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# High-Rate Uninterrupted Internet-of-Vehicle Communications in Highways: Dynamic Blockage Avoidance and CSIT Acquisition

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**Abstract**—In future wireless networks, one of the use-cases of interest is Internet-of-vehicles (IoV). Here, IoV refers to two different functionalities, namely, serving the in-vehicle users and supporting the connected-vehicle functionalities, where both can be well provided by the transceivers installed on top of vehicles. Such dual functionality of on-vehicle transceivers implies strict rate and reliability requirements, for which one may need to communicate at millimeter wave (mmW) frequencies. However, IoV communication at mmW requires up-to-date channel state information (CSI) and blockage avoidance. In this article, we incorporate the recently proposed concept of predictor antennas (PAs) into a *large-scale cooperative PA (LSCPA)* setup where both temporal blockages and CSI out-dating are avoided via base stations (BSs)/vehicles cooperation. Summarizing the ongoing standardization progress enabling IoV communications, we present the potentials and challenges of the LSCPA setup, and compare the effect of cooperative and non-cooperative schemes on the performance of IoV links. As we show, BSs cooperation and blockage/CSI prediction can boost the performance of IoV links remarkably.

## I. INTRODUCTION

Suppose that, sitting in an autonomous drive vehicle driving in a highway, you are watching Game of Thrones, and your smart phone gets disconnected. In ten years, this will bring huge dissatisfaction for the users, leading to poor rating for the network provider. Particularly, in the 6G era, users in their own cars expect the same quality-of-service (QoS) as they have at home. Thus, cellular networks will face with high data rate/reliability demands driven by in-vehicle users running, e.g., 4K/8K video streaming applications. This is a part of the Internet-of-Vehicle (IoV) concept, for which high-rate uninterrupted connections are required.

Such reliable *mobile* IoV links are used not only to serve in-vehicle users but also for connected-vehicle/autonomous drive use-cases relying on vehicle-to-infrastructure/network (V2I), in general V2X (X: everything), communications. Currently, connected automated drive is a large business market with more than \$130 billion revenue in 2019, and is expected to garner more than \$500 billion by 2026. Thanks to V2X communications, traffic information becomes more precise, improving the traffic efficiency/safety and reducing CO2 emissions. However, V2X links have strict requirements. For example, 99.99% reliability is required for network-assisted pedestrian protection, and considerably higher reliability is foreseen with Levels 4/5 of self-driving vehicles being commercially available by 2030 [1].

Along with connected-vehicle related communications, the antennas mounted on top of the vehicles can be utilized as intermediate moving relays (MRs) connecting the base stations (BSs) and the in-vehicle users. This is motivated by the fact that 1) compared to typical user equipments (UEs), such on-vehicle transceivers (OVTs) may be equipped with more antennas/capable of advanced signal processing techniques. Also, 2) compared to direct BS to in-vehicle links, the MR implementation eliminates the vehicle penetration loss, which is measured to be around 25 dB at 2.4 GHz [2] and even higher losses are foreseeable at higher frequencies. Such dual functionality of IoV transceivers, however, increases the rate/reliability requirements of the BS-OVT links even further.

To increase the data rate, different methods are considered, among which network densification and millimeter wave (mmW) communications are the dominant ones. Network densification refers to the deployment of multiple BSs of different types in an area. Particularly, it is expected that soon small cells will be densely deployed to assist the existing macro BSs. On the other hand, mmW transmission offers wide bands and simplifies multi-antenna communications. However, mmW transmission experiences poor propagation characteristics and has high free-space path loss. For these reasons, it is expected that mmW-enabled small cells will be deployed at low heights, e.g., on lamp post, with a short coverage range. With a low antenna height, however, the probability of blockage increases, which reduces the achievable rate of the mmW links significantly. Therefore, to guarantee uninterrupted high-rate communications, it is preferred to avoid blockage.

With stationary networks, a large part of static blockages are avoided via deployment optimization. Also, one can avoid (semi-)static blockages via resource association [3], cooperative (CP) transmission [4] or the incorporation of relays [5]/intelligent reflecting surfaces [6]. Alternatively, back-up non-line-of-sight (NLoS) links can be found during the initial beam training phase and, if a line-of-sight (LoS) link is blocked, the connection can switch to the back-up link(s) [7].

The problem, however, becomes more challenging in moving, e.g., V2I, networks with high-speed vehicles driving in highways. First, deployment optimization does not help in moving networks. Second, the back-up NLoS solution is not of interest because, 1) good reflectors (building, etc.) are rare in highways, and 2) compared to urban scenario with rich scattering, such back-up links sustain for a shorter period [7].

