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Efficient beamforming and spectral efficiency maximization in a joint transmission system using an adaptive particle swarm optimization algorithm

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Next-generation cellular networks and beyond are expected to adopt a frequency reuse factor of one to support high spectral efficiency. Consequently, Inter-Cell Interference (ICI) represents a serious issue among neighbouring cells, especially for cell-edge users. In addressing this, joint transmission (JT) represents one of the most sophisticated techniques for mitigating ICI stemming from implementing a frequency reuse factor of one. Moreover, JT also converts the interfering signals into useful signals to improve the spectral efficiency of the system. However, JT produces enormous overhead on both the feedback and backhaul interfaces; thus, partial JT was proposed as a trade off between signaling demand and increased spectral efficiency. Maintaining an efficient beamforming (BF) matrix based on a sparse aggregated channel matrix is a challenging issue with regard to linear BF techniques such as zero-forcing (ZF). This is mainly because ZF BF can only invert a well-conditioned matrix. Therefore, an adaptive particle swarm optimization (APSO) is included in this paper and used to present an efficient beamformer that achieves equivalent backhaul reduction and high spectral efficiency. Moreover, addressing the lack-of-diversity issue in basic particle swarm optimization (BPSO) is a primary concern of this work. The beamformer obtained with the objective function of sum rate maximization achieves a spectral efficiency of **17.24**% compared to BPSO BF.

1. Introduction

The deployment of a frequency reuse factor of one in next-generation cellular networks attempts to maximize the spectral efficiency. However, cell-edge users are expected to experience high levels of interference, namely ICI, as illustrated in Fig. 1(a). To overcome this issue, Coordinated Multiple (CoMP) Transmission and Reception was proposed in [1]. In this paper, JT is considered as a comprehensive technique under the CoMP framework. JT is a method for the simultaneous transmission of users' data by a subset of cooperating BSs towards maximizing spectral efficiency and mitigating ICI; refer to Fig. 1(b). To alleviate ICI in a coherent JT system, the receivers need to estimate their Channel State Information (CSI) and then feed it back to the cooperating Base Stations (BSs). The interfering signals in JT fashion are also considered to be useful signals. In a centralized architecture, the cooperative BSs forward the CSI of all links to a Central Coordination Node (CCN) to create an aggregated channel matrix, which is used to perform BF and power allocation for ICI mitigation. The CSI in decentralized coordination needs to be available at all the cooperating BSs to perform BF and power allocation. Therefore, a special scheduler needs to be implemented to assign a BS to each User Equipment (UE).

The BF elements and users' data need to be forwarded to the cooperating BSs to be transmitted to the corresponding UEs to control interference via JT. The signaling of BF elements along with users' data is performed through a backhaul interface, which is the connection between the CCN and the cooperating BSs, also known as backhaul overhead. The backhaul interface can be either a microwave link or fibre optics. On the other hand, the signaling process performed between UEs and the cooperating BSs can be

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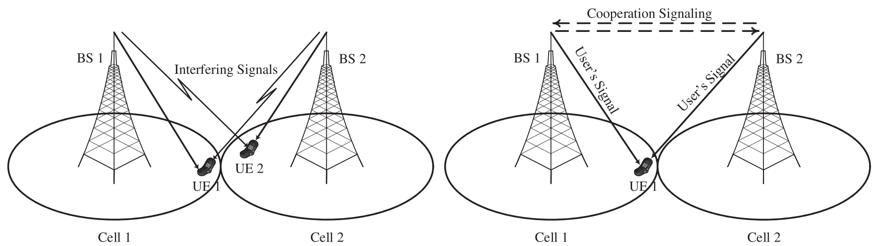
1568-4946/



(a) Effect of ICI without JT. (b) Effect of JT in mitigating ICI.

Fig. 1. Transmission schemes.

defined as feedback overhead. Fig. 2 illustrates feedback and backhaul overhead. JT has a tremendous computational complexity; thus, the clustering approach represents a suboptimal solution that attempts to alleviate the complexity of JT. The clustering topology can be static, which means that a subset of BSs is fixed and does not change with time. In contrast, dynamic clustering always varies to achieve fairness among UEs. Depending on where the clustering decision is held, clustering techniques can be either user-centric or network-centric based on consideration of UE channel conditions.

