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Opportunities for Intelligent Reflecting Surfaces in 6G Empowered V2X Communications

Wali Ullah Khan, *Member, IEEE*, Asad Mahmood, Arash Bozorgchenani, *Member, IEEE*, Muhammad Ali Jamshed, *Senior Member, IEEE*, Ali Ranjha, Eva Lagunas, *Senior Member, IEEE*, Haris Pervaiz, *Member, IEEE*, Symeon Chatzinotas, *Fellow, IEEE*, Björn Ottersten, *Fellow, IEEE*, and Petar Popovski, *Fellow, IEEE*

***Abstract*—The applications of upcoming sixth-generation (6G) empowered vehicle-to-everything (V2X) communications depend heavily on large-scale data exchange with high throughput and ultra-low latency to ensure system reliability and passenger safety. However, in urban and remote areas, signals can be easily blocked by various objects. Moreover, the propagation of signals with ultra-high frequencies, such as millimetre waves and terahertz communications, is severely affected by obstacles. To address these issues, the Intelligent Reflecting Surface (IRS), which consists of nearly passive elements, has gained popularity because of its ability to intelligently reconfigure signal propagation in an energy-efficient manner. Due to the promise of ease of deployment and low cost, IRS has been widely acknowledged as a key technology for both terrestrial and non-terrestrial networks to improve wireless coverage signal strength, physical layer security, positioning accuracy, and reduce latency. This paper first describes the introduction of 6G empowered V2X communications and IRS technology. Then, it discusses different use case scenarios of IRS enabled V2X communications and reports recent advances in the existing literature. Next, it focuses our attention on the scenario of vehicular edge computing involving IRS enabled drone communications in order to reduce vehicle computational time via optimal computational and communications resource allocation. Finally, this paper highlights current challenges and discusses future perspectives of IRS enabled V2X communications in order to improve current work and spark new ideas.**

I. Introduction

The sixth-generation (6G) empowered vehicle to everything (V2X) communications is essential to smart city transportation systems. Robust wireless connections and cutting-edge sensors will completely transform the safety and comfort of the existing transportation systems [1]. The future transportation industry will incorporate a wide range of technologies, including those for passenger and driver protection, autonomous driving, traffic management, and passenger amusement. By providing pervasive connectivity, secure data sharing, energy-efficient transmissions, and quick computation, 6G wireless technology is the backbone of the transportation industry. Furthermore, the 6G transportation system will offer terabit-per-second data rates, which are exceptionally high. As a result, the latency of wireless communications can be reduced to under 1 millisecond, and the packet delivery ratio can be increased to $\approx 100\%$ [2]. 6G will be enabled by technologies including intelligent reconfigurable surfaces (IRS), terahertz (THz) communications, blockchain, ambient backscatter communications, and artificial intelligence.

Besides the promise of the above features, V2X communications also face several challenges. For example, shadowing effects can significantly impact the efficiency and effectiveness of V2X communications due to obstacles like buildings in urban settings or hills and trees in rural areas. Therefore, limited energy reservoirs and spectrum resources would be the main challenges for large-scale V2X communications in 6G. Future V2X communications may also suffer from low transmission latency, unreliable wireless connectivity, and/or limited coverage. Moreover, high-velocity vehicles impact channel stability, having a negative impact on data rates. Accordingly, changing the position of drones in the air complicates communications even further. Keeping a high degree of energy efficiency in V2X communications while attempting to control the propagation and fading of THz signals is an open question. Driving safety and communications security are compromised by V2X communications that are unstable. It is essential to increase the range of communications and strengthen it in a sustainable manner.

The IRS has been seen as a potentially game-changing technology in 6G, with the ability to manipulate signal propagation and develop an intelligent radio environment [3]. Using reflection and programming, IRSs can alter the phase of incoming electromagnetic (EM) waves, allowing for the redesign of channels. IRS reflection can create a new propagation path around an obstacle that is impeding the direct Line-of-Sight (LOS) link between the source and destination. In conventional communications systems, re-engineering the transceiver is the only option for boosting system performance. The IRS adds a new design parameter to wireless networks. Therefore, IRS technology can be used to enhance V2X communications and offer indirect LOS links that are both cost-effective and energy-efficient. Because significant performance gains are achieved only when the transceiver is close to the IRS, a permanently deployed IRS will limit its potential. Given the transient nature of vehicles, mobile IRS is viewed as a viable option for V2X networks.

