Drone-Assisted Vehicular Network Architecture Exploiting Road Weather Information

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***Abstract* — Since the last decade, researchers have been continuously trying to implement and evaluate the performance of Drone Assisted Vehicular Network (DAVN). A DAVN efficiently integrates the networking and communication technologies of drones with connected vehicles. DAVNs have a huge potential to offer a wide range of features for Intelligent Transport Systems (ITS) applications to improve traffic safety on roads. In this paper, we first discuss the architecture of a DAVN and outline its potential services for vehicular networks. Drones cooperate with infrastructure and vehicles to improve Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) network coverage, data collection capability, and efficiency of communication interworking. In this paper, we demonstrate the DAVN concept with regard to Drone-to-Vehicle (D2V) and Drone-to-Infrastructure (D2I) communications utilizing road meteorological data exchange. To perform these pilot scenarios, we use real-time weather and traffic data collected during our pilot measurements in Northern Finland. The executed and generated test scenarios are added to Wireshark and NS-2 (Network Simulators) to evaluate the performance of ITS-G5 and 5G Test Network (5GTN). The performance evaluation for DAVN is carried out by considering the following parameters: end-to-end delay, packet delivery ratio (PDR), packet loss and average throughput. Our results revealed that ITS-G5 performs better and more efficiently than 5G in D2V PDR scenarios, and 5G performs well in D2I PDR scenarios. Moreover, the 5G network presents better performance in the average throughput and D2I (in our case drone-to-RWS (Road-Weather-Station)) delay scenario in contrast to ITS-G5, and this is due to vehicles, haphazard nature of test track and the distance between the cars.**

Keywords— 5G, ITS-G5, CV, VN, DAVN, V2V, V2I, ITS

INTRODUCTION

Vehicle communication is typically seen as a key enabling technology for ITS applications for improving road safety Vehicular Networks (VNs), also known as Connected Vehicles (CVs), combine wireless technologies and mobile networking to connect automobiles. To facilitate vehicle-to-roadside infrastructure (V2RWS) and vehicle-to-vehicle (V2V) communication, the CV facilitates vehicles in connecting to and communicating with a variety of short-range (ITS-G5/VLC) and long-range (5G) network infrastructures [1]. Substantial advances have been made in CV research and implementation in both industry and academia. Despite this, significant obstacles have lately surfaced when integrating CVs into internet-of-things (IoT) and wireless networks. The first problem is dealing with weak wireless links in complex traffic environments and vehicle mobility. In fact, extremely precise 3D map navigation in vehicular communication is heavily reliant on a dependable wireless network. The second issue is that the limited network coverage of CV infrastructures makes CV and vehicular networks (VN) implementation difficult [2]. Indeed, connection quality cannot be assured in areas with poor network coverage or coverage gaps between vehicles and infrastructure. The inflexible design of the network infrastructure makes it difficult to adapt the frequent changing access requirements. Thirdly, there are insufficient bandwidth resources, which remains a fundamental issue in CV networks. Researchers have contemplated using the white space bands for television or cognitive radio as a solution to this issue [3]. It is still very difficult to select or construct an infrastructure that provides CV networks with more bandwidth resources. DAVNs are regarded as an integral component of the Internet of Things. Drones equipped with various communication devices or sensors can assist in a variety of duties, including emergency management, logistics delivery, and communication [4]. In addition, the ability of drones to support wireless communication, such as contributing to the formation of a Flying-Ad Hoc Network (FANET) and communicating with other ground devices, has been conceptually investigated and field-tested [5]. The drone is a new technology that is being used with FANET. It has many advanced features that can improve CV network uses and performance.

