Joint Vehicle-Beam Allocation for Reliability and Coverage in Vehicular Communication Systems

Akinsola Akinsanya, Manish Nair, Huiling Zhu and Jiangzhou Wang
School of Engineering and Digital Arts, University of Kent, Canterbury, CT2 7NT, United Kingdom.
Email: {asta2, mn353, h.zhu and j.z.wang}@kent.ac.uk

***Abstract*—In vehicular communication systems, maximizing the number of served vehicles while simultaneously guaranteeing reliable coverage at all the vehicles can be a challenging proposition. A switched-beam based infrastructure can provide better reliability as the signal-to-interference-plus-noise ratio (SINR) can be improved. However, a simple switched-beam based vehicle-to-infrastructure (V2I) system alone may not suffice for serving all the vehicles because (i) the number of vehicle is more than the number of beam, and (ii) a vehicle may be out of the coverage region of a beam. Therefore, introducing vehicle-to-vehicle (V2V) communication becomes crucial in extending the number of served vehicles. In this paper, a joint vehicle-beam allocation (VBA) and vehicular proximity (VP) algorithms for V2I and V2V, respectively are proposed to guarantee reliable coverage for vehicles. VBA is an SINR optimization algorithm, and VP is based on LTE Mode 4, a proximity based service for V2V communications. It is shown that setting a flexible SINR threshold helps in attaining a reliable beam coverage region in switched-beam based V2I communication. It is proven that the outage probability are also directly dependent on SINR thresholds. Lastly, the concept of utility ratio is also introduced as a metric for reliability. Simulation results show that joint V2I and V2V communication significantly improves the utility ratio.**

***Index Terms*—Millimeter-Wave, V2X, Beam Allocation, RRH, MIMO, Reliability.**

I. Introduction

Millimeter-wave (mm-Wave) multiple-input-multiple-output (MIMO) is a promising solution to offer significant reliable communication in Intelligent Transport System (ITS) [1]. Mm-Wave MIMO now plays a significant role in ITS providing new applications and services to vehicular users by means of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication [2]. Most authors have prioritized their focus, in vehicle-to-everything (V2X) communication research, mainly on maximizing system capacity and sum-rate [3], [4], [5]. However, achieveing reliable communication in V2X is very crucial, especially for critical applications such as delivery of safety messages. Authors in [3] assumed a perfect channel state information (CSI) of each vehicle in a mm-Wave analog beamforming system in order to satisfy quality of service (QoS) constraints. However, this assumption is too optimistic for moving vehicles that result in quasi-static or dynamic channels with imperfect CSI. Moreover, inter-beam interference was not considered. Authors in [4] proposed a beam-frequency algorithm to maximize the throughput by fixing the position of vehicles, which is also an idealistic premise. Additionally, [3] and [4] assume that the achieved SINR should be above a particular threshold. However, it is neither straightforward nor clear how to obtain these threshold SINR values from the requirements of V2I communications, which usually refer to transmission with a certain reliability and within a certain time period. In particular, 1600 byte packets have been considered to be received within 5ms and with a reliability of 99.999% to deliver traffic safety applications [5]. Switched-beam based system is a beamforming approach that features fixed number of beam pattern and simultaneously directed toward different pre-defined directions to serve one or more users within cell coverage and this necessitates the principle of line of sight (LOS) and/or non-LOS [6].

In this paper, we propose a directional beam allocation technique, which involves the joint application of multiple directional beams for V2I and LTE-V2V Mode 4 communications [7], which is a proximity-based service between two vehicles (wherein V2I beam coverage is not available), to improve outage and guarantee maximum network coverage. In LTE-V2V mode 4, vehicles autonomously select and manage resources without any infrastructure support. Importantly, it also reduces the processing burden on remote-radio heads (RRHs) [7], [8], [9], [10], [11], [12]. Our proposed solution features the use of dedicated RRH which can be standalone or located within an existing traffic infrastructure. We also consider unique properties of V2I, such as line-of-sight (LOS) channel with imperfect CSI [13], [14].