Great potential exists for 6G empowered V2X communications thanks to IRS's ability to enable beyond LOS and energy-efficient communications. The IRS promises to help vehicle to infrastructure (V2I), vehicle to vehicle (V2V), vehicle to drone (V2D), and vehicle to satellite (V2S) communications in 6G networks by improving multipath propagation and expanding transmission coverage in high-frequency bands, i.e., millimeter wave (mmWave) and THz. The IRS is also simple

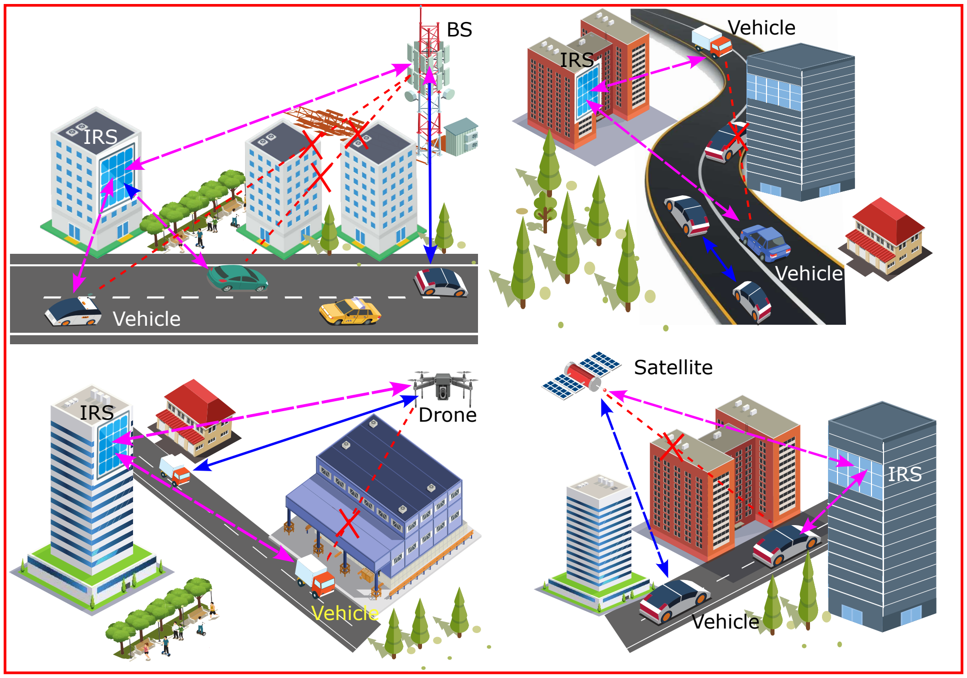


Fig. 1: Potential use case scenarios of IRS enabled V2X communications, i.e., IRS enabled V2I communications, IRS enabled V2V communications, IRS enabled V2D communications, and IRS enabled V2S communications.

to deploy due to its two-dimensional plane surface structure. Furthermore, the passive reflection mechanism enables IRS to operate in a low-energy-consumption mode, meeting the green 6G empowered V2X communications requirements. Recent hardware and material research indicate that it can control the reflection dynamically, allowing the IRS to perform real-time beamforming and serve multiple vehicles. IRS's ability to use reconfigurable passive beamforming to strengthen physical layer security in vehicular communications on the ground and in the air is a major advantage.

This paper describes the IRS opportunities in 6G empowered V2X communications and highlights some existing problems for ground and aerial/space V2X communications. First, it discusses various use case scenarios of IRS enabled V2X communications and provide recent advances in the literature. Then, it presents a case study on vehicular edge computing (VEC) network involving IRS enabled cooperative drone communications, with the goal of reducing vehicle computational time using a new optimization framework. Before IRS can be widely used in 6G empowered V2X communications, some issues need to be resolved. We underline the challenges so as to provide direction for the implementation of IRS in terrestrial and non-terrestrial V2X communications. The rest of this article is structured as follows: Section II contains use case scenarios as well as recent advances. Section III introduces a new optimization framework for minimizing computational time in VEC networks involving IRS enabled drone communications. Section IV discusses unresolved issues and potential future research directions. Section V concludes with closing remarks.

II. IRS Enabled V2X Communications: Use Case Scenarios and Recent Advances

In this section, we first highlight and discuss potential use case scenarios in 6G IRS enabled V2X communications[1]. Then we report and compare recent advances in IRS enabled V2X communications.

A. *Use Case Scenarios of IRS enabled V2X Communications*

The potential use case scenarios of V2X communications involving IRS are shown in Fig. 1, including V2I, V2V, V2D and V2S, respectively. In the following, we discuss these case scenarios in more detail.

1) IRS Enabled V2I Communications: V2I communications can face the challenges of signal blockage and large-scale fading in urban areas. One of the traditional methods in such a use case scenario is to deploy relay devices to improve the received signal strength [1]. However, it requires extra power consumption. The IRS can intelligently reconfigure the signal toward the receiver, which extends wireless coverage and enhances energy efficiency in non-line-of-sight (NLOS) scenarios. In Figure 1, we can see V2I communications where a base station (BS) communicates with multiple vehicles in an urban area, facing signal blockage due to high buildings, compromising their performance. In such a scenario, the IRS can be mounted strategically to assist the signal delivery and thus improve the system performance.

