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Edge Computing Based Applications in Vehicular Environments: Comparative Study and Main Issues

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Abstract Despite the expanded efforts, the vehicular ad-hoc networks (VANETs) are still facing many challenges such as network performances, network scalability and context-awareness. Many solutions have been proposed to overcome these obstacles, and the edge computing, an extension of the cloud computing, is one of them. With edge computing, communication, storage and computational capabilities are brought closer to end users. This could offer many benefits to the global vehicular network including, for example, lower latency, network off-loading and context-awareness (location, environment factors, etc.). Different approaches of edge computing have been developed: mobile edge computing (MEC), fog computing (FC) and cloudlet are the main ones. After introducing the vehicular environment background, this paper aims to study and compare these different technologies. For that purpose their main features are compared and the state-of-the-art applications in VANETs are analyzed. In addition, MEC, FC, and cloudlet are classified and their suitability level is debated for different types of vehicular applications. Finally, some challenges and future research directions in the fields of edge computing and VANETs are discussed.

Keywords cloud computing, edge computing, fog computing, cloudlet, vehicular network

1 Introduction

The vehicular ad-hoc networks (VANETs①) should enable the vehicles to communicate both with each other and with their environment. Therefore, these networks are considered as a key component in the development of cooperative-intelligent transportation systems (C-ITS) and autonomous vehicles. Due to the vehicular environment, they have unique features, including highly dynamic topology, significant volumes of data and frequent disconnections. Moreover, they have specific requirements such as reliable communications or high quality of service (QoS) (latency, throughput, packet loss, etc.). Notwithstanding the wealth of research conducted to date[1−5], they are still facing many challenges[6−8]. Some of these relate in particular to data storage, data processing and network performances.

Currently, cloud computing (CC) is one of the most common technologies providing network, computing or storage resources as a service at several levels: infrastructure as a service, platform as a service or software as a service. CC has different advantages including ease of use, flexibility, manageability and accessibility/cost savings. For these reasons, designing new low cost and global applications (urban surveillance, traffic management, disaster management) becomes easier with CC. This combination of CC and vehicular networks can take different forms[9,10].

Nonetheless, with this model, some communications, data storage and data processing issues are not addressed: low latency and real-time interaction (20 ms for a pre-crash sensing warning for example), context-awareness or network overload. Indeed, CC is a centralized model increasing latency. Therefore, it cannot be an efficient way to deploy real-time services or context-

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Survey

①The meaning of all the abbreviations used in this paper is provided in Appendix.

aware services. Moreover, with an increasing number of connected vehicles, hosting unfiltered data on cloud service provider platforms could lead to network overloading, scaling-up problems and significant costs.

That is why a new computing paradigm, extending cloud to the network edge, was introduced: edge computing (EC)[11]. Using the capabilities of the edge devices, EC aims to offer distributed network, computational and storage capabilities at the network border, overcoming the main CC limitations. Indeed, deploying capabilities at the network edge, as close as possible to users, could reduce the distance between clients and applications and therefore latency[12], enabling real-time operation and higher responsiveness. Moreover, data caching, data analytic and data processing at the edge could significantly reduce the volume of raw data transmitted. Thus, the network load, the system scalability, and the bandwidth efficiency could be improved. Finally, with local CC capabilities, context-aware services could easily be deployed.

Because of many benefits of EC, different surveys, such as [13-15], have already presented this technology and the three main implementations of EC: fog computing (FC), multi-access edge computing (MEC), and cloudlets. Within the vehicular environment context, our paper tackles EC from a different perspective in regard to these papers ([13-15]). In the vehicular environment, a short survey, [16], proposes a comparison of MEC and FC. However this paper focuses mainly on a description of the mobile edge computing and fog computing solutions for vehicular networks, presenting the references and standards architectures. We want to go further by describing these implementations, their strengths, their applications and their specific issues in the vehicular environments. Moreover, fog computing[17] or mobile edge computing[18] has been proposed to improve software-defined networking based vehicular networks. Nevertheless, these papers ([17, 18]) mainly focus on network control. Indeed, they do not attempt to compare the EC implementations and to determine their possible applications. Therefore, this survey is a complement to these papers, presenting the vehicular applications and the benefits of the EC integration, different EC implementations and their applications in the vehicular environment, and the main challenges of the EC implementations.

The rest of this paper is organized as follows. Section 2 offers a brief introduction of the VANETs and their applications while Section 3 introduces the various EC technologies and compares their main characteristics. Then, in a vehicular environment, Section 4 presents the state-of-the-art solutions for each EC technology and their performances are assessed for different kinds of vehicular applications. Lastly, some of the main remaining challenges EC and VANETs are discussed in Section 5.

2 Vehicular Networks

The VANETs are based on three main types of communication shown in Fig.1: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-cellular-network (V2N) communications. The V2V communications, enabling information dissemination thanks to On-Board-units (OBUs)②, are mainly used by the road safety applications such as emergency breaking or lane departure. With V2I communications, using Road Side Units (RSUs), local traffic management and short range downloads are enabled. Finally, the V2N, using cellular communications through base stations (BS), provides a direct access to application servers such as a traffic safety server.

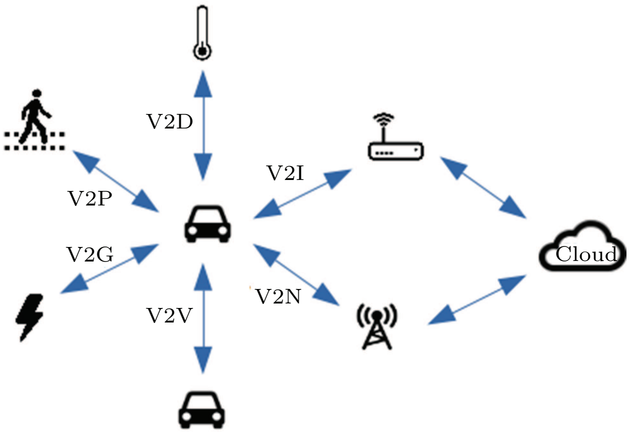

Fig.1. Main types of vehicular communications.

With the emergence of the Internet of Things (IoT), a new concept emerged, the Internet of Vehicles (IoV). It is an extension of the VANETs enabling vehicles to communicate with any kind of entities through Vehicle-to-Everything (V2X) communications. With IoV, new types of vehicular communications are designed including, for example, Vehicle-to-Pedestrian (V2P) improving the pedestrian safety[19], Vehicle-to-Device (V2D)

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②https://ec.europa.eu/transport/sites/transport/files/themes/its/studies/doc/eg06_obu_vehicle_integration.pdf, June 2019.

offering a better user experience, Vehicle-to-Grid (V2G) enabling smart charging for electric vehicles[20], etc.

These different types of communication (V2V, V2I, V2N, etc.) could be used to develop many applications. They are often classified into two broad categories of services[21]: road safety and non-road safety applications. However a more precise breakdown is possible and shown in Table 1: transport management, vehicle management, infotainment and advertising, road safety, driver assistance, and health monitoring.