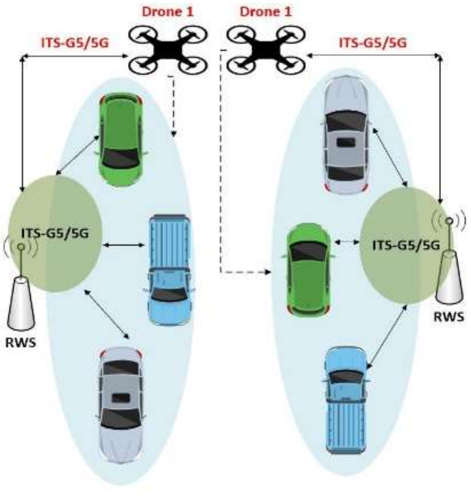

Figure. 1. Drone Assisted Vehicular Networking architecture

In short, a DAVN enables vehicles to communicate with one another and share information on the state of the road or road traffic when they are close to one another and within the range of a wireless link. Cars and roadside weather stations in

DAVNs are outfitted with GPS receivers, data processing modules, and onboard units (OBUs). This aids in the development of several networks. Eight channels make up this DAVN: one for exchanging safety messages, five for non-safety purposes, and one for emergency messages [3-5]. To best of our knowledge, no established framework has yet been developed for addressing the networking and communication issues in integrated drone-supported CV networks. To achieve this, we create a comprehensive design for the Drone Assisted Vehicular Network for real world enviroments, as depicted in Fig.1.

This is how the article is structured: The ITS-G5 and 5G technologies are briefly discussed in Section II. The pilot measurement scenarios are shown in Section III, and the findings are discussed in Section IV. Section V summarizes the article and provides recommendations for further research.

WIRELESS TECHNOLOGIES AND DRONE ASSISTED VEHICULAR NETWORKING

In the DAVN, drones must carry out two essential tasks: relaying V2V interactions and gathering network data. Drones are also capable of setting up a network with a variety of resources that vehicles can use on demand and serving as remote access nodes to expand infrastructure coverage. The architecture of DAVN is shown in Fig. 1.

Components of a Network Vehicle: In order to connect to and communicate with other network components, DAVN vehicles are equipped with on-board units (OBUs). The OBUs enable DSRC communication among vehicles and offer various interfaces to other kinds of networks. Data processing modules (DPMs) are used by automobiles in the DAVN to manage interworking and data transfers among heterogeneous networks because heterogeneity is an unstoppable trend for VNs.

Infrastructure: Infrastructure for DAVN includes both cellular base stations (BSs) and road side units (RSUs) [5, 6]. The infrastructure may use cellular band or DSRC to transfer data directly to drones and vehicles that are in their service region. Where reliable data transmission cannot be guaranteed, V2I communication is supplemented by drone relay outside of coverage or coverage gaps. Similar to the idea of a remote radio head (RRH) in Drones are regarded as remote radio access nodes by DAVN [6]. Some remote radio access node (RRAN) drones can be used to fly over the appropriate coverage holes. Vehicles can link directly to RRAN drones around coverage gaps, while RRAN drones use particular drone-to-infrastructure (D2I) networks to relay V2I data to infrastructures.

Drone: DAVN considers two types of drones: RRAN drones and relaying node (RN) drones. RN drones can be considered as flying vehicular nodes when operating on the expanded spectrum or DSRC for VN. They transmit data for vehicle-to-vehicle communications and use the same infrastructure as automobiles. RRAN drones can be dynamically assigned to required positions to aid V2I data exchanges as remote radio access points. RRAN drones primarily increase capacity for specific connectivity zones and enhance V2I connectivity for coverage gaps. Both kinds of drones have sensors that gather network information [7]. The ability to switch between RRAN and RN drones is also provided by some powerful drones, which also have two different types of interfaces. These drones are then controlled by particular controllers and given particular commands. According to the functions of drones, three networking modes in the DAVN architecture can be enabled: drone assisted mobile access networking, drone assisted V2V networking, and drone swarm networking [8].

