Exploring Mobile Edge Computing for 5G-Enabled Software Defined Vehicular Networks

Xumin Huang, Rong Yu, Jiawen Kang, Yejun He, and Yan Zhang

Abstract

To meet the ever increasing demand of mobile data traffic, 5G enabling technologies are proposed in vehicular networks. Network densification is one of the key 5G technologies for large user throughput and traffic capacity, but there is a great challenge to serve numerous vehicular neighbors. According to observations from a real dataset of vehicles, we discover vehicular neighbor groups (VNGs) consisting of groups of vehicular neighbors. VNGs are crucial to enrich and enhance various services in 5G networks through efficient management. Therefore, we propose 5G-enabled software defined vehicular networks (5G-SDVNs), where software defined networking is exploited to dynamically manage VNGs in 5G and vehicular environment. Furthermore, we leverage mobile edge computing to strengthen network control of 5G-SDVN. By combining software defined networking with mobile edge computing, a programmable, flexible, and controllable network architecture is introduced for 5G-SDVN. The architecture simplifies network management, improves resource utilization, and achieves sustainable network development. We use the universal plug-and-play standard to enable scalable VNG networking. A case study of vehicular cloud computing highlights the advantages of 5G-SDVN. Finally, we also identify and discuss open issues in 5G-SDVN.

Introduction

Nowadays, the global number of vehicles has reached more than 1 billion since 2010 [1]. To provide ubiquitous and reliable connections among vehicles, various fifth generation (5G) enabling technologies have been proposed to integrate with vehicular networks, leading to 5G-enabled vehicular networks [2]. In the emerging networks, network densification is one of the core characteristics for improved traffic capacity and user throughput. Network densification refers to ultra-dense deployment of wireless infrastructures [2]. Thus, dense radio coverage is achieved for vehicles in vehicular networks. Due to the increased system capacities of 5G networks, numerous co-located vehicles can access the network simultaneously, but the number of these connected vehicles is constrained because of limited spectrum resource and lower spectral efficiency in previous work. As a consequence, it is a great challenge to serve vehicular neighbors in 5G-enabled vehicular networks.

In this article, we propose that vehicular neighbors can form a vehicular neighbor group (VNG) to enrich vehicular services, but also improve overall performance of 5G networks. Network densification greatly increases the system capacities of 5G networks. Numerous connected vehicles are allowed to be served at the same time when they are co-located. Co-located vehicles may continuously become vehicular neighbors, especially when proximal vehicles have the same destinations or similar routes. These vehicles can form a VNG and can request for services for common interests, similar goals, and shared experiences. Then a variety of services, such as data sharing, mobile interaction, and resource cooperation, are convenient to be provisioned in VNGs. VNGs will be established frequently along with the implementation of network densification. However, VNGs need to be managed well.

It is challenging to manage VNGs in 5G and vehicular environment. VNG networking includes member selection and group establishment of a VNG, which is a tough task because of the dynamic mobility of vehicles. VNG networking should be scalable due to the increasing amount of vehicles. Flexible resource scheduling is also necessary for supporting various services with different quality of service (QoS) requirements. Besides, on-demand configuration and maintenance of many servers and routers may be required, but in the dense deployment of 5G networks, this is a complex challenge [4].

Software defined networking (SDN) is of great benefit in the management of VNGs in 5G networks. Thus, we propose 5G-enabled software defined vehicular networking (5G-SDVN) where the SDN technology is exploited for efficient management of VNGs. SDN has been envisioned as a novel technology to provide flow programmability and network resilience to optimize network management of 5G networks [5]. In 5G networks, SDN decouples the control plane and data plane, so network state and intelligence are logically centralized. The clear separation of these two planes makes the increase of mobile users become independent of resources of the control plane, and avoids incurring overheads for the control plane [6]. Based on the advantages, we propose the 5G-SDVN in this article.

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For vehicles, the establishment of weak ties is temporary and performed only when driving on the roads. But the establishment of strong ties is regular because these ties are valid in fixed time, for example, in daily life, workmates at a same office leave from a same parking lot and may drive along with each other to dinner together after work time.

However, to realize 5G-SDVN, tight requirements for the computing paradigm need to be satisfied. In 5G-SDVN, the computing paradigm should support services within close proximity of mobile users. Besides, as computation-intensive services (e.g., augmented reality) emerge, less network latency and novel context awareness are required to improve user satisfaction and quality of experience [7]. To overcome the dilemma, we pay attention to mobile edge computing (MEC). MEC is a new computing paradigm that puts plentiful processing capabilities at the network edge. MEC servers are close to users, acquire real-time insight into context information, and directly process user requests. Thus, we utilize the MEC servers as local controllers in the control plane to strengthen network control of 5G-SDVN.

In this article, we introduce 5G-SDVN, where SDN is utilized for efficient management of VNGs with the advent of network densification. By integrating SDN with MEC, a hierarchical architecture is designed for 5G-SDVN. The core idea of the architecture is to separate the whole network into the control plane, social plane, and data plane. The social plane is abstracted for VNG networking, and the data plane is for data transmission. With the introduction of MEC in the control plane, decision making is nimble and optimal by obtaining global knowledge of network states. The architecture simplifies network management and optimizes resource utilization, ultimately achieving sustainable network development.

