# PILOT SYMBOL ASSISTED TCM CODED SYSTEM WITH TRANSMIT DIVERSITY

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## ABSTRACT

In this paper, multiple-input multiple-output (MIMO) system based on concatenated inner space-time block code (STBC) and outer multidimensional trellis coded modulation (TCM) encoder is designed over slow time-varying Rayleigh fading channels. We develop here a novel MIMO channel estimation algorithm that exploits a pilot symbol assisted modulation (PSAM) which has been proven to be effective for fading channels. The proposed concatenated scheme takes advantage of both the high coding gain from its outer-coder and the ease of the channel estimation from the use of PSAM technique. Simulation results demonstrate the good performance of the proposed MIMO scheme against the perfect coherent counterpart for the same spatial diversity.

***Index Terms***— pilot symbol assisted modulation; MIMO system; STBC codes, TCM codes.

## 1. INTRODUCTION

Over the past several years, space-time block coding [1]-[2] has sparked wide interest as it promises to significantly improve the reliability of the transmission in MIMO systems. Owing to its exploiting both the space and time diversities, this linear code is an effective technique for mitigating the impairments of wireless fading channels. Despite its advantages, this coding scheme does not achieve any additional coding gain [3]. In addressing this issue, STBC code should be concatenated to an outer channel coder that provides large coding gain [3]. Several authors have studied the Low-density Parity-check (LDPC) and the trellis coded modulation as outer coders in conjunction with STBC in order to achieve a coding gain [3]-[5]. TCM is a technique that combines error-correcting coding and modulation in digital communications. According to [3], TCM schemes operating on a MIMO system represent a powerful outer code.

For decoding purpose, the TCM-STBC systems require the channel state information (CSI) which is basically obtained through channel estimation techniques or differential detection methods [6]. One of the most popular MIMO channel estimation is to insert training symbols into the transmitted information data and to investigate it at the receiver to render accurate CSI. Indeed, mobile communication systems are characterized by channel responses with time-varying magnitude and phase. In order to efficiently combat variations on a fading channel, the MIMO channel may be estimated using the well-known pilot symbol assisted modulation (PSAM) scheme [7]-[8]. This technique is originally established in [7] for single-input single-output (SISO) systems. It has attracted intense interest as it has been proven efficient in time varying fading channel [9]-[10]. The basic idea of PSAM is to periodically insert a known pilot symbol into data blocks, instead of sending the training sequences at the beginning of transmission. Therefore, the CSI can be extracted at the receiver. There have been a large number of previous works on PSAM. It is widely studied over selective and nonselective fading channels [8]-[11]. The optimum number of pilot symbols was derived in [10] to yield minimum bit error rate of a single antenna wireless system for slow fading channel. In [11]-[12], the achievable rate PSAM of single and multiple antenna systems was analyzed. Recently, channel estimation based PSAM for Alamouti coded transmission has been studied in [13]-[14].

According to the literature, the pilot symbol assisted modulation has recently emerged as a promising MIMO estimator for time-varying wireless communication systems. It offers acceptable performance with reasonable computing complexity [10]. Therefore, the use of PSAM approach to perform channel estimation is suggested here for practical setting. In this work, a performance analysis of the novel pilot symbol assisted modulation system operating on MIMO channels and TCM-STBC codes is explored. There are two broadly classified TCM categories: the conventional TCM [15] and the multidimensional trellis coded modulation [16] which is known to provide high bandwidth efficiency. In this paper, we focus on the performance analysis of the second kind of TCM as an outer code. We study here on the well-known four multidimensional TCM (4D-TCM) scheme described in [4] which offers high data rate. A symbol interleaver is also introduced in the transmission chain in order to reduce the effect of burst error due to fading. The channel characteristics are assumed to be slow fading and constant over the STBC codeword period. The received pilot signals provide information about the MIMO channel as estimated by the novel channel estimation before being interpolated. Simulation results prove the efficiency of the proposed system which shows good bit error rate (BER) performance compared to the perfect coherent system without any excessive complexity growth.

The rest of this paper is organized as follows. We first describe the pilot assisted MIMO system and the channel model in Section 2. Section 3 is devoted to the 4D-TCM design and the pilot insertion into the data blocks in which pilot spacing optimization is presented. PSAM channel estimation and decoding scheme are discussed in the section 4. Numerical results of the proposed coherent MIMO system are presented in Section 5.

