Imperfections to be Considered in mmWave Systems for Hybrid Processing

Imperfeições a serem consideradas em sistemas mmWave para processamento híbrido

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ABSTRACT
This paper describes a methodology to generate mmWave scenarios, where both imperfect channel estimation and noised phase shifters are considered. This methodology is greatly useful to evaluate hybrid precoder performance. Numerical results evidence that the number of antennas required to obtain a workable performance in mmWave systems with no ideal assumptions can be huge, whereas in mmWave systems with perfect conditions only a few dozens are needed. Furthermore, there are mmWave systems on ideal cases with a comparable performance of other systems on no ideal cases.

Keywords: Hybrid precoding, mmWave systems, channel estimation errors, 5G.

ABSTRACT
Este artigo descreve uma metodologia para gerar cenários de onda mm, onde tanto a estimativa de canal imperfeito quanto os deslocadores de fase com ruído são considerados. Esta metodologia é muito útil para avaliar o desempenho do pré-codificador híbrido. Resultados numéricos evidenciam que o número de antenas necessárias para obter um desempenho viável em sistemas mmWave sem suposições ideais pode ser enorme, enquanto em sistemas mmWave com condições perfeitas apenas algumas dezenas são necessárias. Além disso, existem sistemas mmWave em casos ideais com um desempenho comparável a outros sistemas em casos não ideais.
**1 INTRODUCTION**

Millimeter wave (mmWave) systems have attracted the attention for the last years due to the increase of the data rates and its extremely wide bandwidths available spectrum. To mitigate the undesired channel effects (e.g.: path loss) at mmWave frequency, a large number of antennas is required. Although large antenna arrays can occupy very small area in mmWave systems, digital beamforming techniques require one radio frequency (RF) chain for each antenna element. Thus, the number of antennas is very large, increasing the cost and power consumptions.

In order to surpass these drawbacks, hybrid processing alternative designs with lower number of RF chains than antenna elements have received significant attention. This technique enables spatial multiplexing transmission by using a reduced number of RF chains. The precoder/combiner is divided between the analog and digital domains. In the analog domain, only signal changes in phase can be performed, while in the digital domain both amplitude and phase changes are available. A large number of hybrid processing designs have been proposed with different approaches.

Adaptive hybrid beamforming (HB) techniques have been shown to achieve viable performance with a few dozen antenna elements, however, these techniques typically require full channel side information (CSI). To decrease CSI requirements, codebook-based hybrid beamforming has been proposed. However, the number of antenna elements required by these fixed techniques is larger. Many of the hybrid techniques proposed in the literature consider ideal assumptions for their design. This fact has aroused criticism about the applicability of hybrid beamforming in real scenarios, because the required number of antennas can be much larger than that reported.

This paper details a baseline to evaluate hybrid beamforming under no ideal assumptions for downlink mmWave massive MU-MIMO mmWave systems. Extensive simulation results in terms of sum-rate and bit error rate (BER) evidence that the performance degradation of the considered hybrid precoders caused by the no ideal assumptions (i.e., the imperfect channel estimation and noised phase-shifters) only can be mitigated by increasing the number of antennas. We observe that, even considering the signal-to-noise-ratio (SNR) as infinite, the performance loss caused by the no ideal assumptions is not compensated. This finding highlights two important aspects: the need
for more realistic models, and the real number of antenna elements needed to have a workable performance can be huge.

The rest of this paper is organized as follows: the scenario of simulation is present in Section II. Section III presents the numerical results obtained by both adaptive and codebook-based hybrid precoder. In Section IV, some conclusions wrap up this paper.

2 SIMULATIONS SCENARIO

Aiming to capture a simulated scenario closest to the real one, we considered imperfect channel estimation using the methodology proposed in [1] and setting the error channel estimation according to the techniques presented in [2]. In addition, to consider the side effects by the hardware imperfections of the phase-shifters, we adopt the methodology described in [3], where the phase-shifter response is modeled as

$$p = \alpha e^{j(\delta + \theta_d)}$$

where $\alpha \sim \mathcal{N}(1, \sigma^2_{\alpha})$, $\delta \sim \mathcal{N}(0, \sigma^2_{\delta})$ and $\theta_d$ represents the desired direction of the analog combiner/precoder. To find realistic values for this model, $\sigma^2_{\alpha}$ and $\sigma^2_{\delta}$ are obtained as in [4], which belongs a commercial phase-shifter for mmWave frequencies.

