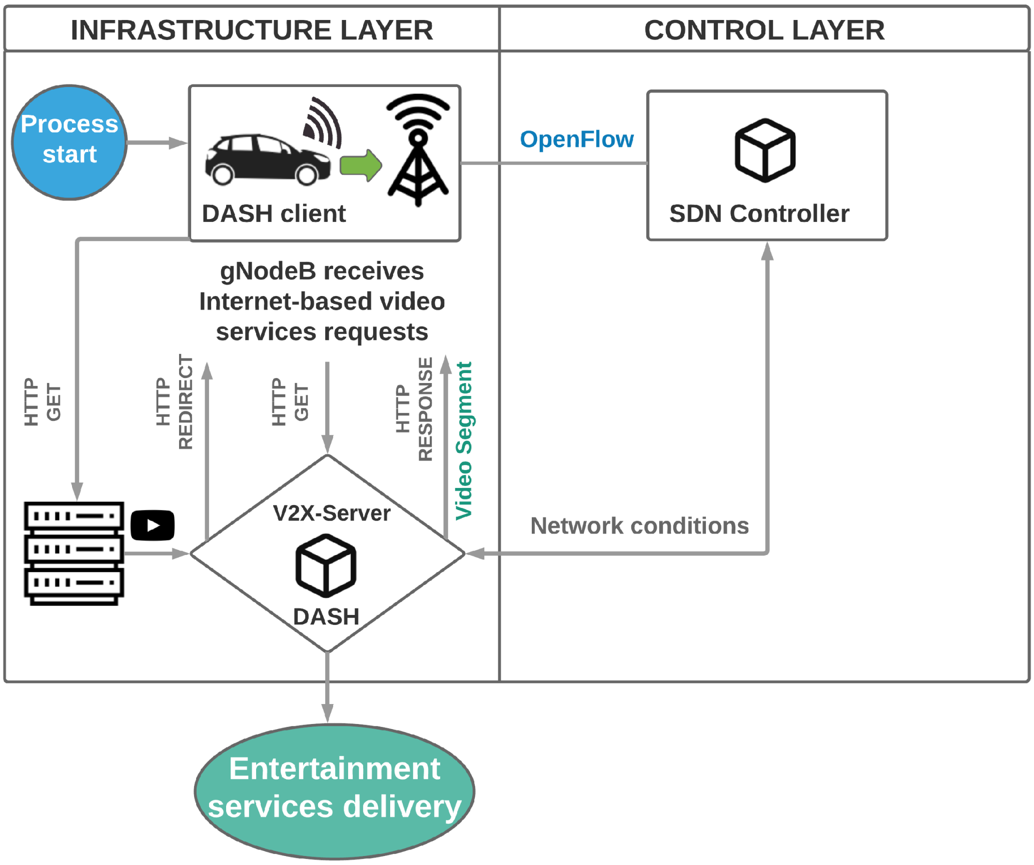
Figure 19: Logical view of SDIoV entertainment services



In the SDN structure, the data plane includes vehicles and gNodeBs and is responsible for collecting data. The control plane includes gNodeBs and V2X-servers and is responsible for deriving control instructions. The SDN controller must count on the data collection module based on the data plane, besides the network monitoring module. Finally, the application plane is responsible for the rules in the SDN structure.

The general scheme of the proposed architecture operation is shown in Figure 20. Initially, gNodeB receives the Internet-based video services requests from each vehicle connected to it. The network condition monitoring is performed on the controller. When the video server receives the HTTP GET, it pushes the video to the V2X-Server and notifies vehicles by sending an HTTP REDIRECT. DASH is considered one of the most successful streaming technologies (TCP stream) for video on demand. DASH was deployed on the V2X-Server using the MEC concept, allowing a processing that is closer to the end-user. Through adaptive algorithms, DASH allows the dynamic adjustment of the video representation for the network conditions. Then, the vehicle sends another HTTP GET request for the video request to the V2X-Server, which answers by providing the appropriate video segment, after processing.

Figure 20: Operation of the proposed architecture



The vehicles can implement the following functions for the various V2X services: vehicle and environmental information collection module through sensors; positioning module; and communication module including V2I and V2V. The V2X association with MEC (V2X-Server that is used for HAS application) counts on a cache module to save recent and popular contents, as well as to process edge information after orchestration decisions by network function virtualization. It can also be used for the SDN application plane processing, such as security and efficiency services.

This section presented the proposal of a 5G V2X ecosystem based on TS 23.501. The proposed ecosystem supports IoV communications and entertainment services delivery.

3.5 Materials and methods

Evaluations through experiments and simulations are crucial to the success of 5G-IoV research and development. Prototypes, simulations, and testing of 5G networks are being carried out by the academic community and many manufacturers around the world. The simulation, the modeling and the prototyping, allow the system evaluation without a real network implementation. It means faster new features, protocols and development with low costs.

3.5.1 Modeling and simulation

Table 11 lists the main tools and available frameworks to promote the 5G technology advance. Among the platforms listed, only the last two are not proprietary. National Instruments is an American company that provides tests, measurements, and embedded systems, besides proprietary software products for solution development. For 5G networks, it offers LabVIEW Communications software that is an engineering one designed for applications that require testing, measurement, and control, with quick access to hardware and information from the data plane, and was specially developed for wireless communication system prototyping (NI, 2019).

Table 11: Tools and frameworks for prototyping and simulation

Supplier	**Name**	**Brief Description**
National Instruments	Lab VIEW Communications	Prototyping of wireless communication systems
MathWorks	MATLAB and Simulink	5G wireless system model
Fraunhofer Institute	5G Playground	Prototyping of 5G networks, including SDN
Riverbed Technologies	Riverbed Modeler	A suite of protocols and technologies to design, model, and analyze
Keysight Technologies	Advanced Cellular Pack for Simulation	Pre-5G physical layer measurements based on the Verizon 5G specifications
Open Air Interface	Open Air Interface	Software and tools for 5G wireless research
NSNAM	ns-3	Discrete-event network simulator

MathWorks is a manufacturer that provides software such as MATLAB (analyses data, develops algorithms, and creates mathematical models) and Simulink (runs simulations, generates code, and tests and verifies embedded systems), that can offer an integrated environment for simulating, testing and prototyping wireless technologies (MATHWORKS, 2019).

Fraunhofer Institute for Open Communication Systems is a German institute that develops 5G networks and SDN research through next generation network infrastructures. Commercially, it provides, for prototyping and testing achievement, a set of tools through the 5G Playground composed by the components: 1st, Open5GCore-scalable, low-delay and highly reconfigurable approach to network core; 2nd, Open Baton-NFV orchestration;

3rd, Open SDN Core-SDN and NFV resources and backhaul addressing; and 4th, Open 5GMTC-connectivity of an endless number of network devices (FOKUS, 2019).

Developed by the Riverbed organization, the old Optimum Network Performance (OPNET) open software has gained a new name: Riverbed Modeler which is a discrete event simulation platform for communication networks analyzing and designing. It has a set of protocols and technologies with a development environment, allowing the network technologies modeling. Among its advantages, cited by the manufacturer, are tests and demonstrations of technology projects before production, productivity increase, protocols and proprietary wireless technologies development and, finally, the improvement evaluation on already consolidated standards-based protocols (RIVERBED, 2019).

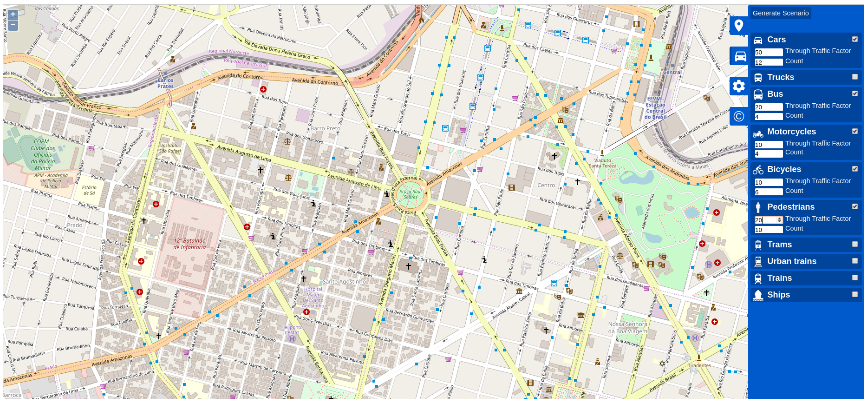
The Open Air Interface Software Alliance (OSA) is a French organization whose open platform of experiments and prototyping is made available to the community, where strategic work areas are established, such as 5G-SDN systems and heterogeneous 5G networks (OSA, 2019).

Several works in the literature use the discrete-event simulator on ns-3 network (NS3, 2019) and the LTE-EPC Network Simulator (LENA) module (CTTC, 2019). It is pointed out that the ns-3 simulator has already been validated for the LTE module and has been indicated as the best choice for complex scenarios, as demonstrated by (ABREU et al., 2015). Completing for the scope of work, the Keysight Technologies is a company that provides tools for 5G signal modulation, such as the Advanced Cellular Pack for Simulation and 5G Protocol R&D Toolset (KEYSIGHT, 2019). The Keysight Technologies provides a set of data transfer rate tests in eMBB scenarios, through emulation. However, there are limitations in this tool, since only layers one to three are emulated. The behavior of the system is not complete since kind of scenarios and the SDN controller are not emulated. It is important to evaluate the lower levels, but the complete upper levels evaluation is also crucial to the system success.

3.5.2 Vehicular mobility simulation

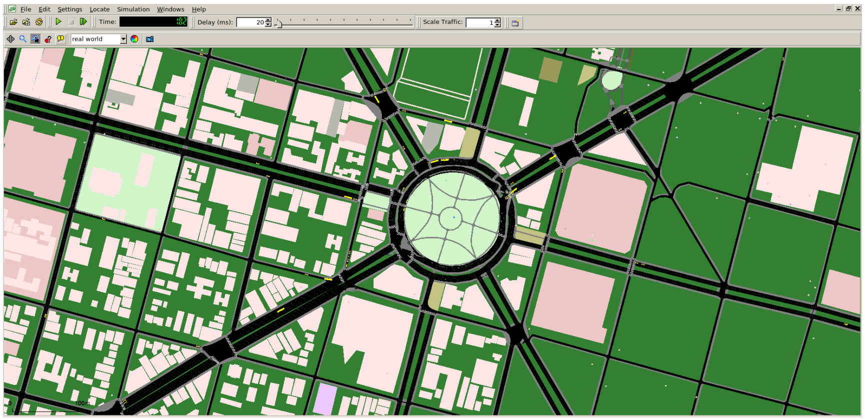
For vehicular network simulations, an interesting feature is the capacity to extract node from mobility tracking. This trace can be generated by the Simulation of Urban Mobility (SUMO) or the V2X Simulation Runtime Infrastructure (VSimRTI). It also can be used to accurately simulate specific scenarios, such as vehicular mobility in an urban setting. The tool adopted in this work is SUMO, which is road traffic simulation software with a strong capacity for generating and operating traffic scenarios. SUMO provides an application programming interface (API) for a road topology created by the recording of two source files. Another method for building a road topology is to use a physical world map database, such as an open street map (OSM), to generate an OSM source file. Using the Raul Soares Square, at Belo Horizonte central area, as an urban setting example, it is possible to use a software such as java open street map (JOSM) editor to get data from the physical world too, as shown in Figure 21. Then, this data is imported into the SUMO, generating the simulation scenario, as shown in Figure 22.

Figure 21: JOSM



Cars ☑
50 Through Traffic Factor
12 Count
Trucks ☐
Bus ☑
20 Through Traffic Factor
4 Count
Motorcycles ☑
10 Through Traffic Factor
4 Count
Bicycles ☑
10 Through Traffic Factor
6 Count
Pedestrians ☑
20 Through Traffic Factor
10 Count
Trams ☐
Urban trains ☐
Trains ☐
Ships ☐

Figure 22: Simulation



Delay (ms): 20
Scale Traffic: 1
real world

Through OSM, it is possible to capture a region on the map by importing into the model a real urban architecture of streets, avenues, forms of access by viaducts, etc. By its time, SUMO is responsible for capturing a map fragment and for inserting moving nodes with real movements in it, such as vehicles, buses, bicycles, and pedestrians. The integration of SUMO with ns-3 can be accomplished through the Traffic Control Interface (TraCI) middleware coupling. TraCI is a road traffic simulation access interface to retrieve the values of simulated objects and to manipulate their behavior in real-time. There are a few options to make integrating with ns-3, for example, creating a Python script or using an ns-3 module called *ns3-sumo-coupling*. TraCI uses a TCP-based client/server architecture to develop a communication mechanism among SUMO and ns-3. Thus, ns-3 sends the desired speed to the vehicle traffic control, and SUMO returns a confirmation message. SUMO is considered as a server while the ns-3 network simulator is a client.

SUMO simulates road traffic and gives ns-3 a door for additional options of the command line. Ns-3 obtains and sends information and instructions to SUMO for the vehicles' conditions update.

3.5.3 DASH: adaptive algorithms

Algorithms can dynamic select a bit-rate segment based on the network conditions. It works as an independent software library platform that can be integrated with different components to evaluate performance in real-world scenarios. The often severe variation in the available bandwidth in mobile wireless networks is a challenge to the bit-rate selection algorithm because a video client needs to predict the future available bandwidth to select the appropriate bit-rate for the video content to maximize the video quality. The algorithmic use is a process of deciding the optimal representation for each of the segments to optimize the viewing experience as a key element and is one of the major challenges in adaptive streaming systems. The challenge for an adaptation algorithm arises from the fact that the available throughput on Internet considerably changes due to multiple reasons which include, on the one hand, cross-traffic, interference, fading, and others while on the other hand, adaptation performs retransmissions and deploys congestion control mechanisms adapting its throughput (OTT; MILLER; WOLISZ, 2017).

DASH is the first international standard on adaptive hypertext transfer protocol (HTTP), which means that DASH uses the existing HTTP web server infrastructure and it has become very popular in the last years (KARAGKIOULES et al., 2017; ISO, 2019). It is currently a widely adopted technology for video delivery over the Internet because it offers relevant advantages, enabling users to switch dynamically between different available video qualities responding to variations in the current network conditions during video playback (LI et al., 2016). DASH is a technique used in multimedia over computer networks, almost exclusively based on HTTP, and efficiently works by detecting a user's bandwidth and central processing unit (CPU) capacity in real-time to adjusting the quality of the media stream accordingly (LEDERER; MULLER; TIMMERER, 2012). Or in other words, DASH is an adaptive method of video streaming where the source content is encoded at multiple bit-rates to decide about which bit-rate segments to download based on the current state of the network, through algorithms that combine throughput and buffer (that are responsible by poor performance), or both types on hybrid architecture (STOCKHAMMER, 2011). So, this subsection is lighting out three algorithms: FESTIVE, PANDA, and TOBASCO2. They are adaptive algorithms through which DASH can be used to allow the dynamic adjustment of the video presentation for the network conditions. They were already implemented in ns3, being both PANDA and FESTIVE throughput-based algorithms; while TOBASCO2 is a buffer-based algorithm category.

Mobile Edge Computing (MEC) gives new opportunities to improve DASH performance. In an adaptive HTTP video streaming architecture tailored to the MEC environment, an adaptation algorithm can be included running as service, aiming to relax network congestion while improving user experience (LI et al., 2016). That is the reason why the DASH hybrid-architecture and enhanced multimedia broadcast multicast services (eMBMS) have attracted great attention from the telecommunication industry and multimedia services. By using standards for adaptive streaming over DASH, the user can playback on-demand and live streaming video with great quality even though if the network is quite saturated. Access to multimedia content, services, and data such as virtual reality and augmented reality are typical applications of eMBB use cases, providing perfect user experience.

Streaming is the transmission of continuous content from a server to a client. Adaptive streaming over HTTP consists in an action to adapt the video to the web by 1st the imitation downloading small chunks to minimize bandwidth waste and by enabling to monitor consumptions and track the clients; 2nd, by the adaptation to dynamic conditions and device capabilities; and 3rd, by the quality of experience improvement enabling faster start-ups and seeking because as the quicker buffer fills, while reduces skips, freezes, stutters, and more. The video-delivery over HTTP starts with a progressive download, like pseudo streaming at the begging, which carries on in a chunked streaming to realize the adaptive streaming (KUA; ARMITAGE; BRANCH, 2017; BENTALEB et al., 2019).

The conventional algorithm is a simple adaptation that equates the available bandwidth as it is measured during the previous segment download, determining the inter-request time of the next segment using a bi-modal scheduler by the next segment request is scheduled either with a constant delay. DASH algorithms can be classified into different categories concerning the required input information. There are throughput-based algorithms, such as FESTIVE and PANDA which require enough number of probes to obtain reliable measurements (KARAGKIOULES et al., 2017).

FESTIVE is a bit-rate adaptation algorithm that consists of a numerical data set used to strive to achieve a trade-off between stability, fairness, and efficiency in a communication system. It works as a method to make a bit-rate selection heuristic and is used to compensate for the biased interaction between the bit-rate and the estimated bandwidth, as well as to trade-off between stability and efficiency using a delayed update approach. However, the method may manifest instability when the users' number increases, likely due to a bandwidth overestimation effect. Furthermore, it is not very responsive to bandwidth fluctuations, because it has difficulty to ensure bandwidth fairness between competing DASH clients efficiently in a distributed shared network environment (BENTALEB; BEGEN; ZIMMERMANN, 2016). As it is robust to the number of users that are sharing a bottleneck, when there are an increase in the bandwidth variability and the available set of bit-rates, FESTIVE can improve the assertiveness by 40%, stability by 50% and efficiency by at least 10% (JIANG; SEKAR; ZHANG, 2014).

PANDA is an advanced variation with two distinct modifications: 1st) it uses a more proactive probing mechanism, that is designed to minimize bit rate oscillations; 2nd) it also uses a more sophisticated scheduler that drives the level towards the maximum occupancy while the inter-request time is matched to the necessary time needed to complete the download based on the smoothed estimated value of the available bandwidth (KARAGKIOULES et al., 2017). The PANDA is a content-aware adaptation algorithm that can be implemented in prototypes based not only on the available bandwidth, the existing technical capacity but also on the content type (LI et al., 2014; HU et al., 2014).

TOBASCO2 is an algorithm able to fragment a video's file into multiple segments with durations of a few seconds, encoding each one at different bit-rates (or different video quality levels). Algorithms such as TOBASCO2 are used to predict the available bandwidth and the vehicular speed based on the measurements of the current and previous trips, respectively, at future locations. These algorithms are similar, can be performed offline, and do not increase the complexity or latency of the DASH player. So, the DASH media presentation server stores video segments, each encoded at different bit-rates, which description contains basic segment information, such as an uniform resource locator (URL), video resolution, bit-rate, codec, time, and duration. The DASH client measures its available bandwidth every time it visits a location and saves the bandwidth measurement and the corresponding location at its local storage (XU; MA, 2015).

3.5.4 The 5G ecosystem simulation methodology

In order to evaluate the 5G ecosystem as the IoV infrastructure support, we have conducted the evaluation of a set of data transfer tests in enhanced Mobile Broadband scenarios with Internet-based video services (STORCK; DUARTE-FIGUEIREDO, 2018). The 5G mmWave communications were used in the simulations. Simulations were conducted through ns-3 simulator. Scenarios were modeled and codes were developed in ns-3. Some modules were modified in order to support the integration of the proposed ecosystem. V2X scenarios were simulated with different vehicle densities. The simulations were executed in a high-performance computing environment provided through cluster F37 of the CEFET-MG, a brazilian public education institution. The cluster is open to students and professors of the institution who wish to develop research and teaching projects. The F37 cluster has 32 machines of shared use, in 3 different configurations which are grouped into the small, medium and large rows. The simulations were executed in the large row (4 Supermicro machines, 64 physical threads without hyperthread, and 128 GB RAM) under QoS requirements called part2d and part10d, which have a maximum time of 2 and 10 days, respectively. This is one of the first works that compares MATLAB's results (GE; LI; LI, 2017; KHAN; ABOLHASAN; NI, 2018) with evaluations of VANETs integrated to 5G. These simulations allow executing all the protocols and modeling real scenarios with an intense mobility of the expected 5G networks. Generally, simulations performed through the MATLAB present a mathematical efficiency. In contrast, they are not able to capture the complexity of the network on a much higher level of details, because it presents limitations on the network important aspects, for example, the mobility deal.

For mmWave communications, the mmWave ns-3 module was used (MEZZAVILLA et al., 2015; DUTTA et al., 2017). On LENA module, it divides the available resources between active flows. On mmWave module, the resources separation is based on time division multiple access with the allocation of time domain symbols inside a periodic sub-frame for different users in Downlink (DL) or Uplink (UL) directions. The flow rate calculation on bits/s (bits by second) for each vehicle is given by T (throughput), where S (M, B) represents the size of the transport block as defined by 3GPP TS 36.213, M is the modulation and coding scheme, B is the transmission bandwidth configuration in number of resource blocks, and τ represents the duration of the Transmission Time Interval (TTI), formulated by the Equation 3.1:

$$T = \frac{S(M,B)}{8\tau} \tag{3.1}$$

For video traffic, the Dynamic Adaptive Streaming over HTTP (DASH) was adopted. Three adaptive algorithms were tested: FESTIVE, PANDA, and TOBASCO2 (OTT; MILLER; WOLISZ, 2017). We suppose that there is one video server, for each video required, across the network.

To support the SDN controller, the OpenFlow 1.3 (OFSwitch13) module was adopted (CHAVES, 2019). Based on the SDN concept, the OF protocol was simulated. The structure was composed by the controller and the network OF elements (LARA; KOLASANI; RAMAMURTHY, 2014; HU; HAO; BAO, 2014). With this module, it was possible to extend the controller application interface to implement the desired control logic to orchestrate the network, in our case, the delivery of multimedia services.

The simulations were executed assuming a complete traffic model which means that the base stations are always transmitting and receiving multimedia data, with download of data through links and mmWave devices, CN based on SDN, and 5G scenarios. The parameters adopted to model each scenario considered the node numbers for each gNodeB (numgNB), gNodeB height (hgNB) in meters, User Equipment height (hUE) in meters, maximum and minimum distance (maxdist, mindist), eMBB active vehicles (numVehicles), and vehicles speed (speed), as Table 12 shown. All users are active and communicate all the runtime.

Table 12: Parameters of 5G V2X scenarios

Parameter	**Rural Macro**	**Urban Macro**	**Urban Micro**
numgNB	1 gNB	1 gNB	1 gNB
hgNB	35 m	25 m	10 m
hUE	1.5 m	1.5 m	1.5 m
maxdist	320 m	250 m	100 m
mindist	35 m	35 m	10 m
numVehicles	[10–60]	[10–60]	[10–60]
speed	120 km/h	30 km/h	30 km/h

Three deployment scenarios based on Technical Recommendation (TR) 38.913 were simulated: rural macro, urban macro and urban micro (3GPP, 2018b). Rural Macro (RMa) scenario supports high-speed vehicles (120 km/h) in distance from 35 to 320 m. Urban Macro (UMa) scenario supports speed of 30 km/h in distance from 35 to 250 m. Urban Micro (UMi) scenario supports speed of 30 km/h in distance from 10 to 100 m. The choice of the RMa scenario is especially due to the expectancy of the cellular network traffic increase, considering the rural area with its implementation sparser than the other 5G deployment scenarios. UMa and UMi are simulated to verify the behavior in urban areas.

The European Environment Agency has defined that the average number of people in a passenger car is 1.45, as during the journey the driver consumes less data than the respective passengers (EAA, 2015). The traffic model used was provided by the Simulation of Urban Mobility (SUMO) (LOPEZ et al., 2018) the support of ns2-mobility helper class of ns-3. This work has simulated an network topology of fog cell at a vehicular density of 10 to 60 active users assuming one user eMBB by vehicle and four street lanes.

Each simulated vehicle was placed on one of the four street lanes. The vehicles move at constant speed in the same scenario (based on the recommendations of 3GPP Technical Recommendation (TR) 38.913) and in the same direction in each one of the tracks, from right to left on the 1st track (1st and 2nd lanes) and from left to right on the 2nd track (3rd and 4th lanes). Since the two tracks with the four lanes are used, each vehicle is randomly assigned to one of the lanes, being positioned following an exponentially distributed inter-vehicular spacing. Considering an expected high mobility of the 5G networks, all vehicles travel at 120 km/h, based on the rural scenario of 3GPP TR 38.913. For urban UMa and UMi scenarios, all vehicles travel at 30 km/h. Through the mmWave 3GPP Channel class, spatial consistency across the entire vehicle motion path was also enabled.

For V2V communication scenarios, the main network goal is to deliver packets for as many vehicles as possible, when it is necessary to inform the critical conditions of the road, such as accidents, road adverse conditions and abrupt braking, in order to avoid collisions between the vehicles. The network becomes reliable when the highest delivery rates are presented. The Packet Delivery Ratio (PDR) is the relation between the number of the vehicles which receive the transmitted packets and the number of vehicles in the network, formulated by the Equation 3.2. In this way, based on 5G V2V communication scenarios, an evaluation was carried out, adopting rural and urban scenarios. The results are presented in the next section.

$$PDR = \frac{Total\ number\ of\ vehicles\ receiving\ packages}{Total\ vehicles\ on\ the\ network} \tag{3.2}$$

Table 13 presents the adopted simulation parameters. The 3GPP mmWave channel model was used to perform the initial connection of the active vehicle to the gNodeB using mmWave communications and considering the parameters of frequency, bandwidth, number of sub-bands, channel conditions, and fading listed in Table. The Round Robin scheduling was used.

Table 13: Simulation parameters

Parameter	**Value**	**Description**
channel	mmWave3gpp	Channel model
frequency	28 GHz	Supported frequency
bandwith	1 GHz	Bandwidth
numSubbands	72	Number of sub-bands
subbandWidth	13.89 MHz	Width of the sub-band (MHz)
propagation	mmWave3gpp	Propagation model
losCondition	true	Channel conditions
shadowing	true	Fading
enableBuildings	true	Consider obstacles
macScheduler	Round-Robin	Scheduler class
harqEnabled	true	Enable HARQ
harqProcesses	100	HARQ for DL and UL
rlcAmEnabled	true	RLC-AM enabled
packetSize	1446 Bytes	Package/Segment Size
segmentSizeFile	matrix	Matrix (n, m)
segmentDuration	2 s	2 s per segment (video)
adaptation	festive, panda and tobasco2	Adaptation algorithm
buffer	524,288 Bytes	Buffer size
simTime	180 s	Total simulation time

The centre carrier frequency is 28 GHz and 1 frame contains 10 sub-frames, each one of 1 ms, and contains 24 Orthogonal Frequency Division Multiplexing (OFDM) symbols with 100 μs resulting in a bandwidth of 1 GHz. Each sub-band corresponds to 13.89 MHz and contains 48 sub-carries.

In addition, Hybrid Automatic Repeat Request (HARQ) and Radio Link Control-Acknowledge Mode (RLC-AM) mechanisms were enabled. For retransmission, V2X incorporates the HARQ with the purpose of achieving greater efficiency at the link level, higher transmission range and reliability on the performance (WANG; MAO; GONG, 2017). The segment size was set to 1446 bytes. On the simulation, we adopted 180 s as total time.

The video adopted in the simulations represents a real DASH encoded one that contains 442 s and 221 segments (2 s per segment) and 8 representations with variable bit rate from 0.088 to 20.5 Mbps. The size of the segments is provided in a Matrix (n, m) where [n] represents each one of the 8 representations and [m] represents each segment.