## 2. SYSTEM MODEL

As shown in Fig. 1, we consider new coherent MIMO scheme based on concatenated inner STBC and outer multidimensional TCM encoder over time-varying fading channel. At the transmitter side, the information bits are encoded through trellis coded modulation. Then the output symbols of the TCM encoder are interleaved by a matrix symbol interleaver. With the aim of enabling MIMO channel estimation, the PSAM technique is applied so that pilot symbols are periodically inserted into the interleaved data symbols. The combined signals are then coded by STBC code equipped by two transmit antennas and one receive antenna. At the receiver side, the received pilot signals are extracted and used in order to estimate the MIMO channel. The eight phase-shift keying (8-PSK) modulation is considered in this paper. The signal amplitude is divided by $\sqrt{2}$ such that the total transmitted power of the baseband signals in the two transmitting antennas system is unitary.

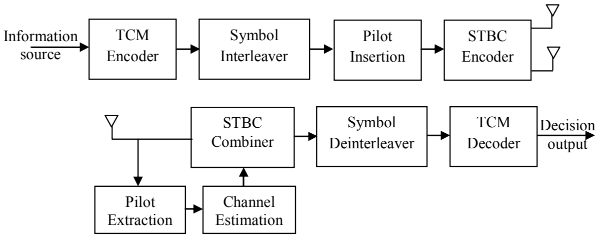

**Fig1.** Block diagram of pilot assisted MIMO system.

Without loss of generality, we consider in this paper only the Alamouti code operating with one receive antenna. Since each two modulated symbols $S = (s_1, s_2)$ are mapped according to the orthogonal linear space-time block coding, the transmission matrix $C$ given by (1) verifies the orthogonality property. The encoder outputs are transmitted throughout consecutive transmission periods using the two transmit antennas. Thus, this STBC coding achieves full diversity with full rate.

$$C = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \quad (1)$$

At the receive antenna, the signal corresponding to two STBC codeword periods, $Y_{1\times 2}$, can be written as:

$$Y = HC + N \quad (2)$$

The vector $H = (h_1, h_2)$ corresponds to the MIMO channel fading coefficients. Its complex path gains are generated according to slow fading channel. We adopt herein the well-known Jakes model that was shown to be sufficient for generating slow channel variations. The real and imaginary parts of $\{h_j\}$ are independent with autocorrelation function $R_c$ formulated by $R_c(\tau) = 0.5 J_0(2\pi f_D T_s \tau)$, where $J_0(.)$ is the zeroth order Bessel function of the first kind and $\tau$ represents the correlation lag. $f_D$ denotes the Doppler frequency shift due to the terminal mobility, and $T_s$ is the transmitted symbol period, then the normalized fading rate is given by $f_{\mathrm{dn}} = f_D T_s$. The complex noise is represented by the vector $N \sim \mathcal{CN}(0, \sigma_n^2)$, where $\sigma_n^2$ denoted the dimensional noise variance.

## 3. TCM DESIGN AND PILOT INSERTION

### 3.1. Four-Dimensional TCM 8PSK Scheme

The STBC coding does not provide any coding gain. In order to achieve better performance over fading channels, concatenated TCM encoder with STBC represents potential viable option. We consider in this paper the multidimensional TCM. We present a concatenation system composed by a multidimensional TCM and the STBC code. TCM schemes using multidimensional constellations can improve the STBC performance.

The convolutional encoder and constellation mapper for the 4D-TCM scheme designed in this paper can be found in [4]-[16]. The outer coder is 4D-TCM with 2 bits/symbol spectral efficiency designed by the CCSDS. The considered coding scheme has a rate of ¾ and a constraint length v = 7 and consequently has 64 trellis states. Note that optimal multidimensional TCM concatenated to STBC scheme are optimal in perfect CSI knowledge cases. Divsalar and Simon show in [17] the design criteria of multidimensional M-PSK TCM codes for fading channels. Its design criterion is maximizing the effective code length (ECL) which is the length of the shortest error event path and also stands for the minimum product distance between any two distinct constellation points [17]. Since we consider a concatenation of multidimensional M-PSK TCM scheme in conjunction with STBC, optimal trellis code contrived for fading channels is considered.

In order to prevent the appearance of long bursts of errors within the received signal and to improve the coding gain, a symbol interleaver is introduced between the outer multidimensional TCM coder and the inner STBC coder. Because of the use of PSAM technique, the interleaver is applied before the pilot insertion into TCM coded symbols.