Our contributions are summarized as follows:

- We discover VNGs by observing a real dataset of vehicles, and propose 5G-SDVN, where scalable VNG networking and flexible resource scheduling can be achieved.
- We integrate SDN with MEC and introduce a programmable, flexible and controllable network architecture. We use the universal plug-and-play (UPnP) standard to enable VNG networking.
- We highlight the advantages of 5G-SDVN by using vehicular cloud computing as a case study, and identify and discuss open issues.

The rest of this article is organized as follows. First, we explore VNG and introduce 5G-SDVN. We then propose the architecture combining SDN and MEC. Next, UPnP for VNG networking is illustrated. A case study to highlight the advantages of 5G-SDVN is presented. After that, we outline a number of research challenges. Finally, conclusions are drawn.

5G-Enabled Software Defined Vehicular Networks

Weak Ties in Vehicular Neighbor Groups

We explore VNG by studying ties among vehicular neighbors. In a VNG, there are weak ties among the vehicles. Vehicles may continuously have stable vehicular neighbors driving along with them for a certain period of time. With the implementation of network densification, such scenarios may frequently occur on the streets in urban cities. Supported by enriched spectrum resource and increased spectral efficiency, a great number of co-locating vehicles can connect to networks simultaneously. As a result, the improved system capacities of 5G networks increase the probability of establishing weak ties among vehicles. Moreover, co-locating vehicles tend to request different services for common interests, similar goals, and shared experiences. In this context, weak ties are easier to be identified and utilized in 5G networks. We define a weak tie of any two vehicular neighbors as follows.

Definition: Consider that v_i and v_j first meet at time slot t_0, and keep meeting over a period of time, Δt. We define that v_i has established a weak tie with v_j in this period of time. The establishment of the weak tie is expressed by

$$\forall\ t \in [t_0, t_0 + \Delta t],\ d^t_{i,j} \leq D, \tag{1}$$

where $d^t_{i,j}$ is the distance between v_i and v_j at time slot t and D is the communication range between any two vehicles.

The weak ties in VNGs are different from the strong ties in typical vehicular social networks (VSNs). Generally, vehicles with strong ties are acquaintances (e.g., family and friends) [8], while most vehicles with weak ties in VNGs are strangers. For vehicles, the establishment of weak ties is temporary and performed only when driving on roads. But the establishment of strong ties is regular because these ties are valid in fixed time; for example, in daily life, workmates at the same office leave from the same parking lot and may drive along with each other to dinner together after work time. Due to constrained wireless connection, proximal vehicles in VNGs only interact with each other online. There are no specified constraints of meeting locations for vehicles with strong ties. The vehicles can interact offline and online if necessary. Moreover, contact time of vehicles with strong ties is generally longer than that of vehicles with weak ties. In urban cities, the contact time of vehicles in VNGs can reach 10 minutes on the streets. Since weak ties are limited by meeting location, contact method, and contact time, after a certain period of time, few weak ties are still kept. Hence, weak ties are difficult to further develop, while it is easy for strong ties. However, strong ties are changeless, so the number of vehicle members with strong ties is generally fixed. Weak ties are convenient to be established as co-locating vehicles can do so easily in the context of network densification. More details on the comparisons between weak ties and strong ties for vehicles are listed in Table 1.

To provide further insights into weak ties, we have observed mobility of 527 vehicles in an actual urban area of San Francisco [9]. The latitude of the observed area is from 37.71 to 37.81, and the longitude is from –122.45 to –122.38. The observed area is approximately 69 km^2. As shown in Fig. 1a, in a random 10 minutes, there are 41 vehicles with stable neighbors within 400 m. This means that in this period of time, 8 percent of the vehicles can establish weak ties because weak ties are only valid under continuous proximity-based conditions. However, every vehicle often gets a chance to establish weak ties when driving along the streets. Figure 1b shows that in 120 minutes, the number of neighbors of a randomly selected vehicle changes over time. The vehicle does meet its vehicular neighbors over time. According to the observations, we summarize the features of weak ties as follows.

- *Proximal*: Only proximal vehicles can establish weak ties and keep them continuously for a certain period of time. In this way, weak ties are constrained in terms of proximity, randomness, and temporariness.
- *Online*: Weak ties are difficult to further develop because most of them are established with limited time periods and only triggered on roads. Weak ties highly depend on online communications.
- *Frequent*: Vehicles on roads always have suitable neighbors to establish weak ties. These scenarios will occur frequently with the trend of serving co-locating vehicles simultaneously in the 5G environment.

Features	Weak ties in VNGs	Strong ties in VSNs
Relationship strength	Strangers	Acquaintances
Meeting time	Temporary	Regular
Meeting location	Proximity	Unspecified
Contact method	Online	Offline/online
Contact time	Approximately 10 minutes	> 10 minutes
Further development	Few	Existent
Amount of members	Large	Fixed
Meeting frequency	High	Low

TABLE 1. The comparisons of two kinds of ties.