Table 1. Presentation of the Vehicular Applications

Service Type	Application Examples
Transport management	Real-time traffic management, parking slots booking, electric charging points
Vehicle management	Personal assistant, remote maintenance systems
Infotainment, advertizing	Multimedia applications, augmented reality, points of interest
Road safety	Cooperative collision warning, intersection coordinator, obstacle detection
Driver assistance	ADAS, parking assistant, cooperative mapping
Health monitoring	Fatigue detection, user comfort, medical assistance
New modes of transportation	Platooning, car sharing

Beyond these obvious applications, a range of new services have been designed. These notably include platooning[22] which enables groups of vehicles to travel together. With this method, vehicles could accelerate and decelerate simultaneously, reducing inter-vehicles distance and therefore limiting traffic congestion, costs and air pollution. Car sharing[23] is another example of these innovations, a new mode of transportation aiming to reduce net emissions and the number of cars. This is a shared transport system where autonomous vehicles are considered as collective public transport.

As the paper [12] shows, micro data centers, located in close proximity to users, could improve energy efficiency and response time. Therefore, for some of the applications shown in Table 1, the benefits of the integration of EC in the vehicular network architecture are obvious. Thanks to context-awareness (location awareness, environment factors and proximity to devices), the performances of different applications (parking slot booking, parking assistance, electric charging points, Point of Interest) could be improved. Similarly, computational and storage capabilities at the edge of the network, enabling data caching, data analytic and higher bandwidth, could significantly improve the performances of the multimedia applications (data caching and processing), cooperative mapping applications (data caching and processing), and traffic management applications (data analytic applications). Moreover, the augmented reality (AR), platooning and road safety applications could benefit from a higher responsiveness and a lower latency.

For some other applications, the benefits are less obvious. The health monitoring applications, for example, could be useful within the vehicle to monitor the driver behavior (fatigue detection, comfort, etc.). However, for prompt response to accidents and effective assistance or prevention of abnormal behavior, sharing information about the health of drivers and passengers at the edge level could be useful. For example, VANETs and EC could be used to provide high-quality healthcare services and quick response to drivers in emergency situations[24]. Similarly, in a city, a local car sharing application, deployed at the edge of the network, may be used to improve the application responsiveness or to optimize pickup and delivery locations on the fly. In addition, new services such as real-time edge-based attack detection in car sharing and ride sharing services could be developed[25].

3 Edge Computing Based Networks

In this section different types of EC technologies are introduced: mobile edge computing (MEC), cloudlet, and fog computing (FC). The first part of this section offers a broad definition of these technologies while the second one presents their main characteristics and main benefits (latency, context-awareness, network offloading, scalability, etc.).

3.1 Technologies

This subsection aims to provide a general description of MEC, cloudlet and FC in terms of supporting organization(s), objectives and architecture.

3.1.1 MEC

Mobile edge computing③, recently renamed multi-access edge computing④, is an industrial (network

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③ETSI. Mobile-edge computing — Introductory technical white paper, 2014. https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf, June 2019.

④ETSI. Developing software for multi-access edge computing, 2017. https://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp20_MEC_SoftwareDevelopment_FINAL.pdf, July 2019.

operators) initiative supported by ETSI ISG⑤ (European Telecommunications Standards Institute Industry Specification Group) including Huawei, IBM, Intel, Nokia Networks, NTT DOCOMO and Vodafone. MEC, deployed by the network operators, makes available storage, computational and connectivity capabilities within the RAN (radio access network) at radio network controller (RNC), LTE macro base station (eNB), and multi-technology cells aggregation sites. A MEC server is managed by an operator and composed of hardware resources, a virtualization layer and an application platform hosting applications developed by third party companies. Thanks to the RAN infrastructure providing real-time network information, proximity and location awareness, this technology is suited for context-aware applications.

3.1.2 *Cloudlet*

Cloudlet⑥ or mobile micro cloud is another EC approach. It was proposed by the Carnegie Mellon University⑦ joined by different companies forming the Open Edge Computing Initiative⑧: Intel, Nokia, Microsoft or Vodafone. Cloudlets are third party small data centers, smaller clouds closer to the end users deployed by the cloud service providers ([26]). They are located between the cloud layer and the mobile device layer within the WLAN or LAN area. This positioning aims to offer computational and storage capabilities one hop away from the users. Cloudlet has the potential to provide many advantages[27] including, for example, privacy enhancing, high responsive cloud services (low latency, offline availability, and high bandwidth) or data traffic reduction. In addition, a cloudlet offers the benefits of a CC platform: virtual machine (VM) based, operator, OS and hardware independent, and easy to deploy and to operate.

3.1.3 *FC*

Like the other technologies, fog computing⑨ brings CC capabilities closer to users, building a cloud-to-things continuum providing low latency, reliability and high bandwidth. Introduced by Cisco⑩, FC is promoted by the OpenFog Consortium⑪ founded by ARM, Cisco, DELL, Intel, Microsoft and Princeton University. It corresponds to a single-layer or multi-layer architecture of heterogeneous nodes with storage, computational and connectivity capabilities. These FC servers, deployed by the manufacturers, are located at different levels between the cloud and the edge of the network: WiFi Access Point, bridges, routers, gateways or even terminal devices. The main idea of FC is to use the available computational and storage capabilities of these legacy devices to deploy virtualized real-time services near users. Each fog node is composed of an abstraction layer and an orchestration layer allowing the deployment of different applications regardless of the type of devices.

3.2 Distinguishing Characteristics

Complementing the definition of the EC technologies, this subsection presents their common characteristics and their differences. Table 2 provides an overview of this subsection.

3.2.1 *Similarities*

Due to their common objective, these different technologies present some related features:

- goal: overcoming the cloud computing limitations and allowing the development of context-aware, real-time, scalable, bandwidth-intensive and data consuming applications;
- idea: reducing the distance between the clients and servers, deploying storage, and computational capabilities at the edge of the network to reduce latency and enable context-awareness, higher bandwidth, etc.;
- geographic distribution: these technologies aim to decentralize the cloud computing capabilities and therefore are geographically distributed;
- interaction with cloud: some services such as big data applications imply high storage and computational capabilities and are not supported at the EC layer and that is why all these technologies are connected with the CC layer;

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⑤ETSI ISG MEC. https://www.etsi.org/technologies/multi-access-edge-computing, May 2019.

⑥Satyanarayanan. Cloudlet-based edge computing. http://elijah.cs.cmu.edu/, May 2019.

⑦Carnegie Mellon University. https://www.cmu.edu/, May 2019.

⑧Open edge computing initiative. https://www.openedgecomputing.org/, May 2019.

⑨OpenFog Consortium. The Internet of Things: Extend the cloud to where the things are, 2015. http://www.cisco.com/c/dam/en_us/solutions/trends/iot/doc/computingoverview.pdf, May 2019.

