Mobility Management in 5G-enabled Vehicular Networks: Models, Protocols, and Classification

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Over the past few years, the next generation of vehicular networks is envisioned to play an essential part in autonomous driving, traffic management, and infotainment applications. The next generation of intelligent vehicular networks enabled by 5G systems will integrate various heterogeneous wireless techniques to enable time-sensitive services with guaranteed quality of service and ultimate bandwidth usage. However, to allow the dense diversity of wireless technologies, seamless and reliable wireless communication protocols need to be thoroughly investigated in vehicular networks environment. Henceforth, efficient mobility management protocols that mitigate the challenges of vehicles' mobility is essential to support massive data loads throughout various applications. In this article, we review different mobility management protocols and their ability to address issues related to 5G-enabled vehicular networks within the related works. First, we provide a broad view of existing models of vehicular networks and their applicability to the next generation of wireless networks. Next, we propose a classification of several vehicular network models that suit the 5G wireless network, followed by a thorough discussion of the mobility management challenges in each of these network models that need to be addressed and then discuss each of their benefits and drawbacks accordingly.

CCS Concepts: • **General and reference → Surveys and overviews**; • **Networks →** *Network protocol design*; *Network mobility*; *Network manageability*;

Additional Key Words and Phrases: Mobility management, 5G networks, machine learning, handoff management, VANETs

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1 INTRODUCTION

The new market demand from end-users, developers, and service providers, for high-speed wireless Internet access, have led both industry and academia to work on the development and design of the next generation of wireless networks [Akyildiz et al. 2016]. Nowadays, people rely on mobile Internet services all the time, while driving vehicles or riding on public transportation. This leads to an enormous increase in data transmissions with the currently available networks. Vehicular networking has been a vital component for mobile technologies to support massive data load through various applications. In general, vehicular networks application can be classified as

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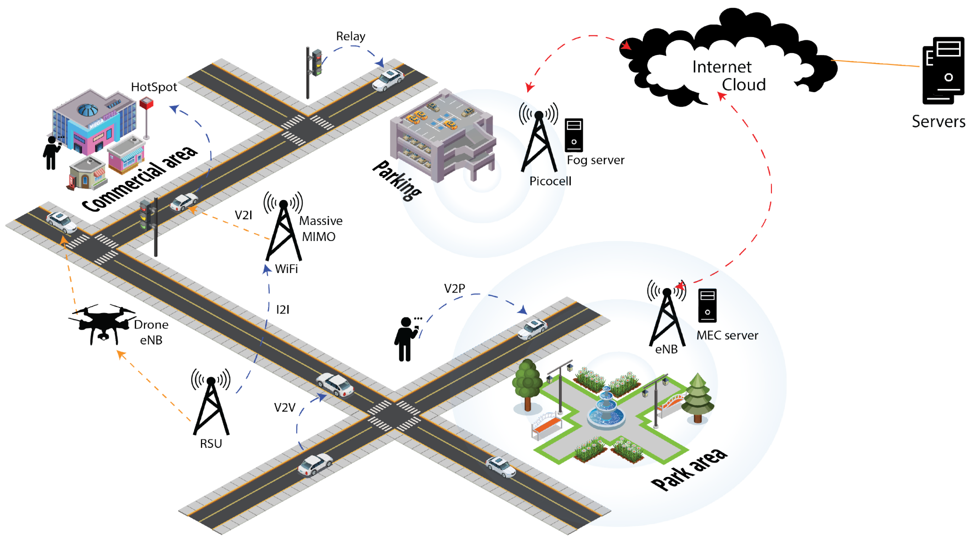

Fig. 1. 5G Vehicular Networks Vision.

safety-based applications and *non-safety* applications [Kim et al. 2018]. The former includes safety messaging, alerts, and warnings, which are disseminated among entities in a vehicular network (i.e., vehicles and roadside units). Safety applications infer high efficiency and very low latency in comparison to non-safety services and applications. As for Non-safety services, they include traffic management services and infotainment applications. Even though traffic management services, like those of traffic monitoring, traffic-lights control, toll road service, road diversion alerts, and local area maps updates, do not require low latency demands. Still, they need to be prepared to handle the amount of data flow in the network [Qiao et al. 2018]. Whereas, traffic control applications include smart navigation, finding optimal routes for intelligent vehicles, and smart traffic light scheduling and traffic flow control through data dissemination.

Furthermore, applications such as autonomous driving are anticipated to be highly accurate and effective in terms of improved data rates transmission, reduced latency, and a wider variety of communication. One promising solution is through the advancement of V2X communication in the next generation of heterogeneous vehicular networks. The next generation of wireless networks, as seen in Figure 1, incorporates several heterogeneous communication techniques to sustain different quality requirements and constraints from service providers, applications, and users. Currently, vehicular networks rely on wireless communications such as WAVE/IEEE802.11p, Cellular Long Term Evolution (LTE), and, most recently, fifth-generation (5G) systems to deliver different kinds of traffic management, infotainment applications, and safety services. However, enabling seamless mobility across various access networks is a fundamental issue to provide services without interruptions.

The 5G technologies are promising solutions for vehicular networks [Shah et al. 2018], in which vehicles will have access to emergency services and high bandwidth-intensive applications in very low latencies such as video streaming and real-time traffic conditions. However, in the 5G-enabled environment, vehicular networks face several significant problems affecting current architecture designs such as mobility management, back-haul networking, air interface, and traffic safety [Mitra and Agrawal 2015]. Mobility management is composed of two main parts, *handover* and *location* management protocols [Aljeri and Boukerche 2018]. The latter is mainly concerned with the mobile terminal's (i.e., vehicle's) location updates and paging techniques, and the former (i.e., handoff management) deals with sustaining an ongoing vehicle's connection while switching between different points of access. As vehicles travel across cells or local radio access boundaries, the network must be able to locate vehicles and automatically route/forward data packets to the new vehicles' location. A seamless handover process with very low handover latency that provides quality of service from source to target access networks guarantees effective mobility management support. Therefore, mobility management is once again getting significant exposure from both academia and industry in the next generation of wireless networks.

In this article, we present a thorough survey and detailed insights into the background, models, challenges, and solutions of mobility management in 5G-enabled vehicular networks. We classify mobility management solutions, based on the used vehicular network model, into several groups: HetNet-based, SDN-based, Fog-based, and Hybrid-based vehicular networks. Therefore, enabling other researchers in the field of Intelligent Vehicular Networks to have an in-depth understanding of mobility management challenges and future directions in the next generation of wireless networks.

The remainder of this article is organized as follows. We start by reviewing the 5G systems requirements and the applicability of current vehicular network technologies in Section 2. Classification of existing solutions and standards for mobility management in 5G-enabled vehicular networks based on their network model is discussed in the following sections. In Section 3, the HetNet-based vehicular networks are surveyed and related literature that proposes solutions for mobility management in HetNet-based vehicular networks. In Section 4, we outline the SDN-based vehicular network models and designs followed by a review and discussion of the mobility management protocols introduced by related proposals. In Section 5, we discuss the proposed solutions that use the fog-computing paradigm for mobility management in vehicular networks. We explain the hybrid methods of the HetNet, SDN, and Fog approaches in Section 6, followed by potential future research directions and conclusions in Sections 7 and 8.

2 5G: AN OVERVIEW

Since 2010, the rapid evolution of wireless communication technologies has been witnessed through industries and research communities, from 4G Long Term Evolution-Advanced (LTE-A) system to high-speed Wireless LANs. The next generation of vehicular networks is expected to be integrated with cellular networks and various wireless technologies, to provide a smarter and safer intelligent transportation systems [Mitra and Agrawal 2015]. Furthermore, the demand for real-time applications and services requires more bandwidth and lower latency to meet the desired Quality of Service [Akyildiz et al. 2016]. All together, lead for a new upgrade to the current communication technologies. Hence, 5G must provide adequate and reliable communication between heterogeneous networks, specifically in ultra-dense networks.

The METIS project [Fallgren et al. 2013] has laid down the building foundation of the beyond 2020 5G mobile and wireless system and specified the technical needs to foreseen the 5G requirements. Many other research groups started identifying the 5G vision, including Huawei [Huawei 2013], 5GNOW [Hossain et al. 2014], Nokia, 5G Forum, and more [Agiwal et al. 2016]. In what follows, we identify the main requirements to enable 5G in vehicular networks, the currently available technologies, and how they fit in the next generation of vehicular networks.

2.1 5G Requirements

The next generation of wireless networks is envisioned to sustain enormous services, devices, and applications, including connected vehicles, the Internet of Things (IoT), and smart city services [Akyildiz et al. 2016]. According to Intel, the next generation of wireless networks will deliver reactive, smart, and connected devices through efficient and reliable communication, massive

Machine-to-Machine (M2M) connectivity, and improved mobile broadband. In what follows, we discuss the requirements of 5G systems.

High data rates: The 5G networks are anticipated to accommodate about 100× data rates over current 4G networks [Fallgren et al. 2013]. Many techniques, such as millimeter-wave communication, heterogeneous networks, device-to-device communication, and massive MIMO, can be used to handle such performance. The Multiple-Input-Multiple-Output (MIMO) utilizes various access points to migrate more information, resulting in a higher flow rate simultaneously. Currently, all 802.11n wireless network standards support MIMO, and the evolved Massive MIMO technology was later introduced to provide superior energy and spectral efficiency [Aujla et al. 2017].

High Scalability: 5G networks are expected to accommodate and support 10 to 100 devices. Hence, an increase in signaling and data transmission, requiring enough frequency spectrum resources. Although current mobile communication systems are dedicated to providing consistent mobile broadband experience, yet many users today do not have a good quality of experience when surrounded by crowds. The objective is to increase the signaling capability and data transmission, which may require enough frequency spectrum resources to accommodate the growth in network size. Hence, providing fast connections and services to satisfy user experience at any time.

Ultra-low latency: The expected latency of 5G systems is to be 2 to 5 ms. The current LTE network round-trip latency is around 15 ms, and the dedicated short-range communication (DSRC) round-trip latency is approximately 10 ms. Several solutions can help in providing such latency through the use of D2D communication, Software-defined networks, and cloud RAN. Surely, in vehicular networks, enabling ultra-low latency will increase the efficiency of different applications. Kim et al. [2018] presented a study of vehicular safety applications' requirements, including speed warning, cooperative forward collision warning, road condition warning, and more, which requires very low latencies.

Reduced energy consumption and increased energy efficiency: To create a fully connected society, millions of devices must be connected, from sensors to actuators, in which, their main concern is low energy consumption and low cost. Some solutions include RF energy harvesting and environmental energy sources [Akyildiz et al. 2016]. 5G systems are envisioned to reach 10× longer battery life. Although several previous works on energy efficiency have been explored, yet it was mostly on legacy wireless networks. Therefore, new studies on 5G networks can be extended from previous concepts. Energy efficiency-aware cells that distribute the load on antenna's and automatically switching off when not needed. Backhaul systems are moving toward being self-organized and self-configured to reduce manual interference to reach energy efficiency.

2.2 5G-enabled Vehicular Networks

In Vehicular Networks, communications are usually exhibited between vehicles through Vehicle to Vehicle (V2V) communication technology, and also with infrastructure through (V2I) communication protocols, such as access routers, roadside units, and cells. With the proposed 5G features, vehicles will now have more flexibility and robustness in communication and applications. Vehicle to Everything (V2X) communication was introduced to provide all types of communication between vehicles, infrastructure, network, and pedestrian [Chen et al. 2017]. Therefore, improving traffic efficiency, on road safety, and QoS-aware infotainment services. Several existing paradigms are starting to shift their work toward enabling 5G by further enhancing the Wireless Communication Networks (WCNs) to reach the requirement of 5G specifications [Fallgren et al. 2013]. As current WCNs are across spectrum resources congestion with limited bandwidth, which raises a new challenge to utilize available sparse spectrum efficiently.

