Full-Duplex UAV Relay Networks for V2X Survey

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Abstract— **For the last 130 years, researchers have been working on that least reliable part of the car, the driver. Almost most of the accidents are due to human error and not machine error, but the machines must prevent the crashes with seat belts, air bags, and in the last decade, trying to make the car smarter to fix this bug. Recently, the automotive manufacturers and communication vendors tend to invest in Vehicle-to-Everything (V2X) communications for safe, information, entertainment and autonomous driving. As result, they have to change the legacy vehicles productions and infrastructure. Furthermore, the V2X generally is standardized in IEEE 802.11p (DSRC-Dedicated Sort Range Communication), implement in LTE-V2X which is available in early 2017 and also V2X introduces as one of the most important of 5G's aims. Additionally, the V2X naturally works and contributes as the multi-hop system then it is better to consider it as a kind of cooperative communication (Relay). Recently, the UAV (Unmanned Arial Vehicle) emerges as a newfound scheme in communication networks, it can be used as UAV-Base Station in V2I communication or play the relay role in V2V communication. Hopefully, it will capable to solve many issues in V2X. In last decades the full-duplex (FD) steps into the field of wireless networks. The FD technique enables the nodes in the wireless communicating to exchange their data bidirectionally without any discontinuities in time and over the same frequency band. If the self-interference can be coped with in FD, the spectrum efficiency and latency will be improved strongly. Then in this research plan, the FD UAV relay network for V2X is focused. On the other hand, the UAV plays the relay nodes in V2X, which will work in FD mode and use a time slot for both send and receive. With the combination of relaying, UAV and FD technique, we have more gains on ubiquitous, reliable coverage, diversity, high spectrum efficiency and low latency. In the system model section, some novel scenarios are introduced, which had not been considered yet. These scenarios use beam-forming, MIMO, and mm-Wave to achieve better performance in this proposed system.**

Keywords—Vehicle-to-Vehicle; Full-Duplex; 5G; Cooperative Communication; Relay Selection; Vehicle-to-Infrastructure; Unmanned aerial vehicle (UAV).

I. INTRODUCTION

This According to the US National Highway Traffic Safety Administration (NHTSA) report, there were 6.1 million crashes in 2014. The number of deaths from vehicle accidents is accounted for 32,675. V2V and V2I wireless communications based on safety applications enable vehicles to inform a driver of roadway hazards and dangerous situations, as well as they will enable drivers to have the 360-degree awareness of dangers and situations they cannot even see [1]. From another perspective, if you take the average commute time in America, which is about 50 minutes, you multiply that by the 120 million workers we have, that turns out to be about six billion minutes wasted in commuting every day. Now, that's a big number [14]. Now the V2X come up with a transportation network to fully integrate innovative technologies such as self-driving cars, connected vehicles, and smart sensors, which will overcome the previously mentioned issues. However, to realize the full potential of vehicular communication, massive challenges need to be addressed and significant efforts need to be made in security, congestion control, low latency connectivity, cooperative driving, scalability, dependability, capacity, and opportunistic channel access. In addition to the above challenges, the V2X networks should accommodate the high degree of heterogeneity in terms of hardware, software, wireless technology, and applications, as well as, the topology control and deployment are comparatively more complex in heterogeneous wireless networks. In addition to the general mentioned challenges the latency and throughput are high critical key features not only in this network but also in all communication networks, imagine in self-driving cars, the car's embedded sensors and cameras can communicate with cloud via infrastructure and other vehicles in high rate and decides in minimum time, the [21] estimates that an autonomous vehicle can generate up to 1 TB of data in a single trip. Or with the V2V communication and telematics the cars would slow as needed to slip into a gap between crossing cars, then a real-time communication network with high throughput capability is highly needed. The FD fundamentally contributes to the wireless networks for low latency and high spectrum efficiency (high throughput). There are some kind of literature on FD or latency in V2V in this regard, some important and related works can be noted. The author in [2] proposes an FD-based scheme for D2D wireless video distribution, it conducts in two scenarios, the first one user devices operate in bidirectional FD mode in which two users can exchange data simultaneously at the same frequency, and second one user devices can concurrently receive and transmit data from two different nodes at the same frequency, and finally they analyze throughput and delay in both scenarios and compared them against conventional HD (half duplex) systems.

