Cell-less Communications in 5G Vehicular Networks Based on Vehicle-Installed Access Points

Lijun Wang, Tao Han, Qiang Li, Jia Yan, Xiong Liu, and Dexiang Deng

Abstract

The development of intelligent transportation systems raises many requirements to the current vehicular networks. For instance, to ensure secure communications between vehicles, low latency, high connectivity and high data rate are required for vehicular networks. To meet such requirements, the 5G communication systems for vehicular networks should be improved accordingly. This article proposes a communication scheme for 5G vehicular networks, in which moving access points are deployed on vehicles to facilitate the access of vehicle users. Moreover, the adjacent vehicle-installed moving access points may cooperatively communicate with the vehicle users by joint transmissions and receptions. In this way, the vehicle users communicate with one or more unspecified cooperative access points in a cell-less manner instead of being associated to a single access point. To manage such cell-less networks, local moving software-defined cloudlets are adopted to perform transmission and scheduling management. Simulation results show that the proposed scheme significantly reduces the latency, while improving the connectivity of the vehicular networks, and can be considered as a research direction for the solution to 5G vehicular networks.

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I. Introduction

For the safety of driving, the drivers or even the auto-pilot controllers have to monitor the real-time vehicle and traffic status. The most important way to obtain such vehicle and traffic status is receiving the information from other vehicles and public services by the vehicular networks (VNETs). This driving-related information includes the traffic status information, safe driving and vehicle fault diagnosis information, and navigation information from the service provider. Besides the mentioned critical real-time information for driving, the entertainment information, information of common communication services, and social information also need to be transmitted by the VNETs [1]. Considering the application prospects of VNETs, it is necessary to construct a universal and powerful communication platform for VNETs. It is feasible to deploy application services and network equipment close to the moving vehicles, such that the latency of network transmission and service response time can be reduced significantly. One of the important approaches to providing services close to the vehicles is the mobile edge computing scheme. By mobile edge computing, computing and storage resources are deployed at a variety of the edge network equipment to provide rapid services for mobile users [2]. Because of the high mobility of vehicles, the traditional mobile computing encounters challenges of efficient and rapid resource scheduling and allocation. Meanwhile, the approach to providing communication services close to the vehicles is to implement the access network among the vehicles themselves. Based on this as-close-as-possible deployment strategy, dynamic, open, self-organized, easy-deploying, and cost-effective VNETs can be realized instead of traditional monitoring-focused traffic assisting systems. Consequently, the study on new architectures of VNET is vital for the future development of intelligent transportation systems (ITSs).

The concept of VNET grows out of an application of wireless sensor networks (WSNs), and in the early days of VNETs, many devices and protocols directly came from WSNs and mobile ad hoc networks (MANETs). However, because of the quick movement of vehicles, many existing protocols including ZigBee and Bluetooth are not suitable for VNETs anymore. In contrast, IEEE 802.11p and Long-Term Evolution (LTE) are recognized as two most important technologies for VNETs [3]. Based on these technologies, various architectures for VNETs have been developed. Generally, the different architectures can be classified into two kinds, that is, the infrastructure-based architectures and the MANET-based architectures. In the infrastructure-based architectures, base stations (BSs) or access points (APs) are deployed along the road, acting as road-side units (RSUs) to provide access services for the vehicle users [4]. On the other side, in MANET-based architectures, vehicle users communicate with each other in a point-to-point manner. Because of the ad-hoc nature of the MANETs, it is crucial to perform routing and resource allocation, for which many technologies and solutions have been proposed. One of the promising approaches is to implement a locally centralized routing and resource allocation scheme based on software defined mobile cloudlets [5]. In the future 5G networks, it is possible to use both infrastructure-based and point-to-point-based communication modes. We can combine the traditional cellular access technology and device-to-device (D2D) technology to construct the future VNETs. It becomes imperative for the studies using these technologies to provide cost-effective, easily-implementable schemes for the new generation of VNETs. The schemes should satisfy the demands for low latency, high connectivity and a large amount of data on the basis of vehicular secure communications. Moreover, the crucial issue on how to efficiently connect VNETs to current and future mobile communication systems remains an open problem.

Both IEEE 802.11p and cellular networks are widely used in VNETs, and many research works are focusing on them, [6] gives a theoretical framework to analyze the performance of VNETs based on 802.11p and LTE, respectively, and concludes that the abilities of current cellular networks to support secure vehicular communications are insufficient. On the other hand, considering that the future 5G mobile communications can provide very attractive quality-of-service (QoS) regarding delay, data rate, and reliability compared to current LTE, 5G mobile communication technology becomes a very competitive candidate for the implementation of VNETs [7]. Moreover, 5G communication-based VNETs can connect to universal mobile communication systems at very low costs.

However, merely using the fixed BSs of 5G communication networks in VNETs may encounter many issues, including frequent handovers, unsatisfactory connectivity, and unpredictable latency, which are caused by the mobility of the vehicle users. Many approaches have been proposed to solve these issues, and some of them are moving relay or moving AP related. Among this kind of approaches, there are two typical application scenarios. The first scenario is about public transportation system, such as high-speed train (HST), buses, etc. With one or more moving relays installed on an HST or bus, the mobile terminals on the HST or bus can communicate with the relays, so as to get access to the core network [8]. In some of these works, moving APs are used instead of moving relays. In this way, the moving small cells on the HSTs or buses provide higher access QoS than fixed cells along the road, because the frequent handovers are avoided. The performances of these moving AP based schemes greatly depend on the performance of backhaul links between the moving APs and the core network, which is investigated in [9]. The second scenario related to moving relays or moving APs is about relays or APs installed on vehicles. In this scenario, users on other vehicles or even pedestrians connect to the core network through the moving relays or APs [10]. Because of the relative movements between the relays or APs and the users, the communications also suffer from unavoidable handovers. Moreover, like the first scenario, the second scenario also faces the issues of the performance limited by the backhaul links between moving relays or APs and the core network. In fact, even in fixed BS based 5G communication networks with mobile users, handover-related issues are critical factors of the system performance.

