VANET (ITS-G5 & 5G Test Network) with Drone-assisted Communication Using Road Weather Information

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***Abstract*—In recent years, the research community has shown increasingly interest in the study, design and implementation of DAVNs (Drone-assisted Vehicular-Network). DAVN can play a crucial role to provide a broad range of vital characteristics for Intelligent Transport Systems (ITS) applications to enhance the road traffic safety. A DAVN provides a dynamic platform by effectively combining the ground networks, namely Connected Vehicles (CV) and aerial communication technologies of drones. In DAVN, due to the small sizes of drones, payload constraints as well as capabilities and flight time limitations, cooperating with traffic infrastructure and vehicles is very important. DAVNs help to improve the Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication range, the information gathering capability, and the efficiency of vehicular networking. In this paper, we develop a novel cooperative DAVN architecture consisting of drones, vehicles, Road Weather Stations (RWS), on-board embedded sensors, processing entities, Global-Positioning-System (GPS), and communication capabilities. We use real-time field measurements of V2V and V2I communications considering weather and vehicular traffic information for drone assisted vehicular communication simulations in Network Simulator-2 (NS-2). DAVN simulations are carried out based on measurements on a real environment (1.7km long test track) at the Finnish Meteorological Institute (FMI) in Sodankylä, Finland. The performance of DAVN was evaluated by considering three parameters: packet loss, network latency and average throughput. Simulation results revealed that ITS-G5 performance is stable in short range, but in long range DAVN, the 5G Test Network (5GTN) and its 4G feature outperformed ITS-G5. Moreover, we identified key challenges in the design and implementation of DAVNs in real environments.**

Keywords—DAVN, V2V, V2I, 5GTN, ITS, VANET

I. Introduction

Since the last two decades, future intelligent transportation systems have required the implementation of key requirements for their communications links, such as low latency, high bandwidth and reliable, seamless connectivity. The Vehicular Ad hoc Network (VANET) in ITS is usually seen as a crucial component of future road safety applications. Mobile networking and VANETs use wireless technologies for vehicular communication to connect vehicles known as Vehicular Networks (VN) and CV. CV support vehicles to communicate and interconnect with multiple types of short-range (ITS-G5/Visible Light Communication) and long-range (4G, 5G) network infrastructures to support Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications [1]. Significant progress has been made in the implementation of CV and research in both academia and industry. However, despite of these technological advancements, there are still important challenges that emerged recently when merging CVs into wireless networks and Internet-of-things (IoT). The first issue is to cope with the unreliable wireless link in the vehicle's mobility and complex traffic environments. In vehicular communication, the use of highly accurate 3D navigation maps greatly depends on reliable wireless link together with accurate location information. The other issue is the deficiency in network coverage of the CV infrastructure that makes the practical deployment of vehicular networks (VN) and CV [2] difficult. This is due to the fact that link quality cannot be guaranteed for uncovered areas or network coverage holes in V2V and V2I communication. The deployment of fixed network infrastructure also affects the ability to adjust according to the demands of dynamic access. The third issue is the limited spectrum availability that remains a severe challenge in CV networks. Some suggestions have been made by researchers regarding solutions exploiting white space bands for TV or cognitive radio to resolve this issue [3]. However, it is still quite difficult to select or build an infrastructure to offer more spectrum resources for CV networks. DAVN's are considered as an important IoT element. Drones with different on-board communication devices and sensors can participate in many services i.e., logistics delivery applications, rescue in disaster management and communication support [4]. Additionally, the drone's capability to assist radio communications, specifically Flying-Ad Hoc-Network (FANET) connection with other on-field devices, have been investigated theoretically and tested during various ground trials [5]. The drone is the enabling technology with FANET providing many advanced features to enhance CV network applications and performance. A DAVN allows vehicles that are close to each other within range of approximately 50 to 1000m to communicate and exchange information regarding the road state or traffic information. RWS, DAVN and vehicles are equipped with onboard units (OBUs), data processing modules (DPM) and GPS receivers. DAVN helps to build a wide range network, having eight channels, one channel for safety message exchange, five channels for non-safety applications and one channel for emergency messages [4, 5]. However, until now no approved drone assisted framework is recommended for current communication challenges and networking during incorporated drone-supported CV networks. To this end, we recommend an advanced architecture for DAVN and conduct measurements considering realistic environments, as presented in Fig. 1.

