Int. J. Electron. Commun. (AEÜ) 80 (2017) 80–85

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

Regular paper

Performance analysis of adaptive space-time coded systems with continuous phase modulation

Guowei Lei [a,b], Yuanan Liu [b], Xuefang Xiao [c,*]

[a] School of Science, Jimei University, Xiamen 361021, China
[b] School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
[c] School of Opto-electronic and Communication Engineering, Xiamen University of Technology, Xiamen 361024, China

ARTICLE INFO

Article history:
Received 9 December 2015
Accepted 27 June 2017

Keywords:
MIMO
Adaptive STC
Continuous phase modulation

ABSTRACT

In modern wireless communications, it is getting urgent to make a better trade-off between reliability and effectiveness in wireless systems. In fact, the use of coded cooperation (e.g. space time coding) in multiple input and multiple output (MIMO) system has drawn much attention for this purpose. However, it needs to be further investigated how to select the space time codes (STC) adaptively. On the other hand, continuous phase modulation (CPM) is a promising technology for its merits of power and spectrum efficiency. This study is to consider adaptive space time coded CPM systems. The criterion of adaptive switching is based on the *Frobenius* norm and the thresholds between STC schemes. Analysis and simulation are made to the proposed system in terms of frame error rate and data rate.

1. Introduction

In wireless communication, mobile internet and multimedia transmission have ongoing demands for capacity. On the other hand, the available radio spectrum is limited. An effective and practical method to meet the demands is to employ multiple-input and multiple-output (MIMO) techniques, which currently have involved in many standards, such as 802.11n for Wireless Local Area Networks (WLANs) [1], IEEE 802.16e for worldwide interoperability for microwave access (WiMax) [2], and so on. In practice, a coding technique, i.e. space-time coding (STC) [3], is used to exploit the MIMO channel fading and minimize transmission errors without expense of extra bandwidth. To date, there have been various approaches proposed in STC. The most common structures of them include layered space-time codes (LST), space-time block codes (STBC), and space-time trellis codes (STTC). LST was first proposed by Foschini [4]. It is a scheme of spatial multiplexing in essence, which can achieve high data rate. But it has not any diversity or coding gain. STBC was first proposed by Alamouti [5], and extended to general orthogonal design, which provides it with diversity gain to counteract channel fading. Although it does not achieve high data rate, it is still pragmatic in implementation owing to its simplicity of decoding. STTC was first proposed by Tarokh [6]. It has better performance by combining error control coding and modulation. But meanwhile, it has to bring forth unbearable decoding complexity as the number of antenna grows. As is well known, there should be several basic criteria to evaluate wireless communication systems, which are called effectiveness (data rate/spectral efficiency), reliability (error performance/quality of service), and complexity of system. To make a trade-off among the various aspects mentioned above, some concepts of "MIMO switching" [7,8] or "hybrid STBC" [9,10] have been brought forward. In so called MIMO switching between spatial multiplexing and orthogonal space time codes [7,8], there is a switching criterion which was based on the minimum Euclidean distance (MED) as a function of the channel condition. In hybrid STBC [9,10], the schemes of STBC and LST were combined together by transmitting parallel streams of data from different antennas. To achieve more efficient link in adaptive MIMO switching, a hardware design of dual-mode STC/SM was presented from an implementation point of view [11], in which the detector was only designed for a 2×2 MIMO system. All those efforts that adjust transmission mode according to the channel information or the needs of different users may be referred to as adaptive space time coding (ASTC). To the best of the authors' knowledge, nominal ASTC mainly involves beamforming [12] or power allocation [13], or adaptive switching between spatial multiplexing (SM) and spatial diversity (i.e. Alamouti scheme) in wireless industrial network [14], or adaptive selecting optimal Alamouti code matrix in cooperative MIMO systems [15]. In addition, great efforts that have followed ASTC are usually focused on linear modulations (such as

