Drone Assisted Vehicular Networks: Architecture, Challenges and Opportunities

Weisen Shi, Haibo Zhou, Junling Li, Wenchao Xu, Ning Zhang, and Xuemin (Sherman) Shen

Abstract

This article introduces the DAVN, which provides ubiquitous connections for vehicles by efficiently integrating the communication and networking technologies of drones and connected vehicles. Specifically, we first propose a comprehensive architecture of the DAVN and outline its potential services. By cooperating with vehicles and infrastructures, drones can improve vehicle-to-vehicle connectivity, infrastructure coverage, network information collection ability, and network interworking efficiency. We then present the challenges and research opportunities of DAVNs. In addition, a case study is provided to demonstrate the effectiveness of DAVNs by leveraging our designed simulation platform. Simulation results demonstrate that the performance of vehicular networks can be significantly enhanced with the proposed DAVN architecture.

Introduction

As an essential component of Internet of Things (IoT) and future 5G networks, vehicular networks (VN) enable vehicles to communicate with each other and connect to various types of infrastructures by leveraging vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication technologies [1]. In spite of the significant progress made in research and implementation of VN in both academia and industry, three challenges have emerged recently when merging VNs into IoT and 5G networks:

First, some emerging IoT or 5G services enabled by VN, such as high-accuracy 3D map navigation, heavily depend on reliable connections, while the vulnerable wireless links caused by the high mobility of vehicles and complex traffic scenarios lead to serious deterioration of VN connectivity. Second, the inadequate coverage of infrastructures prevents practical implementation of VN [2]. The quality of V2I communications in coverage holes or uncovered areas cannot be guaranteed, and the rigid distribution of infrastructures also lacks the flexibility to adapt to the dynamic access demands. Third, the scarcity of spectrum resources remains a serious challenge in VN. Some research works have been proposed using cognitive radio or the TV white space band to solve this problem [3]. However, it is still challenging to choose or build a platform providing additional spectrum resources for VN.

Drones, or unmanned aerial vehicles (UAV), are considered to be an important element of IoT. Equipped with dedicated sensors or communication devices, drones can undertake various services such as low altitude surveillance, post-disaster rescue, logistics application and communication assistance [4]. Moreover, the capabilities of drones to support broadband wireless communications, especially forming Flying Ad Hoc Networks (FANETs) and communicating with ground nodes, have been studied theoretically and validated through field experiments [5]. As an emerging technology, drone communication exhibits valuable features that can enhance VN's performance and applications.

Line-of-Sight Links: Compared with vehicles and infrastructures, drones flying in the sky have a higher probability to connect ground nodes and other drones via line-of-sight (LOS) links, which facilitates highly reliable transmissions [6]. In addition, based on the real-time traffic information collected by embedded sensors, drones can adjust their hovering positions to maintain the quality of links. This attribute makes drones a desirable candidate to enhance the reliability of ground networks.

Dynamic Deployment Ability: Drones can also perform as one kind of network infrastructure allowing ground users to access [6]. Different from traditional infrastructures that are statically fixed on dedicated locations, drones can be dynamically deployed according to real-time requirements, and allocated to different users or controllers on demand. Compared with deploying a large number of static cells to cover the whole area, re-deploying drones based on the spatial and temporal changes of demands is more cost-effective.

Drone Swarm Networks: Apart from infrastructures, a swarm of drones are capable of forming scalable drone swarm networks allowing ground nodes to access. Benefiting from its high flexibility and rapid provision features, the drone swarm network is a feasible solution to recover communication in fast and effective ways, especially for scenarios where communication resources are scarce or unavailable, such as post-disaster environments [7].

Exploring the features of drones has great potential to address the aforementioned challenges confronted by VN. Specifically, integration of drones and VN can bring the following benefits.

Improving Reliability for Wireless Links: Constrained by the two-dimensional VN topology and

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dense vehicle traffic, traditional VN links are frequently obstructed by neighbor vehicles or buildings. As a result, most messages are transmitted through non-line-of-sight (NLOS) wireless links. On the contrary, in drone assisted VN, messages can be relayed or broadcast by drones via LOS links. With the highly reliable links provided by drones, both V2V and V2I connectivity can be enhanced significantly.