The [3] focuses on discovery phase in D2D and it studies how to provide fast discovery in 5G systems supporting D2D communication. The envisioned system design is presented, considering FD as a key technology component to meet the strict 5G latency requirements.

Emmanouel in [4] Introduces an opportunistic relay selection policy related to the propagation characteristics of a V2V relay-based system, where a source communicates with a destination

978-1-5386-4304-4/18/$31.00 ©2018 IEEE.

through multiple vehicle relay nodes. As Channel State Information (CSI) overhead is introduced by the relay selection process. Reactive relaying is exploiting based on instantaneous CSI knowledge. To precisely characterize the corresponding wireless fading channel, a three dimensional model for V2V relay-based channels is constructed. And finally it simulation results depict the throughput and the Packet Error Rate (PER) performance of the proposed relay selection scheme for different scattering conditions. The [5] and [6] introduce NOMA (non-orthogonal multiple access) as a new multiple access scheme for improving the SE (spectrum efficiency) in cooperative communications. The key characteristics of NOMA is to allow multiple users to share the same resource elements (i.e., time/frequency/code) via different power levels. In relay selection communication, the NOMA user with higher SINR can receive data from the base station and forward them towards the NOMA user with lower SINR employing the FD technology at the same time over the same channel. The application of FD D2D-aided cooperative NOMA can significantly improve the downlink performance with high spectrum efficiency and the transmission reliability of the NOMA user with lower SINR. The [21] claims that due to massive data rate from the embedded sensors the mm-Wave Communication can play an important role in next vehicle communications. There are significantly increase in UAV research, it can join to the V2V and improve its capability. A few research were done in this regard, Rui Zhang [22], introduces the opportunities and challenges and focuses on UAV-enabled mobile relaying. The [23] proposes a computationally effective suboptimal algorithm for cooperative relaying in UAV to reduce the complexity of scheduling, where rate adaptation and energy balancing are carried out and decoupled in a recursive alternating manner. In [24] a novel method is proposed to specialize autonomous relay for mm-Wave communications.

In this paper, the section 2, introduces the aims of V2X communication. In section 3, the FD will be browsed. In 4 we can get acquainted with the UAV relaying. In fifth section the channel characterization in V2V and UAV are considered. System model and scenarios will present in sixth section. The seventh section takes a look on the different simulation tools.

II. AIMS OF V2X COMMUNICATION

The connected vehicle and telematics are attempting to bring together a number of different technologies to provide the Safety & Security, Navigation & Traffic Information, Entertainment & Personal Information, Remote Service Functions, V2X communications and finally the Autonomous vehicles [7]. Autonomous vehicles that are aware of their surroundings and position, they are fully capable of driving themselves with or without a human. In this way different projects are trying to reach the aim by 2030 [15 and 16].

For the telematics aims the V2X communications need to be more reliable and trusted; Drivers in cars which are equipped with V2X communications need to rely on the timeliness and accuracy of the exchanged data, the V2X in the autonomous vehicles must be capable to transmit estimated 1 TB of data in a single trip. From the V2X communication point of view, for achieving the ultimate aim (autonomous driving) a communication system must cope with or obtain some cost and quality. These quality and cost in V2X can be specified as below:

Cost can be measured in required

- Transmit power;
- Total power consumption;
- Transmitted signal bandwidth;
- Transceiver complexity.

Quality:

- Probability of error;
- Latency;
- Delivery ratio;
- Throughput;
- And Delay jitter.

By increasing demand of spectrum usage and real-time applications in 5G, a system is required to handle all communications with low latency and high spectrum efficiency. Therefore, this paper is proposed to investigate and carry out research for deal with of some parts of the mentioned cost and quality such as latency, spectrum efficiency (SE) and throughput.