To overcome handover-related performance issues in 5G networks, some researchers present solutions using cooperative communications between BSs or APs. Our previous work presents a cell-less communication architecture based on cooperative communications [11]. Different from the conventional cellular architecture, a user does not associate to a single BS or AP. Instead, it may communicate with cooperative BSs or APs by coordinated multipoint (CoMP) transmissions and receptions. The software defined networking controller is deployed to schedule the traffic and allocate the resource globally. In this way, the cell-less scheme improves the connectivity and reduces the latency caused by handovers. For both cooperative moving relay and moving AP schemes, how to implement the cooperative communications among moving relays or APs, and how to select some of them to cooperate are crucial issues in the cooperative-communication-based VNET. [12] proposes a cooperative communication relaying scheme. In this scheme, abundant vehicles in urban area cooperatively act as relays to provide pedestrians access services. The authors use signal-to-noise ratio (SNR) based relay selection method in the cooperative communications and analyze the performance. However, considering the critical requirements of communication latency and connectivity in VNETs, it is still a significant issue on how the cooperative vehicle-installed APs provide access for other vehicle users on the road.

In this article, accounting for the frequent handover and outage issues caused by the high-speed movement of vehicles, we discuss the 5G-communication-based VNET access technology and applications. We propose a moving-AP-based 5G cell-less VNET scheme, in which, three simple yet workable strategies are given for selecting vehicles as the cooperative moving APs to construct a 5G cell-less moving access network. In simulation results, we present and compare the performance on the connectivity and latency of various moving AP selection strategies for an illustrative scenario.

II. From Fixed Cellular Communications to Moving-AP-Based Cell-less Communications

Currently, one of the important roles of VNETs is to transmit various kinds of traffic security information, such as the vehicular status, nearby vehicular type, vehicular moving and traffic disaster. When transmitting the messages carrying such information, the latency is a very critical factor, and delay or loss of the messages will cause severe damages potentially as well. Therefore stringent latency and connectivity requirements are indispensable in 5G VNETs. In such scenarios, using traditional cellular networks with D2D communication to support VNETs may lead to some issues including frequent handovers, high latency, poor connectivity, and unbalanced load. Among these issues, latency issue is a particularly critical one for VNETs, and the handover issue and connectivity issue can also lead to increase the latency. Moreover, at the intermediate relays in the communication path of a D2D multi-hop relay communication system, it takes non-negligible time to receive, process, and transmit data. Thus the more hops there are in the communication path, the larger latency in VNETs will be resulted in [13].

There will be a significant challenge to overcome latency issue caused by the mobility of the vehicles if 5G technologies are directly applied in VNETs. To solve this problem, as shown in Figure 1, we propose a scheme to deploy vehicle-installed moving APs on some selected vehicles. Some of them can be vehicles on which APs are deployed beforehand, while others may be vehicles with the vehicle-installed transceivers which can increase their transmission powers and reception sensitivity by some methods. For example, millimeter wave transmission may be a key technology in the future 5G networks, which reduces a single antenna to a millimeter size due to its very short wavelength, and makes it possible to deploy a massive multi-input multi-output (MIMO) transceiver on a vehicle. Considering parts of the antennas of massive-MIMO work when the vehicle acts a regular vehicle user, we can activate more backup antennas of the massive-MIMO system if necessary, so that the vehicle can serve as a moving AP as well. The transmission powers of the vehicles that are not selected as moving APs remain unchanged to avoid increasing the interference. Considering the insufficient signal strength at the locations far away from the moving APs or serious interference in the edge area between two adjacent moving APs, we propose that, adjacent APs can cooperatively communicate with vehicle users