- We decomposed the joint resource allocation problem into two sub-problems: SINR optimization problem for V2I and proximity-based V2V optimization problem, to adaptively improve the outage probability and satisfy the QoS requirements of vehicles by taking into consideration the different SINR values and position uncertainties of the vehicles.
- The solution to the optimization problem is divided into two sub-algorithms: (i) vehicular-beam allocation (VBA) algorithm, which is an SINR optimization algorithm for V2I, and, (ii) vehicular-proximity (VP) algorithm based on LTE-V2V Mode 4 for V2V based on channel quality state information (QSI) to ensure reliability amongst all the vehicles within the coverage area.

II. System Model

As shown in Fig. 1, consider downlink transmission through a dedicated RRH with a road segment of length d_R. d_R represents the network coverage range for the vehicles. The RRH

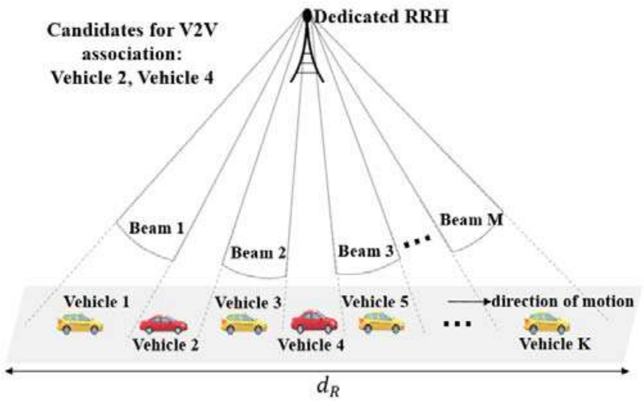

Fig. 1. System model for predefined vehicular users of vehicular broadcast communication scenario at an instance of time

employs a multi-user mm-Wave switched-beam directional antenna with linear array of equally spaced antenna elements. The RRH simultaneously forms M beams toward K dual-antenna aided vehicles. The dual-antenna at the vehicles is for the purpose of simultaneous V2I and V2V transmission at different frequencies. In this system, V2I transmission is carried out at f_1 and V2V at f_2. We adopt the position uncertainty model based on estimated and actual user positions based on the Manhattan mobility model in [15]. In a conventional switched-beam system, the number of users is generally more than the number of beams i.e. $K \geq M$, as such beams are allocated for transmission thereby resulting in a beam allocation problem. In this paper, we assume that only one beam can serve one vehicle. Vehicle-beam association is solved by the VBA algorithm (Section III-B). Since $K \geq M$, the vehicles not served by the RRH beams become candidates for V2V association, which is accomplished by the VP algorithm. We consider that the spatial locations of the vehicles are quasi-static i.e. the locations do not record a significant change within a frame, but dynamic over multiple frames.

A. V2I Communication

$\mathcal{M} = \{1, \cdots, M\}$ denote a set of RRH beams, formed by the Butler network at frequency f_1. Let $\mathcal{K} = \{1, \cdots, K\}$ denote the set of vehicles. The directivity $D_m(\theta_k)$ of the m-th beam with respect to an angle of departure (AoD) of θ_k to the k-th vehicle is given as

$$D_m(\theta_k) = \frac{2(AF_m(\theta_k))^2}{\int_0^\pi (AF_m(\psi))^2 \sin(\psi) d\psi}. \quad (1)$$

where $AF_m(\theta_k)$ is the array factor given by

$$AF_m(\theta_k) = \frac{\sin(0.5M\pi\cos\theta_k - \beta_m)}{0.5M\pi\cos\theta_k - \beta_m}, \quad (2)$$

$$\beta_m = \left(-\frac{(M+1)}{2} + n\right)\pi, m \in \{1, \cdots, M\}. \quad (3)$$

The received power, $P_{k,m}$, at k-th vehicle from the m-th beam, for the V2I line-of-sight (LOS) channel at f_1 is given as

$$P_{k,m} = \sum_{m=1}^{M} \phi_{k,m} \cdot p_m \cdot D_m(\theta_k) \cdot h_{k,m} \quad (4)$$

