Abstract—Internet-of-vehicle (IoV) is a general concept referring to, e.g., autonomous drive based vehicle-to-everything (V2X) communications or moving relays. Here, high rate and reliability demands call for advanced multi-antenna techniques and millimeter-wave (mmw) based communications. However, the sensitivity of the mmw signals to blockage may limit the system performance, especially in highways/rural areas with limited building reflectors/base station deployments and high-speed devices. To avoid the blockage, various techniques have been proposed among which reconfigurable intelligent surface (RIS) is a candidate. RIS, however, has been mainly of interest in stationary/low mobility scenarios, due to the associated channel state information acquisition and beam management overhead as well as imperfect reflection. In this article, we study the potentials and challenges of RIS-assisted dynamic blockage avoidance in IoV networks. Particularly, by designing region-based RIS pre-selection as well as blockage prediction schemes, we show that RIS-assisted communication has the potential to boost the performance of IoV networks. However, there are still issues to be solved before RIS can be practically deployed in IoV networks.

I. INTRODUCTION

With 4G and 5G, wireless networks have made great progress in serving stationary/low mobility devices. At high speeds, however, there are still various issues to be solved. In order to connect everything at anytime and any place, as one of the main objectives of 5G and beyond, vehicle-to-anything (V2X), in general, Internet-of-Vehicle (IoV) communication plays an important role as the passengers on their vehicles expect the same quality-of-service (QoS) as they experience at home. Also, advanced vehicle technologies such as platooning, self driving and remote control require high-rate uninterrupted communications. For instance, according to 3GPP Use Case Groups [1], remote driving may need reliability up to 99.999% and latency down to 5 ms.

The intelligent vehicular communication systems were initially based on dedicated short-range communication (DSRC) standards such as ITS-G5/DSRC. Such technologies, which are based on licensed bands and support speed range ≤ 130 km/h, reach less than 10 Mbps data rates with latency ≤ 10 ms. [1]. In Long-Term Evolution (LTE), V2X has been designed for basic functionalities such as cooperative safety, road management, and telematics applications, requiring moderate data rates up to 100 Mbps. LTE-based vehicular communication is based on spanning multiple bands in 450 MHz-4.99 GHz, with latency 100-200 ms and supported speeds up to 350 km/h. Also, it provides similar types of services as DSRC to support transmission of basic road information, e.g., the location, velocity, and acceleration status of the vehicle [2].

Compared to LTE, 3GPP Release 16 proposes an evolutionary standard for V2X using the 5G new radio (NR) air interface. Particularly, 5G NR V2X considers various levels of automation ranging from Level 0 with no automation to Level 5 with full automation, and the QoS requirement increases with the automation level. Moreover, different use cases such as car platooning, advanced driving, extended sensors and remote driving use cases are defined each with its specific requirements. Specifically, in use cases such as extended sensor and remote driving, the vehicles can share their data obtained from own sensors with the surrounding infrastructure/vehicles. In this way, the perception of the environment is jointly improved for the network and it opens the opportunities for advanced cooperative schemes. Here, mobility management based on handover is the main focus where dual connectivity and UE-based handover, e.g., dual active protocol stack (DAPS)-based handover, are defined. 5G NR V2X standardization has continued in Release 17 for few enhancements (see [2] for details).

With levels 3-5 of self-driving vehicles and the probable standardization of mobile integrated access and backhaul (IAB) in 3GPP Release 18, considerably higher rates may be required compared to those provided by LTE. Here, following 5G NR, there may be a need for using millimeter wave (mmw) communications via small-cell deployments. Particularly, utilizing multiple-input multiple-output (MIMO) techniques, beamforming and advanced resource allocation, as the inherent features of 5G NR, mmw communication has the potential to provide massive bandwidth and the data rates required for IoV communications at typical vehicular speeds.

Although mmw communication supports high data rates, it can be significantly affected by the penetration loss, along with severe path loss and beamforming mismatch. Utilizing small cells, deployed on, e.g., lamp posts, could shorten the transceiver distance. With the low height cells, however, the blockage probability increases. Various blockage avoidance methods have been proposed for stationary and low mobility systems. For example, with context information the network learns the environment and realizes proper resource allocation. The deployment of IAB [3]relays, cooperative transmission [5] and non-line-of-sight (NLoS) back-up links [6] are also options for avoiding blockages.