* Corresponding author.
E-mail address: xfxiao@xmut.edu.cn (X. Xiao).

http://dx.doi.org/10.1016/j.aeue.2017.06.034
1434-8411/

PSK, QAM and so on). Relevant literatures about non-linear modulations have not been found thus far. Continuous phase modulation (CPM) is a promising technology for its features such as constant envelope and phase continuity. Its constant envelope makes it more suitable for low cost non-linear power amplifier, and its phase continuity makes its bandwidth more compact. Therefore CPM signal is of practical importance in satellite and terrestrial communication. In particular, one of its subclass, i.e., GMSK is well applied in both GSM and DECT standards. The combination of STC and CPM has been considered an optimal choice that can improve its performance and capacity without loss of power and spectrum efficiency. Space-time coded CPM system was first proposed by Zhang and Fitz [16]. They also extended PSK and QAM rank criterion to STTC-CPM and gave general STC design rules for CPM MIMO systems in quasi-static fading channel. To simplify the receiver further, a multi-antenna layered space time system with binary CPM was described by Zhao and Giannakis [17]. To take into account the inherent memory of CPM in Alamouti code, Wang and Xia [18,19] used a continuous correction function and proposed an orthogonal STC design for full response and partial response CPM. To derive bit error rate (BER) and frame error rate (FER) conveniently, Silvester et al. [20], proposed a burst-based orthogonal space time block coding for CPM. To evaluate the performance of CPM MIMO systems in Gaussian and Rayleigh channels, the authors [21] derived the average exact bound of bit error probability (BEP) via Laurent decomposition. Unfortunately in both [11,21], their work was mainly focused on MIMO systems with 2 transmit and 2 receive antennas. In this paper, we investigate performance of ASTC in CPM-MIMO systems, which involve three basic STC schemes: orthogonal space time block codes (OSTBC), vertical layered space time codes (VBLAST), and Hybrid space time codes (Hybrid STC). The switching criterion in ASTC is based on the *Frobenius* norm of channel matrix [22]. At the receiver, the space-time superposition of CPM signals is decoupled using method of matrix regrouping [9]. In ASTC system with CPM, signal matrix is used to evaluate the pair wise probability (PEP) of OSTBC and hybrid STC. Variables α and β are used to investigate the performance of FER and data rate in ASTC system. The rest of this article is organized as follows. The proposed system is briefly described in Section 2. The error performances is analysed and the process of calculating data rate is presented in Section 3. In Section 4, simulated results are presented and discussed. Finally, the work is concluded in Section 5.

2. System model

The adaptive space-time coded system with CPM is described in Fig. 1. Information bits $\boldsymbol{I}$ are fed into adaptive STC to get codeword vectors $\boldsymbol{D}$ with the length of N_tN_c, where N_t denotes the number of transmit antennas, N_c denotes the length of one frame. The CPM

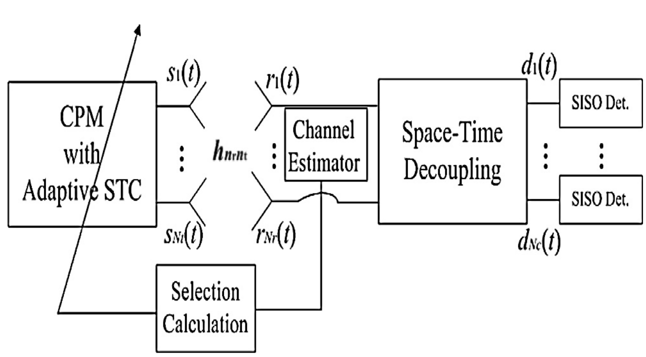

Fig. 1. Adaptive space-time coded system with CPM.