The article is structured as follows: Section II describes the background of ITS-G5 and 5G test network technology. Section III illustrates the DAVN measurement scenarios with real time weather and traffic data followed by Section IV, discussing the simulation results. Finally, Section V summarizes the article with future research directions.

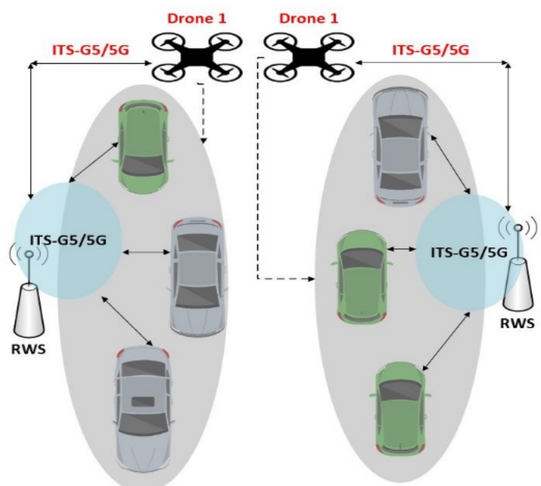

Fig. 1 Drone Assisted Vehicular Networks architecture

II. Drone-Assisted Vehicular Networking and Wireless Technologies

Recently, DAVNs have been designed and implemented for a broad range of ITS applications because they can act the role of multi-function platforms in both rural and urban areas. In DAVNs, drones need to perform two main functionalities: maintaining a seamless vehicular communications and collecting road traffic data. Moreover, drones can perform two additional tasks: establishing a communication set-up with heterogeneous (ITS-G5 + Cellular Network) resources to be accessed by moving vehicles, and functioning as a remote access entity to enhance the vehicular network coverage. Figure 1 shows the architecture of a DAVN [6]. In DAVN, the network components of a vehicle include the embedded onboard units (OBUs) to establish a connection to communication with other network elements. VLC/ITS-G5 networking between vehicles is supported by the OBUs, providing also multiple interfaces to other type of networks. Another main component of DAVNs is the Data Processing Module (DPM), that is needed to manage the inter-working and information exchanges between hybrid networks. The key components of DAVN are briefly described below.

Infrastructure: The Road Weather Stations (RWSs)/Roadside Units (RSUs) and cellular base stations (BSs) together provide the ground infrastructure in DAVNs. This infrastructure can deliver real-time data to vehicles and drones. In DAVN, there is also a option for remote radio access nodes similarly to the concept of Remote Radio Head (RRH) in cellular communications (Cloud Radio Access Network, CRAN)) by drones to provide a seamless/extended communication infrastructure.

Drones: In DAVNs, two kinds of drones are considered; Remote Radio Access Nodes (RRAN) drones and Relaying Node (RN) drones. In VNs, we can use the ITS-G5 network or extended a spectrum band to facilitate RN drones to be considered as airborne vehicle nodes. These nodes perform a similar role as vehicles act in V2V communication to exchange data between vehicles. Additionally, a cluster of RN drones is able to create a swarm network of drones to offer additional platforms to access VANETs. The RRAN drones act like a remote point for radio access that could be allocated dynamically for essential spots to support V2I communication. The RRAN provides better connectivity for holes in network coverage and enhance the dedicated areas capacity. The RRAN and RN drones are facilitated with different IoT sensors to collect real-time weather and traffic data. Additionally, there is a possibility to implement a powerful drone by embedding the both RRAN and RN drone interfaces together, so that they can switch their roles followed by the control commands and dedicated controllers [7, 8].