Third, considering low-height small cells in highways, the blockers are mainly buses and trucks passing by the cars. Thus, probabilistic blockage prediction or (machine learning-based) deployment learning methods may not cope well with the network dynamics at high speeds/frequencies. This is specially because not only the blockage results in excessive signal-to-interference-plus-noise ratio (SINR) degradation, but also the system performance is considerably affected by channel aging phenomena where with high speeds the channel state information at the transmitter (CSIT) soon becomes inaccurate.

In this article, we investigate different methods of dynamic blockage avoidance and CSIT prediction in IoV networks. We concentrate on a highway scenario where OVTs, either used for connected-vehicle applications or as an MR, receive high-rate uninterrupted streams transmitted by CP BSs. We incorporate the recently proposed predictor antenna (PA) concept [2], [8] into a large-scale cooperative PA (LSCPA) setup with CP communications among BSs, and utilize the information provided by different vehicles to avoid not only temporal blockages but also the CSIT out-dating. We compare the performance of various alternative technologies at different frequencies and levels of adaptivity/cooperation, and show that there is not a single method providing the best reliability/throughput. Instead, a combination of different methods gives the best performance. Finally, we extend the PA concept to the cases with multiple-input multiple-output (MIMO) communications, and study its performance with different levels of CSI. As we show, joint dynamic blockage and CSIT prediction improves the throughput and reliability of IoV links by orders of magnitude.

## II. MMW IOV COMMUNICATIONS IN HIGHWAYS

Initial intelligent transportation systems were based on dedicated short-range communication (DSRC) standards, e.g., IEEE 802.11p/DSRC, supporting data rate in the order of 10 Mbps. On the other hand, connected vehicles are currently equipped with hundreds of sensors where, for instance, light-detection-and-ranging (LiDAR) system alone may require data rates up to 100 Mbps for blind spot removal [9]. Obviously, DSRC-based systems are not enough for such applications. Also, although Long-Term Evolution-Advanced (LTE-A)-based solutions boost the rates to up to 100 Mbps [10], we still need higher rates. This is particularly because, with the IoV concept, the OVTs not only provide connected-vehicle communications but also work as MRs.

With this background and motivated by the 5G progress in mmW communications, multi-antenna mmW transmission is a powerful candidate for IoV providing massive bandwidth and high-gain beamforming (BF). MmW systems are typically considered in static networks, e.g., wireless backhaul [5]. With mobility, however, the availability of the mmW-based narrow BF systems is prone to different challenges including CSIT inaccuracy, beam misalignment and blockage. Particularly, with a blockage the path loss exponent increases from  $\sim 2.8$  in the cases with LoS connections to  $\sim 3.9$  in NLoS communication, and outdated CSIT/out-of-beam signal reception lead to significant SINR drop.

The key features of highway environments, however, help to solve the dynamic blockage/channel aging issues to some extent; In a highway, connected vehicles are likely to drive along the same set of lanes with controlled speeds. Here, an example is platooning setup, i.e., a group of vehicles traveling closely together with speed/direction controlled by the lead vehicle. Moreover, as illustrated in Fig. 1, in a highway, slow large vehicles (e.g., buses, trucks) travel typically in the outermost lanes, while high-speed vehicles drive along the innermost lanes. Then, temporal blockage occurs if a large vehicle drives between a user and its serving BS located on lamp posts along the highway. In this case, as we explain in the following, one can use channel prediction and CP communication/information exchange between the vehicles and BSs not only to avoid channel aging but also the temporal blockages.

Few works study mmW communication in highways. The interesting work of [9] develops theoretical models to describe the downlink (DL) V2I network in the presence of blockage and perfect CSIT. Also, [11] designs a model for mmW V2X networks with platooning. Finally, [12] develops a V2V CP network assuming perfect CSIT.

## III. LARGE-SCALE COOPERATIVE PREDICTOR ANTENNA

One option for CSIT prediction at high speeds is to use Kalman-filter based channel estimation (see [2] for a review of different small-scale CSIT prediction schemes at high speeds). Using the PA concept for small-scale CSIT acquisition in MR systems has been studied in, e.g., [2], [8]. Here, the idea is to deploy a PA at the front of a vehicle which is used to estimate the channel quality that is observed by receive antennas (RAs), aligned behind the PA, when they reach the same point as the PA (see Fig. 1). Specially, in the first time slot, the PA estimates the channel and sends CSI back to the BS. In the second time slot, while the BS needs time to transmit to the RA, the vehicle moves forward. The BS will have good estimate of the BS-RA link CSI, if the RA reaches the same point as the PA. As shown in [2], [8], the PA setup can boost the prediction horizon of the Kalman prediction-based schemes with 0.1-0.3 wavelengths prediction horizon to up to 3 wavelengths at 2.68 GHz and a velocity of 45-50 km/h.