Since 2010, the IEEE802.11p/DSRC [Jiang and Delgrossi 2008] has been considered *The* protocol for vehicular networking applications and services. DSRC/WAVE is designed for vehicular environments, as a wireless communication medium that provides fast data packet transmissions between vehicles. DSRC combines GPS positioning and wireless network to disseminate safety services between vehicles and cooperative collision avoidance (CCA), with seven channels in the MAC layer on the 5.9-GHz spectrum, one channel for control packets, and the remaining ones are data service channels.

Since the new era of wireless networks has heterogeneous architecture, to include cellular and non-cellular technologies, a standard interface is needed to facilitate communication and transition between different techniques—one of the first solutions introduced by the IETF, Proxy Mobile IPv6 [Eiza et al. 2018]. The PMIPv6 is a mobility management protocol that works in a centralized manner. It includes a Local Mobility Anchor, referred to as LMA, to establish communication tunnels with the Mobility Access Gateways (MAGs), referred to as the core entity. Each MAG is responsible for users' data packets tunneled to the LMA, then to the Internet. Whereas the LMA is responsible for forwarding packets from the Internet to the end-users through their corresponding MAG. To manage the network status between LMA and MAG, Proxy Binding updates and acknowledgement packets are interchanged.

Another solution to support the heterogeneity of wireless access networks is the Media Independent Handover (MIH) framework [Taniuchi et al. 2009]. The MIH protocol offers a standard platform interface separate from all access technologies. The MIH, known as IEEE802.21, aims to provide interworking between IEEE 802 systems and other wireless access technologies (e.g., IEEE 802.11p and cellular networks). Three primary services are defined by the MIH: Event Services, Control Systems, and Information Services. The event service tracks the changes in the link characteristics and reports them, while the control system passes movement and connectivity-related commands. As for the information service, it eases the handover process by offering a mechanism for discovering possible neighboring networks within a geographic region.

Despite the fact that IEEE802.11p is deemed the *de facto* vehicular communication norm, several research studies investigated the potentials of the Long Term Evolution (LTE) to assist vehicular networks. Araniti et al. [2013] discussed such a possibility through the strengths and weaknesses of LTE in vehicular applications. A discussion on the feasibility of LTE-V2V and V2I for future 5G vehicular networks was presented in Vinel [2012] and Masini et al. [2017]. Cellular networks initiated the fifth generation of cellular networks (5G), as a new leap toward high speed, ultra-low latency network. The integration between 3GPP and non-3GPP wireless access technologies through the Evolved Packet Core was introduced in the 3GPP's Release(15) using Fast Proxy Mobile IPv6. Nonetheless, their protocol does not consider the availability of the resources before selecting the target cells, leading to handover failures and QoS degradations. Also, EPC has no disconnection process from the previous network after switching. Hence, it may lead to high overhead and cache issues, whereas the FMIPv6 and MIPv6 still suffer from additional signaling and traffic load. In Table 1, we present a comparison of different wireless communication technologies used in vehicular networks.

All the aforementioned vehicular communications require proper mobility management for vehicles. The proposed protocols in the literature that work toward mobility management solutions for the next generation of vehicular networks can be categorized based on their network model as follows. HetNet-based, SDN-based, Fog-based, and Hybrid-based solutions, which are summarized in Table 2—each category focuses on solving one or more issues in 5G vehicular networks mobility management.

3 HETNET-BASED VEHICULAR NETWORKS

With the emergence of autonomous driving in 5G-enabled vehicular networks and Intelligent Transportation Systems (ITS), new essential requirements are needed, including an ultra-low

Table 1. Current Radio Access Technologies for Vehicular Communications

Aspect	Wi-Fi	WAVE (802.11p)	LTE-Advanced	5G
Channel spectrum	20 MHz	10 MHz	Up to 640 MHz	1–2 GHz
Frequency Band	5/2.4 GHz	5.9 MHz	5.72–5.75 GHz	1.8 and 2.6 GHz
Coverage	Intermittent	Intermittent	Ubiquitous	Intermittent
Range	100 m	1 km	30 km	50 m
V2V support	Ad hoc	Ad hoc	D2D	C- V2X
flow rate	6–54 Mbps	3–27 Mbps	1.5/3 Gbps	>10–50 Gbps (expected)
Handoff type	Horizontal	Horizontal	Horizontal, vertical	Horizontal, vertical

Table 2. Mobility Management Based on Chosen Network

Classification	Method	Benefits	Challenges
HetNet-based	Adds small cells, interface between different RAT	Improves data rates and reliability	Deployment and transition criteria between different cells, ping-pong, HO failure
SDN-based	Separation of data and control planes	Improves network management	Ping-pong events, Densification and frequent HO issues
Fog-based	Offload control/ functions to fog cluster area	Closer to edge devices	When and where to offload
Hybrid-based	Combination of SDN, Fog, Cloud, Virtualization	Improves network management and data rate	Deployment, Coherence and management between different schemes

transmission delay [Ge et al. 2016]. The integration of cellular networks with the DSRC standard and other wireless technologies is considered a potential solution for meeting the communication requirements of the 5G systems. As we mentioned earlier, the Long Term Evolution (LTE) was introduced to assist vehicular applications [Araniti et al. 2013; Santa et al. 2008] because of the drawbacks in the IEEE802.11p standard in terms of low scalability and low capacity. Hence, the heterogeneity of different wireless technologies is a possible direction toward efficient mobility management and reliable communication in vehicular networks. In this section, we start by describing the overall network architecture, then define the mobility management component and phases, followed by the current issues and solutions.

3.1 HetNet-based Vehicular Networks Architecture

The Third Generation Partnership Project (3GPP) [3GPP n.d.] specified the new generation of wireless networks, the Long-Term Evolution systems (LTE / LTE-Advanced), which provides Internet Protocol (IP) data, and signaling transmissions, with a round-trip time below 10 ms, and transfer latency up to 100 ms. The LTE network architecture comprised of the Core Network (CN) and the Access Network (AN), in which the latter handles the radio channel resources and

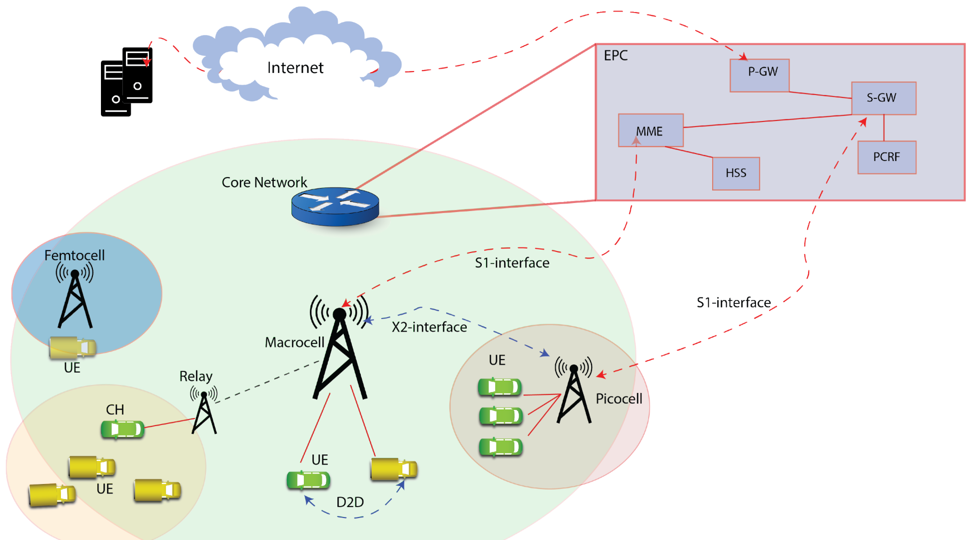

Fig. 2. HetNets architecture.

Table 3. Types of Cells in HetNet-based Networks

Cell	Transmission power	Coverage limit	Location
Macro-	46 dBm	1–30 km	Outdoor
Micro-	30–37 dBm	<2 km	Outdoor
Pico-	23–30 dBm	<300 m	Outdoor-indoor
Femto-	<23 dBm	<50 m	Indoor
Relay	30 dBm	300 m	Outdoor

handover decisions through the eNBs cells or base stations (evolved NodeB). Whereas the CN comprises three primary components, namely the Serving Gateway (S-GW), the Packet Data Network Gateway (P-GW), and the Mobility Management Entity (MME). The mobility management entity monitors authentication, security, and user's location. The S-GW is used to route, forward, and connect to the Policy and Charging Rules Function (PCRF). Finally, the P-GW enables the communication between the IP and the switch. To accommodate the growing load of users and data transmission on the network, the 3GPP introduced the Multi-Tier Heterogeneous Networks (HetNets). Small and simpler base stations define HetNets with different transmission capacity, range, carrier frequencies, backhaul links, and communication protocols, named micro, pico, and femtocells, in decreasing order of powers. Figure 2 portrays a general view of HetNets architecture.

Femtocells or Home eNBs (HeNBs) are wireless short-range access stations with a limited cost and power consumption capability. HeNBs allow signal transmission at high-frequency bands in low range, thus increasing spectral efficiency. The integrating mobile femtocells into a vehicular environment can help improve scalability, signal-to-noise, plus interference (SNIR) and throughput [Chowdhury et al. 2011]. The small cells, in Table 3, are designed to support higher data rates for low-speed UE and allow macrocell traffic to be offloaded to smallcells. Macrocells provide low to moderate communication for the global range so that any UE can be reached at any velocity. Nonetheless, the deployment of a massive amount of smallcells brings another challenge to resource allocations, interference mitigation, mobility management, and QoS efficiency [Xenakis et al. 2013]. For example, in a high-speed mobility environment, an abundant amount of transitioning will occur between small network cells along the road, which will then increase the network overhead and services disruption. Also, because of the different functionalities between macrocells and smallcells, the handover decision (i.e., when to perform handover and to which cell) should be carefully performed. That is to not only rely on network parameters such as signal strength, but also to support intelligent decision making with respect to current UE's service status, available resources, and surrounding network options.

Concerning the interference mitigation issue, the vast expansion of ubiquitous data and network densification (i.e., abundant cell deployment) have resulted in an increased spectrum interference. To enhance the spectral efficiency, a Multiple-input-multiple-output (MIMO) [Rusek et al. 2012] wireless technology is used, which enables various antennas to transmit more data packets with higher channel's ability simultaneously. Furthermore, the millimeter-wave transmission technique has been proposed to link users inside the vehicles and to overcome interference issues [Pi and Khan 2011]. Additionally, the mm-wave allows for more significant bandwidth allocation and expand current channels bandwidth limitation, thereby increasing data transfer rates and capacity. However, in this article, we focus on issues related to mobility management challenges and solutions.

3.2 Mobility Management in HetNet-based Vehicular Networks

Mobility management (MM) has been initially defined in the LTE standard to solely involve macrocells, which has been widely studied in the literature [Gódor et al. 2015] and reported reliable and seamless mobility. One of the reasons is the macrocells massive size, which means minimal handover failure (HOF) and ping-pong (PP) events are expected to occur. However, with the increasing number of smallcells and different radio access technologies that are combined in HetNets, new mobility management for HetNets is needed.

The handover process between cells, Radio Access Technologies (RATs), or carriers is performed differently. It requires proper management to enable vehicles to cross from one cell to another while preserving the same quality of service. The handover management offers a seamless transition between similar types of cells, different cell types, and distinct access technologies. Two main types of handover may occur in HetNets, *Horizontal* handover and *Vertical* handover. The horizontal handover (HHO) deals with the transfer of ongoing sessions within the same technology or the same network, while vertical handover (VHO) happens between cells of different technologies.