III. COOPERATIVE COMMUNICATION AND FULL DUPLEX TECHNIQUE [8, 10]

Cooperative relaying strategy has become a one of the attractive areas in telecommunication, it contributes to overcoming of most challenges, such as the spatial diversity and coverage enhancement. If full-duplex is added to the cooperative relaying in addition to the coverage and spatial diversity the low latency and high data rate theoretically should be doubled in this network. Thus, in recent years, carrying out research on FD is being increased significantly, the figure 1 shows this trend, the full-duplex IEEE's papers increment from 2010 to 2017.

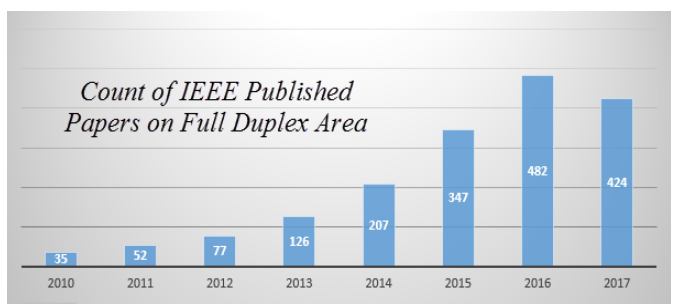

Fig. 1. Full-duplex research count per year in IEEE

The simplified FD in cooperative communications is illustrated in Fig. 2, which generally consists of three types of node: a source node, a relay node, and a destination node. The source node wants to transmit its data signal to the destination node. The relay node is used to increase the coverage of the source node, i.e., it receives, amplifies and retransmits the wireless signal. Let us denote the transmission links from S to R as $link_{SR}$ and R to D as $link_{RD}$, respectively. When FD transmission is applied to the relay node, however, the S and R nodes can simultaneously transmit their signals via $link_{SR}$ and $link_{RD}$ in the same frequency band. The FD cooperative communications can theoretically double the spectral efficiency.

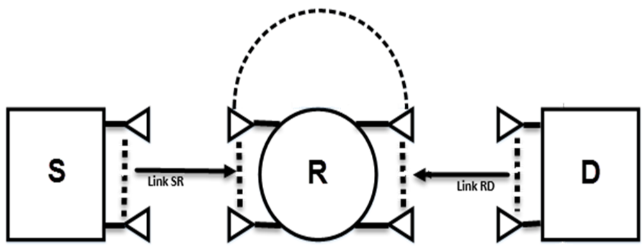

Fig. 2. Full-duplex cooperative communications

Many cooperation strategies have been proposed based on different relaying techniques, such as amplify-and-forward (AF) [36], decode-and-forward (DF), selective relaying (SR), coded cooperation, compress-and-forward (CF).
The foremost challenge in FD wireless devices is to find the techniques to mitigate the performance degradation imposed by self-interference. In three class the self-interference cancellation (SIC) is being done:

- Passive suppression;
- Active analog cancellation;
- Active digital cancellation.

Full duplex likes every technology needs to overcome of its challenges. Some important challenges in FD can be listed as following:

FD device complexity issues:

Carrying out powerful SI cancellation increases both the cost and complexity of FD-based devices. Furthermore, the hardware limitations will also constrain the performance gain of FD.

FD MAC-layer protocol design:

Apart from the physical-layer solutions discussed above, a properly designed FD MAC-layer protocol, which should be backward-compatible with the existing (HD) Half Duplex-based. Furthermore, it requires the access mechanism to be capable of providing a fair opportunity for all nodes to access the shared medium.

FD in the high-SNR/data rate:

The FD philosophy was shown to outperform HD in terms of capacity gain, link robustness, and/or outage probability, provided that the former operates at low to medium SNR values and information rates. Hence, expanding the benefits of FD to the high-SNR/data rate regime is promising but challenging in practical environments.