2) IRS Enabled V2V Communications: In the V2V use case scenario, the communications between different vehicles can be blocked by other vehicles/objects on the road and roadside

[1] While V2X communications encompass numerous use case scenarios, this paper mainly focuses on V2I, V2V, V2D, and V2S communications scenarios.

TABLE I: Recent advances in IRS enabled V2X communications

Ref.	Use case scenario	IRS position	Transmission	Proposed solution method	Performance gain (objective)
[4]	Drones equipped with multiple antennas communicate with single antenna ground mobile users through IRS	On building	V2I	Decaying deep Q-network	Minimizing energy consumption
[5]	Task offloading of Vehicles to RSU through IRS, where RSU equipped with edge computing	On building	V2I	Dynamic task scheduling algorithm	Maximizing average offloading rate, successfully computing rate, and successfully finish rate
[6]	BS communicates with vehicles through IRS and inter-vehicle communications	On building	V2I & V2V	Alternating optimization	Maximizing sum capacity
[7]	Multiple vehicle clusters, each cluster consists of one head vehicle and multiple member vehicles. Processing requests from head vehicles to BSs through IRS	On building	V2I & V2V	DRL algorithm	Optimizing energy efficiency and latency
[8]	RSU communicates with vehicles lying in dark zone through IRS	On building	V2I	DRL & block coordinate descent algorithms	Maximizing the minimum average bit-rate
[9]	Vehicles communicate with BS through IRS, where BS is equipped with multiple antennas	On building	V2I	Alternating optimization	Maximizing average sum-rate
[10]	Vehicles communicate with BS through IRS and vehicles directly communicate directly with each other	On building	V2V & V2I	BCD algorithm	Maximizing sum capacity
[11]	BS communicates with vehicle through IRS, where IRS is mounted on vehicle	On vehicle	V2I	Heuristic transmission protocol & Passive beamforming	Maximizing achievable rate
[12]	(i) Vehicle communicates with vehicle through IRS in the presence of a passive eavesdropper, and (ii) IRS communicates with the vehicle in the presence of a passive eavesdropper	On building	V2I & V2V	Closed-form expression for secrecy outage probability	Improving secrecy
[13]	BS communicates with high speed train through direct, and IRS mounted drone links	On drone	V2I	Binary integer linear programming and soft actor-critic methods	Maximizing minimum achievable rate
[Our]	Vehicles communicate with an access point of vehicular edge computing through IRS enable cooperative drone communications	On drone	V2I	successive convex approximation & standard convex optimization	Reducing the computational time of vehicle task

[2]. Figure 1 illustrates an example of a V2V scenario, where the transmissions between two vehicles are blocked by a high building and vehicle, weakening their channel conditions. IRS can play a crucial role in assisting the signal delivery between two vehicles and enhancing their quality of services. IRS can be efficiently installed on the building wall to provide energy-efficient and secure reflection for incident signals toward the desired vehicle. Other vehicles can receive information signals through direct and IRS enabled communications links.

3) IRS Enabled V2D Communications: The mobility of drones can be efficiently used for communications in densely crowded environments to improve connectivity and reduce the terrestrial network overhead [3]. In particular, large-scale vehicles and other moving objects on roads in big cities can face several issues of performance, connectivity, fading, and transmission latency. It puts an extra burden on the communications network due to the large-scale exchange of data among different vehicles and other objects on the roadside. As shown in Figure 1, the drone can be operated as a flying BS with the assistance of the IRS to improve the performance of vehicles and other road objects facing NLOS connectivity and poor system performance.

4) IRS Enabled V2S Communications: Due to the mega low orbit constellation, satellite communications have recently gained significant attention for supporting a wide range of services throughout the globe. It will play a vital role in successfully deploying future autonomous vehicle networks. However, the high mobility of vehicles, obstacles in the urban areas, and shadowing between vehicles and satellites can disrupt the LOS connection and significantly reduce system performance [14]. IRS can be efficiently deployed to deliver signals from satellites to vehicles and improve the link budget. As depicted in Figure 1, two vehicles on the road are shown to communicate with the satellite, where one vehicle is accessing signal directly from the satellite while the other is facing signal blockage and utilizes IRS to receive signal.

B. Recent Advances in IRS Enabled V2X Communications

Although the application of IRS in wireless communications systems has been widely addressed, its application in vehicular environments has been briefly studied in the literature. In the following, we concisely review the most related works and provide their comparison in Table I[2].