modulated signals are transmitted over N_t antennas. Assuming that the uncorrelated fading channel is invariant within a frame of consecutive N_c symbols, and varies from one frame to another. More specifically, we denote channel coefficients as $\boldsymbol{H}_{N_r\times N_t}$. With these assumptions, the received signals can be represented as

$$r_{nr}(t;\boldsymbol{D}) = \sum_{nt=1}^{Nt} h_{n_r n_t} s(t;\boldsymbol{D}_{nt}) + w_{n_r}(t) \quad n_r = 1,\ldots,N_r \tag{1}$$

where $\boldsymbol{D}_{nt} = [d^1_{n_t},\ldots,d^{N_c}_{n_t}], h_{n_r n_t}$ denotes each entry of channel matrix $\boldsymbol{H}_{N_r\times N_t}$ N_r is the number of receive antennas, $w(t)$ denotes Added White Gaussian Noise (AWGN) with variance $2N_0$. The baseband CPM waveform has complex form as [23]

$$s(t;\boldsymbol{D}) = \sqrt{E_s} exp[j(\varphi(t;\boldsymbol{D}) + \theta_0)] \tag{2}$$

and

$$\varphi(t;\boldsymbol{D}) = 2\pi h_p \sum_{n=-\infty}^{\infty} D_n q(t - nT) \tag{3}$$

where E_s is the power of CPM signal, T is the symbol period, h_p is the modulation index, $j \overset{\text{def}}{=} \sqrt{-1}$, $\{D_n\}$ is the sequence of independent information symbols drawn from $\{\pm1,\pm3,\ldots\}$, θ_0 is initial phase, $q(t)$ is the phase smoothing response.

Channel state information (CSI) is assumed to be estimated by the receiver. The receiver calculates the *Frobenius* norm of the channel matrix and feeds back to the transmitter as the selection criterion of three STC schemes. Meanwhile, the received signals are decoupled into multiple streams of the CPM signals, which are demodulated in the end.

3. Performance analysis

3.1. Frame error rate

Since the pair wise probability (PEP) is allowed to evaluate the performance of STC-MIMO system, the PEP conditioned onto fading channel statistics can be written as follows

$$\boldsymbol{p}(\boldsymbol{S} \to \widehat{\boldsymbol{S}}) = \boldsymbol{Q}\left(\sqrt{\frac{\boldsymbol{E_s}}{2\boldsymbol{N}_0}}\|\boldsymbol{H}(\boldsymbol{S} - \widehat{\boldsymbol{S}})\|\right) \tag{4}$$

where $(\cdot)^H$ denotes the Hermitian operation, $Q(\cdot)$ is the Q-function. In (4), the PEP is determined by the *Euclidean* norm of codeword.

For convenience, the ASTC system with $N_t = 4, N_r = 4$ is analysed as an instance. Complex orthogonal STBC design with CPM signals is presented as Eq. (5), in which, the transmit signals $s_{n_t}(t)$ are zero in certain intervals. During the intervals the corresponding transmit antenna can be simply switched off [20].

$$\boldsymbol{s}(t) = \begin{bmatrix} s_1(t) & -s_2^*(t) & -s_3^*(t) & 0 \\ s_2(t) & s_1^*(t) & 0 & s_3^*(t) \\ s_3(t) & 0 & s_1^*(t) & -s_2^*(t) \\ 0 & -s_3(t) & s_2(t) & s_1(t) \end{bmatrix} \tag{5}$$

Then, the signal matrix $\boldsymbol{C}_s$ for orthogonal design (OD) can be given with reference to the definition in [16]

$$\begin{aligned} C_s^{OD} &= (s(t) - \hat{s}(t))(s(t) - \hat{s}(t))^H \\ &= \sum_{n_t=1}^{3} \int_0^{N_cT} |s_{n_t}(t) - \hat{s}_{n_t}(t)|^2 dt \begin{bmatrix} 1 & & & \\ & 1 & & \\ & & 1 & \\ & & & 1 \end{bmatrix} \end{aligned} \tag{6}$$

As for hybrid STC, transmit matrix of CPM signals is presented as