### 3.2. Pilot insertion

The pilot symbols are inserted equally spaced with a pilot spacing $F$ into the interlevead symbols after being coded by the TCM scheme. The known pilot symbols come from the same signaling set as the 8-PSK modulation. Typically, each pilot symbol is selected from the constellation point with real value, i.e., $s_p = 1/\sqrt{2}$. Let $E_P$ and $E_S$ denote the required pilot and symbol energy, respectively. In the proposed estimation approach, pilot and data symbols have the same transmit power.

The pilot symbol transmission can be viewed as sampling of a band-limited process. Therefore, the pilot spacing in a fading channel with Jakes' spectrum must satisfy the Nyquist criterion. According the sampling theorem, the pilot symbols should be transmitted at least $2f_D$ of rate. Consequently, the pilot spacing $F$ should satisfy the following expression:

$$F \leq \frac{1}{2f_D T_s} \tag{3}$$

Moreover, it should be carefully chosen to balance between the channel estimation error and the pilot sequence. The optimum pilot spacing for MIMO system is given as [18]:

$$F_{opt} = 2.\left[1 + \sqrt{1 + \frac{1}{4f_{dn}}}\right] \tag{4}$$

As clearly seen in (4), $F_{opt}$ does not depend on SNR. The unique dependence of the optimal pilot spacing is on the normalized Doppler spread $f_{dn}$.

After pilot insertion, each transmit vector $S$ composed by two modulated symbols is mapped according to the code matrix $C$ corresponding to the orthogonal STBC.

## 4. PSAM ESTIMATION AND DECODING SCHEME

### 4.1. Pilot Extraction and Estimation MIMO Channel

Consider a MIMO system equipped by two transmitting antennas and one receiving antenna over slow flat fading. The transmitted symbols are formatted into frames of length $F$ in which the pilot symbols are inserted at times $t = iF$ and $t = (iF + 1)$ ($i$ is an integer). Assuming all pilot symbols $s_p$ equal to $1/\sqrt{2}$, the received pilot signals at these times can be written as:

$$\begin{cases} y_1(iF) = (h_1(iF) + h_2(iF))s_p + n_1(iF) \\ y_2(iF) = (-h_1(iF) + h_2(iF))s_p + n_2(iF) \end{cases} \tag{5}$$

Where $y_1(iF)$ is the received pilot signal at time $t$, and $y_2(iF) = y_1(iF + 1)$.

We propose an estimation method of the coefficients channel at pilot locations as follows:

$$\begin{cases} \hat{h}_1(iF) = \frac{y_1(iF) - y_2(iF)}{2s_p} \\ \hat{h}_2(iF) = \frac{y_1(iF) + y_2(iF)}{2s_p} \end{cases} \tag{6}$$

Substituting (2) into (6), the expression of the estimated complex path gains can be expanded as:

$$\begin{cases} \hat{h}_1(iF) = h_1(iF) + \Delta h_1 \\ \hat{h}_2(iF) = h_2(iF) + \Delta h_2 \end{cases} \tag{7}$$

Where $\Delta h_j$ represents the estimation error.

Each element of the complex estimated channel at pilot symbol location is written by:

$$\hat{h}(iF) = \hat{\alpha}(\mathrm{iF})e^{j\hat{\theta}(iF)} \tag{8}$$

Where $\hat{\alpha}(\mathrm{iF})$ is the estimated fading channel envelope and $\hat{\theta}(iF)$ is the estimated phase. The fading distortion at the information symbols can be estimated by interpolation the sequence of $\hat{H}(iF)$ using the Fourier Transform (FFT) interpolation. This interpolation method is done in three steps. Firstly, the estimated channel vector corresponding to pilot positions are transformed from the time domain into the frequency domain by taking the fast version of the Discrete Fourier Transform (DFT). The resulting vector is denoted by $H_{FFT}$. Next, zeros are stuffed in the middle of $H_{FFT}$ to yield the frequency samples with length $L$ equal to that of the coefficients channel vector corresponding to data information, where $L$ is an integer power of two. Then, the inverse fast discrete Fourier transform (IDFT) is applied to the obtained signal. The signal at the output of the IDFT represents the interpolated samples of the estimated MIMO channel coefficients. We note the interpolated channel vector for each data symbols coded by STBC by $\hat{H} = [\hat{h}_1, \hat{h}_2]$. It is necessary to point out that this interpolation method is simple because only the zero padding and the discrete FFT operation are required.

