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Multiuser channel estimation and prediction in two dimensions for MIMO–OFDM uplinks ☆

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ABSTRACT

This paper addresses the pilot-aided multiuser channel estimation for the uplink of multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) systems. The channel estimate is performed in two dimensions, i.e., time and frequency (2D), by exploiting their correlation. With the properly designed separable pilot symbols, a multiuser signal separation can be achieved and a multiuser channel estimator can be designed as well. To reduce the high computational complexity for a truly 2D estimator, two cascaded one dimensional (1D) estimators are used instead, which corresponds to two estimation stages with two different filters. At the 1st stage, the Wiener filter is implemented in the frequency direction, which separates the received multiuser signals and outputs the tentative estimate corresponding to an individual user. Whereas, at the 2nd stage, the Kalman filter is adopted in the time direction to estimate and predict the desired channel state information.

1. Introduction

The explosive growth of wireless communications is creating demand for high rate, reliable, and spectrally efficient communication over the wireless medium. Multiple-input multiple-output (MIMO) systems using multiple transmit and receive antennas can yield improved link reliability through spatial diversity [1] and increased data rate through spatial multiplexing [2] techniques. Orthogonal frequency division multiplexing (OFDM) significantly reduces receiver complexity in wireless broadband systems. The use of MIMO technology in combination with OFDM, i.e., MIMO–OFDM, therefore seems to be an attractive solution for future broadband wireless systems, which have been studied extensively in [3–8]. As most of these studies concentrate on a single user scenario, the multiuser MIMO–OFDM systems are proposed in [22,9], in which many users can share the same frequency band while multiple antennas are installed at the base station and single antenna at the user. In this letter, we shall extend the model to multiple antennas deployed at each user terminal.

Channel state information (CSI) is crucial for coherent data detection, channel equalization and interference suppression. CSI can be acquired in different ways; one is based on pilot symbols that are known to the receiver, and the other one is the blind method, which estimates CSI merely from the received symbols [10]. A subspace-based blind method is proposed for estimating the channel response of a multiuser MIMO–OFDM system in [11]. Whereas, a low complexity pilot based channel estimator is used for an OFDM/SDMA system in [12], and the optimal binary pilot sequences for maximum likelihood (ML) channel estimation of multiuser MIMO–OFDM systems is derived in [13]. Compared with pilot-based scheme, blind methods typically require longer data records, and entail higher complexity. We shall restrict our attention to pilot aided channel estimation in this paper.

Furthermore, for OFDM systems the received signal in frequency domain is typically correlated in two dimensions, i.e., time and frequency (2D). By periodically inserting pilots in the time–frequency grid, the channel response can be reconstructed by exploiting its correlation in time and frequency. The 2D pilot-aided channel estimator is derived in [14,15] for the single-antenna case and in [16] for the multiple-antenna case. A multiuser 2D channel estimator is addressed for the OFDM/SDMA systems in [17]. Unfortunately, those 2D channel estimators give rise to too high computational complexity. To reduce the complexity, two cascaded one-dimensional (1D) estimators in time and frequency are derived in [18] for the single-antenna case, and in [19] for the multiple-antenna case with spatially identically and independently distributed fading channels. However, in terms of multiuser MIMO–OFDM uplinks under spatially correlated time-varying channels, few results have ever appeared according to our best knowledge.

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In this paper, we aim to extend the concept of two 1D estimators for multiuser MIMO–OFDM uplinks with spatially correlated time-varying multi-path fading channels. With the properly designed pilot symbols to be separable, the estimation and separation of superimposed multiuser signals can be divided into two stages. At the 1st stage the Wiener filter is performed in the frequency direction to separate the multiuser signals along with channel estimation. A *tentative* estimate is obtained at this stage. Then, at the 2nd stage, the Kalman filter is cascaded in the time direction to estimate and predict the desired CSI by following the *tentative* estimate. It is noted that both the two 1D estimators are operated in the frequency domain, i.e., estimating channel frequency response.

The rest of the paper is organized as follows. Section 2 introduces the basic multiuser MIMO–OFDM system model. The Wiener channel estimation in the frequency direction is described in Section 3, and the Kalman estimation and prediction in the time direction are addressed in Section 4. The simulation results are given in Sections 5 and 6 concludes this paper.

Notation: We will use $[A]_{m,n}$ and $[A]_{:,n}$ to denote the (m,n) th element and nth column of matrix A, respectively. $\mathrm{Vec}(A) = [[A]_{:,0}^{\mathrm{T}}[A]_{:,1}^{\mathrm{T}} \cdots [A]_{:,N-1}^{\mathrm{T}}]^{\mathrm{T}}$ and $\mathrm{Tr}(A)$ is the trace of matrix A. x_m is the mth entry of the column vector x; I_N is the $N \times N$ identity matrix; $E\{\cdot\}$ stands for the expectation operator, $\otimes$ for Kronecker product and $\lfloor \cdot \rfloor$ for integer floor; The superscripts ^{T,*,H} denote transpose, conjugate and Hermitian, respectively; $\min(a,b)$ denotes the minimum value between a and b.