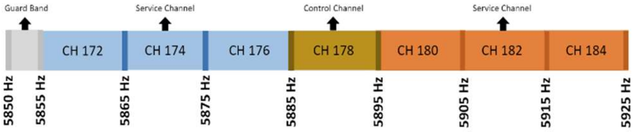

Figure. 2. ITS-G5 Channels

ITS-G5 (IEEE 802.11p)

The integration of in-vehicle sensors, wireless communication, and the Global Positioning System (GPS) is at the heart of vehicular networking, which paves the way for a wide variety of applications in the areas of road safety and traffic efficiency. The Federal Communications Commission (FCC) allotted 75 MHz of spectrum in the frequency range of 5.850 to 5.925 GHz in the year 1999 for intelligent transportation system (ITS) operations [9]. The European Commission (EC/2008/671) designated a special frequency band in 2008 that spans 30 MHz from 5875 to 5905 MHz, or 5.90 GHz [10]. The whole bandwidth of the allocated band is broken up as indicated in Fig. 2 into three channels with a bandwidth of 10 MHz each. These channels are primarily separated into three service channels (SCH0 to SCH2). The upper channel designated as "Service Channel 0 (SCH0)", the lower channel as "Service Channel 1 (SCH1)," and the middle channel as "Service Channel 2 (SCH2)"1. Within ITS-G5's 10 MHz channel capacity, 48 data subcarriers and 4 pilot carriers are used to transmit information. The number of data bits per OFDM signal fluctuates depending on the transfer rate because the duration of each OFDM symbol is fixed at 8s [11]. Fig. 3 depicts the physical layer convergence process (PLCP) protocol data unit (PPDU) used in the transmission of ITS-G5 packets. The receiver can be synchronized with the help of the PLCP preamble. There are four distinct types of service channel assignments introduced by ITS-G5. (See Fig. 2): ITS-G5A is for safety applications, ITS-G5B is for applications that are not safety-related, ITS-G5C defines 5.6 GHz IBRANs (Infrastructure-based Broadband Radio Access Networks) and ITS-G5D is set aside for potential use in the near future [12].

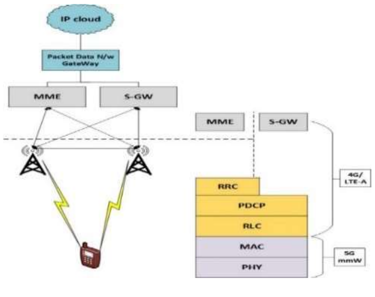

Figure. 3. 5G mmWave Framework with Protocol Architecture.

5G (mmWave)

Early 5G installations frequently employ frequencies that are similar to those of Wi-Fi and 3G/4G mobile networks. This implies that numerous current antenna positions will be used for 5G. While low- and mid-bands may cover a large region, their capacity is fairly constrained. 5G mmWave, on the other hand, offers substantially more bandwidth in very targeted areas for each user and permits larger user densities. The wider range of radio frequencies that 5G can support (above about 24 GHz) is known as 5G mmWave [13]. The mmWave technology is an essential part of 5G cellular networks and is crucial to 5G communication. Fig. 3 depicts the architecture of the 5G mmWave protocol. The carrier frequencies are scattered around 60GHz with a channelization of 2.16GHz, and it works between 30GHz and 300GHz. High array gains will be implemented in mm wave by the use of massive antenna arrays and beamforming technologies, allowing the system to operate at higher data rates—typically up to several gigabits per second [14]. The IEEE 802.11 protocol assures a maximum data speed of 7Gbps and an end-to-end latency of less than 10ms because to its use of millimeter wave technology. Additionally, under ideal propagation conditions, mm wave systems perform better than IEEE802.11p/DSRC and LTE/LTE-A Pro standards for V2X communication [10, 11]. But with mm wave technology there are some challenges as well such as if are multiple mmWave base stations (mmBSs) and cars move around a lot, there will be a large number of handoffs, and it will be challenging to select the correct beam. For 5G mm wave communication in cars, there is a need of a smart and stable system that helps in beam selection procedure. In [15], researchers have introduced a system that learn online to solve the problem of beam selection in 5G mmWave vehicle networks that is guaranteed not to get blocked.

