



Conference Article

Hybrid Beamforming for Multi User Massive MIMO Systems

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Abstract

The increasing demand in wireless communications for enhanced spectral efficiency (SE) and throughput makes massive multiple input multiple output (MIMO) a great choice for meeting those demands by using a vast set of antennas. Despite the advantages of massive MIMO, to implement such systems comes with a huge price tag and consumes a lot of power. Hybrid beamforming (HBF) architecture has drawn considerable attention in the past few years, by significantly decreasing the amount of employed radio frequency (RF) chains and combining high dimensional analog beamforming (ABF) using phase shifters (PS) together with low dimensional digital beamforming (DBF). However, because of the extreme energy consumption and hardware complexity, traditional precoding designs are difficult to implement. In this paper, two HBF techniques are proposed to address the above issue. (i) low complexity precoding known as phased zero forcing (PZF) precoding, which controls phase only in the RF domain (ii) singular value decomposition (SVD) based optimal unconstrained precoding, that can be implemented on inexpensive RF components.

Keywords: Hybrid beamforming, massive MIMO, multi-user.



1. Introduction

In wireless communications, one of the essential technologies to meet the ever growing demand of fifth generation (5G) is considered to be massive MIMO technology. The ability to enhance SE as well as throughput makes this technology a key for developing wireless communication standards [1],[2]. Massive MIMO uses significant number, up to thousands of antennas at each of the receiver side as well as the transmitter side, taking full advantage of traditional MIMO [3], however, as the amount of antenna components grows, digital beamforming which is known to give all antenna elements a dedicated RF chain is not cheap to implement because of the power consumption, high price, and computational complexity [4].

To approach this issue, in past few years hybrid beamforming (HBF) has received a lot of attention by improving energy efficiency as well as the implementing cost for massive MIMO systems. HBF combines high dimensional analog beamforming (ABF) using phase shifters (PS) together with low dimensional digital baseband while using much fewer RF chains to lower the associated high price and the energy consumption of the traditional fully digital processing [5].

In massive MIMO scheme, the mmWave system generally employs a reduced amount of RF chains rather than a large amount of transmit antennas [6]. In order to enhance the HBF design, it is essential to implement baseband precoding on the transmission by employing smaller quantity of RF chains, then decoding of the baseband follows in order to produce a cost-effective in HBF. In addition, using phase shifters, ABF could be employed to attain higher data rate in the RF domain [7].

Some difficulties have developed as a result of optimizing throughputs under HBF limitations while solving the ideal operating patterns of both RF and baseband precoding [8]. There are two possible ways to manage this issue. One option is to create the RF and baseband precoder jointly. Second alternative is a two-stage strategy in which the RF precoder is tuned first, and then the baseband precoder is developed to improve performance of the system even further [9]. For HBF to achieve fully digital performance, the joint strategy is commonly applied to develop HBF to target system performance, since the fully digital approach for an individual user case is known.

For mmWave communications, a matching pursuit technique can partition full digital processing into distinct analog and digital processing, allowing the channel sparsity to be thoroughly explored [10].

In multi user MIMO schemes, the joint scheme technique is also utilized to resemble full-digital linear computing. For HBF, the two-stage technique is typically utilized to tackle



capacity from a different point of view [11]. This technique is commonly applied in the design of HBF for multi user communications.

Furthermore, two architectures that are frequently employed in HBF structures are fully connected and sub-connected [12]. In hybrid precoding techniques, fully connected structure is commonly implemented. Each RF chain in this structure is linked to the entire antennas through PS. Because the amount of PS rises exponentially to the amount of antennas, the energy consumption along with hardware efficiency are both substantial for hybrid precoding schemes. To tackle such issues, sub-connected structure attracted a lot of attention on RF chain and antenna mapping approaches, which could drastically minimize the number of PSs [13]. The authors in [14], proposed spatially sparse precoding employing the basis pursuit principle and compare it to the unconstrained optimal precoding.

In this paper, we propose two HBF structures and then compare the performance of each method. The first hybrid technique has a low-complexity which achieves the performance of full complexity ZF by using a scheme known as phased zero forcing (PZF) hybrid precoding, which reduces the computational complexity by manipulating phase only in the Frequency range and subsequently conducts low dimensional ZF baseband precoding depending on the effectiveness of the channel. In the RF chain, the PZF system applies phase-only management by separating parts of the accumulated DL channels from base-station towards various clients. PZF precoding aims to synchronize the phases of channel components in order to acquire the extensive SE given by large transceivers in massive MIMO networks. The performance of this precoding is comparable to full complexity ZF precoding performance. The second one has the optimal unconstrained precoding that can be implemented on limited RF components. As input, the algorithm uses an unconstrained optimal precoder and simulates to a group of linear beamforming vertices capable of being implemented at RF. This precoder limits the performance of the hybrid precoding system which allows the digital baseband precoder to contain inputs of flexible phase and amplitude, enhancing efficiency while boosting feedback overhead. The issue of maximizing achievable SE may be approached by reducing the Euclidean norm of the gap between the SVD-based unconstrained optimal precoding and the general HBF.