The feasibility of the PA concept in a single vehicle has been verified by testbed experiments. For example, in 2014, Dresden, Germany, we showed that the cross-correlation between the PA and the RA maintains high (more than 97%) for up to three times the wavelength [13]. Also, in 2018, [8] performed channel measurements in Stuttgart, Germany, where a 2.18 GHz system was set up with 64 antennas at the BS and 2 monopole antennas at the vehicle. Assisted by the PA, such a MIMO DL system could reach the ideal BF gain even in NLoS scenarios. Interestingly, [8] showed that, assisted by the PA, applying zero-forcing transmission at the BS to two spatially multiplexed cars leads to 20 to 30 dB SINR gain.

The current PA setups are designed for 1) communication between a single vehicle and a BS, 2) non-cooperative (NCP) communications, and 3) predicting the small-scale fading. Here, we develop the LSCPA concept for both blockage and

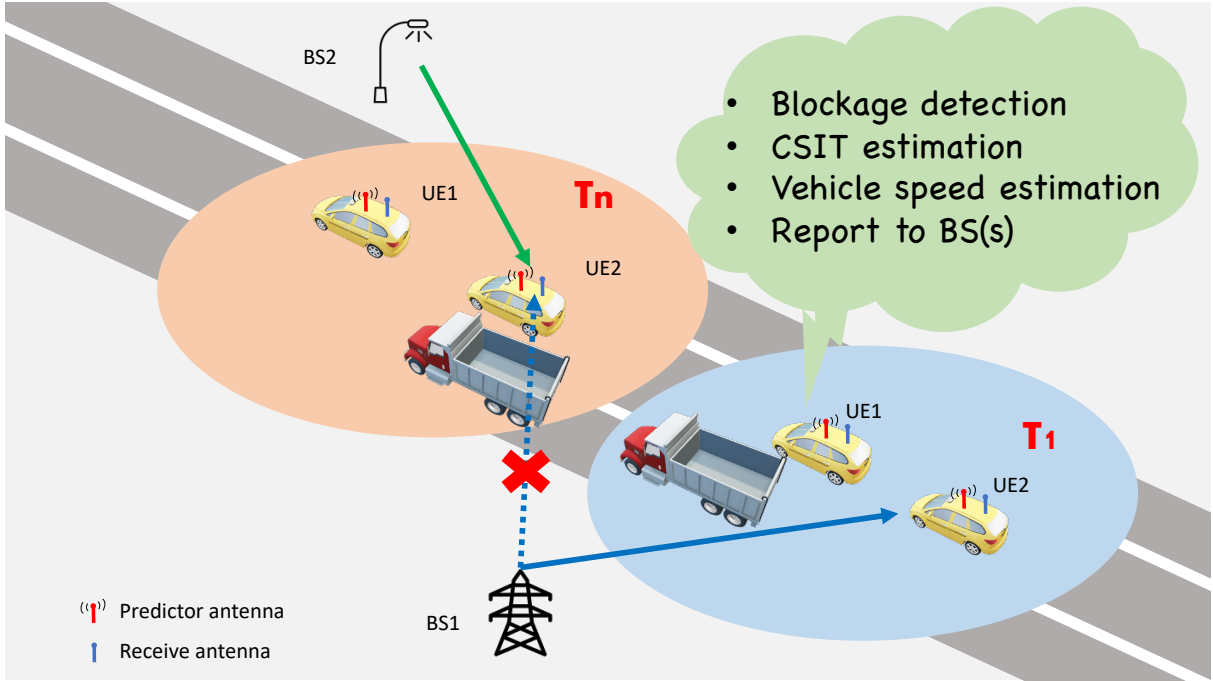


Fig. 1. The proposed LSCPA system. The information provided by the front vehicle (UE<sub>1</sub>) at time  $T_1$  is used to predict both blockage and small-scale fading for data transmission to the following vehicles (UE<sub>2</sub>) at time  $T_n$  via a, possibly different, BS.

channel aging avoidance in a CP fashion as described in the following (see Fig. 1).

