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Interference suppression algorithm based R-TDD for multi-user MIMO heterogeneous network

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ABSTRACT

Aiming at the problem of uplink co-channel interference in multi-user multi-input multi-output (MIMO) heterogeneous network, a reversed time division duplex (R-TDD)-based method is used to improve the performance of interference rejection combining (IRC) algorithm. This method overcomes the difficulty of IRC algorithm in obtaining the interference noise covariance matrix by utilizing the R-TDD transmission scheme. On the premise that the spectrum efficiency is guaranteed, through combining R-TDD with spatial modulation, the transmission complexity is significantly reduced and the uplink co-channel interference is effectively controlled, so as to improve the system performance. Simulation results demonstrate that the R-TDD-based scheme can improve the performance of IRC algorithm in terms of spectrum efficiency.

1. Introduction

The sharp contradiction between the ever-increasing bandwidth demand of users and the limited spectrum resource promotes the continuous innovation of communication technology. Meanwhile, the capacity demand of the future wireless cellular network can be satisfied via effective network densification, which is to deploy small cell, such as pico cellular cell, etc. [1,2]. Although employing pico cellular is an effective way to improve the local capacity, it cannot replace the cellular network that ensures the local coverage and supports high-speed mobile terminals. Thus, the two-layer cellular structure has emerged, however, strong inter-layer co-channel interference exists in the network due to the spectrum sharing between two layers. Therefore, the interference suppression becomes a key problem needed to be solved.

Furthermore, increasing the number of antennas in each cell to form MIMO system is another way for network densification [3]. Considering the upgrading of MIMO technology, massive MIMO undoubtedly enjoys greater advantages of improving spectrum efficiency. Under the same time and spectrum resources, massive MIMO can achieve higher capacity gains via additional freedom and reusing information. In addition, greater antenna array enables radiation energy to accurately focus on the desired receiver, which effectively copes with the intra-cell and inter-cell interference. However, it requires that the channel structure can be used at base station (BS) [4], and the number of antennas at BS is constrained by Frequency Division Duplex (FDD) mode. On the contrary, Time Division Duplex (TDD) mode is capable of reducing the associated channel-signaling overhead through the channel anisotropy. Accordingly, it is necessary to employ the TDD mode for massive MIMO system [5]. Ultimately, multi-user massive MIMO heterogeneous network based on TDD mode has been established. However, it faces numerous difficulties and challenges, such as synchronization, coordination and inter-layer co-channel interference, where the inter-layer co-channel interference greatly attenuates the overall performance of the system [6].

Interference Rejection Combining (IRC) is used to suppress uplink interference at receiver. Nevertheless, it is difficult to obtain the interference covariance matrix for IRC. The classical TDD mode enables BS not only to estimate the channel between itself and mobile user, but also to roughly estimate the covariance matrix of interference signals that derives from pico cellular [7]. Indeed, this kind of rough estimation constrains the interference suppression capacity of IRC algorithm, resulting in a great decline of the system performance. Also, [8] indicated that hardware limitations of the radio frequency front-end and poor covariance matrix estimation may severely restrict the ideal gains of IRC. Based on these considerations, many modified approaches have been proposed to improve IRC performance and obtain accurate interference covariance matrix [9–12]. In [9], IRC is used for space frequency block code transmission diversity in LTE-Advanced downlink. Literature [10] combined IRC and inter-cell interference coordination to control interference for LTE-Advanced heterogeneous network downlink. Interference reconstruction rejection combining was

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proposed in [11] by using twice IRC algorithm to improve the estimation accuracy of interference noise covariance matrix. Combining IRC and Successive Interference Cancellation (SIC), an enhanced IRC-SIC algorithm with beamforming for MU-MIMO system was proposed in [12], which gets better performance with the help of SIC algorithm. However, these approaches more or less increase the complexity of the system, and most of them study the interference through the perspective of signal processing. Therefore, it is feasible to solve the above issue from the system itself, which means that we can exploit the advantages of transmission mode to obtain more accurate interference covariance matrix without increasing system complexity, so as to improve the performance of IRC algorithm. In particular, the transformation of TDD—Reversed TDD (R-TDD) is an effective way to solve the problem.

Unlike TDD, the uplink and downlink are reversed in R-TDD mode. For example, when macro cellular is downlink, pico cellular is uplink, and vice versa. Accordingly, the dual relationship between uplink and downlink is established in [13,14]. Literature [13] proposed a frame structure based on R-TDD mode, and applied it to cognitive femto cell network. The literature illustrated that the BS of second layer can decode the control channel of BS (macro BS) of first layer. Meanwhile, with simple power control, the BS of second layer is capable of bringing high spectrum efficiency to each layer by deploying suitable antennas. Since the different duplex mode changes the interference node between two layers, R-TDD mode is superior to TDD in terms of network topology structure. The advantage of R-TDD is that the interference sub-space can be accurately estimated when the macro BS and pico cell are fixed, that is to say, the interference channel from pico cell to macro BS is quasi-static [7]. Thus, with utilization of the R-TDD as the transmission mode, the interference covariance matrix of IRC can be accurately estimated so as to suppress cross layer interference and improve the overall system performance.