A. ITS-G5

In 1999, the FCC allocated 75 MHz of spectrum at 5.850 to 5.925 GHz frequency range for IEEE-802.11p. In Europe, ITS-G5 is standardized by the European Telecommunication Standard Institute (ETSI). The 802.11p is used as a reference protocol to standardize the ITS-G5 that uses the Physical (PHY) and Media Access Control (MAC) layers of the IEEE 802.11p. ITS-G5 provides an extra feature of Geo-Networking protocol for V2V and V2I communication [9].

In ITS-G5, the total 70 MHz [10] band is divided into seven 10-MHz bandwidth channels mainly of two types, i.e., service channels and control channel (CCH), while the remaining 5 MHz is dedicated for the guard band use. The control channel (CCH) is dedicated to communication management and broadcasting short messages for the road safety applications, whereas the service channels (SCHs) are reserved for the traffic efficiency and infotainment applications. The ITS-G5 offers a dynamic range of data rate from 3 Mbps to 54 Mbps [10, 11].

B. 5G Test Network (5GTN)

The use of cellular technology in vehicular communication has been greatly affected due to the absolute latencies in channel access, lack of quality-of-service guarantees, and short time VANET connection. To overcome the aforementioned issues, cellular standards are continuously evolving. In this section we discuss a 5G test network and more specifically its' 4G component that is based on the Long-Term-Evolution Advance (LTE-A). This 5G test network is used to design and develop 5G applications and services. The 5G test network at the Sodankylä site, however, operates at 2.3GHz using 4G/LTE Time Division Duplex (TDD) [12]. The 5G test network can support data rates ranging from 10Mbps to 50Mbps by using the spectrum with 40MHz in uplink and downlink, respectively having omni and sectorised antennas. Technically, LTE-A may perhaps not the best standard for beaconing vehicular safety-critical applications because it can be easily overwhelmed even in ideal condition. [13, 14].

To resolve these different cellular issues for vehicular communication, the next generation 5th Generation (5G) technology is already launched. 5G is designed to use frequencies from ~600MHz to 54GHz. This 5G cellular systems, exploiting also mmWave technology, will play a crucial role in 5G communication for vehicular communication [15].

Fig.2 Test track equipped with 5GTN and ITS-G5, DAVN and IoT sensors with red spots

III. DAVN PILOT SCENARIOS USING ROAD WEATHER DATA

In this section, we discuss the DAVN simulation scenarios by using the V2V and V2I pilot field measurements. The DAVN used the road weather and traffic data, and this data has been delivered to the nearby vehicles and drones using ITS-G5 and 5G test network in the Drone-to-Vehicle (D2V) and Drone-to-Infrastructure (D2I) simulations [15]. The real-time forecast updates and road friction information is communicated between drones, vehicles, and RSUs/RWSs collected by vehicle and RWSs. In DAVN simulations, the real-time road traffic information supports road safety in D2V and D2I scenarios by delivering road traffic and weather alerts to vehicles with minimum delay. In the simulations, the drones not only collect and deliver the traffic and weather data, but they also work as intermediate nodes to expand the vehicular networking range.

TABLE I. COLLECETD DATA FROM VEHICLES AND RWSS FOR DAVN

Measured Constraints	Transmission Entities	Sensors
Road and Air Humidity	Vehicle	Marwis, Teconer
	RWS	2xDST111, 1xDRS511
Road Friction	Vehicle	Marwis, Teconer
	RWS	2xDSC111, DRS511
Road and Air Temperature	Vehicle	Marwis, Teconer
	RWS	1xPT100 (RWS)

For the DAVN simulations, we used one 5G test network BS (4G-LTE base station with an EPC core in Oulu) and two RWS's featured with ITS-G5. As presented in Fig. 3, the real-time V2V and V2I data was collected by using three vehicles on the 1.7 km long winter test track in Sodankylä. The drone simulations exchanged real-time road weather and friction information, as presented in Table I between RWSs and vehicles in D2I and D2V scenarios. These drones used the collected data by a driving vehicle on a test track in a closed loop, as illustrated in Fig. 2 and Fig. 3.