With LSCPA, each vehicle is equipped with, possibly, one set of PA/RA antennas on top of the vehicle. Here, as illustrated in Fig. 1, while the PA of each vehicle can work as a small-scale predictor for its own RA, as in the existing PA setups [2], [8], the antennas on top of the front vehicle can enable reliable high-rate data transmission to the vehicles behind from different perspectives:

- If the front vehicle, i.e., UE<sub>1</sub> in Fig. 1, detects a blockage, e.g., by a truck passing by, it estimates the speed of the blocker and UE<sub>2</sub>. Then, UE<sub>1</sub> informs one (or, multiple) BS(s) about both the instantaneous CSIT of the location and the speed of the blocker and UE<sub>2</sub>. Knowing the speeds, the BS(s) predict the slots, e.g., Slot  $T_n$  in Fig. 1, when UE<sub>2</sub> will be blocked by the truck and, in those slots, we may switch to a different BS to serve UE<sub>2</sub> blockage-free.
- Without blockage, the instantaneous CSIT provided by the PA of the front vehicle can assist the data transmission to the second vehicle. Here, utilizing the CSIT of UE<sub>1</sub>, both antennas of UE<sub>2</sub> are used for data reception when UE<sub>2</sub> reaches the same position as where the antenna of UE<sub>1</sub> was sending pilots, and no extra pilot transmission is required for UE<sub>2</sub>. Alternatively, the PA of the second vehicle can also be used for CSIT acquisition and such an information is combined with that provided by the first vehicle to improve the CSIT accuracy. Here, one can consider different methods to combine the CSIT provided by different antennas.

Thus, the cooperation is on sharing the speed/location of the vehicles, the CSIT as well as handover between BSs.

In this way, not only the small-scale fading prediction can be improved, but also the temporal blockages are detected and avoided. The former can be utilized to compensate for the channel aging effect, while the latter enables dynamic blockage avoidance by enabling a vehicle to switch to another BS when predicted that a possible blockage may occur to the link from the vehicle to its currently allocated BS. Also, our setup simplifies hybrid automatic repeat request (HARQ)-based retransmissions and reduces the number of retransmissions/end-to-end (E2E) delay. This is intuitively because when blockage is avoided, with high probability, large signal-to-noise ratio (SNR) drops are not experienced. Thus, even if a signal is not correctly decoded, it needs a small boost in the SNR which can be provided by, e.g., a single retransmission. Alternatively, one can rely only on diversity and use Type I HARQ with low complexity. Finally, the blockage prediction may provide seamless handover without service interruption, because the BSs may have  $n \geq 1$  slots gap for handover.

One of the main challenges of PA system is spatial mismatch, i.e., when the RA does not reach the same position where the PA (either on the same or a different vehicle) estimated the channel several time slots before. Such spatial mismatch affects the accuracy of CSIT and, consequently, the system performance. Here, we concentrate on the highway scenario where dynamic blockage is probable. Then, LSCPA setup is applicable as long as the vehicles are on the same lane, in a car platooning setup or with known moving speeds. However, the same approach is applicable in, e.g., trains and trams. With trams/trains, the moving trajectory is more predictable, which improves the positioning accuracy and simplifies communication, specially at high frequencies. Moreover, beam width adaptation and the implementation of multiple antennas, as foreseen in, e.g., mobile integrated access and backhubs

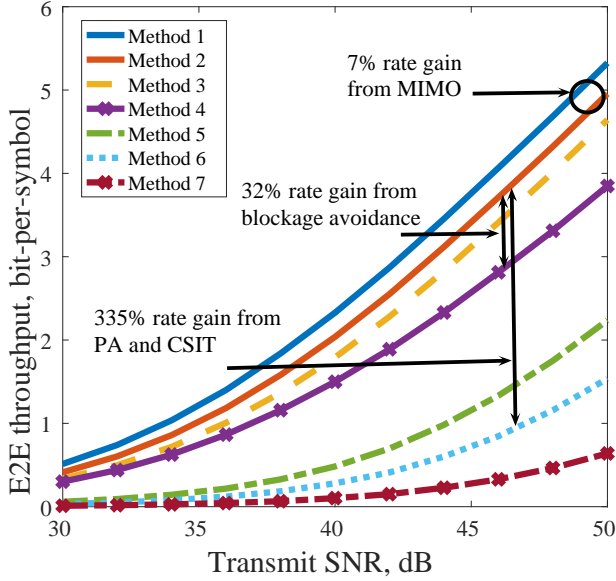


Fig. 2. E2E throughput of the second vehicle vs transmit SNR, 32 antennas at the BS, carrier frequency 28 GHz, speed 50 km/h, BS processing delay 5 ms, codeword length 8000 symbols, antenna separation 6.6 times the wavelength and 33% blockage probability.