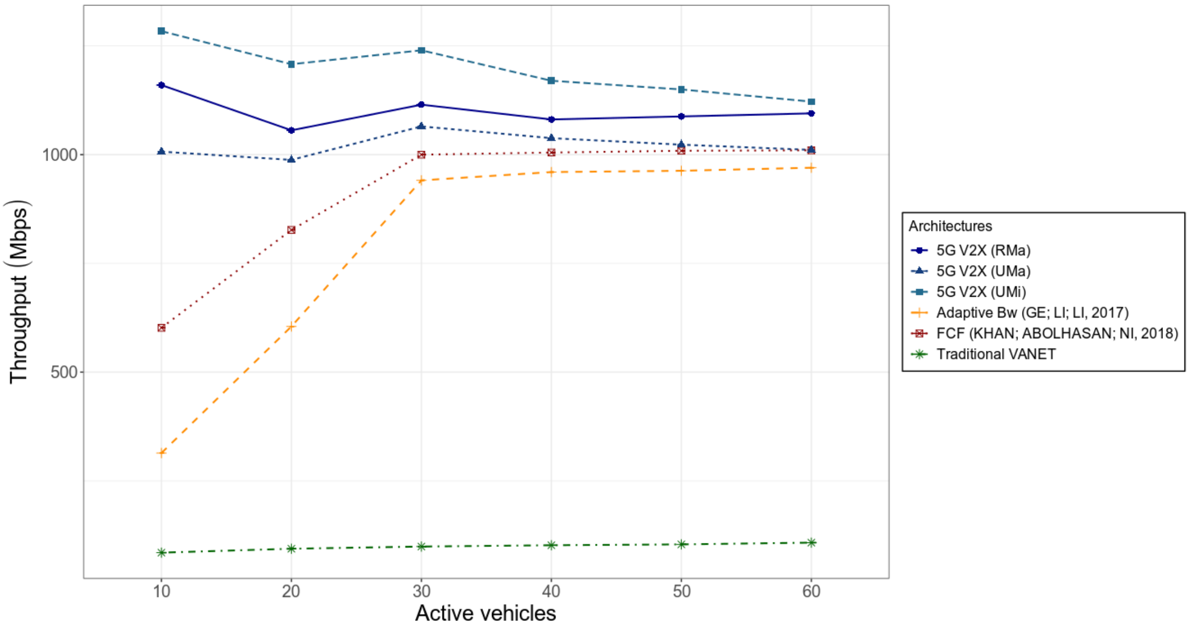
3.6 Simulation results

Video streaming applications are very sensitive to bad connections. In order to show the effectiveness of our 5G ecosystem supporting the V2X IoV connectivity, we show two important performance metrics: throughput and delay. Results obtained through simulations are presented in the Figure 23, Figure 24, and Figure 25 graphics, with 10, 20, 30, 40, 50, and 60 active vehicles.

Figure 23 graphic shows the obtained 5G V2X ecosystem throughput with 95% confidence interval, for 10 simulation trials using PANDA algorithm. The flow rate was obtained through the Packet Data Convergence Protocol (PDCP), which provides, for each TTI, the amount of transferred data by the users. On the 5G network, the reference value of the maximum data rate is 1–10 Gbps, which can support, in some scenarios, up to 20 Gbps. By the experiments, the data rate required by the eMBB use case was reached in simulated scenario.

As seen in Figure 23 graphic, the rural scenario performed well, considering an environment with vehicles traveling at high speed. It was observed that the urban macro scenario presented a minor throughput than the urban micro and rural scenarios. This is justified by the interference of blockages by obstacles considering a larger coverage in an urban area. As expected, with low distance and vehicle mobility at 30 km/h, the urban micro scenario presented higher performance than the rural scenario. For low densities, with 10 and 20 active vehicles, the rural scenario presents better throughput, around 11.9% and 5.6%, respectively, in relation to the urban macro scenario. When comparing the rural to the urban micro scenario, the throughput achieved by the rural scenario is lower, between 9.6% to 12.5%, when 10 and 20 were simulated. The difference between the urban micro scenario and the urban macro scenario is 21.5% for the density of ten active vehicles, and 18.2% for 20 active vehicles. When simulating 30 vehicles, the percentage differences decrease between the simulated scenarios. For densities of 50 and 60 vehicles,

Figure 23: Network throughput



the difference between the urban micro and macro scenarios is 11% and 9.8%, respectively. The difference from the rural scenario to the urban macro scenario is 5.6% for 50 active vehicles and 7.4% for 60 active vehicles. The difference from the urban micro scenario is 5.4% and 2.4%, respectively, when compared to the rural scenario. We can say that the urban micro is the scenario that achieved the best throughput with the 5G ecosystem.

The throughput increases as the density increases in the results obtained by (GE; LI; LI, 2017; KHAN; ABOLHASAN; NI, 2018) because, once the distance decreases between adjacent vehicles, the successful transmission probability increases. The throughput is maintained constant after the density of 30 vehicles. The reason is that all available bandwidth in a fog cell has already been allocated for vehicles. Using the direct communication approach, it was observed that using our 5G V2X ecosystem, the throughput does not depend on the probability of hops between vehicles, like the other literature proposals. The 5G V2X ecosystem has presented better result with any density of vehicles.

Comparing with the best results obtained by the implementation of the adaptive bandwidth allocation (GE; LI; LI, 2017; KHAN; ABOLHASAN; NI, 2018) and the baseline of the traditional VANET architecture (KHAN; ABOLHASAN; NI, 2018), it was verified that the obtained throughput of this achieved solution got a better flow than the previously presented solutions, which guarantees a satisfactory QoS for streaming services in the V2X scenario. One of the factors that contributed to increase in flow is the incorporation of V2X-Server into the 5G V2X ecosystem.

Figures 24 and 25 graphic shows the average delay that reflects the spent time for users' data transmission end-to-end in a fog cell for video transmission. The results compare the adoption of the FESTIVE, PANDA and TOBASCO2 algorithms (OTT; MILLER; WOLISZ, 2017) with the SDN controller in rural macro scenario in Figure 24. Next, the execution of the PANDA algorithm by simulated scenario is depicted in Figure 25.

Figure 24: Adaptation algorithms in rural scenario

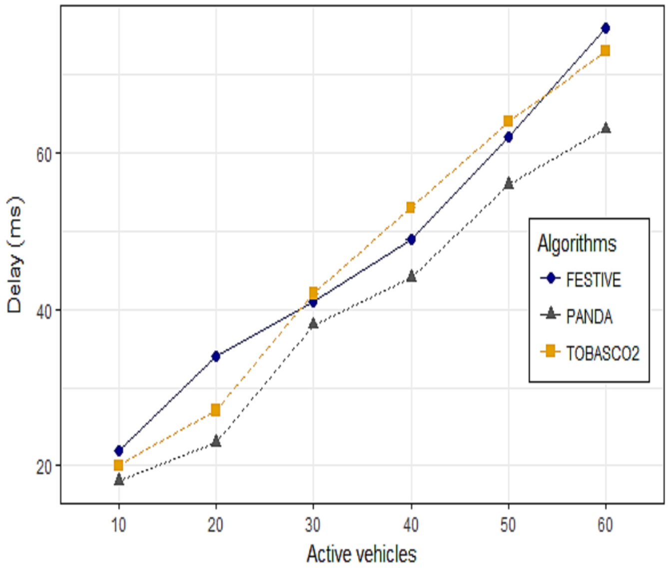
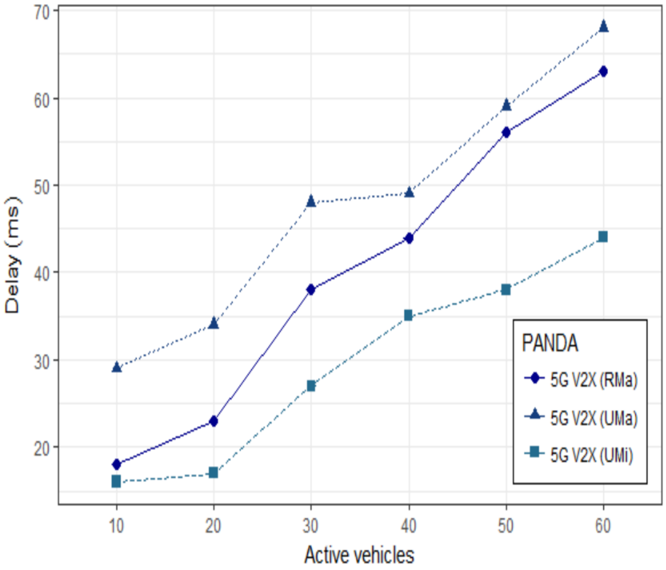


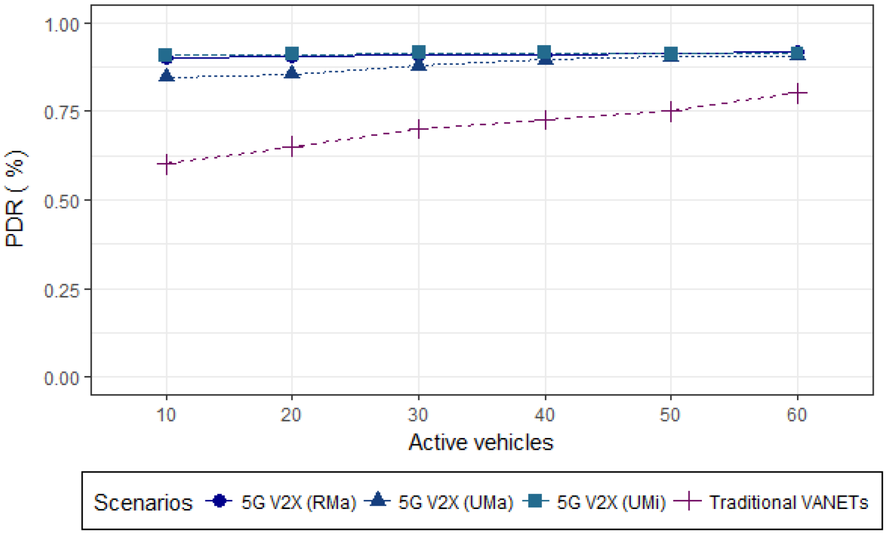
Figure 25: PANDA algorithm in Rural x Urban scenarios



The 3GPP TS 23.203 specification provides latency budgets (3GPP, 2019a). To the video traffic requirements defined by TS 23.203, the maximum delay value is 300 ms. In (GE; LI; LI, 2017), it claims a delay of 0.06 ms, however it is the average transmission delay, adopting the hop of vehicle communications. However, in this work, it was adopted end-to-end average delay in the 5G V2X fog cell for stream video transmission. In Figure 24, from 30 vehicles, the values obtained by the FESTIVE and PANDA algorithms present a similar behavior, unlike the PANDA algorithm that presents a differentiation from the density with 20 vehicles. The obtained results have met the expected value, and the minimum average transmission delay of 18 ms was observed for the maximum distance of 320 m in the end-to-end fog cell 5G V2X with the PANDA algorithm, which demonstrated a better performance and stability when adopted in the proposed 5G ecosystem.

Figure 26 graphic shows the V2V packet delivery results. It is possible to observe, that the delivery rate depends on vehicle density. In the literature, traditional VANETs present the PDR of between 60–80%. By simulations, when adopting 5G millimeter waves to transmit the messages, considering the confidence interval of 95%, a constant behavior is observed, between 84% and 91% of vehicles that received the package, in all vehicle densities. Generally, the delivery rate tends to be low in scenarios with low vehicle density. However, it is noted that the obtained result is due to the adoption of 5G in a cell of mist, evidencing the approach efficiency to provide IoV.

Figure 26: Packet delivery ratio in 5G V2V communications



With this 5G V2X ecosystem proposal, the evaluation of many expected scenarios with SDIoV applications becomes possible. With an SDIoV architecture, services can be improved allowing adequate support for IoV communications, such as the tests performed with on board entertainment services. In addition, this ecosystem proposal contributes to an urgent demand for the construction of scenarios and initial 5G use cases in order to prove that the IMT-2020 standard is feasible for deployment in the short and medium term, thus justifying the investments in CAPEX and OPEX. Possible policies can be thought and projected, as well as new services for SDIoV, with the proposed ecosystem.

3.7 Performance analysis of DASH algorithms in urban scenarios with different 5G vehicle densities

The goal of this section is the vehicular-Internet-based video services traffic analysis in urban scenarios with different vehicle densities. The goal is to find a way to reduce the 5G network congestion and to improve the user experience at onboard entertainment services, which is a critical topic for today's technology.

The scenarios were evaluated with a confidence interval of 95% for 10 simulation trials and the assumed ones are presented in Table 14. Vehicle densities for the urban scenario were defined and classified as light traffic (20 vehicles/km^2), heavy traffic (60 vehicles/km^2), congested traffic (120 vehicles/km^2) and highly congested traffic (240 vehicles/km^2) (SILVA et al., 2019).

Table 14: Urban scenario assumed for evaluation

Parameter	**Value**
Area	1000 m^2
Vehicle densities	20, 60, 120 and 240 vehicles/km^2
Speed (random)	15, 30 and 60 km/h
Macrocells	2 (35 meters height and 46 dBm power)
Microcells	4 (25 meters height and 30 dBm power)
Picocells	16 (10 meters height and 30 dBm power)
Position	Poisson process (vehicles and base stations)

The evaluated metrics that are: the amount of playback interruptions, video quality, quality transitions and average buffer level by studies performed in (OTT; MILLER; WOLISZ, 2017); average bit-rate and bit-rate switching frequency by the searches presented in (XU; MA, 2015; MULLER; LEDERER; TIMMERER, 2012); throughput; unfairness, instability and inefficiency which were found in the work done in (LI et al., 2014), in the case of instability also by the searches that were performed in (KARAGKIOULES et al., 2017). Fairness, stability, and efficiency were found in the work made in (JIANG; SEKAR; ZHANG, 2014) and had helped to understand the opposite metrics.

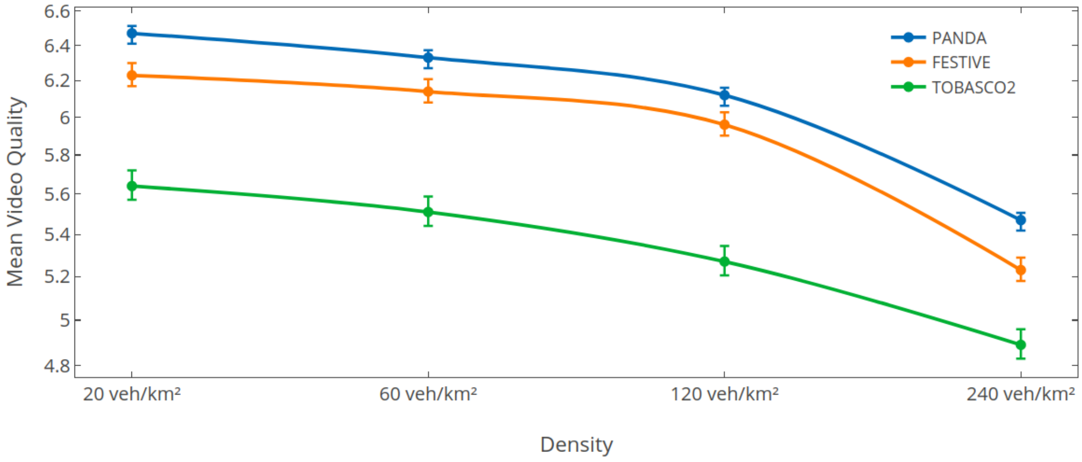
3.7.1 Playback interruptions

Based on the metrics that were evaluated by Ott et al. (OTT; MILLER; WOLISZ, 2017), one was the number of playback interruptions, and the relative buffer under-run duration (which is spent in re-buffering during the streaming session) reached 1%. In the present experiments, the three evaluated algorithms showed an average of less than 0.36% of interruptions. This difference in the reduction of interruptions can be explained by two factors: 1st) the approach proposed in this work deals better with the conditions of the network, and 2nd) because it uses the 5G network where there are more available resources, that decreases interruptions even with highly congested traffic than the assessment made by Ott et al. using Wi-Fi (IEEE 802.11n) (OTT; MILLER; WOLISZ, 2017), on which TOBASCO2 algorithm has presented a lower number of interruptions than the other algorithms, but the video quality was drastically reduced.

3.7.2 Mean video quality

The second evaluated metric was the mean video quality (obtained using the average representation index over all segments in a streaming session). Figure 27 graphic shows the obtained average video quality for the simulated scenarios with different vehicle densities in 5G vehicle communications. As previously mentioned, TOBASCO2 has presented a lower quality of video due to its own operation (which avoids interruptions and intermittent transitions in the quality of the video being played). The PANDA algorithm performed better than the FESTIVE, despite the close results.

Figure 27: Mean video quality



3.7.3 The relative number of quality transitions

The third evaluated metric was the relative number of quality transitions (OTT; MILLER; WOLISZ, 2017). When one segment in an universe of a hundred segments is reproduced in a different quality from its predecessor, the relative number of quality transitions is equal to 0.01. Given a segment length of 2 seconds, this implies a quality transition every 200 seconds on average. The FESTIVE algorithm has shown a relative number of quality transitions equal to 0.09, that is, a quality transition every 182 seconds on average. Both PANDA and TOBASCO2 have shown a relative number of quality transitions equal to 0.02, that corresponds to a quality transition every 196 seconds on average.

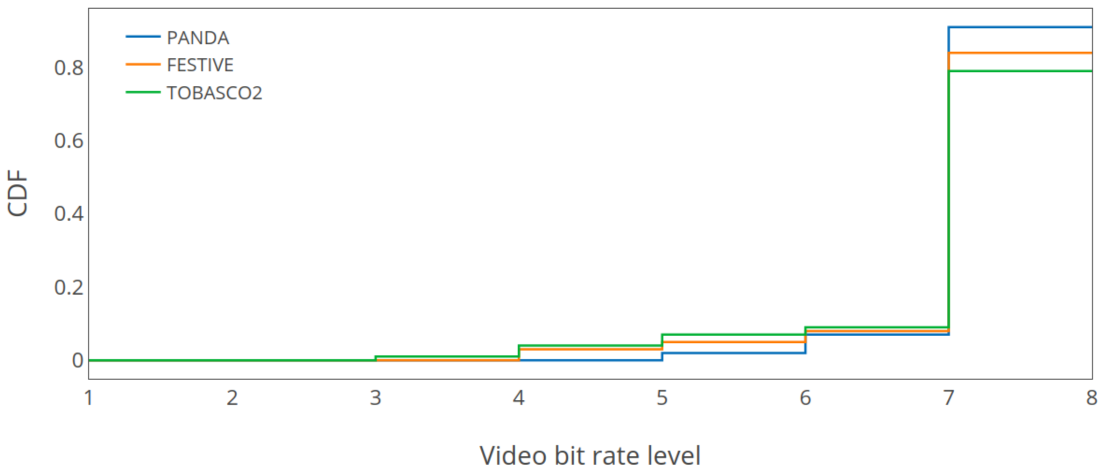
3.7.4 Average buffer level

The fourth evaluated metric was the average buffer level in seconds (OTT; MILLER; WOLISZ, 2017). TOBASCO2 has achieved a level of 28.2 seconds, while FESTIVE and PANDA achieved a level of 20.76 seconds. An important note to be made is that with the SDN controller incorporation to the proposed approach in this work, the adjustment of the video bit-rate in the transfer rate is guaranteed since it prevents the algorithm from systematically failing and results in a low level of a buffer that is responsible by poor performance.

3.7.5 Average bit-rate and bit-rate switching frequency

The video lasts 442 seconds, and every video segment contains 2 seconds of video content. There are 8 video bit-rate levels whose average range from 0.088 Mbps to 20.5 Mbps. The PANDA algorithm provides a smoother bit-rate selection than TOBASCO2 and FESTIVE algorithms: the switching ratio for PANDA is 1.99% compared to 7.4 and 8.5% for FESTIVE and TOBASCO2 respectively. Figure 28 graphic shows the cumulative distribution function (CDF) of the bit-rates for the three algorithms considering all the vehicle densities. It is observed that PANDA presents about 91.44% of the frames as the highest bit-rate level (20.5 Mbps), while with TOBASCO2 and FESTIVE algorithms the percentage is only 79.61% and 84.27% respectively. It shows that the use of a high average bit-rate means that the inefficiency has a value close to zero most of the time, which directly impacts the user experience improvement.

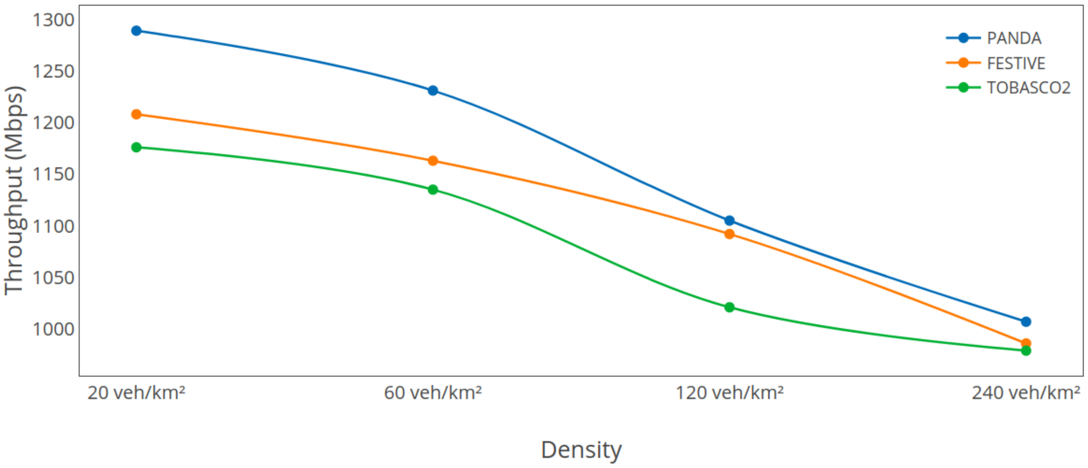
Figure 28: CDF of the bit rates



3.7.6 Throughput

Figure 29 graphic shows the obtained average throughput of all users with a 95% confidence interval, for 10 simulation trials using the DASH three algorithms. The flow rate was obtained through the packet data convergence protocol (PDCP), which provides, for each transmission time interval (TTI), the amount of transferred data. By the experiments, the PANDA algorithm has achieved better performance on DASH, overcoming the FESTIVE and TOBASCO2 algorithms for all vehicle densities. FESTIVE has performed well and TOBASCO 2 has presented a minor throughput than the others.

Figure 29: Obtained throughput



3.7.7 Unfairness

Unfairness consists of a situation while competing clients with comparable signal strength are treated fairly, achieving similar throughput values, clients with lower signal strength are treated unfairly, relinquishing a larger share of the available bandwidth to clients with higher signal strength. It happens because the throughput is unfairly distributed between competing TCP connections experiencing unequal signal strength, at least in a max-min sense of fairness. “Strong” clients dominate the wireless medium, forcing “weak” ones to drop their transmission rate below their fair share (LI et al., 2014; JIANG; SEKAR; ZHANG, 2014). Unfairness is the inherited metric defined in fairness criteria. When overall bandwidth is fixed, the unfairness measure has a high dependence on the specific bit-rate levels chosen, especially in small vehicle density scenarios. In all densities, PANDA has gotten lower unfairness score results and the ranking is fairly consistent as the density of vehicles grows: PANDA, FESTIVE, TOBASCO2. When the result is a value close to zero implies that the throughput is being more fairly distributed between competing TCP connections experiencing unequal signal strength to improve user experience (LI et al., 2014). Table 15 presents the index values found for unfairness to the simulated scenarios with different vehicle densities in 5G vehicle communications.

Table 15: Comparison of unfairness with different vehicle densities

DASH	**20 veh/km^2**	**60 veh/km^2**	**120 veh/km^2**	**240 veh/km^2**
FESTIVE	0.043	0.052	0.063	0.073
PANDA	0.040	0.051	0.058	0.064
TOBASCO2	0.051	0.057	0.070	0.079

3.7.8 Instability

Instability consists of the adaptation frequency and, complementary to that, the amplitude of adaptation, once adaptability is the average selected video bit-rate per segment in a stream over the minimum of either the average throughput available during the current segment or the maximum available representation. Adaptation frequency is the number of representation switches over the total number of segments (KARAGKIOULES et al., 2017; OTT; MILLER; WOLISZ, 2017; JIANG; SEKAR; ZHANG, 2014). Instability is the inherited metric defines in quality smoothness criteria. As the instability increases, the inefficiency also increases moderately; or in other words, as the stability increases, the efficiency increases too. This makes sense intuitively, as when the bit-rate fluctuates, the average fetched bit-rate also decreases, and as the vehicle density increases, the instability increase as well. The PANDA has shown the lowest instability, even when the vehicle density increases being immune to the symptoms of the bandwidth overestimation. PANDA has gotten lower instability score results and the ranking is fairly consistent as the density of vehicles grows: PANDA, FESTIVE, TOBASCO2. When the result is a value close to zero implies that the algorithm is being able to maintain the fetched video bit-rate at a constant level to improve user experience (LI et al., 2014). Table 16 presents the index values found for instability for the simulated scenarios with different vehicle densities in 5G vehicle communications.

Table 16: Comparison of instability with different vehicle densities

DASH	**20 veh/km^2**	**60 veh/km^2**	**120 veh/km^2**	**240 veh/km^2**
FESTIVE	0.003	0.006	0.014	0.037
PANDA	0.000	0.005	0.007	0.022
TOBASCO2	0.002	0.008	0.032	0.039

3.7.9 Inefficiency

Efficiency measure is related to the rate of transmission speed, and of the network availability, but does not help to understand how it is affecting the DASH performance itself or how well it is driving key outcomes. So, as lower an average bit-rate better is the user experience. By its turn, inefficiency is the inherited metric defines in average quality criteria which when the result is a value close to zero implies that the users in the aggregate are using as high an average bit-rate as possible to improve user experience (LI et al., 2014; JIANG; SEKAR; ZHANG, 2014). PANDA has gotten lower inefficiency score results and the ranking of the average results is fairly consistent as the density of vehicles grows: PANDA, TOBASCO2, FESTIVE; or in other words, this is the efficiency ranking. Table 17 presents the index values found of inefficiency for the simulated scenarios with different vehicle densities in 5G vehicle communications.

Table 17: Comparison of inefficiency with different vehicle densities

DASH	**20 veh/km^2**	**60 veh/km^2**	**120 veh/km^2**	**240 veh/km^2**
FESTIVE	0.113	0.125	0.127	0.132
PANDA	0.094	0.119	0.124	0.129
TOBASCO2	0.107	0.118	0.128	0.135

TOBASCO2 had the worst performed mean video quality, throughput, bit-rate level, unfairness, and instability. PANDA performed better than FESTIVE. TOBASCO2 has also presented fewer playback interruptions and higher average buffer level than PANDA and FESTIVE, but the video quality was drastically reduced. These results have shown PANDA as the best DASH algorithm to be used in multimedia, as an adaptive method of video streaming where the source content is encoded at multiple bit-rates to decide about which segments to download. As the PANDA unfairness result is lower than of the other algorithms, its throughput is more fairly distributed between competing TCP connections improving the user experience in 5G vehicle communications. As the PANDA instability result is lower than the others, its inefficiency is also lower, making it immune to the bandwidth overestimation symptoms, and able to maintain the fetched video bit-rate at a constant level to improve user experience in 5G vehicle communications.