For example, the work in [4] has introduced IRS and non-orthogonal multiple access (NOMA) in drone enabled wireless communications. The authors simultaneously optimize the phase shift control, dynamic trajectory design, signal decoding order, and power control to minimize the drone's energy consumption. In [5], the authors have considered both communications and computation in a mobile edge computing enabled vehicular network involving IRS. They address the problem of task scheduling which includes allocating processor and link resources. They propose a dynamic task scheduling algorithm to maximize the computation throughput. Resource allocation for IRS enabled V2X communications has also been addressed in [6], where the authors aim to maximize the V2I capacity while guaranteeing the minimum capacity of V2V links. They address a joint power allocation, IRS reflection coefficients, and spectrum allocation problem, proposing an alternating optimization algorithm. To reduce energy consumption and latency, the authors of [7] have proposed a deep reinforcement

[2]This paper focuses exclusively on vehicular communications, while there are other research papers on the topic of IRS enabled drone communications within conventional networks. Consequently, we have decided not to delve into those works in this study due to space limitations and maintain an appropriate number of references.

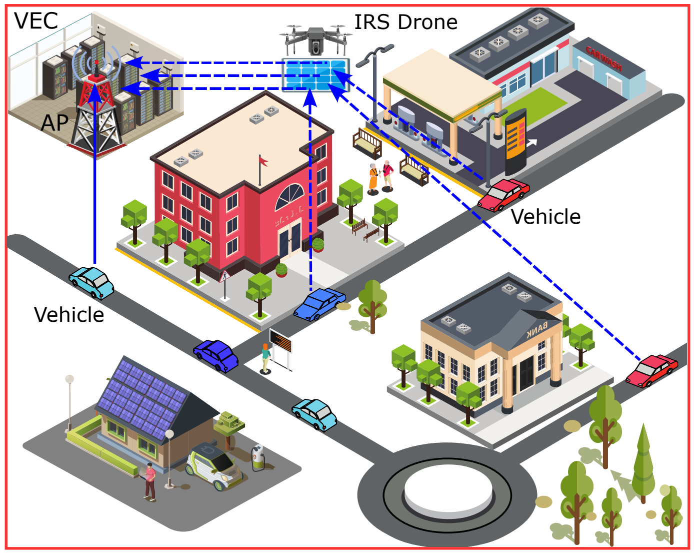


Fig. 2: System of vehicular edge computing empowered by IRS enabled drone communications

learning (DRL) strategy for efficient resource allocation in a 3-plane vehicular framework, which includes the vehicle transmission power, IRS reflection phase shift, and BS detection matrix. Moreover, in [8], the authors consider an indirect transmission from roadside units (RSUs) through IRS deployed on buildings to some dark zones. They formulate a joint resource scheduling and RSU passive beamforming aiming at maximizing the minimum average bit rate. In [9], IRS has been integrated into millimetre wave (mmWave) vehicular communications. The authors addressed the issue arising from high mobility and the challenge of obtaining accurate channel state information (CSI). They maximized the average achievable sum-rate by jointly optimizing the transmit power, multi-user detection matrix and the IRS reflection phase shift. A similar problem is studied in [10], where apart from the optimization parameters in [9], they also consider the spectrum reuse of V2V links in the joint formulated mixed-integer non-convex optimization problem. In [11], the authors study a high mobility communications scenario between passengers and BSs through IRS deployed on the vehicle. They address mitigating the Doppler effect through approximations and tuning the IRS reflection over time. In [12], the secrecy outage performance of IRS enabled vehicular communications is analyzed, where they consider two scenarios of V2V and V2I to derive the closed-form expression for the secrecy outage probability. In [13], the authors have maximized the minimum achievable rate of the system by optimizing phase shift design and trajectory by employing binary integer linear programming and soft actor-critic methods.

III. Resource Optimization for VEC Networks Involving IRS Enabled Drone Communications

The 6G communications networks would deploy a massive number of sensor nodes to facilitate data sensing from real-time applications. In the context of V2X communications, these sensor nodes can be equipped with vehicles to improve the efficiency of the overall system. These sensor nodes are connected to a central control system known as the access point (AP). However, real-time applications generate a significant volume of data that requires immediate processing. This poses a challenge due to the limited computational resources of the sensor nodes deployed on vehicles. As a result, the performance of V2X communications is compromised. To overcome this challenge, the concept of edge computing has emerged as a promising solution. edge computing enables these devices to offload their data using either a partial or binary offloading scheme. In the partial offloading scheme, tasks are divided into two parts: a portion of the task is computed locally on the sensor nodes, while the other part is offloaded to the edge computing server for extensive computation. This approach alleviates the burden on the sensor nodes and enhances the overall performance of the system. Motivated by these observations, we propose a more practical communications scenario based on VEC network involving IRS enabled cooperative drone communications with aiming to improve the efficiency and effectiveness of the overall system. In the following, we first explain the system model, problem formulation, and the proposed optimization solution. Then we validate our proposed solution by presenting numerical results and their discussion.