(IABs) [5], reduce the sensitivity of the PA system to spatial mismatch at mmW band. Finally, note that communications between neighbouring mobile units, normally carried out via sidehaul links, is out of our scope, and we concentrate on V2I communications. This is because we concentrate on BS cooperation where how to acquire/share the CSIT and handover between BSs is determined in a central unit, e.g., a BS. However, the concept of the proposed scheme can be partly extended to V2V systems as well.

Considering the setup of Fig. 1 with two vehicles, two BSs and mmW spectrum, Figs. 2-3 show the E2E throughput and the outage probability of the second vehicle in the cases with 33% blockage probability. We present the results for both cases with and without spatial mismatch. In the cases with no spatial mismatch, one may consider an adaptive-delay transmission scheme where the transmission delay is dynamically adapted, as a function of the speed/antennas distance, such that the BS sends the data to the RA at exactly the same position as the PA performing CSIT acquisition. Here, CSIT is perfect, at the cost of extra transmission delay. Note that the adaptive-delay scheme is applicable only for a range of speeds limited by the BS's minimum required processing delay (see Fig. 5). With a non-adaptive delay method, on the other hand, one can always consider the BS's minimum processing delay. This setup, which is more suitable for slotted communications, is at the cost of possible spatial mismatch/CSIT inaccuracy which can be modeled as a function of the speed/spatial mismatch [2]. Also, to evaluate the effect of MIMO communications, considering 32 antennas at the BS, we present the results for both cases with (one RA, one PA) and (two RAs, two PAs) setups at the UEs.

We compare the performance of our proposed scheme, represented in Methods 1-3, with benchmark alternative techniques of Methods 4-7:

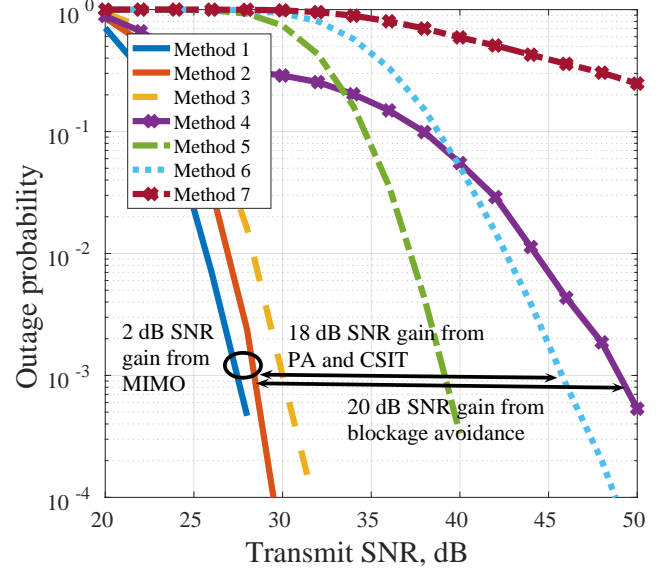


Fig. 3. Outage probability versus transmit SNR, 32 antennas at the BS, 33% blockage probability, carrier frequency 28 GHz, speed 50 km/h, BS processing delay 5 ms (affecting the cases with spatial mismatch), codeword length 8000 symbols, and antenna separation 6.6 times the wavelength. The outage threshold, i.e., the minimum data rate required by the UEs, is 0.07 bit-per-symbol.

- *Method 1: CP-MIMO-perfect CSIT.* With MIMO setup and maximum ratio transmission (MRT) BF, two PAs and two RAs, i.e., a total of four antennas, are deployed on top of each vehicle, and, using the information provided by the front vehicle, CP scheme is used to avoid blockages. Here, we consider perfect CSIT at the BSs, i.e., adaptive-delay scheme, at the cost of extra transmission delay. Finally, the blockage is avoided by switching to the closest non-blocked BS.
- *Method 2: CP-MISO-perfect CSIT.* Here, we consider the same setup as in Method 1, except that each vehicle is equipped with only two antennas; one RA and one PA, i.e., the BS-RA link is MISO (S: Single).
- *Method 3: CP-MISO-mismatched CSIT.* Considering CP BSs to avoid blockage, a non-adaptive delay method is considered, based on the BS minimum processing delay, at the cost of imperfect small-scale CSIT.
- *Method 4: NCP-MISO-perfect CSIT.* Here, we study the case with NCP transmission from a single BS at the cost of possible blockages. However, in each vehicle, small-scale fading is predicted using the self PA.
- *Method 5: CP-MIMO-no CSIT.* With a total of two antennas on top of each vehicle, we deploy CP setup to avoid blockage. However, no small-scale CSIT is considered and random BF is performed while both antennas at the vehicle are used for data reception. This is a benchmark showing the gain of small-scale CSIT acquisition.
- *Method 6: CP-MISO-no CSIT.* The setup is similar to Method 5 with only one antenna at the vehicle.
- *Method 7: NCP-MISO-no CSIT.* The worst-case benchmark with no CP framework/CSIT, and random BF.