$h_{k,m}$ denotes the Rician channel gain between the m-th beam of the RRH to vehicle k. $\phi_{k,m} \in \{0, 1\}$ represents beam allocation indicator. $\phi_{k,m}$ = 1 if beam m is allocated to vehicle k; otherwise, $\phi_{k,m}$ = 0. Therefore, $\sum_{m=1}^{M} \phi_{k,m} \leq 1$. We adopt the close-in (CI) mm-Wave propagation model in [16], [17]. From (4), p_m is the transmit power allocated on beam m given by

$$p_m = \begin{cases} \frac{P_t}{\Sigma_{k=1}^{K}\Sigma_{m=1}^{M}\phi_{k,m}} & \text{if } \sum_{k=1}^{K} \phi_{k,m} = 1, \\ 0 & \text{if } \sum_{k=1}^{K} \phi_{k,m} = 0, \end{cases} \quad (5)$$

where P_t is the total RRH power. The received SINR is given by

$$\gamma_{k,m} = \frac{P_{k,m}}{\underbrace{\left(\sum_{\substack{i=1 \\ i \neq k}}^{K} \sum_{m=1}^{M-1} \phi_{i,m} \cdot p_m \cdot D_m(\theta_k) \cdot h_{k,m}\right)}_{\mathrm{I}_m} + \sigma_k^2} \quad (6)$$

I_m denotes the inter-beam interference. σ_k^2 is the additive white Gaussian noise (AWGN) power of the receiver.

B. V2V Communication

Let $\mathcal{K}_z = \{1, \cdots, k_z, \cdots, K_z\}$ be the set of vehicles associated with RRH beams. It is implied that $K_z \leq K$. Hence K_v denotes the (vehicle) candidates available for V2V pairing i.e. $(K - K_z)$. For any k_z, let $k_{z,j}$ denote the state $j \in \{1, 2\}$, where the state $j = 1 \Rightarrow k_{z,1}$ pairs the vehicle k_z to its nearest neighbour at the front and the state $j = 2 \Rightarrow k_{z,2}$ pairs the vehicle k_z to its nearest neighbour at the back. It is assumed that all the vehicles are moving in the same direction (Fig. 1). The candidates for pairing are selected from the K_v pool. The received SINR for $k_{z,j}$, i.e, k_z-th vehicle in state $j \in \{1, 2\}$ (paired to its neighbour at the front or back) is given by

$$\gamma_j = \frac{P_{k_{z,j}}^T h_{k_{z,j}}(t)}{\underbrace{\left(\sum_{q=1, q \neq k_z}^{K_z} P_{q,j}^T \cdot h_{k_{z,j}}(t)\right)}_{\mathrm{I}_{k_{z,j}}} + \sigma_{k_{z,j}}^2} \quad (8)$$

where $P_{k_{z,j}}^T$ is the transmit power of the k_z-th vehicle ($k_z \in \mathcal{K}_z$) which pairs with the vehicle $j \in \{1, 2\}$, and, $I_{k_{z,j}}$ is the interfering signal to the vehicle j paired to k_z from all other vehicles in the set $\mathcal{K}_z$. $h_{k_{z,j}}$ is the time varying channel impulse response $h_{k_{z,j}}$ between k_z and its pair j.

C. SINR-Aware Link Reliability Policy for V2V Association

In V2X communications, reliability is reflected by packet error rate (PER) which is related to the received SINR values. Therefore, in this paper, we use SINR-aware functions to represent reliability directly. The SINR-aware link reliability is proposed to enumerate a step-by-step procedure, with limited SINR awareness, that filters and determines the preferred values which in turn best fits to the objectives of the policy. This policy helps to meet the V2V communication reliability requirement, because the vehicles out of the V2I coverage range can be served through V2V Mode 4 proximity service. At each time frame, all beams are allocated to k_z vehicles, $k_z \in \mathcal{K}_z$. Each vehicle in the K_v pool computes the received SINR of its nearest neighbouring vehicle $k_z \in \mathcal{K}_z$ to establish V2V link communication.

D. Outage Probability

V2V pairing/association is initiated when a candidate vehicle is outside or in between the coverage areas of any of the individual RRH beams (K_v pool) as shown in Fig.1. The outage probability (OP) [18], [19], [20] defines the coverage area of every beam. OP is the probability that the output SINR falls below specified threshold SINR value γ_k.