2. Data model

2.1. Multiuser MIMO–OFDM system

The multiuser MIMO–OFDM system under consideration consists of U user terminals and one base station (BS), the uplink of which is shown in Fig. 1. Each of the users has N_T antennas, while the BS has N_R omni-directional antennas, which can receive signals from every user in the cell. Assume that all users share the same frequency band, which is split into N subcarriers or tones via the OFDM modulation (N-point *IFFT* operator).

In Fig. 1, we define $s_{u,t}(k,n)$ the symbol being transmitted from the$t$th antenna of the uth user over the kth tone at time n. For a certain user u and antenna t, collecting $s_{u,t}(k,n)$ corresponding to N subcarriers makes an OFDM symbol with size N. Before transmission, it is processed by an IFFT and a cyclic prefix of length CP is added to eliminate inter-symbol interference (ISI). In this paper, we assume that $CP = L$, where $L+1$ is the maximum length of all channels. At the BS side, after removing the CP, the *FFT* process (OFDM demodulation) then follows. Denoting $\mathbf{s}_u(k,n) = (s_{u,1}(k,n), \cdots, s_{u,N_T}(k,n))^{\mathrm{T}}$, the reconstructed signal vector over the kth tone at time n, i.e., $\mathbf{y}(k,n) = (y^1(k,n), \cdots, y^{N_R}(k,n))^{\mathrm{T}}$, is expressed as (c.f. Fig. 1)

$$\mathbf{y}(k,n) = \sum_{u=1}^{U} H_u^{(c)}(k,n)\mathbf{s}_u(k,n) + \boldsymbol{\eta}(k,n) \tag{1}$$

where $\boldsymbol{\eta}(k,n)$ is complex-valued additive white Gaussian noise (AWGN) vector with mean zero $E\{\boldsymbol{\eta}(k,n)\} = \mathbf{0}_{N_R\times 1}$ and variance matrix $E\{\boldsymbol{\eta}(k,n)\boldsymbol{\eta}(k,n)^H\} = \sigma_\eta^2\mathbf{I}_{N_R}$; $H_u^{(c)}(k,n)$ $(N_R \times N_T)$ is the channel frequency response given by

$$H_u^{(c)}(k,n) = \sum_{l=0}^{L} h_u^{(c)}(l,n)e^{-\mathbf{j}2\pi lk/N} \tag{2}$$

where $h_u^{(c)}(l,n)$ $(N_R \times N_T)$ represents the impulse response matrix of the lth path at the time n corresponding to the uth user.

2.2. Basic channel assumption

While considering the spatially correlated channel, we shall define $R_{Tx}^u(N_T \times N_T)$ the transmit correlation matrices corresponding to uth user and $R_{Rx}^B(N_R \times N_R)$ the receive correlation matrix of BS (In the simple case, each tap component exhibits similar spatial correlation for a certain time interval.). Following the I-METRA model [20], the $R_{\mathrm{MIMO}}^u(N_RN_T \times N_RN_T)$ spatial correlation matrix of

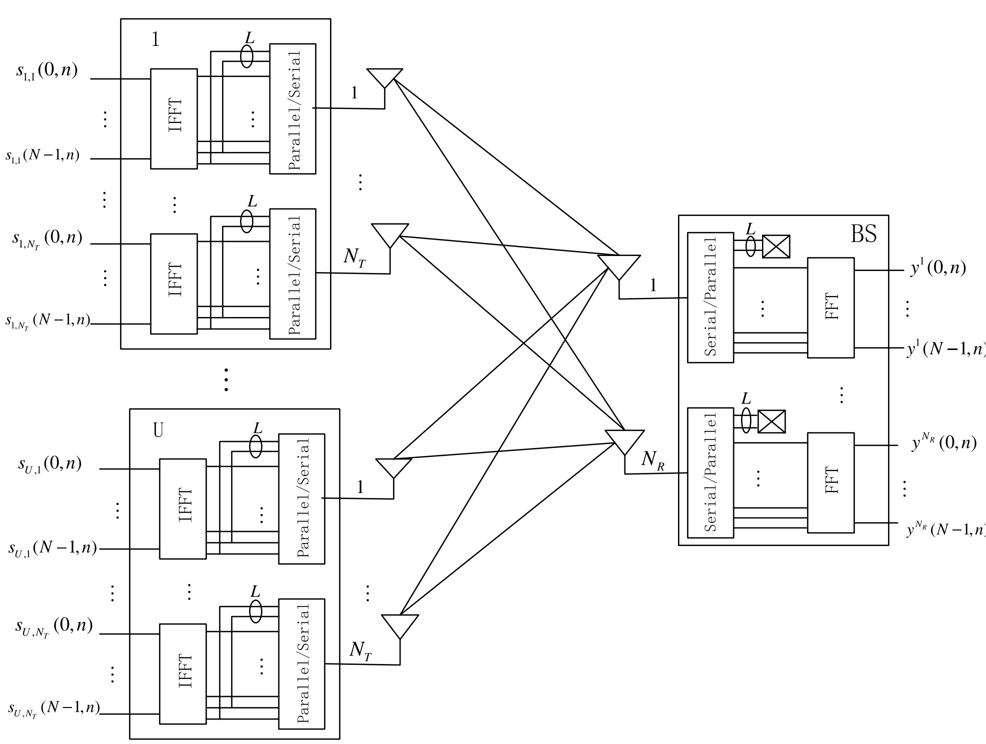

Fig. 1. Block diagram of multiuser MIMO–OFDM system (uplink).