IV. UAV RELAYING

Wireless communication systems that include the UAVs promise to provide cost-effective wireless connectivity for devices without infrastructure coverage. Compared to terrestrial communications, the on-demand wireless systems with low-altitude UAVs are in general more flexibly re-configured, faster to deploy and are likely to have better communication channels due to the short-range line-of-sight (LoS) links [25]. Furthermore, the UAV systems are used in a large number of contexts to support humans in dangerous or difficult-to-reach environments.

The UAV will be used in wireless communication for:

- Ubiquitous coverage;
- Information dissemination/data collection;
- Relaying.

In case of ubiquitous coverage, the UAV can provide seamless coverage or if the infrastructure fails the UAV contributes as part of failed infrastructure (aerial base stations), as well as it can play as aerial base station offloading at hotspot. For the second usage it can gather the data and information for periodic sensing and information multicasting. In most and last UAV usage, it can use as relay node in cooperative communications. Therefore, the V2X can use the relaying capability of UAV in its communications for coping with some V2X issues [22, 23, 24 and 30].

A. Advantages of UAV in V2V System:

The UAV can contribute to the vast applications; particular, the V2X as a one of the most important parts of 5G, can be most effective if the UAV helps V2X. The advantage of using the UAV in V2V can be listed as follows:

- Cooperative communication (Relay) can improve the spatial diversity and coverage enhancement;
- UAV can disseminate the traffic and accident Information
- Overcome the obstacle constraint;
- Bring seamless coverage;
- Vehicle positioning can be done;
- UAV can play the base station role for offloading at the hotspot or temporary events;
- If the UAVs use as flying base stations then it can boost the coverage and capacity of existing wireless networks;
- In case of Infrastructure failure UAV can support;
- UAV can improve the SNR by finding the better position;
- UAV can have the better performance due to LOS path;
- Dynamically UAV's coverage based on its height;
- The mm-wave can implement in UAV relay networks, due to LOS communication.

UAV is likely to have better communication channels because of the line-of-sight (LoS) links. As result, due to the UAV's characteristics, the most above V2X challenges will solve spontaneously. For instance, the UAV (relay) can see the transmitter and receiver's nodes without obstacles. Relay (UAV) can cover an area without any gap and shadow fading less affects. By simply detecting of vehicles the positioning issue will be solved in V2V networks. If a base station (BS) fails or in the high traffic jam the UAV can serve and contribute as BS in V2I communications. Because of the UAV's movement, the UAV can improve the SNR by changing its location; on the other hand, UAVs can easily move from one place to another in order to provide on-demand communication support. It can change their locations to avoid shadowing /blockage. The UAV usually will communicate with vehicles in LOS, In particular, UAVs can maintain LOS connectivity (or at least a reasonable NLOS link) with the desired user, and then mm-wave and beam-forming's communications will be done in better performance. The coverage can be decreased or increased by means of UAV's height. Along with the mentioned advantages of the UAV, it encounters some challenges [22, 23].

B. Challenges in UAV Communication

The most important challenges in UAV are listed:

- UAV's Size, weight, and power (SWAP) constraints force the communication to have more limitations;
- There is more interference in height of UAV than Terrestrial device;
- High mobility of UAV systems generally results in highly dynamic network topologies;
- Because of the mobility of UAV-aerial base stations as well as the lack of fixed backhaul links and centralized control, the interference coordination among the neighboring vehicles is very challenging than in terrestrial cellular systems;
- Impact of inclement weather (windy, rainy And stormy) on UAV performance;
- In UAV swarm operation, the interference mitigation and Inter-UAV coordination are important issues;
- In case of swarm UAV, the mobility management should be done with terrestrial base station, and this task will be added to the base station load;
- A new communication protocols should be designed with taking into account the possibility of network connectivity in sparse and intermittent situation.

The SWAP are important constraints even in communication design, the size must be enough for appropriate antenna design. Based on field experience, the interference in high elevation is more than the terrestrial elevation then it is serious challenge. If the UAV has to work as BS, the wireless backhaul is a disadvantage for it. The safety application in V2X much more uses in inclement weather, but in this situation the UAV's performance faced with the crucial problem.