III. SINR-Aware Optimization Algorithms

A. Problem Formulation

Our goal is to maximize the SINR and improve reliability by jointly considering VBA problem for V2I and proximity-based V2V pairing based on QSI to ensure reliability amongst all available vehicles within the coverage area. We formulate the optimization problem as a twin-timescale allocation problem. The VBA optimization problem for V2I is formulated as

$$\max_{\phi_{k,m}} \sum_{k=1}^{K} \sum_{m=1}^{M} \gamma_{k,m} \tag{10}$$

$$\text{C1:} \sum_{m=1}^{M} \phi_{k,m} \leq 1, \forall k \in \{1, 2, \cdots, K\} \tag{10a}$$

$$\text{C2:} \sum_{k=1}^{K} \phi_{k,m} \leq 1, \forall m \in \{1, 2, \cdots, M\} \tag{10b}$$

$$\text{C3:} \sum_{k=1}^{K} p_m \leq P_t, \forall m \in \{1, 2, \cdots, M\}, \tag{10c}$$

$$\text{C4:} \phi_{k,m} \in \{0, 1\}, \forall k \in \{1, 2, \cdots, K\}, \tag{10d}$$

$$\text{C5:} \forall k \in \{1, 2, \cdots, K\}, \forall m \in \{1, 2, \cdots, M\} \tag{10e}$$

Constraints (10a)-(10b) indicate that each beam can be used by at most one vehicle and only one vehicle can associate with at most one beam. Constraint (10c) indicates that the sum of power over all beams is less or equal the total RRH power allocated. Constraint (10d) specifies the decision variables of the formulated problem, which takes a value of 1 if beam m is allocated to at most one k_z vehicle and 0 otherwise. The optimization problem for proximity-based V2V pairing is formulated as

$$\max_{\phi_{k_v,z}} \sum_{k_v=1}^{K_v} \sum_{z=1}^{Z} \gamma_{k_v,z} \tag{11}$$

$$\text{C1:} \sum_{z=1}^{Z} \phi_{k_v,z} \leq 1, \forall k_v \in \{1, 2, \cdots, K_v\} \tag{11a}$$

$$\text{C2:} \sum_{k_v=1}^{K_v} \phi_{k_v,z} \leq 1, \forall z \in \{1, 2, \cdots, Z\} \tag{11b}$$

$$\text{C3:} \sum_{k_v=1}^{K_v} P_{k_v}^{T} \leq P^{\text{V2V}}, \forall k_v \in \{1, 2, \cdots, K_v\} \tag{11c}$$

$$\text{C4:} \phi_{k_v,z} \in \{0, 1\}, \forall k_v \in \{1, 2, \cdots, K_v\} \tag{11d}$$

$$\text{C5:} \forall k_v \in \{1, 2, \cdots, K_v\}, z \in \{1, 2, \cdots, Z\} \tag{11e}$$

where (11a) and (11b) follow the constraints that each k_z vehicle can associate with at most one user in (K_v) pool and each vehicle in (K_v) pool can pair with at most one k_z vehicle Constraint (11c) indicates that the sum of power per vehicle is less or equals the total transmit power of all the vehicles P^{V2V}. Constraint (11d) specifies the decision variables of the formulated problem, which takes a value of 1 if there exists a V2V communication to at most one k_v vehicle and 0 otherwise. The optimization problems (10)-(10e) and (11)-(11e) are solved by respectively applying vehicular-beam allocation (VBA) which is an SINR-aware optimization algorithm for V2I and vehicular proximity (VP) algorithm based on LTE-V2V Mode 4 for V2V.

B. Vehicular-Beam allocation (VBA) algorithm

The purpose of beam allocation is to guarantee a maximum communication coverage for most vehicles within the transmission region. Each vehicle at corresponding angular location computes the received SINR of M-switched beams and returns the information on maximum SINR with the corresponding index to the RRH. Beams are assigned to vehicles with largest SINR. The key aspect of our VBA algorithm is that, it allocates to all users located within the coverage of each beam at a time frame.

C. Vehicular Proximity (VP) algorithm

VP algorithm is developed to focus on proximity-based V2V pair problem in (11) based on the LTE-V2V Mode 4. Algorithm 2 describes the steps implemented for V2V association.