A. System Model, Problem Formulation and Proposed Solution

We consider VEC empowered uplink V2I communications where N low-powered sensor nodes equipped with vehicles are randomly located over a predefined geographical area. All the vehicles are connected to a central control system in VEC called Access Point (AP). We consider that all the nodes are equipped with single antenna scenario. Due to the mobility of vehicles, we consider errors in channel estimation, which is modeled using the minimum mean square error (MMSE) model. According to this model, the modeled channel consists of estimated channel gain and channel errors, where both are assumed to be uncorrelated. In considered VEC system, the AP enables extensive on-demand computation. However, vehicles generate a significant amount of data that necessitates real-time processing, posing a challenge due to their limited computational resources. Consequently, the performance of vehicular networks is compromised. To overcome these limitations, we present a partial offloading scheme that divides tasks into two parts: local computation on the vehicles and offloading to the VEC server for extensive computation. Task segmentation is achieved by analyzing the monotonic relationship between local computation time and offloading time. As the local computation time increases, indicating a larger portion of the task being computed locally, the offloading time decreases. Conversely, when a significant portion of the task is offloaded to the VEC server, the offloading time increases while the local computation time decreases. Thus, a point is reached where the local computation time becomes equal to the offloading time. This critical point is determined by a mathematical equation called the task offloading percentage, which optimally allocates the task between local computation and offloading.

The task offloading percentage relies on various factors such as local computation resources, edge computation resources, and the achievable data rate over the communication channel. Among these factors, the achievable data rate plays a crucial role, influenced by channel characteristics. In the context of smart cities, high-rise buildings result in higher path loss, leading to increased task offloading time. To address this issue, we consider an IRS enabled cooperative drone communications to provide an alternative wireless communications link, enhancing the channel and received signal gains[3]. Consequently, the achievable data rate of vehicles increases, which significantly reducing the task offloading time. The IRS is mounted over drone and consists of K reconfigurable elements that intelligently manipulate the phase shift of incident signal.

The proposed framework seeks to reduce the computational time of the task in VEC system involving IRS enabled cooperative drone communications. This can be achieved by formulating and solving an optimization problem. In particular, the proposed framework simultaneously optimizes the computational and communications resources among VEC AP and vehicles subject to various practical constraints such as vehicle energy consumption, VEC AP computational resources, drone placement, and efficient phase shift design at IRS, respectively. This framework exploits a partial offloading scheme such that Φ_n percent of the task is computed locally using local resources while the rest is offloaded to the VEC AP for extensive computation. For instance, the amount of computational resources allocated to vehicle n at the local and VEC AP levels can be represented ρ_n^l and ρ_n^e, where $n \in N$. The optimization problem of computational task minimization is formulated as non-convex because of the non-linear objective function. Moreover, coupling decision variables further complicates the optimization problem, and it is very hard to obtain a joint optimal solution. To address the challenges mentioned above and make the optimization more tractable, the original joint optimization problem is divided into multiple subproblems, i.e., drone placement optimization, phase shift control, and computational and communications resources between vehicles and VEC AP, using block coordinate descent (BCD) method. Then, phase shift control and communications resources problems are further transformed using successive convex approximation (SCA) method. The Successive Convex Approximation (SCA) method is valuable for tackling complex optimization problems, especially when dealing with non-convex objectives and constraints. It is an iterative method that can approximate non-convex problems with convex subproblems, making it widely used in wireless communications. After decoupling and transformation, all subproblems are convex, and a standard convex optimization solver, such as CVX, is used to achieve an efficient solution for convex subproblems. Specifically, the proposed method is iteratively updated to find the best possible solution that meets all system constraints. The mathematical method of the related optimization framework can be found in [15].