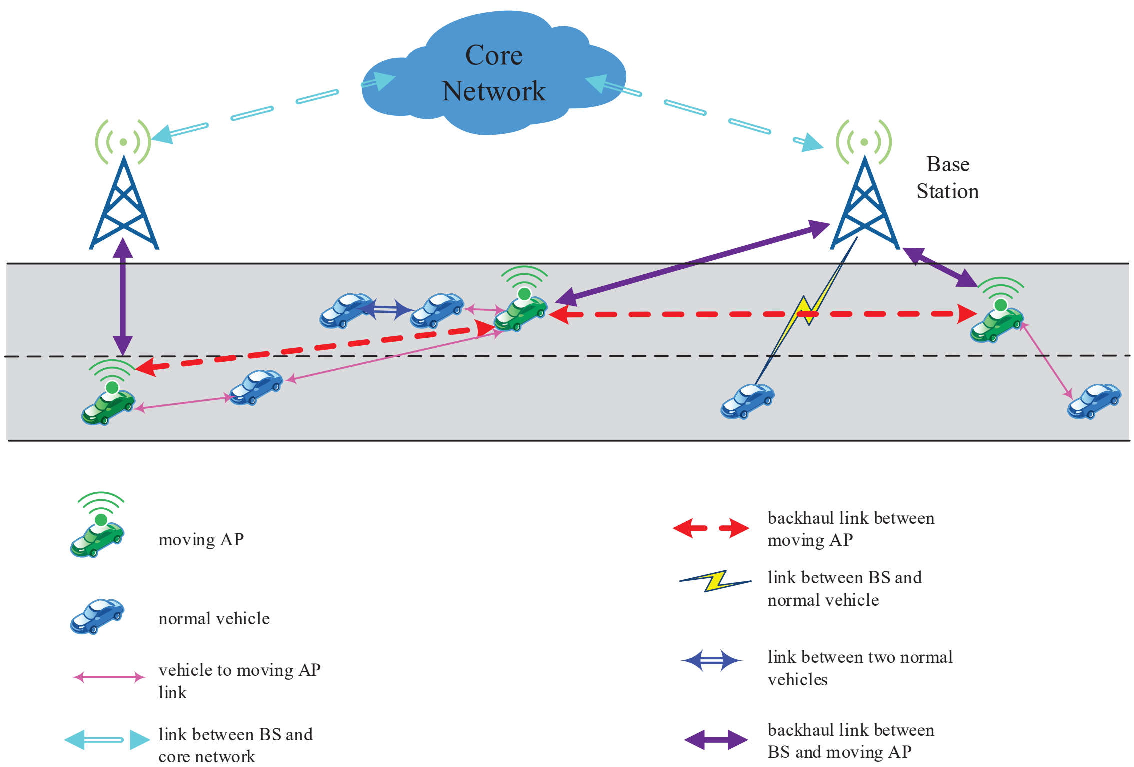

Fig. 1. An illustration of 5G moving-AP-based cell-less VNET

by joint transmission and reception to provide vehicle users access services. In this way, there is no *cell* of the coverage area for any single moving AP, where they cooperatively communicate to vehicular users in a similar *cell-less* way as described in [11]. Some advantages of this access scheme are listed below.

1) Fewer handovers and outages. When the selected moving APs move together with the vehicle users at the similar speed along the road, it is possible to maintain the available links between them for longer durations than between vehicle users and fixed BSs, thus reducing frequent handovers and outages. To be specific, most of the handovers will be soft handovers due to cooperative communications, and other unavoidable handovers will be replaced by D2D communications between vehicle users or accesses to fixed 5G BSs.
2) Lower latency. Compared to accessing to fixed 5G BSs or D2D multi-hop communications that require extra time, there will be much less latency when vehicle users in a local area communicate with each other by accessing to nearby moving APs.

3) Better connectivity. 5G moving-AP-based cell-less accessing can provide better connectivity than fixed-BS-based accessing or D2D-based multihop transmissions for two reasons. That is, accessing to fixed BSs will cause frequent handovers of vehicle users, whereas multihop D2D communications may increase the outage probability while increasing the hops of transmissions.
4) More balanced loads. Because the moving APs are selected from vehicles heading in the same direction on the road, the density of moving APs will increase along with an increase in the density of vehicular users in the congested road. Then the data traffic loads at moving APs will be more balanced than accessing to fixed BSs.

In the scheme above, to perform joint transmission and reception, one of the critical factors is how to build the backhaul links between adjacent moving APs [14]. A feasible approach is to allocate more bandwidth to APs for backhaul links than conventional cellular network links and D2D links. Moreover, besides the traditional cellular microwave transmissions, the emerging 5G transmission technologies including millimeter wave transmission, massive MIMO and visible light communication (VLC) can also be utilized to support the backhaul links for moving APs. Generally, VLC technology can be used for the backhaul links between moving APs, when they are in the line of sight of each others moving on the road. However, for the backhaul links between the core network and moving APs, it is better to use traditional radio technologies.

III. Architecture and Modeling of 5G Moving-AP-based Cell-less Communications in VNETs

A. Architecture of 5G Moving-AP-based Cell-less Communications

The architecture of the proposed 5G moving-AP-based cell-less communications consists of three tiers, that is, the vehicle user tier, the moving AP tier, and the core network tier. Communications can occur between tiers or within a tier.

As shown in Figure 2, in the vehicle user tier, vehicular users can communicate with each other by D2D communications, especially when they are unable to access to a nearby vehicle-installed AP or cooperative APs. Moreover, if they cannot communicate with adjacent vehicle users by D2D links, or there are too many relay hops in the transmission path of D2D links, then they may try to access to the nearby or road-side 5G BSs that generally have larger coverage areas.