Blockage becomes more problematic for high mobility IoV systems, e.g., in highways or rural areas. Here, due to the lack of good reflectors (e.g., buildings) and the mobility of vehicles, the NLoS back-up links are rare and sustain for a short period which limit the effectiveness of NLoS back-up
Fig. 1. An example of the proposed setup. At time $T_1$, the UE and the blocker speed/position information is reported to the BS. Then, the BS exploits the information, along with the large-scale channel properties, to pre-select the appropriate RIS to be used in Slot $T_n$. 

Our results reveal that with region prediction, our proposed RIS-assisted scheme can reach performance close to the cases with additional BSs utilizing handover as well as RIS- or network controlled repeater-assisted schemes with perfect CSIT, yet with low complexity. On the other hand, the cost-efficiency trade-off of the RIS may affect the usefulness of RISs in practice.

II. INTERNET-OF-VEHICLES USING RIS

RIS is composed of a 2D array of reflecting elements, where each element acts as a passive reconfigurable scatter that can be programmed to change an impinging wave in a controlled way. The elements are low-cost passive surfaces with no need for dedicated power sources, and the radio waves impinged upon them is forwarded without the need of employing power amplifier/RF chain. As a result, RIS requires only low-rate control link, low energy supply, and no backhaul connections.

One of the main applications of RIS is to remove blind spots and provide the UEs with alternative links when the direct UE-BS link experiences poor channel quality due to, e.g., blockage [8], [9]. This is specially of interest in mmw communication, as the mmw signal suffers from high penetration loss/low diffraction from objects.

To integrate the RIS into the network and bypass the blockage, the beam patterns of the BS and the RIS need to be jointly reconfigured. This, however, requires accurate CSIT of both the BS-RIS and the RIS-UE links as well as
accurate positioning. To acquire the CSIT, one can turn the RIS into the absorbing mode (if RF chain is deployed) and apply conventional channel acquisition methods. Alternatively, without explicit CSIT, the reflection coefficients of the RIS can still be optimized from the feedback of the UEs. For example, with pre-defined codebook, the BS and the RIS can sweep through all beam patterns and iteratively obtain the best option. Such an additional overhead, compared to the direct BS-UE link CSIT acquisitionbeamforming planning, may be acceptable in the cases with stationary UEs, as the CSIT acquisition and beamforming update can be performed during the network planning with no need for frequent updates. The problem, however, becomes challenging in high-speed IoV communications; With IoV, both the vehicular UEs and the blockers move quickly, which affects the CSIT accuracy of the BS-RIS-UE link. The problem becomes even more challenging in, e.g., highways and rural areas, where to guarantee high reliability at high-speeds, one may require multiple RISs and, depending on the UEs/blockers position, select the best RIS-assisted path based on the instantaneous channel quality of the links/UEs' positions. This is important because in a road scenario it is preferred to have a precise reflection pattern resulting in long beams covering the road over a long distance. Consequently, proper RIS deployment will be critical to minimize beam tracking. However, as we explain in the following, present RIS designs result in fuzzy and thereby short reflection pattern and, as a result, multiple RISs are required to cover the road increasing beam tracking complexity.

Recent works [9], [10] study RIS-assisted V2X communication in highways. Particularly, [9] concentrates on beamforming optimization in the presence of random blockages, assuming perfect CSIT. Then, [10] investigates the optimal deployment of the RIS in highway taking both the size and the operating mode of the RISs into account without explicit study on CSIT acquisition.

### III. RIS-assisted Dynamic Blockage Pre-avoidance

To enable multi-RIS IoV communications, one needs to reduce the RIS selection and configuration overhead as well as the sensitivity to the vehicles speed. For this reason, we propose a large-scale based RIS pre-assignment (LSRPA) scheme in which the UEs and the blockers speed/position information is utilized along with the large-scale channel properties to predict and pre-select the RIS of interest, among multiple ones.

Consider the cases with either a macro or a small BS along a highway/inter-city road, as illustrated in Fig. 1. With network planning, the BS location is normally optimized such that it covers a wide area of the road and static blockages are preferably avoided. However, dynamic blockages, due to, e.g., trucks, buses, are not encountered during the network planning and affect the achievable rate, specially in mmw bands. As an inexpensive and low-power solution to avoid dynamic blockages, specially if power supply is not available, RISs with, e.g., off-grid solar cell deployment, can be installed along the road which will provide back-up links to the vehicular UEs when required.