IV. Performance Analysis and Evaluation

This section evaluates the coverage and reliability performance of the joint application of VBA and VP for V2I and V2V respectively, using the MATLAB simulation platform. As shown in Fig. 1, a dedicated RRH with $M = 6$ directional beams and $K = 10$ dual-antenna aided vehicles are deployed for vehicular mobility in a single direction (direction of motion as shown in Fig. 1.). Vehicles travel along defined road segment length d_R with an average speed of 30km/h. To evaluate the performance of the proposed sub-algorithms, we consider that

Algorithm 1 VBA Algorithm

Input: $\mathcal{M} = \{1, \cdots, M\}$, $\mathcal{K} = \{1, \cdots, K\}$, $\forall k \in K$, $\forall m \in M$, $\phi_{k,m} \leq 1$
for $k = 1$ **to** K **do**
  for $m = 1$ **to** M **do**
    Compute the directivity of each beam at all vehicle locations
    $b_m = \max\limits_{\phi_{k,m}} \{D_m(\theta_{k,m})\}$
    Select vehicle k according to (10)
    $k = \underset{\phi_{k,m}}{\operatorname{argmax}} [\gamma_{k,m}]$
    Allocate V2I beam m to vehicle k
    $\phi_{k,m} = 1, \phi_{k^*,m} = 0 \ \forall k \neq k^*$
    Pair beam m to vehicle k with b_m
  end for
end for

Algorithm 2 VP Algorithm

Input: $\mathcal{K}_z = \{1, \cdots, K_z\}$, $\mathcal{Z} = \{1, \cdots, Z\}$, $\forall k \in K$, $\phi_{k,z,} \leq 1, \mathcal{K}_z = k, \tilde{\mathcal{K}} = \mathcal{K} \backslash_k$
for $k = 1$ **to** K **do**
  If $\phi_{k,m} = 0$ then
  compute $k_d = \underset{k_z \in \mathcal{K}}{\operatorname{argmin}} \{d_{k_z,k_v}\}$
  Update $\mathcal{K}_z = k^*$ and $\tilde{\mathcal{K}} = \mathcal{K} \backslash_k$
  End If
end for

the RRH is located at the centre of the coverage range, d_R, at a height of 75m from the road.

Fig. 2 shows the coverage range for $M = 6$ beams spread over angular locations of $10°$ to $50°$, which are represented in terms of the received SINR. With simple geometry, it can be derived that the RRH height of 75m approximately corresponds to a road length of $d_R = 54$m (for perspective, the length of a football field is 100m). In Fig. 2, six distinct coverage regions can be clearly observed, each corresponding to its respective RRH beam. Total RRH transmit power $P_m = 50$dBm (approximately 125Watts) is assumed to be equally allocated to all the beams. The directivity of each beam is set to 30dB (equations (1) and (2)). It can be seen in Fig. 2 that the received SINR for all the beams, and hence the beam coverage regions, are interleaved. The interleaving of coverage region builds up a guaranteed range of coverage, thus reliability of service and QoS, for all vehicles.

Fig. 3 shows the outage probability, with 95% confidence, for the respective beam coverage regions. QPSK modulation is applied to 2^8 bits. The received SINR threshold is taken as -7.5dB since it is approximately above the value of SINR$= -7.5$dB in Fig. 2 shows that the respective beam coverage regions can be clearly identified. Since the SINR are interleaved (Fig. 2), lowering the SINR threshold can minimize the outage probability. However, the trade-off is that it will be difficult to distinguish between the beam coverage regions, i.e. which coverage region belongs to which beam. At the set SINR

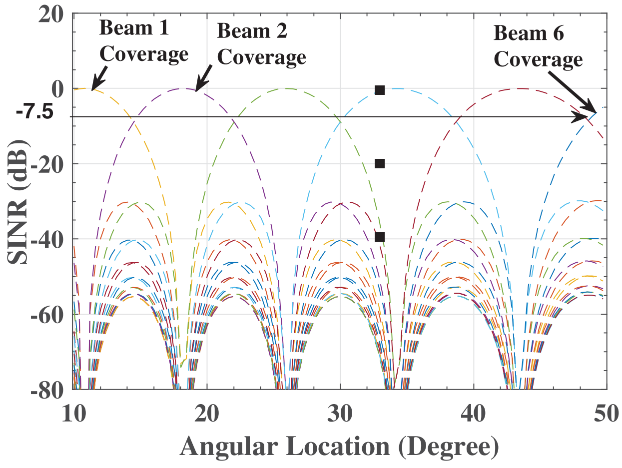

Fig. 2. Received SINR with VBA algorithm. $M = 6$.

threshold of -7.5dB, the probability of outage is moderately high in between the adjacent beam coverage regions, but each beam coverage region can be clearly identified. The setting of an SINR threshold can be flexible so as to ascertain a reliable and contiguous beam coverage region at any road segment (d_R) of interest.