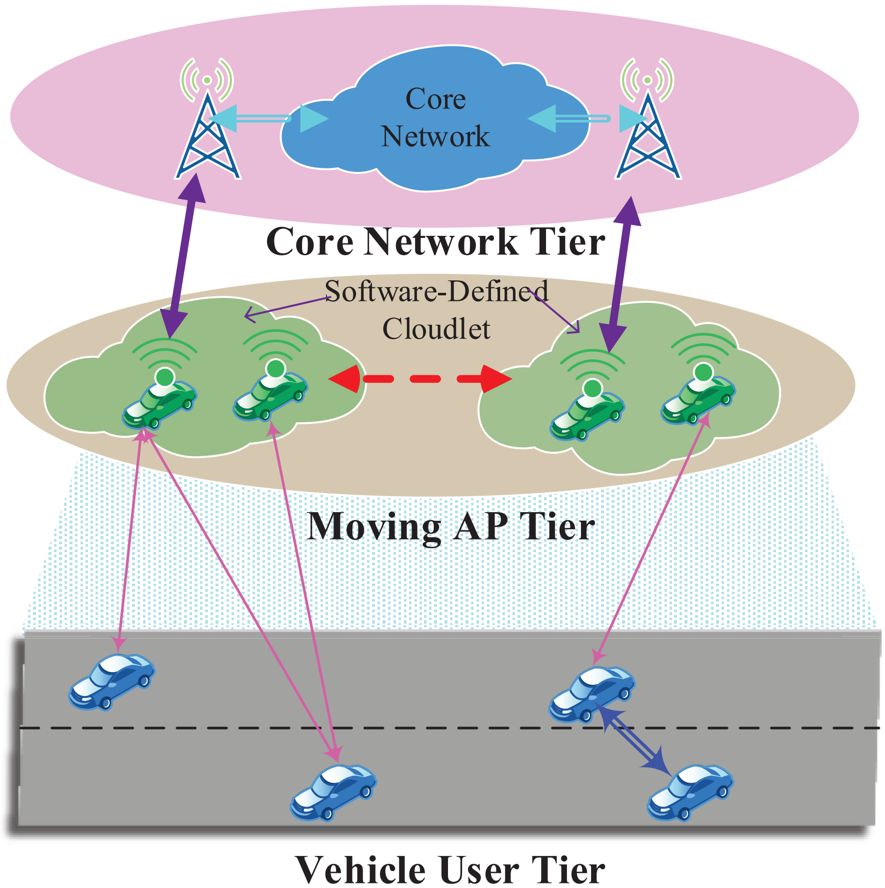

Fig. 2. Architecture of 5G cell-less VNETs based on moving APs

Generally, a common vehicle user accesses to the nearest moving AP if the communication link meets its communication demand. When accessing to a single moving AP cannot provide enough data rate or QoS, a vehicle user will communicate with its adjacent moving APs which can cooperatively communicate with it by joint transmission and reception. This cooperative communication can decrease the co-channel interference from moving APs and improve signal-to-interference-plus-noise ratio (SINR), thereby improving the data rate and expanding the coverage area. If the channel status is even worse and the vehicle users cannot access to cooperative moving APs, it will try to use D2D links to establish a multi-hop path to its communication peer. Eventually, there always remains the choice to access to the nearby 5G BSs, in case that the multi-hop D2D link may also lead to a considerable latency.

Within the medium moving AP tier, the backhaul links need to be established among the cooperating APs. In case that it is hard to establish stable backhaul links with sufficient data rate among the moving APs, backhaul links between the 5G fixed BSs and moving APs will be used to transmit control information and data for the cooperative communications. For the coordination and scheduling management of backhaul links among the moving APs, local software-defined cloudlets need to be deployed to manage the moving APs in a particular local area. To be specific, the candidate cloudlet controllers are deployed together with some of the moving APs, and among them, the effective cloudlet controllers will be selected dynamically.

The 5G core network tier consists of the backbone network and the traditional fixed BSs that are connected to the backbone network. To support the proposed moving-AP-based scheme, the mobility management entity of the 5G network should be responsible for the mobility management of both the mobile user terminals and the moving APs. The cloudlet controllers in the medium moving AP tier will play a vital role to help the mobility management entity of the core network to oversee the mobility in the whole network.

There are several approaches for those vehicles acting as moving APs to transmit their own information. One of the approaches is to transmit their information by using extra transceivers if they have. Another one is a virtual software-only approach, in which a virtual vehicle user terminal is implemented inside the AP to always access the AP itself for information transmission.

B. Transmission Modeling for Various Cases of Peer-to-peer Communications

Vehicle users usually transmit information to other vehicle users not far away from them, for example, vehicle security information shall be forwarded among vehicle users within a local area typically. It means that the communication peers are only a few of hops away from each other, even if there is no direct link between them. In 5G cell-less VNET based on vehicle-installed moving APs, the transmissions in peer-to-peer communications can be typically modeled as the several scenarios, as shown in Figure 3.

The case (a) in Figure 3 shows the D2D-based communication path, in which there can be one or more hops between the communication peers. The case (b) shows the scenario of the moving-AP-based transmissions, in which the communication peers access to a single AP or a group of cooperative APs, and it requires two hops for the communication peers to reach each other. When the communication peers are sufficiently far away from each other, they have to access to separate APs, between which backhaul links are built to transmit information and it requires three hops for the communication peers to reach each other, as shown in case (c).

