Location-Based Broad-Range Null-Steering in V2X Multiuser MIMO Transmission

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***Abstract*—This paper proposes an intensive null-steering around the target in angular domain to effectively suppress inter-user interference (IUI) leakage caused by channel varying environment such as vehicular multiuser spatial multiplexing. Multiuser MIMO can enhance spectral efficiency by multiplexing a number of user terminals in spatial domain. Suppose applying multiuser MIMO downlink in vehicle-to-everything (V2X) scenario, vehicles move at high speed which causes IUI. Null-space expansion has been conceived that can improve IUI suppression capability by steering nulls to the past and the present channel states on interfered users. Collective perception in intelligent transport systems (ITS) provides location information of vehicles every 100 ms. Exploiting this feature, this paper proposes angular-domain null-space expansion; broad-range null-steering (BRNS). Computer simulation verifies its effectiveness.**

I. INTRODUCTION

Coordination of connected autonomous vehicles (CAVs) through the integration of communications is gaining momentum as part of vehicle-to-everything (V2X) communication [1]. It will require large amounts of sensor information, such as LiDAR, to be distributed via wireless links. Supposing employing millimeter-wave massive array, we have proposed a fast beam tracking scheme by using the information held by coordination of CAVs [2]. Previous studies only focused on single-user beamforming. It is necessary to multiple vehicular communications for versatility. Assuming multi-user MIMO downlink, it is essential to eliminate inter-user interference (IUI) through a precoding. However, vehicles are moving at high speeds and thus steered nulls based on channel state information (CSI) are outdated. Null-space expansion (NSE) has been proposed as a technique to improve the performance of multiuser MIMO transmission in such a time-varying channel environment [3]. By utilizing past CSI estimates and extending the null space region, interference reduction can be achieved even for future time-varying channels. Suppose a line-of-sight (LoS) channel for moving vehicles, this paper newly proposes the angular-based null-space expansion; broad-range null-steering (BRNS). Its effectiveness is clarified in a typical street environment by computer simulation.

II. MULTIUSER MIMO

A. System Model

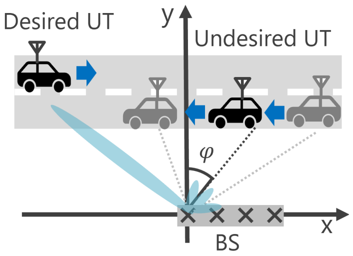

Fig. 1. System structure of multiuser MIMO.

Throughout the paper, matrices and vectors are written by boldfaced capital letters and lowercase letters. $(.)^T$ and $(.)^H$ indicates transpose and conjugate transpose, respectively. On the notation of time variables, let t_0, T, and τ denote CSI acquisition instant, its acquisition interval, and the elapsed time from t_0, respectively. We consider a multi-user MIMO downlink in V2X with time-varying channel as depicted in Fig. 1. The BS with N_t antennas simultaneously transmits N_u signal streams $\mathbf{s}(t_0+\tau) \in \mathbb{C}^{N_\mathrm{u}\times 1}$ to N_u moving user terminals (UTs) as vehicle with single antenna at the time instant $t_0+\tau$. The channel matrix $\mathbf{H} \in \mathbb{C}^{N_\mathrm{u}\times N_\mathrm{t}}$ is composed of individual channel vectors for UT $\mathbf{h}_k \in \mathbb{C}^{1\times N_\mathrm{t}}$. In LoS propagation environment, the channel coefficient between the k-th UT and te j-th antenna of BS, h_{kj}, is given by,

$$h_{kj} = \frac{g\lambda}{4\pi d_{kj}} \exp\left(-\mathrm{j}\frac{2\pi d_{kj}}{\lambda}\right), \tag{1}$$

where d_{kj} denotes the geometrical distance, and λ is the wavelength. g stands for the antenna gain. The precoding weight matrix $\mathbf{W}_\mathrm{t} \in \mathbb{C}^{N_\mathrm{t}\times N_\mathrm{u}}$ is written as

$$\mathbf{W}_\mathrm{t} = \left[\begin{array}{cccc} \mathbf{w}_1 & \mathbf{w}_2 & \cdots & \mathbf{w}_{N_\mathrm{u}} \end{array}\right], \tag{2}$$

where $\mathbf{w}_k \in \mathbb{C}^{N_\mathrm{t}\times 1}$ is the weight vectors for the k-th UT.

B. Null-Space Expansion

In previously proposed NSE [3], multiple nullification can be attained by exploiting past Q CSIs for interfering UTs. In general cases, the precoding weight vector $\mathbf{w}_k(t_0)$ is designed using latest estimated CSI $\mathbf{h}(t_0)$ as

$$\mathbf{h}_i(t_0)\mathbf{w}_k(t_0) \neq 0, \ \text{for} \ \ i = k. \tag{3}$$

$$\mathbf{h}_i(t_0)\mathbf{w}_k(t_0) = 0, \ \text{for} \ \ i \neq k. \tag{4}$$

where $i, k(=1\cdots N_u)$ are identifier of UT. On the other hand, NSE performs null-steering not only to the latest CSI but also past $Q-1$ CSIs, therefore it follows

$$\mathbf{h}_i(t_0 - qT)\mathbf{w}_k^{\mathrm{nse}}(t_0) = 0, \ \text{for} \ \ i \neq k, \ q = 0, \cdots, Q-1. \tag{5}$$

TABLE I
Simulation Parameters.