Here, transmit SNR is defined as the transmit power of

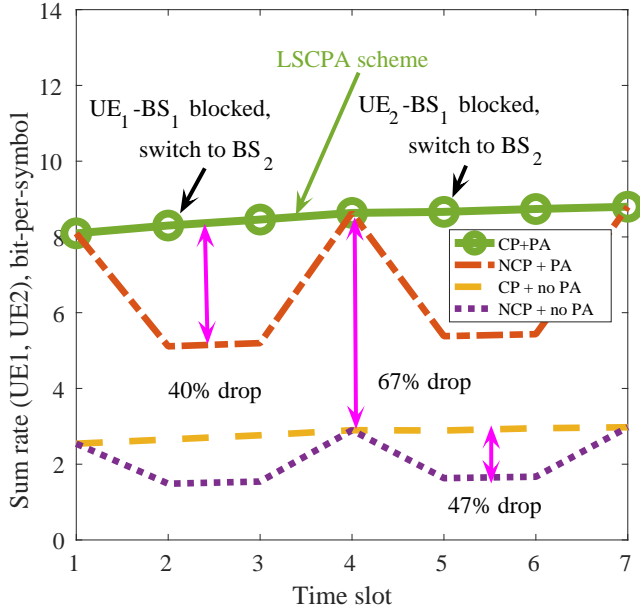


Fig. 4. An example of the sum throughput of UE<sub>1</sub> and UE<sub>2</sub> in different time slots, 32 antennas at the BS, carrier frequency 28 GHz, transmit SNR 50 dB, channel bandwidth 50 MHz with noise figure -174 dBm/Hz and antenna separation 6.6 times the wavelength.

the BS normalized with unit-variance noise, and the details of the parameter settings are given in the figure captions. E2E throughput is defined as the average number of correctly decoded information bits per the E2E delay. The E2E delay is given by the transmission delay plus the possible processing delay at the BS. The results are presented for spatially-correlated Rayleigh fading conditions using the Jake's correlation model. In Figs. 2-3, we study the case that, while the information provided by the front vehicle is used for blockage avoidance, the small-scale CSIT is obtained from the PA(s) in self vehicle. The potential of using the small-scale CSIT from the front vehicle is studied in Fig. 6.

According to Figs. 2-3, blockage predication and avoidance via BSs cooperation leads to considerable E2E throughput and outage probability improvement, at the cost of overhead for acquisition and exchange of information about the vehicles speed/CSI. For instance, considering the cases with single PA and RA on each vehicle and 46 dB transmit SNR, blockage avoidance results in 32% throughput increment, compared to the cases with NCP transmission (Fig. 2). Also, with an outage probability  $10^{-3}$  and the parameter settings of Fig. 3, the proposed LSCPA scheme gives 20 dB SNR gain, compared the NCP scheme experiencing possible blockages, even in the presence of perfect small-scale CSIT. Finally, using PA to predict small-scale CSIT could reach a 335% gain in E2E throughput at 46 dB transmit SNR as well as 18 dB SNR gain with an outage probability  $10^{-3}$ .

In summary, blockage (resp. small-scale CSIT) prediction is the main performance booster in terms of outage probability (resp. throughput). Hence, the proposed LSCPA method, with both blockage and CSIT prediction can be an enabler for *uninterrupted high-rate* IoV communications. Finally, although increasing the number of antennas at the vehicles