The channel estimation error related to the user $k$, $H_{ek}$, is modeled following a Gauss-Markov formulation as

$$H_{ek} = \tau H_k + \sqrt{1 - \tau^2} E_k$$

where each entry of the matrix $E_k$ follows a $\mathcal{CN}(0, 1)$. Moreover, the scalar parameter $\tau \in [0, 1]$ is used to indicate the quality of the channel estimation, where $\tau = 1$ corresponds to perfect channel estimation whereas $\tau = 0$ corresponds to only random channel $E_k$ [1].

We consider downlink massive MU-MIMO mmWave systems under the following conditions: (i) ideal assumptions i.e., perfect channel estimation, perfect phase shifters and SNR = 6 dB; (ii) no ideal assumptions i.e., imperfect channel estimation and noised phase shifters, and infinite SNR; and (iii) no ideal assumptions and SNR = 6 dB. Additionally, we consider the adaptive hybrid precoders proposed in [5] and [6], whereas the used codebook-based hybrid precoder is described in [7]. On this paper, we will call it as HB MMSE, HB MMSE SVD (Singular Value Decomposition) and HB MMSE OMP (Orthogonal Matching Pursuit), respectively.
Furthermore, the base station (BS) has a variable number of antenna elements, $N_t$ and sends $N_s = 2$ information streams to $K = 8$ users equipped with $N_r = 4$ antennas.

3 SIMULATIONS RESULTS

The simulated results are presented on Figures 1 and 2. Comparing no ideal assumptions curves to ideal assumptions curves for BER, we see that the performance decreases with influence of imperfect CSI and noised phase-shifters, especially for HB MMSE and HB MMSE OMP-based. For HB MMSE OMP-based, this is more relevant, as increasing SNR to infinite caused almost no effect on BER.

Figure 1: BER results. Consider a system using QPSK with 8 users equipped with 4 antennas and receiving 2 data streams. Furthermore, $\tau = 0.92$, $\sigma_\alpha^2 = 0.08$, and $\sigma_\delta^2 = 0.1$.

Moreover, even for ideal case, BER for HB MMSE OMP-based is considerably high and many antennas on BS are necessary to make BER as low as $10^{-3}$. Therefore, for no ideal cases, it might be necessary to use much more antennas on BS than is commonly used on the literature. For HB MMSE SVD, in contrast, considering SNR as infinite makes performance close to the ideal case.
Checking the results for achievable sum-rate, we see that HB MMSE OMP-based has the worst performance. However, the increase on SNR improves considerably the value of achievable sum-rate when compared to BER case. Additionally, although BER for HB MMSE in ideal case is the best among all the other curves, this case for achievable sum-rate is not true. Even though it has the best performance, it is only slightly better than HB MMSE SVD for ideal case and for HB MMSE and HB MMSE SVD. It means that not always minimizing the BER implies maximizing the sum-rate.

Figure 2: Achievable sum-rate. Consider a system using QPSK with 8 users equipped with 4 antennas and receiving 2 data streams. Furthermore, $\tau = 0.92$, $\sigma^2_d = 0.08$, and $\sigma^2_\delta = 0.1$.

4 CONCLUSIONS

In conclusion, HB MMSE had a good performance for BER and sum-rate on ideal case. However, simulation results have shown that HB MMSE SVD was more robust to imperfect CSI and phase-shifters noise for BER performance. Moreover, we concluded that HB MMSE OMP-based even with ideal assumptions is worse when compared to the adaptive hybrid precoders analyzed. Finally, depending on the mmWave system used (notably for HB MMSE OMP with no ideal assumptions), the number of antennas on BS can be huge, and currently impractical, to obtain a workable performance.
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