JT implies a huge overhead on both backhaul and frequency resources in the cooperative cluster. Regarding feedback overhead, JT heavily consumes frequency resources due to the simultaneous transmission of users' data. Thereby, feedback overhead will reflect and place enormous requirements on backhauling speed. Therefore, to relax the burdens on backhaul and frequency resources, several studies have been performed based on limited feedback [3] and limited backhaul [4–6]. One of the suboptimal solutions that addresses the high overhead issue on feedback and backhaul resources is Partial Joint Transmission (PJT) [7]. In the CCN where the PJT is deployed, UEs are instructed by the cooperating BSs to feed back the CSI of all links that fall within the active set threshold or predefined window. The cooperative cluster in the PJT framework is dynamically formed depending on the channel conditions that were fed back by the UEs. In this context, the clustering approach is considered as a user-centric approach. Full Joint Transmission (FJT), however, is a special case of PJT when the active set threshold goes to infinity. In PJT, UEs identify the best BS channel link as a reference and arrange the other links with respect to the reference channel. The decision of sorting the links is performed based on the channel strength or energy of the frequency selective channel. In that sense, BSs' links that fall within the active set threshold are indicated as active; the remainder are mapped as inactive. In this context, the active and inactive links are indicated by "1" and "0", respectively, when forming the active set threshold matrix; refer to Algorithm 1.

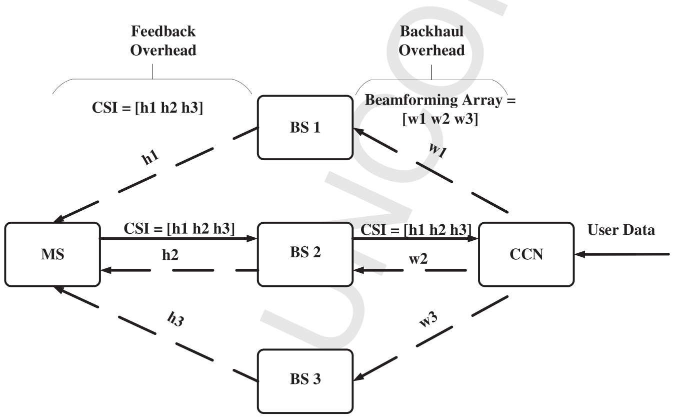


Fig. 2. Feedback and backhaul overhead illustration [2].

Algorithm 1. Active set thresholding for limited feedback based on [7].

choose: *threshold* = 10 dB
for each UE **do**
  Measure the channel gain from all BSs
  bestLink = max{channel strength from all BSs}
  if (*bestLink* − *otherLink*) ≤ *threshold* **then**
    UE feeds back the CSI of *otherLink*
    CCN marks this link as *active*
  else
    Feedback loadis reduced:
    UE does not feed back the *otherLink*
    CCN marks this link as *inactive*
  end if
  UE feeds back the *bestLink*
  CCN marks this link as *active*
End for

Linear BF techniques such as zero-forcing (ZF) are only able to invert well-conditioned aggregated channel matrices to remove interference. However, achieving equivalent backhaul reduction based on a sparse aggregated channel matrix that results from PJT is challenging when linear techniques, such as ZF BF, are used, thus leading to the use of a modified ZF BF instead. Hence, zero-forcing for Backhaul Load Reduction (ZF-BLR) BF has been proposed in [8] to achieve backhaul equivalence with respect to limited CSI feedback. The main limitation of ZF-BLR BF approach is that it does not guarantee high spectral efficiency owing to its failure of inverting a sparse aggregated channel matrix. Therefore, a stochastic adaptive particle swarm optimization (APSO) BF has been proposed in this paper to achieve equivalent backhaul reduction and high spectral efficiency. Moreover, addressing the lack-of-diversity issue in basic particle swarm optimization (BPSO) BF presented in [2], is the primary concern of this paper in order to maximize the spectral efficiency.

1.1. Related works

A sophisticated technique that attempts to maximize spectral efficiency in wireless communication systems is the use of Multiple-Input Multiple-Output (MIMO) antennas. However, the major drawback of deploying MIMO systems is co-channel interference. Therefore, BF, as a directional signal transmission or reception technique, can be used at both the transmitter and receiver terminals to achieve spatial selectivity and alleviate co-channel interference. Dirty Paper Coding (DPC) is one of the most comprehensive beamforming techniques; however, its computational process becomes significantly complex when the number of terminals increases [9]. To reduce the complexity of DPC, several BF approaches have been proposed to select optimized BF vectors. One such technique is depending on the CSI that is fed back by the UEs to the cooperative BSs.

Recently, a considerable literature has developed around the theme of JT under clustered scenarios. Large cellular networks

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