Twofold Channel Estimation for B5G MIMO Systems

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Abstract

Recently, increasing the demand of low-cost multiple-input and multiple-output (MIMO) systems for the next generation cellular systems. Therefore, we propose a twofold beamspace (TB) MIMO channel to enable a multiple frequency band (eg. millimeter wave and a tera-hertz band) for beyond fifth-generation (B5G) systems. A conventional beamspace MIMO system leads a single-fold beamspace (SB) channel including a unique frequency band, which does not satisfy the demand of B5G channel quality. In addition, we consider a double lens antenna array system to utilize a multiple analog beamformer in the B5G transceiver. The effectiveness of the proposed TB channel outperforms the SB channel and is verified in terms of normalized mean-square-error through computer simulation.

I. Introduction

A high quality of multiple-input and multiple-output (MIMO) channel is an important issue for the beyond fifth-generation (B5G) systems. Although, communication devices leading high frequencies are investigated widely in [1-3], this paper uses both millimeter wave (IEEE 802.11ad) and tera-hertz (IEEE 802.15.3) frequency band in the same channel environment. Here, we revise the earlier beampace MIMO channel model in [4-5] and propose a twofold channel model to achieve a satisfactory normalized mean-square-error (NMSE) performance.

A twofold channel demonstrates a double lens antenna array system with a parameter $c \in \{0,1\}$. The parameter c leads as an ON/OFF switch in the double lens antenna array system. It should be observed that the key point of this paper is to combine a double-standard frequency band that choose a reliable band by each user and mitigate the error performance issues. Through computer simulation, we compare the nobility of the proposed twofold channel over the single-fold channel, in terms of the NMSE.

II. System Model

Consider a single-cell massive MIMO uplink system using N_t transmitting antennas at the base station (BS). The BS equipped with N_{RF} radio frequency (RF) chains, which simultaneously serve K single-antenna users and satisfy $N_t \gg K$ and $K \le N_{RF} \le N_t$ in [1-3]. The system model of the twofold beamspace MIMO is shown in Fig. 1. Now, we adopt a twofold massive MIMO uplink channel $\mathbf{h}_h = \left[\mathbf{h}_{mmW,k}^H \quad \mathbf{h}_{tz,k}^H\right]^H \in \mathbb{C}^{N_t \times 1}$ between the twofold BS antennas and the k-th user where $\frac{N_t}{2} \times 1$ spatial millimeter wave (mmWave) channel $\mathbf{h}_{mmW,k}$ is given by

$$\mathbf{h}_{mmW,k} = \sqrt{\frac{N_t}{2L}} \sum_{l=1}^{L_k} \alpha_{l,k} \mathrm{a}(\phi_{l,k}^{mmW}), \quad (1)$$

and $\frac{N_t}{2} \times 1$ spatial terahertz wave (THz) channel $\mathbf{h}_{tz,k}$ is given by

$$\mathbf{h}_{tz,k} = \sqrt{\frac{N_t}{2L}} \sum_{l=1}^{L_k} \alpha_{l,k} \mathrm{a}(\phi_{l,k}^{tz}) \quad (2)$$

L_k is the number of dominant channel paths, $\alpha_{l,k}$ is the complex gain, the spatial direction $\phi_{l,k}^{mmW} = \frac{f_c^{mmW}}{c} d^{mmW} \sin\theta_l^{mmW}$ and $\phi_{l,k}^{tz} = \frac{f_c^{tz}}{c} d^{tz} \sin\theta_l^{tz}$, where f_c^{mmW} is the carrier frequency for mmWave MIMO and f_c^{tz} is the carrier frequency for terahertz MIMO, c is the light velocity, θ_l^{mmW} and θ_l^{tz} is the physical direction for mmWave and terahertz channel, antenna spacing, $d^{mmW} = \lambda^{mmW}/2$ and $d^{tz} = \lambda^{tz}/2$, and the wavelength, $\lambda^{mmW} = c/f_c^{mmW}$ and $\lambda^{tz} = c/f_c^{tz}$, respectively. The received signal y_k at the k-th subcarrier can be modeled as

$$\mathrm{y}_k = \mathbf{F}_h^H \mathbf{h}_h s_k + \mathrm{n}_k \quad (3)$$

where $\mathbf{F}_h = \left[\mathrm{c}\mathbf{F}_g^H \quad (1-\mathrm{c})\mathbf{F}_d^H\right]^H$ is an $N_t \times \frac{N_t}{2}$ twofold RF precoder, $\mathbf{F}_g$ is an $\frac{N_t}{2} \times \frac{N_t}{2}$ Golden-Hadamard based radio frequency (RF) precoding, $\mathbf{F}_d$ is an $\frac{N_t}{2} \times \frac{N_t}{2}$ discrete Fourier transform based RF precoding, s_k is a transmitted signal and $\mathbf{n}_n \sim \mathcal{CN}\left(0, \sigma^2 \mathrm{I}_{N_t}\right)$ of size $N_t \times 1$ is the noise vector with σ^2 representing the noise power.