With multiple RISs, the main problem is to perform beam management in the BS and each RIS and select the best path. In the optimal case, one needs to know the instantaneous CSIT of all paths for joint beamforming optimization and RIS selection [9], [11]. This, however, not only increases the CSIT acquisition overhead, but also is not feasible at moderate/high speeds due to the channel aging effect where the CSIT acquired at a position soon becomes outdated due to the high mobility of the UE/blocker.

With this background, the LSRPA scheme follows the following procedure. At time slot $T_1$, if the vehicular UE detects a dynamic blockage, e.g., by a truck, it estimates the speed and the position of the blocker, e.g., using cameras, lidars. Then, along with its own speed/position information, the UE informs the BS about the speed and the position of the dynamic blocker (As an alternative approach, each vehicle can inform the BS about its own speed/position information). Knowing the blocker speed/position information at $T_1$, the BS predicts the blocker position at Slot $T_n$. Then, the BS utilizes the large-scale channel condition, i.e., the average performance which has been learned over time for the different blocker positions, to find the appropriate regions of interest to be covered by different RISs in different time slots. Then, the BS exploits the UE speed/position information provided at $T_1$ to predict the UE position at Slot $T_n$ and pre-select the appropriate path towards the UE, either through direct BS-UE connection or via an RIS-assisted link. Finally, at Slot $T_n$, only the instantaneous CSIT of the pre-selected path, and not all possible paths, is acquired and the BS/RIS beamforming is adapted accordingly.

In this way, the LSRPA setup reduces the CSIT overhead/channel aging effect, and makes it possible to provide the vehicular UEs with fairly constant QoS. Note that, to determine the regions, one does not need to have extremely accurate information about the speed and position information of the UE/blocker. Such information is well achievable in, e.g., car platooning, connected vehicle or cruise control setups. Specifically, in highways/inter-city roads, slow large vehicles (resp. high-speed vehicles) travel typically in the outermost (resp. innermost) lanes with predictable trajectory, which simplifies the positioning. Thus, with a fairly predictable vehicles mobility, a limited number of beam transitions may be required and, consequently, e.g., an AI-based blockage prediction scheme can well reduce the RIS selection/coordination overhead.

Considering the cases with one BS and two or three RISs with (im)perfect reflection efficiency, in the following, we evaluate the performance of the LSRPA scheme, in comparison with other alternative techniques. We use typical RIS setups as in, e.g., [11], and the RIS beamforming is performed using [11] Algorithm 1. As the metric of interest, we consider the outage probability and the throughput where the throughput is defined as the total number of successfully decoded bits per total transmission delay. We consider both sub-6 GHz (2.8 GHz) and mmw (28 GHz) bands and different numbers of RIS elements (10-500), with the details of the parameter settings given in the figures captions. In Figs. 2, 3 and 6 the effect of the hardware impairments are studied, otherwise ideal RIS is considered. To evaluate the efficiency of the LSRPA scheme,
we compare its performance with the following alternative schemes:

- **Additional BS.** Here, instead of RISs, an additional BS, considerably more expensive than an RIS and requiring backhaul, is added to the network, and cooperative handovers are used to bypass the blockage [1]. Note that, compared to the RIS setup, the deployment of BS is less intensive and it normally has larger coverage area.

- **Network controlled repeater.** Network controlled repeater is a normal repeater with beamforming capabilities which forwards the signal to the destination using amplify-and-forward relaying. That is, compared to RIS, network controlled repeater is a more advanced and expensive node with more focused beamforming capability/accuracy and active signal amplification.

- **Benchmark.** A genie-aided scheme using RISs where, in each time slot, the BS utilizes the instantaneous CSIT of all links to search over all, possibly RIS-assisted, paths with optimal beam management at the BS/RIS, and selects the one with the best performance.

- **Random phase.** Here, while we follow the same approach as in the LSRPA scheme to select the appropriate RIS, the phase matrix of the selected RIS is not optimized and, instead, is considered to be random. The setup is of interest in the cases where either the instantaneous CSIT of the selected path is not available or the RIS has no adaptation capability.