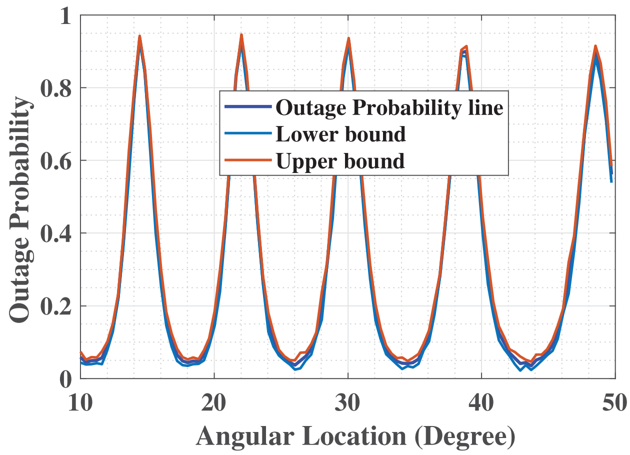

Fig. 3. Outage Probability within the beam coverage of the angular locations with VBA algorithm and 95% confidence interval lines . $M = 6$.

Some vehicles might be out of a specific coverage region of an RRH beam, since $K \geq M$. If a vehicle is not served for a long period, system reliability can be compromised, which is undesirable for reliability sensitive scenario. Therefore, reliability is again a crucial performance measure for vehicular communication systems. Utility ratio is also used to evaluate the reliability, which is defined as the ratio of the number of served vehicles to the total number of vehicles.

$$\text{Utility Ratio} = \frac{\sum_{k=1}^{K} \sum_{m=1}^{M} \phi_{k,m}}{K}. \tag{12}$$

Fig. 4 shows that the utility ratio and hence reliability can be significantly improved by the joint application of VBA and VP algorithms which facilitates simultaneous V2I and V2V communications. Moreover, as the number of vehicles increases, the utility ratio initially increases before saturating when the number of vehicles served equals the number of beams.

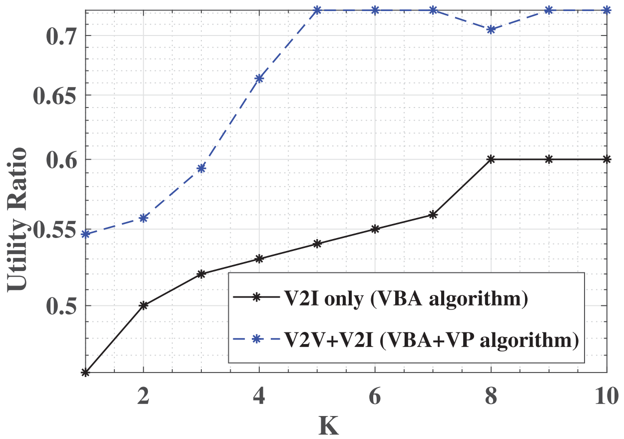

Fig. 4. Utility ratio comparison for V2V+V2I vs. V2I only. $M = 6.K = 10$

V. Conclusion

This paper has presented the first evaluation of the performance and operation of a vehicle-beam allocation technique, which accounts for application of multiple directional beams for V2I and LTE-V2V Mode 4 communication, a proximity-based service between two vehicles, for V2V. By applying both algorithms, our results showed that the outage for each vehicle is determined by the set SINR threshold. It was shown that the outage probabilities correspond directly with the beam coverage regions. Simulation results show that the utility ratio of the joint application of VBA and VP algorithms improves the average rates as well as the utility ratio and hence the reliability.

Acknowledgement

This work is currently supported by the European Union's Horizon 2020 Research and Innovation Programme, grant agreement No: 814956 (5G-DRIVE).

References

[1] J. Wang and H. Zhu, "Beam Allocation and Performance Evaluation in Switched-beam Based Massive MIMO Systems," in *2015 IEEE International Conference on Communications (ICC)*, June 2015, pp. 2387–2392.

