On channel quantization for multi-cell cooperative systems with limited feedback

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Abstract Coherent multi-cell cooperative transmission, also referred to as coordinated multi-point transmission (CoMP), is a promising strategy to provide high spectral efficiency for universal frequency reuse cellular systems. To report the required channel information to the transmitter in frequency division duplexing systems, limited feedback techniques are often applied. Considering that the average channel gains from multiple base stations (BSs) to one mobile station are different and the number of cooperative BSs may be dynamic, it is neither flexible nor compatible to employ a large codebook to directly quantize the CoMP channel. In this paper, we employ per-cell codebooks for quantizing local and cross channels. We first propose a codeword selection criterion, aiming at maximizing an estimated data rate for each user. The proposed criterion can be applied for an arbitrary number of receive antennas at each user and also for an arbitrary number of data streams transmitted to each user. Considering that the resulting optimal per-cell codeword selection for CoMP channel is of high complexity, we propose a serial codeword selection method that has low complexity but yields comparable performance to that of the optimal codeword selection. We evaluate the proposed codeword selection criterion and method using measured CoMP channels from an urban environment as well as simulations. The results demonstrate significant performance gain as compared to an existing low-complexity method.

Keywords base station cooperative transmission, channel quantization, limited feedback, codeword selection

1 Introduction

Base station (BS) cooperative transmission, also known as coordinated multi-point transmission (CoMP) in Long Term Evolution Advanced (LTE-A), is an effective way to avoid inter-cell interference in universal frequency reuse cellular systems. CoMP joint processing (CoMP-JP) provides the full benefit of CoMP systems, if both data and channel state information (CSI) can be obtained at a central unit (CU) \cite{1,2}. For simplicity, we refer to CoMP-JP as CoMP in the following.

CoMP is often viewed as a large multiple-input and multiple-output (MIMO) system with a “super BS” (i.e., the CU). However, there are distinct features in CoMP channels and systems. CoMP channel is an aggregation of multiple single-channel channels from the cooperative BSs to each user. Considering

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that the number of cooperating BSs in a cluster may be dynamic, the dimension of the CoMP channel seen by a user may be dynamic. Furthermore, the average channel gains from different BSs to each user are different [2,3], due to different antenna power gains, path losses and shadowings. As a result, the channels are no longer independent and identically distributed (i.i.d.) and the channel statistics of each user highly depend on its position.

Limited feedback techniques are widely applied for reporting CSI to transmitter in frequency division duplexing (FDD) MIMO systems and have been extensively studied [4]. If conventional methods for single-cell systems are directly applied to design the codebooks for high-dimensional channel matrices in CoMP systems, prohibitive complexity is required to dynamically generate the location-dependent and cluster-dependent codebooks and to search for the optimal codewords. Moreover, frequently re-generating large codebooks is neither flexible nor compatible to existing systems.

In fact, since CoMP channel is an aggregation of multiple single-cell channels, we can reuse the codebook designed for single-cell systems to separately quantize multiple single-cell channels in the global CoMP channel, which is referred to as per-cell codebook quantization [3]. Though this does not yield the optimal codebook for CoMP channel, it can reduce the complexity to generate the codebook as well as the complexity to select the codeword.

In this paper, we study codeword selection for CoMP transmission with per-cell codebook quantization. We first provide a unified codeword selection criterion to maximize an estimated data rate at the user side, which can exploit the feature of CoMP channel, and can accommodate general cases with an arbitrary number of receive antennas at each user and an arbitrary number of data streams transmitted to each user. Codeword selection criteria and methods are well explored for single-cell limited feedback MIMO systems [5–9]. When each user is equipped with a single antenna and zero-forcing beamforming (ZFBF) is applied, or when each user has multiple antennas and multiple data streams are transmitted to each user with zero-forcing block diagonalization (ZFBD), a widely applied codeword selection criterion is to minimize the chordal distance between the channel direction and the codeword [5,6]. When multiple antennas are deployed at each user and a single data stream is transmitted to each user, the codeword can be selected with various criteria [7–9]. It was shown in [8,9] that the codeword selection jointly designed with a receive combiner outperforms the method of finding the codeword closest to the direction of singular vector corresponding to the maximum singular value of channel matrix. Considering that the selection of per-cell codewords via exhaustive searching is of high complexity [3], we proceed to propose a low complexity method which selects the codewords for per-cell channels in a serial manner. Both simulation results and the results using measured CoMP channels in [10] show that the proposed codeword selection method has minor performance loss from the optimal selection, and outperforms the low-complexity codeword selection method proposed in [3].

To the best of our knowledge, there are few available researches on the codeword selection for CoMP multi-user MIMO (MU-MIMO) systems. A codeword selection method for CoMP MU-MIMO systems with per-cell codebooks was proposed in [3]. Our work differs from that in [3] in three aspects: 1) codeword selection criterion, 2) codeword construction method and 3) codeword selection method to reduce complexity. Due to the first difference, our method can be applied for various numbers of the antennas and data streams at each user, but the method in [3] can only be used when each user has multiple antennas and the received antennas do not provide diversity gain. Due to the second difference, in general cases where the large scale fading gains of a user are different, the proposed method can exploit the difference in the per-cell channel energies to improve the performance of codeword selection. This is because the CoMP channel was normalized by the large scale fading gains of per-cell channels to mimic an i.i.d. single-cell channel in [3]. As a result, the single-cell codeword selection method in [6] can be applied, which selects per-cell codewords by minimizing the chordal distance between the normalized CoMP channel and the aggregated codewords without large scale fading gains [3]. Finally, due to the third difference, we can achieve the same performance as the method proposed in [3] with much lower complexity. Simulation results demonstrate the performance gain of proposed codeword selection criterion and method over that in [3].

Notations: \((x)^*\) and \(\Re(x)\) denote the conjugate and real part of scalar \(x\), respectively. \((X)^T\) and \((X)^H\)