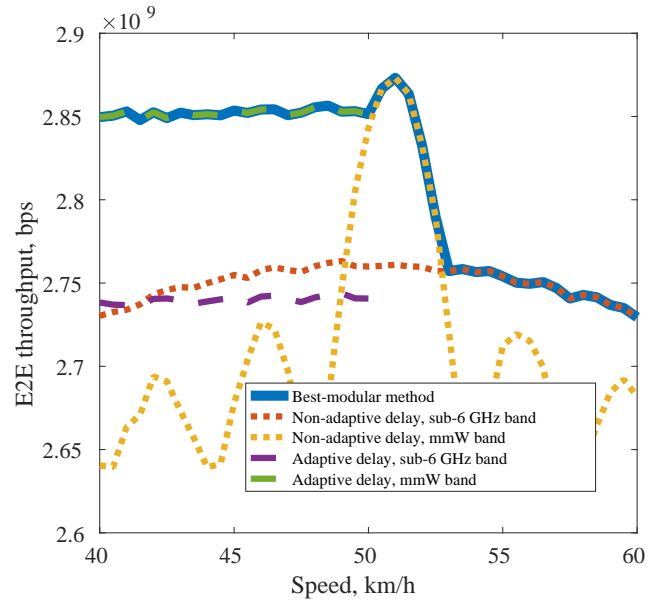


Fig. 5. E2E throughput in bit-per-second (bps) as a function of the speed. We consider both 2.8 and 28 GHz frequencies and 32 antennas at the BS. We set the transmit power to 50 dBm, noise spectrum density as -174 dBm/Hz, and channel bandwidth for mmW (resp. sub-6 GHz) as 80 (resp. 70) MHz, codeword length 10000 symbols, antenna separation for mmW and sub-6 GHz are 6.6 and 0.6 times the wavelength, respectively.

improves the achievable rate/reliability, for a broad range of parameter settings, the relative gain of MIMO communication is marginal in the cases with perfect CSIT. With no/partial CSIT, however, MIMO setup leads to considerable outage probability/throughput improvement (Figs. 2-3).

To demonstrate the LSCPA procedure in detail, considering an UE<sub>0</sub> – UE<sub>1</sub> – UE<sub>2</sub> car platooning setup, Fig. 4 presents the sum throughput of UE<sub>1</sub> and UE<sub>2</sub> following UE<sub>0</sub>, possibly used as a predictor, within seven sample time slots. We present the result for four cases, namely, 1) LSCPA using self PA for CSIT acquisition, 2) non-LSCPA using self PA for CSIT acquisition, 3) LSCPA but no PA CSIT and random BF, and 4) no blockage avoidance/CSIT. As seen in Fig. 4, the blockage deteriorates the system performance, during  $T_2 - T_3$  and  $T_5 - T_6$  where UE<sub>1</sub> and UE<sub>2</sub> are blocked by a truck, respectively, resulting in almost 40% throughput drop with small-scale CSIT prediction. For both cases with and without blockage detection, the lack of small-scale CSIT leads to significant throughput reduction, for instance, 67% throughput drop with blockage avoidance. However, deploying LSCPA the system experiences an *almost constant* QoS and the throughput is improved, compared to the considered benchmark schemes (the slight throughput increase in these sample slots is because of the UEs getting closer to the BSs).

The performance of the LSCPA method depends on the considered carrier frequency and delay adaptation capability. For this reason, Fig. 5 studies the effect of spatial mismatch, considering both 2.8 and 28 GHz without blockage. Here, the E2E throughput is demonstrated for both adaptive- and non-adaptive-delay methods.

Compared to 2.8 GHz, the throughput is more sensitive to

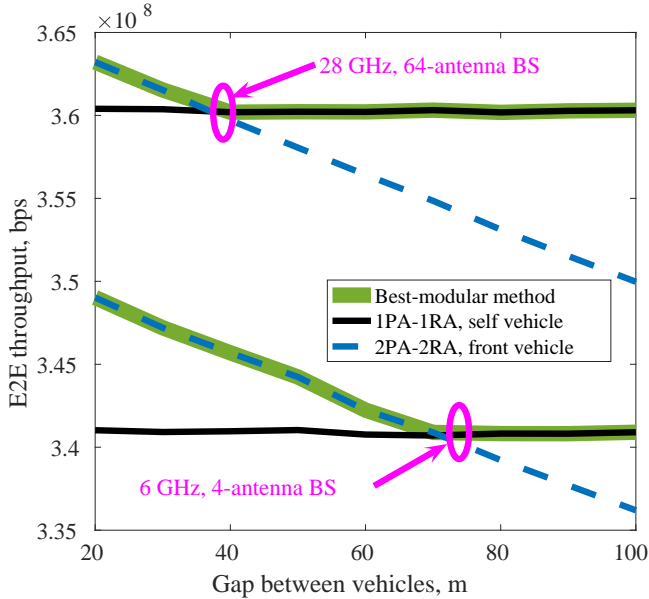


Fig. 6. E2E throughput as a function of the gap between the front and behind vehicles. Carrier frequencies are set to 6 and 28 GHz. Numbers of antennas at the BS are 64 for mmW and 4 for sub-6 GHz. The channel bandwidth is set to 10 MHz for both cases, vehicle speed 80 km/h, delay at the BS 5 ms, transmit power 40 dBm, and the codeword length 8000 symbols.

spatial mismatch and speed variation at 28 GHz (Fig. 5). On the other hand, adaptive-delay method shows robust performance in various carrier frequencies. However, the feasibility of adaptive-delay scheme is limited within a speed range, e.g., less than 50 km/h in Fig. 5, determined by the BS minimum required processing delay. Importantly, there is not a single method providing the maximum throughput; at low speeds, utilizing adaptive-delay method at mmW spectrum leads to maximum throughput. At moderate speeds, however, the highest throughput is achieved by exploiting spatial correlation and using non-adaptive-delay scheme at 28 GHz. Finally, at high speeds, where the sensitivity to spatial/BF mismatch increases, the maximum throughput is achieved via non-adaptive-delay method operating at 2.8 GHz.