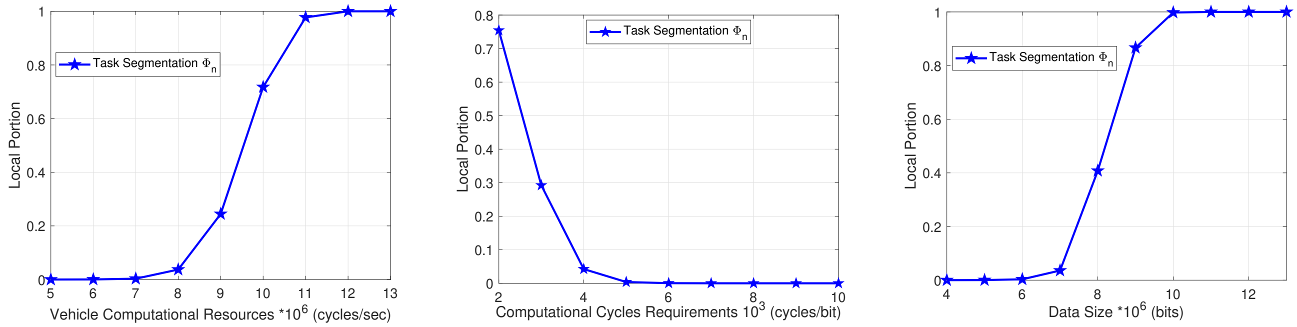
[3]In this work, we assume that the direct link between vehicles and VEC AP is NLOS dominant due to large objects. Thus, we consider an IRS enabled cooperative drone communications to assist transmission between vehicles and VEC AP.

TABLE II: Simulation Parameters and their values [3].

Symbol	Value
Carrier frequency	2 GHz
Vehicle drop model	spatial Poisson process
Path-loss model	$128.1 + 37.6 \log_{10}(d)$, d in km
VEC AP radius	500 m
Number of IRS reflecting elements	30
Number of vehicles	10
Height of drone	80 m
Bandwidth of the system	20 MHz
Cycles	$[2 \;\; 10]$ Kcycles/bits
Data Size	[10 100]Mbits
Additive white Gaussian noise	-174 dBm
Maximum local computational resources	1 Mcycles/sec
Maximum edge computational resources	25 Gcycles/sec
Velocity of vehicles	60 km/h
Shadowing distribution	Long-normal
Shadowing standard deviation	8 dB
Fast fading	Rayliegh fading

B. Numerical Results and Discussion

Here, we provide numerical results of the proposed optimization framework based on Monte Carlo simulations. For optimization, we use the CVX toolbox in MATLAB. The proposed V2I scenario is configured using vehicle drop and mobility according to 3GPP TR 36.885 (see [3] and references therein), where the spatial Poisson process generates vehicles connected to VEC AP, and density is decided through the velocity of the vehicles. Moreover, the channels between IRS enabled drone and infrastructure are established using 3GPP TR 36.777. Unless mentioned otherwise, the simulation parameters are given in Table II. We compare the following three optimization approaches. 1) *IRS Enabled VHA:* This is the proposed approach involving IRS enabled drone communications, provided in Section III-B, where the tasks are divided into two parts: a portion of the task is computed locally on vehicles, and the remaining part is offloaded to VEC AP. 2) *IRS Enabled VEC:* It refers to a benchmark approach involving IRS enabled drone communications, where all the



(a) (b) (c)

Fig. 3: Impact of Vehicle computational resources, Cycles requirement and data size of task offloading

tasks of vehicles are offloaded to VEC AP. 3) *Without IRS VHA:* It is a benchmark approach without IRS enabled drone communications, in which tasks are partitioned optimally into two portions, one portion of the task is computed locally. At the same time, the other is offloaded to VEC AP without the assistance of IRS enabled drone communications.

In the VEC, task segmentation Φ_n is an important parameter as it directly influences the performance of the system. Φ_n mainly depends on the computational resources of the vehicles, the number of cycle requirements, and the data size of the task, as shown in Fig. 3. In the following, we discuss them one by one.

1) Impact of Local computational resources on task segmentation: Computational resources allocated locally play an essential role while determining the task segmentation variables, as shown in Fig. 3a. Results demonstrate that, for the small number of computational resources, the task as a whole is offloaded to VEC AP for extensive computation. This is because local computational resources are not enough to compute it in minimal time. As a result, latency is experienced in a system; hence the quality of service is highly compromised. On the other hand, as the local computational resources increase, the percentage of tasks offloaded decreases, and more tasks are computed locally.

2) Impact of computational cycles requirements on task segmentation: Similarly, computational cycle requirements are also an important parameter while determining the task segmentation parameter. As perceived from Fig. 3b, for the small number of computational cycle requirements, it is efficient to compute the task on the VEC server because of its substantial computational resources. On the other hand, as the computational cycle requirements increase, computational tasks move toward local computation. This trend is because, at the VEC AP, computational cycles are shared among the vehicles, and significant computational cycle requirements demand extensive computation. Whereas shared computation resources at the VEC AP are not enough to meet the high demand; as a result, latency is introduced in a system. To overcome this, local computation is an effective solution to meet the desired requirements, as proved in Fig. 3b.

3) Impact of data size on task segmentation: Following that, Fig. 3c demonstrates the impact of data size (bits) on task segmentation. The trend reveals that the task is computed at the VEC AP for the small number of bits. As the data size increases, the computational task shifts toward a local computational scheme. This trend is because offloading a small number of bits consumes less offloading energy than a task's computational energy locally. In contrast, as the data size increases, the offloading energy consumption is more than the local computational energy. So it is efficient to compute the task locally.