V. V2V AND UAV CHANNEL CHARACTERIZATION [9, 17]

The V2I channel model looks like the common mobile networks, but the channel models of V2V and UAV are somewhat difference, and they have their own channel characteristics, for instance in V2V the antenna heights of both receiver and transmitter are low, and both of them mobile. In addition, due to rapid time variation or multiple scattering, amplitude fading may be more severe than in the most common cellular fading model [27]. Now an accurate channel model for V2V is still a topic of scholars' research interest, also the UAV has been started to standardize, formulate and shown in several papers that vehicular (unmanned aircraft or terrestrial vehicle) wireless channels exhibit specific characteristics that make them quite different from the very well characterized wireless cellular channels.

A. V2X Channel Charactristics:

Notably, in V2V communications as a type of V2X, the radio channel is challenging, due to:

- Its high variability in time;
- Different propagation environment;
- Tx and Rx approximately are at the same height;
- Higher mobility;
- In a V2V channel, both the TX and the RX are moving;
- V2V communications operate mostly in the 5GHz band then the signal attenuation is higher while specific propagation processes are less efficient.

Besides, the V2I channel are more similar to common cellular network channels, but it differs in environment and mobility. For V2X and V2V channel modeling some different scenarios must be considered:

- Urban (crossroads, Buildings, parked vehicles, NLOS, vehicle platooning)
- Rural (LOS, few vehicle, low coverage)
- Highway (high mobility and high speed vehicle)
- Tunnels

B. UAV Channel Charactristics:

It should be noted that, the UAV channel characteristic consists of two types of channels, UAV-UAV and UAV-ground channels or (AG) air-ground channel, which exhibit several unique characteristics as compared to the terrestrial communication channels. [25, 26 and 29]

- Multipath propagation due to reflections on the ground
- There are number of multi-path components because of reflection, diffraction and scattering, by foliage, mountains, ground surface, and so on;
- The UAVs over sea or desert experience more surface reflection components;
- The UAV-Vehicle channels may have even higher Doppler shift frequencies than the V2I counterparts;
- When both air-ground and air- air links are required, routing schemes must be designed to maintain efficiency and minimize latency;

- The UAV AG channels will often be more dispersive;
- AG experiences larger terrestrial shadowing attenuations;
- The AG change more rapidly due to flight maneuvers than channels incurred by conventional aircraft.

The UAV channel modeling must be considered in different scenarios:

- Hilly & Mountainous area
- Over-water
- Suburban Environments
- Urban Environments

VI. System Model and Scenarios

We can proceed and combine some techniques to the UAV-V2X relay. Each technique can add its advantages to the UAV-V2X system and improve the performance, it goes without saying that the implementation of all techniques to the UAV-V2X can make a jump in V2X performance, but carry out research on all of them may take many times and increase the complexity. Then some scenarios are introduced for improving the V2X performance.

A. Adding the Full-Duplex to UAV-V2X relay:

Replacing the half-duplex relay with Full-Duplex relay can improve the spectrum efficiency and latency. The air-ground link and V2I connections can use the FD as a relay.

B. Using the MIMO and also beamforming:

MIMO and beamforming relay will contribute to the UAV-V2X for increasing the coverage. Since the UAV can communicate with the vehicles in LOS path, then it is good condition to use the beamforming technique. Using MIMO in the UAV systems is still obstructed by several factors.
First, the lack of required scattering in the UAV environment significantly limits the spatial multiplexing gain in MIMO. Second, the high complexity of signal processing besides the power consumption and hardware costs make it quite costly to employ MIMO in UAVs. Regardless of, these challenges, some recent results show great potential of MIMO technology in UAV systems [25].

C. Combining the scenario A and B:

With scenario A and B together we can add their advantages but the complexity will be increased.

D. Using the mm-Wave and beamforming:

In mm-Wave the short wavelength allows multiple antennas to be integrated in a small space. In addition to mm-wave communication the beamforming technique can reduce the interference and prolong the communication range. Also due to tiny size of mm-wave antenna in UAV, making the aircraft will be easier. It goes without saying that the mm-Wave communication due to the high bandwidth can exploit the high throughput. And in UAV due to exploiting the LOS communication, the mm-wave can be used easily.