In HHO HetNets, several scenarios may occur, which include *Hand-in*, when the mobile device moves from macrocell coverage to smallcell coverage; *Hand-out*, when the mobile device returns from smallcell coverage to macrocell coverage; and *Inter-(H)eNB*, when a mobile device transition between smallcells. As for VHO, three possibilities of handoff can be present, inter-RAT, inter-LTE, and inter-Technology. The latter is concerned with the handover process between 3GPP and non-3GPP access technologies. The handoff process between different radio access technologies within the cellular networks is referred to as inter-RAT. While, the inter-LTE handoff is done between different versions of LTE (3G, 4G, etc.). The 3GPP has since presented the Access Network Discovery and Selection Function (ANDSF) [Gódor et al. 2015] as a new element to the Evolved Packet Core (EPC). This function supports the UEs to locate and connect to different RATs (e.g., WiFi, WiMAX).

The 3GPP specifies two standard interfaces between the wireless access point and the network core, namely X2 and S1. The X2 interface is designed for the handover between two eNBs served within the same MME pool and considered faster than S1 and defined only for Intra LTE handover. While S1 is used for Intra LTE and occasionally inter-RAT, only if the two eNBs are not connected

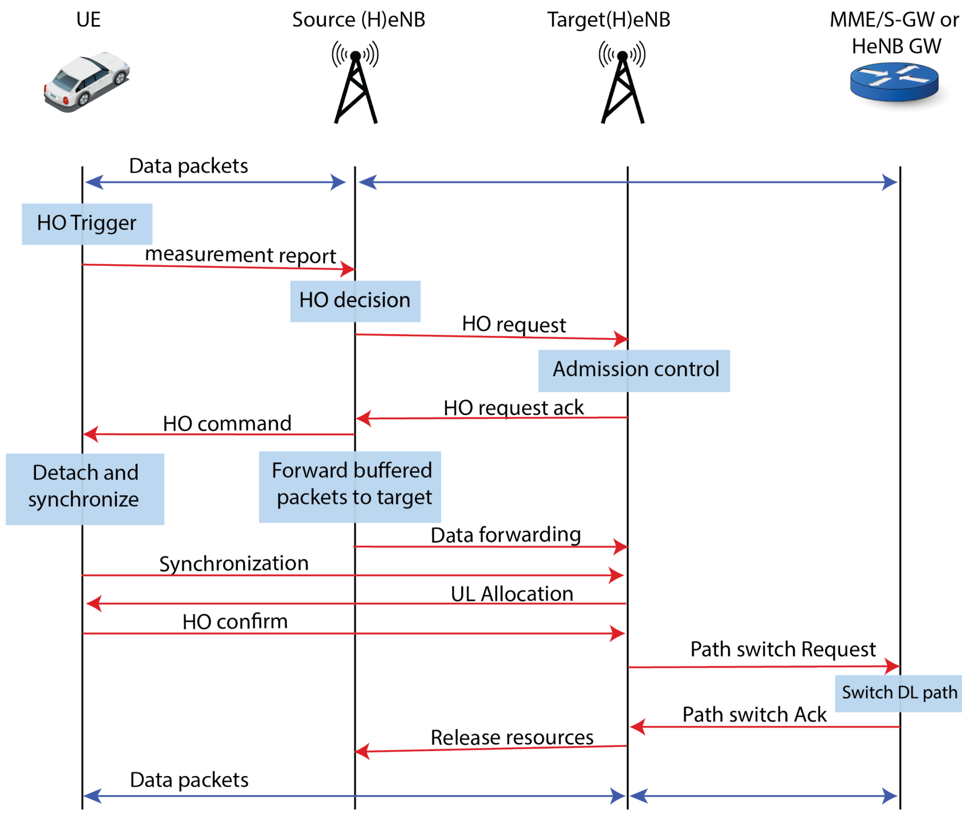

Fig. 3. Handover Process in HetNets.

to the same MME, X2 interface is not defined between two eNBs, or X2 procedure has failed due to errors. An illustrative scenario is introduced in Figure 2. In the case of inter-HeNB, either S1 or X2 interface is used, except when control access is required in the Mobility Management Entity, thus requiring the transition of handover requests through the EPC. The hand-out process can be directly done through the X2 interface unless it does not exist. Therefore, control packets need to be delivered through infrastructure links to the CN. However, because cells have different backhaul routes, it is the most challenging case.

In general, the handover process in HetNets is known to be a network-based terminal-assisted process, which means that the serving cell is the one responsible for the handover decision, while the user equipment (UE) (i.e., vehicle) gathers the measurement information. The handover process is divided into several phases: measurement/initiation (Trigger), decision making (Network selection), and execution, as seen in Figure 3. The handover initiation may be done on the UE or by the network. In either way, multiple measurements of near approximate access networks are gathered by the UE, such as Bet Error Rate, the distance between UE and cells, and received signal strength. Then, when the UE detects a trigger event, a measurement report is sent to the source cell to derive a handover decision. In the decision making (selection) step, a choice is made to which cell should the vehicle connects to next depending on the measurement report, resource availability, and network load. Finally, the execution phase is when a new link is set up with the target cell to authenticate, synchronize, and reconfigure network resources and settings. However, each step of the handover process may lead to an unpleasant experience for users. In the following, we address each stage of the handover procedure independently in HetNet-based vehicular networks and report on the methods currently suggested in the related works.

3.2.1 Handover Initiation (Trigger) Phase. Typically, the handover trigger is initiated due to several factors, either to offload high data traffic from macrocell, to enhance the received signal strength at the terminal device, or about to leave the current serving cell. In HetNets, the handover trigger is made at the serving cell with the assistant of the UE measurements report. Each vehicle integrated with a User Equipment (UE) will periodically monitor the downlink signal strength of nearby cells and processes the information by eliminating the signals' fading impacts and estimating defects in the handover measurements. If a criterion of the handover event is encountered within Time to Trigger (TTT), then a measurement report will be transferred by the user equipment to the current serving cell.

The standard rules of the handover function are categorized from A1 to A6 and B1 to B2 events, as specified in 3GPP [n.d.]. Event A3 is the most commonly used event to trigger the handover process, which is when the RSS value of the new cell exceeds the current cell. The Time to Trigger guarantees that a ping-pong event can be eliminated by specifying a time window in which a triggering event occurs to transfer the measurement record to the current cell. However, the static selection of the handover hysteresis and TTT values is no longer effective in HetNets [Lee et al. 2010]. A large TTT value with a high-speeding vehicle may experience an increased degradation in the reference signal received power (RSRP), referred to as the HO failure problem. Whereas a low TTT value will cause very frequent handover to or from cells, referred to as ping-pong problem, leading to high-performance degradation.

Besides, the reference signal received power (RSRP) estimations are conventionally used for handover measurements. However, in heterogeneous networks, different coverage area sizes may lead to mobility performance degradation if we continue using the same set of parameters. Several studies worked on adding more measurements such as user preferences, velocity, cost, power consumption, security, handoff latency, RSS, available bandwidth, network connection duration. In the following, we discuss the solutions presented in related works that address the drawbacks of the conventional handover trigger phase. An overall comparison between several related studies is provided in Table 4.

RSS-based HO trigger schemes: The Received Signal Strength is the computed signal power amount that is received by the end entity. Many schemes continued to use the received signal strength (RSS) as an indication to initiate or trigger the handover process. Each vehicle moving within the communication range of a cell will periodically measure the RSS value from each neighboring cell. However, a fixed threshold value is not anymore applicable in heterogeneous networks. Some research studies proposed the use of a dynamic RSS threshold value depending on mobile node velocity [Mohanty and Akyildiz 2006]. A vertical handoff protocol based on MIH/PMIPv6 for optimization is proposed in Omheni et al. [2017], in which they added a pre-handover process of resources checking, authentication, resources reservation, and IP assignment. The authors defined two thresholds to help predict the degradation of link quality. However, additional context messaging overhead is introduced in their work.

SINR-based HO trigger schemes: The signal-to-interference and noise ratio (SINR) defines the quality of wireless cells by computing the average received power from a signal reference signal, which can represent noise and interference from the network. A two-tier LTE network handover decision is proposed in Xenakis et al. [2012] to reduce the transmission energy of mobile terminals. The proposed scheme is dependent on adjusting the handover Hysteresis Margin to a defined signal-to-interference and noise ratio threshold and using the quality measurements of the target cell. However, having a predefined threshold value is not an optimal solution with the presence of several radio access technologies.

Table 4. Handover Trigger Schemes in HetNet-based Vehicular Networks

Related work	Measurements	Method/ Model	Goal	Network	Limitation
Xenakis et al. [2012]	SINR	dynamic hysteresis margin	reduce UE's power transmission	Two-tier femtocells	ping-pong effect, not applicable for high speed
Wu et al. [2013]	RSSI, Velocity	Low/high speed triggers	offload macrocells traffic, reduces redundant HO	Femto-macrocells	highway environment only, overhead of scanning
Li et al. [2012]	RSRP	Time-series prediction	Reduce HO latency	Two-tier femtocells	limited to single measurement
Becvar et al. [2011]	RSSI	Two-thresholds prediction	Reduce redundant HO	Macrocells	Insufficient use of recourse
Omheni et al. [2017]	SINR, RSSI	Pre-HO threshold	Reduce HO delay and signalling	Inter-RAT	movement and velocity is not considered
Kitagawa et al. [2011]	RSRP, failure cause, failure rate	Adjustable HO margin	reduce HO failure, ping pong	macrocells	Limited to macocells

Mobility-based HO trigger schemes: In heterogeneous vehicular networks, a single indicator such as RSS or SINR is inefficient, since different criteria need to be looked at before a decision is reached, in which some of them might be conflicting. The authors in Wu et al. [2013] proposed a speed-based handover scan trigger scheme in Femto-Macro-cell Networks. When the speed of the mobile terminal is higher than a pre-defined value, then the mobile terminal will only scan macrocells, thereby avoiding unnecessary handover to femtocells. However, pre-defined values usually tend to be unrealistic, which needs to be redefined for different scenarios and environments. It is noteworthy that mobility-based solutions (i.e., vehicle's location/speed) have been intensively used for the handover decision (selection) phase, and very few studies used mobility for the handover trigger phase.

Prediction-based HO trigger schemes: Predicting the handover process ahead of time could save a lot in handover latency by initiating the handover early enough to complete the necessary resource allocation in the target cells. Li et al. [2012] proposed a predictive solution based on time-series analysis theory using the reference signal received power (RSRP). The handover trigger works in two-priority event evaluation method, in which the classical handover trigger first initiated, if no target cell meets a specific condition, then the predictive trigger method is commenced. Results showed that the handover latency is reduced with high prediction accuracy. In another work [Becvar et al. 2011], a two threshold-based handover mechanism is proposed using the RSSI parameter with hysteresis. Their scheme uses a sequence of RSSI samples to determine the number of estimated handovers between the current and the target cells. Therefore, assessing the handover probability of the available cells. Additionally, the authors studied the impact of RSSI fluctuations on the handover prediction. Another work by Song et al. [2014], used a grey theory to implement a handover trigger scheme for 5G HetNet in railways. A handover trigger prediction is performed by using the received signal quality (signal-to-interference) from the measurement report, into the grey model, to predict the next measurements; thereby triggering the handover ahead of time to enhance the overall performance. Furthermore, a predictive handover trigger scheme based on dynamic time to trigger (TTT) value for HetNet was proposed in Niya and Stiller [n.d.]. The presented model uses several measurements, including SINR, RSRQ, velocity, and Time of Stay (ToS), to calculate the best TTT value and the estimation of the mobile user's next location and velocity through Gauss-Markov model.