Enhancing Flexibility for Infrastructures: Some pioneer works leverage drones' dynamic deployment ability to assist ground infrastructures [6]. By dispatching drones to coverage holes or traffic burst areas on demand, vehicles can connect with drones and access infrastructures through drones' relay. Performing as the remote extension of static infrastructures, drones bring flexibility to V2I communications.

Providing Connectivity for Resource-less Scenarios: Two types of resource-less scenarios occur in VN: one is lacking infrastructure coverage in rural areas, the other is using up spectrum resources in dense vehicle scenarios. Since the connectivity demands in both scenarios are temporary but unpredictable, it is uneconomical to deploy additional infrastructures, while drone swarm networks can be rapidly formed over dedicated areas on demand, and perform as an access platform for resource-less vehicles. The coverage and topology of such a platform can be extended or changed dynamically due to the high flexibility of drone swarm networks.

Many works have been conducted to validate drones' benefits for specific VN applications. However, to the best of our knowledge, until now no systematic architecture or framework has been proposed for the communication and networking issues in the integrated drone assisted VN. To this end, we propose a comprehensive architecture of Drone Assisted Vehicular Networks (DAVN). In DAVN, drones are integrated with classic VN to improve the connectivity between vehicles, extend coverage of infrastructures, facilitate network information collection, and provide additional accessing resources for vehicles. Based on the DAVN architecture, some enhanced VN applications, such as ubiquitous Internet access, dynamic transportation surveillance, and seamless hand-off among infrastructures or networks, can be enabled through the assistance of drones.

The remainder of this article is organized as follows. Related works regarding the integration of drones and VN are introduced in the following section. The architecture of DAVN is then proposed, and the enabled services are introduced. Challenges and open research issues of DAVN are then discussed. Then a case study is conducted through a dedicated simulation platform to validate the performance of DAVN. Finally, the conclusion is given.

Literature Review on Integrating Drones with Vehicular Networks

Existing works investigating drone communications mainly focus on three aspects: leveraging drones to improve network connectivity; enhancing information collection ability through drones; and intra-networking issues for a swarm of drones. For network connectivity improvement, multi-hop data relays between aerial and ground networks are achieved through drones. In [8], Goddemeier *et al.* propose a role assignment strategy for drones to facilitate self-optimized air-to-ground connectivity. Specifically, drones are assigned with different roles (e.g. sensing agent, relay node, articulation point and returnee), and switch roles based on current network status. For information collecting enhancement, drones are used to rapidly and autonomously acquire network information. For example, Motlagh *et al.* leverage drones to monitor traffic conditions and pedestrians for eHealth applications [4]. For drone swarm networks, Mobile Ad Hoc Network (MANET) architecture is integrated into drone communications to form FANET. Solutions for the routing and connecting issues caused by FANET's dynamic 3D topology are explored in [5]. In [9], Fadlullah *et al.* propose a dynamic trajectory control algorithm for drone swarm networks. By allocating the distance between the trajectory centers of neighbor drones, the throughput and delay performance of drone swarm networks can be improved.

As for the integration of drone communication and VN, traditional works treat drones as surveillance devices to monitor vehicular flows. For instance, in [4] Motlagh *et al.* introduce some airborne traffic surveillance systems leveraging drones. On the other hand, with the maturity of flying control technology and commercialized drone products, using drones or drone swarm networks as supportive platforms to enhance VN performance is no longer a fantasy. An increasing number of articles concerning the drone enhanced VN have emerge in recent years. For example, Zhou *et al.* built an aerial-ground cooperative vehicular networking architecture and validated its performance through road tests [10]. In this architecture, drones form an aerial sub-network to aid the ground vehicular sub-network through air-to-air (A2A) and air-to-ground (A2G) communications. The aerial sub-network not only collects network and road information for vehicles, but also performs as an intermediate relay in V2V communications. In [11], Oubbati *et al.* propose a UAV-Assisted Vehicular Routing Protocol (UAVR) for VN. Drones monitor traffic density and vehicle connectivity status, and then exchange collected information with vehicles through dedicated messages. Based on that information, UAVR can guide vehicles to find the best multi-hop path for V2V communications.

Though many works have leveraged drones to relay V2V data and collect network information, infrastructures in VN are seldom integrated with drones. Following the trend that VN is merging into the IoT and 5G ecosystem, infrastructures turn out to be indispensable gateways between vehicles and the core network. In addition, pioneering trials have been conducted to

> Pioneering trials have been conducted to explore drones' ability to assist infrastructures or radio access networks. To fully exploit drones' potential in enhancing VN performance, it is urgent to design a new DAVN architecture integrating drones, vehicles and infrastructures simultaneously.