Vehicular Neighbor Groups in 5G-SDVN

By discovering weak ties, a lot of VNGs are established, which provides an impetus to exploit them well in 5G networks. Information about driving safety, driving efficiency, and common interests can be shared in VNGs. By content sharing in VNGs, the newest content can be obtained. A vehicle can always get the same content that it receives from acquaintances independently. But another new content should be obtained via strangers (e.g., vehicular neighbors in VNGs).

For entertainment, mobile interaction is also potential to emerge and be developed in VNGs. Moreover, the establishment of a VNG provides an opportunity for enhanced resource cooperation among the vehicles in the VNG.

We summarize these new benefits brought by VNGs for 5G networks into the following aspects:

Efficient data sharing: Proximity-based conditions promote data sharing and overcome time sensitivity requirements. The newest content is shared promptly, and content dissemination efficiency is improved.

Ubiquitous mobile interaction: Due to entertainment needs, interaction is supported in VNGs (e.g., playing games and charting). This enables drivers and passengers to have comfortable and joyful driving experience.

Reliable resource cooperation: Based on continuous connections with neighbors, available resources are accessedm and stable resource cooperation is ensured for scheduling resources on demand and guaranteeing QoS in real time.

However, the above expected benefits are based on optimized management of VNGs, so we propose 5G-SDVN to manage VNGs dynamically in 5G networks. SDN is a promising networking diagram to separate control logic of networks from underlying infrastructures (e.g., devices and routers). The control plane and data plane are decoupled for facilitating control functionality and data traffic, respectively. The software-based control in the control plane is centralized. By using software components, network intelligence is improved to reduce hardware limitations. When SDN is applied to vehicular networks, all vehicles can be equally abstracted as SDN switches and managed with a unified interface to clearly simplify network management [10]. The control plane can also promptly coordinate among vehicles and allocate network resources according to fast changing external context resulting from the dynamic mobility of vehicles. Efficient flow programmability enables seamless interoperability between various networks. This significantly strengthens the foundation for 5G networks. Hence, in the vehicular environment, the integration of different vehicular services can become more straightforward and feasible.

Recently, SDN has been applied to vehicular networks for significantly improving the flexibility, programmability, and efficiency of the networks. Reference [10] studied opportunities for utilizing SDN to optimize heterogeneous vehicular communications. The authors propose the SDVN, where all network components are abstracted as SDN switches to mitigate the heterogeneity of the vehicular network and to achieve rapid network innovation. Several case studies are also presented to exhibit the strength of the SDVN. To support highly dynamic and time-sensitive vehicular behaviors, an SDN-based framework, VeShare [11], was introduced for managing networks over time, namely, controlling group construction and determining efficient resource allocation. The previous work in [12] also exploited the SDN technology to extend the flexibility and programmability of pseudonym management in vehicular clouds. The article introduces the software-defined pseudonym system and also demonstrates that the system improves pseudonym resource utilization.

Similarly, we are motivated to exploit SDN for efficient management of VNGs in 5G networks. The increasing amount of vehicles leads to the exponential growth of mobile data traffic in the context of network densification. This means that for VNGs, a centralized management scheme is required to consolidate all information of user requests, network states, and so on for service provision with higher efficiency. In 5G-SDVN, centralized management is achieved by obtaining global knowledge and automatically reacting to changes of network states. The abstraction of control logic enables independence of the deployment, extension, change, and upgrade of underlying infrastructures. Besides, the proposed 5G-SDVN also provides an application program interface for external vehicular services to modify and update QoS requirements conveniently. Thus, 5G-SDVNs are proposed for good service provision in the context of network densification.