2. Materials and Methods

Figure 1. illustrates the considered multi user massive MIMO downlink (DL) channel in which the base station (BS) has N_{BS} transmit antennas sending K data streams. This string constraint limits the highest amount of transmissions sent is K also for smooth single

stream transmission, we consider to program precisely single K antenna users. $\mathbf{F}_B \in \mathbb{C}^{k \times k}$ denotes digital baseband precoding matrix, while $\mathbf{F}_{RF} \in \mathbb{C}^{K \times N_{BS}}$ denotes analog RF precoding matrix [15].

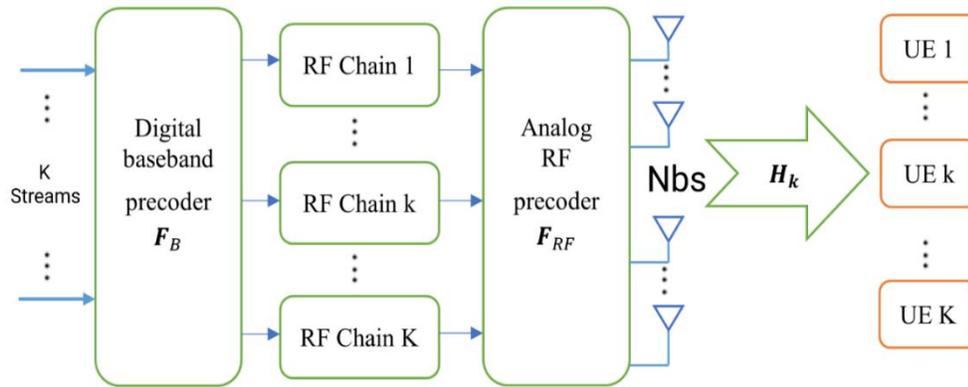


Figure 1. Typical massive MIMO multi user system.

\mathbf{F}_{RF} precoder is fixed to meet $|\mathbf{F}_{RF}(i, j)| = 1/\sqrt{N_{BS}}$, since phase alteration in the \mathbf{F}_{RF} precoder can only be made with adjustable combiners as well as PSs, where $|\mathbf{F}_{RF}(i, j)|$ implies the magnitude of the $(i, j)^{th}$ component of \mathbf{F}_{RF} . Moreover, \mathbf{F}_B is normalized such $\|\mathbf{F}_{RF}\mathbf{F}_B\|_F^2 = K$, to meet the power restriction. The transmitted signal is.

$$\mathbf{x} = \mathbf{F}_{RF}\mathbf{F}_B\mathbf{s}, \quad (1)$$

where the symbol vector for K users is denoted by $\mathbf{s} \in \mathbb{C}^K$ and has $E\{\mathbf{s}\mathbf{s}^H\} = \frac{\rho}{K} \mathbf{I}_K$, ρ here denotes the transmitted power at the BS and \mathbf{I}_K is K by K identity matrix [16]. At k^{th} user \mathbf{y}_k , the signal is received and could be presented as

$$\mathbf{y}_k = \mathbf{H}_k\mathbf{F}_{RF}\mathbf{F}_B\mathbf{s} + \mathbf{n}_k \quad (2)$$

where $\mathbf{H}_k = [h_1, \dots, h_k]^H$ denotes the DL channel from BS to the k^{th} user, $\mathbf{n}_k \in \mathbb{C}^{K \times 1}$ denotes Gaussian noise satisfying $\mathbf{n} \sim \mathcal{CN}(0, \delta^2 \mathbf{I}_k)$.

The SE of the system could be presented as

$$R = \sum_{k=1}^K \log_2 \left(1 + \frac{\frac{\rho}{K} |\mathbf{H}_k \mathbf{F}_{RF} \mathbf{F}_{Bk}|^2}{1 + \sum_{j \neq k} \frac{\rho}{K} |\mathbf{H}_k \mathbf{F}_{RF} \mathbf{F}_{Bj}|^2} \right) \quad (3)$$

where \mathbf{F}_{Bj} indicates the j^{th} column of the digital precoder \mathbf{F}_B .



2.1. Hybrid Beamforming Design

Zero-forcing (ZF) precoding is known to be an important linear precoding scheme because it can accomplish a nearly peak capacity performance.

The illustrated figure 1 is utilized to achieve the proposed of HBF in which the \mathbf{F}_B digital precoder changes the phases and amplitudes of the receiving signals, on the other hand, \mathbf{F}_{RF} analog precoder can only manipulate the phases of the upscaled RF signals. Our goal is to achieve just phase control in the RF domains through isolating the phases of the combined DL channel from the base station to various operators. As a result, the phases of the channel components are aligned and massive MIMO systems that utilize enormous antennas may profit from their wide variety of advantages.