For flexibility, one infrastructure can be served by multiple RRAN drones, and one RRAN drone can also be shared by multiple infrastructures. A global algorithm allocating RRAN drones among infrastructures is needed to maximizing drones' utility.

explore drones' ability to assist infrastructures or radio access networks (RAN) [6]. To fully exploit drones' potential in enhancing VN performance, it is urgent to design a new Drones Assisted Vehicular Network (DAVN) architecture integrating drones, vehicles and infrastructures simultaneously.

Drone Assisted Vehicular Networks Architecture

In DAVN, drones maintain two basic functions: relaying V2V communications and gathering network information. Moreover, two additional tasks can also be conducted by drones: functioning as remote access nodes to extend the coverage of infrastructures, and forming a network with heterogeneous network resources that can be accessed by vehicles dynamically. Figure 1 depicts the architecture of DAVN.

Network Components

Vehicle: Vehicles in DAVN are embedded with on board units (OBUs) to communicate with other network elements. The OBUs support DSRC communications between vehicles, and also provide multiple interfaces to other type of networks. Since heterogeneity has become an irreversible trend for VN [1], vehicles in DAVN also implement a data processing module (DPM) in order to handle the interworking and data exchanges among heterogeneous networks.

Infrastructure: Both road side units (RSUs) and cellular base stations (BSs) are regarded as infrastructures in DAVN. Within their coverage area, infrastructures can directly distribute data to vehicles and drones through DSRC or the cellular band. However, outside of coverage or coverage holes, where reliable data transmission cannot be guaranteed, V2I communications are complemented by drones' relay. Similar to the concept of remote radio head (RRH), a group of remote radio access nodes (RRAN) are formed by drones in DAVN. Each infrastructure dispatches some RRAN drones hovering over its coverage holes. Vehicles around coverage holes directly access RRAN drones, then RRAN drones relay their V2I data to infrastructures through dedicated drone-to-infrastructure (D2I) links.

Drone: Two kinds of drones are considered in DAVN: relaying node (RN) drones and RRAN drones. Working on DSRC or the extended spectrum band for VN, RN drones can be treated as flying vehicular nodes. They relay data for V2V communications and access infrastructures the same as vehicles. In addition, a group of RN drones can form a drone swarm network to provide an additional access platform for vehicles.

Performing as remote radio access points, RRAN drones can be dynamically allocated to required positions to assist V2I data exchanges. Two main tasks are fulfilled by RRAN drones: enhancing V2I connectivity for coverage holes, and improving capacity for dedicated regions.

Both kinds of drones are equipped with sensors to collect network information. Moreover, for some powerful drones embedded with two kinds of interfaces, they can even switch their roles between RN and RRAN drones following the control commands from dedicated controllers.

Vehicle-Drone-Infrastructure Integrated Networking

According to the roles performed by drones, three networking modes can be enabled in DAVN architecture: drone assisted V2V networking, drone assisted mobile access networking, and drone swarm networking.

Drone Assisted V2V Networking: In-depth experiments have demonstrated that lacking LOS links is the most essential reason for degraded throughput and delayed performance between connected vehicles [12]. In DAVN, RN drones are able to connect multiple vehicles with LOS links simultaneously. Working on Drone Assisted V2V (DA-V2V) networking mode, RN drones keep sensing traffic topology within their coverage and adjusting flying positions to maintain LOS vehicle-to-drone (V2D) links. Vehicles forward V2V data to corresponding RN drones, then RN drones relay or ferry the data to receiving vehicles. Furthermore, the broadcasting messages are disseminated by RN drones, since more vehicles can be reached by LOS links through RN drones.

Drone Assisted V2I Networking: RRH is introduced to amplify the coverage of traditional VN infrastructure [13]. However, the fixed RRH topology constrains infrastructures' flexibility to cope with varying traffic loads and coverage holes in spatial domains.