⑩Cisco. https://www.cisco.com/, May 2019.

⑪OpenFog Consortium. https://www.openfogconsortium.org/, May 2019.

Table 2. Presentation of the Edge Computing Approaches

Characteristic	MEC	Cloudlet	FC
Founder	ETSI	Carnegie Mellong University	Cisco
Supporting organization	ETSI ISG (network operators)	Open Edge Computing Initiative (Service Providers)	OpenFog Consortium (Manufacturers)
Architecture	Cloud Computing node End user	Cloud Computing node End user	Cloud One or X node(s) End user
Equipment type	RAN equipment (eNB, RNC, etc.)	Mobile Micro Cloud	Router, gateway, WiFi AP, etc.
Communication technology	Mobile network	WiFi	Mobile network, WiFi, BLE, etc.
Inter nodes cooperation	N.C.	N.C.	Yes
Non IP based communications	No	No	Yes
Software platform	NFV	OpenStack, etc.	Fog abstraction layer
Storage capabilities	High	High	Low
Computational capabilities	High	High	Low
Fault tolerance	Low	Low	High
Deployment cost	High	Medium	Low
Potential users	Mobile subscribers	Everyone	Everyone
Context awareness	Location (accurate) Proximity (low) Device status information	Location (inaccurate) Proximity (high) -	Location (inaccurate) Proximity (high) -
Coverage	High	Medium	Variable
Hops number	One	One	One or multiple
User proximity	Medium	High	Variable
Flexibility	Low	Medium	High
R-T interaction	Partial	Partial	Partial

Note: N.C. means "Not Communicated".

- use cases: MEC, FC and cloudlet are designed to support many use cases and many types of applications including infotainment services, sensor data processing, transport management, home automation, smart buildings, etc;
- applications providers: virtualized and designed for multiple use cases, these platforms support the applications developed by third party providers.

3.2.2 Differences

Despite their common objective, these technologies are supported by different types of companies: service providers (cloudlet: Open Edge Computing Initiative), network operators (MEC: ETSI ISG), and manufacturers (FC: Open Edge Consortium). These companies play different roles with different skills. Moreover, they act at different levels using different means. That is why these edge computing approaches present different characteristics in terms of architecture, proximity, context-awareness, computational and storage capabilities.

- *Architecture*. Fig.2 shows the node positioning of the different EC techniques. Cloudlets and MEC servers are located one hop away from the end users forming a three-layer architecture: cloud – computing node – terminal equipment. FC nodes can be located one hop or multiple hops away from the user and are interconnected composing an architecture with at least three layers: cloud — one or multiple layers of fog nodes — terminal equipment.

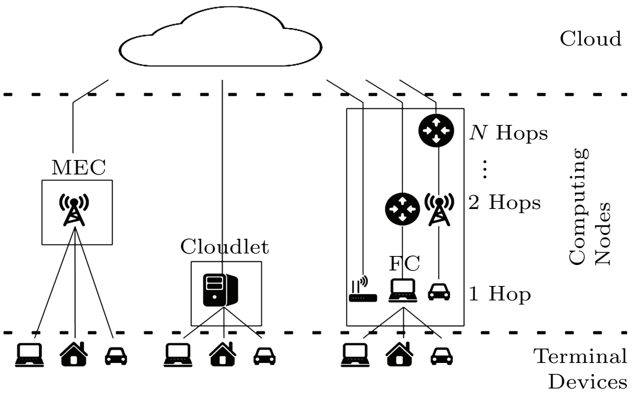

Fig.2. Edge computing technologies positioning.

- *Equipment Type*. Cloudlet is a third party "data center in a box" added to the network while MEC servers use RAN as hosting infrastructure (eNB site, multi-technology cells aggregation site or RNC site).

Finally, FC nodes can be hosted in any edge network equipment (router, gateway, WiFi Access Point, etc.).

- *Communication Technology.* MEC, integrated within RAN, exploits the mobile network. Cloudlet can be reached through WiFi and FC through different technologies such as mobile network, WiFi, Bluetooth and Li-Fi depending on the type of equipment and the manufacturer. Therefore, it could be possible to access the FC servers using non IP-based communications widening the scope of this technology.
- *Nodes Cooperation.* So far, FC has been the only technology fully supporting inter node communications and providing an effective cooperation between the fog nodes forming the network.
- *Fault Tolerance.* Contrary to the other technologies, using a multi-layered architecture enabling the deployment of higher specifications servers, FC should be highly fault-tolerant.
- *Storage and Computational Capabilities.* FC should be integrated in the legacy devices (routers, gateways, etc.) using a virtual layer, without any addition of computational or storage capabilities. Therefore the capabilities of these devices should be more limited than those of MEC servers and cloudlets.
- *Deployment Cost.* Deploying FC in legacy devices seems to be the cheapest and easiest solution. Indeed, it just needs a virtualization layer. Deploying cloudlets is also an easy solution but more expensive, because small data centers need to be deployed. Finally, deploying MEC servers in the existing network architecture is a more complex and more expensive solution.
- *Potential Users.* As cloudlet and FC are WiFi-based, they should be accessible by any user while MEC servers could only be accessed by mobile subscribers.
- *Coverage and User Proximity.* Using the cellular network, the coverage area of the MEC technology could be more important than the coverage area of FC and cloudlet. The cloudlets and FC nodes should always be located in the WLAN area while the MEC servers could be located at the base station level or the radio network controller level. Therefore the latency of the MEC applications could be affected. Moreover, the cloudlet and FC using WiFi or short range communication should be closer to the user.
- *Context-Awareness.* Context information encompasses different types of information: location, proximity to devices, environment factors (temperature, weather, time, traffic, etc.), and devices status. Cloudlet and FC should be closer to users (higher proximity) and therefore could be more interesting to deploy local services such as PoIs. Nevertheless as the MEC servers are integrated in the cellular network, they can use real-time network information, status information of devices and accurate location.
- *Flexibility.* FC is not based on a fixed deployment and therefore adding or removing FC servers could be really simple. Moreover, cloudlets and FC are independent from the network and could be easily managed. Therefore these solutions are more flexible than MEC.
- *Virtualization Layer.* These different architectures are based on a virtualization layer. However, depending on the implementation, different technologies are used: fog abstraction layer, NFV or OpenStack (enabling the deployment of cross-platform applications).

4 Edge Computing Improving the Vehicular Networks

Fig.3 presents a basic VANETs architecture integrating the EC technologies and the principal nodes corresponding to these approaches. Even if different types of nodes such as vehicles, BS or RSUs can be used, each technology is characterized by a specific type of nodes. All the MEC applications are implemented in the cellular network. Therefore, they mainly use BS as hosting infrastructure while the fog nodes are primarily hosted in the vehicles and the cloudlets in the RSUs.