DEVELOPING DAVN FILED MEASUREMENTS USING ROAD WEATHER INFORMATION

This section discusses the DAVN pilot scenarios including the delivery of road weather data in the area employing ITS-G5 and 5G network. Forecast updates and road friction data are shared by drones and RWS obtained by various vehicles. In DAVN, real-time road traffic information is critical for avoiding automobile crashes and delivering weather alerts to RWS and vehicles in drone-to-vehicle and drone-to-rws situations. The DAVN not only collects road weather data for cars, but it also acts as an intermediary relay to increase the range of V2V communications.The ITS-G5 and 5G tst network (5GTN) parameter settings for DAVN networking on the test track are shown in Table I. According to the measurements of our DAVN pilot, the drone's altitude never exceeded 200 meters. The packet delivery ratio between drones, vehicles, and infrastructure based on transmission antenna orientation (horizontal, vertical) and receiving antenna location (external, internal).

TABLE I. PARAMETER SETTINGS FOR THE ITS-G5 & 5G

Parameters	5G Network Settings	ITS-G5 Settings
Power Transmission	41.8 dBm	-10 to +23 dBm
Operating Frequency	2.3 GHz	5.9 GHz
Modulation	QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Transmission Rate (Max)	10 Mbps (Each User)	27/54 Mbps
Data Traffic	66.66us	Bi-directional
Duration of Symbol	Bi-directional	16, 8, 4 us
Bandwidth	40 MHz	5, 10, 20 MHz
Supply Voltage	230 volts	12V
Temperature	19 dBi	-40 ºC to +85 ºC
Range (Max)	1000-1700 m	1000 m

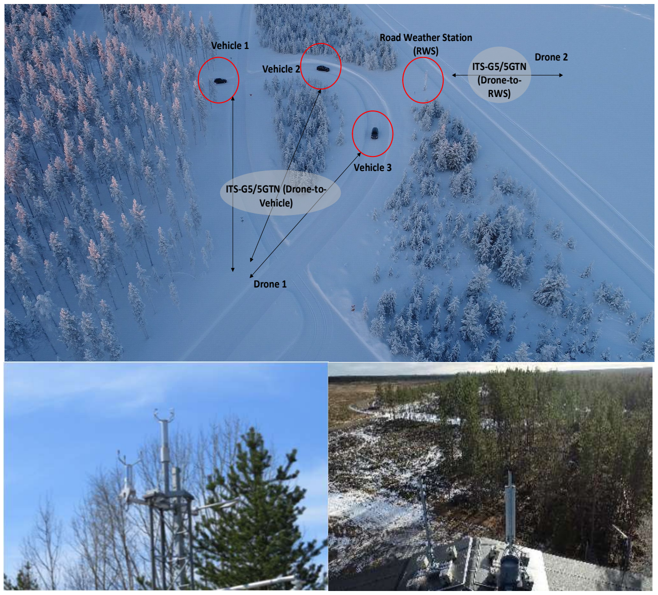

Figure. 4. Pilot scenarios using D2I and D2V.

In pilot filed measurements, we have employed one 5G test network, two RWSs, and two vehicles on a winter test track (1.7 km in length) in Sodankylä, Finland, close to the airport for our pilot scenarios. Drones drove automobiles in a closed loop on a testing track, gathering data from two RWS in D2I and D2V scenarios (see Fig .4). To test the DAVN, we used a Samsung Galaxy smartphone, a Cohda MK5 radio transceiver, and a DJI Mavic drone. The system's connectivity options included USB 3, Bluetooth 4, a Thunderbolt port 2.0, and 802.11ac Wi-Fi, which is backwards-compatible with all IEEE 802.11 standards. While connected to the public telecommunications network, the 5G network operates independently on the test track. The antenna and RWS for the 5G base station are shown in Fig. 4. The drone in DAVN remained stationary while the vehicles moved away. The smartphone and a SUNIT F-series vehicle PC serve as the car's user interface (UI) [16]. Android tablets are another option for a user interface. This allows the vehicle to easily connect to the DAVN and exchange traffic and weather data. Drone and RWS data packets are also exchanged in the moving vehicle. The GPS coordinates and information packets received by the vehicle are also stored. Using these GPS coordinates, the receiver (vehicle/drone) may be located with high precision while receiving UDP messages. We developed a Python software to transmit UDP packets and included a Raspberry Pi in the drone's hardware. UDP packets were generated at a rate of 10 Hz, with an approximate packet size of 1202 bytes.