In Drone Assisted V2I (DA-V2I) networking mode, RRHs are replaced by RRAN drones, which can be dynamically allocated to needed positions according to demands. Vehicles communicate with RRAN drones through V2I interfaces as they access infrastructures directly. Since RRAN drones can adjusts their positions to ensure relatively static and reliable wireless channels between infrastructures and themselves, the D2I links hold the potential to relay V2I data in a highly reliable way [6]. Dedicated wireless protocols should be considered in the D2I links to guarantee high-throughput and low-latency data transmission simultaneously.

Since both coverage holes and access demands keep changing spatially, RRAN drones have to be reallocated to different infrastructures or locations frequently. For flexibility, one infrastructure can be served by multiple RRAN drones, and one RRAN drone can also be shared by multiple infrastructures. A global algorithm allocating RRAN drones among infrastructures is needed to maximizing drones' utility.

Drone Swarm Networking: Drone-to-drone links are considered in the DAVN architecture to connect a swarm of drones. The drone swarm networks not only support control messages exchanging among drones to avoid collisions and calculate flying paths, but also transmit data for vehicles accessing them. Most drone swarm networks in the existing literature are organized

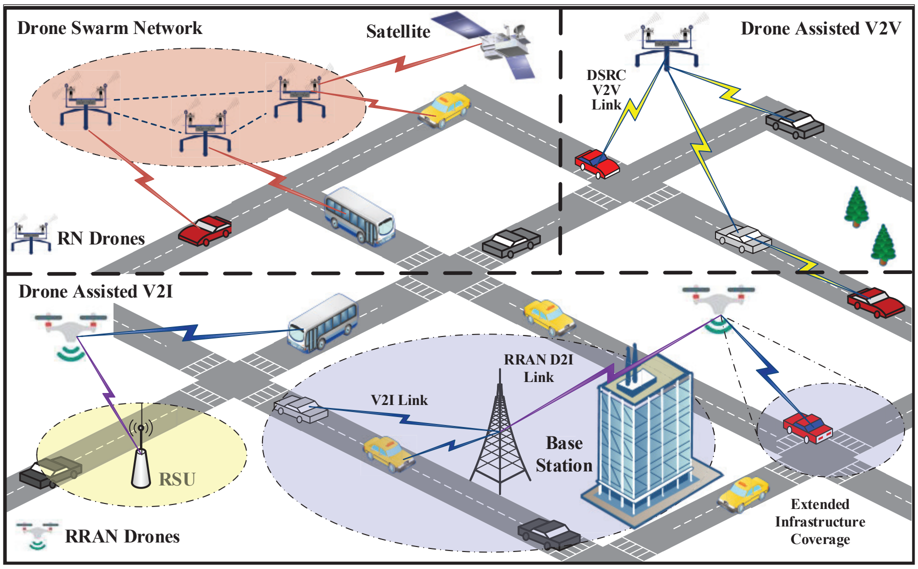

FIGURE 1. Drone Assisted Vehicular Networks architecture.

in a self-organized way for scalability and easy implementation. Specific drones in drone swarm networks are equipped with interfaces to communicate with infrastructures or satellites, which establishes gateways between drone swarm networks and other networks.

In rural or post-disaster areas where infrastructure coverage is lacking, drone swarm networks are formed as temporary aerial infrastructures for vehicles.

When the drone swarm networks operate on different spectrum from IEEE 802.11p and cellular bands, they can provide additional spectrum resources to alleviate spectrum scarcity in dense vehicle scenarios.

Drone Assisted Vehicular Networks Services

By leveraging drones, various VN services can be enhanced in the DAVN architecture.

Drone Assisted Safety Message Broadcast: As flying surveillance nodes, RN drones keep monitoring traffic conditions through embedded cameras or sensors. When emergency issues are detected or reported by vehicles, the corresponding RN drone directly broadcasts safety alerts to all vehicles within its coverage, and its neighbor RN drones in drone swarm networks. By doing so, safety messages can be quickly disseminated over large areas through less hops and more reliable LOS links.

Drone Assisted Ubiquitous Internet Access: RRAN drones provide infrastructures with mobile extensions to mitigate the impacts from VN's dynamic topology. Infrastructures can schedule the number and positions of RRAN drones to maximize their coverage according to dynamic traffic distribution. Shared by multiple infrastructures, RRAN drones flying among infrastructure coverage gaps can help realize seamless handoff. Not only to complement coverage issue, drones can also be exploited to adjust capacity for certain areas on demand, based on the spatial and temporal traffic dynamics. For instance, during rush hour, more drones can be allocated over major roads to provisionally extend the capacities of road-side infrastructures. With RRAN drones' assistance, ubiquitous Internet or multimedia accesses are available for vehicles in DAVN.

