Semi-Blind Equalization for OFDM using Space-Time Block Coding and Channel Shortening

Literature Survey

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Abstract

Space-time coding is a powerful way to leverage spatial diversity gain and improve reliability in multiple input multiple output (MIMO) communication systems. In this paper, we examine a semi-blind adaptive time-domain equalization (TEQ) strategy in conjunction with Alamouti space-time coding to achieve channel shortening. Channel shortening is necessary when the channel response is longer than the cyclic prefix (CP) in a multi-carrier modulation scheme, which precludes low complexity equalization in the frequency domain. Although several TEQ schemes for MIMO systems exist, there has been limited research in leveraging Alamouti space-time coding to enhance channel shortening capabilities. We propose a cascaded receiver design, which first performs channel shortening with a blind algorithm developed by Martin et al. in [1]. The receiver then decodes the Alamouti code using a semi-blind channel estimation technique [2], and uses the resulting channel estimate to perform frequency domain equalization.

I. Introduction

Space-time coding is a powerful way to leverage spatial diversity gain and improve reliability in multiple input multiple output (MIMO) communication systems. We consider a multi-carrier MIMO system model with additive noise and inter-symbol interference (ISI). Symbols sent at different times can arrive simultaneously at the receiver after traversing multiple reflective paths, causing ISI. Many spatial-temporal algorithms have been developed to suppress this interference, ranging from high-complexity maximum likelihood sequence estimators to simple minimum mean square error equalizers [3].

Frequency domain equalization is a popular technique for recovering the transmitted signal. However, in a multi-carrier modulation (MCM) scheme, channel shortening is necessary when the channel response is longer than the cyclic prefix (CP). Although several TEQ schemes for MIMO systems exist, there has been limited research in leveraging Alamouti space-time coding to enhance channel shortening capabilities.

This report is organized as follows. Section II introduces MIMO concepts such as modulation, channel modeling and equalization. Section III presents Alamouti coding and its advantages. Section IV describes a blind multi-channel shortening algorithm, while Section V details how the Alamouti space-time code can be used for channel estimation, enabling equalization after shortening. Section VI provides concluding remarks and summarizes this paper.

II. Background

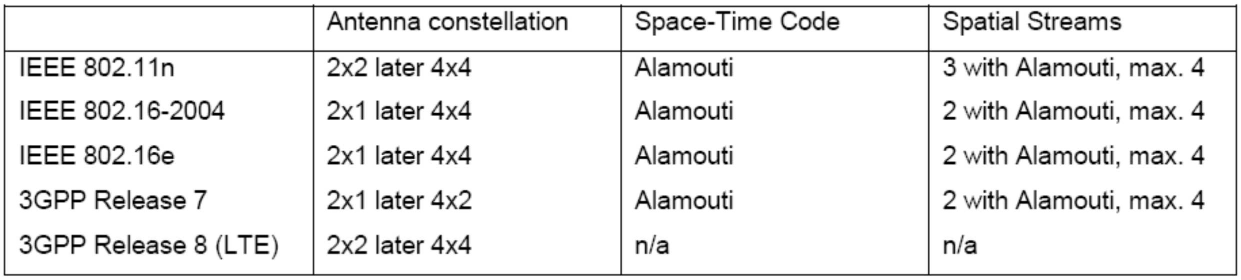
With MIMO communications, we are faced with more challenges in equalization such as increased transmitter and receiver complexity. Many wireless standards which incorporate

MIMO, such as 802.11n, 802.16e, 3GPP LTE, and 802.20, have chosen MCM, also known as orthogonal frequency division multiplexing (OFDM), for its simplified equalization and resilience to multipath [4]. In multi-carrier systems, channel equalization is simplified because we can partition the channel into many narrowband flat-fading sub-channels that can be equalized individually. This is only the case, however, when the channel impulse response length is less than the length of the cyclic prefix (CP), a redundant block of symbols appended to the beginning of the packet. To ensure that this is true, one can send a long CP or employ a time domain equalization (TEQ) strategy to shorten the channel length.