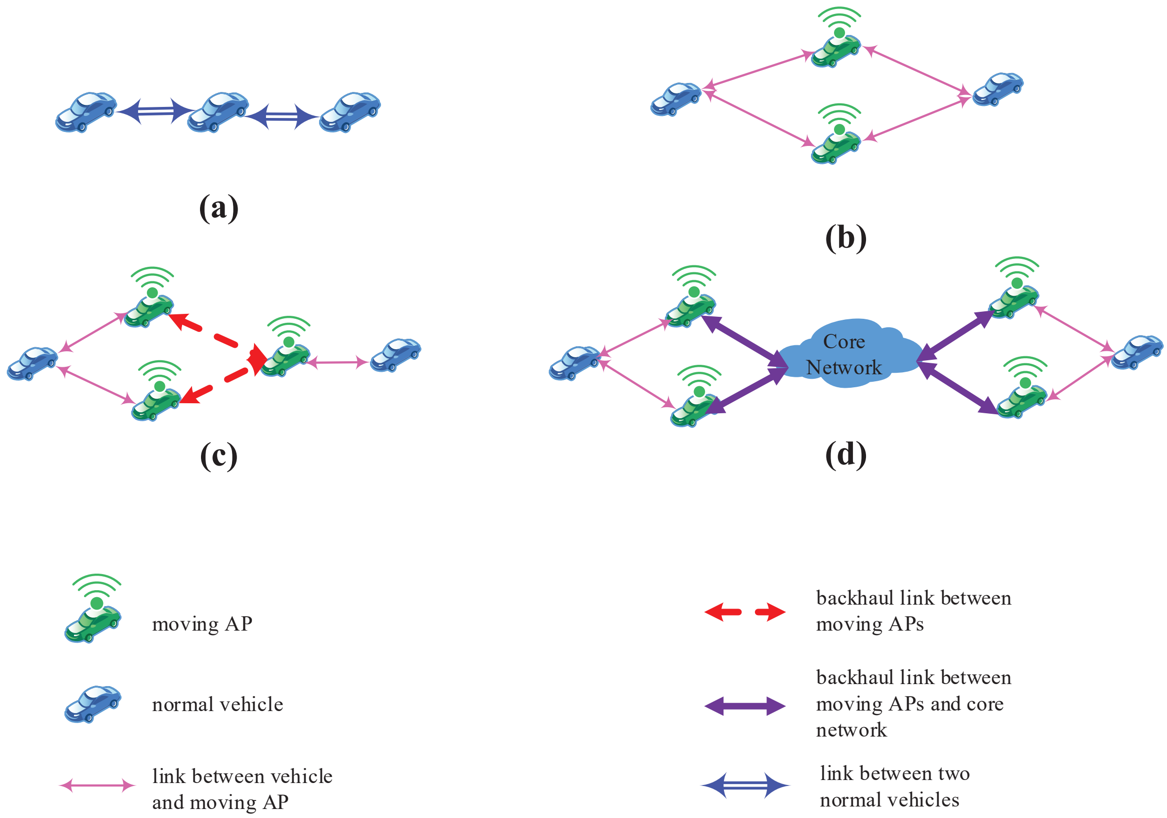

Fig. 3. Illustrations of transmission paths

Furthermore, when it is impossible to establish backhaul links between two accessing APs or two groups of cooperative APs, the APs transmit information via the 5G core networks by the backhaul links between the cooperative moving APs and the core networks. It will result in more hops in the transmission path, as shown in case (d) in Figure 3.

IV. Connectivity and Latency

A. Selection Scheme of Moving APs

For analyzing the performance of the proposed 5G cell-less VNET scheme, it is necessary to determine the spatial distribution characteristic of the vehicle-installed moving APs, which is indeed decided by the moving AP selection methods employed. The moving AP selection schemes can be classified into three kinds, including the predefined selection, independent random selection, and cooperative selection schemes.

The simplest moving AP selection scheme is the predefined moving AP selection scheme. By this selection scheme, moving APs are deployed on some of the intentionally selected vehicles beforehand. Compared to the ordinary vehicle users, the moving APs should have higher transmission power and reception sensitivity, which can be achieved by deploying powerful on-board units on some of the vehicles. For simplicity in performance analysis, the pre-deployed moving APs can be regarded as independent and randomly distributed in the vehicles. Then it is reasonable to assume that the moving APs also follow a Poisson point process. The predefined moving AP selection method is easy to implement, and there is no overhead for selection in run-time. However, this predefined selection method cannot adapt to the constantly changing traffic situation and communication demands.

Compared to the predefined selection scheme, the independent random selection scheme and the cooperative selection scheme can adapt to the actual traffic situation. In the independent random selection scheme, vehicles need not exchange information with one another for the selection. According to a certain probability, every vehicle that is capable of acting as a moving AP decides independently to be a moving AP or not. This selection scheme is straightforward and easy to implement, and it does not require additional communication and computing overhead. Similar to the predefined selection scheme, for simplicity, we can assume the candidate vehicles follow a Poisson point process in the performance analysis. In this way, it leads to a thinned Poisson point process for the distribution of the moving APs. This assumption makes it easy to analyze the performance of the VNETs owing to the tractability of Poisson point process.

Considering uncertain distributions of the vehicles and varied communication demands in the real scenario, the independent random selection will not be the better choice than cooperative selection schemes for moving APs. In cooperative selection schemes, vehicles exchange information with other vehicles to decide or elect moving APs. According to the selection manner for the moving APs, the cooperative selection schemes for moving APs can be divided into two categories that are centralized selection schemes and decentralized selection schemes. For the centralized selection schemes, a centered controller of the global or local area collects all the necessary information from vehicles and then decides which vehicles are chosen as the moving APs. One of the feasible methods to realize a centralized selection scheme is to form vehicles as local moving software-defined cloudlets. If a software-defined cloudlet controller is deployed on a vehicle, it will be responsible for assigning local moving APs, and act as a moving AP itself as well. On the contrary, in decentralized selection schemes, all the candidate vehicles exchange information and operate equally to select moving APs. The selection will be organized in a manner of distributed election or broadcasting competition. Apparently, there are high overheads for exchanging information while selecting the moving APs, which also bring a great challenge for the strict latency requirement in VNETs. One of the possible approaches to reduce the communication overheads is the RSU-assisted selection. The RSUs, which are connected to each other by high-speed backbone networks, can exchange information efficiently so that they can possess the location and velocity information of vehicles.

Whichever cooperative selection scheme is chosen, there are many selection strategies available for adopting. For simple examples, in this article, we consider the real locations of vehicles, and then evenly choose the moving APs over the balanced distance or an equal number of mediate vehicles between two adjacent moving APs. To be specific, we investigate the following three kinds of simple selection strategies.