Hovering over roads, drones can collect network information from their unique perspective. Crowd sourcing algorithms can be employed to process and combine the data gathered by each vehicle or drone, then present accurate traffic and network information to VN controllers.

Drone Assisted Transportation Surveillance: Compared with traditional transportation surveillance systems consisting of fixed cameras, drone assisted transportation surveillance systems are constituted by both vehicles and drones carrying sensors. Hovering over roads, drones can collect network information from their unique perspective. Crowd sourcing algorithms can be employed to process and combine the data gathered by each vehicle or drone, then present accurate traffic and network information to VN controllers.

Drone Assisted Additional Spectrum Provision: Due to the flexibility and fast deployment features, drone swarm networks are a desirable platform to provide additional spectrum (e.g., TV white space) for VN. When licensed VN spectrum is used up in dedicated area, a drone swarm network is dispatched over it, and builds communications with ubiquitous access points, such as high altitude platforms (HAPs) and satellites. Vehicles leverage specific communication interfaces running on additional spectrum to access drones, then relay V2V messages, or access ubiquitous access points through drone swarm networks' assistances.

Challenges and Open Issues in Drone Assisted Vehicular Networks

In this section, we present the main challenges faced by DAVN, and discuss opportunities for future DAVN research.

Challenges in Drone Assisted Vehicular Network

Mobility Control Schemes for Drones: The flying control algorithm for a single drone has been well-studied, and has even been embedded in commercialized products. However, the control

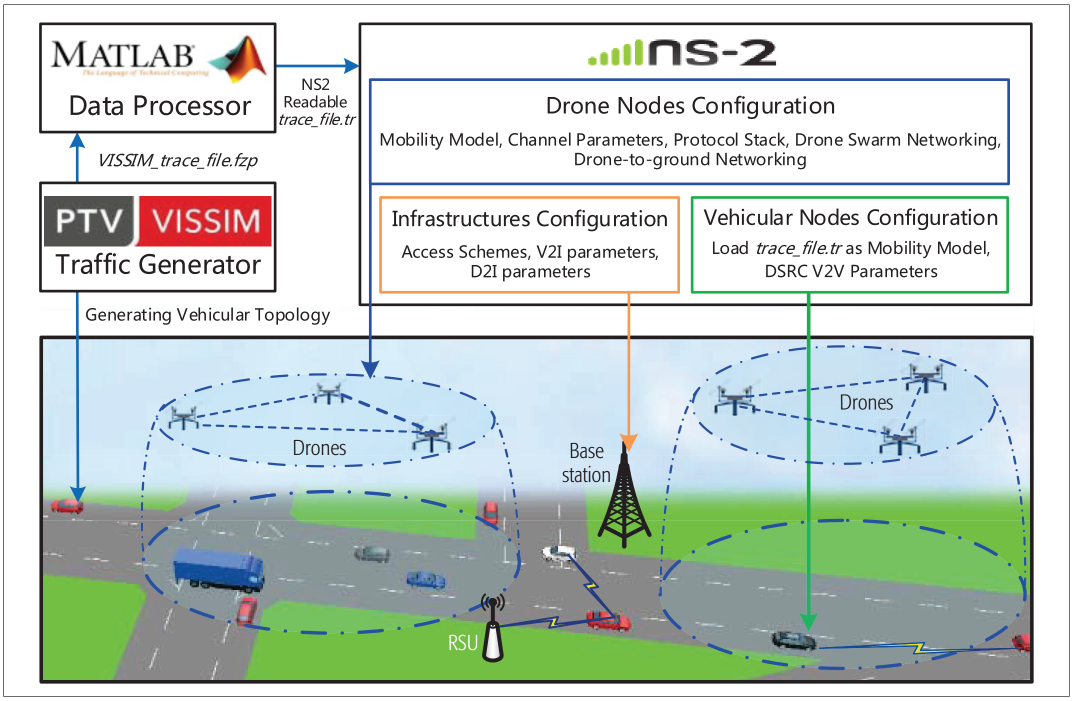

FIGURE 2. Integrated simulation platform for DAVN.