[2] S. Pyun, W. Lee, and D. Cho, "Resource Allocation for Vehicle-to-Infrastructure Communication Using Directional Transmission," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 4, pp. 1183–1188, April 2016.

[3] H. Miao, M. Faerber, M. Fresia, and V. Frascolla, "Joint Beam-Frequency Multiuser Scheduling for Millimeter-Wave Downlink Multiplexing," in *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*, May 2016, pp. 1–5.

[4] L. Shen and K. Feng, "Joint Beam and Subband Resource Allocation with QoS Requirement for Millimeter Wave MIMO Systems," in *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, March 2017, pp. 1–6.

[5] M. Bennis, M. Debbah, and H. V. Poor, "Ultra-Reliable and Low-Latency Wireless Communication: Tail, Risk and Scale," 01 2018.

[6] F. Gross, *Smart Antennas for Wireless Communications*, McGraw-Hill, 2005.

[7] R. Molina-Masegosa and J. Gozalvez, "System Level Evaluation of LTE-V2V Mode 4 Communications and Its Distributed Scheduling," in *2017 IEEE 85th Vehicular Technology Conference (VTC Spring)*, June 2017, pp. 1–5.

[8] J. Wang, H. Zhu, and N. J. Gomes, "Distributed Antenna Systems for Mobile Communications in High Speed Trains," *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 4, pp. 675–683, May 2012.

[9] H. Zhu, "Performance Comparison Between Distributed Antenna and Microcellular Systems," *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 6, pp. 1151–1163, June 2011.

[10] H. Zhu and J. Wang, "Radio Resource Allocation in Multiuser Distributed Antenna Systems," *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 10, pp. 2058–2066, October 2013.

[11] H. Wei, D. Wang, H. Zhu, J. Wang, S. Sun, and X. You, "Mutual Coupling Calibration for Multiuser Massive MIMO Systems," *IEEE Transactions on Wireless Communications*, vol. 15, no. 1, pp. 606–619, Jan 2016.

[12] C. Pan, H. Zhu, N. J. Gomes, and J. Wang, "Joint Precoding and RRH Selection for User-Centric Green MIMO C-RAN," *IEEE Transactions on Wireless Communications*, vol. 16, no. 5, pp. 2891–2906, May 2017.

[13] A. Ghazal, C. Wang, B. Ai, D. Yuan, and H. Haas, "A Non-Stationary Wideband MIMO Channel Model for High-Mobility Intelligent Transportation Systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 2, pp. 885–897, April 2015.

[14] X. Cheng, C. Wang, B. Ai, and H. Aggoune, "Envelope Level Crossing Rate and Average Fade Duration of Non-Isotropic Vehicle-to-Vehicle Ricean Fading Channels," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 1, pp. 62–72, Feb 2014.

[15] R. Ismayilov, M. Kaneko, T. Hiraguri, and K. Nishimori, "Adaptive Beam-Frequency Allocation Algorithm with Position Uncertainty for Millimeter-Wave MIMO Systems," in *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)*, June 2018, pp. 1–5.

[16] W. Zhang, Y. Wei, S. Wu, W. Meng, and W. Xiang, "Joint Beam and Resource Allocation in 5G mm-Wave Small Cell Systems," *IEEE Transactions on Vehicular Technology*, pp. 1–1, 2019.

[17] L. Wang, B. Ai, D. He, K. Guan, J. Zhang, J. Kim, and Z. Zhong, "Vehicle-to-Infrastructure Channel Characterization in Urban Environment at 28 GHz," *China Communications*, vol. 16, no. 2, pp. 36–48, Feb 2019.

[18] H. Zhu and J. Wang, "Chunk-Based Resource Allocation in OFDMA Systems-Part I: Chunk Allocation," *IEEE Transactions on Communications*, vol. 57, no. 9, pp. 2734–2744, Sep. 2009.

[19] H. Zhu and J. Wang, "Chunk-Based Resource Allocation in OFDMA Systems-Part II: Joint Chunk, Power and Bit Allocation," *IEEE Transactions on Communications*, vol. 60, no. 2, pp. 499–509, February 2012.

[20] H. Zhu, "Radio Resource Allocation for OFDMA Systems in High Speed Environments," *IEEE Journal on Selected Areas in Communications*, vol. 30, no. 4, pp. 748–759, May 2012.