1) Independent random decision strategy. In this strategy, every vehicle independently decides if or not it will become an AP according to a given probability. It is a simple strategy without any extra communication overhead.
2) Sequence-based selection strategy. Vehicles are assigned sequential number according to the order of their locations on the road. The moving APs will be selected from the vehicles according to a given selecting ratio. For instance, if the selecting ratio is 0.1, one moving AP will be sequentially selected from every ten vehicles. This strategy is simple and requires low communication overhead for counting the sequential numbers by exchanging information with the adjacent vehicles. This approach will help precisely balance the load of the moving APs, and improve the connectivity for dense vehicles in a local area.
3) Distance-based selection strategy. In this strategy, the moving APs are selected spatially evenly over distance, so that the coverage ranges of every moving AP are comparable. The goal of the strategy is to improve the coverage range on the road. The distance-based selection strategy requires higher communication overheads than the sequence-based one, because it needs to exchange location data besides sequential information.

The above strategies are simple yet workable. They can be performed by the vehicles in a distributed manner, and also can be carried out by a local software-defined cloudlet controller. Some complicated strategies, such as the auction-based selection and distributed competition, can be further considered as well.

B. Connectivity to Moving APs

The connectivity of 5G moving-AP-based cell-less communications can be evaluated from three aspects, including the connectivity probability that vehicle users can access to moving APs, the probability that vehicle users can access to the network by D2D links, and the probability that vehicle users can access to nearby fixed 5G BSs. In this article, we focus on the connectivity probability that vehicle users can access to moving APs.

We set up an illustrative simulation scenario for performance analysis where the vehicles on a $10\,\mathrm{km}$ of road follow a Poisson point process with the density of $0.02\,\mathrm{m}^{-1}$, and their velocities follow a uniform distribution within $[50, 80]\,\mathrm{km/h}$. The velocity of every vehicle keeps constant during the simulation. It is assumed that the communication channels follow independent Rayleigh fading with a pathloss exponent 4, the transmission power of the moving APs is $2\,\mathrm{W}$, the noise power received at vehicle users is $-100\,\mathrm{dBw}$. In this simulation, a vehicle user uses received SINR to choose a moving AP to communicate with in the non-cooperative mode, or two cooperative APs in the cooperative mode. The downlink connectivity probability of a vehicle user accessing to cooperative moving APs is compared to the connectivity probability of the vehicle user accessing to a non-cooperative moving AP. The impacts of different moving AP selecting probabilities and different selection strategies are evaluated as well.

Figure 4 shows the relationship between the connectivity probabilities and the moving AP selection probability, as independent random decision strategy is adopted. It can be seen that for accessing to both cooperative APs and a non-cooperative AP, the connectivity probabilities increase as the moving AP selection probability increases. That is, a higher density of moving APs makes it easier for the vehicle users to access to the network. Furthermore, it is observed that the connectivity probabilities approach a floor, where it is not always beneficial to increase the moving AP selection probability. It means that the density of moving APs needs to be properly designed to reach a balance between the connectivity and the corresponding energy consumption and costs.

Figure 5 shows the relationship between the downlink connectivity probability that a vehicle user can directly access to a moving AP, or APs by cooperative communications, and the SINR threshold of the reception at the vehicle user. In the simulation, we compare three kinds of the moving AP selection strategies, including the independent random decision, sequence-based selection, and distance-based selection. In all the scenarios for these three strategies, we choose