Next, Fig. 4 represents the impact of task segmentation and communications links on the system's performance. The results reveal the proposed *IRS Enabled VHA* approach outperforms the others by considering computational task time as a performance metric. For the small number of data sizes, the performance of *IRS Enabled VEC* closely follows the other approaches. However, as the data size requirements increase, the proposed *IRS Enabled VHA* approach and *Without IRS VHA* start performing better. This trend is due to the fact that offloading a large number of bits constitutes more time and energy than the *IRS Enabled VEC* approach. Whereas in the proposed *IRS Enabled VHA* and *Without IRS VHA* approaches, the task is divided into two portions optimally. One portion of the task is computed locally, whereas the other is offloaded to VEC AP. Likewise, offloading a portion of the task also constitutes less time and energy than complete offloading, compared to *IRS Enabled VEC* approach.

In addition, the results also demonstrate the IRS's impact on the system's performance. Comparative analysis of *IRS Enabled VEC* and *Without IRS VHA* further reveal the effectiveness of IRS in the VEC network. *Without IRS VHA* is a traditional approach in which users offload their portion of the task to VEC AP for extensive computation. At the same time, the presence of an obstacle in the paths results in a weakness in the received signal strength. Therefore, reducing the achievable data rate requires more time to offload the task to VEC AP. Hence, latency is introduced into the system. Whereas in *IRS Enabled VEC* approach, the drone is equipped with IRS to assist the communications between vehicles and VEC AP, resulting strong signal that helps minimize the offloading time. Overall computational time decreases as a result.

IV. Open Issues and Future Research Directions

In this section, we discuss and highlight all open issues and future research directions.

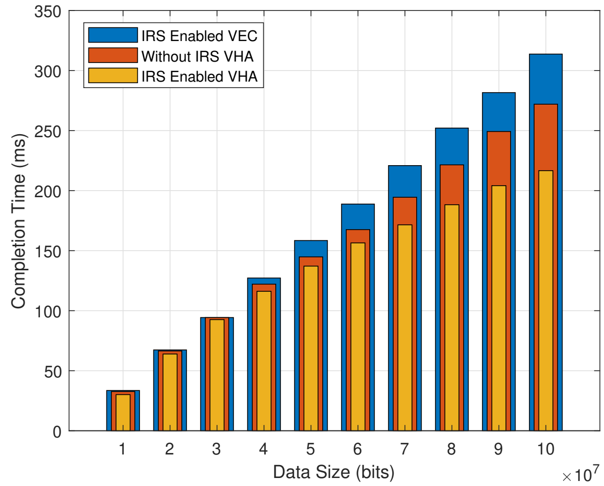


Fig. 4: Impact of IRS on task's completion time.

A. Machine Learning Techniques

In future 6G systems, numerous machine learning (ML) techniques are envisioned to perform intrinsic and complicated tasks related to resource allocation and signal processing. In this regard, ML techniques offer a competitive edge over traditional methods or algorithms for seamlessly performing computationally intensive tasks. In this context, ML techniques could solve various optimization, classification, prediction, and decision-making tasks which could be extremely useful for facilitating IRS enabled V2X communications.

B. Drone IRS enabled V2X communications

The upcoming 6G systems will support non-terrestrial networks based on drones serving as aerial BSs or relays. According to 3GPP Release 15, a drone flying at an altitude of 80 meters or above has a 100% probability of achieving LOS communications capable of mitigating shadowing and signal blockage. IRS can be efficiently mounted on drones to satisfy the QoS requirements of vehicles, such as ultra-reliable and low-latency communications. Therefore, its deployment in V2X communications is a promising research direction to investigate.

C. Power Consumption and Energy Efficiency

IRS requires powering a large number of elements to manipulate the electromagnetic environment. Optimizing performance while managing power consumption is essential, especially in vehicle environments with limited resources. Research is still being done on developing power allocation algorithms and energy-efficient IRS systems.

D. Optimal beamforming

Beamforming optimization in IRS enabled terrestrial and non-terrestrial networks is challenging. In drone-based non-terrestrial networks, wind gusts can cause random jittering, which can miscalculate the IRS and vehicle angle of departure. Most IRS studies assume continuous phase shifts, which is difficult owing to hardware constraints. Signal misalignment and IRS beamforming may result from this assumption. Beamforming optimization with discrete phase shifts at IRS in V2X communications is essential and a promising area of study to address this problem.

E. Scalability and Complexity

The deployment of IRS should be scalable to handle the growing number of users because V2X systems frequently involve a large number of vehicles. Large-scale IRS implementation, however, adds complexity to signal processing, synchronization, and control. Creating scalable and manageable designs to handle the complexity is an immense challenge that should be addressed.

