The Impact of Channel Aging in Full-Duplex Massive MIMO-Enabled UAVs

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Abstract

This paper studies a full-duplex (FD) massive multiple-input multiple-output (mMIMO) system consisting of a base station (BS) communicating with several mobile unmanned aerial vehicles (UAVs). FD mMIMO antennas are deployed at both the BS and UAVs. Due to the mobility of the UAVs, the channels between the BS and UAVs are fast varying leading to a phenomenon termed as channel aging. The impact of channel aging on the spectral efficiency (SE) is studied in this paper. It is shown that it has a negative impact on the SE. Also, the proposed system deploys low-resolution ADCs at the BS and the UAVs. Therefore, the benefit of using massive antennas is also analyzed with regards to the impact of quantization noise (QN).

Ⅰ. Introduction

Full-duplex massive MIMO systems serve as an SE enhancement technique in current communication systems. This system is however affected by self-interference (SI) due to the simultaneous transmission and reception on the same time-frequency resources [1]. Also, considering mobile users in this architecture introduces a phenomenon called channel aging. In [2], a rate splitting multiple access (RSMA)-enabled mMIMO system is studied. It is realized that channel aging outperforms spatial division multiple access (SDMA) when the channel ages faster. This paper focuses on the downlink (DL) performance of a FD mMIMO system consisting of a FD mMIMO BS sending data to FD mMIMO UAVs. Due to the mobility of the UAVs, the impact of channel aging is studied. Also, low resolution ADCs are deployed both at the BS and UAVs hence the impact of the resulting QN is analyzed.

Ⅱ. Method

The system considers a FD BS deploying W_{tx} massive transmit antennas and W_{rx} receive antennas equal in number to the UAVs. The k-th UAV deploys Z_{tx} massive transmit antennas and a single receive antenna. The BS sends data signals to U UAVs in the DL. Due to the UAV mobility, the channel estimate acquired in the pilot training phase changes when data transmission starts hence the onset of channel aging. It should be noted that the data transmission phase is assumed to undergo block fading. The channel model employed here is Rician fading. To consider the impact of channel aging, the aged DL channel is modeled with respect to its previous state at a time instant δ as follows :

$$\mathbf{c}_k[n] = \mu_k[\delta - n]\mathbf{c}_k[\delta] + \bar{\mu}_k[\delta - n](\tilde{\mathbf{c}}_{L,k} + \mathbf{a}_{u,k}[n]), \qquad (1)$$

where $\bar{\mu}_k = \sqrt{1-\mu_k^2[n]}$, $\mathbf{a}_{u,k}[n] \sim \mathbb{CN}(0, V_{u,k})$. $\tilde{\mathbf{c}}_{\mathbf{L},\mathbf{k}} = \mathbf{c}_{L,k}\sqrt{K_{u,k}(K_{u,k}+1)^{-1}}$. $a_{u,k}[n]$ is called the innovation component and the temporal correlation coefficient, $\mu_k[n] = J_0(2\pi f_{d,k} T_s(n))$ [3]. $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind, T_s is the sample time, and $f_{d,k} = v_k f_c / c$ is the Doppler shift with v_k being the k-th UAV velocity. $V_{u,k} = \varrho_k \tilde{K}_{u,k}$, where ϱ_k is the pathloss component and $\tilde{K}_{u,k} = (K_{u,k}+1)^{-1}$ with $K_{u,k}$ being the Rician K-factor.

The received signal at the k-th UAV at the n-th time instant is given as:

$$y_{qu,k} = \underbrace{\epsilon\sqrt{p_w}\mathbf{c}_k[n]^H \mathbf{g}_{w,k}[n]s_k[n]}_{\text{Desired signal}} + \underbrace{\epsilon\sqrt{p_w}\sum_{j=1,\, j\neq k}^{U} \mathbf{c}_k[n]^H(\mathbf{g}_{w,j}[n]s_j[n])}_{\text{Multi-user interference}}$$

$$+\underbrace{\epsilon\sqrt{p_u}\mathbf{t}_{u,k}\mathbf{g}_{u,k}[n]x_k[n]}_{\text{Self-Interference}} + \underbrace{\epsilon\sqrt{p_u}\sum_{j=1,\, j\neq k}^{U}\mathbf{t}_{c,kj}\mathbf{g}_{u,j}[n]x_j[n]}_{\text{UAV-to-UAV interference}} + \underbrace{\epsilon\mathbf{v}_k[n]}_{\text{Noise}} + \underbrace{\mathbf{v}_{q,k}}_{\text{Quantization noise}},$$

(2)

where $s_k[n] \sim \mathbb{CN}(0,1)$, $x_k[n] \sim \mathbb{CN}(0,1)$ are the signals from the BS and k-th UAV, respectively. p_w and p_u are the BS and k-th UAV transmit powers, respectively. ϵ is the ADC bit-resolution at the k-th UAV. $\mathbf{g}_{w,k}[n] = \varphi_{w,k}\hat{\mathbf{c}}_k[\delta]$ and $\mathbf{g}_{u,k}[n] = \varphi_{u,k}\hat{\mathbf{h}}_k[\delta]$ are maximum ratio transmission (MRT) precoders at the BS and k-th UAV, respectively. MRT is employed due to its simplicity and decentralized nature. $\mathbf{t}_{u,k} \sim \mathbb{CN}(0, \zeta_{u,k}^2)$ and $\mathbf{t}_{c,kj} \sim \mathbb{CN}(0, \zeta_{c,kj}^2)$. $\zeta_{u,k}^2$ and

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Due to space constraints, the channel estimation is omitted.
This can however be obtained from [2].