3.2.2 Handover Decision (Network Selection) Phase. According to the measurement report, the serving cell or eNB chooses the best-reported target cell for the upcoming handover (usually A3 event). Then the preparation for the handover begins, where the handover procedure is completed by the current serving cell and, together with the target cell, performs the handover execution. The impact of the network choice is more notable in the presence of larger heterogeneous dense networks and varying cells' coverage. Many handover decision algorithms for HetNets were proposed in the literature, in which most of them choose the target cell based on the type of traffic, signal strength, or UE speed.

However, the handover decision should not be any more limited to the RSS evaluation but also the cells' interference levels, the required quality of service, available bandwidth, cell load, current user preferences, and cost. Each set of measurements is categorized as network metrics, user preferences, or application requirements. The network metrics include cell coverage, cost, available capacity, load, communication latency, and more. In terms of user preferences, it consists of the available budget, desired quality, energy conservation needs, and so on. Finally, the application requirements combine the quality threshold, delay, throughput needs, jitter, and packet loss. A general comparison of several handover decision solutions is provided in Table 5.

MADM-based network selection schemes: Multiple Attribute Decision Making (MADM) provides a decision-making tool to consider multiple criteria for decision making. The literature presented several MADM techniques, each with a distinct way to process the measurement's set. The Simple Additive Weighting (SAW) [Yu and Zhang 2018] is one of the most common MADM techniques that compute the weighted sum of each network cell's values that can be reached by the vehicle. Whereas the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) chooses the access point closet to the optimal selection that is relatively stable and far from adverse. The Multiplicative Exponential Weighting (MEW) utilizes multiplication to connect each cell's parameter score. In addition, ELECTRE is focused on a pair-wise contrast between the applicant networks' parameters. A performance evaluation comparison of MADM methods is presented in Trestian et al. [2015], for cell selection in wireless networks.

A network selection scheme is proposed by Ndashimye et al. [2018] for V2I communication over multi-tier HetNets, in which vehicles are designed with two interface cards for both LTE-A and Wi-Fi. Their network measurements include signal strength, trajectory, distance, average link duration time, and load, where the vehicle is responsible for initiating the network selection before approaching the target cell coverage. Their model was driven by the Access Network Discovery and Selection function (ANDSF), as discussed in Rel-8 [3GPP n.d.]. However, they eliminate opposite direction cells from the selection method, which could be problematic in some scenarios where the vehicle movement is unpredictable. They tested their scheme on macrocells and smallcells network with LTE-A and IEEE802.11n communication technologies, showing high throughput and packet delivery ratio in comparison to conventional RSS-based network selection method.

A network selection scheme for HetNets was presented in Yu and Zhang [2018], based on the user-selected features and network attributes, by combining multiple MADM approaches. The mixed-methods calculates the utility function value of each adjacent network and uses a threshold

Table 5. Handover Decision Solutions in HetNet-based Vehicular Networks

Related work	Measurements	Model	Goal	Network
Stevens-Navarro et al. [2008]	link reward function QoS, signal cost function	Markov decision process	Reduce number of VHO, Maximize QoS	Inter-RAT
Guidolin et al. [2014]	SINR, TTT	Markov Chain	Reduce Ping-pong events	Macro-, Femtocells
Zang et al. [2018]	(connection, location, and velocity) (power, bandwidth, and location of BSs)	Reward Markov Decision Process	Reduce Frequent HO	mmWave small-, Macrocells
Moon et al. [2015]	SINR, state	state-dependent, probability	reduce HO failure	small-, Macrocells
Guidolin et al. [2015]	context-aware cell traffic load	non-homogeneous Markov chain	reduce frequent HO	femto-, macrocells
Lee et al. [2010]	UE speed, cell configuration	UE speed grouping	reduce HO link failure and ping pong event	pico-, macrocells
Jeong et al. [2011]	movement pattern	Next location prediction	Reduce unnecessary HO	femto-, macrocells
Wang et al. [2014]	RSS, data rate, BER, movement trend	decision-tree and feedback	Reduce frequent HO	inter-RAT
Demarchou et al. [2018]	distance, trajectory, X-threshold	Markov chain Skipping technique	Reduce HO failures	ultra-dense cells
Wu et al. [2015]	RSRP (trigger), CDR and HOR	dynamic fuzzy Q-Learning	Reduce number of HO	macro-, smallcells

value to avoid the ping-pong event. Their simulation scenario is based on the selection between WLAN, LTE-A, GSM, and UMTS. The UE collects six network parameters, including capacity, bit error rate, latency, delay, packet drop rate, jitter, and service cost. A network selection process is performed given the surrounding set of available base stations, network parameters, and traffic classes. The FAHP method is used to compute the network parameters' weight and use preference values. The TOPSIS method is used to calculate user preference's utility values, while the Entropy method finds the network parameters' weights. Then an integration between Entropy and FAHP results is used to find the ultimate network's parameter values combined with the user's preference values to derive a utility rate for each base station. Their findings indicate a decrease in the number of handovers with relatively high gain values compared to different hybrid-based network selection methods. However, their work is constrained by a static threshold value that needed to be adjusted according to that specific scenario.

Intelligent-based network selection schemes: The selection process of the next network cell was proposed in Ndashimye et al. [2016] based on fuzzy logic for V2I communication over heterogeneous wireless networks. In which, vehicles will self-evaluate nearby access points candidates to select the best network based on fuzzy logic inference system. The selected network environment includes WLAN roadside units and LTE macrocell, in aim to decrease the delay in handover by preselecting the target network ahead of time. Vehicles calculate candidates' dwelling time using the cell's location and the vehicle's direction and choose the maximum one. However, their work doesn't take into account any QoS parameters and users' preferences, which are both essential in nowadays vehicular application. To tackle this problem, a handover decision approach has been introduced in Goyal et al. [2018] based on the fuzzy Analytic Hierarchy Process (AHP). The work in Goyal et al. [2018], presented a fuzzy matrix containing several network parameters (bandwidth, delay, jitter, BER, and cost) depending on the used application (voice, video, or best-effort application) to derive crisp weights. Another work in Wu et al. [2015] proposed a dynamic fuzzy QLearning method for smallcell network mobility management, in which Fuzzy rules are constantly generated through system learning. They simulated a UE movement with 10 km/h average speed and compared to CDR (measures user experience) and HOR (measures signaling load) with different time-to-trigger thresholds.

A vertical handoff protocol proposed in Wang et al. [2014], based on the decision trees model for network selection using WiMAX, WAVE, and cellular networks. They first define the transition probability distribution through multiple parameters, which include transmission rate, signal strength, bit error rate, location trend, and blocking probability. The movement trend is described as the relationship between vehicle movement trend and access points [Wang et al. 2014]. They introduced four types of user preferences, continuous network, network bandwidth, network cost, and service orientation priorities. The handoff decision will then be measured according to the chosen user preferences. A feedback mechanism is added to the handoff decision in Wang et al. [2014] based on the vehicle service and motion states. However, their decision tree model calculation time was reported to be over 180 ms, which is relatively high for time-sensitive applications and high-speed vehicles.

Several studies investigated the handover design in mmWave-based heterogeneous networks [Giordani et al. 2018; Mezzavilla et al. 2016; Zang et al. 2018]. A handover decision scheme method was introduced in Zang et al. [2018] using a Markov Decision Process (MDP) to enhance users' quality of experience in mmWave-based heterogeneous networks using user movement data. To estimate the quality of experience, the weighted sum of link throughput and the handover costs are used. Additionally, they added a candidate elimination method to reduce the model complexity according to specific options. Their algorithm avoids excessive handovers compared to other benchmark schemes (SINR-based handoff, Simple additive weight, and reinforcement learning [SARSA, Q-learning]). Mezzavilla et al. [2016] introduced Value Iteration Algorithm (VIA) and a Markov decision process (MDP) framework for optimal handoff decisions in mmWave Cellular networks. Another work in Chen and Li [2016] proposed a vertical handover decision algorithm based on a Markov model using several networks and mobility parameters. A reward and cost functions are used to derive a total QoS reward value. Results were compared to SAW and RSS-based network selection methods. A dual connectivity protocol with an uplink control signaling system was proposed in Giordani et al. [2018] to improve handover in 5G mmWave Mobile Networks. However, having an intelligent-based handover scheme could introduce higher complexity rates and decision processing delays, in addition to elevated signaling overhead.

Decision Functions-based network selection schemes: The use of cost functions has been seen as another approach for network selection to support performance efficiency for different types of quality specifications in energy, cost, and service use. An energy-utility function-based network selection scheme, proposed in Nguyen-Vuong et al. [2008], for heterogeneous networks. The network selection is user-centric, where the terminal user chooses the access network based on several measurements, including cost, link quality, battery consumption, network load, and velocity. Their goal is to provide an efficient energy-based handoff management scheme to reduce

Table 6. Handover Execution Types

Type	current RSU	new RSU	HO	interface
1	eNB	eNB	Normal-	X2
2	HeNB	eNB	Hand-out	S1
3	eNB	HeNB	Hand-in	S1
4	HeNB	HeNB	Inter-	S1/X2
5	3GPP	non-3GPP	inter-RAT	Xn, MIH

power consumption. The used cost function is based on the billing of voice call duration and downlink data volume. Their utility function relies on power usage gain, cost, network burden, and link stability to produce the best network selection decision.

Cost-based decision-making techniques for mobility handover combine several variables, such as energy consumption, cost, and bandwidth. Different measurements are assigned different weights according to the network's environment and user preferences. A utility function optimization method was proposed in Wu and Du [2016] for network selection in heterogeneous networks. Taking into account the mobile terminal QoS requirements and preferences, distinct services, user channel state information, and network traffic load. However, a decision function is usually a reactive approach that may yield an increased handover latency and is unsuitable for real-time applications.

D2D-based network selection schemes: Communication technologies such as WiFi Direct, Bluetooth, and Near Field (NF) can be used to assist in the handover process, named Device-to-Device (D2D) communications. Orsino et al. [2015] proposed a handover scheme that incorporates D2D communication to reduce energy consumption and increase packet delivery ratio, using a stochastic geometry tool. The UEs have the opportunity to connect through the D2D channel when the cell's signal quality value degrades, which generally happens due to the UE moving toward the edge of a cell's communication range. Simulation was conducted using macrocells and compared to conventional LTE handover methods based on several conditions, A2 to A4 events (as presented in 3GPP LTE release 8).

Chen et al. [2015] proposed a D2D joint and a half handover scheme using the devices' signal quality. The handover decision method takes into account several parameters, including RSRP, time to trigger, and a threshold value. A Time-to-Trigger and a threshold value are explicitly assigned to D2D handoff decisions. In another work, Yilmaz et al. [2014] introduced a cluster-based solution for D2D handoff trigger, by postponing the handover decision between two cells and the UEs until the RSRP value is below a predefined D2D control condition threshold. The use of D2D can lead to several challenges [Ouali et al. 2018], including an increase in energy consumption of mobile devices, interference management, resource allocation, and handover management.

3.2.3 Handover Execution/Completion Phase. In the final step of the handover process, the serving and target cell carry out with the aid of the UE, the execution or completion phase through specific network protocols. During this phase, the communication link of a UE is migrated to the target cell and finished with the handover process completion. The amount and direction of the HO execution method signaling rely on the type of the serving or target cells, and the need to use the access control, as seen in Table 6.