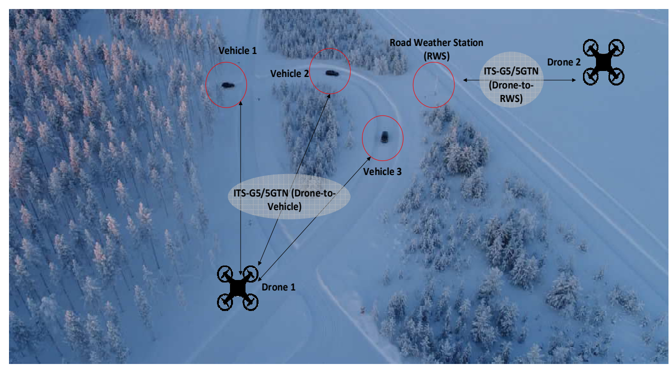

Fig. 3 Simulation scenarios using D2I and D2V

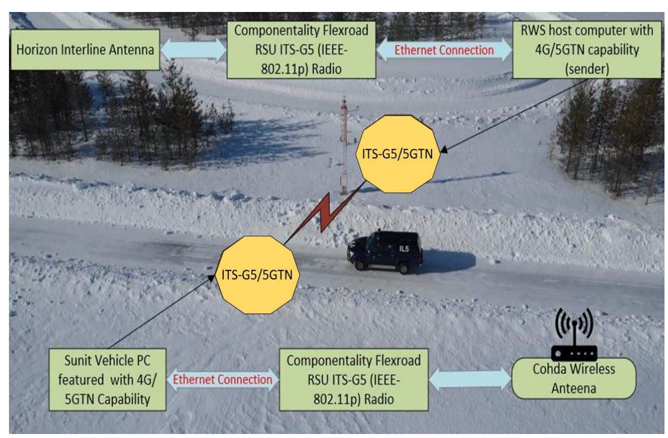

Fig. 4 Real-time V2V and V2I communication setup

For V2V and V2I field measurements, we used 5GTN-supported mobile phones (Samsung-S7), a Cohda MK5 radio-transceiver as well as IoT road and traffic sensors [16, 17]. The DAVN communication system is also complemented by the 802.11ac Wi-Fi that supports different IEEE 802.11 standards. For drivers User Interface (UI), we have used the SUNIT F-series vehicle PC in vehicles. The 5GTN system is a private network and operates separately from the public telecommunication network. The 5G test network base station antenna, RWS and road weather sensors are deployed on the test track, as depicted in Fig. 2. Fig. 4 shows the communication setup for V2V and V2I scenarios for real-time field measurements. Table II illustrates the ITS-G5 and 5G test network (4G-LTE) parameter settings for DAVN simulations and V2V and V2I communication in real-time.

TABLE II. ITS-G5 & 5GTN PARAMETER SETTINGS

Parameters	ITS-G5 Settings	5GTN Settings
BS Transmission Power	0.0001to + 0.199 watts	15.135 watts
UE Transmission Power	25mW	100mW
Frequency Band	5.9 GHz	2.3 GHz
Modulation Technique	BPSK, QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM
Maximum Transmission Rate	27/54 Mbps	20/10 Mbps (For each user)
Data Traffic	3, 6, 9, 12, 18, 24, 27 and 54 Mbps	60 Mbps
Symbol duration	16, 8, 4us	66.67us
Bandwidth	5, 10, 20 MHz	40 MHz
Temperature	-40 °F to 185 °F	-40 °F to +185°F
Maximum Range	1000 m	2000 m