The acquired data for the DAVN system is shown in Table II; it comes from the vehicle's external sensors (friction measurements). Table II shows road condition (temperature, friction, and status) data collected from the sesnor i.e., Marwis, Teconor WCM-411, and RCM-411 sensors utilized in these pilot studies.

TABLE II. DATA COLLECTED DAVN COMMUNICATION

Measured Parameters	Communication Entities	Sensors Data
Road Temperature	Vehicle	Marwis, Teconer
	RWS	2xDST111, 1xDRS511
Road Friction	Vehicle	Marwis, Teconer
	RWS	2xDSC111, DRS511
Air Temperature	Vehicle	Marwis, Teconer
	RWS	1xPT100 (RWS)
Infrared camera	Vehicle	-
	RWS	Zavio B7210 Full HD
Humidity	Vehicle	Marwis, Teconer, E3
	RWS	HMP45D

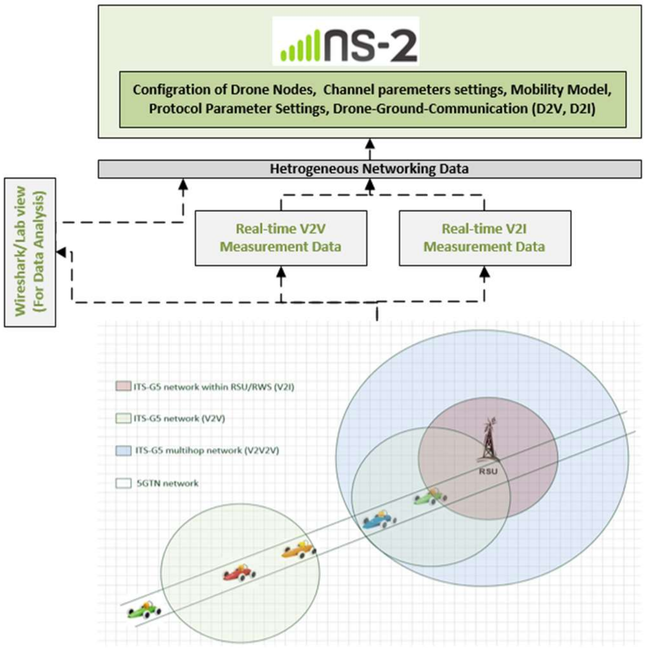

Figure. 5. Simulation based platform utilizing real-time road weather and traffic data

The simulation platform using field measurements for in-depth data analysis and drone behavior using real-time data are shown in Fig. 5 of the network simulator NS-2. As shown in Fig. 5, we used Wireshark and NS2 to examine the data flow and assess its performance. To transmit the data packets, we used a Python script together with the iperf tool. Pilot measurements, for which we have piloted 20–25 drives, have been used to evaluate and assess the behavior and performance of ITS-G5 and 5G in DAVN. We used Wireshark to do some preliminary analysis, and we utilized the network simulator NS-2 to do some more in-depth study of the data and the behavior of our test measurements that will be briefly discussed in the next section.

RESULT ANALYSIS AND DISCUSSION

This section examines the performance of ITS-G5 and 5G in communication situations involving drones and vehicles, as well as drones and infrastructure. The performance evaluation in our trials considered several criteria, including packet delivery ratio, average throughput, packet loss and average end-to-end delay. The subsequent analysis pertains to the outcomes obtained from the pilot measurements.

