Training for Synchronization and Multiple Channels Estimation

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***Abstract*—We design training patterns to estimate multiple channels and multiple carrier frequency offsets (CFO) that emerge with block transmissions over multi-input multi-output (MIMO) frequency-selective fading links. Our novel training scheme consists of non-zero pilot symbols along with zeros, which separate CFO and channel estimation from symbol detection, and thereby lead to low-complexity estimators. The resulting training sequences are flexible to accommodate any space-time coded transmission. We investigate the performance of our estimators analytically, and compare them with an existing algorithm using simulations.**

I. INTRODUCTION

Demand for higher data rate leads to frequency-selective fading in wireless channels. Space-time multiplexing with multiple antenna arrays at both the transmitter and receiver has been proved effective in combating fading, and enhancing data rates (see e. g., [1], [5] and references therein). However, as the number of antennas increased, channel estimation becomes challenging as the number of unknowns to be estimated increased accordingly. This problem was considered for this multiple antenna system under frequency selective fading scenario in [7]. They designed a low complexity optimal training scheme which maximize a lower bound on the average capacity and minimize the mean square error of the linear channel estimator for both single- and multi-carrier systems. The problem of finding training for flat fading MIMO channels was addressed in [5].

Most existing approaches assume zero frequency offset between the carrier and the local reference at the receiver [5], [7]. In practice, however, using stable oscillators would be impossible. Furthermore, even ideal oscillators would be of no use in a mobile communication environment experiencing significant Doppler shifts. This motivates the question of estimating CFO as well as frequency-selective fading channels. This related works for SISO systems can be categorized as data-aided schemes [2]–[4] and non-data aided schemes [6]. Blind methods typically require longer data records, and have rather high computational complexity. On the other hand, data-aided methods use known training symbols between transmitter and receiver. Although bandwidth consuming, they have the distinct advantage of being computationally attractive.

In this paper, we deal with training design for estimating the distinct CFOs and MIMO frequency-selective channels in block transmission systems, which is to be contrasted with previous works where CFOs do not depend on transmit antenna [8] and only SISO channel is considered [3]. We design training symbol in transmission block, which enables decoupling CFO and channel estimation from symbol decoding, which in turn leads to low-complexity receiver compared to blind method. Moreover, we focus on designing the lower overhead training and estimator with enhanced CFO acquisition range compared to existing algorithms [3], [4]. In addition, our schemes are flexible to accommodate any Space-Time Coded transmission.

II. SYSTEM MODEL

We will consider the discrete-time equivalent baseband model of a block transmission system communicating over MIMO frequency-selective channels in the presence of CFOs. Every information symbol block, $[\mathbf{s}(k)]_n = s(kN_s + n)$, is drawn from a finite alphabet. At the transmitter, each block $\mathbf{s}(k)$ is first encoded and/or multiplexed in space and time to result in $\{\mathbf{c}_\mu(k)\}_{\mu=1}^{N_t}$ with length N_c, which are forwarded to each transmit antenna. Training symbols, which can include non-zero or zero training, are then inserted to form $\bar{\mathbf{u}}_\mu(k)$ with length N.

Following the insertion of training symbols, we operate the guard insertion matrix $\mathbf{T}$. After parallel to serial (P/S) multiplexing, the blocks $\{\mathbf{u}_\mu\}_{\mu=1}^{N_t}$ with $P \times 1$ size are transmitted through the frequency-selective channels, which in discrete-time equivalent form have a finite impulse response $h^{(\nu,\mu)}(l)$, $l \in [0, L]$. These channels account for transmit/receive-filter $g_\mu(t)/g_\nu(t)$ and the frequency-selective multipath $g_{\nu,\mu}(t)$; i. e., $h^{(\nu,\mu)}(l) = (g_\mu \star g_{\nu,\mu} \star g_\nu)(t)\,|_{t=lT}$, where T is the sampling period which is chosen equal to the symbol period. In the presence of a frequency offset $f_o^{(\nu,\mu)}$, the samples at the ν-th receive-antenna filter output can be written as:

$$x_\nu(n) = \sum_{\mu=1}^{N_t} e^{j\omega_o^{(\nu,\mu)} n} \sum_{l=0}^{L} h^{(\nu,\mu)}(l) u_\mu(n-l) + \eta_\nu(n) \qquad (1)$$

where $\omega_o^{(\nu,\mu)} := 2\pi f_o^{(\nu,\mu)} T$ are the normalized CFOs, which could be due to the Doppler effect or mismatch between the μ-th transmitter and ν-th receiver oscillators; and $\eta_\nu(n)$ is zero-mean, white, complex Gaussian distributed noise with variance σ_η^2. The sequence is then serial to parallel (S/P) converted into $P \times 1$ blocks $[\mathbf{x}_\nu(k)]_p = x_\nu(kP+p)$. Selection of our block size greater than the channel order implies that each received block $\mathbf{x}_\nu(k)$ depends only on two consecutive

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