### 4.2. STBC combiner and TCM decoder

For the considered system and slow time-varying fading channel ($f_D T_s \ll 1$), the MIMO channel coefficients are assumed be constant over STBC codeword period, therefore the conventional STBC combiner can be applied at the receiver side. However, in the case of fast fading channel such as in [14], when the channels vary on a symbol-by-symbol basis, the ML detection has high complexity.

$$\begin{cases} \tilde{s}_1 = \hat{h}_1^* y_1 + \hat{h}_2 y_2^* \\ \tilde{s}_2 = \hat{h}_2^* y_1 + \hat{h}_1 y_2^* \end{cases} \tag{9}$$

The symbols at the output of the STBC combiner are then deinterleaved and fed into the TCM decoder which uses the well-known Viterbi algorithm. At the decoder's output, we determine an estimate of the binary input sequence.

## 5. RESULTS

In this section, we provide simulation results for evaluating performance of the proposed pilot assisted 4D-TCM-STBC system. For all computer simulations, the outer code is assumed to be the four dimensional trellis coded modulation scheme, 4D-8-PSK-TCM, with 2bits/symbol spectral efficiency. Pilot symbols are equally spaced as described in section 3. The channel is assumed to be slow fading corresponds to a typical digital cellular system operating at carrier frequency $F_c = 900\ MHz$. The speed of the mobile user is $v = 120\ \mathrm{Km/h}$. We assume that the sampling frequency $F_s$ is 100 KHz. The maximum Doppler frequency is $F_D = 100\ Hz$. Hence, the normalized fading rate is 0.001. Considering the optimization of pilot symbol spacing given by (4), the optimal pilot period is $F_{opt} = 32$. The interleaving depth (ID) is chosen to be equal to 16 coded symbols. In Fig. 2, we present the BER performance, as function of SNR, of the novel pilot assisted 4D-TCM-STBC system equipped by two transmit antennas. For comparison purpose, the BER performances of the perfect coherent scheme are also plotted in this figure. The curves indicate that the BER performance of the 4D-TCM-PSAM-STBC is within 2.5 dB apart from the perfect coherent counterparts at typical SNR range in slow fading channel. This BER performance loss can be explained both by the power loss due to the pilot insertion and the errors of the pilot estimation and the interpolation function.

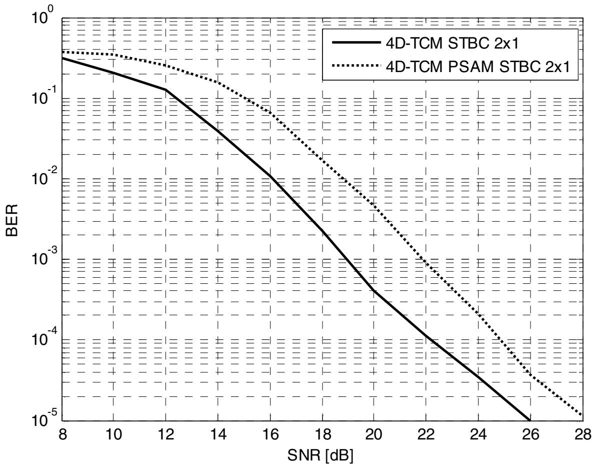

**Fig.2.** BER performance both of 4D-TCM-STBC and 4D-TCM-PSAM-STBC schemes for MIMO 2x1 systems

## 6. CONCLUSION

A simple pilot assisted MIMO scheme has been presented for 4D-TCM-STBC system over slow time-varying fading channel. Indeed, we studied in this contribution two issues: the MIMO PSAM channel estimation and achieving a coding gain by concatenation STBC code with multidimensional trellis coded modulation as outer code. At first, the transmitter just inserts known equally and optimally spaced pilot symbols into TCM coded symbols after being interleaved. The combined signal is then coded by Alamouti code. The transmitted signal is corrupted by slow fading and additive noise. The slow fading channel is modeled by Jakes model; also it is chosen to be constant over the STBC codeword period. The receiver estimates the channel measurements provided by the pilot symbols. The estimated channel responses are then used by the STBC combiner that is followed by a deinterleaver and the TCM decoder. The performances of the proposed system are simulated and compared with the perfect coherent design. A tolerable signal-to-noise penalty is shown compared to perfect CSI case. Further investigations could be devoted to estimate the MIMO fading channel using the PSAM technique considering fast fading channels.

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