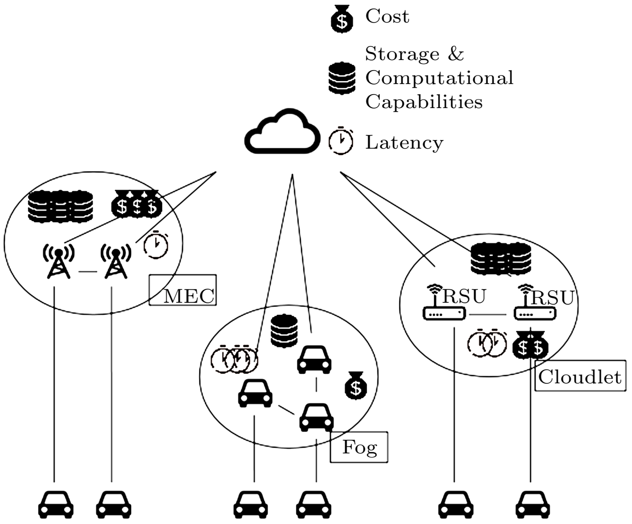

Fig.3. EC technologies in the vehicular environment: basic architecture.

The characteristics of edge computing, including high bandwidth, low latency and context-awareness, are very suitable for the VANETs applications. That is why many applications using the different EC technologies have already been proposed. These applications aim to benefit from the advantages of edge computing. Nevertheless, this integration is not without challenges: resource management and allocation, general purpose computing in edge, security and privacy, scalability, data management, fault tolerance and QoS ([28]). Some of these challenges are solved by existing work.

MEC, cloudlets and FC are associated with different types of applications in the vehicular environment. These applications are described in this section. In Table 3, their goals, their approaches, their limits and their features are presented. Moreover, the advantages of MEC, cloudlets and FC are evaluated according to the kind of applications targeted.

4.1 Cloudlet Applications for Vehicular Networks

Even if cloudlet is the latest technology, it has already been tackled by different researchers with two main objectives: improving QoS and QoE on one hand and improving network scalability on the other hand.

Providing a high quality of experience (QoE) of video streaming over VANETs is a complex challenge. Indeed, the traditional cloud model faces the limitations of the vehicular networks: high mobility, limited end-to-end bandwidth, and high packet loss. That is why, to improve QoE, the authors of [29] proposed a system based on an existing cloud-based VANETs architecture ([47]). This system is built upon different components (QoE-Controller, QoE-Monitor, Popular Video Data Based, etc.) deployed within the vehicles and the roadside cloudlets. Thanks to the cloudlets, the video streaming server and popular video contents are deployed and cached as close as possible to the vehicles. Thus, the end-to-end latency is reduced. Moreover, the high context-awareness enables a video streaming scheduling depending on the vehicle speed and direction. Nevertheless, the challenges of VM-migration and orchestration and optimal use of limited resources (popular video database update, cloudlets synchronisation, inter-cloudlet load balancer, variable inter-cloudlet communication link quality, etc.) are not addressed here.

More broadly, guaranteeing a high QoS in the ve-

Table 3. Comparison of Different Studied Approaches

EC Techonolgy	Goal	Approach	Limit	Features
Cloudlet	QoS	Cloudlet-based streaming[29]	VM orchestration, resources use	Latency (ultra low), computation (low), storage (low), CAPEX (medium), flexibility (high)
		CaaS[30]	Variable vehicular density, cloudlet management	
		Resource management[31]	System scalability, inter-cloudlet communication	
		DTN Cloud[32]	Data synchronisation, resources control	
	Network scalability	Vehicular micro clouds[33]	Optimal path, cluster capabilities	
		Serviceability analysis[34]	Not enough parameters considered	
MEC	QoS	MEC-based architecture[35]	Implementation evaluation	Collaboration (high), innovation (NFV), latency (low), computation (high), storage (high), bandwidth (high), context-awareness
		MEC content caching[36]	QoS, vehicle mobility	
		MEC assisted control plane[37]	Handover, data synchronisation	
	Network scalability	Predictive mode transmission[38]	Network congestion, load balancing	
		SDN-MEC architecture[39]	QoS, optimal path	
		QoE-aware caching[40]	Not enough parameters considered	
FC	QoS	One M2M architecture[41]	Data management, services management	Latency (ultra low), computation (low), storage (low), CAPEX (low), flexibility (high)
		Fog-enabled off-loading[42]	Load balancing, vehicles resources	
		FVC architecture[43]	Implementation comparison	
		VFC architecture[44]	Vehicles mobility, capacity analysis	
	Big data analysis	CFC-IoV[45]	Nodes cooperation, vehicles resources	
		Fog-based real-time ITS[46]	Implementation and deployment, big data integration	

hicular environment is a challenging issue. The authors of [30] introduced a cloud communication as a service (CaaS) system. Their main objective is to deal with the limited resources of the vehicular networks and provide a high QoS (delay, throughput, packet loss rate) using Cloudlets. Indeed, with vehicular-cloudlets, it could be possible to share computation and connectivity between vehicles extending the RSU network coverage using V2V communications and an optimal path computation depending on the user requirements. Similarly, roadside-cloudlet could be used to deal with mobile vehicles and close services deployment. Nonetheless, in this paper, the ideas of heterogeneous networks interoperability, vehicular-cloudlet formation and variable vehicular density are not discussed.

Similarly, according to the authors of [31], cloud computing and cloudlets will be one of the key enablers of the 5G vehicular networks offering high bandwidth and high computational and storage capabilities. This distributed architecture, mismanaged, could be energy-intensive, inefficient and very expensive. To deal with that, and to improve profit and reduce power consumption, this paper introduces a mechanism to allocate resources and share resources between the different cloudlets. With this system, the resource utilization of the different cloudlets could be optimized. However, different ideas still need to be considered: system scalability, inter-cloudlet communication and system cost.

To deal with disaster situations (earthquakes, tsunamis, etc.), an efficient emergency service is essential. In this context, to improve QoS, cloudlets could also be useful. Different types of services, including disaster area information sharing and safety information, should be managed. However, the network infrastructure could be destroyed and the network traffic congested. The work[32] aims to provide local cloud computing services in a delay-tolerant network (DTN) environment. The car is transformed into a virtualized cloudlet and a mobile disaster server. When the communication network is unavailable, the vehicle goes around the disaster area, collects data from the local servers, and shares this information with the global datacenter using the DTN protocol. In this system, the cloudlet approach provides a high level of flexibility. Indeed, the storage and computational resources allocated to the different services (disaster area information sharing, safety information) are dynamically managed according to the system load. However, for this system to be applied, allocated resource control, data synchronisation, and data transmission should be considered.