- **No RIS.** The UE is served by direct BS communication, either at low or mmw band, at the risk of possible blockage. Here, we model the blockage by the vehicle penetration loss (VPL) which is set to 20 dB in sub-6 GHz (e.g., 2.8 GHz) and 40 dB in mmw frequencies (e.g., 28 GHz).

As expected, without RIS/network controlled repeater/cooperative BSs, if the BS switches to sub-6 GHz when blockage occurs, better throughput is observed compared to the cases with mmw communications, thanks to lower VPL at low frequencies (Fig. 2). However, compared to the cases with no RIS, the implementation of the RISs improves both the coverage and the throughput significantly. For instance, considering the parameter settings of Fig. 2 and the BS transmit power 30 dBm, RIS-assisted communication in mmw range increases the throughput, compared to no-RIS scenario operating in 2.8 GHz, by 118% and 150%, in the cases with two and three RISs, respectively. Moreover, as shown in Fig. 3 with an outage probability $10^{-2}$, bypassing dynamic blockages by two RISs leads to 30 dB gain of the transmit power.

Importantly, our proposed LSRPA scheme shows the same performance as in the genie-aided benchmark approach with perfect instantaneous CSIT of all paths, and no coverage/throughput loss is observed by RIS selection based on large-scale fading. This leads to considerably lower overhead, specially as the number of RISs increases, and reduces the channel aging effect. Interestingly, the performance degradation due to the implementation of the RIS instead of cooperative BSs is negligible. For instance, with the BS transmit power 30 dBm (resp. outage probability $10^{-2}$), only 18% throughput reduction (resp. 2 dB power increment) is observed, compared to the cases with cooperative BSs, when the network is equipped with two RISs (Figs. 2 and 3). Also, with three RISs the relative throughput loss, compared to the cases with additive BSs, reduces to only 6%. This is important because not only the additional BS installation leads to considerable cost/energy consumption increment, but it also is at the cost of backhauling and handover with possible delays/failures. Finally, as expected, the implementation of network controlled repeater leads to slightly higher throughput compared to RISs since, along with phase adaptation, network controlled repeater is capable of power amplification also. However, compared to RIS, network controlled repeater is a relatively more expensive node requiring dedicated power supply. In this way, the proposed LSRPA scheme can be considered as a cheap solution for high-rate uninterrupted IoV communications in highways/rural areas with low signaling overhead, especially when electricity connection is not available.

To demonstrate the efficiency of the LSRPA scheme, in Fig. 4 we present the UE throughput in an example scenario, with possible dynamic blockages. Moreover, Fig. 5 shows the BS’s and the RIS’s regions of responsibility, determined based on the large-scale fading, for different positions of the dynamic blocker. As shown, with high frequencies, dynamic blockage deteriorates the system performance significantly. However, with blockage pre-avoidance, either through RISs or
Throughput, bps

In general, mmw-based communication outperforms that in the sub-6 GHz with more bandwidth resources, if the blockage is avoided via RISs/cooperative BSs. This is not the case if the blockage is not bypassed. Finally, for a given number of antennas/transmit power at the cooperative BS, increasing the number of RIS elements may end up in better throughput, at the cost of CSIT acquisition overhead and RIS cost increment.

IV. TOWARDS RIS PRACTICALITY

Although the simulation results show great potentials for RIS-assisted communications, there are key issues to be solved before RISs can be used in practice. In the following, we elaborate on some key challenges.

A. Cost-efficiency Trade-off

One of the main motivations of using RIS, and not small access points such as relays, network controlled repeaters, and IABs, is the cost and energy reduction. With a cheap node, however, hardware imperfection may affect the reflection quality of the RISs. Particularly, it is likely that, in practice, RISs may provide an imperfect reflection because of, e.g., transceiver impairments and phase noise. To study the effect of hardware impairment, in Figs. 2, 3, and 6 we consider two different imperfection models:

• **Transceiver impairments.** The performance of the RIS-assisted system could be affected by a mismatch between the intended transmitted/received signal and the actual transmitted/received signal. Such a mismatch can be modeled as inherent hardware impairments caused by, e.g., non-linear amplifier and quantization error [12]. Specifically, the impairment at the RIS side can be modeled as uniformly distributed random variables, while at the transceiver side the additive distortion noise as well as the phase drift and the thermal noise are used to describe the hardware imperfection [12]. In this way, the ergodic capacity of the system can be bounded as a function of the transceiver proportionality coefficients that describe the severity of the distortion as well as the signal-to-noise ratio (SNR) [12, Theorem 1].