Each type of handover treats the execution phase differently. In the case of hand-out handover (i.e., from smallcell to macrocell), an SN status transfer is established between the serving smallcell to the target cell through the Mobility Management Entity (MME), and the target cell will start buffering packets from the serving cell. For the handover from macrocell to smallcell, a request for transfer will be sent directly to the MME, including the information of the target HeNB. Then, the MME will validate the UE status on the target HeNB, and transfer the UE information to the target cell (i.e., HeNB). The target cell will then verifies the reported handover and allocate a set of resources for the UE. Finally, an acknowledgment message will be sent by the target cell back to the MME, and the handover confirmation is returned to the UE through the serving cell. Moreover, if the handover is from smallcell to macrocell, then the target cell will receive the handover request directly. After the handover command is completed, a path switch request is received by the MME and the serving cell to redirect the DL path, and a UE context release is made by the source cell.

3.3 Discussion

Depending on the network structure, given scenario, and available measurements, choosing the optimal set of criteria to evaluate the handover trigger, decision, and execution is vital. In efforts to reduce traffic load, control overhead in the overall network performance, many research studies presented solutions in each step of the handover process, and with different measurements set. Although several methods were proposed to enhance the handover trigger phase, it yet suffers from very early or late handover initiations. Hence, the development of an intelligent handover trigger scheme is still an open challenge for 5G-enabled vehicular networks. In the handover decision making solutions, MADM-based network selection methods are simple and straightforward, relying on specific formulas to obtain a result. However, Intelligent-based network selection schemes that usually undergo many iterations by probabilistic rules to achieve optimal results. However, with very few numbers of repetitions, this would yield incorrect results [Yu and Zhang 2018]. Besides, even though sophisticated mathematical techniques usually produce intelligent-based models, it suffers from an increased processing delay [Ndashimye et al. 2018].

Recently, the 3GPP has released new documentation on fully independent 5G systems [Rel. 15/16], which specify a new standard for 5G cellular systems, and include three main components, 5G access network (5G-AN), 5G core network (5GC) and user equipment (UE) [3GPP n.d.]. Furthermore, a new separation of control and user planes functions have been introduced, where the MME entity in previous releases is replaced by a session management function (SMF), in control of the UE IP address allocation and PDU session control, Access and mobility management function (AMF), controls idle state mobility handling and NAS security, and user plane function (UPF), controls packet processing and transmission operations. Besides, the 5G introduced some new functionalities, such as network slicing, new QoS framework, and a new approach for service-based architecture concept. The handover procedure uses a new Xn or N2 reference points to transfer a UE from a source NG-RAN node to a target NG-RAN node. The triggering of a handover process is similar to the previous LTE-A protocol, such as new radio conditions, load balancing, or due to specific QoS flow events. Several types of handover process presented, inter NG-RAN handover (Xn based, with three variances, and N2-based), and handover process between 3GPP and non-3GPP access. Nonetheless, due to the lack of recent research studies on such systems for vehicular network environment, one can foresee similar mobility management issues and concerns that appear in cellular 5G networks.

4 SOFTWARE DEFINED-BASED VEHICULAR NETWORKS

Software-Defined Networks paradigm is based on the concept of dividing the network architecture into control (Network) and data (forwarding functions) planes. The SDN data plane includes forwarding devices connected through wireless radio access networks (WRANs) or wired network, whereas, the control plane includes SDN controllers. Each controller is provided with an open Application Programming Interface (API) to support the programming capability of network infrastructure. A southbound API (SI) between the centralized SDN controller and

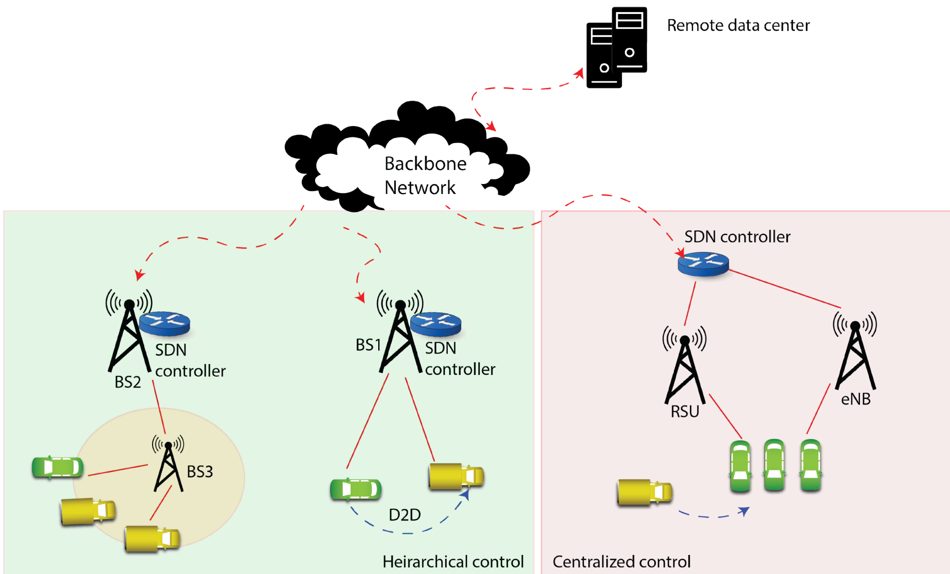

Fig. 4. SDN-based Vehicular Networks architecture.

forwarding nodes, where OpenFlow [McKeown et al. 2008] is the commonly used protocol. A northbound API (NI) is used to communicate between the SDN controller and the application layer, which enables administrators to control the forwarding plane rules and policies remotely.

SDN architecture's primary concept is the forwarding of packets based on several data flow policies. The network configuration can be adapted in real time, allowing the control management plane to update or add new services and devices. In addition to the network abstraction, there is parallel management of common functions such as bandwidth management, security, and control access. The IETF, IRTF, ONF, and IEEE802 LAN/MAN standards committees all worked on exploring the concept of software-defined networks and its components.

The Open Networking Foundation (ONF) [ONF 2012] works on standardizing the SDN architecture entities, including the OpenFlow protocol [McKeown et al. 2008]. OpenFlow defines the communication rules or policies that ensure high-performance efficiency between the control and data planes. An OpenFlow switch comprises of several tables (i.e., flow, group, and meter), in addition to a communication link to the controller. For each record, the flow table is used to map and forward packets and comprised of counters and actions. For example, with each data packet arriving at the switch, it will either uses a similar record action or forward that packet to the controller. The flow record includes a match field, priority, counters, instructions, time-outs, cookie, and flags [McKeown et al. 2008]. Upon receiving the packet, the controller decides the route in which that packet can follow and maintaining the switch flow-table. Multiple flow-tables may be assigned to an OF-switch while the meter-table triggers the performance operations of the data flow. An overview of OpenFlow can be found in Liu et al. [2017] and ONF [2012].

The deployment and integration of new services and protocols are now possible through the simplified networking design and implementation in software-defined networks while centralizing and controlling protocols without accessing individual network hardware equipment, as shown in Figure 4. Therefore, enabling centralized management and control of networking devices with common APIs. Many research studies worked on standardizing the design of wireless SDN with 5G networks such as SoftAir [Akyildiz et al. 2015], OpenRoads [Yap et al. 2010], CloudMAC [Vestin et al. 2013], and many more [Trivisonno et al. 2015]. In what follows, we discuss some of the architectures proposed in the literature that have worked on the design of SDN with 5G networks; specifically, those related to vehicular network communication and applications.

4.1 Vehicular SDN-based Architecture

The implementation of the Software-Defined Networks (SDN) concept within the next generation of vehicular networks can be of great help in elevating several issues, including mobility management and improving current wireless networks (e.g., WiFi, Cellular, and vehicular networks) [Duan et al. 2016]. SDN was initially tested and designed for wired network environments, such as campus networks, with high-speed switches. Because SDN architecture is broadly general, we can easily integrate it into wireless networks.

An SDN-based heterogeneous vehicular network, named SDVN, proposed in He et al. [2016], which aims to narrow the barrier between the application's requirement and vehicular network's limitation. This is done through the integration of vehicle-to(-vehicle, -infrastructure, and -cloud) communications. To overcome the SDN management overhead, they added a trajectory-based prediction policy to update vehicle status. Several vehicular application scenarios were studied to demonstrate the efficiency of such architecture using traffic-based simulation. In their model, He et al. [2016], authors divided the data plane into stationery data plane (such as base stations and cells), and mobile data plane. As for the control plane, it monitors the state of every switch on vehicles and RSUs. Whereas, the vehicles' location, speed, and the overall state of the network define the switch status. Moreover, the standard OpenFlow is used as a communication interface between the planes.

Another work in Atwal et al. [2018] proposed an SDN-based architecture that takes advantage of the cloud to improve vehicular network mobility management issues. They identified several challenges in SDN-based vehicular networks, including the lack of a straight-forward solution of SDN deployment in vehicular networks. Their model introduces a cloud-based global controller for seamless connectivity and mobility through the use of local controllers. The local controller will enable continuous communication sessions even when global controllers fail or unavailable. This is done by using a logically distributed control plane, in which the control functionality of the central cloud controller is outsourced to local controllers on each on-board units. Two QoS applications are implemented to illustrate the mobility management efficiency of the proposed model.

An SDN-based vehicular network proposed in Duan et al. [2017] and Duan et al. [2016], to handle the high data traffic and improve heterogeneous network management, by introducing a dual cluster head structure and adaptive beamforming coverage. They argue that vehicular HetNet is facing several challenges, such as network densification, due to high data rates and complexity of dynamic hardware adaptation. The cluster head vehicle is in charge of forwarding traffic from vehicles and communications to the base station, therefore reducing the network signaling overhead. Different vehicle groups can be identified by the transmission angle and Received signal strength (RSS). The performance of the proposed scheme has been evaluated using MATLAB simulation in terms of bit error rate, SNR, and throughput rate. The authors in Zhang et al. [2017a] proposed a software-defined-based strategy for safety-based vehicular networks, SOVCAN, which focused on road traffic safety that is dependent on the driver stress monitoring and mental awareness. However, they did not address the issue of frequent handover.

An early study on the cloud-based software-defined heterogeneous vehicular network (SERVICE) proposed in Zheng et al. [2016]. In which, they present three levels of cloud resources: Micro cloud, local cloud, and remote cloud, each has a different characteristic. The SDN design is divided into a network, control, and application layer. The network layer, which corresponds to the SDN data plane, includes communications, computing, and storage resources. The control

Table 7. Vehicular SDN-based Approaches

Related Work	Features	Motivation
Zheng et al. [2016]	Multi-layer cloud-RAN	Networks Heterogeneity
He et al. [2016]	Adds vehicle to cloud communication	Networks Heterogeneity
Atwal et al. [2018]	Distributed control plane (Cloud-based)	Guarantees QoS
Duan et al. [2017] [Duan et al. 2016]	Introduced a dual cluster head selection method	Supports increasing data traffic
Zhang et al. [2017a]	Adds vehicular controller area network	Targets safety-oriented applications

layer, located in the middle as a service proxy that provides control functions and translates the requirements of users.

Due to the vehicles' high mobility, the centralized structure of the SDN controller will affect the performance of real-time communications. A work by Zheng et al. [2016] proposed a hierarchical control layer to reduce the number of handovers, by defining a primary and secondary controller. The latter serve one area that includes macrocell and smallcell. They discuss four kinds of handover, Intra-/Inter Service Area and Intra-/Inter- System. The former happens when vehicles move from the same service area or to another service area without leaving the wireless access system, while the latter occurs when vehicles move between different systems in the same service area or different service areas. In Table 7, we show a comparison between different vehicular SDN-based network architecture.

The IP addresses have only local significance in SDN-based networks, and the controller specifies the policies for forwarding each flow based on OpenFlow protocol [Kukliński et al. 2014]. Because of the SDN framework design, it would be simple to customize the network management functions, where operators can effectively program the control plane. As mentioned earlier, the OpenFlow protocol was initially created for fixed networks and did not support mobile networks' specific functions, such as configuration and monitoring mobile network cells. Therefore, to implement the SDN concept on wireless base stations, requires the support of OpenFlow protocol, to enable communication with the controller and benefit from SDN properties.