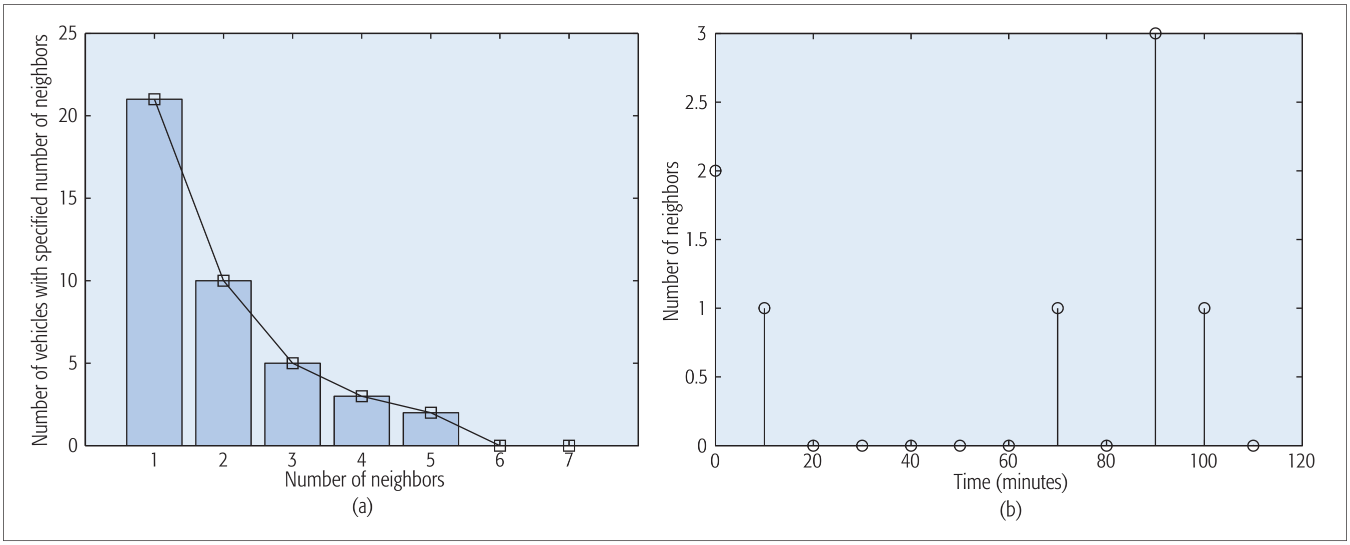

FIGURE 1. Observations of the weak ties among vehicular neighbors: a) weakness of the weak ties among vehicular neighbors; b) frequency of the weak ties among vehicular neighbors.

A Hierarchal Architecture Supported by Mobile Edge Computing for 5G-SDVN

Functions of MEC for 5G-SDVN

MEC is leveraged for strengthened control of 5G-SDVN in this article. MEC introduces new network elements (e.g., MEC servers) that enable advanced computing and storage capabilities at the network edge. MEC servers are deployed in close proximity of vehicles, directly process requests, and serve vehicles with less network latency and novel context awareness. The proposed MEC servers can be used for management of VNGs in 5G-SDVN as follows.

Real-time instruction distribution: Generally, the MEC servers are deployed in underlying planes and typically physically connect to access points in the networks (e.g., base stations and roadside units). Various instructions on the management of VNGs can be transmitted to vehicles in real time.

Network state monitor: MEC servers at the network edge are convenient to collect dynamic status information of vehicles. The information includes user requests, safety messages, available resources of vehicles, and so on. The information is uploaded and synthesized for subsequent optimization of management.

Local decision making: Decisions on VNG networking, resource scheduling, and QoS management can be made directly by the local MEC servers. Thus, the proposed 5G-SDVN spreads the control logic from the network core to widely distributed network edges. Supported by the MEC servers, the process of decision making is boosted. Location awareness and mobility support are also achieved for improving user experience.

According to the functions, the MEC servers can be deployed in the control plane and are capable of acting as local controllers to spread and localize the control plane of 5G-SDVN. As the entire network state is monitored in real time, the control logic of the control plane is optimal and nimble in coping with dynamic changes of network topology, configuration, and functionality. By integrating MEC into the SDN-based architecture, the control plane is enhanced, and 5G-SDVN significantly evolves to be more controllable.

A Hierarchical Architecture with Three Planes

Figure 2 illustrates our MEC-supported architecture for 5G-SDVN. The architecture extends the programmability for VNG networking and data transmission, and logically separates the control plane, the social plane, and the data plane. The control plane consists of two sublayers, the core layer and edge layer, which are in the network core and at the network edge, respectively. In the core layer, there is a global controller, while multiple MEC servers act as local controllers in the edge layer. The control plane assisted by MEC is responsible for real-time decision making for VNG networking and data transmission. Every vehicle is abstracted as an SDN switch instructed by the controllers. In the social plane, sociality flows are separated and forwarded among the vehicles for efficient VNG networking. A sociality flow consists of data packets that indicate key features of a VNG. By forwarding the sociality flows, suitable vehicles are discovered to establish weak ties for establishment of a VNG. Thus, the social plane performs VNG networking tasks. In the data plane, data traffic is also controlled by following the instructions designed by the control plane. Data flows are forwarded among vehicles, so various services are provisioned in VNGs. More details about each plane are described as follows.

Control plane: The control logic is split from the physical network devices to the centralized control plane. In the core layer, the global controller has a whole view of the network states. The global knowledge of the network states includes identity information of all entities, status information of vehicles, and switches. This useful knowledge can be used for security management, efficient networking, and fault diagnosis. By the Internet, the global controller instructs the distributed MEC servers to coordinate for centralized management of VNGs. The coordination is achieved by communications and cooperation among the MEC servers. In the edge layer, every MEC server easily detects events on VNGs in a region, such as which vehicle joins a specified VNG or leaves from the VNG. Then the servers update members and estimate the topology of the VNG. The MEC servers also make local decisions for service provision in VNGs. When a VNG is formed, due to different demands, services among vehicles (e.g., data sharing) need to be mapped properly to work well. Resource allocation and QoS management are also under the control of the MEC servers for efficient facilitation of services.

Social plane: VNG networking is performed by forwarding the sociality flows in the social plane. Establishment of a VNG is a user-centric manner. First, a vehicle requests forming a VNG. When the request is permitted, packets on the VNG are transferred for selecting members. The sociality flow refers to the packets with the following format:

VNG_ID	*Route*	*Size*	*Time*

VNG_ID is the identity of the new VNG. *Route* and *Size* are two important items on the VNG. *Route* and *Size* indicate the traveling route of the requesting vehicle and capacity of the VNG, respectively. *Time* refers to the time slot at that time. According to the instructions designed by the control plane, other vehicles decide whether to join the VNG.