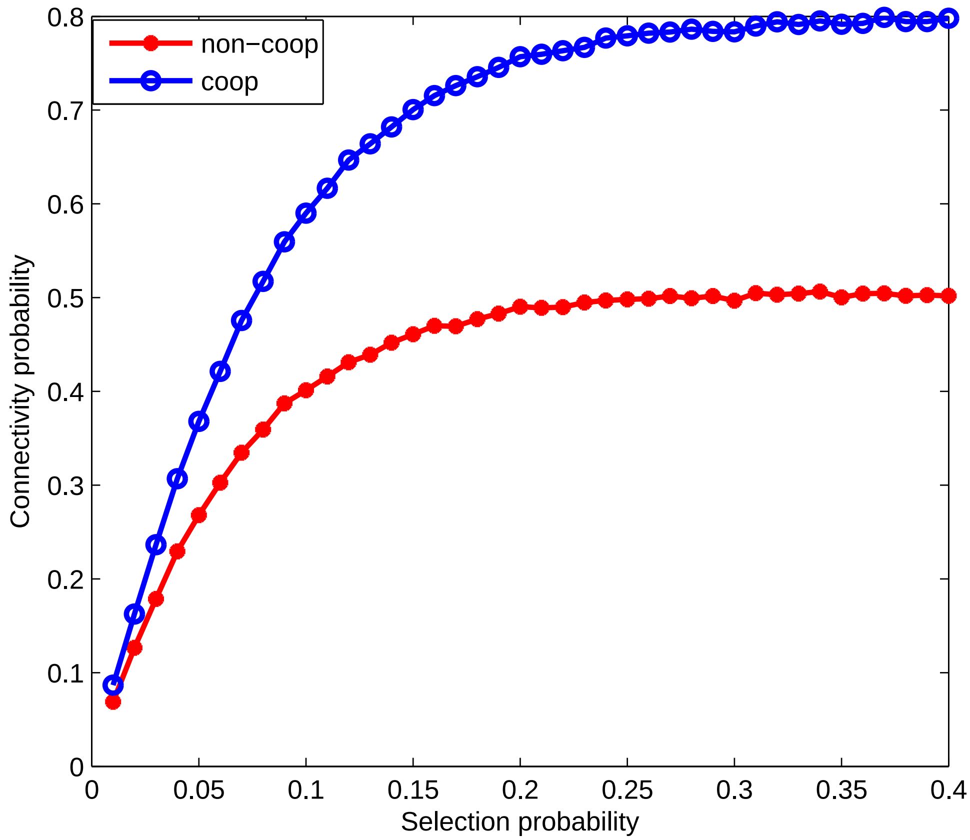

Fig. 4. Connectivity with respect to the moving AP selection probability

the parameters so that there are the same number of the vehicles, that is 200 vehicles, in these three scenarios. It can be seen that the connectivity probabilities of accessing to moving APs in the cooperative manner are significantly higher than that in non-cooperative ones. The results also indicate that the distance-based moving AP selection strategy and the sequence-based selection strategy outperform the independent random decision strategy. The distance-based strategy is aimed at the extending the spatial coverage along the road, and the sequence-based one is designed to balance load and leads to more moving APs selected among locally dense vehicle users than sparse users. Selection depending on the real distribution of the vehicles is the reason that both of them are better than the selection strategy by totally random decision.

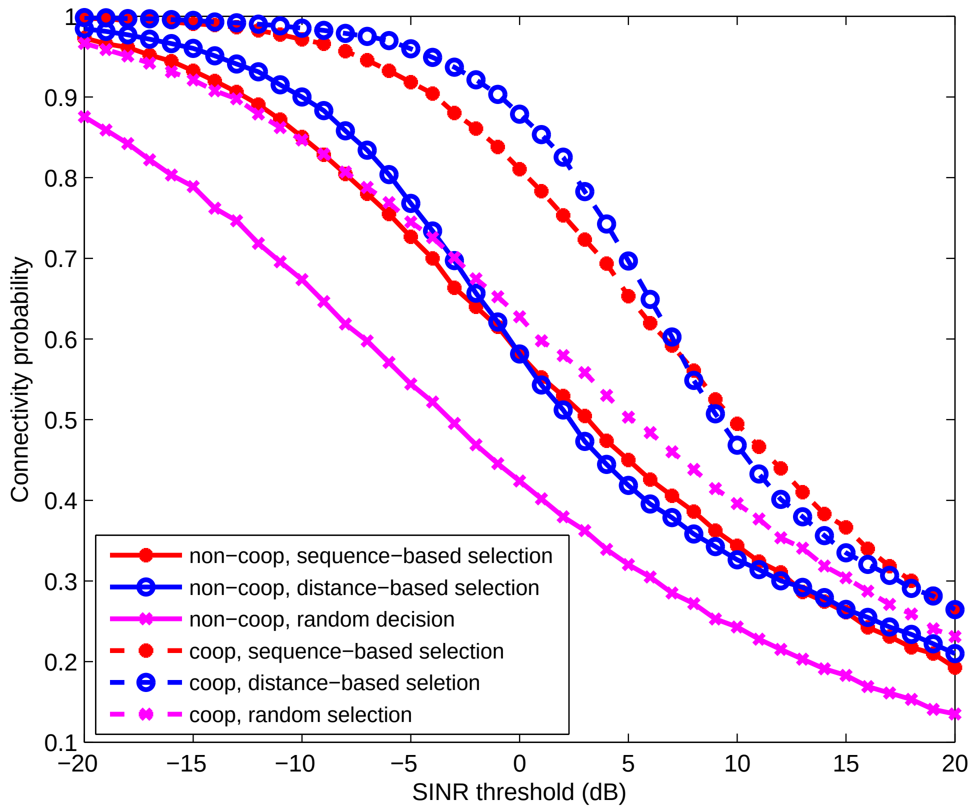

Fig. 5. Connectivity probabilities of accessing to moving APs under different selection strategies

C. Latency in Terms of Relay Hops

Latency performance is crucial in VNETs, especially for vehicle secure communications. The latency in 5G moving-AP-based cell-less communications is affected by many factors including the number of hops from peer to peer, relay forwarding time, outage probability and time, and other processing time incurred along the communication path. In this article, we focus on the number of hops in the communication path between two end vehicle users, which significantly affects the latency.

Following the same configurations as in Figure 4 and 5, Figure 6 shows the relationship between the average number of hops between two vehicle peers and their distance under both cases of using moving-AP-based access scheme and using only multi-hop D2D links. In the moving-AP-based access scheme, we compare the average hops for the case of accessing to cooperative moving APs to the case of accessing to non-cooperative moving APs. It can be