3.8 Final remarks

This chapter presented a 5G V2X ecosystem with the eMBB use case and V2V communications evaluated scenarios. Internet-based video services were simulated through the ecosystem with the goal to analyse it. The provision of IoV application (entertainment onboard services delivery) through a SDIoV architecture was evaluated, and it was simulated through the ns-3 simulator, which is indicated as the best choice for complex scenarios and cellular systems. The presented results show that the proposal can improve the IoV communications requirements under high-mobility (120 km/h vehicles in a rural environment) and high-density conditions (urban scenarios with good performance results).

The future will have everything connected and integrated. A full technology convergence is expected with the 5G evolution. Previous works used MATLAB to evaluate the radio network in 5G vehicular architectures (GE; LI; LI, 2017; KHAN; ABOLHASAN; NI, 2018). The present work analyzed the results using ns-3 simulations, making it one of the firsts with a practical evaluation of E2E 5G integrated with VANETs obtained by ns-3 and compared with the MATLAB's ones. In this way, simulations were conducted showing the satisfactory performance of the evaluated 5G scenarios. The IoV services efficiency in 5G V2X networks can be reached with the integration of different technologies. In this way, scientific efforts are being presented all around the world to find appropriated solutions such as the SDIoV architecture, which comes as a light for future directions.

The proposed approach was evaluated to check the multimedia services efficiency by the use of DASH through adaptive algorithms to allow the dynamic adjustment of the video presentation. The network conditions on the V2X-Server using the MEC concept, allowing the processing closer to the end-user was the focus. So, the multimedia service delivery, and Internet-based video services traffic in urban scenarios with different vehicle densities in 5G network simulator ns-3, employing mmWave were analysed. Based on the obtained results, PANDA algorithm has shown better behavior as the adaptive streaming algorithm to be used in 5G networks for video performance in vehicular communications in urban scenarios.

Studies and researches about the 5G architecture, implementation, and management are urgent. That is why the 5G V2X ecosystem was conceived as an open architecture project, enabling the integration of various technologies, enhancement, and extension of new protocols. The incorporation of elements into the proposed ecosystem structure, for example, SDN, V2X, and MEC servers aim to allow the creation of new mechanisms for improved network services. Evaluations of other types of services can be carried out with the 5G network implantation.

The next chapter describes a vehicle-centric probabilistic approach to virtual cell management in ultra-dense 5G networks. It was conceived as a new criteria based on user speed and complex network metrics, using the SDN as the controller.

4 A VEHICLE-CENTRIC PROBABILISTIC APPROACH TO VIRTUAL CELL MANAGEMENT IN ULTRA-DENSE 5G NETWORKS

This chapter presents a virtual cell selection probabilistic approach focused on V2N communications which motivation is the search for a handover decisions solution for 5G UDN to connect vehicles by IoV in a 5G V2X ecosystem. It also describes how the 5G cellular networks tend to be ultra dense and the consequent challenges of it. Among them, it is the creation and the management of virtual cells centered on the user, considering scenarios involving high mobility, such as IoV or V2N communications, where this challenge becomes even greater. The literature still does not present any other work that has directly associated a vehicle-centric probabilistic approach to V-cell management in 5G UDN as it is proposed in this thesis. In reason of it, this is a contribution to the technological development on 5G networks use, what indicates the originality of the present work. All the processing based on speed criteria and complex network metrics is performed inside a controller that is required to manage the virtual cells. The motivation to use different Key Performance Indicators (KPIs) of radio masts is that one has physical applications in purely mathematical contexts, while others find wide application in network theory. Simulations were performed through the Network Simulator ns-3. The results show that the proposed approach allows more assertive virtual cell selection, improving the services offered by IoV through the 5G networks.

In the section 4.1 the objective and the scope are be presented. In the section 4.2, related works show that virtual cells allow the creation of users centered approach. As the V-cells are transmission points with associations for each user mobility pattern in cooperative ways, adapting themselves to it, moving as the user movements. So, a controller is required to dynamically configure and manage the virtual cells by the network slice according to specific service requirements. In the section 4.3, the proposed approach introduces the cell selection rules for vehicle-centric V-Cells formation using the 5G UDN. In the section 4.4, the methodology is used to evaluate the proposed approach by the ns-3 network simulations in different scenarios. Section 4.5 brings the simulation results and their analyze lighting the active V-Cells in common, the total radiated power, and throughput. Section 4.6 presents the conclusions about the 5G UDN virtual cells management requires to guarantee the services offered by the network.

4.1 Goal and scope

The 5G networks will be an UDN and heterogeneous. These characteristics generate several challenges such as the ubiquitous wireless broadband connectivity (CARMO et al., 2019). In 5G UDN, users are connected to radio mast (5G cell site or 5G new radio base station (gNodeB)) through a virtual cell known as V-Cell or VC that allows the user-centered approach creation (RIGGIO et al., 2014) that is directed by the cell selection rules for vehicle-centric V-Cells formation using the 5G UDN. However, the virtual cell based on vehicle needs is still an underutilized area (HUNG et al., 2019). It lacks new mechanisms for 5G services improvement, like IoV through 5G V2X communications.

The main goal of the proposed approach is the virtual cells formation through a criteria based on user speed and complex network metrics, because they help in the solution of problems in vehicular networks as indicated by works in the literature and by the authors themselves. More specifically, this work presents a virtual cell selection probabilistic approach focused on V2N communications as the technological development of the search for a handover decisions solution for 5G UDN. This selection can improve the services offered by the IoV through the 5G networks but virtual cells also enable new types of services. The optimization in the V-Cell management to save resources (like e.g. active virtual cells) was carefully planned by a new virtual cell selection strategy. This is the contribution of this work for the technological development of the V2X communications. In this way, a SDN controller that has the network topology knowledge, in its control plane, is used to apply speed rules to the first cells selection by size and radius range. Once this available cells subset is chosen, probabilistic approaches are applied together with a greater network knowledge, in particular, the neighbor radio masts of a particular vehicle.

The different radio masts metrics analyzed were the vertex and the betweenness degrees based on complex networks, besides the distance from the vehicle to a radio mast. Moreover, different metrics of the radio masts were analyzed: 1st) vertex that is an algebraic structure that plays an important role in two-dimensional conformal field theory and has physical applications as algebras operator in purely mathematical contexts; 2nd) betweenness centrality that finds wide application in network theory representing the degree to which nodes stand between each other on complex networks; and 3rd) the distance from the vehicle to a radio mast. These metrics are mathematically modeled by probabilistic equations. The results, obtained by the equations, are classified and combined. The combination result indicates the choice decision of an optimized subset of cells that constitutes a virtual cell. Once the best candidate radio masts are chosen, the SDN controller updates the virtual cell.

Some scenarios were simulated with the proposed approach: two different urban scenarios and a freeway one, with variations in the user densities (active vehicles) and with the radio masts available in their topologies. For the evaluation, the number of active virtual cells in common, the total radiated power, and the throughput were analyzed and compared with the literature results.

Considering the State of Art, the search for “virtual cell management in ultra-dense 5G networks”has presented just 14 papers since 2016. Among these works, 9 are used in the present study (RIGGIO et al., 2014; CHEN et al., 2016; BEHNAD; WANG, 2017; LIU et al., 2017; SAHIN et al., 2017; GHARSALLAH; ZARAI; NEJI, 2018; SAHIN et al., 2018; SHI et al., 2018, 2019). In this search, it was not found any work that has directly associated a vehicle-centric probabilistic approach to V-Cell management in ultra-dense 5G networks as proposed in this chapter.

4.2 Related work

V-Cells allow the creation of a user-centered approach. They are several transmission points (TPs) with an association for each user mobility pattern (SAHIN et al., 2017). The virtual cells are formed by the association of a user with some near transmission points. It is highlighted that TPs should act in a cooperative way and also should adapt themselves to user mobility. Thereby, the V-Cell moves as the user moves with the device. A controller is required to dynamically configure and manage the virtual cells that can be instantiated by the network slice according to specific service requirements. Previous works about virtual cells are summarized in Table 18.

In (RIGGIO et al., 2014), the authors present virtual cell abstraction so that the resources of heterogeneous cells can compose a single set of resources managed by a controller. The V-Cell is logically seen as a single macrocell. Each user is associated with a virtual cell with a unique and dedicated identifier, allowing that a zone without handover can be obtainable within a V-Cell.

In (CHEN et al., 2016), a new ultra-dense network architecture is presented with a dynamic grouping of base stations or UE acting as access points, mobility management (virtual cell dynamic adjustments to the UE movement), resources (detection of system capacity), interference (a data flow transmission together with and cooperatively to improve the spectrum efficiency and the quality of experience (QoE)) and security (radio masts authentication and UE in V-Cells).

In (BEHNAD; WANG, 2017), an approach about the small virtual cell for 5G formation is proposed. The ideal density of small virtual cells is obtained in order to increase the total capacity of the network. The authors present a virtual formation of

Table 18: Related Work

References	**Main Features**	**Highlights**	**Ponderations**
(RIGGIO et al., 2014)	It presents a view of the design and system architecture of V-Cell.	Each user is associated with a V-Cell.	A controller manages the heterogeneous cells as a single set of resources.
(CHEN et al., 2016)	It shows a new UDN architecture.	User equipment (UE) acts as an access point.	The UDN architecture needs dynamic groups to act.
(BEHNAD; WANG, 2017)	It has a probabilistic formation of small V-Cells by the density of users.	The number of small V-Cells increases logarithmically with the density of users.	Other features as the user speed need to be considered.
(LIU et al., 2017)	It presents V-Cells constructed by optimal radius and analyzes the load-aware user-centric design in UDN.	The proposed scheme avoids cell congestion and works for a balance between resources and performance.	An optimal radius most be found before the charge is analyzed.
(GHARSALLAH; ZARAI; NEJI, 2018)	Addresses handover management.	The V-Cells creation occurs considering cell size and speed of the UE.	This proposal was evaluated by MATLAB considering the long term evolution (LTE) handover process.
(SAHIN et al., 2017) and (SAHIN et al., 2018)	It presents V-Cells for 5G V2X communications.	Transmission V-Cell points are determined with those that are closest to the center of each user.	A dynamic environment was not considered. This proposal was evaluated by MATLAB considering LTE parameters.
(SHI et al., 2018) and (SHI et al., 2019)	It presents the performance analysis of user-centric V-Cell dense networks over millimeter wave channels.	The authors adopt a strategy called *K-nearest*, i.e. a UE chooses the k Access points (APs) closest for V-Cell formation.	The APs are supposed to be in the line of sight (LOS) to increases the network density.

small cells through the choice of some users by probability, which acts as radio mast and will attend other neighbor users in the network. The number of small cells increases logarithmically with the density of users. The idea is to reduce the connections with the macrocells. It is possible to understand that other features need to be considered, for example, the user speed. A user's overload to attend his/her neighbors and the reward for such tasks were not exploited, as well as the performance gain.

The V-Cell design centered on the user is presented by Liu et al. (LIU et al., 2017), based on load (load-aware). The user reference signal received power (RSRP) measurements are sent to a network controller. In the first step, an optimal radius is found by the saturation point of the system average spectral efficiency. Then so, the charge is analyzed. The results demonstrated that the proposed scheme avoids cell congestion and finds a balance between resources and performance.

The 5G UDN and HetNets generate frequent handovers, unwanted, unnecessary (ping-pong effect) and failed handovers and, delay increase in the handover process. Thus, a software-defined handover (SDHO) solution for 5G networks is presented by (GHARSALLAH; ZARAI; NEJI, 2018). The developed solution is divided into 4 phases: data collection, data processing, V-Cells creation, and handover execution. As a differential, the V-Cells creation considers the size of the cells (small, medium, or big) depending on the user speed. However, the speeds are not explicit. In this work, the authors implement a software-defined handover management engine (SDHME) and simulate the proposal through the MATLAB, comparing results with the traditional LTE handover process. But SDHO is simulated considering the LTE parameters. The authors demonstrate that the presented proposal reduced two metrics: delay rates and handover failure.

Sahin et al. (SAHIN et al., 2018) present a V-Cell concept, which can be applied in several V2X use cases where broadcast communications for a group of vehicles occur, for example, cooperative awareness messages (CAMs) and decentralized environment notification messages (DENMs). For this, the authors have adopted the steps of intra-VC optimization (transmission weight selection), power control, and admission control. The authors assume that through co-operative beamforming all the TPs in a V-Cell are transmitting the same data in parallel to a vehicle. So there is no intra-VC interference. However, inter-V interference needs to be considered. A s data symbol of a data flow in a V-Cell is transmitted with a p transmission power and distributed throughout all TPs of the V-Cell according to the w weighting factors. This proposal was evaluated by MATLAB simulations considering LTE systems channel parameters.

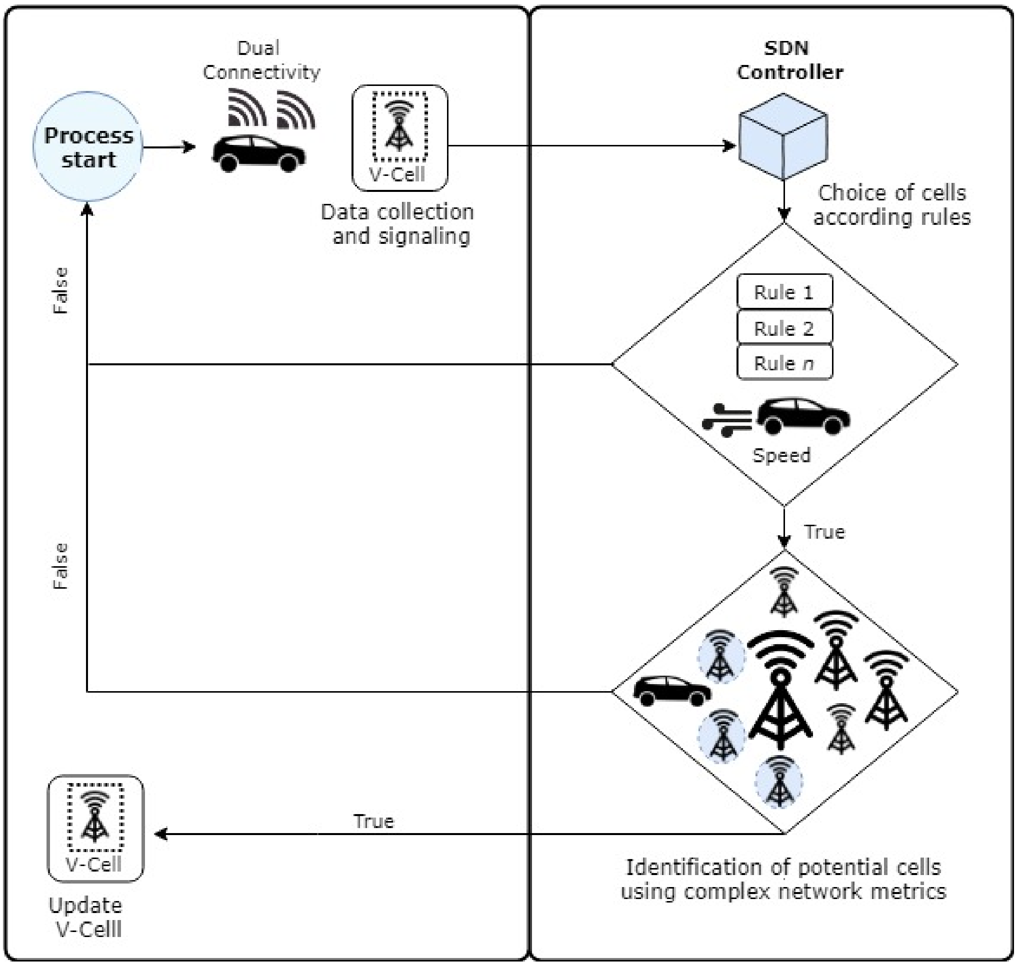
The data transmission with cooperative millimeter wave (mmWave) antennas is discussed by Shi et al. (SHI et al., 2018, 2019), which derived integral expressions for the coverage probability and the ergodic capacity of user-centered dense networks. The sensitivity of locks, different distributions of small scale fading (Nakagami, Rayleigh, and no fading) and APs cooperation were considered for derivations. One detail is that the APs were supposed to be in the LOS since the results demonstrated that the probability of the APs being in LOS increases as the density increases, and tends to be 1. The authors still assume that the APs transmit to the UE with maximum antenna gain via beam alignment and all APs have the same power. The authors consider that the *K-nearest* APs association strategy is more practical than the *K-best* strategy (which considers the power) and thus, there is a lower signaling overload. For the simulations, the authors considered that the APs were distributed within a radius of 100 meters (m), with a transmission power of 30 decibel miliwatt (dBm), with a frequency band of 73 Gigahertz (GHz) and a bandwidth of 2 GHz. The authors conclude that the characteristic limited by the communications noise in mmWave is closely related to the APs density and that the APs co-operation provides high coverage performance and capacity gain when the density is low.

4.3 The proposed approach

This section presents the proposed approach, introducing the cell selection rules for vehicle-centric V-Cells formation using the 5G UDN. The virtual cells allow overcoming most of the limitations of physical layer techniques in conventional wireless networks.

As the surge of mobile broadband Internet traffic increases, the mobile networks have to greatly increase their availability to meet the growing capacity demand for mobile applications and services. In this way, the virtual cells are fundamental to allow the continuous connection and to increase the mobile network capacity. The general scheme of the proposed solution is shown in Figure 30 and the V-Cell update procedure is shown in Figure 31.

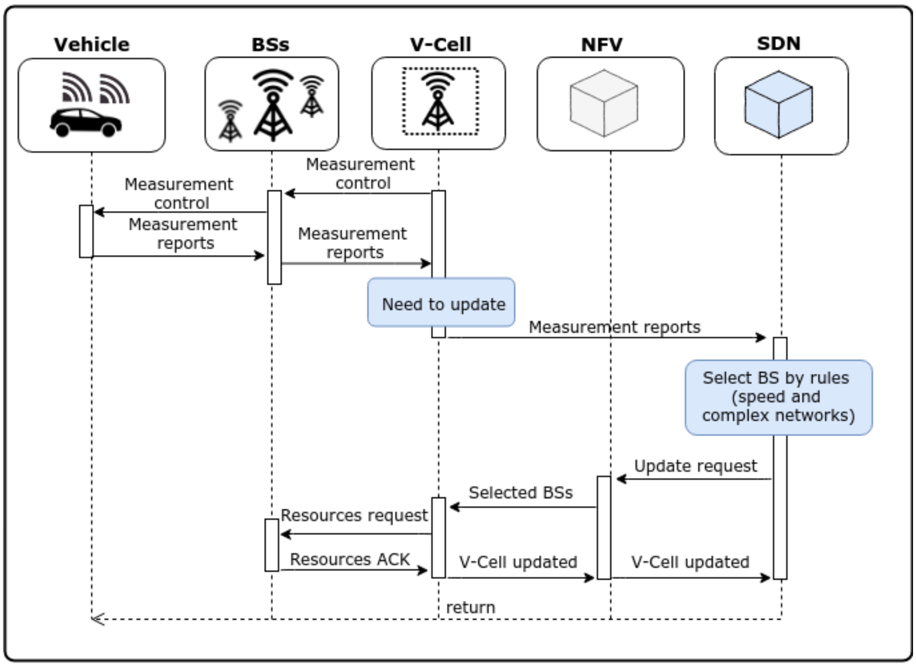
Figure 30: Functional diagram



When a vehicle initially registers itself within the network, it is assumed that its connection occurs primarily in the 4G macrocell as described in (ZANG et al., 2019). It is further assumed that the data transmission occurs cooperatively at the V-Cell and that all the available radio masts are in the line of sight (LOS), as well as described in (SHI et al., 2018, 2019). An initial virtual cell is instantiated by the matching of all the available radio masts for each vehicle using the k-nearest strategy by its range (up to 300 meters). It is also further assumed that each V-Cell is a network slice for a specific IoV service.

When an IoV service is required or a handover is needed, the first step consists of an SDN controller selecting cells by specific rules. The size of the cells that best suit the speed of the vehicle is an important one. The radio mast in which the vehicle is being

Figure 31: V-Cell update procedure



served is maintained during the update. Then, up to three radio mast can be identified in the selection process. If no potential cells are identified, the approach returns to its initial state. If potential cells are selected, the V-Cell is updated. Finally, it is emphasized that the main processing is performed in the controller. In this way, signaling costs are minimized as the core of the operations is performed by the controller.

4.3.1 Speed rules

In the first step of the proposed approach, the choice occurs by the speed ranges and the cell size. To ensure good service experience to any user or vehicle, specific rules about the cell size that best match with the vehicle's speed were created. The speed thresholds were defined based on the 3GPP Technical Report (TR) 38.913 which were adequate by cell type (small, medium and big). So, it is assumed small cells (picocells) with a coverage radius between 100 to 200 meters, medium cells (microcells) between 200 to 500 meters, and big cells (macrocells) from 500 meters. In this paper, it is considered the following sizes for the best case: small cells (picocells) for speeds between 0 and 30 kilometers per hour (km/h); medium cells (microcells) for speeds between 31 and 120 km/h; and big cells (macrocells) for extremely high speeds (between 121 and 500 km/h). These rules are presented in Table 19.

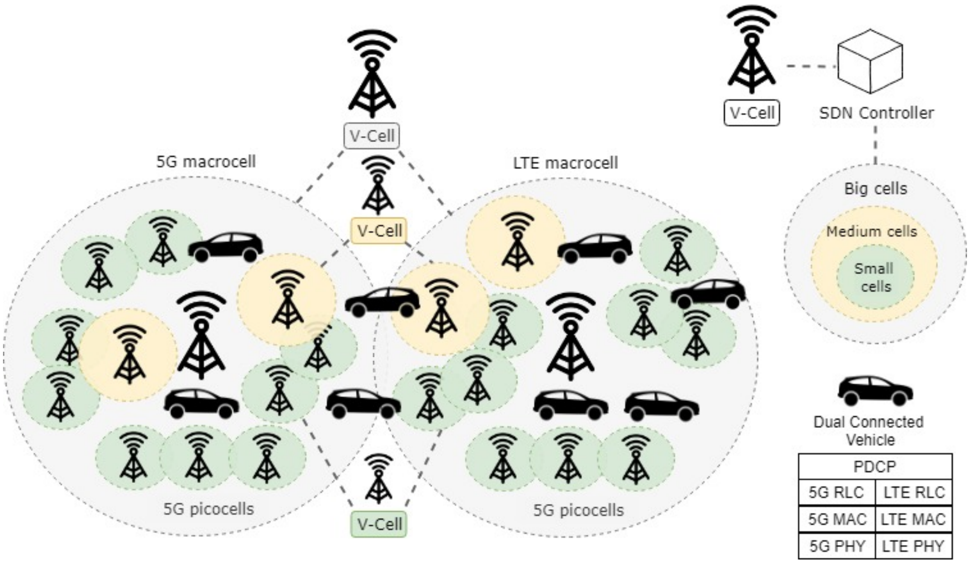
If it is not possible to allocate according to the size of the cell, in the worst case, it is applied the second or the third option according to the topological network availability, that is previously known by the SDN controller through its control plane.

Table 19: V-Cell rules to speed ranges

V-Cell	**Low speed 0-30 km/h**	**High speed 31-120 km/h**	**Very high speed 121-500 km/h**
1st option	Small size cell	Medium size cell	Big size cell
2nd option	Medium size cell	Big size cell	Medium size cell
3rd option	Big size cell	Small size cell	Small size cell

Figure 32 illustrates the application of V-Cell instances according to vehicle speeds in a 5G UDN network topology, and also shows the vehicle connects to the LTE and the 5G base stations simultaneously, that is, each vehicle has two interfaces to improve the robustness of communication systems.

Figure 32: Proposed macrodiversity solution in 5G UDN



Each vehicle can maintain connections to multiple cells including both 4G-LTE or 5G-mmWave. The LTE cell is a backup for the user plane since the UE is already connected, so when the signal quality of the mmWave link degrades there is no need to perform a complete handover because the control message from the LTE - evolved Node Base (eNB) to the UE is enough. These connections take place through PDCP (POLESE et al., 2017).

As in (SAHIN et al., 2018), in this study, it is assumed that all instantiated V-Cells are network slices for each IoV application or specific vehicles, and the resources are shared by different V-Cells. This means that each vehicle has its own V-Cell, distinct from other vehicles, and thus n V-Cells are instantiated by the SDN controller, even for broadcasting use cases. Each user or vehicle is unique in the network, even if a group has the same radio masts in common in a subset of n V-Cells, due to the network dynamics, V-Cells are updated independently of the broadcast communication that is still received by the group.

4.3.2 Use of complex networks to the cell selection

In the second step of the proposed approach, the cell selection is based on complex network metrics. Complex network metrics are based on the base station (BS) relevance in the network and on the position of the user or vehicle on the road. In this paper, the solution assumes up to three available potential cells in the topology of the network as candidates to become a V-cell. The network metrics can characterize asymmetric connectivity patterns, so, the motivation for the choice of these network metrics is because they are formulated to quantitatively reflect connectivity features on each speed limit range. This motivation is completed by the fact of other studies have shown that complex network metrics help in the solution of problems in vehicular networks (REZENDE et al., 2011; LOUSADA et al., 2019).

Thus, the present chapter combined probabilistic approaches together with better network knowledge, in particular, the neighboring base stations of a user or vehicle. It is known that each node or BS computes the metric by using the context information collected on the neighborhood but, the resulting metrics only provide the node perspective and not the overall centrality of the nodes. However, once the three best BSs or candidate cells are chosen by the probabilistic calculation, the update of the V-Cell is performed. Each user or vehicle maintains a table of contextual knowledge of its neighboring BSs as well its neighboring vehicles to allow the best radio mast choice in terms of both proximity and available network resources. The following metrics are used:

- BS degree: the BSs that have a high degree are the most active in the network. The higher is the cell degree, the smaller is its probability to be chosen as a candidate cell.
- Betweenness: it is the centrality of intermediation that provides a measure of the centrality of a network node based on short paths. It can also be seen as the entity's capacity to make connections with other entities or groups. So, the higher it is the betweenness, the smaller is the probability to be chosen as a candidate cell. Or in other words, the smaller it is the betweenness, the higher is the probability to be chosen as a candidate cell.
- Vehicle distance to BS: the position of the vehicle in the network is one of the main factors to choose or not the potential candidate cell. Thus, the smaller it is the vehicle distance to BS, the higher is the possibility to be chosen as a candidate cell.