Data plane: By decoupling the control plane from the data and social planes, the whole control logic is concentrated in the network core and at the network edge supported by MEC. Thus, vehicles in VNGs just become simple forwarding devices. Vehicles can interact with each other, leading to forwarded data flows in VNGs. For instance, 3D maps for navigation are shared and reused among proximal vehicles. Online chatting and playing games are also supported for entertainment in VNGs.

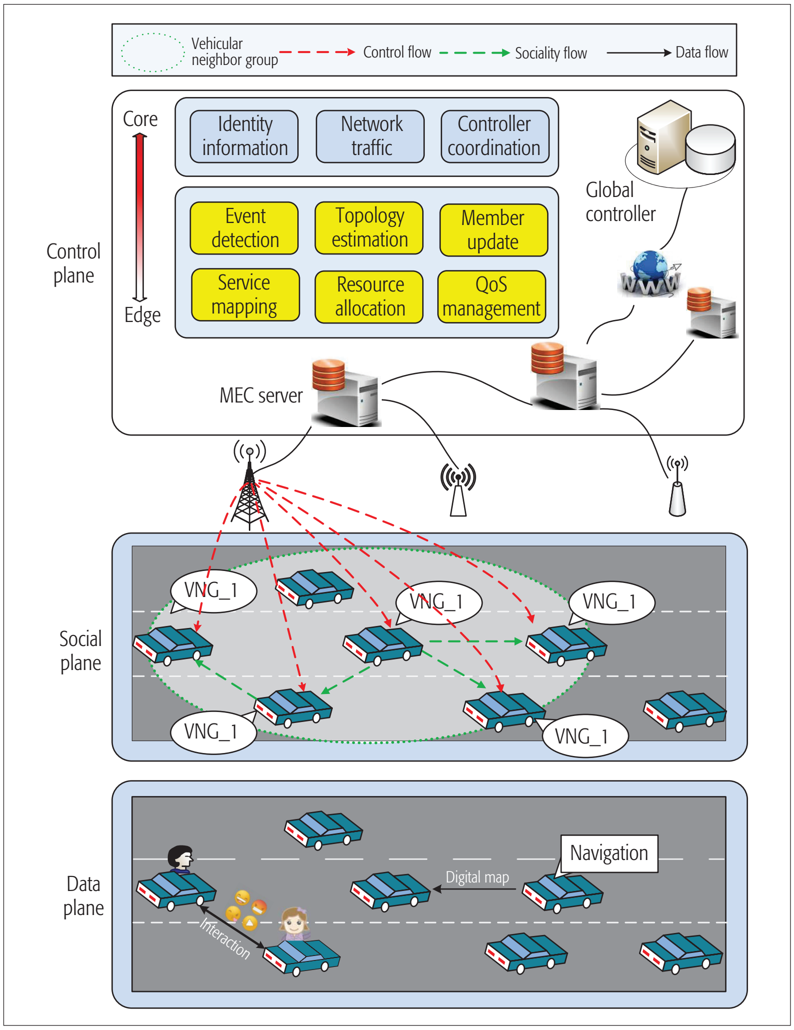

FIGURE 2. MEC-supported architecture for 5G-SDVN.

Advantages of the Proposed Architecture

In the architecture, the abstracted control plane is to configure VNG networking and optimize data transmission from a global perspective. Through the software-based control, network intelligence is achieved and enhanced by utilization of the MEC servers. With efficient programming, it is easier to control the network infrastructures as well as simplify the development and deployments of new applications and management policies. Based on various resource requirements, the network schedules all available resources, including computing and communication resources, in a flexible way to improve resource utilization. For example, with decisions by a local MEC server, dedicated wireless channels can be allocated promptly for broadcasting emergency warning messages or delivering content with high priority. Thus, constraints on the network development are also broken to expedite network evolution. We summarize the advantages of this architecture in the following aspects.

Simplify network management: The architecture has excellent scalability to manage a variety of services in VNGs. Due to the remarkable reconfigurability and programmability of the network devices, administrators can use the controllers to conveniently assign the new management policies to any switch. This clearly simplifies the network management.

Improve resource utilization: By adapting the global-aware controllers, efficient cooperation among vehicles in VNGs is promoted to enable the unprecedented flexibility of resource scheduling. Available resources are allocated on demand. The resources are shared among different vehicles according to the various resource requirements of services and different resource capacities of vehicles. Thus, resource utilization is improved with a global optimum.

Achieve sustainable development: With the separation of the social plane, the data plane, and the control plane, the architecture eases restrictions of the development and deployment of new network features. The architecture considers mobility support, network topology changes for vehicles and QoS guaranteed for various services. Thus, the strengthened and centralized network control brings sustainable development of more sophisticated networking functions, services, and applications.

UPnP describes an intelligent peer-to-peer network where network devices are discovered and configured automatically. It is essentially independent from any particular platform, operation system and programming language. This enables an open and flexible network connectivity and processing for the network devices.