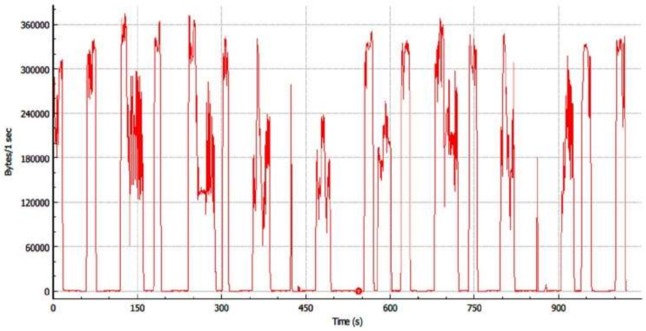

Figure. 6. ITS-G5 UDP packet capture.

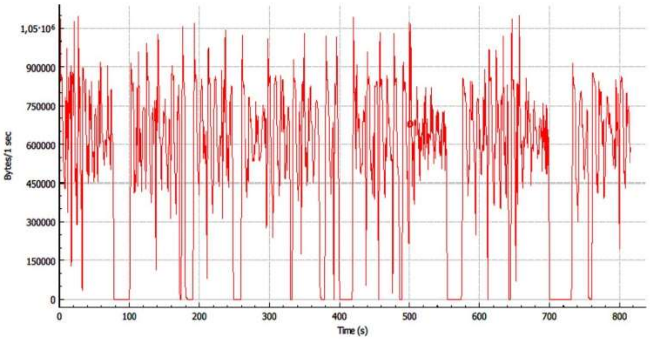

Figure.7. 5G UDP packet capture.

The UDP packet capture in DAVN using ITS-G5 and 5G are illustrated in Fig. 6 and Fig. 7, respectively. The ITS-G5 has less packet capture than the 5G, as shown in the Fig. 6. The pilot measurements of the 5G range showed superior results, although the average delay was somewhat higher than that of the ITS-G5, as shown in Table III.

On the basis of the PDR, Fig. 8 shows how the ITS-G5 and 5G standards worked in DAVN for both D2I and D2V scenarios. For DAVN networking the communication range shown in Fig. 8 is between 50 and 200 meters, however we will perform more tests with extended range in future. Both wireless technologies performed well when exchanging road weather and traffic data in D2V and D2I scenarios. The value of PDR was dependent on the D2V scenario because we used two vehicles and a different topology than in the D2I scenario. As in the D2V scenario, the PDR of the ITS-G5 scenario is higher than that of the 5G D2V scenario. The PDR of the ITS-G5 is also higher in the D2I scenario, as compared to the D2V scenario. Therefore, the PDR of ITS-G5 is significantly greater than the PDR of 5G, as seen in Fig. 8.

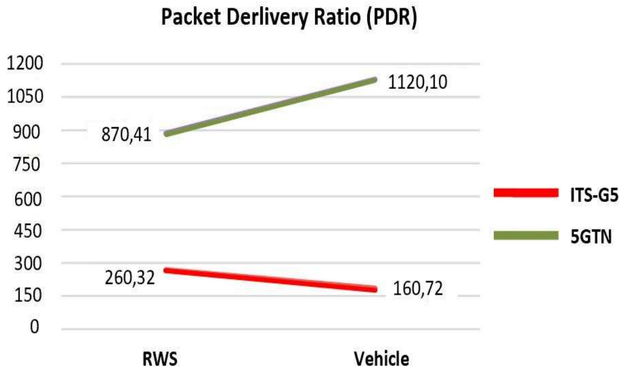

Figure. 8. PDR in D2V and D2I using ITS-G5 and 5G network.

Fig. 9 illustrates the average end-to-end latency when the same parameters are used for ITS-G5 and 5G in D2I and D2V in, Fig. 9 shows that the ITS-G5 has a longer average end-to-end delay than the 5G. We also found that with the ITS-G5, D2I has more latency than the D2V case. Due to the close proximity of the vehicles, the average latency of ITS-G5 is reduced in the D2V scenario.