What motivates the cell selection is its potential to aim at maximizing each user's utility. For the candidate cell selection as the contribution of this work, it is proposed the choice of the radio masts that have a lower grade value. This grade is calculated by the candidate cell selection probability, called *pS*, and it is formulated using the product of the probability associated with the BS degree (*pBSdegr*) and the probability associated with the betweenness (*pBetw*), divided by the vehicle distance to BS (*distVehBS*), formulated by the equation (4.1):

$$pS = \frac{pBSdegr \times pBetw}{distVehBS} \tag{4.1}$$

For the *pBSdegr* calculation of a particular BS, it is necessary for the BS to know the degree of the vertex of all its BS neighbors and vehicles connected. This value is maintained and updated in its neighbors' table. The *pBSdegr* calculation is given by 1 (one) minus the division between its vertex degree (*vDeg*), obtained by counting the number of vehicles and radio masts reachable (this information is kept in the neighbors' table of the BS itself), and the sum of the vertex degrees of its neighbors (*VDegNeig*), as shown in equation (4.2).

$$pBSdegr = 1 - \frac{vDeg}{VDegNeig} \tag{4.2}$$

Following the same reason as the previous metric, for the selection of the candidate cells, it is interesting the radio masts choosing that have a lower betweenness value. The normalized betweenness calculation (in undirected graphs), to measure the BS importance, is shown in the equation (4.3), where g_{st} is the shortest path from source (s) to destination (t), and n^i_{st} is the shortest path from "s"to "t"passing through "i".

$$pBetw = \frac{1}{\frac{(N-1)\times(N-2)}{2}} \sum_{s \neq i \neq t} \frac{n^i_{st}}{g_{st}} \tag{4.3}$$

After all metrics calculation, the Algorithm 1 is executed for each cell to be added in the "nodes choice" array. It is a control to indicate the optimum way at all. The idea of this algorithm is that the optimum way is used to choose the cells with the best metrics. The algorithm selects three cells through the optimum way to create a V-Cell.

Algorithm 1: VirtualCell

```
Input: range = range[targetCell]
Input: allBetwenessMetrics = CalculateAllBetwenessMetrics()
Input: allDistanceMetrics = CalculateAllDistanceMetrics()
Input: allDensityMetrics = CalculateAllDensityMetrics()
Input: nodesChoice[]
for aux = 0; aux < 10; aux ++ do
    Input: smallerBetweness=MaxDoubleValue
    Input: chosen = -1
    for aux2 = 0; aux2 < numberOfCells; aux2 ++ do
        if allBetwenessMetrics[aux2] < smallerBetweness then
            chosen = aux2
    allBetwenessMetrics[chosen]=MaxDoubleValue nodesChoice[chosen] ++
    Input: smallerDistance=MaxDoubleValue
    Input: chosen = -1
    for aux2 = 0; aux2 < numberOfCells; aux2 ++ do
        if allDistanceMetrics[aux2] < smallerDistance then
            chosen = aux2
    allDistanceMetrics[chosen]=MaxDoubleValue nodesChoice[chosen] ++
    Input: smallerDensity = MaxDoubleValue
    Input: chosen = -1
    for aux2 = 0; aux2 < numberOfCells; aux2 ++ do
        if allDensityMetrics[aux2] < smallerDensity then
            chosen = aux2
    allDensityMetrics[chosen]=MaxDoubleValue nodesChoice[chosen] ++
```

To create a V-Cell, it is very important to analyze the type of each cell that each algorithm has chosen. As presented before, the V-Cell creation has to follow the rule based on the vehicle speed. The variable range is used to know which is the user speed. At the end of the V-Cell creation, the Algorithm 1 tries its own rules first, but if it cannot choose a good cell, it tries other rules. This means that the Algorithm 1 changes the variable range, invoking the Algorithm 2, and it tries other cells to create a V-Cell.

As the differential of this work, this step suggests the adoption of complex network metrics to assist the choice of radio masts that will constitute virtual cells. Thus, we aim to improve the efficiency of the radio resource use, and the current service or IoV service user experience, especially in ultra-dense networks, such as 5G.

Algorithm 2: PickingCellsToVirtualCell

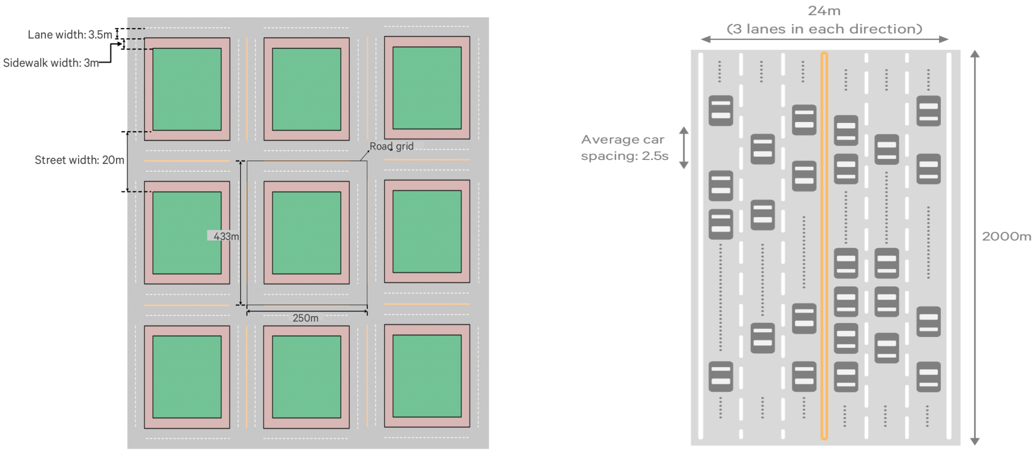
```
Input: VirtualCells[3]
Input: end = 1
Input: insert = 0
repeat
    end = 1 Input: index = -1
    Input: biggest = -1
    for aux = 0; aux < numberOfCells; aux ++ do
        if nodesChoice[aux] > biggest then
            //Dealign with smallest Cells if range == 1 then
                if !smallestCells(aux) then
                    biggest = nodesChoice[aux] index = aux
                else
                    break
            //Dealing with medium cells else if range == 2 then
                if !mediumCells(aux) then
                    biggest = nodesChoice[aux] index = aux
                else
                    break
            else
                if !biggestells(aux) then
                    biggest = nodesChoice[aux] index = aux
                else
                    break
    if index != -1 then
        VirtualCells[insert] = index biggest = 0 nodesChoice[index] = 0 //cant chose this cell again
    else
        biggest = 0 if range == 1 then
            range == 2
        else if range == 2 then
            range == 3
        else
            range == 1
    end == 1 //Not fill all VirtualCells for aux = 0; aux < 3;aux ++ do
        if VirtualCells[aux] == -1 then
            end = 0 break
until end == 0;
```

4.4 Evaluation methodology

The proposed approach was tested using the ns-3 network discrete event simulator which was designed to simulate different technologies and scenarios. Several works in the literature use the ns-3 and their modules, such as LTE-evolved packet core (EPC) network simulator (LENA) and ns3-mmWave. In this work, the ns3-mmWave and the OFSwitch13 modules (OpenFlow 1.3 module for ns-3) were used. The OFSwitch13 allows the inclusion of a SDN controller in the scenarios. The traffic model was created through the simulation of urban mobility (SUMO) and the scenarios were evaluated with a confidence interval of 95% for 10 simulation trials. The assumed scenarios are presented in Table 20, based on the literature (SAHIN et al., 2018; ZANG et al., 2019) and urban road and freeway scenarios (Figure 33) in accordance with the 3GPP R1-164679 document (NGUYEN et al., 2017).

Table 20: Simulation Scenarios

Parameters	**Scenario I** **Sahin et al. (SAHIN et al., 2018)**	**Scenario II** **Urban**	**Scenario III** **Freeway**
Structure	1000 x 1000 m	4 lanes of 3.5 m each, 2 lanes in each direction (9 grids with 250 x 433 m each)	6 lanes of 4 m each, 3 in each direction (2,000 meters)
Active vehicles	25, 75, 125 and 250 vehicles	25, 75, 125 and 250 vehicles	25, 75, 125 and 250 vehicles
Speed (random)	15, 30 and 60 km/h	15, 30 and 60 km/h	70, 140 and 300 km/h
Position	Poisson process	Poisson process	Poisson process
Spacing	2.5 s	2.5 s	2.5 s
Macrocells	2	2	2
Microcells	8	4	5
Picocells	40, 90, 140 and 190	16	-



(a) Urban scenario

(b) Freeway Scenario

Figure 33: Urban road and freeway scenarios. Source: adapted from (NGUYEN et al., 2017).

The physical BSs or radio masts were distributed in the following way: in the scenario I, based on (SAHIN et al., 2018), the radio masts were randomly distributed, as the vehicles were randomly positioned; in scenario II, based on (ZANG et al., 2019), 20 radio masts (dense scenario as suggested by the 3GPP simulation guideline) were positioned in 2 macrocells so that 4 microcells may form the center of the grid and 16 picocells are in each corner of the grid; in scenario III, based on (SAHIN et al., 2018) and (ZANG et al., 2019), 5 radio masts (sparse scenario) are randomly placed within macrocells having a radius of 500 meters each. In the scenario I, for the analysis purpose of the transmission point density impact, the number of picocells was increased considering the same network area (SAHIN et al., 2018).

Table 21 presents the adopted simulation parameters, based on 5G V2X ecosystem (STORCK; DUARTE-FIGUEIREDO, 2019). The 3GPP mmWave channel model was used to perform the initial connection of the active vehicle to the radio mast using mmWave communications and considering the parameters of frequency, bandwidth, number of sub-bands, channel conditions and fading. The Round Robin scheduling was used. The number of in common active V-Cells, the total radiated power (TRP), and the throughput were used as metrics to evaluate the probabilistic approach proposed, considering that each simulated vehicle has its own V-Cell.

Table 21: Simulation parameters

Parameter	**Value**	**Description**
channel	mmWave3gpp	Channel model
frequency	28 GHz	Supported Frequency
bandwith	1 GHz	Bandwidth
numSubbands	72	Number of sub-bands
subbandWidth	13.89 MHz	Width of the sub-band (MHz)
propagation	mmWave3gpp	Propagation model
losCondition	true	Channel conditions
shadowing	true	Fading
enableBuildings	true	Consider obstacles
macScheduler	Round-Robin	Scheduler class
harqEnabled	true	Enable HARQ
harqProcesses	100	HARQ for DL and UL
rlcAmEnabled	true	RLC-AM enabled
packetSize	1446 Bytes	Package/Segment Size

For comparison purposes, we check the average number of active V-Cells that share the same radio masts. In other words, vehicles that have one V-Cell equal to another one at a given time in the simulation and, we compare with the maximum number of the served hotspots (HSs) by V-Cells of (SAHIN et al., 2018). In (SAHIN et al., 2018), the TRP is the sum of all power distributed by all virtual cells in the system. Each V-Cell thereby distributes its signal with power p_k dBm over different transmission points by using the weight vector w_k and the total distributed signal has power p_k. The maximum output power per TP used is 26 dBm. In (HUO; DONG; XU, 2017), the maximum output effective isotropic radiated power for the 28 GHz band is 43 dBm. The total received power in dBm is given by the equation (4.4), where the total transmission power is $TxPow$, the beamforming gain is $TxBGain$ and $RxBGain$, the shadowing is $ShadW$ and, the path loss is $PLoss$.

$$RxPow = (TxPow + TxBGain + RxBGain) - (ShadW + PLoss) \tag{4.4}$$

4.5 Results and discussion

The simulation results are presented and analyzed in this section.

4.5.1 Active V-Cells in common

This subsection presents the impact analysis regarding the increase of density considering the same network area for V-Cells formation. Fig. 34 shows, through the y-axis, the average common active V-Cells for each 5G UDN network density variation (50, 100, 150, and 200 radio masts) by the x-axis in the scenario I with 75 active vehicles in the network. Fig. 35 shows, through the y-axis, the average common active V-Cells for each vehicle density variation (25, 75, 125, and 250) by the x-axis in the scenario I with 100 radio masts.

Figure 34: Impact of the total number of radio masts with number of common active V-Cells vs. the maximum number of served hotspots by V-Cells and 75 vehicles

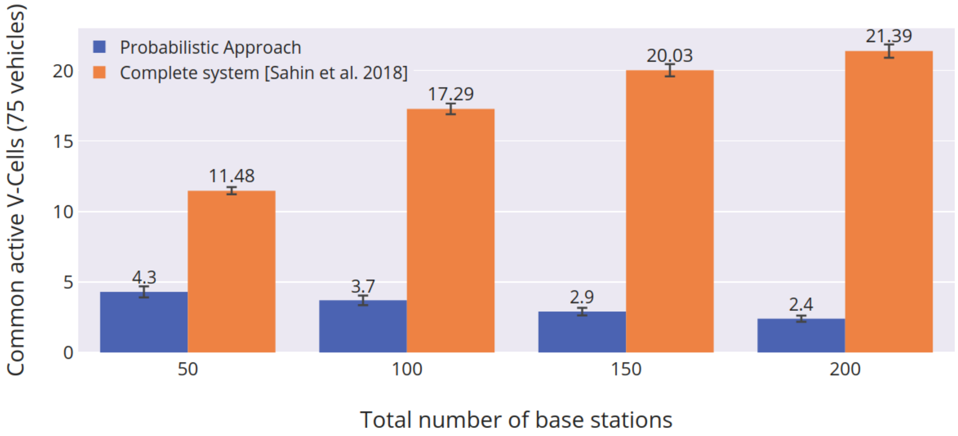
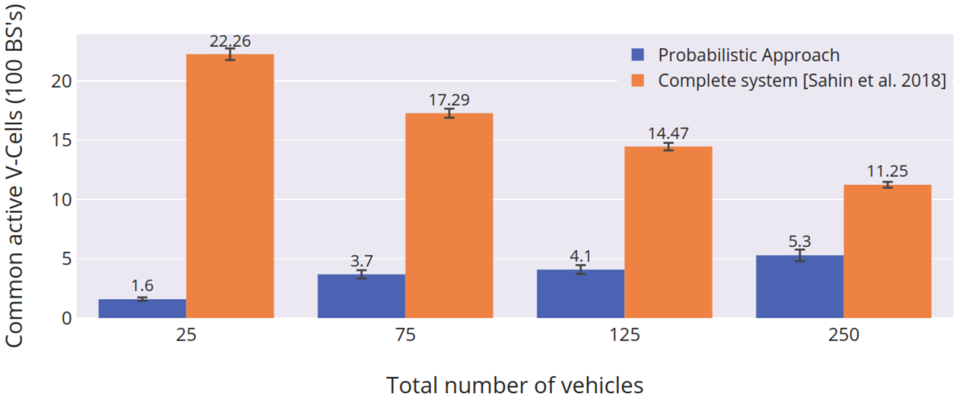


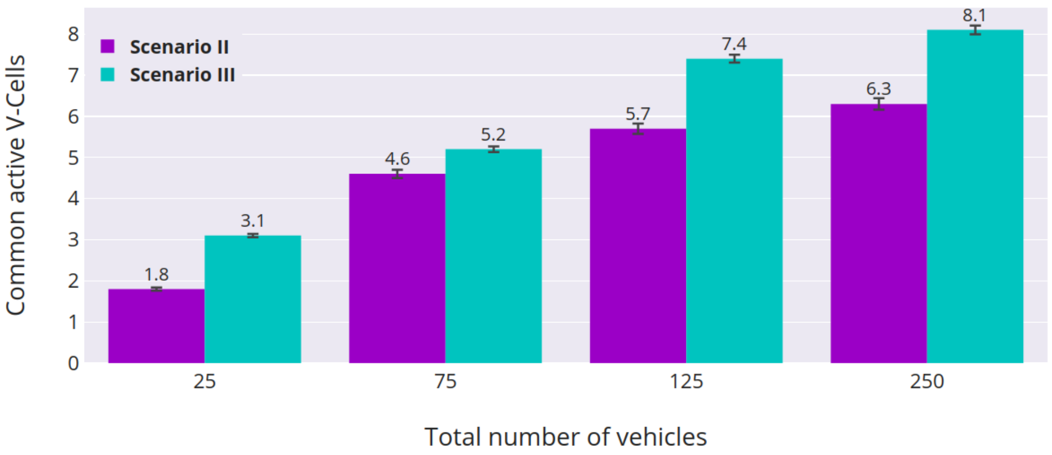
Figure 35: Impact of the number of vehicles with number of common active V-Cells vs. the maximum number of served hotspots by V-Cells and 100 radio masts



Although in (SAHIN et al., 2018) vehicle speeds were not specified and the authors adopted LTE network operating standards, the base values presented for comparison with our proposal are higher. However, this means that in practice, the number of vehicles that can be regrouped in the same active V-Cell is much smaller than that reported by (SAHIN et al., 2018) and depends on several factors. Therefore, the instantiation of V-Cells in a vehicle at a time was concluded based mainly on the dynamic mobility of vehicles associated with high speeds; this is the best approach to be adopted in IoV.

Also, to evaluate our proposal in a highly mobile and dynamic network environment, we have tested our proposal with a distinct urban scenario configuration (dense scenario) and also in a freeway scenario (sparse scenario), as shown in Section 4.4, both considering 25, 75, 125 and 250 active vehicles in the network. Fig. 36 shows the average active V-Cells in common for each one of the two scenarios.

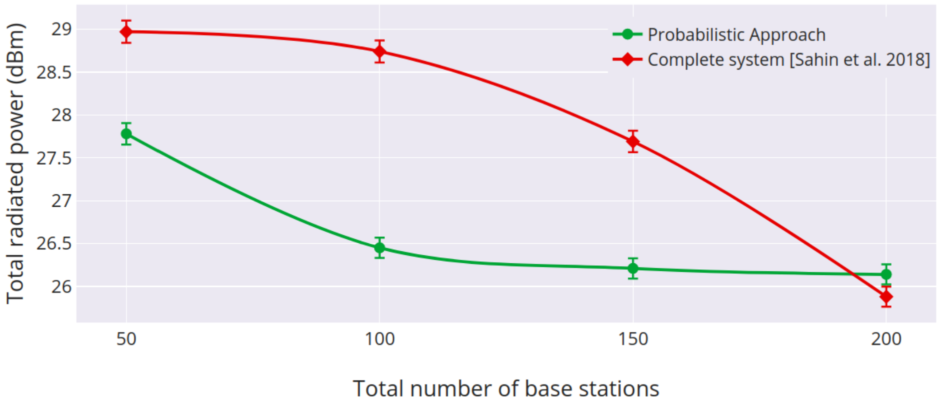
Figure 36: Impact of the number of vehicles with number of common active V-Cells in urban and freeway scenarios



4.5.2 Total radiated power

In this subsection, the average radiated power is analyzed and compared with (SAHIN et al., 2018) according to the density of the 5G UDN network in scenario I. Fig. 37 shows, through the y-axis, the TRP in dBm for each 5G UDN network density variation (50, 100, 150, and 200 radio masts) by the x-axis in the scenario I with 75 active vehicles in the network.

Figure 37: Impact of the number of base stations with total radiated power [dBm] and 75 active vehicles



Sahin et al. (SAHIN et al., 2018) concluded that the as HSs are associated with closer TPs, less attenuation is experienced in transmissions, hence, a less transmit power becomes sufficient. Comparatively, our proposal can save 4.22% of the network energy. This occurs mainly because the V-Cells are created only for active vehicles considering that each V-Cell is a network slice for a particular vehicle, or service together with the application of our proposed approach.

4.5.3 Throughput

The flow rate was obtained through the PDCP which provides for each transmission time interval (TTI) the amount of transferred data by the vehicles. On the 5G network, the reference value of the maximum data rate is 1-10 Gbps which can support in some scenarios up to 20 Gbps. By the experiments, the obtained average throughput with 95% confidence interval for 10 simulation trials was 1175.15 ± 25.56 Gbps in the scenario I under different vehicle density on the network. The scenario II showed an average of 1141.04 ± 23.55 Gbps. And in scenario III, an average of 1037 ± 17.64 Gbps was obtained.

4.5.4 Discussion

The simulation results have shown efficiency improvements in V-cells management, which is the specific solution to guarantee quality to the services that are offered through the network. As the intense mobility in the mobile network makes the process to be complex and challenging, this chapter has proposed an approach about some 5G vehicular communication aspects, for when dynamic changes are detected in the network topology by a controller, considering the cell selection and V-Cell instantiation individually in each vehicle. Furthermore, the approach connects each vehicle to the most available radio masts to those which are least congested, using complex network metrics, if the service can be provided without compromising quality. In this way, network balancing is also performed.

The proposal developed makes a more assertive decision for V-Cell management. It was demonstrated by the rate of active V-Cells in common. Among the employed techniques, the choosing of radio masts adopting vehicle speed rules and cells' size, combined with the probability of choosing through complex network metrics, manages the virtual cells for each vehicle. The V-Cells management based on complex network metrics proposed in this paper was a good choice as the results have shown. As future works, simulations with other scenarios will be conducted, as well as the evolution of the proposed approach employing recent techniques to overcome frequent handovers.

4.6 Final remarks

This chapter has presented a probabilistic approach to 5G UDN V-Cell management based on vehicles which goal was evaluated through the ns-3 simulator, adopted in this work. Other works indicate ns-3 as the best choice for complex scenarios and cellular systems, and this chapter has also compared its results with the proposal presented by Sahin et al. (SAHIN et al., 2018) before they have been presented and discussed. At the end, it was emphasized that the proposal approach has improved the evaluated metrics.

In the following chapter, the 5G cellular network is presented as a support technology for IoV which require full-time connectivity. But since 5G cellular network needs solutions and breakthroughs for new network requirements, the next part of this work presents a solution of handover decision for cars connected in ultra-dense 5G networks, which was tested using the ns-3 network discrete event simulator, and the results have shown considerable gains in the handover metrics. In this proposal, it is going to be presented the goal and the scope of the solution and it is going to discuss the related works lighting over the recent handover techniques that are applied on vehicle and cellular networks.

5 FiVH: AN INTER-V-CELL HANDOVER DECISION FOR CONNECTED VEHICLES IN ULTRA-DENSE 5G NETWORKS

This chapter presents a handover decision solution for connected vehicles in 5G UDN. The main goal here is to increase the vehicular mobility providing performance gains in handover for the mobile communications. The densification of the cellular network causes, despite the expected capacity gain, difficulties in the cells selection, increases the number of failed and unnecessary handovers (ping-pong effect), longer delays and energy consumption, and high packet losses. The solution is based on the V-Cells presented in the previous chapter which has presented the vehicle-centric probabilistic approach to address the problem of V-Cells management in an UDN with scenarios of vehicles in high mobility, discussing the evaluation results of the use of complex networks to the cell selection. The solution relies on the SDN controller which has centralized network information, as mentioned before. Simulations were conducted in Network Simulator, ns-3. The results show that the solution is effective to the FiVH decision for vehicles that are connected in 5G UDN.

The chapter 5 organization brings, in section 5.1, the goal and the scope of the handover solution, considering aspects and components that are relevant to the handover decisions that are present in previous works. In section 5.2, there are the related works presenting recent handover techniques applicable to cellular and vehicular networks. In section 5.3, the proposed approach is presented with attention to its functional view in accordance with the 3GPP standards that define how a handover can be triggered by different events such as signal strength, signal quality, and others. It carries on exposing that the V-Cells adoption allows user-centered approaches and that the congestion control and cell balancing is performed by a utility theory function which considers bandwidth and throughput as ascending criteria. Also, the average speed and the QoS rules are explained as relevant factors during the handover decision process. In section 5.4, the used methodology to test the proposed approach through the ns-3 simulator is exposed. In section 5.5, the results discussion present a significant reduction in the number of handovers executed and an excellent packet loss rate. And In section 5.6, there are the final remarks.

5.1 Goal and scope

Worldwide, driving systems for driver assistance have been developed using VANETs. The wireless communication networks, especially cellular networks, are the infrastructure pillars to support such systems. Vehicle-oriented systems have new network requirements such as high throughput (between 1 and 20 Gbps), the massive density of connections (estimated at 1 million of devices and connected vehicles by km^2), ultra-reliable communications of low latency (1 ms) and support to high-speed mobility (up to 500 km/h) according to ITU-R M.2083-0 recommendation (ITU, 2015; YU; LEE; JEON, 2017; MINOLI; OCCHIOGROSSO, 2019).

Since a vehicle or User Equipment (UE) is capable of traveling at high speeds and in random directions, it is not always possible to maintain it connected to the same base station or cell. In this kind of connection, the transition between different cells is a conception called handover (HO) and involves great information related to the network. Congestion, cell coverage, mobility, network available resources, protocols, and topology parameters are some examples of information needed for the handover process. Consequently, the quality of the service delivered to the users is influenced by handover decisions, evidencing the importance of an assertive cell selection.

Vehicle applications involve V2V communication, V2I communication, or V2X communication. Techniques and awareness of handover for users at high speeds are necessary for the success of communications between vehicles and everything (SELVANESAN et al., 2018). Due to the dynamic mobility associated with high speeds, despite the expected capacity gain, vehicles present frequent handovers and disconnections (KHAN; FAN, 2018), in addition to the network density, difficulties in the selection of cells, a greater number of failed and unnecessary handovers (known as the ping-pong effect), greater delays and energy consumption, high packet losses and poor quality of experience (TAYYAB; GELABERT; JANTTI, 2019), which makes the handover process more complicated, being a challenge to do it in an effective way.

The purpose of this chapter is to present the 5G Vehicular Handover (FiVH) solution for connected vehicles to 5G-UDN. With a unified view of the network, provided by the SDN controller adoption, FiVH becomes aware of the network general context, centralizing some decisions. The adopted procedure is hybrid: user-centric for the best cell choices to form a V-Cell and network-centric for the handover properly execution. FiVH uses the optimum way to select the cells to make up virtual cells that are dynamically updated. It also selects cells by the 3GPP quality criteria specification and by complex network metrics in the formation of the V-Cells.

The main contributions of this chapter are: a handover solution for 5G-UDN connected vehicles; V-Cell action associated to the SDN to support the handover procedures; creation of specific rules according to vehicle mobility; probabilistic equation modeling; the adoption of complex network measurements; the adoption of the utility theory for a better choice of cells; and scenarios simulation with the proposed approach.

5.2 Related work

Over the years, several works have been developed for handover treatment. Initiatives to increase handover efficiency are proposed in the literature. In some works (POLESE et al., 2017; GHARSALLAH; ZARAI; NEJI, 2018; MOUAWAD; NAJA; TOHME, 2018; RIZVI; AKRAM, 2018; PENG et al., 2019; ZANG et al., 2019; OLIVEIRA; STORCK; DUARTE-FIGUEIREDO, 2019), some approaches are presented and developed, however, some of these works do not evaluate the characteristics of the new 5G radio or did not use enabling technologies such as SDN. Others did not consider ultra-dense scenarios with high-speed vehicles, which make FiVH different from the other proposals. So, new proposals are needed for vehicular communications in ultra-dense 5G networks. Table 22 provides a summary of related work.

Table 22: Approaches adopted in related works

References	**Main Features**	**Highlights**	**Ponderations**
(GHARSALLAH; ZARAI; NEJI, 2018)	Handover solution with 4 phases: collection, processing, virtual cells creation, and handover execution.	Virtual cells consider the cell size according to mobility. Validation by means of a high performance interactive software focused on numerical calculation, MATLAB.	Characteristics of the new 5G radio were not considered in the simulations.
(PENG et al., 2019)	Handover strategies for network layer (VANETs).	Vertical handover is centered on the user or the network.	Only an overview of the strategies is provided.
(POLESE et al., 2017)	Dual connectivity protocol.	Protocol implemented in the ns-3 simulator.	Simulates the urban scene in an area of 200 x 115 meters.
(MOUAWAD; NAJA; TOHME, 2018)	Network-centered handover is the responsibility of the SDN controller.	Selection of the network occurs based on the theory of utility.	Simulations consider 802.11p and Long Term Evolution (LTE) for vehicles (LTE-V) through Mininet-wifi.
(RIZVI; AKRAM, 2018)	V2X handover management based on 5G SDN; it is done through the X2 interface.	Handover is the main event triggered in network cutting and virtualization techniques.	Simulations considering only LTE network parameters.
(ZANG et al., 2019)	Management of vertical handover in heterogeneous networks.	MDP-based proposal using speed and user location.	Speed in high mobility scenarios was 4.57 m/s (16.46 km/h).
(OLIVEIRA; STORCK; DUARTE-FIGUEIREDO, 2019)	Soft Handover (SoftH) mechanism is presented.	SDN-based proposal.	It considers active connections in up to two potential cells only, and has been rated at 4G LTE.
FiVH	New handover solution focused on 5G vehicle communications as an evolution of SoftH.	Approaches considered specifically for an efficient handover process for high-speed vehicles in ultra-dense scenarios.	

