Space-time Code Design with CPM Transmission [1]

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Abstract — **Design criterion for space-time codes with continuous phase modulation (CPM) in quasi-static fading channel is given. Space-time codes are proposed and simulation results will demonstrate their good performance.**

I. Introduction

Space-time codes have shown considerable promise for reliable transmission over wireless fading channels by efficiently employing transmit diversity [1]. Space-time coding research has to this point focused on linear modulations but continuous phase modulation (CPM) has many desirable characteristics for land mobile wireless communications. This work examines space-time coded CPM and generalizes the previously proposed design rules and provides several optimal codes for CPM.

II. Design Criterion

The system considered in this paper is limited to single modulation index CPM, consequently, the complex envelope of the transmitted signal from the i^{th} antenna, $X_i(t)$, $i = 1, \cdots, L_t$, is given by:

$$X_i(t) = \sqrt{\frac{E_s}{T}} \exp\left(j\phi(t, \vec{D}_i(k))\right)$$

$$\phi(t, \vec{D}_i(k)) = 2\pi h \sum_{l=0}^{k} D_i(l) q_m(t - lT), \quad (k-1)T \leq t < kT$$

where $D_i(k)$ is the kth modulation symbol, h is the modulation index, $q_m(t)$ is the phase smoothing response function, T is the symbol time and E_s is the symbol energy.

Assume a transmission of length N_c in quasi-static Rayleigh fading, the pairwise error probability (PWEP) between two elements of the space–time code, denoted as $P(\vec{\alpha} \to \vec{\beta})$, can be shown to be upper bounded by:

$$P(\alpha \to \beta) \leq \frac{\begin{pmatrix} 2\Delta_H(s) - 1 \\ \Delta_H(s) - 1 \end{pmatrix} N_0^{\Delta_H(s)}}{\prod_{i=1}^{\Delta_H(s)} \lambda_i^{(s)}}$$

where $\vec{\lambda}^{(s)}$ are the nonzero eigenvalues of the signal matrix C_s while $\Delta_H(s)$ is the number of nonzero eigenvalues. The signal matrix is given as

$$\begin{bmatrix} \int_0^{N_cT} |\Delta_1(t)|^2 dt & \cdots & \int_0^{N_cT} \Delta_1^*(t)\Delta_L(t)dt \\ \vdots & \vdots & \vdots \\ \int_0^{N_cT} \Delta_1(t)\Delta_L^*(t)dt & \cdots & \int_0^{N_cT} |\Delta_L(t)|^2 dt \end{bmatrix}$$

where

$$\Delta_i(t) = x_i(t, \vec{\alpha_i}) - x_i(t, \vec{\beta_i})$$

$\Delta_i(t)$ is the continuous time difference between the transmitted signal and the decoded signal on the i^{th} antenna. That the integrated continuous time difference between the two codewords is important in nonlinear modulation produces a more difficult design problem than is seen with linear modulation. As with linear modulation it is desirable to achieve a minimum rank of all the signal difference matrices equal to the number of transmitted antennas (especially when a small number of receive antennas is available). This condition will be denoted full space diversity.

In order to achieve full space diversity, C_s should be full rank. It can be shown that making C_s full rank is equivalent to making

$$\Delta(t) = a_1\Delta_i(t) + \cdots + a_L\Delta_L(t) \qquad (1)$$

nonzero unless $a_1 = \cdots = a_L = 0$ for all $a_1, \cdots, a_L \in \mathcal{C}$

From (1) we can have the following conclusions:

1) Delay diversity schemes always work with CPM transmission as they do with linear modulation.

2) If the number of transmit antennas L is less than the code alphabet size M, using different mapping rules over each transmit antenna can give full diversity without involving memory in the space-time code as with linear modulation.

3) Furthermore, if we assume we are equipped with only 2 transmit antennas we can show that as long as every nonzero M-ary codeword $\vec{\alpha}$ is a matrix of full rank over the field $GF(M)$, then for any CPM transmission full spatial diversity is guaranteed. A straight consequence is that for any code which satisfies the binary rank criterion in [2], it achieves full diversity in CPM transmission.

Given the above observances, we can design good space-time CPM system which is given in Fig. 1. As long as all the interleavers over all the antennas are the same, the diversity level is preserved.

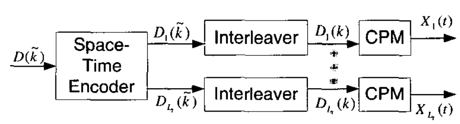

Figure 1: Block diagram of the space-time CPM

References

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[2] A.R.Hammons Jr. and H. El Gamal, "On the theory of space-time codes for PSK modulation", *IEEE Info. Theory*, vol. 46, No. 2, pp. 524–542, Mar. 2000.

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