Comprising DSRC networks, cellular networks and other types of drone swarm networks, DAVN is a heterogeneous network for vehicle users. To deal with the interworking issues between networks and improve network performance, well designed network architecture is required for DAVN.

schemes scheduling a swarm of drones are still under research [4]. Two challenges faced by the control schemes are:

- Scheduling the mobility of drones, including physical collision avoidance, flying path design, drone swarm formations, and so on.
- Forming a scalable network to exchange control messages.

For RRAN drones, infrastructures naturally perform as their central control nodes, while for RN drones and drone swarm networks, cluster heads based networking, which has been widely discussed in Vehicular Ad Hoc Networks (VANET), is a promising solution to delivering control messages.

Interworking between Drones and Ground Networks: In DAVN, drones access heterogeneous ground network resources through various links. Some essential services also require drones to be the gateways between different networks. In such a complex network environment, it is crucial to design interworking mechanisms between drones, vehicles and infrastructures to realize ubiquitous connections. Meanwhile, high data rate and low latency performance should be guaranteed simultaneously for specific links, e.g., D2I links between RRAN drones and infrastructures. Dedicated cross-layer protocol designs are needed to ensure link reliability.

Efficient Power Consumption of Drones: Constrained by battery capacity, drones cannot keep flying or hovering for a long time, and they have to balance the power between communication and flying control. Tseng. *et al*. measure the power consumption of drones through experiments [14]. The results show that three types of flying modes (hovering, horizontal flying, and vertical flying) consume the same level of energy, and the weight of loads carried by drones impacts power consumption most. Meanwhile, the power consumption requirements for different drone applications vary greatly. For instance, more energy can be allocated to communication modules when drones serve temporal traffic bursts lasting a short time, while in rural areas with scare traffic, communication modules can turn to energy-saving mode to enable longer flying times. In future research, the energy trade-off between the flying control module and communication module can be an essential but challenging topic.

Regulation and Security Issues in DAVN: Most of the purchasable drones are individually controlled, and the use of them is constrained by various regulations in many countries [4]. To ensure the legal use of drones, both RN and RRAN drones in DAVN are monitored by communication service providers or governments directly. Hacking a drone not only imperils cyber-security for vehicles or the core network, but also threatens public safety when the hackers took over drones' control right. To prevent drones becoming victims, suitable security schemes are urgently needed in DAVN.

Open Issues for Drone Assisted Vehicular Networks

Besides the challenges, some open issues need to be investigated for DAVN.

Architecture Design for Drone Assisted Vehicular Network: Comprising DSRC networks, cellular networks and other types of drone swarm networks, DAVN is a heterogeneous network for vehicle users. To deal with the interworking issues between networks and improve network performance, well designed network architecture is required for DAVN.

One of the promising directions is Software Defined DAVN. Decoupling the control plane and data plane to facilitate network reconfiguration, Software Defined Networking (SDN) is regarded as an essential technology bringing flexibility and agility to future networks. Pioneering works have conducted trials to introduce SDN into VN [15], but inefficient network information collection and control message delivery remain two challenges in Software Defined Vehicular Networks (SDVN).

In the DAVN architecture, LOS links provided by drones, which support gathering network information and disseminating control messages in an efficient and reliable way, build the foundation for implementing SDN. On the other hand, infrastructures in DAVN naturally form a group of controllers, while drones and vehicles can perform as SDN switches working on data plane. Helped by SDN, network reconfiguration and resource allocation among a swarm of drones or vehicles can be conducted in a more flexible way.

Cross-Layer Optimization for D2I Communication: Similar to the fiber links between RRHs and base stations, the D2I links connecting RRAN drones and infrastructures must support high data throughput and ensure low latency. Though LOS channels can be guaranteed by adjusting drones' flying positions, cross-layer optimization is still required to handle unexpected wireless fading and interference. For example, dedicated spectrum bands and high MAC priority can be allocated to D2I links; some authentications or routing discovery processes can be simplified or removed to reduce delay.

Drone Resource Sharing: As an important networking component carrying heteroeneous network resources, drones, especially RRAN drones, are also regarded as one type of resource for DAVN. How can drones be allocated among infrastructures? How can one RRAN drone be shared among different vehicles or services? The emerging network virtualization technology has the potential to address these issues. Abstracted as an access point resource for vehicles, each drone can be allocated to multiple virtual network slices simultaneously. Considering the data flow features and drone topology of DAVN, designing appropriate networking slicing strategies for different services is an interesting topic for future research.

