Journal of Systems Engineering and Electronics, *Vol. 17*, *No. 1*, *2006*, *pp.* *54~58*

Novel time-frequency differential space-time modulation for multi-antenna OFDM systems*

Tian Jifeng, *Jiang Haining*, *Song Wentao*, *Luo Hanwen* & *Xu Youyun*
Dept. of Electronic Engineering, Shanghai Jiaotong Univ., Shanghai 200030, P. R. China
(Received December 8, 2004)

Abstract: Differential space-time (DST) modulation has been proposed recently for multiple-antenna systems over Rayleigh fading channels, where neither the transmitter nor the receiver knows the fading coefficients. Among existing schemes, differential modulation is always performed in the time domain and suffers performance degradations in frequency-selective fading channels. In order to combat the fast time and frequency-selective fading, a novel time-frequency differential space-time (TF-DST) modulation scheme, which adopts differential modulation in both time and frequency domains, is proposed for multi-antenna orthogonal frequency division multiplexing (OFDM) system. A corresponding sub-optimal yet low-complexity non-coherent detection approach is also proposed. Simulation results demonstrate that the proposed system is robust for time and frequency-selective Rayleigh fading channels.

Key words: differential space-time modulation, MIMO, OFDM, time-varying channel.

1. INTRODUCTION

Recently, there has been considerable interest in the wireless communication system with multiple transmit and receive antennas[1,2]. So far, most research on space-time modulation has assumed that accurate channel estimations are available at the receivers.

Differential space-time (DST) modulation schemes were proposed to achieve diversity gains without channel state information (CSI)[3]. DST modulation schemes allow for slowly changing channels that have to remain invariant within two consecutive symbols. So it is less effective in rapidly fading environments. In order to allow for fast time varying fading channels, double differential space-time (DDST) block coding was proposed in Ref. [4], in which channel delay resulting from multi-path fading is assumed to be smaller than the symbol duration. However, this cannot be guaranteed in wireless channels.

Orthogonal frequency division multiplexing (OFDM)[5], the spectrum efficient multi-carrier modulation technique, transforms a frequency-selective wide-band channel into a large number of non-selective narrow-band slices. To combat frequency-selective fading, an approach is proposed that OFDM is concatenated with DDST, in which DDST is applied between adjacent OFDM frames in frequency domain[6].

In this paper, a novel time-frequency differential space-time (TF-DST) modulation scheme is developed and applied to OFDM systems. This system adopts the differential modulation in both time and frequency domains, and it is robust for time-and frequency-selective Rayleigh fading channels. Moreover, our TF-DST scheme has a better performance than DDST-OFDM system in a fast fading channel, and it has less detection delay in receiver.

2. SYSTEM MODEL

Figure 1 depicts the block diagram of our proposed TF-DST-OFDM system with N_c subcarriers, N_t transmit antennas, and N_r receive antennas. At the transmitter, each information symbol is mapped into a space-time code word, which spans N_x adjacent OFDM symbols and one subcarrier. We define the N_x OFDM symbol intervals as one OFDM time block and denote TF-DST code matrix as $c(k, i)$, in which k is the index of subcarriers and i is the index of OFDM time blocks. $c(k, i)$ is an $N_x \times N_t$ matrix, as shown below

* This project was supported by the National Natural Science Foundation of China (60272079) and National "863" High Technology Development Project of China (2003AA123310).

$$C(k,i)=\begin{bmatrix} c_1(iN_x) & \cdots & c_{N_t}(iN_x) \\ \vdots & \ddots & \vdots \\ c_1(iN_x+N_x-1) & \cdots & c_{N_t}(iN_x+N_x-1) \end{bmatrix} \tag{1}$$

Consider the time-varying channel response between the mth transmitter antenna and the nth receiver antenna. The time-domain channel impulse response can be modeled as a tapped delay line[7].