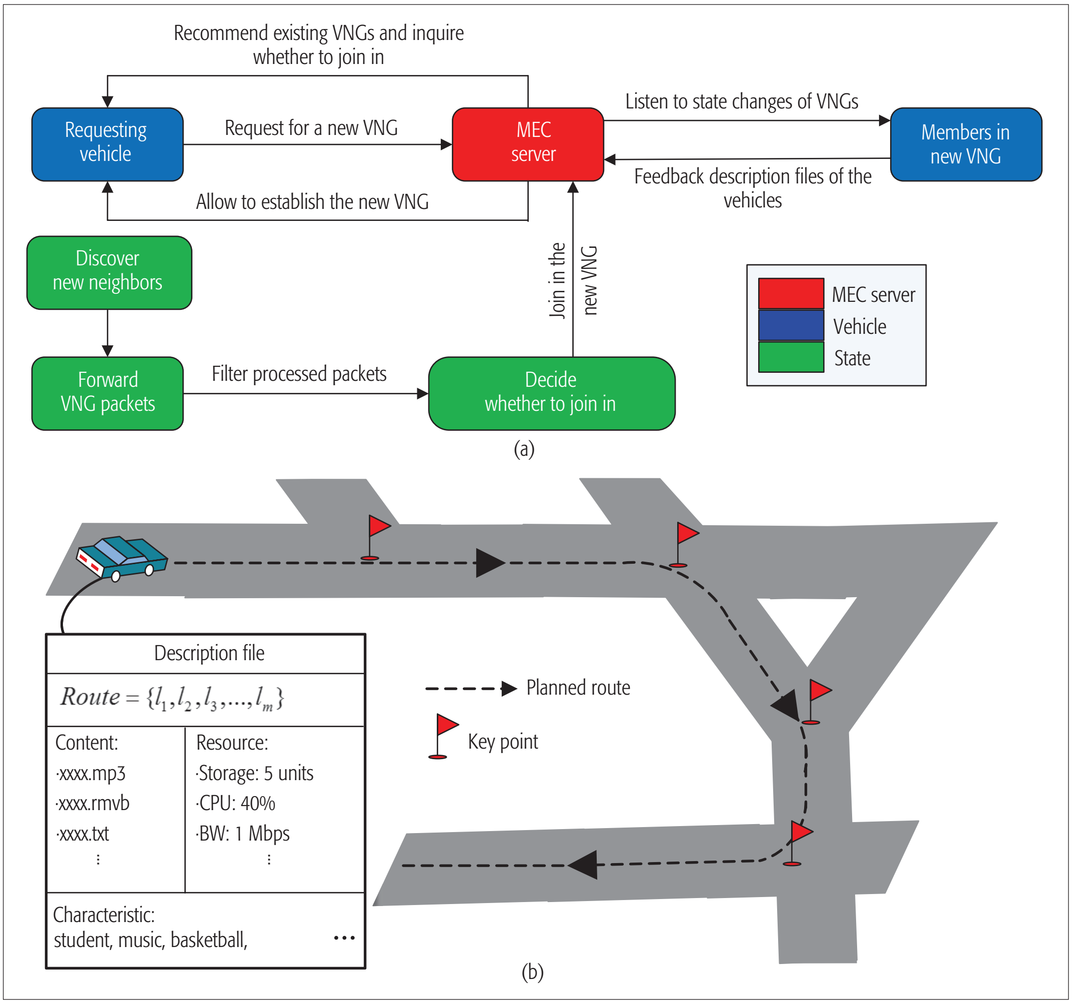

FIGURE 3. Details of VNG networking using UPnP: a) diagram of UPnP for VNG networking; b) a description file of a vehicle.

A Key Issue in the Proposed Architecture

In 5G-SDVN, a challenging task is VNG networking, and we utilize UPnP to address this issue. UPnP is defined by the UPnP Forum, which is organized by a number of vendors in the fields of computation, mobile services, entertainment, and so on [13]. UPnP describes an intelligent peer-to-peer network where network devices are discovered and configured automatically. It is essentially independent of any particular platform, operating system, or programming language. This enables an open and flexible network connectivity and processing for the network devices, greatly increasing interoperability of various end devices, network technologies and management policies. Besides, UPnP describes how the network devices exchange their information and invoke services transparently to users. This is of great benefit to data sharing among vehicles in VNGs. Nowadays, UPnP has been widely adopted as a simple and robust standard for ad hoc networks, and this motivates us to exploit the technology for VNG networking in 5G-SDVN.

In UPnP, there are two key components: controlled devices and control points. Here, they refer to vehicles and MEC servers, respectively. For VNG networking, the novel advantage behind UPnP is the PnP concept. In this article, this means that once a target vehicle is discovered for a VNG, the UPnP protocol automatically configures the network connection settings for the vehicle. If necessary, the available resources of the new member are scheduled for the other members of the VNG on demand. By supporting automatic discovery and high-efficiency coordination, UPnP facilitates the relevant operations of VNG networking, such as member selection, service discovery, and content exchange among vehicles. The operations can be achieved via simple standardized mechanisms, such as simple service discovery protocol (SSDP). Thus, VNG networking is based on the UPnP processes of discovery, description, event detection, and control. Figure 3 shows the procedure of VNG networking using UPnP. More details are described as follows.