Beyond that, cloudlets could also be useful to improve the network scalability and to deal with limited bandwidth thanks to data pre-processing. Indeed, with computing and storage capabilities at the edge of the network, it could be possible to eliminate redundancies and transfer only the pertinent information. The authors of [33] suggested the idea of vehicular micro clouds as virtual edge servers improving the communication between the vehicles and the cloud infrastructure. Using an innovative clustering algorithm, the access points (APs), RSUs and eNB create clusters of vehicles. These clusters are composed of cluster members and a cluster head. The cluster head pre-processes safety data collected from the cluster members. This paper demonstrates the benefits of a cloudlet approach but there are some outstanding questions: cluster formation, optimal cluster size, intra-cluster optimal communication path, cluster head recalculation, and head cluster computational capabilities awareness.

The authors of [34] answered some of the questions raised in [34]. The work focuses on mobile vehicular cloudlets (MVCs) and aims to evaluate the serviceability of this approach. To do so, the vehicular network topology over a time span is modelled and a serviceability calculation algorithm is defined. Using the taxi mobility trace of Beijing, this paper demonstrates that depending on different parameters (delay tolerance, connectivity and mobility), the serviceability can be estimated and predicted. Nevertheless, various problems including vehicle speed, network congestion and vehicle capabilities should be considered.

Thus, to conclude this subsection, the cloudlet-based vehicular applications mainly focus on two important points: QoS and scalability. However, there are still some important open issues, not considered in these papers: security and privacy, application placement, and communication reliability.

4.2 Multi-Access Edge Computing Applications for Vehicular Networks

Because of the links between MEC nodes and cellular networks, many applications aiming to improve the network performances have been imagined. Similarly to the couldlet-based applications, two main objectives were identified: QoS on one hand and network scalability on the other hand.

In the future, the vehicular networks should be integrated within the 5G-cellular network and it raises some QoS challenges, in particular, latency and flexible service delivery. To overcome that, the authors of [35] introduced a MEC-based architecture for future cellular vehicular networks. The MEC servers are placed between the core network (CN) and the edge of the network and are connected with several BSs. According to the authors[35], this architecture could bring many benefits to the cellular network, including latency reduction, flexible services, real-time radio network information, congestion minimization and BSs collaborations. In addition, the MEC advantages are discussed for two applications: network slicing and vehicular handover. However, this is a proposal paper and to demonstrate the benefits of the proposed improvements, in-depth development, implementations and evaluations are necessary.

The paper[36] also aims to design a cellular network enabling a content delivery meeting the needs of the automated driving services: delay, throughput and location awareness. For this purpose, a two-level edge computing architecture composed of wireless infrastructure (BSs, RSUs) and vehicles is proposed. The vehicles perform the same functions as BSs: uploading, caching and sharing content. The authors[36] described a mechanism for content caching at the BSs level and content sharing among vehicles. This system is evaluated using real taxicab traces in Beijing. Nevertheless, to provide a complete evaluation different points should be considered: vehicles speed, network congestion, vehicle capabilities, and service differentiation.

The work introduced in [37] is the third paper focusing on latency reduction and high-bandwidth guarantee. Here, MEC is used to assist the software-defined vehicular network (SDVN) architecture through data transmission time decrease and QoE enhancement in delay-sensitive applications. A complete architecture (data plane, MEC-assisted control plane, application plane) is described. This architecture is validated in an urban traffic management system through an evaluation of the benefits of MEC in terms of reliability, latency, and bandwidth. However, as noticed by the authors[37], this architecture could be improved by an efficient handover mechanism and data synchronisation.

Several papers focus on another important point: network scalability and data off-loading. In fact, because of the increasing demand for Internet content, the cellular network could be overloaded. Therefore, providing solutions enabling to off-load the core network is necessary. That is why the work described in [38] proposes a cloud-based MEC off-loading framework for VANETs. The MEC servers are associated with RSUs, exchanging data with each other through wireless backhauls. In this paper a new system using predictive mode transmission is proposed. With this computational off-loading scheme, in a high density vehicular network, the vehicle move is predicted and through V2V communications the computational task is transmitted to a MEC server that the vehicle will reach in the near future. Therefore, when the vehicle reaches the corresponding MEC server, it receives the computational task result. This scheme reduces the inter RSUs communications and therefore the off-loading transmission costs. However, the network congestion and load balancing issues are not discussed here.

As the previous paper emphasizes, data off-loading is an important challenge for cellular networks. To tackle this issue, some studies associate MEC with other technologies. For example, the paper [39] proposes a V2V data off-loading solution for cellular network based on the software-defined network (SDN) integration in a MEC architecture. With this system, the MEC servers are also SDN controllers calculating the V2V communication path between communicating vehicles in order to off-load the cellular network. The integration of the SDN controllers in the SDN-MEC architecture enables the system to realize a centralized calculation of the V2V communication path. In this paper two algorithms are proposed and compared with the existing GD-NSR (greedy routing-network state routing) solution: lifetime-based routing and lifetime-based path recovery. To complete this approach and to meet the vehicular applications' needs, the required QoS for a given task (service differentiation) and V2V optimal path (reliability) should be considered in the off-loading process.

Finally, using a different approach, the authors of [40] also aimed to off-load the cellular network. Here, the BSs are used to dispatch the content between different vehicles in order to provide services to the end users. Thus the BSs and vehicles computing and storage capabilities are both used. A QoE metric and a QoE-aware caching policy are introduced in order to design a content allocation system optimizing the user-QoE and the amount of off-loaded data. Nevertheless, to evaluate the benefits of this approach, different parameters must be discussed: vehicles speed, network congestion, vehicle capabilities, and service differentiation.

To conclude this subsection, these MEC-based applications tackle two important issues related to the integration of edge computing in the vehicular networks: QoS and network scalability. However some important challenges, including security and privacy, communication reliability and resource management, are not discussed.

4.3 Fog Computing Applications for Vehicular Networks

As suggested in a previous paper ([48]), the applications of FC in a vehicular environment are numerous: smart traffic lights, parking systems, content distribution and decision support systems are only part of the endless possibilities. This subsection aims to present the main studies in this field. They can be categorized into main groups: applications improving QoS and big data solutions for the vehicular networks.

The authors of [41] aimed to improve the QoS of applications (bandwidth and latency) in the highly mobile and dense vehicular environment. To do so, a system based on the one machine-to-machine (M2M) architecture is proposed. In this system, the fog nodes are deployed in RSUs and M2M gateways, using the storage and computational capabilities of these devices and forming a platform communicating with a cloud system. Using the data of vehicles and smartphones, the main goal of this project is to provide consumer centric services such as an M2M data analytics with semantics web technologies, IoT services discovery or connected vehicles management. This system should be able to inter-connect vehicles and fog nodes located near these vehicles. Nevertheless, this solution is just a proposal and has not been implemented and evaluated yet. Moreover, different improvements could be considered: data management, services management, and crowdsourcing.