$\zeta^2_{c,kj}$ are the covariances of the SI at the k-th UAV and UAV-to-UAV interference, respectively. $\varphi_{w,k} = U / \mathrm{tr}(\mathbb{E}\{\hat{\mathbf{c}}_k[\delta]\hat{\mathbf{c}}_k^H[\delta]\})$ and $\varphi_{u,k} = 1 / \mathrm{tr}(\mathbb{E}\{\hat{\mathbf{h}}_k[\delta]\hat{\mathbf{h}}_k^H[\delta]\})$ are power normalization factors. The DL sum SE expression is given as:

$$R_{u,k} = \frac{1}{\tau_c}\sum_{n=\delta}^{\tau_c}\log_2\left(1+\frac{\mathbb{E}[\mathbb{D}_{u,k}]}{\mathbb{E}[\mathbb{I}_{u,k}]+\mathbb{E}[\mathbb{Q}_{u,k}]}\right), \qquad (3)$$

where τ_c is the total coherence period. $\mathbb{D}_{u,k}$ is the variance of the desired signal term; $\mathbb{I}_{u,k}$ is the variance of the sum of the interference terms plus noise; $\mathbb{Q}_{u,k}$ is the variance of the quantization noise term.

Fig. 1 shows a plot of DL SE against transmit BS antennas. The plot configuration is set for varying ADC-resolution bits. The first deduction that is realized is the increasing SE as W_{tx} increases. It can also be seen that the SE improves with increasing bit resolution. This is due to the consequent decrease in the quantization noise. However, it can be deduced that increasing transmit antennas mitigates the impact of quantization noise. For example, at perfect quantization for $W_{tx} = 50$, an SE rate of 9.7 bps/Hz is obtained. This SE rate can be obtained for a 4-bit resolution when $W_{tx} = 60$.

In Fig. 2, a plot of SE vs Doppler shift is shown. This configuration compares our FD system with the conventional HD model. The HD system is obtained by doubling the powers of the FD system and setting SI and UAV-to-UAV interference to 0. Also, the rate expression is halved. This plot analyzes the impact of channel aging on the FD mMIMO UAV-enabled system. It is realized that an increase in Doppler shift with respect to increasing UAV velocity results in a decreasing SE. This is due to the resulting deterioration of the quality of the channel state information due to the increase in the varying nature of the channels.

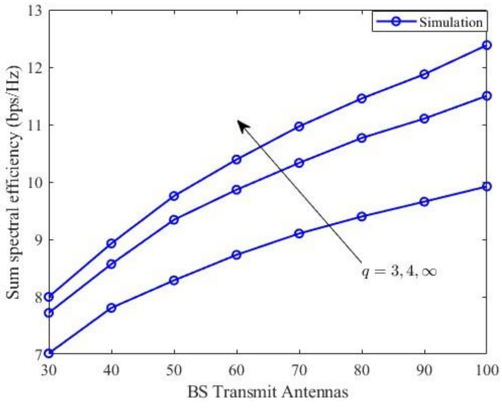

Fig. 1. DL SE vs Transmit Antennas ($p_w = 60$ dB, $p_u = 15$ dB, $U = 4$, $f_d T_s = 0.002$, $K = -10$ dB)

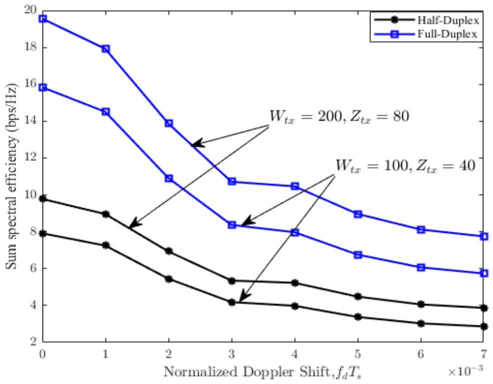

Fig. 2. DL SE vs Normalized Doppler Shift ($p_w = 60$ dB, $p_u = 15$ dB, $U = 10$, $K = -10$ dB)

Ⅲ. Conclusion

We have studied the impact of channel aging in a FD mMIMO UAV-enabled communication system deploying low-resolution ADCs. From the analysis it is realized that increasing transmit antennas compensates for the SE loss due to quantization noise. This helps to reduce the power consumption of the system. Also, due to the mobility of the UAVs, channel aging is present in the system. Our results show that increasing mobility leads to a decreasing SE. This occurs due to the decline in the quality of the CSI as the varying nature of the channels increases.

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