Drone Assisted Vehicular Networks Case Study

To validate DAVN's performance, we build an integrated simulation platform to conduct a case study. As shown in Fig. 2, the simulation platform consists of three modules: a traffic generator, a network simulator, and a data processor. The traffic generator takes charge of generating vehicle traffic and recording the mobility data of each vehicle into the trace file. In our simulation platform, we use VISSIM, a well known commercial software simulating large-scale transportation scenarios, as the traffic generator. After VISSIM creates the trace file, the data processor, which is performed by Matlab, translates the trace file into a dedicated format readable for the network simulator. Finally, NS-2, the network simulator, loads the translated trace file to define the mobility behaviors of vehicles, then configures different type of nodes and conducts simulations.

Simulation parameters	Numerical values	Simulation parameters	Numerical values
Simulation parameters for the 802.11p based VN		Simulation parameters for drone relayed V2V communications	
IEEE 802.11std	802.11p	Frequency	2.4 GHz
Frequency	5.9 GHz	Bandwidth	100 MHz
Transmission power	1 mW	Transmission power (drone)	280 mW
Antenna gains (transmit and receive)	1	Receiving threshold (drone)	–80 dBm
Carrier sensing threshold	–85 dBm	Transmission power (vehicle)	50 mW
Noise floor	–99 dBm	Receiving threshold (vehicle)	–72 dBm
Power monitor threshold	–102 dBm	Antenna gains (drone and vehicle)	1
Modulation scheme	BPSK	Modulation scheme	GMSK
Bandwidth	10 MHz	Mac Protocol	TDMA
DCF inter-frame space (DIFS)	58 μs	TDMA slot packet length	640 bytes
Short inter-frame space (SIFS)	32 μs	TDMA max node number	10
CWmin	15 time slots	CBR packet length	512 bytes
CWmax	1023 time slots	CBR packet interval	15 ms
CBR packet length	512 bytes	Drone flying heights	90 m – 150 m
CBR packet interval	15 ms	Maximal supported vehicle number	25
Road length	2 km	Road length	2 km
Duration of each simulation	10 s	Duration of each simulation	10 s

TABLE 1. Simulation parameters for DAVN.

In the case study, we simulate a basic scenario where vehicles travel along a bi-direction two-lane straight highway; two mobile drones flying over them form a relay platform. Detail simulation parameters are shown in Table 1. Since the 40 m total width of two lanes is much less than the 2 km highway length, it is reasonable to describe the vehicle density in the one-dimensional form (*/km per lane*). The case study compares the throughput and delay performance between DAVN and the 802.11p based VN. In 802.11p based VN, one-hop V2V communications are considered between vehicles.

In the DAVN scenario, some vehicles can randomly relay their V2V communications by accessing a drone platform via the 2.4GHz band, which is widely used for drone-to-controller communications of commercial drone products. Since each drone is connected by multiple vehicles, the MAC scheme of drone assisted V2V communication is set at TDMA mode to avoid collisions and ensure fairness. In each simulation trail, 25 percent of simulated vehicles are randomly chosen to access

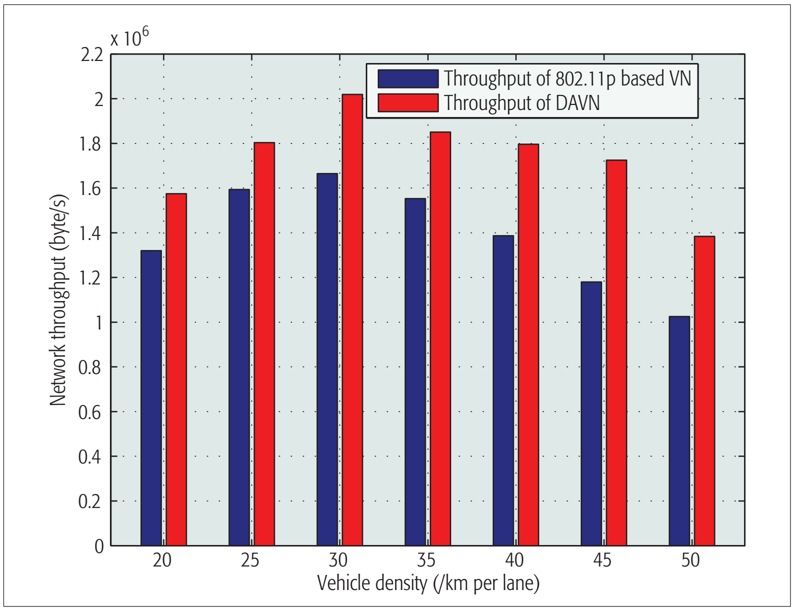

FIGURE 3. Throughput performance comparison between the 802.11p based VN and DAVN.