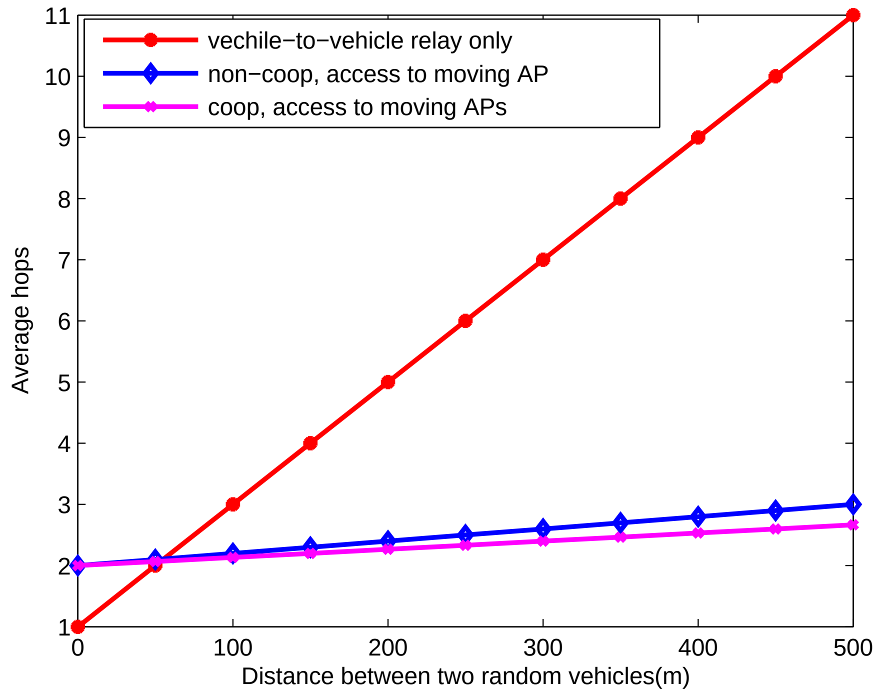

Fig. 6. The number of hops along the transmission path between two random vehicle users

seen that with an increase in the distance between peers, the average number of hops of the moving-AP-based scheme is much smaller than the D2D-only-based one. The average number of hops between end users by accessing to cooperative moving AP is always lower than accessing to non-cooperative moving APs. Furthermore, when the distance between two communicating vehicle peers is less than $500\,\mathrm{m}$, it is observed that the average number of hops of the moving-AP-based scheme between them is between 2 and 3. It is owing to the various transmission models, especially in case (b), as discussed in Figure 3.

V. Future Challenges

Although performance gains in terms of latency and connectivity can be expected, the 5G moving-AP-based cell-less VNETs also face many challenges. Some future challenges are listed below.

1) In the future 5G VNETs, the interference and routing issues caused by the heterogeneity of the 5G networks will be major challenges. Using 5G technologies in VNETs will lead to interference with the common 5G networks in the same areas. Considering the

heterogeneous 5G networks consist of various radio technologies, when the vehicle users move on the road and communicate with the moving APs, they will encounter fast-changing and complicated interference from the fixed 5G networks near the road. Especially in the future 5G ultra-dense networks, the mobility of the vehicle users become major concerns for evaluating and eliminating interference. On the other side, the moving AP will also cause severe interference to the ordinary users associated to BSs along the road. Besides interference, the mobility of the vehicle users and the heterogeneity and ultra-density of 5G networks can also cause serious routing issues. The transmission path should be determined over rapid-changing topology and across the different heterogeneous network tiers. Although the cell-less manner access alleviates the routing problems, how to choose the optimal transmission path from the source moving AP to the destination moving AP is still a performance-critical issue.

2) More efficient backhaul links are required for 5G moving-AP-based cell-less VNETs. To cooperatively communicate with vehicle users, the moving APs have to establish stable, high-rate wireless backhaul links among them. However, due to the movements of vehicle users and the quick change of the surrounding radio environments, it is not easy to maintain the quality of the backhaul links. To solve this problem, some new backhaul management schemes should be proposed to provide ready-to-use communication links for backup backhaul transmissions. Efficient prediction on the vehicle movement and communication channel status will help to create and maintain the backhaul links.
3) The application of new technologies, such as VLC and millimeter wave transmissions, will bring new technical challenges to 5G moving-AP-based cell-less VNETs. Intuitively, VLC is suitable for vehicle-to-vehicle (V2V) communications where modulatable LED lights can be used to replace the traditional vehicle lights easily, thus providing a much higher data rate than other rivals [15]. However, when many vehicles move along the road, and one of them tries to communicate with one another using the VLC technology, it very likely receives the light interference from the vehicles after or in front of it, and the vehicles running on the middle way of the communications peers probably block the transmitted signal. Then how to maintain VLC links over the rapidly changed environment is an important issue that remains to be investigated in the future. Similarly, although millimeter wave transmissions can provide significantly high-rate communication links in line-of-sight situations, they suffer from noise and propagation loss in air. Therefore, the

transmission performance of millimeter wave communications in such environment remains to be investigated.

4) Application-awareness is also required in future 5G moving-AP-based cell-less VNETs. Many vehicular applications tend to send broadcasting information, such as the traffic accident information that should be received by all the nearby vehicles as soon as possible, while some other vehicle applications tend to send unicasting or multicasting information such as the entertainment data. Depending on the specific application requirements, the application-aware VNETs would better provide broadcasting and multicasting services besides the unicasting one, such that huge duplicated transmissions can be avoided. To realize such application-aware VNET services, some cross-layer protocols need to be designed for the future 5G moving-AP-based cell-less VNETs.

VI. Conclusions

The access network technology is very critical in VNETs, which is a decisive performance factor of VNETs. With the trend that more and more V2V communications in VNETs are supported by 5G communication technologies, it is necessary to adapt the fixed cellular communications to moving-AP-based cell-less communications. In this article, we propose a moving-AP-based 5G cell-less VNET scheme, in which fixed BSs are replaced with on-board moving APs for ease of user access. To strengthen the connectivity and reliability of the VNET communications, joint transmission and reception are employed by the moving APs to communicate cooperatively with the vehicle users. The proposed moving AP scheme utilizes the cooperative communications between APs to improve the connectivity in VNETs, whereas a traditional simple moving AP or moving relay scheme does not use cooperative communications. Taking advantage of the cooperative communications, the proposed cell-less moving AP scheme is better than the simple moving relay or moving access schemes regarding connectivity performance. Illustrative results show that the connectivity is improved and the number of transmission hops is reduced significantly.

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