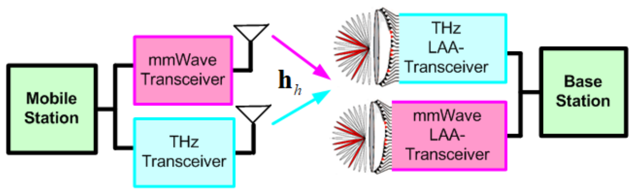

Fig.1 Architecture of the uplink twofold beamspace MIMO channel.

III. Channel Estimation and Performance Analysis

During the signal transmission, the BS employ a combiner to combine the receive uplink signal. Hence, the channel estimation error vector $\mathbf{e} = \tilde{\mathbf{h}}_h - \hat{\tilde{\mathbf{h}}}_h$ where $\tilde{\mathbf{h}}_h = \mathbf{F}_h^H \mathbf{h}_h$ is a twofold beamspace channel, $\hat{\tilde{\mathbf{h}}}_h = \mathbf{W}\mathbf{F}_h^H \mathbf{h}_h$ is the estimated twofold beamspace channel, $\mathbf{W} = \left[\mathbf{W}_g \quad \mathbf{W}_d\right]$ is $K \times N_t$ combiner, $\mathbf{W}_g$ is an Golden-Hadamard based radio frequency (RF) precoding, and $\mathbf{W}_d$ is an discrete Fourier transform based combiner. We now use the normalized mean square error to quantify the estimated channel accuracy for every user, which is modeled by

$$NMSE = E\left\{\frac{\|\mathbf{e}\|_2^2}{\left\|\tilde{\mathbf{h}}_h\right\|_2^2}\right\}. \quad (4)$$

In computer simulation, we consider twofold beamspace channel where the base station (BS) equips a lens antenna array with $N_t = 256$ antennas and $K = 16$ single antenna users. The number of RF chains $N_{RF} = K$ and $L = 3$ for both mmWave and THz channel. We also consider $f_c^{mmW} = 60$ GHz, $\lambda^{mmW} = 5$ mm; $d^{mmW} = \lambda^{mmW} / 2$, $f_c^{tz} = .1$ THz , $\lambda^{tz} = 3$ mm; and $d^{tz} = \lambda^{tz} / 2$, respectively. The channels are azimuth angle of arrivals (AoAs) or angle of departures (AoDs) are considered to be uniformly distributed in $[0, 2\pi]$ and the elevation AoAs/AoDs are uniformly distributed $[-\pi / 2, \pi / 2]$.

Fig.2 illustrates the NMSE for both the proposed twofold and the conventional single fold channel. We observe that the error performance of almost 30% increased than the single fold channel estimation scheme in [5-6].

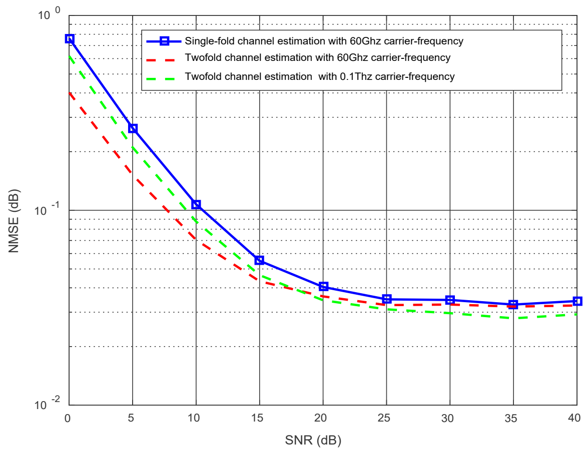

Fig.2 NMSE performance comparison among single and two-fold channel estimation with orthogonal matching algorithm.

III. Conclusion

In this paper, we investigated a twofold beamspace (TB) channel model to enable multiple frequency bands in the same channel environment and increase the channel quality. Simulation result confirms that the proposed TB channel significantly outperforms the conventional SB channel, in terms of channel accuracy. This work can be extended further to apply more scenarios in the sixth-generation wireless communications.

ACKNOWLEDGMENT

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