When vehicle *i* acts as a mobile controlled device and drives on a road, it can request to establish a new VNG. Driving vehicles always obtain a planned route. Hence, the requesting vehicle substitutes the planned route to *Route* in the sociality flow. The route can be quantified into a set of known key points, $Route_i = \{l_1, l_2, \ldots, l_m\}$. These key points refer to road junctions (e.g., crossing and intersection), as shown in Fig. 3b. The vehicle forwards the sociality flow to a control point (i.e., the closest MEC server). For the request, the MEC server first searches for an existing VNG fitting for the requesting vehicle. Consider that there is a VNG j, whose parameter $Route^j = \{l_1, l_2, \ldots, l_n\}$. Every nearby vehicle chooses to join the VNG by comparing its route with *Route* of the VNG. Vehicle i joins the recommending VNG j with the following probability calculated by

$$P_i^j = \frac{\left\|Route_i \cap Route^j\right\|}{\left\|Route_i\right\|}. \qquad (2)$$

$\|Route\|$ returns the length of *Route* and $\cap$ is an operation to extract the common path between two routes. Clearly, with the common path lengthening, the vehicles are more willing to join the recommended VNG. Only when there are no suitable VNGs or the requesting vehicle refuses to join will the MEC server allow the requesting vehicle to establish the new VNG. After receiving permission, the requesting vehicle begins to forward the sociality flows on this new VNG to nearby vehicles.

The MEC server keeps listening to the surroundings of this new VNG. Once it discovers a suitable vehicle (e.g., with almost the same velocity and direction) for the VNG, the MEC server instructs a specified vehicle of the new VNG to forward the sociality flow. After receiving an unprocessed flow on the VNG, the nearby vehicle makes a decision on whether to join the VNG according to the probability calculated by Eq. 2. If the vehicle would like to join, it uploads the reply to the MEC server, and *Size* in the packet is increased. When *Size* reaches the upper bound, VNG networking ends.

For the established VNG, description files of its members need to be known for facilitating services in the VNG. The UPnP protocol defines a basic set of standards and conventions for describing devices and services. Here, the description file provides general information about the vehicles. As shown in Fig. 3b, the description file of every vehicle is about travelling route, storing content, residual resource, and characteristic indication of the driver. As a control point, the MEC server collects the description files of all members in VNGs and listens to state changes of VNGs, such as service discovery. In this way, the MEC server makes real-time decisions for service provision in VNGs. For example, the MEC server detects that a vehicle requests the content of its interests in a VNG. The MEC server first finds the target vehicle according to the uploaded description files. Then the MEC server instructs the target vehicle to transfer the content to the requesting vehicle according to an optimized transmission path by considering the dynamic topology of the VNG.

Case Study

We use a case study to highlight significant advantages of the proposed 5G-SDVN in this article. We consider a scenario of vehicular cloud computing in 5G-SDVN. Vehicular cloud computing is established among a group of nearby vehicles cooperating with each other, and dynamically allocates resource to authorized vehicles for avoiding idle resource, as shown in Fig. 4. In previous work, vehicular cloud computing is formed without real-time and optimized control. For example, when vehicle i needs to establish

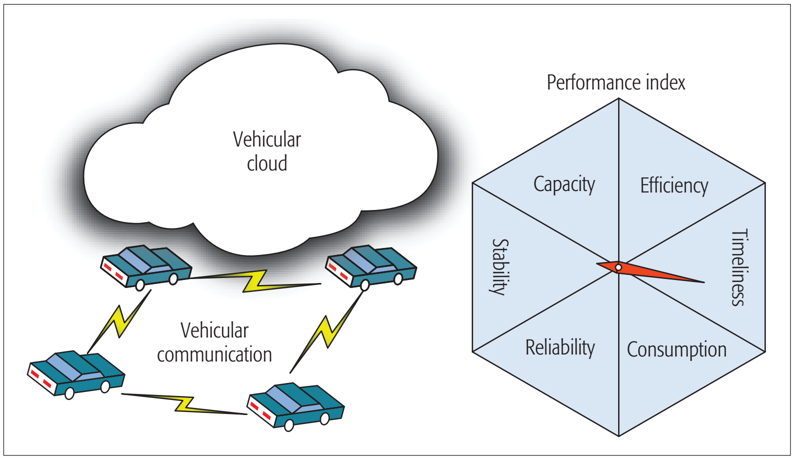

FIGURE 4. Vehicular cloud computing and performance index.

a vehicular cloud, it will contact nearby vehicles without adequate considerations. Proper member selection for the vehicular cloud is generally neglected. Most existing work only focuses on whether there are positive responses from nearby vehicles when establishing a vehicular cloud (e.g., the work in [14]). Some vehicles may just stay in the vehicular cloud for only a short time, which clearly may result in frequent changes of the vehicular cloud. Availability of resource provision cannot be guaranteed. Vehicle i does not ensure that members will leave the vehicular cloud at any time. So vehicle i keeps listening to the members, which causes high communication overhead for the vehicle. Due to the dynamic mobility of nearby vehicles, real-time member update and topology estimation are also challenging as these tasks are generally performed by the requesting vehicle acting as the cloud leader.