In traffic management systems, transmission delays are a critical limiting factor for large-scale deployments. That is why, to reduce transmission delays, a fog-enabled off-loading algorithm, minimizing the average response time of a real-time traffic management, is proposed in [42]. This algorithm is based on a three-layer architecture: the cloud layer formed by traffic management server and trust third authorities, the cloudlet layer storing road traffic conditions' information of a narrow geographic area, and a fog layer corresponding to vehicles connected to RSUs. Using load balancing, this multi-layer architecture of computational nodes aims to reduce delays for traffic management systems. However, we can notice that only the vehicles connected to RSUs are considered. Therefore, this solution could be extended and improved by integrating vehicles outside the RSUs communication range. Moreover, a load balancing realized by the vehicles could also be an interesting point.

The idea behind this paper ([43]) is that fog computing capacity will not be enough to deal with consumer demand during peak hours. Fog vehicular computing (FVC) is presented as a solution augmenting the FC capabilities thanks to VCC. Therefore, it could be used to guarantee a high QoS and to improve the network scalability. In this paper a three-layer architecture is proposed for FVC. The first one is the application and services layer, in other words, the real-time applications of end users. The second layer, the policy management layer, manages the life cycle of tasks and is composed of three sublayers (policy sublayer, fog sublayer, and vehicular cloud sublayer). Finally the abstraction layer enables FVC to deal with heterogeneous platforms. Besides this, a decision-making process allowing FVC to select the sublayer (FC or vehicular cloud computing) providing the lower completion time is also proposed and compared with the existing FC solution. To complete this solution and evaluate its relevance, the implementation in a real environment and the comparison with existing state-of-the-art solutions would be necessary.

As in the work described in [43], the authors of [44] aimed to deal with the increasing number of vehicles and vehicular applications by providing a scalable and low cost solution. To achieve this, vehicles are considered as FC nodes and a system called vehicular fog computing (VFC) is proposed. In this paper the vehicles are split into two groups with different characteristics: moving and parked vehicles. The main idea is to highlight the ability of VFC to improve the global network capacity and to complement the existing cloud system. To do so, a capability analysis, using the actual data of the vehicular activity in different cities, has been carried out. The results show that VFC could improve network connectivity, data packet transport and computational performances. Nonetheless, to make this proposal a reality, many points still need to be considered: vehicle mobility, capacity analysis, implementation, and evaluation.

Big data for the vehicular applications (traffic management, navigation, remote fault diagnostics, etc.) is very important. A central cloud for big data management presents different limitations: latency, mobility support, scalability, and efficiency. That is why the authors of [45] proposed a regional cooperative fog computing-based intelligent vehicular network (CFC-IoV). CFC-IoV presents three particular characteristics. It is an open system handling heterogeneous networks and a geographically and hierarchically organized network. It is also a local and regional architecture. CFC-IoV is composed of two main layers, the fog layer including local fog servers (LFSs), cloud servers and a coordinator server monitoring the LFSs, and the edge layer including the VANETs, IoT and mobile cellular networks. With this architecture, this paper also tackles two fog computing issues: cooperation and hierarchical resource management. Cooperative fog computing is addressed by means of user mobility support, multiple sources data acquisition, and computational and storage services aggregating different LFSs and multipath data transmission for resource intensive applications. Thereafter, a hierarchical resource management for FC optimizing inter-fog QoS and intra-fog energy consumption is proposed and evaluated by simulations. However, in this approach the vehicle resources are not used and this direction could be explored. Moreover, the inter-fog node cooperation mechanism and their exchanges are not clearly defined.

Given that a centralization of geo-distributed data induces latency and cost, big data management and analysis is also the central subject of another paper: [46]. Its specific objective is to provide a fog-based Real-time Intelligent Transport System Big Data Analytics for delay sensitive ITS applications. This architecture is decomposed into three different dimensions. These dimensions are the computing dimension corresponding to CC and FC and composed of four layers, the real-time big data processing dimension composed of three layers (batch layer, speed layer and serving) and the Internet of Vehicles dimension divided into six layers (perception, infrastructure network, artificial intelligence, communication, application and business). To provide directions for future research, a list of key points enabling to design a fog computing-based architecture and a big data analytic system in a vehicular environment are mentioned in this paper. Moreover, different research directions are highlighted by the authors: real implementation and deployment of FC in the vehicular environment, and integration of big data analysis in an FC-based vehicular environment.

As a conclusion of this subsection, two main improvements have been discussed: QoS and big data analysis (data management). However, different important issues still need to be tackled: security and privacy, orchestration and communication reliability.

4.4 Comparative Analysis: Application and EC Technology Choice

This subsection aims to present the strengths and benefits of each EC technology for different types of applications.

The different tables introduced in the previous parts (Table 1–Table 3) provide useful information about the different applications of EC technologies. The main differences of these technologies and some examples of applications implementing these technologies are described. Coupling them, it is possible to determine which technology is the best for a specific type of applications: FC, cloudlet, or MEC. Different parameters presented in Table 2 and Table 3 seem to be interesting to make a wise choice: context-awareness, access technology, end-user proximity and latency, capabilities (storage, communication and computation), cost and flexibility. Fig.4 identifies the strengths of each technology according to these four parameters.

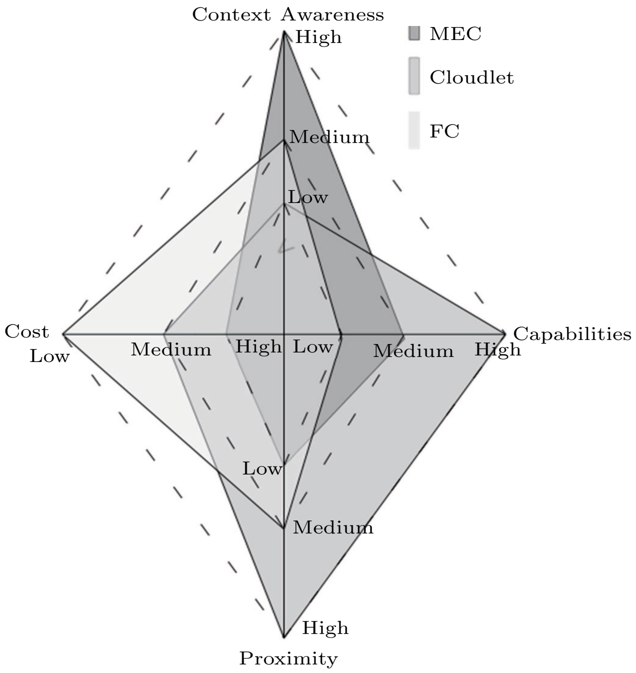

Fig.4. Benefits of the EC technologies in the vehicular environment.

Subsection 4.1–Subsection 4.3 show that some features and some benefits are related to one EC implementation only. For example, according to Table 3, low cost deployment is a common motivation for FC implementations. Indeed, using the computational and storage capabilities of legacy devices, with no additions, does not need any deployment and therefore is a low cost solution. This system is also really flexible. It does not need any physical deployment and because of that it could be really simple to add, remove or modify FC nodes. However, with FC, the vehicles are individually considered and therefore each FC server only provides low storage and computational capabilities.