Despite the advantages of SDN, several issues might arise with the implementation of SDN-based Vehicular networks, especially with the 5G heterogeneous type networks [Mahmood et al. 2019]. This includes the deployment of SDN controllers, centralized controller [Assefa et al. 2017] (i.e., a single point of failure) [Nguyen et al. 2016], scalability in dense areas in real-time applications, and vulnerability to many security attacks. A distributed mobility management based on SDN for 5G networks, named (S-DMM), presented in Nguyen et al. [2016], in which all components related to mobility are independent of various techniques. Their results indicate more scalability compared to well known mobility management solutions. Moreover, their work showed lower mobility costs while maintaining similar handover latency and delay compared to other solutions. Nonetheless, seamless handover between multiple domains is still an open issue and the impact of the enormous computational complexity of mobility management on the centralized control plane.

4.2 Mobility Management in Vehicular SDN-based Networks

The concept of an SDN-based vehicular network introduces a significant advantage in handling and managing the various technologies for the next generation of vehicular network communications. In Kukliński et al. [2014], a theoretical comparison of the performance of X2

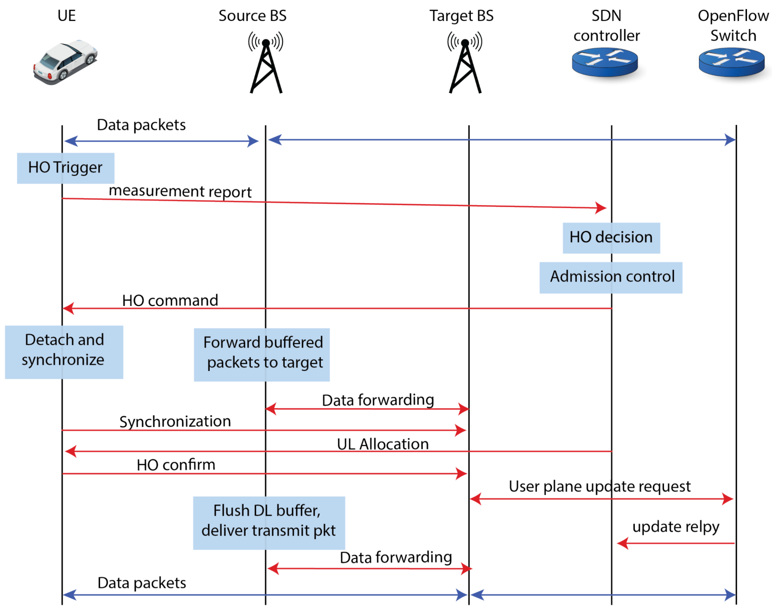

Fig. 5. SDN-based Vehicular Network handoff process.

handover and SDN-based handover in terms of signaling cost and the influence of the network size. It is noticed that by increasing the number of access points and mobility rates, the handover based on SDN managed to reduce the signaling cost compared to the X2 standard. A general illustration of the handover process in SDN-based networks is presented in Figure 5.

4.2.1 Offloading Mechanism. Even though current smartphones provide an offloading mechanism from cellular to WiFi, it is still not recommended for latency-critical safety applications or in case of autonomous driving. Therefore, efficient handover mechanisms are needed to transfer communication from cellular to WiFi and vice versa without having QoS degradation. When and to which access point should the traffic offload go to, is one of the questions that need to be answered before performing a handover decision. Huang et al. [2017a] introduced a predictive control method named OHD-SDN for offloading V2I communication using SDN-based architecture. They used velocity, direction, location, and neighboring roadside units to derive a handover decision between cellular and IEEE802.11p networks. The SDN structure is used as a mobility management controller to decide on the time of the handover trigger. Their goal was to reduce the traffic load of cellular networks without losing the quality of service.

Aujla et al. [2017] proposed an SDN-based offloading mechanism for vehicular networks through the use of a priority manager and a load balancer. They defined different types of offloading techniques, including the WiFi and IP flow offloading. They stated four procedures for implementing their protocol, a network selector, a priority manager, an offload manager, and traffic load balancing method. Starting off with the offloading manager, that calculates the load on a controller using the total number of packets one controller can handle and the number of received packets. Then, messages will be either routed using the flow tables or delivered to the priority manager based on a threshold value. A handover decision is based on one-leader multiple-following Stackelberg games to select networks. A comparison was made over generated traffic movements from the city of Patiala. Results indicate less number of handovers occurred while maintaining reasonable data throughput. However, this work does not consider the movement of the vehicle in different networks.

4.2.2 Network Densification. The centralized concept of SDN networks could lead to massive traffic congestion, especially in ultra-dense networks. The new trend of fully distributed handover decision is considered in recent works. Sharma et al. [2017] proposed an enhanced SDN structure by utilizing unmanned aerial vehicles (UAVs) as on-demand forwarding switches. The UEs acts as terminals to UAVs, and the latter are terminal to macro Base stations (MBSs). They proposed two approaches, a centralized approach, with central mobility management entity, and a distributed approach. The measurements report from the UE includes the RSSI, RSRP, RSRQ, and channel quality indicator. Performance evaluation was measured in terms of signaling overhead, handover latency, and delay.

Bilen et al. [2017] proposed a handover scheme based on the Markov chain in a software-defined 5G network with the presence of ultra-densification. They argue that minimizing the handover delay will improve the performance in ultra-dense 5G networks. The Markov chain scheme is based on the estimation of available resources and transition probabilities to assign the most optimal base station to the mobile node's OpenFlow table ahead of time, thus reducing the delay of the handover process. The authors in Bilen et al. [2017] modeled the transition probability from one cell to neighboring cells through the physical movement of the mobile node. However, no further parameters were considered in the model, such as mobile node speed, direction, or QoS requirements.

Kaul et al. [2018] proposed a handover and load balancing scheme on top of their previous work on dynamic network control for ITS, named (D2-ITS). Their early work is focused on implementing a hierarchical control, which can be altered to the network conditions and environment. Their objective is to transfer one vehicle's control functionality to another device as the vehicle moves. Handover activation and next controller selection are based on RSSI values and can be triggered either the controller or the vehicle.

In Zhao et al. [2018], a context-aware handover scheme based on multiple criteria is proposed for software-defined 5G heterogeneous networks, using fuzzy logic rules. The parameter gathered from the user equipment is sent to the centralized SDN server, including the network measurements, user preferences, and usage requirements. In particular, they consider both network and mobile user measurements, such as the network RSSI, range, throughput, and the mobile user's speed, direction, and quality of experience. Then the handover process is triggered based on the changed behavior of the gathered measurements by a predefined threshold. The authors proposed three fuzzy-rule layers that consider multiple factors, including mobility, network, and satisfaction. Their protocol was compared to the based RSSI-based handover scheme in terms of throughput, bandwidth cost, and handover frequency. The users' mobility model is simulated on random way-point with an average speed of 10 m/s. Still, it was not clear how their work would react in case of high-speed vehicle mobility, although it could be adjusted for low-speed movement and intersection areas.

Fondo-Ferreiro et al. [2019] introduced a fast handover decision protocol in SDN-enabled wireless networks using flow-type predictions of past user behavior. Both centralized and distributed algorithm allocation was tested using real data. The flow predictor is based on a simple Markov chain model to estimate the next service flow of a user. The handover decision is based on the current state of the access point, quality of radio links, and user needs' based on past application usage history.

4.3 Discussion

The SDN paradigm is recently considered one of the solutions to the heterogeneity between different network technologies. SDN-enabled Internet of Vehicles (IoVs) is reported to provide high

Table 8. Handover Solutions in SDN-based VeNET

Work	Model	Performance metrics	Goal
Huang et al. [2017a]	HO decision - Offloading technique	Throughput, Packet loss	Reduce load on cells
Aujla et al. [2017]	Network selection based on Game theory	number of HO's	Reduce load on cells
Sharma et al. [2017]	On-demand UAVs forwarding switches	End-to-End delay, signaling overhead, and handover latency	Distributed approach
Zhao et al. [2018]	Multi-attribute hierarchical fuzzy inference	throughput, bandwidth cost	Reduce Frequent HO's
Bilen et al. [2017]	Markov chain (available resource estimation and transition probabilities)	HO delay, HO failure ratio	Reduce handover delay

resource utilization efficiency and ease mobility management [Atwal et al. 2018]. In the aforementioned handover solutions, two main concerns have been studied, namely offloading mechanism and densification issues in SDN-based vehicular networks. A comparison of current handover solutions in SDN-based vehicular networks is presented in Table 8.

The handover decision in such networks is either to reduce the load on macrocells or communication session needs to be transferred to another better quality cell. One of the main challenges in SDN-based vehicular networks is in the presence of ultra-dense systems because of the centralized nature of SDN structure; this may lead to traffic congestion issues. Several surveys have investigated the distributed principle of SDN networks, but the implementation and governance of such networks are still underway. While most mobility management solutions aim to either reduce the load on cells or reduce the overall handoff delay, not many research studies have been done toward secure- and energy-efficient mobility management schemes in vehicular SDN-based networks.

5 FOG COMPUTING-BASED VEHICULAR NETWORKS

The rapid increase of large scale cloud-based applications that provide several services, from infrastructure to software as a service, has introduced a new challenge to cloud computing systems. For example, connected vehicles and content delivery applications require constant communication with cloud servers. Bonomi et al. [2012] first introduced fog computing in 2012, which grants storage, data, and services to end-users in a virtualized system. The fog cannot operate as a standalone mode and requires the cloud, since its main objective is to offer cloud computing services in a real-time strategy, by providing data migration from cloud centers to the network edge. Therefore, saving bandwidth resources, reduce energy consumption, and shorten latency. Many services can take advantage of such architecture to efficiently deliver information to clients such as location-aware services.

Fog computing (FC) is a paradigm proposed as an expansion to the cloud paradigm [Skondras et al. 2019]. The fog enables functions to be located at the network edge closer to end-users. It addresses the drawbacks in cloud computing for latency-critical applications, such as connected vehicles, and emergency alerts, and data content delivery. Moreover, fog reduces service latency, improve Quality of Service, and user experience [Mouradian et al. 2017]. The fog-based access points (F-APs) are responsible for hosting services at the network edge or on smart devices.

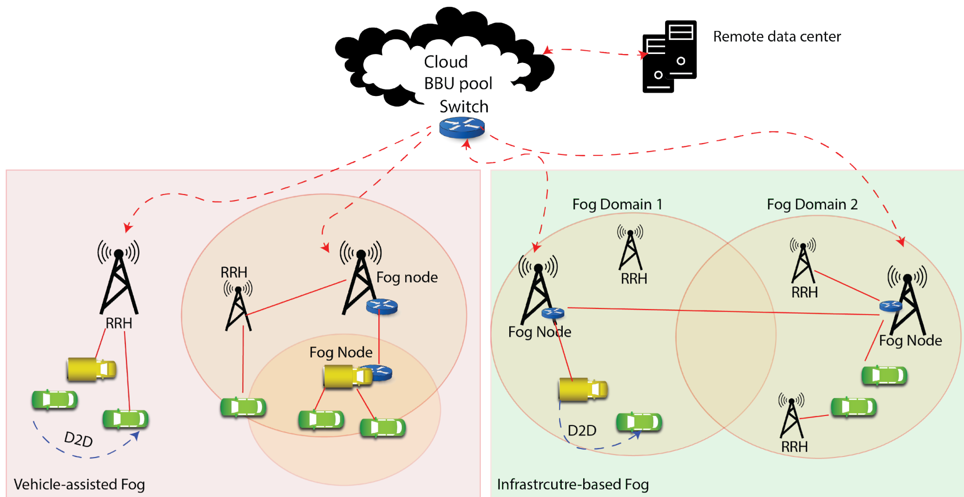

Fig. 6. Vehicular Fog-computing architecture.