Note that, although adaptive-delay method at gives the highest throughput for a range of speeds, from a network perspective, it may not be of interest as it may introduce unplanned interference to the network. Moreover, in practice cellular networks have a limited transmission time interval granularity which may limit the efficiency of the adaptive-delay scheme.

Whether to use the self or the front vehicle PA for small-scale prediction depends on, e.g., the carrier frequency, speed and number of antennas. Figure 6 elaborates on this point where, considering both 28 and 6 GHz bands and two antennas per vehicle, we study the throughput versus the gap between the vehicles for the following alternative schemes:

- One PA, one RA, self-vehicle PA: As in typical PA scheme [2], the front antenna is used only for channel estimation required for data transmission to the behind RA.
- Two RAs, front vehicle PA: Here, the BS obtains the CSIT from the front vehicle. Thus, using adaptive-delay

scheme, both antennas of behind vehicle are utilized for data reception while the transmission parameters are adapted based on CSIT achieved through front vehicle with a delay penalty.

As seen, at mmW band the highest throughput is achieved by utilizing the self-vehicle PA, unless for the cases with small gap between the vehicles where exploiting the front vehicle CSIT and using both antennas of the behind vehicle for data reception improves the throughput. At 6 GHz, however, exploiting the CSIT provided by the front vehicle is useful for a broad range of gaps between the vehicles. In summary, there is a trade-off between utilizing both antennas for data reception and the extra delay for data transmission due to utilizing the front vehicle CSIT, and the maximum throughput is achieved in a modular setup where the front vehicle (resp. the self-vehicle PA) CSIT is used in the cases with small (resp. large) gap between the vehicles. In practice, handling the spatial mismatch by utilizing the CSIT from the front vehicle requires good alignment along the moving direction. This can be achieved with cm-level by, for example, coordinated control over platooning setups, advanced location methods [14], or different coaches in trains/trams, whereas mmW-level localization are involved in ongoing research projects such as EU Hexa-X.

#### IV. STANDARDIZATION PROGRESS FOR IOV

Since Rel. 16, 3GPP is deeply involved in standardizations enabling IoV. To complement LTE V2X, 3GPP Rel. 16 developed a new V2X standard based on 5G new radio (NR) air interface. Here, different levels of automation levels ranging from no automation (level 0) to full automation (level 5) and various car platooning, advanced driving, extended sensors and remote driving use cases are defined (see [15] for details). Particularly, with advanced driving and extended sensor use-cases, the vehicles share the data obtained from their own sensors with the surrounding vehicles/infrastructure, to improve the perception of the environment beyond that obtained by vehicles' own sensors. Also, to better serve the mobile nodes, dual connection-based mobility management and UE-based handover are defined. These can be enablers for practical implementation of the LSCPA method.

From relaying perspective, 3GPP Rel. 16-17 have specified standardizations for IAB as the main relaying method in 5G NR [5]. Here, although mobile IAB were not considered, a large part of the specifications are compatible with mobility. More importantly, Rel. 18 IAB, to start in early 2022, will be fully dedicated to mobile IAB/vehicle-mounted relays. In that case, different issues such as movement of mobile IAB between different central units, dynamic adaptation of routing tables, interference management, etc., need to be handled. With both V2X and MR functionalities, the sensitivity of the mmW narrow BF to inaccurate CSIT/BF mismatch and blockage should be carefully taken care of, where, along with other methods, the LSCPA concept may be an attractive candidate.

## V. CONCLUSIONS

Aiming for uninterrupted IoV communications, we demonstrated the potentials of utilizing the front vehicles information for dynamic blockage and small-scale fading prediction in high-speed links. Introducing the ongoing standardization attempts enabling IoV communications, we verified the effect of MIMO transmission and different carrier frequencies on the network performance, where the best E2E throughput is obtained in a modular setup of different carrier frequencies/data transmission techniques, depending on the vehicles distances/speeds. Our simulations show that the proposed LSCPA concept is a potential solution to support future high-speed IoV links. However, there is still room for theoretical/testbed evaluations identifying the potentials and challenges of LSCPA.

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