Let $\mathbf{H}_k = \mathbf{U}\mathbf{\Sigma}\mathbf{V}$ represent SVD of the channel. \mathbf{U} denotes $N_{BS} \times K$ orthogonal matrix, $\mathbf{\Sigma}$ denotes $K \times K$ singular vectors of scaling matrix placed in declining order, and \mathbf{V} denotes $K \times K$ orthogonal matrix.

The SVD of \mathbf{H}_k in the mmWave channel is represented as[14]

$$\mathbf{F}_{RF}\mathbf{F}_B = \log_2 \left(\left| \mathbf{I}_k + \frac{\rho}{\delta^2 \mathbf{I}_k} \mathbf{\Sigma}^2 \mathbf{V} \mathbf{H}_k \mathbf{F}_{RF} \mathbf{F}_{Bk} \mathbf{V} \right| \right) \quad (4)$$

Let $\mathbf{F}_{RF}(i, j)$ denote as the $(i, j)^{th}$ component of \mathbf{F}_{RF} and then the RF analog precoding is performed as

$$\mathbf{F}_{RF}(i, j) = \frac{1}{\sqrt{N_{BS}}} e^{j\varphi_{i,j}} \quad (5)$$

$\varphi_{i,j}$ indicates conjugate transpose of the channel matrix of the $(i, j)^{th}$ component. For simplicity, perfect channel information is assumed in the BS, which could be attained.

The effective channel estimate methods utilizing hybrid configurations and the management of frequency selectivity are still a hot topic for researchers [17]. Once the analog precoder is obtained, the corresponding base-band channel for k^{th} user is presented as

$$\mathbf{H}_e = \mathbf{H}_k \mathbf{F}_{RF} \quad (6)$$

where $\mathbf{H}_k = [h_1, h_2, \dots, h_k]^H$ implies the DL channel.

Then, at the baseband precoding low dimensional zero forcing is presented as

$$\mathbf{F}_B = \mathbf{H}_e^* (\mathbf{H}_e \mathbf{H}_e^*)^{-1} \mathbf{\Lambda} \quad (7)$$

$\mathbf{\Lambda}$ indicates a diagonal matrix. In order to guarantee simultaneous transmission of K data streams in the PZF scheme, the hardware complexity is reduced, which requires just K RF chains, contrasted to N_{BS} needed by full complexity ZF scheme.



3. Result

The efficiency of the hybrid low complexity PZF precoding technique is presented and then compare it to the unconstrained precoding. The plotted rates in Fig. 2 and 3 are spectral efficiency obtained from (2). Fig. 2 illustrates the SE attained by precoding scheme using a typical Rayleigh fading channel. NBS which is the transmit antennas in the BS is set to 128 with $K = 2$ data streams and the channel number set to 1000. In Fig. 2, we statistically analyse the suggested PZF precoding structure in its quantised form with the full-complexity zero forcing architecture, which is considered realistically desirable in the bigger network plan however nearly unfeasible because of the necessity of N_{BS} high-priced radio frequency chains. Furthermore, we notice that the PZF precoding behaves noticeably near compared to the optimal unconstrained precoding by even less 1 dB yet considerably lower complexity. Fig. 3 illustrates the SE attained by precoding scheme with mm Wave channel. In this case, K data streams = 4, $N_{BS} = 128$ antennas in the BS and $N_p = 10$ with the channel number set to 1000. In Fig. 3 sparsely scattered Mm Wave channel the PZF scheme performs slightly less than the one in Fig. 2 which is in Rayleigh fading channel, with a one and a half dB loss, also we can observe that both the unconstrained precoding and the low complexity PZF precoding outperforms the beamspace MIMO (B-MIMO) precoding.