Fog is usually introduced in macrocell base stations and WiFi access points as fog servers. When users or vehicles move between different fog servers more frequently, it will lead to service disruptions and degradation in the user experience. The fog server supports mobility by using routing and addressing protocol, named Locator/ID separation protocol (LISP), that is developed by Cisco Systems. Therefore, allowing Fog servers to communicate with end-devices. Several solutions on Fog-based Radio Access Network (FRAN) are introduced in Peng et al. [2015] and Ku et al. [2017]. Since our focus is merely on vehicular networks enabled solutions for 5G mobility management, we only look into the solutions introduced in fog computing that involves the design of vehicles networks.

5.1 Vehicular Fog-based Networks (VFN)

Recently, the fast rise in the number of vehicles in public transport infrastructure brought heavy road congestion and presented more slow-moving vehicle conditions. In addition to the increased amount of parked cars, particularity in down-town regions making vehicles a valuable resource to the design of networks. Henceforth, the utilization of vehicles as infrastructures for communication and computational resources comes as an added value solution to reduce the cost and time for vehicular applications [Hou et al. 2016].

Vehicular fog-based networks (VFN) employs end-vehicles clients or edge-vehicles to carry out some communication and computation functions, as seen in Figure 6. One of the main advantages of VFN is its proximity to clients, exploiting the best options to enable vehicles to collaborate to deliver services. The multi-tier architecture of the VFN is illustrated in Figure 6, compared to the original model of the fog-computing paradigm, VFN uses vehicles as part of the fog server layer. Specifically, VFN may take advantage of slow-moving vehicles and parked vehicles to either communicate services to other vehicles or aggregate computation resources from remote clouds to vehicles. In Hou et al. [2016], the capability of utilizing vehicles as part of the fog is studied in terms of communication link quality to evaluate how reliable communication is between vehicles.

In Hou et al. [2016], a vehicle fog-computing system was implemented, using vehicles as infrastructures to expand network assets by evaluating the vehicle's velocity and movement status. The authors added four scenarios in which vehicles can be used as infrastructure. They defined two types of vehicles moving and parked vehicles that can carry service and applications. By understanding the connectivity relationship between vehicles, one can better assess the usability of vehicles as infrastructure. A capability analysis was done on real mobility traces from both Shanghai and Beijing in urban scenarios, where they found that more than 80% of moving vehicles have relatively low-speed. In contrast, parked vehicles tend to be significant in numbers during specific times in a day. However, authors only considered one type of fog nodes (i.e., vehicles), and quality of service was not considered as a factor to latency.

In the same context, an architecture for vehicular fog computing was presented in Huang et al. [2017b] along with vehicular applications use cases and security problems. Considering most vehicular applications require on-the-fly knowledge and information for traffic control and safety applications. Their framework includes three primary components, cloud servers as the cloud layer, vehicles in the data layer, and infrastructure in the fog layer. By integrating fog into vehicular networks, cloud servers will have the ability to migrate some of its functions closer to the edge for real-time efficiency, storage, and communication. Several challenges can be present along with the integration of fog-computing and vehicular environments, including the rapid changes in vehicles' mobility, making it harder to predict where and when the fog should be deployed or used. Moreover, efficiently utilizing vehicles power supply will also affect the overall system, since rechargeable embedded batteries in vehicles could help in performing vehicular fog-computing tasks even when vehicles are parked.

An intelligent vehicular network based on regional fog architecture is proposed in Zhang et al. [2017b] to accommodate big data in smart cities. The authors introduced two primary levels; the fog level is responsible for the cloud servers, local fog servers, and coordinator server, and the edge level includes vehicles communication through WAVE or cellular networks, and the Internet of Things applications. Several scenarios were considered in their work, including handover between fog servers to support mobility, distributed computation, multipath file downloading, and multi-source data acquisition. Furthermore, the authors included a hierarchical resource management model in which the energy-aware model is introduced among similar fogs networks and QoS-aware management among different fogs, to optimize the efficiency of their architecture.

5.2 Mobility Management in Fog-based Vehicular Networks

With conventional heterogeneous vehicular networks, several problems may occur during the handover process such as ping-pong, radio link failures, small coverage area, severe co-channel interference, and heavy load on the core network. Unnecessary handovers or radio link failures are common, either due to the serving cells small coverage region or the high speed of vehicles. A vehicular fog-computing network shifts some of the BBU pool's control methods from/to the Fog-Access point (F-AP), Macro-Remote Radio Heads (MRRH), or Small-Remote Radio Heads (SRRH). The handover decision making and the process will be different than in HetNets or Cloud-RAN, to guarantee QoS to end-users.

Fog-enabled vehicle nodes (F-VNs) can be categorized into either high-speed vehicles or low-speed vehicles. The high-speed F-VN are preferably connected through macrocells with large coverage areas, whereas low-speed vehicles connect to smallcells or access points with lower coverage areas. Henceforth, handover management in such networks is a relatively challenging problem. Several types of handoffs may occur depending on the involved entities in the handover process. For example, when a vehicle (i.e., F-VN) moves between F-AP and MRRH, a measurement report is collected by the F-AP from the F-VN to perform a handover decision. Then a request for handover is processed by the F-AP to the MRRH using the F-AP gateway and BBU pool. An acknowledgment of request is then sent back to the source F-AP, and the same process happens between SRRH and MRRH. The handover process between similar points of F-APs or SRRHs is made through an S1 interface. Typically, the handover decision between MRRH to an F-AP is usually more challenging because of the many available F-APs around.

A fast handover scheme based on neighboring vehicles, namely CVFH, for vehicular fog communication is proposed in Bi [2018]. They present a proactive handover mechanism to establish an advanced handoff process that relay on neighboring vehicles to select the new access router and acquire the IP address in advance. Meanwhile, vehicles can continue its communication link with the serving AP. Each vehicle keeps track of nearby vehicles through beaconing, where the most qualified neighbor is chosen to be the aided-vehicle. Qualification is based on several conditions; (i) the chosen aided-vehicle must be served by a different access point, and two, and (ii) its position must be in front of the current vehicle, and no broadcast reply was sent to the current vehicle. If all conditions are met, then that neighbor vehicle will send a response after a defined time interval [Bi 2018]. The authors specified each packet format, authentication, association, association reply, neighbor request, neighbor reply, and success fail messages. Their scheme was compared with the IEEE802.11 handover standard in NS-2 simulation in terms of handoff delay and throughput. It was only tested on highway small scale scenario with vehicles' speed between 50 and 90 km/h.

Fog-based deployment on vehicles or access points will help in getting resources closer to edge devices. However, this feature creates a new issue, as some vehicles will be closer than others to the fog nodes. In the case of high-velocity vehicles, fast handovers will occur between fogs. One solution is to minimize the disruption time during the handover process, which has been studied in Memon and Maheswaran [2019]. The authors presented a handover scheme based on a machine learning model for vehicular fog computing, using a feed-forward neural network to estimate an optimal fog-node. In addition, they used a recurrent neural network approach to assess the projected results at a particular location and time to minimize transition disruptions during fog-to-fog handover. The distance between the vehicle and fog node is initially used as a handover criterion, which will be used as heuristic data to identify the transition points between fogs. A comparison between different fog predictors and cost predictors showed their model selection is the highest in terms of accuracy. However, their work was limited to fog-to-fog handoffs and was not tested on heterogeneous networks and built on the assumption of known vehicles' trajectories.

In the same context, several related works focused on the network selection method in fog-based vehicular networks using the fuzzy logic approach. Recently, in Jabri et al. [2019], a vehicular fog architecture is proposed combing both fog computing and multi-access edge computing (MEC) paradigms. In which, the MEC is used on the vehicular cloud as a centralized control. A proper selection methodology is needed to allow vehicles, acting as fog nodes, to access the MEC server or cloud. The fog gateways selection approach in Jabri et al. [2019] is to initially select a group of possible cells based on fuzzy logic and then optimize the number of selection through the Ant Colony Optimization technique. In the initial step, the selection of candidates is based on a specified set of parameters and the fog's type. The authors introduced two types of vehicular fog, static and mobile. In the static vehicular fog, that metric used to evaluate the candidates includes the quality of available networks links (i.e., RSSI), the number of neighbors, and the rate of stay (RoS) the vehicles spent in a parking space (represented by low, medium and high). As for the mobile vehicular fog, when vehicles are not parked and rather moving at low speed, the used parameters include only the amount of adjacent cells and link quality (RSSI). After the candidate set is formed, they used the ACO approach to optimize the selection set. The authors used NS3 as a simulator tool with vehicles equipped with both LTE and IEEE802.11p interfaces and one cell placed in the area. However, vehicles movement are usually unexpected and vary in speed, which may affect the performance of their model.

Follow Me Fog (FMF) framework proposed in Bao et al. [2017] to support a seamless handover scheme between access points. The idea of pre-migrate computation jobs through monitoring

Table 9. Handover Solutions in Fog-based Vehicular Networks

Related Work	Model	Measurements	Goal	Limitation
Memon and Maheswaran [2019]	Neural Networks	distance between fog and vehicle, time	predicting the best fog node	assumes known vehicles trajectory, only fog-to-fog HO
Bao et al. [2017]	pre-migration concept	RSS	reduce HO latency	Limited to RSS for HO triggers
Jabri et al. [2019]	Fuzzy logic + ACO	RSSI, RoS	Reduce comm. cost (bandwidth, cellular fees)	uncertainty in vehicles movements
Bi [2018]	vehicle-assisted HO	RSSI, packet loss rate	Reduce HO latency	Adds comm. overhead

received signal strengths. Their objective was to reduce latency when handover is triggered by using a pre-handover approach. The authors presented their method through a state transition model. To initiate the pre-migration state, each IoT device must keep track of the received signal strength of its serving and neighboring fog cells. When the handoff trigger threshold value is reached, the migration is also triggered. Following that, in case the trigger was falsely initiated, the migration stops and the IoT devices will go back to the initial step. However, relying on the received signal strength only may introduce higher communication overhead and unreliable handoff triggers.

5.3 Discussion

The fog has shown to be an efficient solution to meet 5G requirements in terms of latency and scalability by providing data content and services closer to users rather than on the centralized cloud. Several proposed schemes considered utilizing slow-moving vehicles and halt vehicles as fog nodes to offload resources. However, the accuracy and efficiency of choosing vehicles and clusters have not been thoroughly explored. In addition, many related works did not look into the heterogeneity of wireless technologies in 5G-enabled vehicular networks. Rather than that, most related works focused on one type of migrating or handover of information from one fog to another fog. A comparison of different fog-based networks is presented in Table 9.

6 HYBRID-BASED VEHICULAR NETWORKS

Current development in 5G-enabled vehicular networks seeking to guarantee users and application requirements has encouraged many researchers to design efficient system architecture for vehicular networks [Ge et al. 2017]. The integration of fog computing in software-defined networks aims to capture the benefits of both paradigms to enhance the overall systems, networking, and services [Nobre et al. 2019].