Next, we consider vehicular cloud computing in 5G-SDVN. Vehicle i in a VNG uploads the request to establish the vehicular cloud to the local MEC server. The MEC server obtains sufficient information around vehicle i, and more vehicles can be selected for establishing the vehicular cloud. The selection of suitable members primarily considers location proximity, traveling route, available resources, and existing workloads of the vehicles. At the same time, with UPnP, the MEC server detects events of the vehicular cloud in real time, and consequent operations, e.g, task allocation and resource scheduling, are optimized for the vehicular cloud. In summary, overall performance of vehicular cloud computing is improved in 5G-SDVN in terms of the following indexes (shown in Fig. 4).

Extended capacity: More suitable vehicles for establishing the vehicular cloud are discovered, and the capacity of the vehicular cloud is significantly extended.

Stable construction: The MEC server selects those nearby vehicles with similar velocity and route to the requesting vehicles, and thus the construction of the vehicular cloud becomes stable.

Reliable resource provision: The members establishing the vehicular cloud would not leave suddenly, and expected reliable resource provision is achieved.

Low communication overheads: As event detection is absolutely moved from the requesting

The architecture extends the programmability and flexibility for VNG networking and data transmission. Meanwhile, by integrating MEC with SDN, the control plane is exactly strengthened and offers the improved controllability for 5G-SDVN. Thus, the architecture simplifies network management and improves resource utilization, eventually achieves sustainable network development.

vehicle, redundant communication overheads are lowered, which avoids high energy consumption.

Real-time scheduling: With the ubiquitous communications and computing capabilities of MEC, local decisions are made and forwarded to vehicles promptly to achieve real-time scheduling.

Efficient resource utilization: Resource cooperation among the vehicles is under the centralized control from a global perspective to improve resource utilization.

Research Challenges in 5G-SDVN

5G-SDVN establishes suitable VNGs and exploits the SDN and MEC to manage VNGs for enriching vehicular services and improving QoS as well. However, there are still some research challenges that need to be addressed. We identify the key issues and discuss them in detail.

VNG Management

Due to the vast number of connected vehicles, VNG management poses new challenges in 5G-SDVN. First, we consider the size of a VNG. When the size of a VNG is set to be larger, clearly, this is beneficial to the improvement of services in the VNG. For example, newer content can be shared. However, this also incurs large management overhead. When the size is set to be smaller, both shared content and available resources are limited, impeding normal services and affecting user satisfaction. We consider that the size of every VNG needs to be determined well according to different conditions (e.g., traffic density). On the other hand, interaction among different VNGs can be considered. Generally, few isolated VNGs exist in the networks. A vehicle may join multiple VNGs, and these vehicles can become coordinators utilized for the interaction among different VNGs.

Resource Allocation

When integrating emerging technologies into 5G-SDVN, strategies of resource allocation tend to become comprehensive. For example, to enable high-rate content delivery, two proximal vehicles may use device-to-device (D2D) communication to communicate with each other directly, for improving spectral reuse, acquiring hop gains, and enhancing system capacity. But D2D communication easily leads to interference for cellular communication caused by the reuse of a cellular user's spectrum. To address the issue, various strategies of optimizing spectrum resource allocation have been designed in different scenarios [15]. Thus, resource allocation for D2D communication should be combined with these strategies. In this way, based on the specified conditions, the control plane can choose an optimal strategy for decision making.

Privacy Preservation

It is of paramount importance to protect sensitive privacy information of vehicles in 5G-SDVN. Sensitive privacy information of a vehicle includes whether to join a VNG, which VNG the vehicle joins, the description files uploading to controllers, and so on. Some of the issues have been addressed in existing vehicular networks. For instance, we can leverage a group signature scheme for secure communications among vehicles in VNGs. But these schemes need to be exploited well for working at high efficiency in the control plane.

Conclusions

In this article, we explore mobile edge computing in 5G-enabled software defined vehicular networks. Through observations of a real dataset, we study weak ties among vehicular neighbors and realize the benefits brought by VNGs in the context of network densification: enriching vehicular services and enhancing the quality of the services. To achieve these benefits, efficient management of VNGs is required, so we propose 5G-SDVN, where SDN is exploited for managing VNGs with scalability and flexibility in 5G networks. To enable 5G-SDVN, we design the MEC-supported architecture. The architecture separates the whole network into the social plane, data plane, and control plane. The architecture extends the programmability and flexibility for VNG networking and data transmission. Meanwhile, by integrating MEC with SDN, the control plane is strengthened and offers improved controllability for 5G-SDVN. Thus, the architecture simplifies network management and improves resource utilization, eventually achieving sustainable network development. We leverage UPnP for VNG networking and use a case study to highlight the advantages of 5G-SDVN. We also outline a number of research challenges in 5G-SDVN.

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