5G networks are ultra-dense and heterogeneous, which alone generates frequent handovers that are unwanted, unnecessary (ping-pong effect), and failure, besides increasing the processing time of the handover (BILEN; CANBERK; CHOWDHURY, 2017). A Handover Solution Software-Defined (SDHO) for 5G networks is presented (GHARSALLAH; ZARAI; NEJI, 2018). The developed solution is divided into 4 phases: data collection, data processing, V-Cells creation, and handover execution. As differential, the V-Cells creation considers the size of the cells (small, medium or large) depending on user speed for 4G LTE networks. However, the speeds are not explicit. In this paper, the authors simulate the proposal through MATLAB, comparing with the traditional LTE handover process. SDHO is simulated considering the LTE network parameters. The authors have shown that the presented proposal has decreased the handover delays and failures in LTE.

Applied in vehicular networks, handover strategies can be classified as horizontal, which uses the same wireless access technology; or vertical, which needs to maintain a connection in coverage area overlapped by more than one type of network technology (PENG et al., 2019). V2V, Device-to-Device (D2D), and V2I communications are scenarios of horizontal handover. By its turn, the vertical handover is the most user-centric triggered mechanism that considers QoS and financial cost. In network-centric handover, the maximization of the throughput, or the network balancing, or both are considered. The network selection performance generally occurs by centralized calculations, by using SDN controllers to facilitate the process.

Since the millimeter Waves (mmWave), adopted in 5G, suffer channel intermittence by the block of objects, a dual connectivity protocol in 4G and 5G is presented in a work (POLESE et al., 2017) where it was proposed that the base stations track the UE channel quality across all possible multiple links and spatial directions, in addition to angular directions (directional scanning), thus reducing the exchange time when necessary. A dynamic Time-To-Trigger (TTT) algorithm for the Secondary Cell Handover (SCH) triggering is compared to the standard handover with the fixed TTT algorithm.

The mobility management is a challenging issue in 5G vehicular networks. The Always Best Connected (ABC) concept is relevant to meeting vehicle QoS requirements. One work (MOUAWAD; NAJA; TOHME, 2018) has proposed two schemes for vertical handovers: the first is user-centered, with the handover process performed on vehicles and the final decision sent to an SDN controller; the second is network-centric whose handover process is transferred to the SDN controller. In both approaches, the network selection is based on the utility theory, also employed by other work (PUSKA; NOGUEIRA; SANTOS, 2018). The simulations of protocol IEEE 802.11p and the LTE-V technologies, used through Mininet-WiFi (FONTES et al., 2015) and SDN framework (RYU, 2019) controller, show improvements regarding the delay to the network load and the re-selection number of handover rate. These authors conclude that the user-centric approach can be used in congested networks to reduce the signaling costs, and the network-centric approach shall be applied when the network presents a normality state.

In 5G, for both network slice and virtualization techniques, handover is the main triggered event and the handover management in 5G SDN-based V2X communication was already presented (RIZVI; AKRAM, 2018). In the conventional LTE architecture, considering a base-line (PRADOS-GARZON et al., 2016), the handover preparation and conclusion times are 6.94 ms and 8.31 ms, respectively, totaling 15.25 ms the handover total execution time. From the results, obtained through simulations on ns-3 and the LTE structure, the authors present the handover preparation and conclusion optimization of 5.76 ms and 7.48 ms, respectively.

For the management of vertical handover between mmWave networks that have highly directional antennas and conventional microwaves (Fourth Generation - 4G), one work (ZANG et al., 2019) has proposed an algorithm based on a Markov Decision Process (MDP) using UE location and velocity. Thus, for the handover decision, the algorithm considers the characteristics of the mmWave channels and the mobility information. This paper aims to avoid excessive handovers and, effectively, address signal blocking and beamforming (beam formation) misalignments. An action elimination method was applied to reduce the MDP complexity. At that work, theoretical analysis and simulations were performed. The presented results have shown that with increasing cell density in the 5G network, the user receives a higher Signal to Interference plus Noise Ratio (SINR), as well the handover rate also increases, but as expected, its performance decreases and degrades itself faster in high-mobility scenarios.

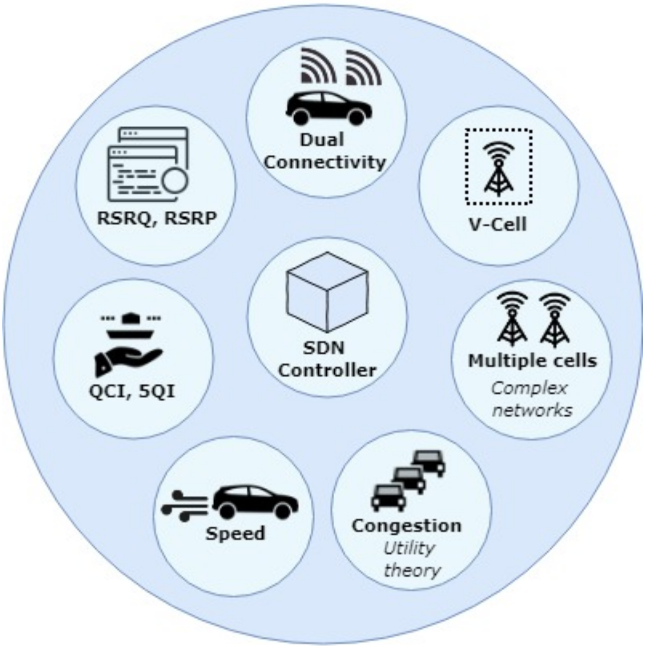
SoftH uses the concept of SDN and is capable of making handover decisions in a more assertive manner (OLIVEIRA; STORCK; DUARTE-FIGUEIREDO, 2019). It is a mechanism that considers measurements by the quality indexes of the Reference Signal Received Quality (RSRQ) and has two ranges of rules for the users' average speed (the maximum speed considered was 100 km/h). The congestion control occurs by the number of active connections in up to two potential cells and finally it was evaluated considering the 4G LTE network parameters. The results have shown that the SoftH architecture did not cause a significant impact on handover times. Concerning other handover mechanisms, SoftH and another mechanism proposed in (KHAN; PORTMANN, 2016) have presented a continuous flow increase and they did not have falls during the transition period, whereas mechanisms that do not use SDN had a flow rate decrease. The network was always greater for SoftH, and the packet loss rate was lower in all scenarios. These results show that the SDN concept use is very appropriate in cellular and handover contexts.

So, this chapter presents FiVH as SoftH evolution, highlighting that it is a new handover mechanism focused on 5G vehicular communications, with the use of dual connectivity; identification of physical cells for the formation of V-Cells using metrics of complex networks; instantiation of V-Cells by SDN and NFV; congestion control and cellular balance applying utility theory; vehicle average speed rules changed considering the Quality of the Service (QoS) through the QoS Class Identifier (QCI) and the 5G QoS Indicator (5QI), which are network parameters that determine the QoS of a specific application, defined by the RSRQ indexes and Reference Signals Received Power (RSRP).

5G-UDN scenarios evaluation has considered specifically for a professional handover and aware access for high-speed vehicles. From what is known, this is the first work that deals with 5QI in the handover decision process.

The used multicriteria is shown in Figure 38 differentiate FiVH from the proposed solutions in the literature and provide performance gains in the handover, such as the decrease in handover execution time, decrease in the number of unnecessary (ping-pong effect) and failing handovers, and decrease in the number of lost packages.

Figure 38: Multicriteria of the FiVH solution



Other decision strategies, different from those used in this work, such as fuzzy logic, Analytical Hierarchical Process (AHP), Q-learning, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and reinforcement learning are also found in the literature (SOUZA et al., 2020) to treat and reduce the number of handovers.

An overview of other studies is presented in Table 23. They present some references discussing their relevance to the theme and differences from what was proposed in this work.

Table 23: Differences concerning other relevant works

References	Relevance	Differences
(CHAO; CHEN; WU, 2011)	It presents solutions to provide longer battery lifetime by improving the power saving mechanisms of Machine to Machine (M2M) communications devices, in RAN and CN where they can work well with simplified activities under optimized signaling flow.	It uses RAN and CN adaptations to save power on M2M devices while this paper uses V-Cells to improve 5G-UDN efficiency, which consequently, reduces the power wasting.
(LUO et al., 2012)	It proposes a high-speed train communication using the cloud system for providing continuous broadband services to highly mobile users. This framework is featured with a new virtualized single cell design to mitigate conventional handover failures and the frequency reuse by a highly efficient joint transmit beamforming algorithm compensates the inter-carrier interference.	1st the use of cloud system while this paper cares about the V-cells by 5G-UDN use as solution for the handover failures. 2nd the scenario is the onboard train while this paper talks about urban roads and freeways. 3rd the Remote Radio Head (RRH) is used as evaluation method.
(WU, 2012)	It shows that green wireless communications focus on energy efficiencies and sustainable energies by using renewed materials in less space, producing less electromagnetic pollution, reducing wastes and costs. This proposal is answered by the combination of C-RAN and Mobile Edge Computing (MEC).	It presents C-RAN as an architectural solution to the problem of energy-efficiency requirements for cellular networks while this paper presents the FiVH able to select the best V-Cells to provide faster and more efficient handovers improving the 5G-UDN efficiency.
(FOH et al., 2016)	It is about how the Intelligent Transportation System (ITS) is improved by the Internet connectivity to vehicles, which is already important for safety in driving experience because of the real-time information access about traffic conditions by vehicular cloud services.	It points the cloud service as the better support for Internet connectivity to vehicles to improve ITS while this paper indicate this improvement by V-Cells use on V2V, V2I and V2X communications.
(AN et al., 2017)	It considers the Ultra-Dense Heterogeneous Network (UDHN) as a promising technique to answer the requirements of the increasing data traffic in 5G networks. It uses Cloud Radio Access Network (C-RAN) architecture to improve efficiency while reducing the signaling overhead, with Downlink and Uplink Decoupling (DUDe) strategy to offer better quality in the communication.	It is focused on the C-RAN and DUDe use for UDHN while this paper is interested in use the FiVH for offer the best V-Cells for 5G-UDN.
(WU et al., 2018)	It presents the correlation between the sustainable development goals and the information and communications technologies.	It is worried about how social, economic, and environmental perspectives are involved with sustainable development by communications technologies while this paper points on how to solve the problems on vehicular connections to improve such involvement.
(ZENG et al., 2020)	It presents Vehicular Edge Computing (VEC) as a mechanism able to improve the QoS using a computation offloading by a volunteer assisted model for cost and utility functions.	It uses VEC to improve QoS in mobile communications while this paper uses a multicriteria mechanism in FiVH for the proposal to assure QoS in the handover decision process, including a utility theory function.
(ESHTEIWI et al., 2020)	It shows vehicular communications by the performance of V2V cooperative wireless communications of full-duplex amplify and forward relaying-based over Nakagami-m fading channels, where the communication links suffer from co-channel interference, residual self-interference, and blockage from other vehicles on the road but also from SINR.	It presents mechanisms to avoid different interferences in vehicular communications while in this paper the focus is on RSRP for 5QI.
(LE; KADDOUM, 2020)	It presents the optimal access control of vehicles in multi-agent drive-thru systems that use limited bandwidth of Roadside Units (RSUs), where each vehicle acts as an independent agent that has to contend for the access to the data service provided by RSUs. To solve this problem it proposes a distributed access algorithm that combines the statistic learning method and the dynamic programming technique.	It proposes a distributed access algorithm to solve the problem of the vehicle contends for access to the data service provided by RSUs while this paper, adopting complex network metrics proposes four algorithms to improve the efficiency of nodes choice and the use of V-Cells selection resource in 5G-UDN.

5.3 FiVH - Proposed Approach

This section presents the proposed solution and the approaches used for the handover decision process considering high-speed vehicles in 5G-UDN.

Under the standards defined by the 3GPP, a handover can be triggered by different events. Most of the time, there are thresholds of minimum strength of signal which trigger handover when exceeded. The main events are:

- **Event A1:** triggered when the current cell parameters reach best values than the operator previously established thresholds;

- **Event A2:** triggered when the current cell parameters reach worse values than the operator previously established thresholds;
- **Event A3:** triggered when a neighboring cell becomes better than the current cell by a set o set values. These values can be either positive or negative;
- **Event A4:** triggered when the neighboring cell reaches best values than the operator previously established thresholds;
- **Event A5:** triggered when the current cell becomes worse than the operator previously established thresholds, while the neighboring cell becomes better than the operator previously established thresholds.

Most proposals use event A2 or event A3, which are both used in this work. As already mentioned before, the results have shown that the SoftH architecture did not cause a significant impact on handover times, but compared with the A2-A4-RSRQ algorithm, using the traditional LTE architecture, the mean handover time was very similar, with just 1 ms of difference. In this way, compared to such A2-A4-RSRQ algorithm, the network was always better for SoftH, and the packet loss rate was lower in all scenarios.

The developed procedure is shown in Figure 39 that represents the operating cycle of the handover operation, performed by FiVH: each vehicle is linked to a set of antennas on the Base Stations (BSs) that make up virtually a V-Cell, which by its turn is created and managed by NFV. The virtualization by NFV is necessary for the instantiating V-Cells proposal that receives the SDN controller parameters, which is necessary for previous knowledge of the topology, performing calculations and making decisions according to rules, both for updating the V-Cells and triggering the handover command.

To ensure better QoS for vehicle applications and to enable the best connection, the mobility by Dual Connectivity (DC) is indispensable in the FiVH proposed solution. In it, a vehicle connects itself to 5G and LTE cells, which means that each vehicle has two interfaces and the connection is established through the Packet Data Convergence Protocol (PDCP) (POLESE et al., 2017).

To minimize problems that were arisen from high vehicular speed, there is a selection of better cells forming a V-Cell for the vehicles. In this work, the speed thresholds were defined based on the 3GPP Technical Report (TR) 38.913 which were adequate by cell type (small, medium and big). So, it is assumed small cells (pico-cells) with a coverage radius between 100 to 200 meters, medium cells (micro-cells) between 200 to 500 meters, and big cells (macro-cells) from 500 meters.

Figure 39: Handover procedure of the FiVH

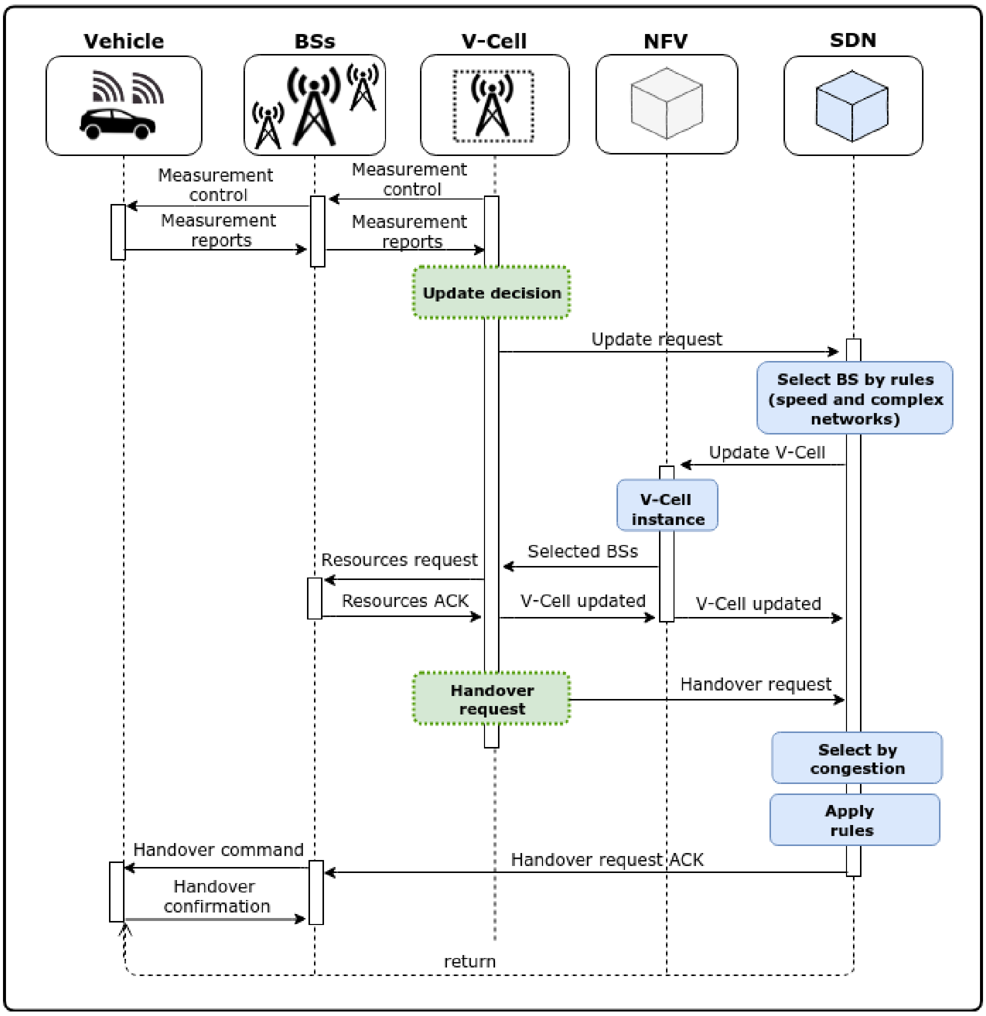


Figure 32 (Chapter 4 - subsection 4.3.1) illustrates the application of V-Cells' instances according to vehicle speeds in a 5G-UDN topology, considering the following sizes for the best case: small cells for speeds among zero and 30 km/h; medium cells for speeds among 31 and 120 km/h; and big cells for extremely high-speeds (among 121 and 500 km/h).

The physical BSs receive the individual measures of the cells and compare them with the RSRQ and RSRP indices of each vehicle connected to them. To the RSRQ, the vehicle is responsible for sending signal measurements to the BSs which are inspected together. This strategy aims primarily to reduce the handovers and frequent disconnects through handovers between BSs of the same virtual cell (intra-V-Cell), still being possible to apply a data stream transmission together and cooperatively to improve the spectral efficiency and the quality of experience. Once the need for the V-Cell update is identified, the main processing is performed on the controller unleashing a handover request between inter-V-Cell.

So, the controller requests V-Cell updating by the application of specific rules about which cells-size best match to the vehicle speed, applying a probabilistic approach that is based on complex network metrics for the BS identification. If potential cells are not identified, the procedure has to return to the initial state; but if potential cells are identified and resources are available, the V-Cell is updated. After updated, the cells are inspected by rules that check congestion, balancing, and whether there is a need for inter-V-Cell handover.

The following subsections present more details about V-Cells operations, congestion and balancing control, medium speed rules and QoS adopted by FiVH.

5.3.1 V-Cells

The adoption of V-Cells (Chapter 4) allows user-centered approaches to be created, once they consist of several transmission points with an association pattern for each user and its expectation of mobility (SAHIN et al., 2018). When a vehicle first registers itself on the network, its connection is assumed to occur primarily in the 4G macro-cell (ZANG et al., 2019). An initial V-Cell is instantiated by associating BSs to each vehicle within its range (up until 300 meters). When the BSs are inspected and the handover algorithms are triggered, the SDN controller processes the information and requests a V-Cell update for a given vehicle following rules for vehicle intervals by speed and cell size ranges.

It is noteworthy that the V-Cell BSs where the vehicle is being serviced are labeled as a current virtual cell (cvc) for further handover inspection. In the worst case, if it is not possible the cell size allocation, it is applied the second or third option following the topological network availability that is previously known by the SDN controller through the control plane. These rules are presented in Table 19 (Chapter 4 - subsection 4.3.1).

Once the available cells have been verified according to the rules presented in Table 19, the selection phase of candidate antennas to the V-Cells update is performed using complex network metrics. The choice of components to calculate the selection probability was based on the vehicle position, on the intermediation degree and centrality of a cell in the network. All possible cells (previously known by the SDN controller) are analyzed, selecting up to three potential candidate cells ($k = 3$), if they are available in the topology.

This probabilistic approach differentiates FiVH from other virtual cell-based solutions. Once the three best BSs or the candidate cells of the vehicle-specific V-Cell are chosen by this calculation, the selection of the cell by congestion is performed in another step by FiVH. Thus, the user-centered procedure occurs by the parameters that select the best virtual cells for each vehicle, which are formed through an algorithm that calculates for each metrics the best value acquired by each cell that is added in a matrix.

After the candidate cells have been selected, the new V-Cell is then instantiated and the chosen BSs are labeled as the neighboring virtual cell (*nvc*) for immediate inspection of the handover. If at least one handover is gone off for the new V-Cell, the *cvc* labels are removed and the new V-Cell becomes the current new cell. As differential presented in this work, this component adopts complex network measures for the network planning, assisting in the following steps regarding the handover process.

5.3.2 Congestion control and balancing

In this subsection, congestion control is performed by a utility theory function, also employed in other work (MOUAWAD; NAJA; TOHME, 2018) that has shown the sigmoid form as the best suitable to model the utility for each selection criterion. Therefore, the utility function considers ascending criteria such as bandwidth and throughput. In this way, the attributes are transformed into utility values after calculating the sigmoid utility function (MOUAWAD; NAJA; TOHME, 2018).

In the SDN controller, the cells (j) that were identified and instantiated in the new V-Cell during the previous step in "J" (possibility set) are considered to select the less crowded cell and/or the balance of each vehicle (v_i) in "V" (set of vehicles present in the scenario) that want to perform the handover process. A "$Uv_{ij}(V \times J)$" matrix is then created by calculating the global utility for the vehicle "v_i" and the "j" cell, which if not available for "v_i", returns "zero" to the source. This procedure occurs according to Equations 5.1.

$$max \sum_{vi} \sum_{j} (Uv_{ij}) \times s_{vij} \tag{5.1}$$

Next, the current load of "j" cell is checked through a "$L(1 \times J)$" matrix represented by "l_j". The "$L_{max}(1 \times J)$" matrix contains the maximum load supported thriugh the "j" cell by "l_{maxj}". Thus, a "$S(V \times J)$" matrix selection is generated to select the least congested cell or to perform cell balancing, applying weights to each "s_{vij}" for a data stream transmission to occur together and cooperatively in a balanced manner by the new V-Cell. This procedure occurs according to Equation 5.2.

$$\sum_{i \in V} s_{ij} + l_j \leq l_{maxj}, \forall j \in J \tag{5.2}$$

These implementations are shown in the Algorithm 3 and Algorithm 4.

Algorithm 3: Global Utility

```
for int vehicles = 0; vehicles < totalVehicles; vehicles++ do
    for int antennas = 0; antennas < 3; antennas++ do
        Input: float result = 1;
        for int k2 = 0; k2 < k; k2 ++ do
            result *= pow(x[k2][antennas],w[vehicles][k2]);
        U[vehicles][antennas] =result;
```

Algorithm 4: Cell balancing

```
Input: float s = 0
Input: float aux = 0
for int i = 0; i < 10; i ++ do
    for int j=0; j < 3; j ++ do
        aux = U[i][j]*1; if aux > s then
            s = aux;
for int i = 0; i < 3; i ++ do
    if 1 + L[v][i] < Lmax[v][i] then
        S[v][i] = 1;
    else
        S[v][i] = 0;
```

As presented, the objective function and the global utility for the vehicle are maximized, ensuring that each vehicle connects itself to one or more "j" cells in a balanced manner, still considering the available resources of each cell.

5.3.3 Average speed and QoS rules

Once the new V-Cell is instantiated, the current BSs (labeled as *cvc* during the upgrade) are immediately and together inspected for the handover execution, comparing with the newly selected and labeled *nvc* cells. In this process, it is important to note other relevant factors during the handover decision process: one of these factors is the medium speed of the vehicle movement. The first performed classification is in relation to speed, sharing vehicles into distinct groups so that each vehicle is classified according to its QCI or its 5QI which defines the transmission quality. So, the vehicles are divided into groups by priority. In this proposal, 5QI values are added under the 3GPP TS 38.300 specification. The QCIs 75 and 79 for V2X messages and the QCI 84 for Intelligent Transport Systems (ITS) are highlighted. The handover rules were defined for each group, by the RSRP and by the RSRQ ranges, which is the signal quality indicator. The intervals are used for decisions about the handover limit from *cvc* to *nvc*.

These rules are presented in Table 24, where for carrier management (logical connection established among vehicle and BS), different QoS classes defined by QCI for 4G networks, and new classes added for 5QI are applied to 5G networks (3GPP, 2019). Carriers can be classified as Guaranteed Bit Rate (GBR) and immune to packet loss (in which the A3 event was applied), or non-Guaranteed Bit Rate (non-GBR) which share the bandwidth limit with other carriers and are susceptible to packet loss (in which the A2 event was applied). In this classification, 35 value ranges were defined through the RSRQ mapping for a 3GPP index table, with poor quality connections being rated from zero to 14; while connections with acceptable levels range rated from 15 to 21; and finally, with great quality connections rated from 22 to 34. For 5QI, RSRP measurements were used, assuming that in the 5G network, the blocking signal and the beamforming misalignment affect the SINR and, consequently, the RSRP.

Table 24: 5G-UDN speed range HO rules

QCI (4G)	**Low speed 0-30 km/h**	**High speed 31-120 km/h**	**Extremely high speeds 121-500 km/h**
1, 2, 3 and 4 (GBR)	RSRQ *cvc* < RSRQ *nvc*	RSRQ *cvc* < RSRQ *nvc*	RSRQ *cvc* < RSRQ *nvc*
5 and 7 (*non*-GBR)	RSRQ *cvc* <= 23 (-8.5 dB)	RSRQ *cvc* <= 24 (-8.0 dB)	RSRQ *cvc* <= 25 (-7.5 dB)
6, 8, 9 (*non*-GBR) and *default*	RSRQ *cvc* <= 22 (-9.0 dB)	RSRQ *cvc* <= 23 (-8.5 dB)	RSRQ *cvc* <= 24 (-8.0 dB)
5QI (5G)	**Low speed 0-30 km/h**	**High speed 31-120 km/h**	**Extremely high speeds 121-500 km/h**
65, 67, 75 and 84 (GBR)	RSRP *cvc* < RSRP *nvc*	RSRP *cvc* < RSRP *nvc*	RSRP *cvc* < RSRP *nvc*
69 and 79 (*non*-GBR)	RSRP *cvc* < 50 (-90 dBm)	RSRP *cvc* < 60 (-80 dBm)	RSRP *cvc* < 70 (-70 dBm)
70 (*non*-GBR) and *default*	RSRP *cvc* < 40 (-100 dBm)	RSRP *cvc* < 50 (-90 dBm)	RSRP *cvc* < 60 (-80 dBm)

The SINR calculation is formulated by the sign among a base station ($gNodeB_1$) and the user equipment (UE_1), with an interfering base station ($gNodeB_2$). “$P_{Tx,ii}$” represents the transmission power of the base station “i”; “PL_{ij}” is the attenuation of the signal between the base station “$_i$” and the “UE_j”; “G” is the gain of the beam formation, and “$BW * N_0$” represents the noise as demonstrated by the Equation 5.3.

$$SINR = \frac{\frac{P_{Tx,11}}{PL_{11}} G_{11}}{\frac{P_{Tx,22}}{PL_{21}} G_{21} + BW * N_0} \tag{5.3}$$

In tests conducted by Samsung, in dense urban settings, poor quality connections are rated among RSRP values from -110 dBm to -101 dBm; but connections with acceptable levels are between -100 dBm and -71 dBm; and finally, great quality connections have values equal to or greater than -70 dBm (BENN, 2018). These values are adjustable by operators as the results of actual network signaling measurements. In the end, it is assumed that the beamforming gains of the transmitter and receiver are zero dBi when the user is connected to the LTE network (ZANG et al., 2019).