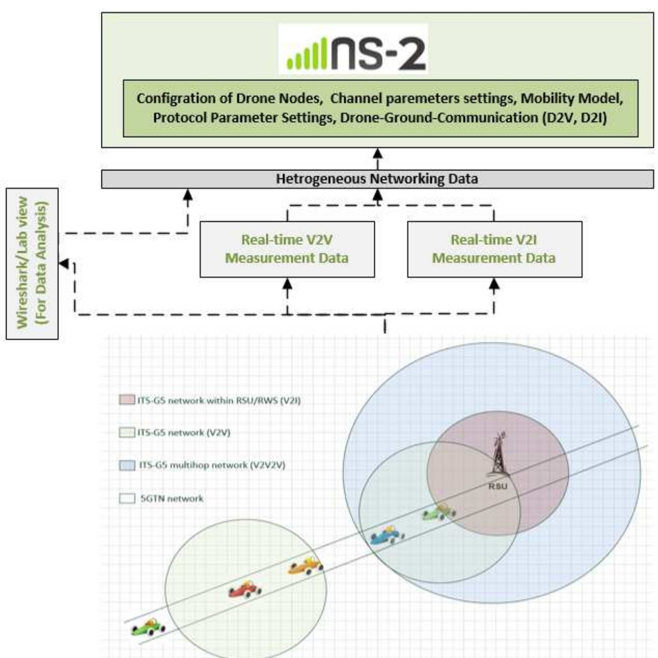

Fig.5 Simulation platform using real-time data

In DAVN simulations, we used the collected data in V2V and V2I scenarios from the external sensors for friction measurements installed on the test track, vehicles and RWSs. In field measurements, we used different sensors, such as Marwis, WCM-411 and Teconor RCM-411 [18, 19] sensors to get information on road conditions (road temperature, frictions, and state), as illustrated in Table I. In DAVN, we transferred the fixed size UDP data packets of 1450 bytes for D2V and D2I communication. We conducted 15 field measurements to assist DAVN to compare and analyze the behavior and performance of ITS-G5 and 5GTN in DAVN. Fig. 5 shows the simulation platform utilizing the field measurements for detailed data analysis and behavior of drones using real-time data in the network simulator "NS-2". We used trace files in NS-2. For initial data analysis of field measurements, we used Wireshark, and then later, for the final data analysis and performance evaluation of DAVN, we used NS-2.

IV. RESULTS AND DISCUSSION

In this section we discuss the results of our simulations by using the real-time field measurements for DAVN. These simulations and field measurements are aimed to analyze the performance of ITS-G5 and 5GTN in D2I and D2V communication considering the real-time road weather and traffic data. In our simulations, we have considered the three parameters for performance evaluation, i.e., network latency (end-to-end delay), packet loss and average throughput.

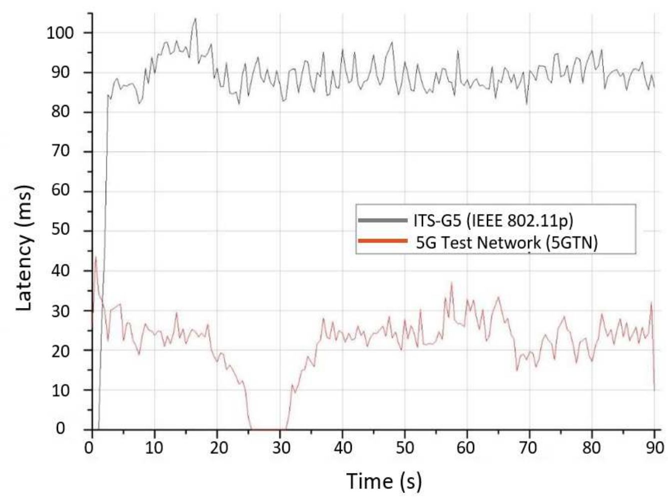

Fig.6 DAVN network latency (end-to-end)