• **Phase noise.** Another hardware limitation is when the channel cause additional phase deviation and it is not estimated properly at the receiver side. The phase noise can also be caused by the discrete set of phases. Here, the phase noise can be modeled as a uniform distribution over certain region (determined by, e.g., estimation accuracy and quantization phases) which is symmetric around zero with mean zero [13].

As shown in Figs. 3 and 6, the effect of phase noise on the outage probability and the throughput is negligible, as long as the phase noise is not considerably high. However, the effect of phase noise increases slightly at mmw range (Fig. 6). Also, as illustrated in Fig. 2, the effect of transceiver impairment on the throughput is negligible at low SNRs. At moderate/high SNRs, however, which is the range of interest, transceiver impairment reduces the efficiency of the RISs significantly, where even higher throughput may be achieved by direct communication of the BS operating at sub-6GHz compared to mmw communications.
to the cases with RIS-assisted communication in mmw range (Fig. 2). Moreover, to reach the same performance as in the cases with cooperative BSs, significantly larger number of RIS elements are required, if realistic conditions with transceiver impairments are taken into account (Fig. 5). This, in turn, increases not only the implementation cost but also the RIS management overhead.

In this way, there is a cost-efficiency trade-off where with low cost the poor performance of the RIS may affect its efficiency while with an expensive RIS other alternative technologies such as IABs and network controlled repeaters may be better choices with higher capabilities. Thus, the practical implementation of the RIS still requires further justifications.

B. Standardization and Network-level Performance

RIS has not yet been considered by 3GPP in Release 17 and before. During the initial discussions on 3GPP Release 18, RIS-assisted communication was suggested by some companies as a possible technology to be considered in Release 18 study-item on network controlled repeaters, e.g., [14]. However, it was decided not to continue with it, and to leave it for possible use in beyond 5G.

Without standardization, the integration and utilization of RISs may be challenging, as it may affect the performance of the rest of the network. Importantly, RIS networks may suffer from an increased network interference, specially in the cases with fuzzy reflections of the RISs. Such an interference may possibly also affect the adjacent channels which is a potential show stopper for the RIS implementation, at least in present day RIS implementations. Furthermore, if RIS performance is not specified, it may still reflect the incoming signals in different directions that are not desired. For these reasons, there is a need for standardized mechanisms where, while the RIS-assisted communication improves the experienced QoS of the intended receiver, reliable network-level performance is guaranteed.

Along with cost-efficiency trade-off, standardization and interference management, there are still other issues to be investigated in RIS networks. For instance, although there are few practical evaluations, e.g., [15], multiple testbed evaluations are required to validate the efficiency of the RIS, in
competition to alternative technologies. Here, the practicality and the propagation model of the RIS still require tested evaluations specially in high frequencies and MIMO setups. Finally, the relative cost reduction of the RISs, compared to, e.g., network controlled repeaters and IABs, is not yet clear as a large part of, e.g., site rental and installation, costs still remain in RISs. This calls for realistic cost analysis of the RIS networks.

In summary, the selection of the best approach depends on different parameters such as backhaul availability, implementation cost, availability of electricity connection and the deployment. However, while more advanced nodes such as network controlled repeaters and IABs seem to be more appropriate candidates guaranteeing proper interference management/network-level performance, RIS may offer a low-power alternative with, e.g., off-grid solar cell deployment if electricity connection is not available. Here, RIS could provide fast deployment to improve the network coverage/reliability until/if electricity connection is provided.

V. CONCLUSIONS

We studied the potentials and challenges of RIS-assisted communication for blockage pre-avoidance in moving networks. As we showed, RIS pre-selection and blockage prediction gives the chance to robustify the network performance against dynamic blockages with an acceptable CSI acquisition overhead. However, there are still various issues such as hardware impairment, cost-efficiency trade-off, interference management, standardization and performance improvement, to be competitive with alternative technologies, which should be solved before RIS can be practically implemented in IoV networks.

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