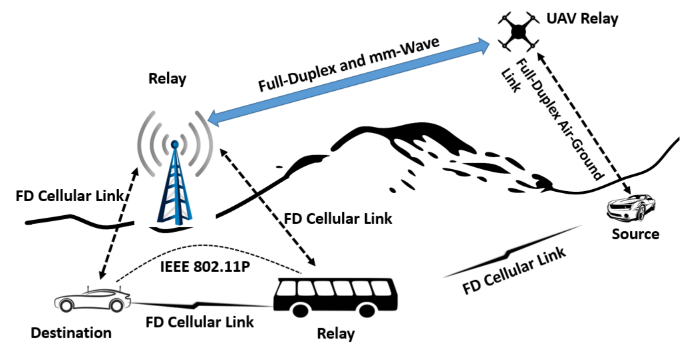

Fig. 3. System Model

The Fig. 3 shows that how the V2I, V2V and UAV can communication to each other.

VII. V2X and UAV Simulation tools [12, 13, 17]

Furthermore, realistic simulation of V2X is one of the main challenges in the vehicular research domain. There are some tools to simulate the V2X in different scenarios but they are not optimized for them. Since the UAV is new and they have not contributed to the V2X (as the most of them are open source) then these simulators must be modified. The V2X and UAV simulation system should include all layers for various scenarios, which are mentioned in section 6.
This concept can be simulated by the following simulators along with the general simulation tools such as MATLAB or …

C. OMNeT++ (for Discrete Event Simulator):

OMNeT is a modular, component-based C++ simulation library and framework, primarily for building network simulators.

E. Venis

Veins is an open source framework for running vehicular network simulations

F. SUMO

SUMO allows modeling of intermodal traffic systems including road vehicles, public transport, and pedestrians

G. Plexe

Plexe is an extension of the popular Veins vehicular network simulator which permits the realistic simulation of platooning (i.e., Automated car-following) systems.

H. VSimRTI [20]

The V2X Simulation Runtime Infrastructure (VSimRTI) is a comprehensive framework for the assessment of new solutions for Cooperative Intelligent Transportation Systems. Vehicle movements and sophisticated communication technologies like V2X communication and cellular networks can be modeled in detail. VSimRTI is one of the most flexible systems available in the automotive research arena to dynamically simulate Smart Mobility applications and to assess their impacts and benefits.
The Fig. 4 illustrates that, with Veins each simulation is performed by executing two simulators in parallel: OMNeT++ (for network simulation) and SUMO (for road traffic simulation).

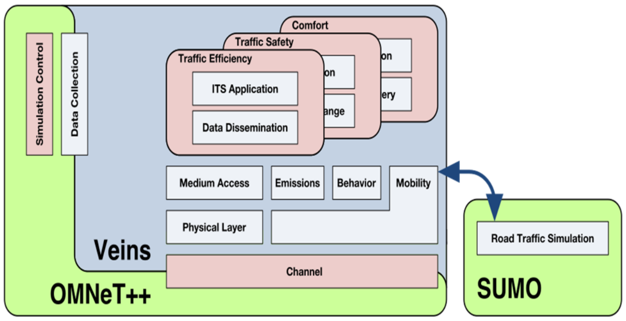

Fig. 4. Venis, OMNeT and SUMO relations for different Scenarios

I. CONCLUSION

The V2X are focused as part of 5G and autonomous driving. The low latency, high spectrum efficiency are concentrated for these goals, on the other hand a future self-drive needs to communicate with the infrastructure and other vehicles in short time with high data rate. As well as, the UAV can help the V2X to have a reliable communication along with high quality performance. Some technologies such as Full-duplex, MIMO, Beamforming, mm-Wave are promising schemes which contribute to the ultimate achievements. Now, this paper tries to start a new way in this regard. Besides, Because a node in FD uses the same frequency in send and receive at one time slot, maybe the Doppler issue can be formulated and find new scheme to mitigate the effect of it.

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