After shortening, a frequency domain equalizer (FEQ), which is composed of a complex one tap filter for each frequency bin, corrects the residual amplitude scaling and phase rotation. The two traditional approaches to adaptive channel shortening are training-based and blind, extensively studied by Martin et al. in [5] and Melsa et al. in [6]. While the training-based approach usually yields faster equalizer convergence, the system can suffer from a decrease in throughput due to the frequent transmission of training symbols in a time-varying channel. Blind methods excel in this regard, but may not converge as quickly as trained equalizers, nor do they provide a straightforward way to compute the optimal FEQ. [1] A semi-blind technique can offer a good compromise, combining a limited amount of training with the known signal structure.

The multipath channel can be modeled in several ways, such as with a multi-tap FIR filter or a Rayleigh random process which is comprehensively examined in [3,7]. An FIR filter can simulate the effect of discrete signals transmitted at different times arriving simultaneously, while a Rayleigh random process is a good model when there is no dominant direct-path component in the channel. We will examine channels which vary slowly in time due to a mobile transmitter, such as in the case of a walking pedestrian, requiring the receiver to track the evolving channel.

III. Space-Time Coding - Alamouti Codes



	Antenna constellation	Space-Time Code	Spatial Streams
IEEE 802.11n	2x2 later 4x4	Alamouti	3 with Alamouti, max. 4
IEEE 802.16-2004	2x1 later 4x4	Alamouti	2 with Alamouti, max. 4
IEEE 802.16e	2x1 later 4x4	Alamouti	2 with Alamouti, max. 4
3GPP Release 7	2x1 later 4x2	Alamouti	2 with Alamouti, max. 4
3GPP Release 8 (LTE)	2x2 later 4x4	n/a	n/a

Table 1. MIMO configurations for several standards [4]

Transmit-diversity schemes are a powerful way to improve reliability, data rate, and capacity of a MIMO system. The Alamouti space time code (STC) [8] in particular, is a simple, low complexity transmit-diversity scheme that does not require any feedback from the receiver to the transmitter. As Table 1 shows, Alamouti coding has been readily adopted in many recent communication standards. In cellular systems, the advantage of utilizing transmit diversity is that only the base-station is required to have multiple antennas, while the mobile receivers, typically cost and size constrained, only need one antenna [2].

Figure 1 illustrates the simple structure of the Alamouti code. A benefit of this particular code is that it does not require any feedback from the receiver. Also, since two packets are simultaneously transmitted from two antennas over two time slots, the code does not sacrifice rate to gain full spatial diversity, providing robustness against channel distortions. At the receiver, the redundancy in the signal structure allows training based and semi-blind techniques for channel estimation and decoding. Blind estimation is not possible due to the inherent ambiguity in the Alamouti code as discussed in several papers [2]. Training must be sent frequently in time-varying channels to update the receiver's channel estimate, reducing the bandwidth efficiency of the system. Semi-blind techniques which use only a minimal amount of training may be preferable.

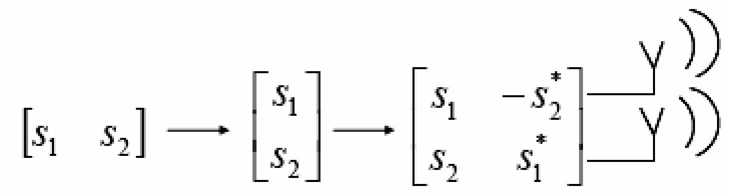

$$\begin{bmatrix} s_1 & s_2 \end{bmatrix} \longrightarrow \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \longrightarrow \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}$$

Figure 1. Alamouti space time code for a two antenna transmitter [4]

Although the decoded result provides the same diversity gain as maximal-ratio receiver combining (MRRC) with multiple receive antennas, a STC alone does not eliminate the effects of intersymbol (ISI) and intercarrier (ICI) interference [2]. Hence equalization is necessary.