F. mmWave and THz Communications

High-traffic vehicle networks require mmWave and THz frequency to meet user demand. Data rates of 10 Gb/s across 850 m have been achieved at 120 GHz. Transceivers beyond 300 GHz need power, sensitivity, and low noise to overcome the issue of a high path loss. mmWave and THz V2X communications are restricted by penetration losses, significant Doppler dispersion, and blockage. IRS can overcome such challenges and contend for V2X communications in mmWave and THz frequencies. Mutual coupling and electromagnetic interference make IRS development for mmWave and THz bands a viable research topic.

G. Interference Mitigation

Interference is a big challenge in heterogeneous V2X scenarios where different vehicles simultaneously share the same spectrum. IRS can be applied to manage the reflected signals, reducing interference actively. While multiple vehicles and IRS elements coexist in V2X environments, minimizing interference is a challenging problem. Effective interference management algorithms and tactics are needed to maximize system performance and guarantee reliable V2X communications.

H. Standardization and Deployment

Although IRS technology has a lot of potentials, some practical hurdles must be overcome before it can be practically used in V2X communications systems. These difficulties include standardization of IRS enabled V2X networks, cost-effectiveness, regulatory issues, and integration with current infrastructure.

V. Conclusion

The IRS has been regarded as an emerging technology in 6G, with the goal of controlling signal propagation and creating a smart radio environment. The IRS is designed to provide LOS-like propagation and energy-efficient communications in 6G V2X networks by leveraging intelligent reflection capabilities. The IRS can help V2X communications in 6G networks by improving multipath propagation and increasing transmission coverage in high spectrum situations. This paper discussed the potential and opportunities of the IRS in 6G empowered V2X communications. In particular, we described different use case scenarios in IRS enabled V2X communications and discussed recent advances. Then, we provided a case study on resource optimization of VEC network involving IRS enabled cooperative drone communications. The numerical results showed the benefits of IRS in terms of task computational time. Finally, we also highlighted current issues and some potential research directions in IRS enabled V2X communications.

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Biographies

Wali Ullah Khan [M] (waliullah.khan@uni.lu) received a Ph.D. degree in information and communication engineering from Shandong University, Qingdao, China, in 2020. He is currently working with the SIGCOM Research Group, SnT, University of Luxembourg.

Asad Mahmood [S] (asad.mahmood@uni.lu) received his Master degrees in Electrical Engineering from COMSATS University Islamabad, Wah Campus, Pakistan. He is currently pursuing the Ph.D. degree with the Interdisciplinary Centre for Security, Reliability, and Trust (SnT), University of Luxembourg.

Arash Bozorgchenani [M] (a.bozorgchenani@leeds.ac.uk) received a Ph.D. degree in Telecommunications and IT from the University of Bologna in Italy. In 2019. He is currently an Assistant Professor with the School of Computing, University of Leeds, UK.

Muhammad Ali Jamshed [SM] (muhammadali.jamshed@glasgow.ac.uk) received a Ph.D. degree from the University of Surrey, Guildford, U.K, in 2021. He is currently working with the James Watt School of Engineering, University of Glasgow, UK.

Ali Ranjha (ali-nawaz.ranjha.1@ens.etsmtl.ca) received a Ph.D. degree in Engineering from Ecole de Technologie Superieure (ETS), Universite du Quebec, Montreal, Canada in January 2022, where he is currently pursuing his postdoctoral research.

Eva Lagunas [SM] (eva.lagunas@uni.lu) received a Ph.D. degree in telecommunications engineering from the Polytechnic University of Catalonia (UPC), Barcelona, Spain, in 2014. She currently holds a research scientist position in the SIGCOM Research Group, SnT, University of Luxembourg.

Haris Pervaiz [SM] (h.b.pervaiz@lancaster.ac.uk) received a Ph.D. degree from Lancaster University, U.K., in 2016. He is currently an associate professor at the School of Computer Science and Electronic Engineering, University of Essex, UK.

Symeon Chatzinotas [F] (symeon.chatzinotas@uni.lu) received Ph.D. degrees in electronic engineering from the University of Surrey, Guildford, United Kingdom, in 2009. He is currently a full professor or Chief Scientist I and the co-head of the SIGCOM Research Group, SnT, University of Luxembourg.

Björn Ottersten [F] (bjorn.ottersten@uni.lu) received his Ph.D. degree in electrical engineering from Stanford University, California, in 1990. He is currently the director for SnT, University of Luxembourg.

Petar Popovski [F] (petarp@es.aau.dk) received his Ph.D. degree from Aalborg University in 2005. He is currently a full professor with Aalborg University, Denmark.