If the vehicle is characterized by one of the average speeds, there are six rules to control handover, listed in Table 25.

Table 25: Vehicle characterization

QCI/5QI	**Low speed 0-30 km/h**	**High speed 31-120 km/h**	**Very high speed 121-500 km/h**
QCIs 1, 2, 3 and 4	The bearers classified with the QCIs between 1 and 4 are defined as GBR. In case of these be imputed to the vehicle, the handover always is performed if the RSRQ of the current V-Cell is smaller than the RSRQ of the neighboring V-Cell.	The same rule number 1 defined for the first speed group.	The same rule number 1 defined for the first and second speed group.
QCIs 5 and 7	Bearers classified with QCIs 5 and 7 are defined as non-GBR however they have a delay limit of 100 ms, and they also have less priority than the first group but more priority than the last group of rules. In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 23.	In the case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 24.	In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 25.
QCIs 6, 8, 9 and default	The bearers classified with QCIs 6, 8 and 9 are defined as non-GBR however they have a delay limit of 300 ms, and they also have to be less priority than the first and second groups. The bearers are classified as default, from the moment when a UE connects itself to the base station and is not imputed to any specific carrier. In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 22.	In the case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 23.	In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRQ of the current V-Cell is smaller less than or as big as the index 24.
5QIs 65, 67, 75 and 84	The bearers classified with the 5QIs 65, 67, 75 and 84 are defined as GBR. In case of these be imputed to the vehicle, the handover always is performed if the RSRP of the current V-Cell is smaller than the RSRP of the neighboring V-Cell.	The same rule number 4 defined for the first speed group.	The same rule number 4 defined for the first and second speed group.
5QIs 69 and 79	Bearers classified with 5QIs 69 and 79 are defined as non-GBR however they have a delay limit of 60 ms and 50 ms, respectively, and they also have less priority than the first group but more priority than the last group of rules. In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 50.	In the case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 60.	In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 70.
5QIs 70 and default	The bearers classified with 5QIs 70 are defined as non-GBR however they have a delay limit of 200 ms, and they also have to be less priority than the first and second groups. The bearers are classified as default, from the moment when a vehicle connects itself to the base station and is not imputed to any specific carrier. In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 40.	In the case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 50.	In case of these bearers be imputed to the vehicle, the handover is triggered when the RSRP of the current V-Cell is smaller less than the index 60.

Vehicles and UEs can travel in high-speeds, or not. 1st) when they do not travel at high speeds, they tend not to change their measurement of RSRQ or RSRP suddenly. In this way, they can stay connected in their cells until reach minimum levels that still represent connections in good-quality. 2nd) when they travel in high-speeds, they tend to change their RSRQ or RSRP suddenly, causing faulty handovers. In this way, it is important to define boundary values with a higher level of security than in low-speed scenarios. The FiVH controls the threshold activated by the solution to manage the handover, implemented by the SDN controller. The handover evaluation algorithms provide the necessary information to the SDN controller. They decide when to trigger ther handover in an instantiated virtual cell after checking the rules created.

5.4 Evaluation methodology

The proposed FiVH approach was evaluated through the ns-3 network discrete event simulator. In this work, the Cellular Network Simulator (ns3-mmWave) module, which allows the addition of 5G and LTE communication interfaces simultaneously, and the OpenFlow 1.3 module for ns-3 (OFSwitch13) module are used. OFSwitch13 allows the inclusion of an SDN controller in the scenarios. The traffic model was created through the Simulation of Urban Mobility (SUMO).

The evaluated parameters were: the structures of the scenarios, the speeds, the positioning, the average spacing, and the density. In addition to these, the number and power of the 5G Next Generation Base Transceiver Stations (gNodeB) were also evaluated, as well as the number and power of the Evolved Node Base (eNodeB). The scenarios were evaluated with a confidence interval of 95% for 10 simulation trials, as shown in Table 26, based on the literature (ZANG et al., 2019). The scenarios of urban roads and freeways are presented in Figure 33 (Chapter 4 - section 4.4), according to document 3GPP R1-164679.

Table 26: Scenarios

Parameters	**Scenario I** **Urban road**	**Scenario II** **Freeway**
Structure	9 road grids (250 m x 433 m each) and 2 lanes of 3.5 m each one on each side	6 lanes of 4 m each, 3 in each direction, with 2 km length
Speeds	15, 30 and 60 km/h	70, 140 and 300 km/h
Positioning	Poisson process	Poisson Process
Average spacing	2.5 seconds (s)	2.5 s
Density	20, 60, 120 and 240 vehicles/km^2	5, 10 and 20 vehicles/km/lane
Number of gNodeB's	20 (dense scenario)	5 (sparse scenario)
Power (gNodeB)	30 dBm	30 dBm
Number of eNodeB's	1	2
Power (eNodeB)	46 dBm	46 dBm

Scenario I, presented in Figure 33(a), consists of an urban area with 9 road grids (250 m x 433 m) and 2 lanes on each side with 3.5 m each. The vehicles move clockwise to make possible the conversions in each quadrant. Distinct speeds were adopted (15, 30 and 60 km/h) to make possible the cell classification by the handover rules for low-speed and high-speed ranges, using the FiVH solution. Vehicle densities for urban roads were defined and classified as light traffic (20 vehicles/km^2), heavy traffic (60 vehicles/km^2), congested traffic (120 vehicles/km^2), and highly congested traffic (240 vehicles/km^2) (SILVA et al., 2019). In scenario I, 20 physical BSs are positioned in 1 macro-cell so that 4 micro-cells make the center of the grid and 16 pico-cells are located at each corner of the grid (ZANG et al., 2019).

Scenario II, shown in Figure 33(b), consists of a 6 lanes freeway with 2 km length. The vehicles move in opposite directions, what is from top to bottom in the first 3 lanes, and from the bottom to the top in the other 3 lanes. Distinct speeds were adopted (70, 140 and 300 km/h) to make possible the cell classification by the handover rules for high-speed and very high-speed ranges, using the FiVH solution to support the communication on high-speed mobility. The considered densities for the freeway scenarios were 5, 10 and 20 vehicles/km/lane (VUKADINOVIC et al., 2018), which support 60, 120 and 240 vehicles. In scenario II, the physical BSs are randomly distributed, as the vehicles are randomly positioned (SAHIN et al., 2018; ZANG et al., 2019).

The 5G architecture was based on previous studies (STORCK; DUARTE-FIGUEIREDO, 2019). The 3GPP mmWave channel model was used to make the initial connection from the active vehicle to gNodeB, using mmWave communications and considering the parameters of frequency, bandwidth, number of sub-bands, listed channel conditions and fading. The simulations were performed in a high-performance computational environment provided by CEFET-MG F37 cluster. The adopted simulation parameters are presented in Table 21 (Chapter 4 - subsection 4.4).

The metrics that were evaluated during the simulations and their respective definitions are listed below:

- **Packet Loss Ratio (PLR)**: a metric that is characterized by the loss rate packet during transmission, that is, those packets that were not successfully transmitted. As shown in Equation 5.4, the percentage of PLR is calculated by the ratio among the number of successfully delivered packets (P_D) and the total number of transmitted packets (P_T).

$$PLR = 1 - \frac{P_D}{P_T} \tag{5.4}$$

- **Average time of handovers**: a metric that is related to the handover execution times. As shown in Equation 5.5, the average handovers runtimes for a scenario is calculated by the ratio among the handover runtimes summation (TH_i) and the total number of executed handovers (H_T).

$$Handovers\ average\ time = \frac{\sum_{i=1}^{N} TH_i}{H_T} \tag{5.5}$$

- **Failed handovers**: a handover may be considered as failed when the UE runs the transition among cells, and the RSRQ or RSRP index of the original cell and of the destination one is smaller than the advisable value for a good connection; or when it occurs prematurely, that is, in a short time, it performs again another handover. As shown in Equation 5.6, the percentage of failed handovers is calculated by the ratio among the number of successful handovers (H_S) and the total number of executed handovers (H_T).

$$Failed\ handovers = 1 - \frac{H_S}{H_T} \tag{5.6}$$

- **Unnecessary handovers**: metric that is also known as ping-pong rate, is characterized when a UE performs an handover, and in a short time it performs again an handover for the original cell. Considering the Equation 5.7, the percentage of unnecessary handovers can be calculated by the ratio among the number of required HOs (H_R) and the total number of executed HOs (H_T).

$$Unnecessary\ handovers = 1 - \frac{H_R}{H_T} \tag{5.7}$$

The analysis results obtained in the experiments are presented in the following section.

5.5 Results and discussion

From the results, obtained with a confidence interval of 95%, the HO by the user was 7.8, and the packet loss rate was 2.94%. The average time to perform the presented HO was 1.9590 ms, and excellent rates of failed HOs and unnecessary HOs were obtained by FiVH, of 2.884% and 3.550%, respectively. Table 27 presents the results that were obtained in the simulations of the two scenarios.

Table 27: Results obtained

Scenario I	**PLR (%)**	**HO average time (ms)**	**Failed HOs (%)**	**Unnecessary HOs (%)**
20 veh/km^2	2.687 ± 0.377	1.8665 ± 0.2277	2.777 ± 1.071	2.868 ± 0.857
60 veh/km^2	2.873 ± 0.641	1.9511 ± 0.2090	2.571 ± 1.292	3.375 ± 0.701
120 veh/km^2	3.207 ± 0.623	1.8440 ± 0.2289	3.428 ± 1.589	3.857 ± 0.638
240 veh/km^2	3.252 ± 0.477	2.1939 ± 0.1532	3.444 ± 1.337	3.791 ± 0.153
Scenario II	**PLR (%)**	**HO average time (ms)**	**Failed HOs (%)**	**Unnecessary HOs (%)**
5 veh/km/lane	2.722 ± 0.416	1.9833 ± 0.2536	2.175 ± 1.289	3.178 ± 0.895
10 veh/km/lane	2.786 ± 0.433	1.8235 ± 0.4601	2.475 ± 1.587	3.608 ± 0.535
20 veh/km/lane	3.045 ± 0.436	2.0507 ± 0.3022	3.318 ± 1.264	4.174 ± 0.405
	2.938 %	**1.9590 ms**	**2.884 %**	**3.550 %**

Table 28 presents the results obtained in the simulations of scenario I with highly congested traffic (240 vehicles/km^2) divided by average vehicle speed ranges, that is, 15, 30 and 60 km/h.

Table 28: Results obtained in scenario I (240 vehicles/km^2)

Speeds	**PLR (%)**	**HO average time (ms)**	**Failed HOs (%)**	**Unnecessary HOs (%)**
15 km/h	2.908	2.4106	3.059	3.567
30 km/h	3.119	2.0597	3.311	3.689
60 km/h	3.729	2.1114	3.962	4.117
	3.252 %	**2.1939 ms**	**3.444 %**	**3.791 %**

Table 29 presents the results obtained in the simulations of scenario II with 20 vehicles/km/lane divided by average vehicle speed ranges, that is, 70, 140 and 300 km/h.

Table 29: Results obtained in scenario II (20 vehicles/km/lane)

Speeds	**PLR (%)**	**HO average time (ms)**	**Failed HOs (%)**	**Unnecessary HOs (%)**
70 km/h	2.646	2.2216	2.952	3.898
140 km/h	3.012	1.9812	3.193	4.054
300 km/h	3.477	1.9493	3.809	4.571
	3.045 %	**2.0507 ms**	**3.318 %**	**4.174 %**

As expected, in the two evaluated scenarios, as the speeds increase, the metrics evaluated for PLR, failed HOs and unnecessary HOs also increase, being higher in the scenario I due to their greater density. However, the average time obtained for the execution of the HO was shorter at very high speeds in both scenarios, thanks to the handover rules created by the speed and size ranges of the cells managed by the SDN controller, which proves the efficiency of the solution. It is also observed that in scenario II there were more unnecessary HOs (ping-pong effect) than in scenario I, justified by the smaller number of cells available in the evaluated structure.

Table 30 depicts the first fifteen handovers that occurred during the simulation of the scenario I in congested traffic which means that are 120 vehicles/km^2 under the International Mobile Subscriber Identity (IMSI). The ping-pong effect and failed handovers have occurred when the interval between two handovers is smaller than 1 second which is applied to cellular networks according to 3GPP TR 36.839; however, it is easily adjustable to another value. The average HO runtime is 1.7416 ms and two events that characterize the handovers as unnecessary or failed were recorded in the first fifteen occurrences.

Table 30: Handover events occurred

Vehicle (IMSI) [1]	**Source (V-Cell)**	**Target (V-Cell)**	**Runtime (ms)**	**Interval between two handovers (ms)**	**Occurred event**
84	84	101	1.4083	-	-
71	71	102	1.4083	-	-
84	101	103	2.9083	2375.7	-
63	63	104	1.4083	-	-
84	103	101	1.9083	1235.8	Ping-pong effect
8	8	105	1.4083	-	-
71	102	106	1.4083	4406.4	-
79	79	107	1.4083	-	-
63	104	108	1.4083	2742.4	-
88	88	109	2.9083	-	-
17	17	110	2.9083	-	-
8	105	111	1.4083	-	-
25	25	112	1.4083	-	-
17	110	113	1.4083	475.3	Failed handover
25	112	114	1.4083	-	-
			1,7416		**2 events**

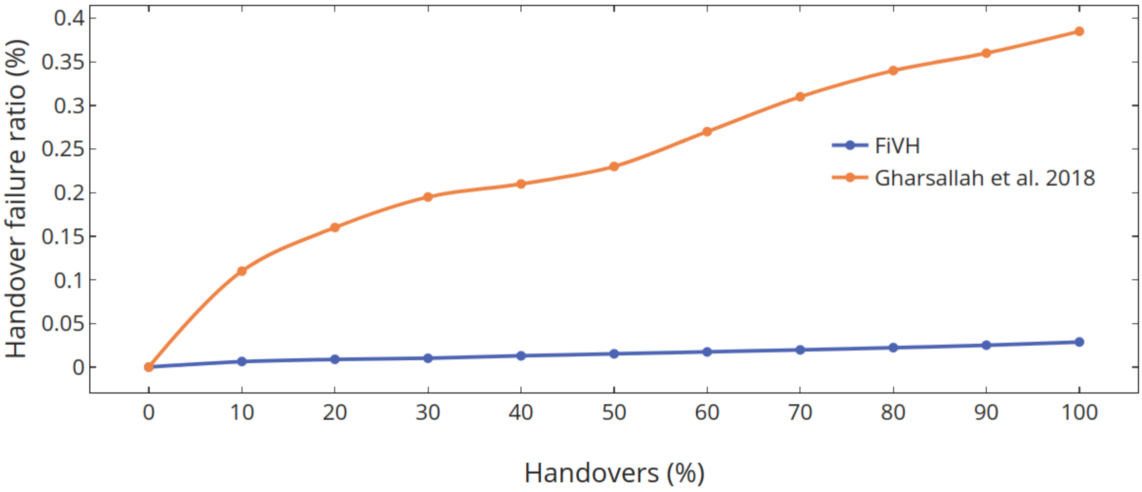
[1] *International Mobile Subscriber Identity*

For validation ends, the FiVH proposal was evaluated and compared with the scenarios presented in the literature (POLESE et al., 2017; RIZVI; AKRAM, 2018; PRADOS-GARZON et al., 2016; GHARSALLAH; ZARAI; NEJI, 2018). The work of Polese et al. (POLESE et al., 2017) has presented an average number of HO events between 21 and 43, and packet loss between 7% and 15%, in a single user scenario, considering an area of 200 x 115 m. Under the same conditions, FiVH has had 3.8 as the average number of HO events, and packet loss of 1.89%. Considering also the general results obtained by scenarios I and II, FiVH presents a significant reduction between 63 to 82%, in the number of handovers performed per user due to the V-Cells use that is composed by the three best user-centered BSs, in addition to low packet loss, which represents a considerable gain in the successful delivery of packages.

Comparing the results under the same conditions as the work of Rizvi and Akram (RIZVI; AKRAM, 2018), in which the handover time is 13.24 ms in a unique user scenario, FiVH presents an overall average total handover execution time of 1, 4083 ms. When considering the general average of the total handover execution time of 1.9590 ms obtained in scenarios I and II, there was the gain equivalent to 85.20%. Comparing, still, with the analyzes of Prados-Garzon et al. (PRADOS-GARZON et al., 2016), in which the handover execution time was 15.25 ms, in a scenario with an area of 500 x 500 meters, containing 20 base stations and 100 users moving at 21.6 km/h (6 m/s), FiVH has a total handover execution time of 1.8233 ms. When considering the general result, obtained by FiVH of 1.9638 ms in the urban road environment in the scenario I, there was an optimization equivalent to 87.12%.

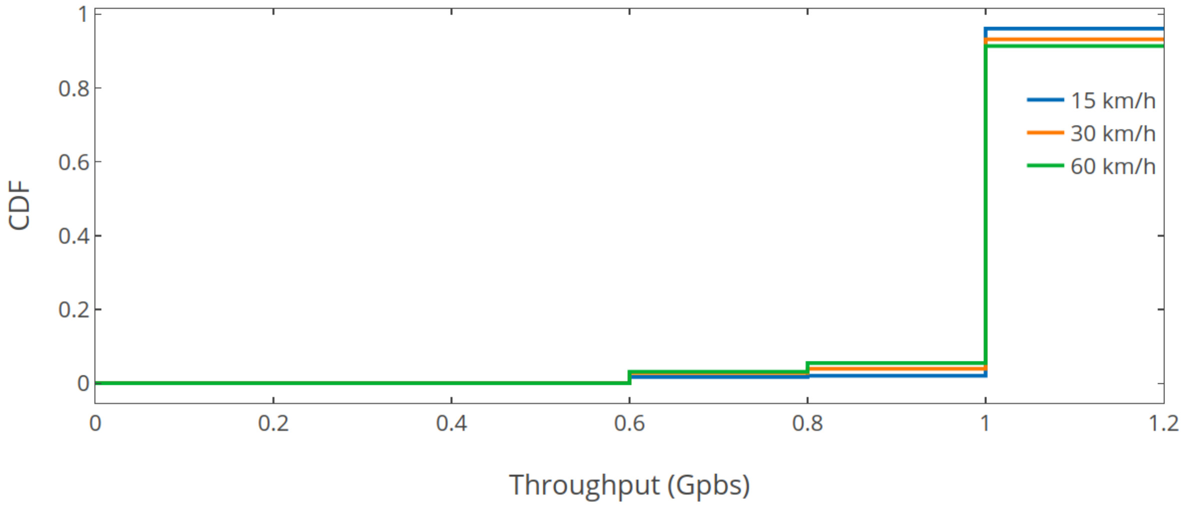
According to the work of Gharsallah et al. (GHARSALLAH; ZARAI; NEJI, 2018), the average handover delay is close to 200 ms (in 4G), and the rate of failed handovers is higher when compared to FiVH, as shown in Figure 40, which represents the percentage of failed HOs by the percentage of HOs performed over time.

Figure 40: Handover failure ratio



Regarding overload and processing time, the results have shown that the impact of the SDN controller on the solution was irrelevant but it has achieved good results in relation to the flow and the average handover execution time, as observed in the SoftH mechanism (OLIVEIRA; STORCK; DUARTE-FIGUEIREDO, 2019). Generally, signaling overload has a significant impact on the flow rate, which did not occur as shown in Figure 41 and Figure 42. Figure 41 is a graphic that shows the Cumulative Distribution Function (CDF) of the throughput for the scenario I with speeds in highly congested traffic (240 vehicles/km^2).

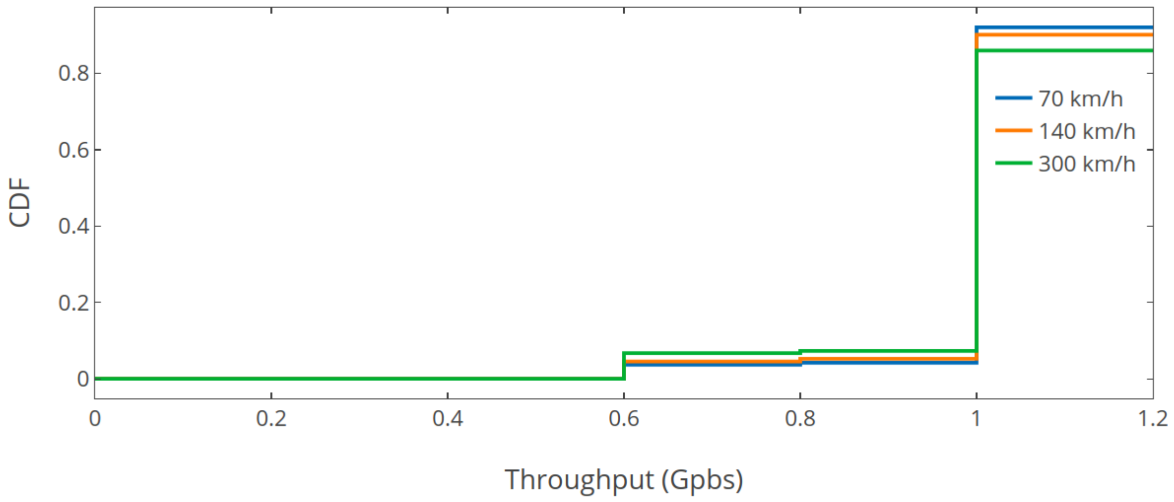
Figure 41: CDF of the throughput for scenario I (240 vehicles/km^2)



Source: from author.

Figure 42 is a graph showing scenario II, evaluated with 20 vehicles/km/lane. Considering the two scenarios, the vehicles that move at low-speeds (15 and 30 km/h) reach a throughput next to 96.18% and 93.23% above 1 Gbps, respectively. Those which move at high-speeds (60 and 70 km/h) get throughput next to 91.44% and 92.07% above 1 Gbps on throughput, respectively. And finally, those vehicles that move at very high-speeds (140 and 300 km/h) have throughput of 90.13% and 85.94%, respectively.

Figure 42: CDF of the throughput for scenario II (20 vehicles/km/lane)



Finally, the combination of SDN with V-Cells has provided a reduction on the network signaling, since no X2 interface is necessary for intra-V-Cell handovers. The congestion and balance control adopted ensured and contributed to the distribution of the network load. With decisions centralized in the controller, messages are reduced by the fact that the SDN controller is responsible for decisions about the source and destination V-Cells, making FiVH more and more effective than the other proposals. All operations, referring to a 5G network (PRADOS-GARZON et al., 2016), had a processing time of less than 15 ms; thus, it was concluded that the latency requirements of the control plan in 5G networks, around 15 ms, are fully satisfied by FiVH. In addition, the number of frequent handovers, which were mainly caused by network density and high vehicle mobility, was reduced by FiVH and has contributed to the results achieved.

5.6 Final remarks

This chapter presented FiVH as a solution for the handover decision-making for vehicles connected to ultra-dense 5G networks. To minimize the handover problems that are caused by a high vehicular mobility, FiVH uses the optimum way to select the cells to make up V-Cell that are dynamically updated, which provides faster and more efficient handovers. In the formation of the V-Cells, FiVH selects cells by the quality that is specified by 3GPP and by complex network metrics. The used multicriteria differentiate FiVH from the solutions proposed in the literature and provide performance gains in the handover, decrease in the handover time, decrease in the number of unnecessary (ping-pong effect), decrease in the number of failured handovers, and also decrease of lost packets. In order to deal with high mobility of the vehicles and provide performance gains in the handover, the SDN controller allows a set of information to be processed more wisely, with a single view of the network.

As future works, can be cited other techniques analysis, including heuristic approaches, simulation of different scenarios, and new elements integration. Also, it is important the investigation about the latency, the complexity, and the spectral efficiency in order to evaluate QoS solutions in agreement with DSRC and IEEE standards. Another interesting aspect that deserves to be investigated is the impact of the dynamic cluster capacity of parallel handover.

In the following chapter, 5G network technology structure model is described as a facilitator that can provide new services to several segments in smart cities. It also incorporates SDN and virtualized controllers to support new services in smart cities.

6 LOCATION-BASED SERVICES: A 5G NEW SMART CITY SERVICES FACILITATOR MODEL

Smart cities are gaining, increasingly, notoriety and, through them, the population can have better services and urban quality of life. Applications in smart cities include citizens and pervasive devices interactions. They require continuous monitoring to provide collaborative support and to raise environmental awareness. With the 5G networks, it will be possible to collect data from various sources throughout the city, such as sensors and actuators, vehicles, mobile devices, mobile and telephone networks, among others. In this scenario, it will be necessary to analyze large volumes of data, in order to get knowledge and useful information for a dynamic and clever mobility planning.

This chapter describes a 5G network technology structure model as a facilitator that can provide new services to several segments in smart cities. In order to implement the expected goals from the 5G ecosystem, this model incorporates SDN and virtualized controllers to support new services through the service modules. In this way, a service module model named Urban Computing Framework in 5G Networks (CoUrbF5G) is presented and applied. To first validate the module, real standards of a mobile network were found and analyzed in the proposal by applying data mining techniques along with ancillary methods in the conducting of Data Science processes, such as Knowledge Discovery in Databases (KDD) and Big Data. Next, the evaluation of the model was conducted through emulations on Mininet and POX controllers adopting CoUrbF5G as a system service module. The results were analyzed using the Gephi tool, and they have demonstrated that the proposed model is applicable to support and provide new services such as intelligent transportation, road monitoring, energy consumption, public safety, among others, in smart cities. Any of these services will be able to get information from their users and from the network through our model, once an important issue in smart city is the challenge to collect or deliver useful and processed data to stakeholders.

Section 6.1 presents the IoT 5G networks scope that will integrate people, things and vehicles in several environments. Its relevance was demonstrated by a global financial information and service company that has conducted a study about the global economic impact, concluding that in around fifteen years 5G will produce several benefits to the world's population and will be a new network infrastructure to service provision. Section 6.2 describes the related works. It has the main smart cities concepts. The new domains require integration and coordination among several monitoring departments to deal with different issues such as sustainable development. In section 6.3, it is presented the proposed approach with a 5G model as a new service facilitator in smart cities. Among the basic ecosystem capabilities, it is the context-aware one. With this 5G approach, smart cities are expected to have several sensors installed around that are going to be associated to the logical SDN structure that include applications, priority communications and an infrastructure layer.

In section 6.4, it is described an urban computing framework for 5G Networks based on cognitive wireless. It is going to perform an adequate urban planning, checking patterns or predictions of future city demands to make the mobility easier and safer, since the communications can be continuous and fast. This section also presents the evaluation methodology that is going to employ big data analytics and/or data mining developed on a method able to aid in the conduction and integration of human perception in the KDD process. The results discussion is also in this section based on grouping steps of outlier and data cluster analysis. In section 6.5 it is presented an example of a service module, created through Mininet, and applied to evaluate the proposed approach for a 5G model as new services facilitator. The test has used the big data analytics process to deliver services to the environment. The observation module checked the context-aware behavior based on the results. This section includes the emulation methodology that used the CoUrbF5G service module to illustrate the performed tests by the POX controller and the Mininet emulator that are virtual networks. The section 6.5 includes the results discussion to explain how the model passes information to the smart cities services.