Flexibility is also a cloudlet feature. Indeed this architecture uses fixed deployments (RSUs) but, in many applications, is also based on the vehicular cloud computing (VCC) idea. Therefore this approach uses the combined resources of groups of vehicles, regarded as one single entity, to enhance the storage and computational capabilities of the global network. Using fixed deployments (RSUs) this approach is more expensive and less flexible than FC, and using a distributed decision system, the latency could be more important. However, VCC could easily integrate new vehicles according to users' needs, providing a high flexibility.

Finally, context-awareness is the main benefit of MEC. Indeed, as Cloudlet, MEC provides high storage and computational capabilities at the edge of the network. However it is only based on fixed and expensive deployments within the cellular network architecture and therefore it is a less flexible and more expensive solution. Nevertheless this solution can use the network real-time information and the users' information to optimize the global network functioning, to reduce transmission costs and enable fast innovation thanks to the deployment of virtual network functions.

Thus, with such differences between the different EC technologies as flexibility, context-awareness, access mechanism, deployment cost, latency storage and computational capabilities, it is possible to link vehicular applications with optimal EC technology.

FC is only able to provide low storage and computational capabilities. However, it is a less expensive and more flexible solution. That is why for low-value-added services or lightweight application requiring low latency and fast processing, FC seems to be the best choice. Thus, for the road safety applications (intersection coordinator, obstacles detection, collision avoidance systems) or driver assistance applications (cooperative mapping, cruise control) and health monitoring services, FC is an interesting solution. Moreover, in an IoV environment, different types of nodes could communicate using different protocols of communication (vehicles-to-pedestrian, vehicles-to-grid, etc.) and different access technologies (BLE, WiFi, etc.). FC could be an efficient way to deploy applications interconnecting heterogeneous systems.

Cloudlet is based on the deployment of servers at the RSUs level and therefore it is a more expensive solution than FC. However, it is also a flexible solution using the VCC capabilities, limiting the cost of infrastructure and providing high computational and storage capabilities. Therefore, for low latency, computation-intensive and data-intensive applications, cloudlets seem to be the best choice. For different applications, in particular, infotainment and advertising applications (augmented reality, multimedia applications or points of interests) requiring a guarantee of QoE and QoS or transport management applications (parking slot booking), cloudlet is an interesting solution.

Finally, MEC is a more expensive and less flexible solution requiring important deployments. However, even if FC nodes and cloudlets provide basic context-aware applications (location aware, high proximity, etc.), MEC servers, using the BSs or RNCs as infrastructure, can benefit from important real-time network information, accurate location and status information of the devices. With the emergence of VANETs networks, network off-loading is an important challenge. Many MEC applications presented in this paper aim to tackle this issue. Indeed, using network information, different types of MEC applications could be designed: packet prioritization, content delivery, and edge caching. In addition, MEC also provides important computational capabilities and proximity. That is why, with context-awareness (including accurate location awareness) and proximity, MEC could be useful for high-value added applications such as transport management applications including geo-distributed real-time traffic management systems and also network services such as SDN.

In this part, each technology, depending on their strengths (context-awareness, access technology, end-user proximity, latency, resources, cost and flexibility), is associated to different kinds of applications and this classification is summarized in Fig.4 and Table 4.

Table 4. Targeted Application and Technology Choice

Technology	Application
Cloudlet	Infotainment and advertising (AR, multimedia, etc.), transport management (parking slots booking)
FC	Road safety applications (intersection coordination, etc.), driver assistance (cooperative mapping, etc.)
MEC	Network off-loading (prioritization, edge caching), transport management (R-T traffic management systems), network services (SDN)

5 Open Issues and Future Directions

Different applications of EC in the vehicular environment have been presented in Section 4. As shown in Table 3, different important challenges related to the integration of EC in the vehicular networks have already been considered: QoS, data management and network scalability. Nevertheless, different challenges have not been discussed yet: security and privacy, communications reliability, applications placement and resource allocation, integration in the future 5G ecosystem. In this section, these issues, the existing solutions, and the open challenges are presented.

5.1 Security and Privacy

In the vehicular environment, security is paramount to developing road safety application. A vehicle can be the target of several external attacks including threats to wireless interface (malware, sybil, spam, etc.), to hardware and software (message suppression, routing attack, etc.), and to infrastructure or to sensors input. The work detailed in [49] lists the major attacks and also presents solutions and countermeasures for each attack. With EC, the protection of the edge computing nodes (RSUs, Cloudlets, BSs, vehicles, etc.) is an important concern. Beyond security, privacy is another important aspect. In the future, vehicles will store and share many personal data such as users' preferences or travels. These pieces of information and the users' anonymity must be protected and that is why EC privacy preserving schemes are being developed ([50]). However, despite these theoretical proposals, the vehicular networks are still vulnerable to cyber-attacks, and in a multi-tenant application environment, privacy will be an important challenge.

In [51], the authors presented the main security and privacy issues related to FC and the existing research. They also introduced the open challenges including authentication of the fog nodes and trust establishment in this flexible environment, privacy preservation of the users, anonymity and intrusion detection systems. In [52], the authors focused on the vehicular fog computing (VFC), one of the applications introduced in the Section 4. In this paper, a specific use case is analyzed: a compromised fog node in a traffic management system. For this selfish attack, potential countermeasures are discussed.

With MEC, integrating cloud capabilities within the edge of the cellular network could lead to physical and cyber-attacks.

With Cloudlets, trust establishment and privacy preserving are important concerns[53]. Indeed, the cloudlets could be deployed by independent small businesses and companies, and the security of these devices should be guaranteed by these companies. Moreover, the privacy of the data in these private infrastructures could also be a problematic issue. Finally, with VCC a trustworthy environment among the vehicles should be established.

To conclude, efficient technological solutions need to be developed, simulated and tested for large-scale deployments.

5.2 Communications Reliability

For road safety applications, reliable communications enabling cooperative collision warning, obstacle detection or intersection coordination is essential. The highly dynamic topology of the vehicular network and the traveling speed of the vehicles cause frequent disconnections and many studies propose solutions to overcome the communications limitation (for example, [54]). Moreover, broadcast protocols allowing fast information dissemination and quick responses and therefore providing efficient end-to-end warning messages are required[55]. With the EC technologies, if a vehicle is too far from the EC node (RSUs, BSs, cloudlets), V2V communications must enable the information dissemination and the current broadcast limitations could be problematic. For the EC services including road safety or advertising, Quality of Service (high throughput) is also an important subject. As efficient Medium Access Control (MAC) protocols are required for reliable communications, the authors of [56] presented some MultiChannel Medium Access Control (MCMAC) WAVE protocols and demonstrated their current limitations in terms of QoS, highlighting future research and development opportunities.

For the cloudlet implementation, the communication reliability is really important[10]. Indeed, the storage and processing system is based on moving and communicating vehicles. While taking into account the network constraints, the Cloudlet system should be able to provide a high QoS. This is an ongoing challenge. Moreover, the cloudlet operating should not interfere with the communications of the vehicles hosting the cloud services.