To reduce the complexity of employing pico cell in heterogeneous network, the number of transmitter antennas is also constrained. Moreover, the number of receiver antennas is required bigger than the number of transmitter antennas for some transmitter' designs. It results in great limitations regardless of the transmitter or the receiver. Obviously, all of these problems hinder the practical application of MIMO technology, especially massive MIMO technology, at mobile station side. Therefore, in order to overcome the obstacles of practical application and remain the benefits of MIMO technology, the transmission mode that combines the Spatial Modulation (SM) and R-TDD can be considered.

SM [15] as a promising transmission technology is widely concerned in 5G communications. In particular, SM can achieve both transmitters' low complexity design and high spectrum efficiency just with simple modulation and encode principles. SM is one of advanced modulation technologies for multi-antennas transmission [10,16]; it can utilize the unique and random character of wireless channel to communicate. Simple and effective encoding mechanism is the core of this technology, which establishes a one-to-one mapping between transmission bit block and the transmission antenna's position of the antenna arrays. The goal of SM is to reduce complexity and overhead of MIMO system without attenuating end-to-end performance, meanwhile guarantee good data rate. SM improves the data rate and is also very beneficial to small terminal designs due to the low system complexity [17], which shows high spectrum efficiency and bit error performance even under correlated channel.

In general, aiming at the issue of co-channel interference for multi-user MIMO heterogeneous network, this paper proposes an interference suppression approach based on R-TDD mode to improve the performance of IRC algorithm. The approach accurately estimates the interference covariance matrix via R-TDD transmission mode. It overcomes the difficulty of IRC in obtaining the interference covariance matrix. Furthermore, the scheme that combines R-TDD and SM is proposed to achieve high spectrum efficiency and reduce the transmitter complexity, meanwhile, suppress the uplink co-channel interference of heterogeneous network.

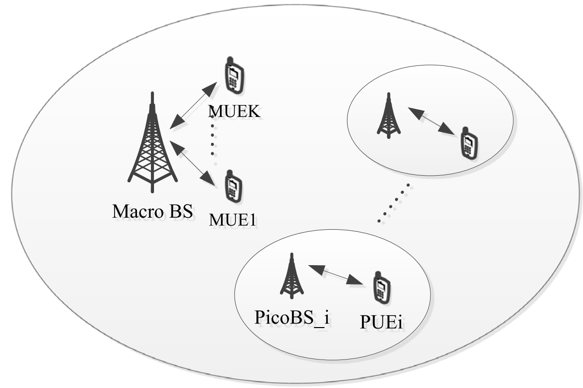

Fig. 1. System model.

The rest of this paper is organized as follows. In Section 2, we describe the multi-user MIMO heterogeneous network model and discuss the details of IRC algorithm. In Section 3, we analyze different transmission mode for co-channel interference suppression, and a method that combines R-TDD and IRC is proposed. Some numerical results are provided in Section 4. In Section 5, we conclude the paper.

2. System model

Considering a multi-user MIMO heterogeneous network consists of one macro BS and S-pico cell that all of them share the same spectrum with macro BS as shown in Fig. 1. Each BS configures N_t transmitting antennas, K single antenna users—Macro User (MUE) are serviced by macro BS, pico BS utilizes the available resources to service one assigned single antenna user—Pico User (PUE). Assuming that the communication between two-layer is synchronous, and the two-layer shares the same W spectrum based on common reuse principles. All transmission are placed on Rayleigh Flat Fading Channel, furthermore, the maximum transmission power of each nodes is constrained.

Due to the sharing of same spectrum in uplink, macro BS will receive the interference signals from each pico user; one of the pico BS will receive the interference signals from macro users and other pico users. Thus, the received signal $\mathbf{y}_{BS}(t)$ at t moment of macro BS and the received signal $\mathbf{y}_{PBS,i}(t)$ at t moment of pico BS are represent as follows

$$\mathbf{y}_{BS}(t) = \mathbf{H}\mathbf{x}_{MUE}(t) + \mathbf{z}_{BS}(t) \tag{1}$$

$$\mathbf{y}_{PBS,i}(t) = \mathbf{h}_{ii}x_{PUE,i}(t) + \mathbf{z}_{PBS,i}(t) \tag{2}$$

where, $\mathbf{H} = [\mathbf{h}_1, \mathbf{h}_2, \dots, \mathbf{h}_K]$ is the $N_t \times K$ dimension channel matrix between MUE and macro BS, $\mathbf{h}_k$ is the N_t dimension channel vector between k MUE and macro BS; $\mathbf{x}_{MUE}(t) \sim CN(0, P_{MUE}\mathbf{I}_K)$ is the transmitting signal vector between MUE and macro BS; $\mathbf{h}_{ii}$ is the N_t dimension channel gains between pico BS and PUE, $S = \{1, 2, \dots, S\}$ is the index of set of pico cell; $x_{PUE,i}(t) \sim CN\left(0, P_{PUE,i}\right)$ is the transmitting signal between i PUE and i pico BS; $\mathbf{z}_{BS}(t)$ and $\mathbf{z}_{PBS,i}(t)$ are the interference and noise part that received by macro BS and i pico BS respectively, and further represented as follows

$$\mathbf{z}_{BS}(t) = \sum_{i \in S} \mathbf{a}_i x_{PUE,i}(t) + \mathbf{n}_{BS}(t) \tag{3}$$