6.1 Goal and scope

The 5G networks will integrate IoT, people and vehicles in several environments. Its relevance was demonstrated by the Information Handling Services of Markit (IHS Markit), a global financial information and service company that has conducted a study about the global economic impact (IHS, 2017). The conclusion was that in 2035 5G will produce USD 12.3 trillion (United States dollars) in goods and services, with USD 3.5 trillion in the value chain, and 22 millions of jobs. It shows that 5G mobile technology will produce benefits to the world's population and will be a new network infrastructure to service provision.

In this direction, 5G can support the smart cities that overcome challenges associated with increasing worldwide urbanization rates. Many companies are working on the smart cities' ecosystems to create technologies and employment opportunities, such as International Business Machines Corporation (IBM), Intel Corporation, General Electric Company (GE), and other ones. They have projects to integrate their products and services into smart cities frameworks (TANG et al., 2015). It is clear that smart cities integration with the 5G networks is unavoidable. This fact will connect billions of devices and sensors, allowing their dynamic reaction in the applications' context. In such a scenario, the data are collected by several sources spread throughout the cities, as sensors for temperature, humidity, energy, presence, vehicle and telephone networks, among others. New services and applications will emerge in different areas through the cyber-physical systems by the 5G network.

The creation of a 5G model as new services facilitator to smart cities is the main idea of this chapter. Integrated environments will have connections among people and IoT to offer better controlled urban services everywhere and every time. So, this 5G model proposal includes service modules, SDN, NFV, MEC, fog and big data concepts. Through emulations, we have show that it can be used in the smart city and 5G contexts.

6.2 Related work

This section describes the related works that address the main smart cities concepts: information and communication technology, IoT, integration, continuous monitoring, cloud, fog computing, big data, MEC, cloudlet servers, and services.

Smart cities are still seen as futuristic places because there are several challenges on the urban infrastructure building about resource management, cooperative mobility management, and increasing of the next generation ICT use which requires a wide range of domains such as: cloud and mobile edge computing, sensing and actuation, low power communication, mobile crowd sensing and big data analysis (DATTA et al., 2016). In (KHAN; KIANI, 2012), the authors say that those challenges require thematic data crossing and harmonization. They also suggest that will be necessary the integration and the coordination among several departments to monitore future smart cities. Besides it, each one of these smart cities must deal with different issues to get sustainable development and, by the ICT availability and advancement, the citizens' participation will add value to the governance initiative in them.

In that work, the cloud applications in smart cities include citizens and pervasive devices interaction through IoT, what requires continuous monitoring to 1st, provide collaborative support based on the evidence for urban planning policy decisions; 2nd, raise environmental awareness based on the daily citizens' information to eventually propose behavioral changes in their lifestyle. Also, the interconnected devices make easier the environmental data gathering to help on the solution of the challenges. But for that, enough computing data storage resources and real-time processing are required; because a city is a single unit that deals collectively with challenges related with the environment, socio-economy, public services, security, health and well-being, education, and others (KHAN; KIANI, 2012).

Perera et al. (PERERA et al., 2017) explained that IoT intends to connect all devices through the Internet to support the smart cities viability, as the large amount of data that they generate must be sent to the cloud for further knowledge processing. The fog computing pushes the data analyses to the edges even their devices having limited computational capabilities. But both cloud computing or fog computing not overcome their challenges alone, that´s the reason why they need to work together to build a sustainable IoT infrastructure for smart cities.

In the work developed in (TANG et al., 2015), the authors present a fog computing architecture for big data analysis in smart cities. Nowadays, in several enterprises, the cloud computing is used to address the big data analysis by its scalable and distributed data management scheme, but data centers in the cloud got an over expected amount of big data that has asked for additional requirements of location awareness and low latency at the network edge. For this reason, the fog appears with latency-sensitive applications at the network edge, and also with latency-tolerant tasks at powerful computing nodes on networks intermediation, what means that above the fog, cloud computing still can be used for deep data analysis; since the computing nodes provide a faster control to ensure the critical infrastructure components safety. Hu et al. (HU et al., 2015) completed affirming that some network edge applications include business transformation, technology integration and industry collaboration and, all of these can be enabled by MEC and a wide variety of use cases can be supported for new and innovative markets, such as e-Health, connected vehicles, industry automation, augmented reality, gaming and IoT services.

That is the reason why, in (RAHMAN et al., 2018), a fog-cloud hybrid architecture was proposed to support context-aware of smart city services like finding a lost person, location-aware notifications about events of interest, and helping to deal with emergencies.

The work developed by Enayet et al. (ENAYET et al., 2018), explained that the smart city conception involves the integration of healthcare, transportation, communication, and other services to improve urban citizens' quality of life. But most services have become a great volume data-driven that require real-time access, sharing, storing, processing and analysis at anywhere in any time to support intelligent decisions. The mobile cloud computing is what allows the devices to access and offload big data from powerful cloudlet servers that ensure the end users QoS demands. Cloudlet is a data center in a small scale or a computer cluster designed to provide cloud computing services as quick as possible to mobile devices. The problem is that the mobile devices connectivity is sporadic with varying signal strengths and, the cloudlet resources heterogeneity is a great challenge to the community takes the better decision about which execution code must be used.

For this integration, in (LEE; LEE; RHEE, 2013), smart ubiquitous networks have been developed by International Telecommunication Union (ITU) with frameworks like telecommunication infrastructures to smart and ubiquitous environments which need operational processes to support context-aware networking. Vilalta et al. (VILALTA et al., 2017) proposed the TelcoFog architecture, validated through a proof of concept for IoT services. It is a fog computing infrastructure that is new, secure, highly distributed, and ultradense. It is able to support wired/wireless network extreme edge to allow a telecommunication operator to provide new 5G services, such as NFV, MEC, and for third parties like smart cities, vertical industries and IoT. In this way, it is expected the distributed and programmable fog technologies strengthen the mobile network and cloud markets position by its integrating capability in network ecosystems. Its dynamic new low-latency services deployment ask for an architecture that consists of three main building blocks: a scalable specific node which is integrated in the telecom infrastructure; a controller which is focused on service assurance and integrated in the management and orchestration architecture of the telecom operator; and services which are able to run on the telecom infrastructure.

The work of Rao and Prasad (RAO; PRASAD, 2016), lighted out that the services shall be available on multiple portable devices and its interactions and interfaces may include all kinds of user recognition. With it is expected that mobile communication will be always available for smart socio-economic well-being, which requires since nowadays the delivery of faster connectivity anytime and anywhere. As the demand for data, new services and network performances continues to increase, operators must evolve their existing infrastructures to support full digitalization and meet current and upcoming market trends.

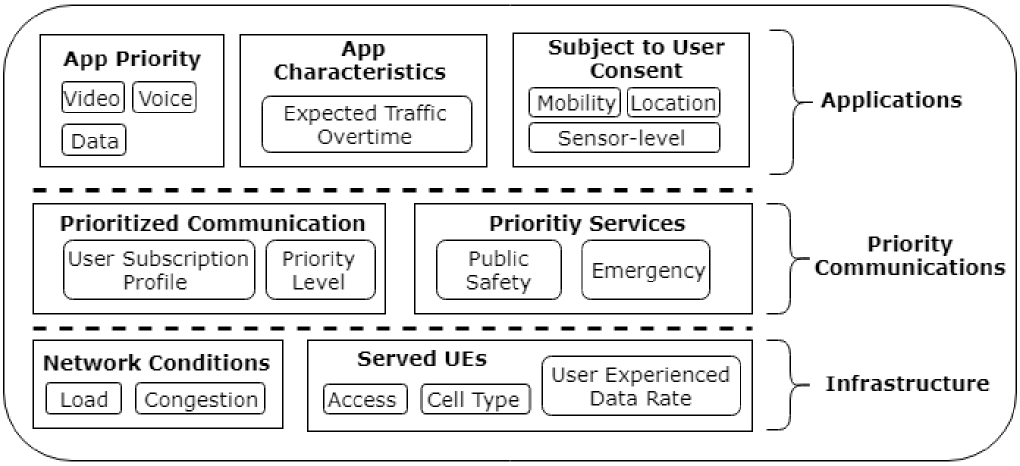
In summary, the increasing ICT use in 5G requires domains such as cloud and mobile edge computing. The new domains require integration and coordination among several departments of monitoring to deal with different issues such as sustainable development. Citizens ubiquotous and pervasive devices interaction through IoT will be the solution to the environment challenges such as security, public services, and others.

6.3 Proposed approach

To propose a 5G model as a new services facilitator in smart cities, among the basic capabilities expected from the 5G ecosystem, it is a context-aware network. Smart cities will have several sensors installed around them but, in addition, smart phones themselves may contain built-in sensors such as accelerometer, gyroscope, magnetometer, barometer, proximity sensor, and global positioning system, providing useful information as long as it is authorized by the user in accordance with protection rules of each country. The information collected, according to the time scale configured by each operator will, then, be provided and processed by applications in the UE or in the 5G ecosystem, depending on the application's context.

As shown in Figure 43, based on TS 22.261, the context requirements are classifed into three layers following the logical SDN structure: applications, priority communications and infrastructure. Contexts such as prioritization of certain applications and the collection of smartphone data with user consent are at the application layer. The priority communications layer has contexts of emergency services, security, priority level or type of user signature. The infrastructure layer has contexts such as network conditions and customer service at the operational level. All of these contexts are just examples that can be addressed by the proposed model. Other contexts can be elaborated. For example, contexts that involve metrics of complex networks with the similarity of interest and social bonds as trust between users, vehicles or any other object in the network.

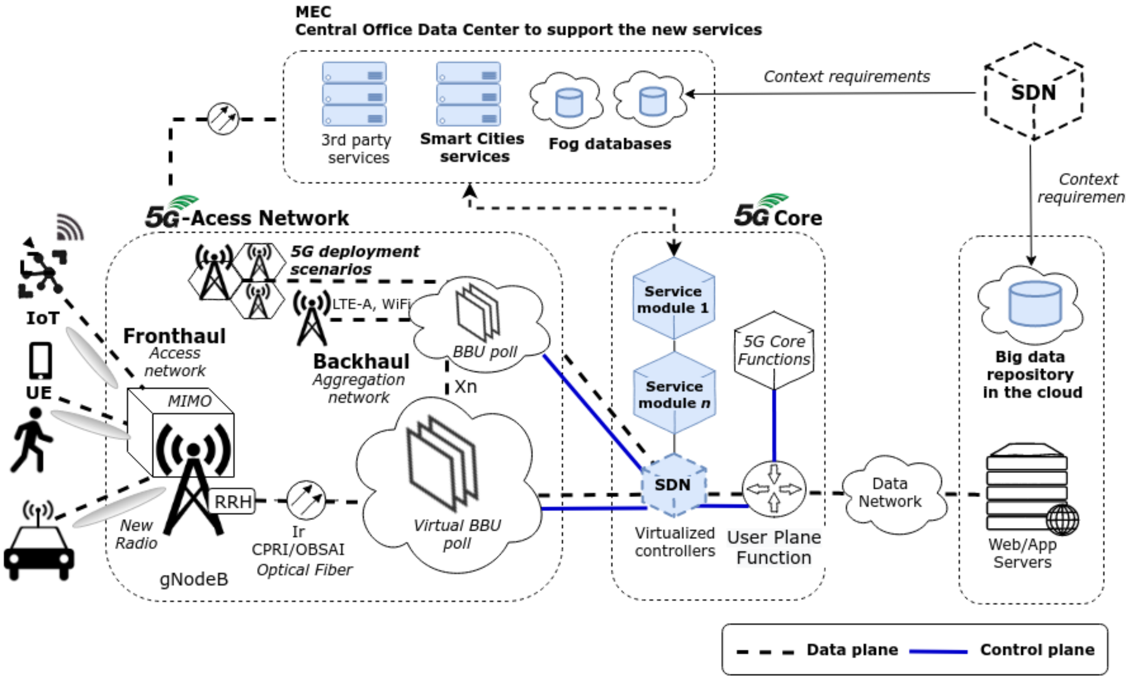
Figure 43: Context requirements



A 5G network is more than a connectivity infrastructure collection, but a programmable platform able to make available new applications based on collaboration among several systems. The set of resources model and functionalities to develop the 5G network is provided through the reference architectures found in the 3GPP Release 15 and TS 23.501. Important trends and key technological enablers for the 5G architecture realization were developed by the 5G Infrastructure Public Private Partnership initiative of a working group, which has harmonized the architectural concepts developed in various projects and has also provided a consolidated view over the technical architecture design directions the 5G era.

The use of SDN supports new services on the fog and smart cities environments. In order to implement the expected objectives from the 5G ecosystem, a model in which SDN elements and the virtualized controllers are incorporated and specific servers can be enabled in the central data center office to support the new services is shown in Figure 44.

Figure 44: 5G model proposal



A general 5G cellular network architecture was presented by Gupta and Jha (GUPTA; JHA, 2015). Its core network is the support for the servers and to the Internet. The authors introduced the concepts about interconnectivity among different technologies making the connection between the MIMO antennas and the NFV cloud. In our model, the SDN controller allows the separation of the control plane from the data plane that is critical in a network whose dominant traffic will be the online things, often device-to-device. In addition, data science processes, such as knowledge discovery in databases and big data, will allow adjustments in the quality of service, performance, and capacity planning. SDN offers the prospect of the network as a programmable resource configured on-demand because it has the power to change how services will be delivered in the future, bringing new revenue, streamline network maintenance, and automate creation. Such as SDN and NFV, network slicing is a form of virtual network architecture that allows a network operator to provide dedicated virtual networks with specific functionality to the service or customer over a common network infrastructure, what means that it will be able to support the numerous and varied services envisaged in 5G.

In this direction, the model architecture adopts the SDN Mobile Control (SDMC) concept by focusing on wireless-specific functions. It splits wireless functionality into

SDN functions that are being controlled and remain relatively stable, and the overall network control functions are executed at the controller. As the SDMC concept is not limited to data plane functions but includes control plane functions of the mobile network, so it can be placed arbitrarily in the edge cloud or the central cloud, where the wireless functionality is controlled. If it is associated with the 3GPP network management system, it can take advantage of the legacy performance monitoring, forming a logical global Radio Access Network (RAN) information base that can be used to control various network functions. The control of wireless networks comprises, among others, channel selection, scheduling, modulation and coding scheme selection, and power control. The name of it is inter-slice resource control, in which following the network slice concept, infrastructure domain-hosted SDMC allows the infrastructure provider to assign unutilized resources to support third-party services (ROST et al., 2016).

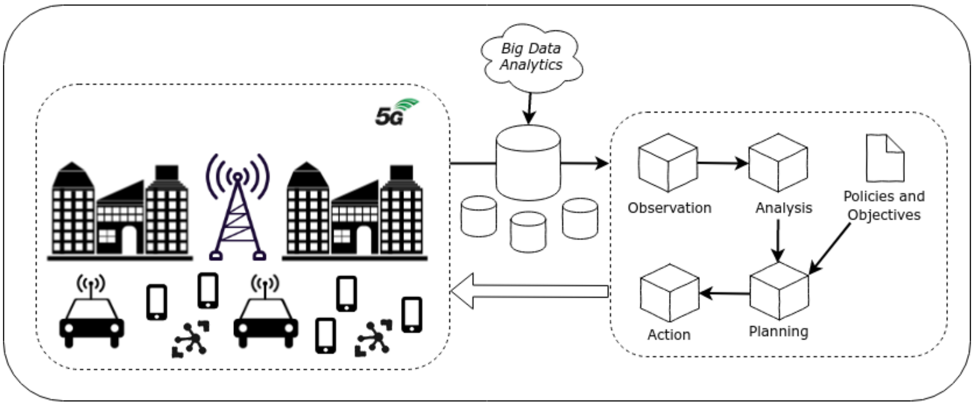
Industry and academia got an important agreement that future 5G mobile networks adopt the NFV and SDN principles. In this way the 5G network architecture specified by the Novel Radio Multiservice Adaptative (NORMA) project has already been flexibly allocated on an infrastructure of interconnected central and distributed clouds, facilitating the setup of various network slices that can be optimized for the specific services they support. A specific virtual network associated with NFV and the required infrastructure resources to run them is called a “network slice”. However, some network infrastructure may comprise types of equipment often used by “multiple slices”that do not support virtualization so, the Physical Network Function (PNF) is characterized by a tight coupling of functionality and underlying hardware, and it is the base station equipment that provides the physical radio layer functions to PNF. The types of equipment that support virtualization are called “common parts” but such technology is still far from the maturity level where they would be suitable to allow NFV. So the better decision is the creation of specific network slices within its infrastructure that can rely on common (not slice-specific) NFV and on common PNF equipment to provide the best (complete) mobile connectivity service (SCHNEIDER; MANNWEILER; KERBOEUF, 2018).

Anyway, from a commercial standpoint, there is a hole in the automation of external processes that make the third party access to mobile networks be clunky and expensive, making external deployment impossible. To offer an alternative process for third-party deploying to networks, the innovation cannot be focused only on the internal processes automation. The supplying services demand shift in both technical and ecosystem dynamics which requires a new platform to orchestrate the communication next generation that can be deployed anywhere to anything, unifying edge resources into an abstraction layer to simplify its deployment.

6.4 Urban Computing Framework in 5G Networks (CoUrbF5G)

In this section, CoUrbF5G is the proposed framework based on Cognitive Wireless Network (CWN) for 5G networks, presented by Figure 45. With the 5G network data collected, through various sources scattered around the city and stored in data centers, the framework has the input to an urban computing-oriented data mining. It is useful to an adequate urban planning, and to check patterns or predictions of future city demands. For example, many people attending a particular event, such as concerts or stadium games, will demand a better network provision.

Figure 45: CoUrbF5G module representation

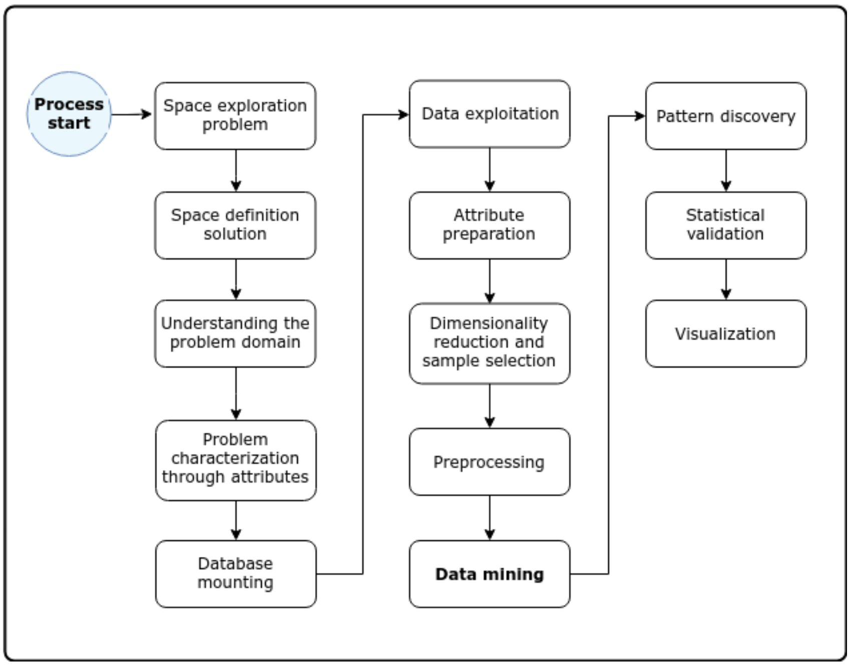


As shown in Figure 45, the CoUrbF5G is a framework that has several components. The CoUrbF5G collects various types of data from urban computing through the infrastructure of future 5G networks, which will be stored in large databases hosted in data centers. The urban computing-oriented data mining is performed, delivering the results to the CWN environment. In this environment, the observation module checks the context-aware behavior based on data mining results, and the analysis module checks the current network conditions. Observing the behavior, and performing the analysis, the desired parameters are consulted through the policy and objectives module. The resource allocation and urban planning modules are triggered, making the appropriate dynamic changes on the system and on the network through the action module, enabling the system to learn from experience by the learning module, which can change the parameters of the observation module (STORCK et al., 2017).

6.4.1 Evaluation methodology

As an input module, the big data analytics is proposed. The data mining was developed based on the various steps proposed by the PICTOREA method, described by (MONTEVECCHI, 2012). The method served as basis to aid in the conduction and integration of human perception in the KDD process. The Figure 46 shows the method workflow, consisting of thirteen steps in its main flow, and is characterized by the flow itself maintaining the conciseness of the project steps. The steps range from the problem understanding to the validating and testing of standards that were found for expert analysis. For the context of this work, the data mining was limited to the application of data mining standard methods.

Figure 46: PICTOREA method workflow



Source: adapted from Montevecchi (2012).

A real mobile telephony data set was adopted, and collected during a week in Milan and in the Trentino region, during November 2013. The data were made available by Telecom Italy, in ODbL format, for the Big Data Challenge competition. The database consists of more than 15 million records, each record having the antenna assignment, or base radio station, and the accounting made by type of service and by schedule. The database is formed by the attributes of receiving and making telephone calls, receiving and sending SMS, and Internet usage, being valid for carrying out a preliminary planning analysis of future 5G networks. The Weka tool was used to analyze the dataset (WEKA, 2019), and consists of an algorithms collection of learning machine for data mining tasks, that is an open code, and was developed by the University of Waikato in New Zealand.

The first step is the exploration of the problem space for knowledge of each domain applied in urban computing. It is noted that several domains can be created from the problems faced by cities. One of them is the mobility verification to overcome the challenges of urban congestion. To achieve the goal of this step, a pairwise problem matrix was used, presented in Table 31, assigning weight of 0.5 for problem importance and weight 0.25 for ease and return. The target problems raised were: the investigation of peak schedule and antenna demand, as well as the similarity between the provided services, aiming a correct future planning.

Table 31: Pairwise problem matrix

Problem	**Importance**	**Facility**	**Return**	**Total**
Peak schedule	3	2	3	2.75
Antenna demand	2	3	2	2.25
Similarity between services	2	3	1	2.00

The next suggested step is the solution space defining. At this stage, data mining and visualization techniques were defined, considering the expected results. It was adopted as the mining technique to meet expectations, the clustering technique.

To understand the domain of the problem and its characterization, it was verified which characteristics would emphasize the useful and non obvious knowledge, so it can be evaluated using Domain Driven Data Mining (D3M) concepts and aspects, where each step of the KDD process must be followed and validated by a domain expert. The characterization of the problem through attributes identified that the date-time, cell-ID, SMS, call and internet attributes are the most relevant considering the defined problem and what will be analyzed.

One of the most time and resource consuming steps is the database mounting. In this work, the database was assembled in Comma-Separated Values (CSV) file format, by language scripts “C#”, verifying its dimensionality. The consistency and coherence of the instances attributes, the presence of pollution in it and the data integrity were verified. The final basis was considered representative for knowledge discovery.

After the database assembling, the statistical representativeness analysis was performed through the data exploration step. The correlation analysis was also sought to evaluate the relationship degree between the variables.

In the attribute preparation stage, the missing values and the analysis of outliers present in the database were verified. For missing values, it was opted to delete all records found.

The reduction of dimensionality and sample selection is very important for a good representation of the knowledge discovery, being necessary to evaluate the attributes for this execution. The SMS-in and SMS-out attributes were merged into a single SMS attribute, because it considers the independent send or receive count. The same thing happened with the Call-in and Call-out attributes. In this work, two representative samples of database instances were used, resulting in a first subset of data formed by 499,999 instances, and a second subset containing 2,008,105 instances, being that the original database containing 15,085,579 records.

6.4.2 Results and discussion

For the grouping step, the outliers analysis, which represent non-standard data values, is essential, as outliers can cause distortions in group formations. For this purpose, for outlier analysis, the mean with two standard deviations was applied, being found 60,313 records considered non-standard, representing 12.06% of the first data subset. In a second experiment, with a subset of 2,008,105 records, 97,840 records considered outliers were found, representing 4.87% of this second data subset.

For data cluster analysis, the k-means partitioning technique was first used, which is considered a simple, relatively scalable and efficient application technique for large databases, with the goal of similar records identification. A proposal for cluster analysis is found in (SERRA; ZARATE, 2015). Two (Table 32) and five clusters (Table 33) were adopted, being respectively "k = 2" and "k = 5"; being "k" the number of desired clusters that are previously provided by the user, which will be represented by their centroids. The adoption of five clusters as cluster evaluation measure has presented a good representation regarding to the number of clusters by the sample size, being this value also used in the study of (MORE; LINGAM, 2015). In Table 33, it is verified that two groups (clusters 2 and 3) had presented a larger size, which means that the services provided on certain antennas and by schedule follow a similar pattern.

Table 32: k-means with two clusters

Cluster	**Instances**	**Result**
0	267.686	54%
1	232.313	46%

Table 33: k-means with five clusters

Cluster	**Instances**	**Result**
0	75.021	15%
1	65.283	13%
2	118.672	24%
3	187.536	37%
4	53.487	11%

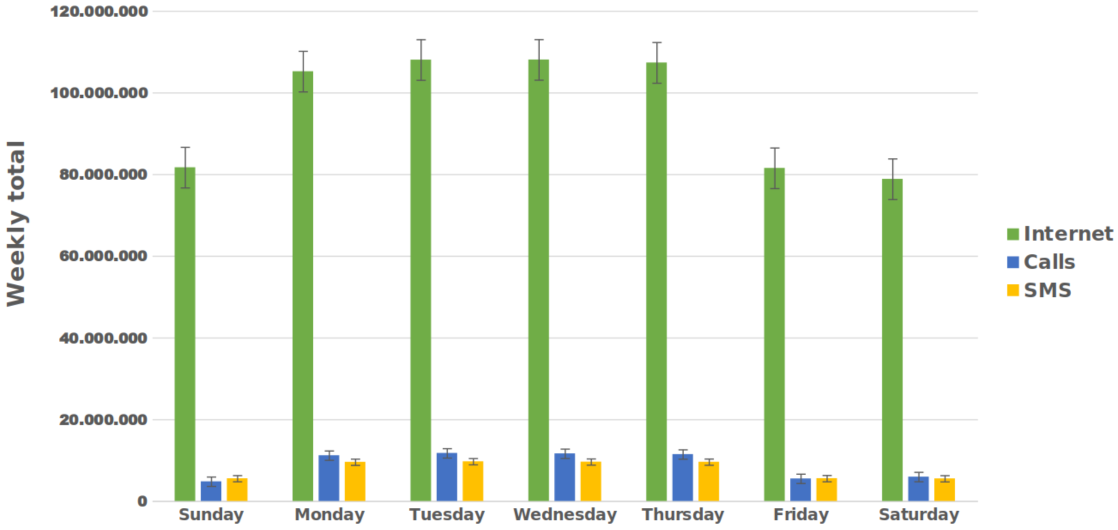
Then, the Expectation Maximization (EM) algorithm, which is a method based on probabilistic models, was executed for comparison ends with k-means, as shown in Table 34. The purpose of the comparison was to verify if there was a significant difference in the evaluation of the clusters, using another algorithm. However, as with k-means, it appears that two groups (clusters 0 and 3) had presented a larger size, which means that the services provided on certain antennas and by schedule follow a similar pattern.