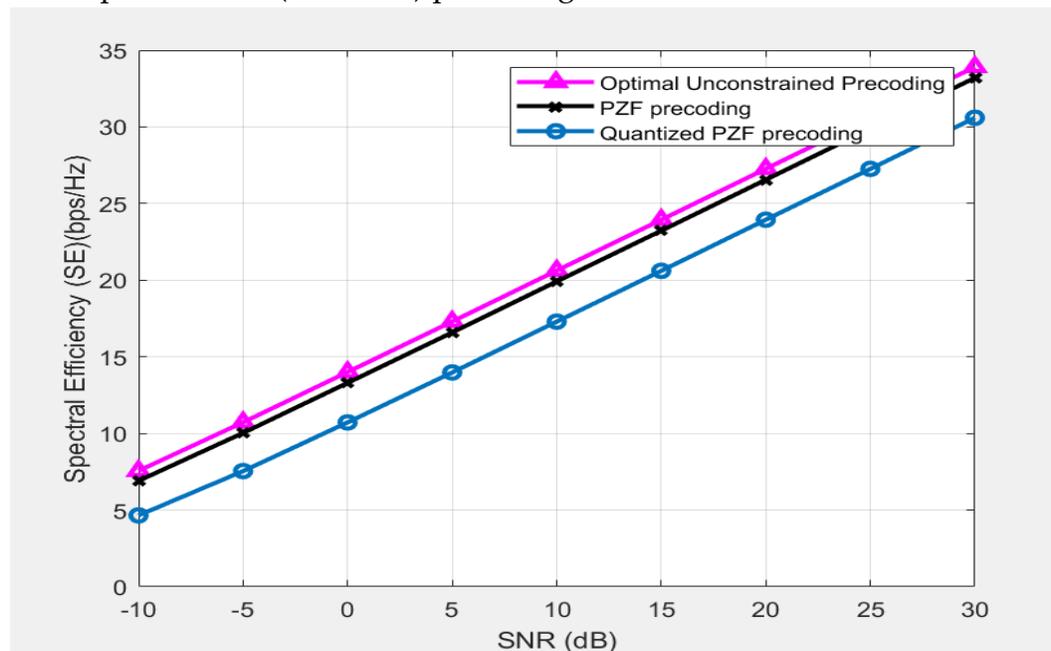


Figure 2. The average achievable SE (bps/Hz) vs SNR with Rayleigh fading channels where $N_{bs} = 128$ and $K = 2$.

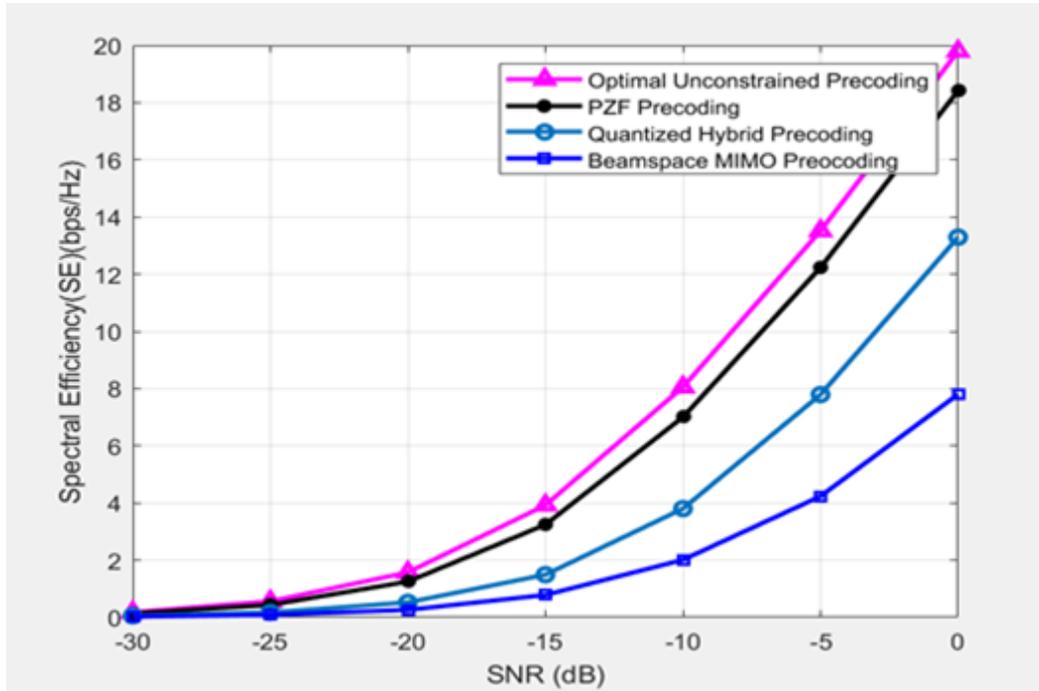


Figure 3. The average achievable SE (bps/Hz) vs SNR with mm-Wave MU techniques where $N_{bs} = 128$, $K = 4$ and $N_p = 10$.

4. Discussion and Conclusion

In this paper, two hybrid precoding/combining architectures and their performances have been examined. PZF precoding and optimal unconstrained precoding. Due to its power efficiency and cheap cost in massive MIMO systems, over the past years hybrid beamforming systems have gained a lot of attention. Hybrid beamforming combines digital baseband precoding with analog RF precoding to allow spatial multiplexing gains in massive MIMO systems, which achieves nearly fully digital beamforming performance while significantly plummeting the amount of RF chains which have a tendency to consume a lot of energy and power. The proposed PZF precoding performs well in simulations achieving closely compared to the and optimal unconstrained precoding while having substantially lower complexity.

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