IV. Blind Channel Shortening

In [1], Martin et al. have developed the Forced Redundancy with Optional Data Omission (FRODO) cost function which is a low-complexity, blind channel shortening algorithm for a multi-carrier MIMO system. FRODO works to restore the redundancy of the cyclic prefix, inducing a shortened channel. The FRODO algorithm is a generalization of the Multicarrier Equalization by Restoration of RedundancY (MERRY) algorithm, presented in [9], that has been extended to work in a MIMO configuration with fractional spacing. In their paper, Martin et al. avoid the complication of an FEQ design by using differentially encoded binary phase shift keying. However, they mention that an adaptive FEQ can be designed without training when given a finite alphabet or constellation. In addition, they do not address how to spatially separate the two signals, noting only that the joint SNR is enhanced after channel shortening.

V. Semi-Blind Channel Estimation/Equalization

For most OFDM systems, training symbols are sent out intermittently in order to maintain an updated channel estimate and perform channel equalization. These training symbols, however, consume bandwidth and lead to a loss in the overall data rate of the system. Hence, blind and semi-blind approaches, which rely on redundancy and knowledge of transmitted messages, have become increasingly relevant.

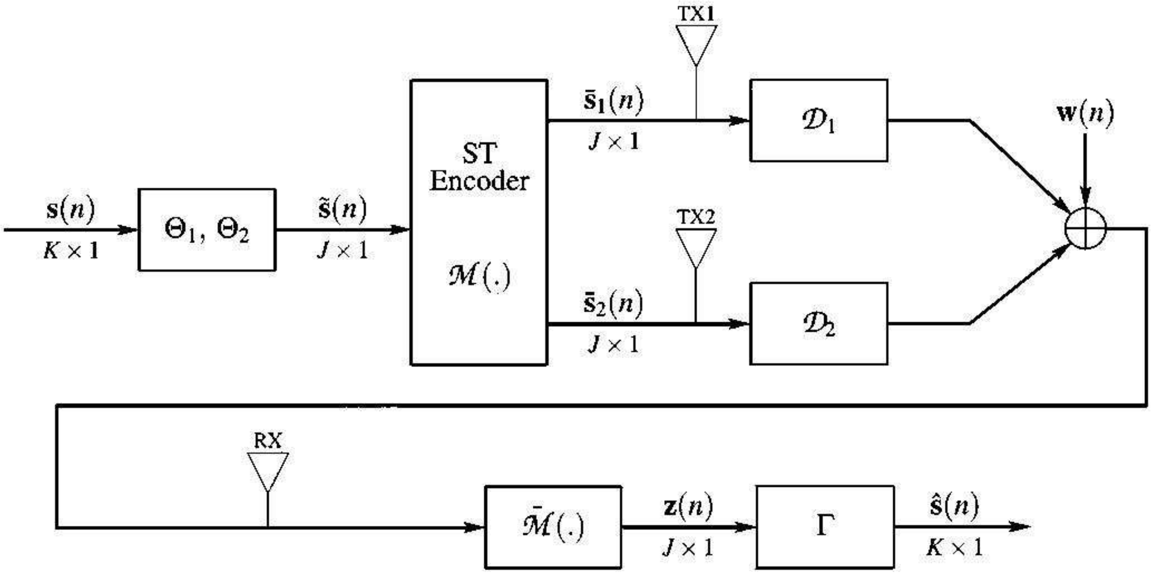


Figure 2. Zhou- Block Precoded ST-OFDM Transceiver Model. Precoding added to s(2n) by Θ_1 and s(2n+1) by Θ_2, then Alamouti coded and transmitted in parallel through channels D_1 and D_2. Both signals received by a single antenna forming w(n), then decoded and equalized by $\overline{M}$ and Γ. [10]