Table 34: Expectation Maximization with five clusters

Cluster	Instances	Result
0	145.396	29%
1	92.946	19%
2	80.155	16%
3	114.593	23%
4	66.909	13%

For temporal analysis, it was verified the distribution of the services types (telephone calls, SMS and Internet), by days of the week, counting the total of each service type in the whole network, as ilustre then Figure 47, considering all geographic areas of the base.

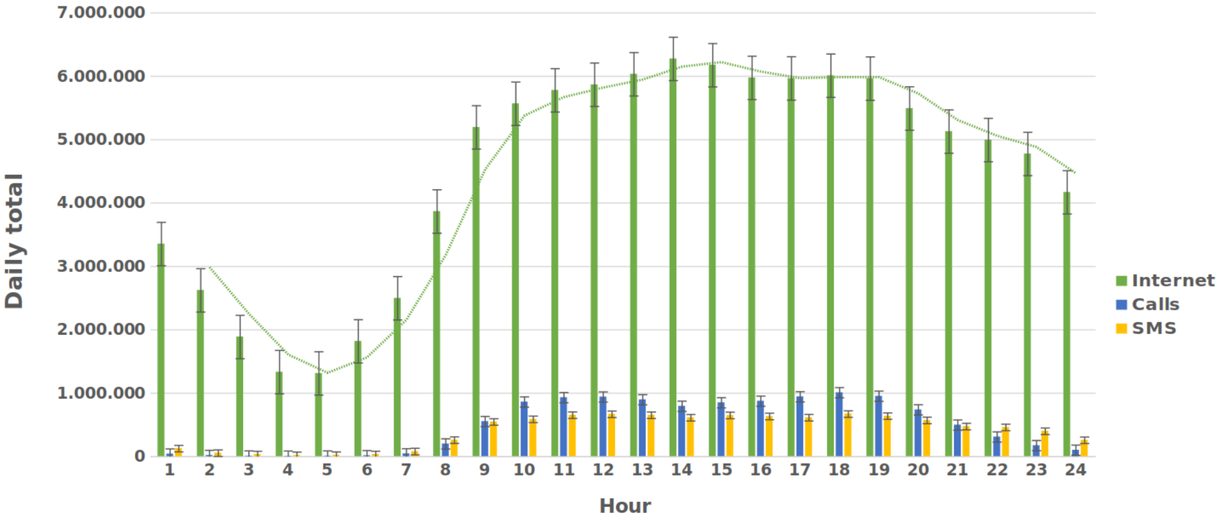
Figure 47: Distribution of service types by day



The results show that the day with the higher demand was Tuesday, followed by Wednesday and Thursday. By the analysis, it was verified that there is a strong seasonal component, indicating more intense work routines, study and business on these days. The days that are closest to the weekends, Monday and Friday, by their turn, may have been affected precisely by the proximity with the beginning of the week and the weekend, caused by a slower pace of activity represented by temporal human behavioral patterns.

After identifying Tuesday as the higher demanding day, it was sought to find the behavior by a schedule range considering all services types. The Figure 48 shows that the longest service request period comprises two intervals: the first interval between 12 and 15 hours and the second interval between 17 and 19 hours.

Figure 48: Services breakdown by schedule during tuesdays



By the Figure 48 it is verified that there is a strong seasonal component during certain intervals of the day, which may have been influenced by daily routine activities. It was observed that the demand usually begins when people wake up, usually at 7 am, and increase during the day. From 7 pm onwards, the demand probably decreases because when people return home from work, they prepare for night rest.

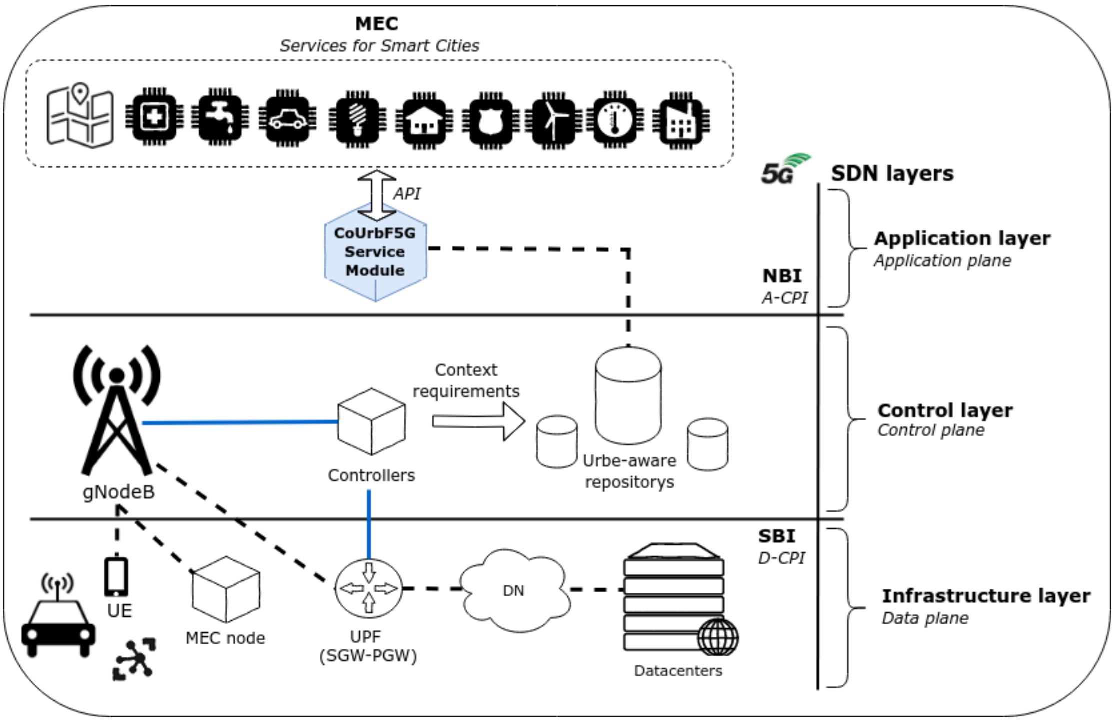
With the results obtained by data mining applied on the mobile phone network, it is expected a better planning and the delivery of quality mobile services in smart cities supported by next generation networks. As the graphs showed, through the performed analysis, it can interfere in network configurations.

6.5 Example of a service module applied to our model

The CoUrbF5G proposed can be used as an example of a service module applied to our 5G model as new services facilitator. In this thesis we have created a module through Mininet to evaluate the model. The CoUrbF5G module developed was the facilitator to a smart city application. It also can pass valuable evaluation information to any application or service. The CoUrbF5G has several components and collects several urban computing data types through the 5G infrastructure, which will be stored in fog or cloud databases. The big data analytics process is executed delivering the results to the environment, where the observation module checks the context-aware behavior based on the results. While the analysis module verifies the current conditions of the network, passive monitoring is indicated by does not generate an overload in the network. This incorporation makes the framework sensitive to the contexts of smart cities applications (STORCK et al., 2017).

After the network behavior has been observed and the analysis has been done, the desired parameters and the Key Performance Indicators (KPIs) are consulted through the policy and objectives module. The resource allocation and the planning modules are triggered together with the observation module. The infrastructure layer consists of the vehicles, IoT and UE, User Plane Function (UPF) and other service provider elements to the users. In the control layer, the SDN controller manages the next generation node base (gNodeB) station and repositories. The application layer represents the abstraction provided by the controller through the services delivery. Between the layers, there are theSBI and NBI that are communication interfaces which, respectively, pass along the characteristics of the network elements to the controller, via the D-CPI and via the A-CPI. The services are geo-location applications, healthcare, water monitoring and leakages, IoV and smart roads, smart lighting, smart house, security-related services, air quality monitoring, vertical automation, and smart manufacturing. The logical structure for CoUrbF5G based on the SDN concept and application, divided into three layers is illustrates in the Figure 49.

Figure 49: Logical view of the CoUrbF5G service module



6.5.1 The emulation methodology

In this work, the use of the SDN controller in the CoUrbF5G service module was illustrated on the performed tests by the POX controller and the Mininet emulator that are virtual networks running on the kernel of a physical or virtualized system. POX is an open source development platform for Python-based on SDN control applications, such as OpenFlow SDN controllers. The Mininet emulator by its side is from an open source and also allows testing and development with OpenFlow protocol and SDN and Gephi is the leading visualization and exploration software for all kinds of graphs and networks, being also a free open-source.

Exemplifying the routing to repositories, the data were collected at two intervals with ten interactions that were performed for each interval. The adopted topology in the first interval was 01 controller, 06 OpenFlow switches and 500 devices; and in the second interval counted with 01 controller, 06 OpenFlow switches and 1000 devices. The Gephi tool was integrated into the Mininet for the network observation and analysis, as proposed by CoUrbF5G. The emulated service was the streaming reception, such as geo-location services in a smart city context, and for that it was necessary to add a streaming client using the door 8282, receiving streams in a constant way.

The complex networks metrics used to compare the two networks intervals were: average path length, network diameter, average grade, density, modularity, and connected components. The average path length is the measure of the information's efficiency, and it represents the extension of the path to all possible pairs of nodes, or in other words, how much the nodes are close to each other. Its calculation considers $d(v_i,\ v_j)$ as the length of the shortest path that exist between two vertices, and n is the number of nodes in the network, by the Equation 6.1:

$$l_G = \frac{1}{n \times (n-1)} \times \sum_{i \neq j} d(v_i, v_j) \tag{6.1}$$

The network diameter refers to the length of the longest of all the computed shortest paths between all pair of nodes in the network. The diameter is completely dependent on the network design and is the maximum number of switches that has to be crossed in order to link any two switches in the bridged network which includes source and destination.

The average degree is the sum of all vertices of a graph, divided by its number of vertices. This degree is the sum of all edges represented by m, divided by its number of vertices, n, in the network, by the Equation 6.2:

$$A_d = \frac{2m}{n} \tag{6.2}$$

The network density describes the portion of connections between two or more nodes in a network, considering the quotient of the "actual connections" (that actually exists) by the "potential connections", P_C, (that could potentially exist) got on the Equation 6.3:

$$P_C = \frac{n \times (n-1)}{2} \tag{6.3}$$

The Modularity, Q, represents the division of the network nodes into dense communities inside of a graph, which is usually sparsely connected. The ability to view and to analyze the network structure becomes easier when these groups are found. It is the fraction of the edges, m, that fall within the given communities less the expected fraction if edges were distributed at random, and it was designed to measure the strength of network division into 2 nodes modules or clusters, k, by the Equation 6.4:

$$Q = A_v w - \frac{k_v \times k_w}{2m} \tag{6.4}$$

Finally, the connected component is a maximal set of nodes such that each pair of them is connected by a path in a network that is generated by laying down a number of nodes and adding edges between them with a independent probability for each node pair.

6.5.2 Results and discussion

To exemplify how the model can pass information to the smart cities services, Table 35 shows the comparison among computed complex network metric means, during the two network execution intervals.

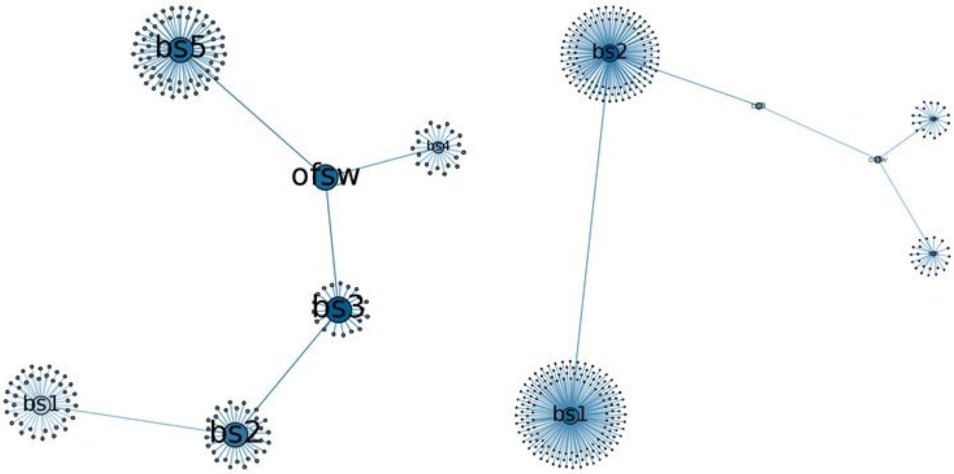
Table 35: Metric means comparison

Metrics	**1st interval**	**2nd interval**
Average path length	3.949	3.178
Network Diameter	6	6
Average grade	2.011	2.019
Density	0.012	0.006
Modularity	0.737	0.597
Connected components	1	1

In Table 35, the average path length is bigger on the first interval (3.949) than on the second one (3.178). The network diameter is the same for both that represent the presence of six OpenFlow switches. The first interval shows an average grade of 2.011 while the second has presented a bigger measure (2.019). The density indicates that the graph has a number of vertices totally connected together or, at least, in large part, unlike a sparse graph that has not many connections between its elements. The first interval has presented higher density (0.012) when compared with the second one (0.006). The modularity in the first interval exhibits greater modularity (0.737) over the 2nd one (0.597). Networks with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules. In the realized tests, the intervals present only one connected component. It means that the graph does not have isolated elements, because it is totally connected, or in other words, from any vertices, it is possible to get connected to any other.

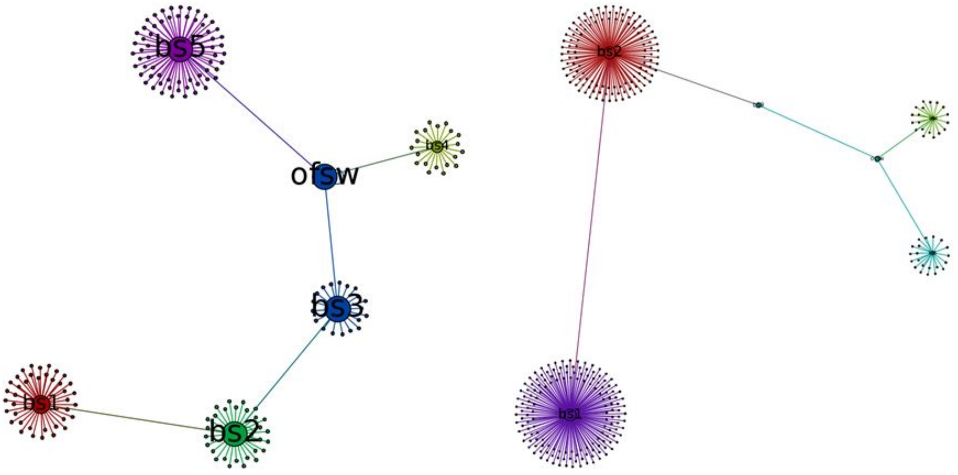
In this context, the intermediation centrality, or the betweenness centrality appears as a detecting way about the amount of influence a node has over the information flow in a graph. It is often used to find nodes that serve as a bridge from one part of a graph to another. In other words, it indicates the most influent nodes inside the network which if be removed all connections in the graph would be cut off because it ensures that no nodes are isolated. The betweenness is one of the most interesting measures in the model representing the measure of how many times a node appears in short test paths between nodes in the network. It means that a vertice which occurs in many shorter paths between other two vertices possesses greater betweenness. It can also be seen as the entity's capacity to make connections with other entities or groups. The network with the calculated betweenness and the most influential nodes in the network of these two intervals are shown in Figure 50.

Figure 50: Determining betweenness of two intervals



Another fundamental point is the detection of communities or clusters, which allows the graph decomposition into groups for their properties mining. The Louvain method, one of the most popular approaches, is an algorithm for communities detecting in networks that maximizes a modularity score for each community, being one of the fastest modularity-based algorithms and working well with large graphs. It also reveals a hierarchy of communities at different scales, which can be useful for understanding the global functioning of a network. This method aims to optimize locally the communities in this model proposal, as illustrates in Figure 51.

Figure 51: Detection of clusters between two intervals



In the performed emulations, the first interval has detected 5 communities in which it is observed that the largest one is represented by 36.21%, followed by 22.98%, 16.67%, 13.07%, and 11.07%. The second interval has detected 4 communities in which it is observed that the largest community is represented by 48.25%, followed by 38.0%, 7.90%, and 5.85%. From these results obtained through a service module, we demonstrate that it is possible to provide useful information and create new services in various segments of smart cities through the 5G ecosystem and that the proposed model is applicable.

6.6 Final remarks

This chapter presented the 5G network as an important infrastructure for smart cities. It makes a fully mobile, collaborative and connected society. However, there are several challenges involving urban environments to the use of this mobile communication system to perform various new services. That´s why this chapter has presented a 5G model as a facilitator for smart cities and new services infrastructure.

The proposed simple and agile model is able to support many smart cities features and services. In this direction, the operators can provide a basic structure to stakeholders to develop new and personalized services and innovative applications. The suggestion for future works is to carry out new tests in 5G scenarios and the development of real services applied to smart cities.

The next chapter presents the conclusion of this research work, highlighting the main contributions as well as the future research prospects.

7 CONCLUSIONS

This chapter presents this thesis summary, conclusions, contributions and future works. Section 7.1 remembers the subject problems, as well the thesis statement and goals. Section 7.2 reviews the proposal and the contributions for the technological development around the IoV 5G network use on C-V2X. Section 7.3 outlines the perspectives for future works.

7.1 Summary

This thesis presents IoV approaches to run in a 5G V2X ecosystem and to improve vehicle connections and services provided. The thesis statement was that by integrating the IoV approaches with the 5G SDN controller, solutions in connected vehicles were proposed. To prove this statement, the objectives were organized into five modules:

- In relation to the **GM1** goal, the IoV architecture characterization has considered standards and technological challenges.
- In relation to the **GM2** goal, a 5G V2X ecosystem based on SDN controller was proposed. Vehicular Internet-based video services traffic by mmWave technology in urban and rural scenarios through the Network Simulator ns-3.
- In relation to the **GM3** goal, a probabilistic user-centered V-Cells selection was proposed. It can be considered as the biggest 5G UDN challenge on the IoV connections.
- In relation to the **GM4** goal, the thesis has indicated a solution to handover decisions for 5G UDN connected vehicles. The results have shown that this solution has achieved its main objective by reaching assertiveness levels in the handover decision process.
- In relation to the **GM5** goal, a 5G network technology structure model was shown as a facilitator to provide new services for several segments in smart cities.

The chapter 2 highlighted the 5G network as the top technology for wireless interaction. It is able to increase the speed and the security to transmit great volume of data by IoV connections on V2X communications in connected vehicles. It has shown that technology changes are already going on to use 5G V2X communications. The cellular network is going to enable information exchanges between vehicles and other infrastructures and people, providing accurate knowledge about the environment. In this context, the chapter argued that the C-V2X is going to provide longer communication range and higher reliability with a chipset solution that is going to be compatible with 5G and ADAS sensors as part of a specific platform designed to offer IoV connections.

The chapter 3 has explained how a V2X ecosystem can provide IoV. This chapter evaluated SDIoV entertainment services, through simulations of vehicular Internet-based video services traffic and V2V communications in urban and rural scenarios. Three metrics (data transfer rate, transmission delay and PDR) were analyzed and compared on rural and urban IoV scenarios with eMBB use case and V2V communications, and the results have shown satisfactory IoV performance 5G V2X ecosystem.

The chapter 4 presented a vehicle-centric probabilistic approach, based on speed criteria and complex network metrics, to V-cell management in 5G UDN. The proposed approach considered scenarios that involve high mobility, such as IoV or V2N communications. The results have shown that the more assertive V-Cells selection improves the services offered by IoV through the 5G networks.

Chapter 5 described a solution of inter-V-cell handover decisions for 5G UDN in connected vehicles. It considered the integration among the handover with an SDN controller to provide solutions and breakthroughs for 5G network requirements, such as high-speed mobility support to increase the assertiveness of transition decisions between different V-Cells. The simulation results have shown considerable gains in the handover metrics when evaluated and compared with other studies in the literature.

Chapter 6 described a 5G network technology structure model as a new services facilitator to several segments in smart cities. It incorporated SDN controllers to achieve the expected goals of the 5G V2X ecosystem. This chapter presented a service model named CoUrbF5G. It was validated through the analysis of mobile network real standards and by the application of data mining techniques along with ancillary Data Science methods. The model evaluation was conducted through emulations on Mininet and POX controllers, and the results were analyzed using the Gephi tool. The proposed model is applicable to support and provide new services such as intelligent transportation, road monitoring, energy consumption, public safety, among others, in smart cities.

7.2 Final remarks and contributions

As already said, this thesis proposed specific approaches to provide the demanded onboard video entertainment, the virtual cell selection, the deal with frequent handovers, and an ecosystem to facilitate the C-V2X communication applications supported by the 5G network through IoV connections. Each chapter has its specific contribution considering the goals interaction on the thesis development. Basically, from the data collection, it was possible to define the 5G network on C-V2X communications architecture characterization (chapter 2), the 5G V2X ecosystem model proposition (chapter 3), the V-Cell solution presentation (chapter 4), the indication of the proposed V-Cell solution test through an efficient handover decision model (chapter 5), and the validation of the model through the urban service facilitator framework (chapter 6).

The chapter 2 presented IoV by 5G and car connectivity on cellular networks as a big challenge. It emphasized that the 5G technology is the best well-positioned technology to the global solution for V2X communications, supporting new automotive applications. Previous works from the author have contributed to this chapter by describing the IoV by 5G C-V2X, on its architecture approach and the V2X application types; by pointing the 5G V2X standards used on 5G infrastructure for V2X ecosystem, and that for a dynamic management, the network intelligence should be controlled by SDN; by arguing that the proposed architecture for the 5G V2X ecosystem ensures resources reserve for various slices which are demanded by the V2X services; by the indication of 5G V2X studies and projects about targeting radio regulations, operational aspects, protocols, test specifications, performance, QoS, QoE, security and much more; and by the indication of challenges and future directions about the solution for vehicular communications.

The 5G V2X ecosystem model was described in chapter 3. The rural and the urban scenarios with the eMBB use case and V2V communications were compared and the results have shown the propose potential under high-mobility and high-density conditions. Previous works from the author have contributed on this chapter by pointing the 5G ecosystem simulation methodology, the materials and methods to provide IoV on 5G-V2X, indicating the data transfer evaluation in eMBB scenarios with Internet-based video services conducted in modeled scenarios with codes developed in ns-3 simulator, using mmWave technology.

The solution presented by the chapter 4 contributed with an approach to 5G UDN V-Cells management based on vehicles. Previous works from the author have contributed to this chapter by presenting the adopted simulation parameters, and the evaluation methodology based on 5G V2X ecosystem for the vehicle-centric probabilistic approach to V-cell management in 5G UDN.

The indication a handover decision solution on chapter 5 has just presented the V-cell action associated to the SDN to support the transfer procedures, the creation of rules according to the vehicle mobility, the probabilistic equation modeling, the adoption of complex network measurements and the adoption of the utility theory for a better choice of cells. The previous works from the author have contributed to this chapter with the demonstration that FivH and SoftH, using the SDN conception, are able to make handover decisions in a more assertive way for connected vehicles to 5G UDN.

The validation of the evaluated model on chapter 6 has shown that, besides several challenges, 5G network has an important role for smart cities in reason to make a fully mobile, collaborative and connected society. So, it was presented a 5G model as a facilitator for new services infrastructure to allow the innovative applications and services.

The author previous works that contributed as base structure for the thesis development area highlighted as it follows: the chapter 2 used “A Survey of 5G Technology Evolution, Standards, and Infrastructure Associated with Vehicle-to-Everything Communications by Internet of Vehicles” (IEEE Access Journal, Qualis A1); the chapter 3 used “A 5G V2X Ecosystem Providing Internet of Vehicles” (Sensors Journal, Qualis A1) that was referenced on chapters 2, 4, and 5, “5G V2X Ecosystem Providing Entertainment on Board using mmWave Communications” (LATINCOM 2018, Qualis B2), that was referenced on the chapter 2 and 3, and “A Performance Analysis of Adaptive Streaming Algorithms in 5G Vehicular Communications in Urban Scenarios” (ISCC 2020, Qualis A3); the chapter 4 used “A Vehicle-Centric Probabilistic Approach to Virtual Cell Management in Ultra-Dense 5G Networks” (ISCC 2020, Qualis A3), it has also used “Using Complex Networks Metrics to Mitigate the Broadcast Storm Problem” (ISCC 2019, Qualis A2), and “Protocolo Baseado em Métricas de Redes Complexas para Mitigação de Tempestade de *Broadcast*” (SBCUP, Qualis B4 with honorable mention); the chapter 5 used “FiVH: A solution of inter-V-Cell handover decision for connected vehicles in ultra-dense 5G networks” (VEHCOM Journal, Qualis A1), “SoftH: Soft Handover Multicriteria Mechanism” (SAC 2019, Qualis A2), and “Uma Solução de Decisão de *Handover inter-V-Cell* para Veículos Conectados em Redes 5G Ultradensas” (SBCUP 2020, Qualis B4); the chapter 6 has used ”A 5G Urban Computing Framework Service Model” (BJD Journal, Qualis B2), “A 5G New Smart City Services Facilitator Model,” (LATINCOM 2019, Qualis B3), “Proposta de um Framework Baseado em Mineração de Dados para Redes 5G” (RESI Journal, Qualis B3), and “CoUrbD2M: Mineração de Dados Orientada à Computação Urbana em cenários de *Big Data* e Redes 5G” (I CoUrb - SBRC 2017).

7.3 Future research directions

It is expected that in the future there will be millions of network-connected vehicles, behaving like cell phones. This is possibly a relevant aspect for the proposal of architecture's models and network management in future works. Nowadays, SDIoV use presents a promising architecture. Its architecture involves multiple communication technologies that can be used to support fully autonomous driving. So, it´s important to develop some more studies on this direction.

The 5G technology requires the use of mmWave that is an extremely high frequency used to achieve the requirements of better reliability, lower latency, and higher data rate. In a short time, 5G is going to promote a great model business change by enabling new services and improving the existing ones, because of the technology enablers in RAT areas for V2X communications and network virtualization. The way these enablers affect business relationships is also changing. The V2X communications and the technologies associated to 5G create more collaborative business environments to find solutions for the increasing industrial and commercial demands in this new universe of possibilities. International standards, protocols and security concerns about the network connectivity, the user privacy, and autonomous vehicles effective control require several more studies.

The 5G performance is going to support V2X services, and has also implemented new key 5G capabilities with multiple devices operating in the mmWave. Some reported tests have shown multiple connected-vehicle-use cases, such as V2V communication, that represents the very first step toward achieving fully autonomous driving. These tests have accelerated the 5G development, but the integration of technical requirements from various industries into upcoming international 5G-standardization activities need more researches. There are also other important interests to feed future works in this context such as: the perspectives for the 5G V2X development involving IoV on commercial business; the improvement of vehicle surveillance and real-time tracking; monitoring and analysis of traffic data, and logistic movement; centralized storage and management of massive data in the data center; technological advances in cars communications and controls systems as sensor platforms; the evolution of autonomous vehicles as instance of the IoT by IoV communications, storage, intelligence, and learning capabilities.

Integrated and full technology convergence is expected with the 5G evolution as soon as everything will be connected to everything. The IoV services efficiency in 5G V2X networks that can be reached with the integration of different technologies require scientific efforts to find appropriated solutions, such as the SDIoV architecture, which comes as a light for future directions that shall be studied. It means that with the 5G and beyond networks implantation, researches are urgent. Future works shall bring new tests in 5G scenarios with the development of real services applied to smart cities.

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