In contrast to the D2V situation, the latency in the 5G D2I scenario is significantly smaller. The average delay grows in a D2V scenario because vehicles are constantly on the move. Fig. 9 shows that in both cases, the 5G network has lower end-to-end delay than the ITS-G5.

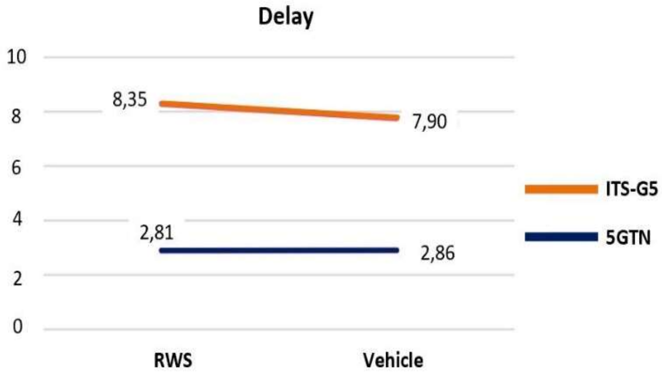

Figure. 9. Average end-to-end delay in D2V and D2I using ITS-G5 and 5G

TABLE III. COLLECTED RESULTS OF ITS-G5 AND 5G

Communication Scenario	Pacekt loss (%)	Average Dealy (ms)	Throughput (Mbps)
ITS-G5	11.3	19	1.43
5G	14.5	16	2.41

Our measurement data is presented in Table III. In terms of packet loss, the ITS-G5 performs marginally better than the 5G. However, the high average end-to-end delay of ITS-G5 and 5G has an impact on throughput. The pilot measurements revealed that ITS-G5's latency (delay) was exacerbated by the time needed to initiate the connection and the often-unstable quality of the link between nodes. The 5G has better performance in both D2V and D2I scenarios, as shown in Table III and Fig. 10.

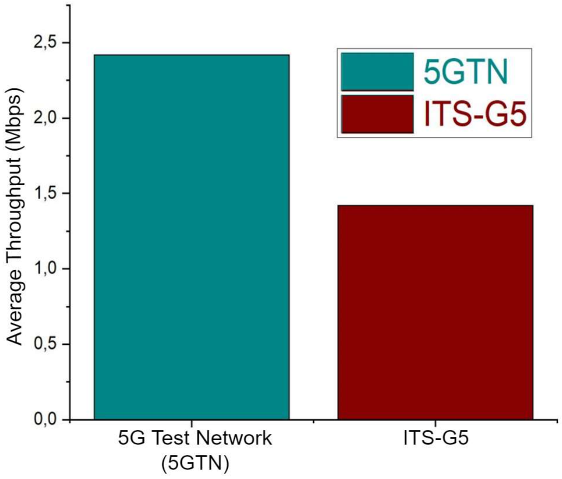

Figure. 10. Average throughput of ITS-G5 and 5G.

CONCLUSION

DAVN has a great potential to improve communication in wireless vehicular networks in the coming years. We provided the DAVN pilot measurements exploiting ITS-G5 and 5G in this paper. The performance of these wireless technologies was evaluated in a communication range of 50m-1000m, taking into account the PDR and average end-to-end delay in D2I and D2V communication scenarios. Because of the dynamic vehicular mobility on the test track, our pilot measurements revealed that the PDR of the ITS-G5 is higher than the PDR of the 5G. On the contrary, 5G requires less time for data delivery (end-to-end latency) than ITS-G5. This is due to the haphazard nature of the test track and the communication link's line of sight (LoS) and non-line of sight (NLoS) conditions. Thus, this research demonstrates the efficacy of DAVN for vehicular communication, which has been proven by our pilot measurements.

In the future, more pilot measures will be required to efficiently link vehicular networks with drones, and we are conducting additional research on DAVN real-time solutions that will be piloted in the near future.

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