In Ge et al. [2017], the authors proposed a 5G-enabled vehicular network that integrates fog, cloud, and SDN paradigms. Three main planes are introduced, the control plane derives control instructions, and the data plane gathers data, while the application plane generates rules. Adding the fog cell structure to the network model reduces the handover frequency problem in typical SDN networks. The design is composed of SDN controllers, Cloud centers, Roadside Unit Centers, regular roadside units, fog clusters, and vehicles. Vehicles positioning information is gathered through onboard GPS sensors and communication between vehicles, and access routers or vehicles are provided, with a fronthaul link between roadside units and roadside center. Each fog cluster is composed of an area of vehicles and roadside units, including one vehicle acting as a gateway link. When the gateway vehicle leaves the transmission range of the RSU, a handover process is established to delegate another vehicle to be the gateway. Issues may arise with such structure, as proper selection of the gateway vehicles must be done and also the optimal size of a fog cluster. Transmission delay was reported to be less than 1 ms when the transmission distance was 300 m.

Lee [2015] define the fog as a collection of RSUs and base stations controlled by an RSU center communicating with the SDN controller. Deployment is an issue in this case, whether it is taking into account the mobility and density of vehicular areas and traffic. Their architecture operates in the hybrid control mode, in which the system control is shared by the controller and Cellular base stations and SDN Roadside unit controllers. The SDN controllers only send abstract policy, and the RSUs specify the rules' behavior according to local information. The benefit of using Fog controllers is to assist in services migration to multiple base stations along the road and updating data forwarding rules and services hosting. However, their work requires overhead communication to send back data information to the SDN controllers.

A hierarchical 5G VANET architecture proposed in Khan et al. [2018] by integrating SDN and Cloud-RAN to efficiently allocate resources, including fog-computing framework at the edge, to avoid frequent handover. The topology structure of their architecture comprised of Fog-Zone controllers, Fog-Cluster-heads, Fog-vehicles, Fog-BBU-controllers, SDN controller, and optical transmission networks. Their hierarchical architecture reduces the overhead on the centralized controller. In their simulation, the controllers' transmission delay and control overhead is evaluated and have shown minimal results in different vehicles' densities. However, integration issues with various technologies is a problem.

6.1 Mobility Management in Hybrid-based Vehicular Networks

In the previous section, we discussed that the presence of frequent HO reduces the performance of SDN at roadside units. A possible solution is to derive a distributed or decentralized approach to deal with the vast control overhead that goes to the control plane. Some solutions worked on the integration of the fog and cloud on the network edge either on approximate small-cells or through vehicle clustering techniques. However, the proper deployment of such architecture and communication structure is essential to avoid performance degradation.

A hybrid handover scheme proposed by Zhang et al. [2018] for a software-defined and fog-based vehicular network, which models a QoS constraint for vehicles. The SDN controller is assumed to be charge of allocating appropriate communication links according to the vehicle speed, communication distance, and QoS requirements. The handover process is preformed on the edge cloud by the controller, therefore removing the load from the core cloud. Two types of HOs are considered in their work, Intra-edge cloud handover (same cloud) using the X2 interface and inter-edge handover (different clouds) using the S1 interface. To avoid failure, they proposed a hybrid access handover scheme with two progressive conditions to decide the handover trigger time based on the SINR threshold value. Simulation results showed that their method presents better performance without the redundant signaling overhead. Authors failed to specify when to user Intra-/Inter-edge handovers. Also, they only consider the RSS-based trigger event of the X2/S1 handover, which doesn't take into consideration the dynamic nature of vehicles' movements and vehicular topology, leading to frequent unnecessary handoff's. A recent study looked into the integration between fog and mobile edge computing paradigm in Palattella et al. [2019], which can provide a considerable gain in terms of monetary cost and latency. For latency-sensitive applications at the edge of networks, the authors introduced a fog-assisted architecture for handover management in vehicular networks. Driven by OpenFog Consortium, services are moved close to the end devices and users, including the application logic, data, and networking services.

Table 10. Handover Schemes in Hybrid-based Vehicular Networks

Related Work	Network	Measurements.	Model	Goal
Skondras et al. [2019]	5G-Cloud	User satisfaction, Speed, delay, pkt loss.	Fuzzy Logic	always best connected
Zhang et al. [2018]	SDN and Fog	SINR	two-threshold conditions	Reduce signaling overhead
Prados-Garzon et al. [2016]	SDN and partial virtualization	RSRP (A3 event)	MPLS-tunnels, X2-HO	Reduce HO delay
Qiu et al. [2017]	NFV and Fog	RSRP (A3 event)	direct X2-interface between fogs	reduce signaling cost

For 5G vehicular cloud computing technologies, Skondras et al. [2019] proposed a fuzzy-based network selection method. The vertical handover trigger is performed in the fog, given the velocity of vehicles, and the network SINR, which are reported by vehicles, to assess whether or not a handover trigger is required. The cloud will select the new network cell depending on the velocity of the vehicles; in addition, vehicles will be notified of the decision via the fog infrastructure. The initiation of the transition and selection of networks is based on the Pentagonal Fuzzy interval values. In contrast, the Pentagonal Fuzzy ANP algorithm is used to estimate the weights of the handover trigger and the selection of the network. Their results indicate that the measurement of Always Best Connected is satisfied and outperformed existing vertical handover schemes in terms of user satisfaction grade and handover count.

Additionally, several solutions used Network Function Virtualization (VFN) to aid in the handover decision, which introduces an added-value in terms of scalability, cost, and energy consumption. Prados-Garzon et al. [2016] proposed a handover scheme based on partial virtualization of 5G SDN-based networks. Their goal is to reduce the handover process execution time (i.e., latency), by operating at the link level. As for the measurement report trigger event, the conventional handoff trigger method is used, when a target cell's received reference signal (RSRP) exceeds a predefined threshold value (A3 event). Furthermore, they used MPLS tunnels for the data plane to replace the GPRS protocol, which has shown to produce high overhead. Two types of handover are conducted in their simulation, the handover between similar switch domain (intra-switch) and the handover between different switch domains (inter-switch). With the assumption of sufficient channel resource is present to handle the data rate requested by each device. Results conducted on NS-3 simulation have shown that the handover initiation and completion times are nearly stable up to 1 Gbps of data rate per user, which satisfies the control plane delay constraints for 5G networks. In Table 10, we present several handover schemes that address mobility management issues in hybrid-based vehicular networks.

7 OPEN ISSUES AND FUTURE RESEARCH DIRECTIONS

Although many research studies have been investigated and presented on mobility management in HetNets-based, SDN-based, Fog-based, and Hybrid-based vehicular networks, several directions have not yet been fully explored and studied toward enabling 5G in vehicular networks. In the following, we address a few more concerns and potential research directions that can be further explored.

Security issues: With the rapid increase of vehicular applications operating in vehicular fog-computing networks (VFC), SDN networks, and HetNet-based vehicular networks, Internet connectivity, and seamless mobility became a vital component of wireless communications. However, an important issue and challenge of security and privacy is always present and not fully considered [Hou et al. 2016]. The concept of content sharing and data exchange will introduce several security issues, such as authentication, protection, and misuse of protocols [Sharma et al. 2018]. In consequence, vehicles will face more danger from Malware attacks and information sniffing. A work in Lai et al. [2017] aimed to address security issues, specifically in SDN-based vehicular networks, by implementing group authentication and key agreement protocols during the handover process.

Deployment and Configuration Issues: While heterogeneous vehicular networks provide different QoS technologies and access points to choose from depending on the desired services, another issue comes along with such densification of cells. The deployment and configuration methods in 5G-enabled vehicular networks are essential, due to the highly dense deployment and small coverage area of roadside units. Enabling self-optimization and self-configuration systems (SONs) would help in tackling those issues. In SON-based networks, each base station is capable of determining the optimal parameters autonomously [Kitagawa et al. 2011]. However, effective deployment techniques and networks design, stay an ongoing challenge that the research community has not addressed widely. Furthermore, with the proposed solutions of distributed SDN-based networks, a deployment and selection problem is presented. The question of how to model the distributed system and where to deploy controllers is still an open issue in vehicular networks environment, Especially with the presence of dynamic mobility patterns in vehicle movement and speed. Some works have been done toward the use of smart clustering techniques for distributed SDN-based networks [Xiao et al. 2016; Wang et al. 2017]. Nonetheless, limited research work considered vehicles' mobility patterns and changes in the design of the clustering-based SDN network.

Energy-aware models: Introducing the fog-computing-based paradigm to vehicular networks, empowered many applications to deliver services with high scalability and ultra-low latency. Nonetheless, with the rapid expansion in the number of vehicles and the frequent handover, an increase in network load is imminent. Limited battery power constraint in wireless devices is greatly influenced by the number of control and data signaling between different entities in wireless networks. Few works concentrated on energy-efficient solutions in mobility management protocols [Sharma et al. 2018]. However, vehicular networks is a highly dynamic environment, making it a challenge to the design of energy management solutions in such rapidly changing conditions. The common assumption of the vehicles' substantial storage, computing, and power resources might not be valid in the next decade, since people are shifting more toward gas-free vehicles (i.e., Electrical vehicles). Thus, making them now inclined to power constraint and requires proper management. In all previous mobility management solutions, the assumption of endless power supply will soon become a new factor in the handover decision, and next network selection process.

Distributed mobility management: The fast-growing requirement for broader internet traffic is driving network carriers to search for options to expand the bandwidth usage without increasing the load on the core network. As mentioned before on SDN-based networks, several solutions were toward a distributed approach [Giust et al. 2015] or increasing the number of cells and reducing their coverage in HetNet-based networks. A distributed mobility management that allows traffic to be offloaded closer to the edge might be a suitable solution for ultra-dense systems. However, the proposed distributed networks are very primitive and have not been thoroughly investigated to better fit in real-time scenarios.

Integration of Satellite Access in 5G: The integration of satellite access in 5G is another aspect that may be considered in future directions that focuses on enhancing the performance of the vehicular network to meet the specified 5G requirements. In a recent study [Yang et al. 2016], a seamless handover scheme based on software-defined satellite networking architecture is proposed. The protocol was evaluated on the physical layer and compared to current hard and hybrid handover schemes for satellite networks. In the case of various satellite deployment with different coverage ranges, the network selection is based on the highest cell's quality, precisely, the received signal strength indicator. If the RSSI decreases under a specific limit, then the handover method will be initiated. However, the research direction in using satellite access for 5G systems is still immature, and very few works have been done toward using satellite access to improve the performance of the network.

Beyond 5G: The recent advancements toward the deployment of 5G wireless technology have witnessed a tremendous increase due to the promoted efficiency and low-latency of such systems. However, many debates have been raised by the research community, which states that the promise of a 5G system will be insufficient due to the abundant growth in network devices and applications. This has initiated a new set of directions toward the vision of beyond 5G systems, which is still unclear [O'Hara et al. 2019]. Recent studies considered Terahertz communication to be one of the building blocks to beyond 5G wireless technology [Busari et al. 2019]. In which, wireless networks can utilize communication bands all the way to 10 THz in comparison to millimeter-wave systems with 10 GHz. With this in mind, mobility management may not anymore have problems in network densification and latency issues—a recent study on millimeter-wave and THz-based smart railway mobility presented in Guan et al. [2016]. However, many new challenges are expected to be present before reaching that goal [Busari et al. 2018; Cacciapuoti et al. 2018].

8 CONCLUSION

Mobility management is fundamental for managing and improving the performance of vehicular networks. In 5G-enabled vehicular networks, several networking paradigms are currently studied to satisfy 5G requirements. However, managing vehicles' mobility throughout different networks is problematic. Without efficient management of vehicles' movement, service disruption, and QoS degradation is inevitable. In this article, we studied the related works' efforts to overcome mobility management problems in 5G-enabled vehicular networks. We classified the current methods based on their network design models and discussed each network architecture, mobility management process, advantages, and disadvantages. Moreover, each network's mobility management scheme is further categorized according to their issues within the vehicular networks' environment. Finally, we discussed potential research directions and open problems that require further investigation.

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