In [10], Zhou et. al. showed that for a general MIMO space-time coded orthogonal frequency division (ST-OFDM) system, redundancy introduced by linear precoding in conjunction with Alamouti coding can be used to identify and equalize frequency-selective FIR channels. Linear precoding spreads symbols onto multiple subcarriers, providing robustness to common channel nulls, which normally may result in unrecoverable data. Two distinct precoding matrixes,Θ_1 and

Θ_2 can be constructed from the first K and (2:K+1) columns of a JxJ Walsh-Hadamard matrix where J is the length of the OFDM symbol including the CP and K is the number of information symbols. [10]

In addition, they show that by using a distinct precoder for each transmitter in conjunction with Alamouti coding, it is possible to resolve channel estimates up to a single scalar ambiguity. Then, only a small number of pilot symbols are required to eliminate this unknown. They find that using distinct precoders leads to a 3db gain over identical precoders which suffer from greater channel estimation error due to an additional scalar ambiguity that must be resolved. Inserting the pilot symbols before precoding ensures that the symbols are robust towards channel nulls, whereas inserting them after precoding will place the symbols at a specific subcarrier frequency. [10]

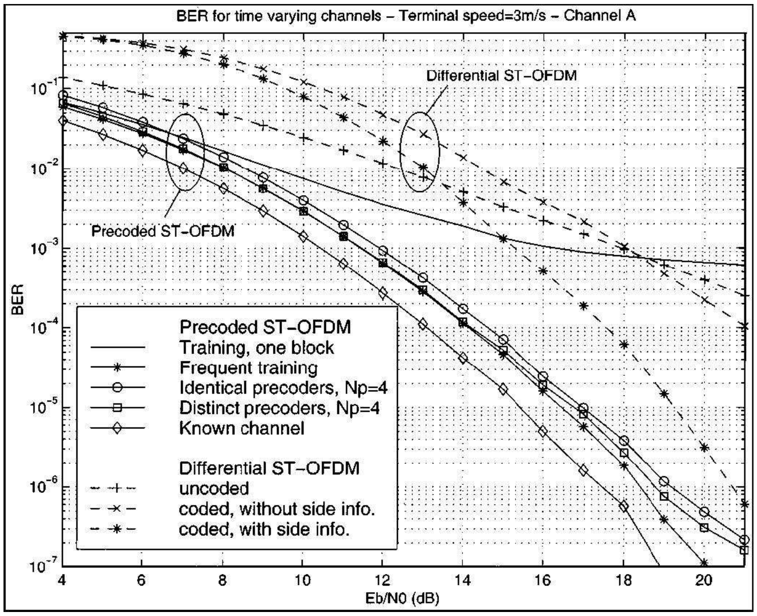


Figure. 3. BER comparisons v = 3 m/s W = 150 blocks.[10]

Simulations of slowly time-varying FIR channels generated using channel model A specified by HIPERLAN/2 [11], as shown in Figure 3, indicated that precoded ST-OFDM using semi-blind channel estimation nearly matches the performance of a frequent training approach detailed in [12] except at very high SNR. However, the OFDM symbols consisted of 32 subcarriers with an 8 symbol long CP. This incurs a 25% rate penalty which we can reduce with channel shortening.

VI. Conclusion

In multi-antenna, multicarrier modulation communication systems, low complexity channel equalization is desired. For OFDM systems in particular, a simple FEQ is preferred, and hence channel shortening is required to keep the channel impulse response length less than that of the guard interval. In this paper, we motivated the need for blind channel shortening and semi-blind equalization. We proposed a three-stage receiver structure combining a low complexity blind channel shortening algorithm with semi-blind channel equalization utilizing Alamouti coding.

We will develop simulations using a MIMO LabVIEW Toolkit [13] and Matlab in order to assess the overall performance, robustness to errors such as symbol/frame timing errors, and packet efficiency of our receiver design. A ST Equalizer and Viterbi decoder algorithm using 24 data symbols and CP length of 8 on a Ralyeigh fading channel will be used for comparison.

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