TABLE III. DAVN FILED MEASUREMENT RESULTS

Network Technology	Latency (ms)	Packet loss (%)	Throughput (Mbps)
ITS-G5	88	22	1.72
5GTN	28	13	2.64

Fig. 6 and Table III illustrate the network latency (end-to-end delay) considering ITS-G5 and 5GTN in D2I and D2V scenarios using the same parameters, as shown in Table II. Fig. 6 presents the performance of both wireless standards using road weather information in a 50m-1700m communication range. We can see that the end-to-end delay of the ITS-G5 is slightly longer than that for 5GTN. As we can see from Fig. 6, the 5G test network connection between

25 (s) to 30 (s) is lost at one spot. This is because at that test track, the amplitude of the received signal was low, resulting in a low-quality connection. But still, 5GTN perform better in contrast of ITS-G5. Also, the network delay in ITS-G5 is affected by the initial connection setup because we used Python and iperf tools in V2V and V2I communication at the sending and receiving ends. In DAVN simulations, the average delay is also affected by the dynamic mobility of vehicles using real-time data.

Fig. 7 DAVN packet capture using ITS-G5 and 5GTN

Table III shows the packet loss (%) and it can be verified by the packet capture, as shown in Fig. 7, where DAVN (D2I and D2V) shows that the packet loss in ITS-G5 is slightly higher than the 5GTN. The packet loss in ITS-G5 is high because of packet collisions and interference between transmitter and receiver, in contrast to the 5GTN case [20].

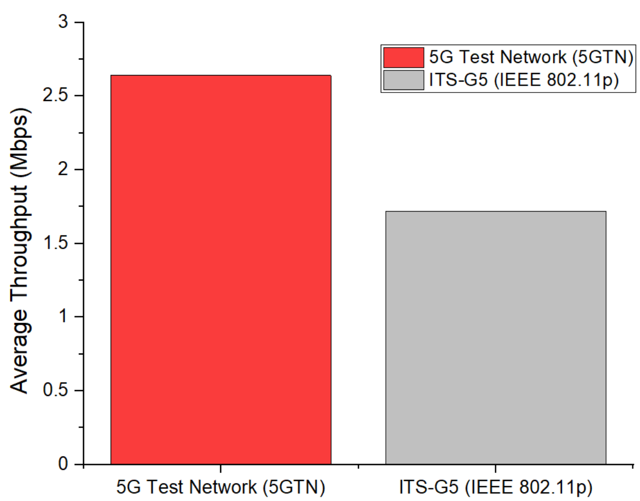

Fig. 8 DAVN Average Throughput

Fig. 8 and Table III also show the average throughput of DAVN in our simulations using real-time data exploiting ITS-G5 and 5GTN networks. The network latency and packet loss are time sensitive constraints that affect the network throughput. Similarly, Fig. 8 reveals that the 5GTN has a better average throughput in contrast of ITS-G5 using the real-time road weather and traffic data, as shown in Table III.

V. Conclusion

Drones have an undisputed potential in coming years to enhance the vehicular network performance in terms of network range and efficiency. This paper presents DAVN simulation results using real-time field measurements exploiting ITS-G5 and 5GTN networks. Performance analysis of these wireless technologies with drone simulations have been performed in a communication range of 50m-1700m by three parameters: network latency, packet loss and average throughput. Our results indicate that the ITS-G5 and 5GTN networks fulfill the minimum requirement (<100ms) [18] for DAVN communication. 5GTN has a slightly better performance as compared to ITS-G5, due to better network coverage on the test track. We also noticed that the delay involved in data delivery (end-to-end delay) of 5GTN is shorter than that of the ITS-G5. This is mainly due to the fact that 5GTN is LTE-A based technology with scheduled resources and ITS-G5 having competition-based resources. This paper shows the effectiveness of drones for DAVN communications, validated through simulation results. In the future, we will conduct more pilot measurements in real environments to effectively combine vehicular networks with drones using real-time road traffic, weather data and 5G connectivity.

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