Parameters	Value
Frequency	28 GHz
Number of BS / UT Antennas	16 / 1
BS/ UT antenna gain	8/0 dBi
BS transmission power	40 dBm
Feeder loss	3dB
Number of UTs	2
UT speed	60 km/h
Channel Model	LoS, Free space propagation
Symbol duration	17.84 μs
Channel estimation interval	100 ms (5600 symbols) [4]

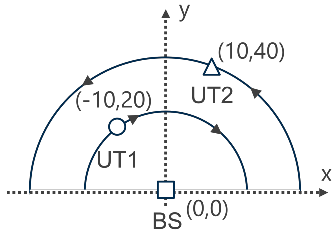

Fig. 2. Simulation environment.

III. Proposal: Broad-Range Null-Steering (BRNS)

BRNS steers additonal nulls to each UT based on angles of departure (AoDs). When the azimuth and zenith angle are defined in Fig. 1, the AoD-based estimated channel $\tilde{h}_{\phi_q j}$ can be expressed as follows.

$$\tilde{h}_{\theta_q \phi_q j} = \exp\left\{ \mathrm{j}\frac{2\pi l}{\lambda}(m_t - 1)\cos\phi \right\}, \tag{6}$$

where l denotes BS antenna element spacing. m_t represents the indices of linear array antenna. With the estimated channel vector $\tilde{\mathbf{h}}_{\phi_q} = \left[\tilde{h}_{\phi_q 1}\ \tilde{h}_{\phi_q 2}\ \cdots\ \tilde{h}_{\phi_q N_t}\right]$, precoding weight vector design for BRNS follows

$$\mathbf{h}_i(t_0)\mathbf{w}_k^{\mathrm{brns}}(t_0) = 0 \quad, i \neq k, \tag{7}$$

$$\tilde{\mathbf{h}}_{\phi_q}\mathbf{w}_k^{\mathrm{brns}}(t_0) = 0 \quad \text{for } q = 1, \cdots, Q-1. \tag{8}$$

Compared with the conventional NSE, BRNS can simply realize null-steering to the present, past and future channel states. In this paper, AoD information ϕ are assumed to be derived by location information on collective perception message (CPM) provided by CAVs in 100 ms intervals [4]. Further, future AoDs are also assumed to be perfectly predictable. The simulation part examines the following BRNS variants.

1) BRNS #1 : Past 2 AoDs with the present CSI.
2) BRNS #2 : Predicted 1 AoD with the present CSI.

IV. Computer Simulation

Simulation parameters are summarized in Table I. We assume the BS is equipped with linear array in two-dimensional space as shown in Fig. 2. Figs. 3 and 4 show the beam pattern of precoding weights and the time variability of SINR. From Fig. 3, NSE and BRNS#1, performing null-steering to the past channel states, can produce deeper and wider null-region than that of the simple Zero-Forcing (ZF) in CSI interval. As for BRNS#2, which conducts nulling to predicted AoD, provides further enhanced null-region wider than other schemes. As a result, BRNS#2 can keep highest SINR as verified in Fig. 4.

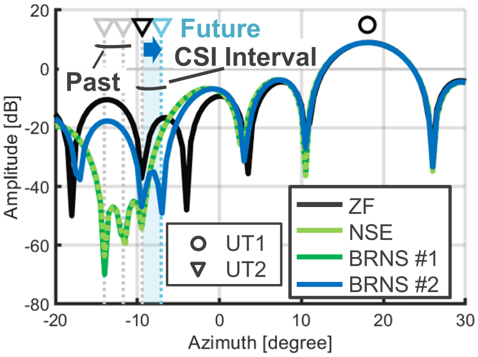

Fig. 3. Beam pattern.

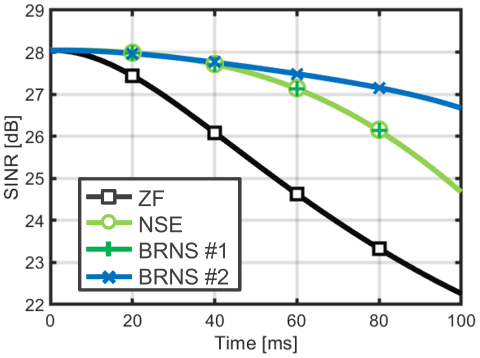

Fig. 4. SINR transition.

V. Conclusion

This paper proposed an angular-based broad-range null steering scheme and demonstrated its effectiveness through computer simulation. Future work verifies the effectiveness of the proposed scheme in more realistic environment with planar array and general road environment.

Acknowledgments

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