For FC, if different communication technologies are available, the implementation of software-defined and cognitive radio systems would be an interesting challenge. Indeed, thanks to this radio the FC server could be able to determine, at any time, which access technology should be used to provide the best performances (error rate, latency, etc.).

Finally, with MEC servers integrated in the cellular network at the BSs or RNCs level, to ensure the availability of the mobile network, it is necessary to guarantee the robustness and resilience of the MEC servers[57].

5.3 Applications Placement, Resource Management and Orchestration

EC technologies aim to bring cloud capabilities closer to users providing lower latency, context-awareness and higher bandwidth. That is why the placement of the application is really important. Indeed, the computing nodes provide applications to the surrounded users and therefore, to be useful, the services hosted in the EC servers should meet the users' needs.

The application placement cannot be de-linked from resource management. In fact, the resource allocation aims to maximize the resource utilization of each EC node and optimize the global computation time, the latency and the energy consumption. Therefore, a fair allocation of the available communication, computational and storage resources between the different applications and the different clients, is an important problem.

End-user mobility is a recurrent issue with EC; however in a vehicular environment, with vehicular FC or VCC, the EC nodes can be moving vehicles. For this reason, the placement of applications should be based not only on the end-user mobility and the node capabilities but also on the EC node mobility.

This mobility represents an open issue for the resource management and orchestration of the Cloudlet implementation and, therefore, the scalability of this architecture[58]. Indeed, the vehicles are moving and providing a stable cloud and stable computational and storage capabilities as a whole is an important issue.

With FC, the capabilities of an FC node depend on the type of equipment and the development of QoS-aware fog service placement algorithms respecting the hardware and software constraints is necessary[59]. Moreover, FC is a really flexible architecture and nodes should be easily added or removed. Therefore, the FC orchestration should be efficient, fast and scalable. The scalability of the control layer and the efficiency of the scheduling are open issues[60]. The task distribution among the members of a cloudlet or the management of large groups or vehicles, for example, could be improved.

Even if a MEC server has high storage and computational capabilities, these resources are limited. Therefore, it should be important to optimize the resource utilization and tasks scheduling according to the requirements of the different applications and users, the available resources and the tasks synchronization to provide high performances (latency, throughput, packet loss, etc.) with limited resources[61].

5.4 Integration in the Future Ecosystem

Finally, the 5G network will be another important technology to consider in the future. Indeed, the 5G network will offer new uses including VANETs, industrial monitoring or Smart City, forming a global sliced network. These different services can be classified into three main types of communication with specific requirements: capacity enhancement (enhanced Mobile BroadBand, eMBB), massive connectivity (massive Machine Type Communications, mMTC), and ultra-high reliability and low latency (Ultra-Reliable and Low Latency Communications, URLLC). Different improvements will be possible thanks to a new virtual network architecture, Network Slicing[62]: services differentiation, performance guarantee, and diversity management. Moreover, many technologies such as software-defined network (SDN), network function virtualization (NFV), artificial intelligence (AI) or blockchain should be part of the future ecosystem. They could offer different benefits such as the flexibility of the network, lower operating costs, the dynamic management of the network, higher security, big data processing, network programmability and decentralization.

As shown in [32, 38, 40], some studies are now trying to merge these different technologies with EC in order to improve the network performances using the advantages of each technology. In fact, EC technologies with low latency and context-awareness could offer solutions to the current SDN limitations: hierarchical and decentralized architecture. Moreover, Blockchain, NFV and AI have a great deal to offer in the development of EC. 5G networks are the future. These studies and research work are in the early stages, and many developments and improvements are still possible.

For MEC, integrated in the cellular network architecture, a main challenge will be the interaction with the environment deployed at the BSs level. Indeed, in the future, SDN and NFV should be deployed at this level and defining the functioning of these different technologies as a whole will be important[63].

In order to answer the challenges of the cloudlet and FC challenges, integrating SDN could be a valuable solution[14]. This technology could resolve many issues including virtual machines mobility, scalability, flexibility or communications and resource management.

Finally, for these different technologies (MEC, FC, cloudlet), it could be relevant thinking about integrating AI techniques (machine learning or deep learning for example) at different levels: security, reliability, mobility and resource management or orchestration.

6 Conclusions

This paper focuses on the integration of an emerging paradigm, edge computing (EC), within the vehicular ad-hoc networks (VANETs). With EC, communication, storage and computational capabilities are brought closer to end users. This could offer many benefits to the vehicular networks: low latency, high bandwidth, and context-awareness.

The principal characteristics of the vehicular environment and the benefits of EC for some vehicular applications are introduced in the first part of this paper. Then, the three main approaches of EC (mobile edge computing (MEC), fog computing (FC) and cloudlet) are presented and their standard features compared: founder, supporting organization, architecture, equipment type, communication technology, etc.

After that, these different technologies and their applications within the vehicular environment are analyzed. For each application, the aim, the motivations, the benefits and the limitations are presented. Moreover, the most appropriate technology for different types of vehicular applications (infotainment and advertising, road safety, transport management, etc.) is evaluated. This classification is realized according to different criteria: cost, access mechanism, context-awareness, proximity and storage and computational capabilities.

Finally, integrating the EC technologies in the VANETs is not without challenges. The most important challenges are presented for each technology: security and privacy, communications reliability, applications placement, and resource management and integration in the future 5G ecosystem.

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Appendix

Appendix 1. Acronyms

Acronym	Meaning
AI	Artificial intelligence
AP	Access point
AR	Augmented reality
BS	Base station
C-ITS	Cooperative-intelligent transportation system
CaaS	Communication as a service
CAPEX	Capital expenditure
CC	Cloud computing
CFC-IoV	Cooperative fog computing-IoV
CN	Core network
DTN	Delay tolerant network
EC	Edge computing
eMBB	enhanced mobile broadband
ETSI	European Telecommunications Standards Institute
FC	Fog computing
FVC	Fog vehicular computing
GD-NRS	Greedy routing network state routing
GDC	Global disaster cloud
IaaS	Infrastructure as a service
LDC	Local disaster cloud
LFS	Local fog server
IoV	Internet of vehicles
M2M	Machine-to-machine
MEC	Mobile edge computing
mMTC	Massive machine type communications
MVC	Mobile vehicular cloudlet
NFV	Network function virtualization
NS	Network slicing
OPEX	Operating expenses
PaaS	Platform as a service
PoI	Point of interest
QoE	Quality of experience
QoS	Quality of service
R-T	Real-time
RAN	Radio access network
RNC	Radio network controller
RSU	Road side unit
SDN	Software-defined network
SDVN	Software defined vehicular network
URLLC	Ultra reliable and low latency communications
UX	User experience
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VANET	Vehicular adhoc network
VCC	Vehicular cloud computing
VFC	Vehicular fog computing