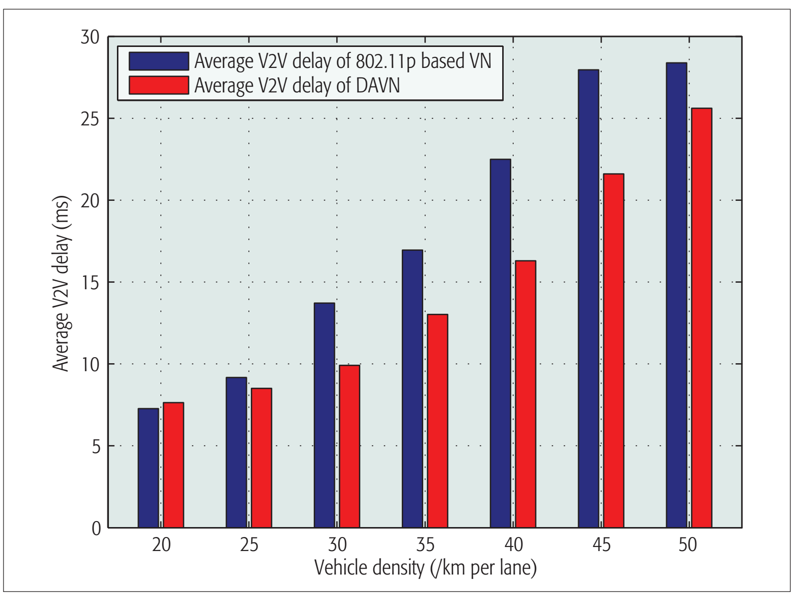

FIGURE 4. Average delay performance comparison between the 802.11p based VN and DAVN

the drone platform. If 25 percent of the vehicle number were larger than 25, at most 25 vehicles can access the platform due to the limitation of the maximal supported vehicle number.

Figure 3 shows the comparison of throughput performance between the 802.11p based VN and DAVN. In a sparse vehicle scenario, throughput of DAVN merely exceeds 802.11p based VN's throughput. As vehicle density increases, more collisions and spectrum competitions occur in the 802.11p based VN, which leads the network throughput to reach the upper bound then drop down. However, benefiting from additional spectrum provided by the drone platform, higher throughput is achieved by DAVN. Moreover, with some of the vehicles accessing drone platforms, fewer vehicles are involved in direct V2V communications. Therefore, the V2V MAC competition can be alleviated, which significantly increases the whole network throughput, especially in a dense vehicle scenario.

The average delay performance is shown in Fig 4. In a sparse vehicle scenario, less congestions are involved in the MAC competition of 802.11p based VN, which leads to the higher success probability of one-time V2V transmission. Compared with the drone-relayed V2V transmission, which consists of two hops, the one-hop 802.11p based V2V transmission can achieve the same level of delay performance, while in a dense vehicle scenario, the average delay of the 802.11p based VN rapidly increases to almost 30 ms due to the more severe MAC competitions. Nevertheless, the DAVN V2V average delay remains at a lower level because of the involvement of stable and low-latency drone relayed V2V communications.

According to the case study, better throughput and delay performance can be realized by DAVN when compared with the 802.11p based VN, especially in a dense vehicle scenario. The case study validates drones' ability to form the relay platform, and provide additional spectrum resources to enhance vehicular network performance.

Conclusion

In this article, we have proposed a comprehensive DAVN architecture to integrate drones with ground vehicular networks to efficiently improve system performance. We have discussed the challenges and open research issues in DAVN. The effectiveness of DAVN has been verified through a case study. This article expects to shed light on drone assisted vehicular networks. To efficiently integrate drones into vehicular networks, more research focusing on practical solutions in DAVN should be conducted in the future.

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