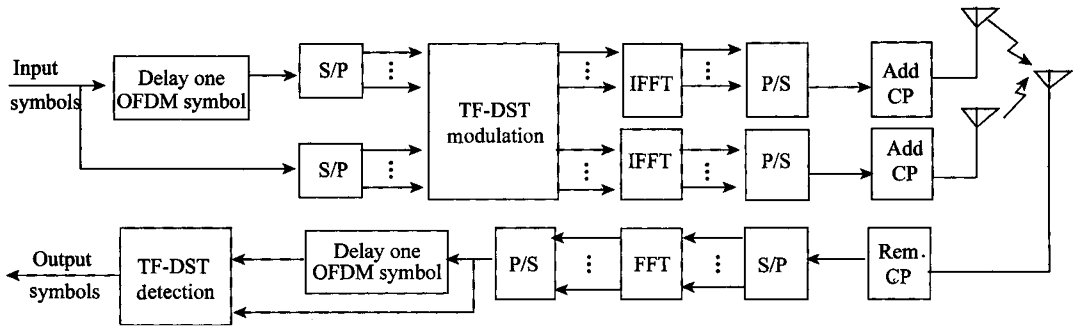

Fig. 1 Block diagram of TF-DST-OFDM system

$$h_{mn}(\tau;t)=\sum_{p=1}^{L}\alpha_{mn}(p;t)\delta\left(\tau-\frac{n_p}{N_c\Delta f}\right) \tag{2}$$

where $\delta(\cdot)$ is the Dirac delta function, L denotes the number of nonzero taps and $\alpha_{mn}(p;t)$ is the complex amplitude of the pth nonzero tap, whose delay is $n_p/(N_c\Delta f)$, where n_p is an integer and Δf is the tone spacing of the OFDM system. We assume that the time-varying effect is small and the Doppler frequency shift is invariable during the period of maximum channel delay. Then, $\alpha_{mn}(p;t)$ can be expressed as

$$\alpha_{mn}(p;t)=\tilde{h}_{mn}(p)\exp(\mathrm{j}2\pi f_n t) \tag{3}$$

where f_n is the Doppler frequency shift caused by relative motion between the transmit antennas and receive antennas. After discrete Fourier transform (DFT), the frequency-domain channel response can be derived from the time-domain response as

$$H_{mn}(k;t)=\sum_{p=1}^{L}\alpha_{mn}(p;t)\exp(-\mathrm{j}2\pi kn_p/N_c)=$$
$$\left[\sum_{p=1}^{L}\tilde{h}_{mn}(p)\exp(-\mathrm{j}2\pi kn_p/N_c\right]\cdot\exp(\mathrm{j}2\pi f_n t)=$$
$$\tilde{H}_{mn}(k)\cdot\exp(\mathrm{j}2\pi f_n t) \tag{4}$$

It is assumed that $\tilde{H}_{mn}(k)$ remains invariant during at least two consecutive OFDM symbols and the Doppler frequency f_n is common to all transmit antennas. For simplicity for description, $\tilde{H}_{mn}(k)$ is called fading component and $\exp(\mathrm{j}2\pi f_n t)$ is called Doppler component in the rest of the paper.

At the nth receive antenna, DFT is applied to the signals received from N_t transmit antennas, and the received signal at the kth subcarrier and during the ith OFDM time block, denoted as $X_n(k,i)$, is obtained as

$$X_n(k,i)=\mathrm{e}^{\mathrm{j}2\pi f_n iN_x}\Lambda_n C(k,i)H_n(k)+Z_n(k,i) \tag{5}$$

where $\Lambda_n := \mathrm{diag}\,(1,\mathrm{e}^{\mathrm{j}2\pi f_n},\cdots,\mathrm{e}^{\mathrm{j}2\pi f_n(N_x-1)}),H_n(k):=(\tilde{H}_{1n}(k),\tilde{H}_{2n}(k),\cdots,\tilde{H}_{N_tn}(k))^{\mathrm{T}},Z_n(k,i)$ is the noise and defined as $Z_n(k,i):=(z_n(k,iN_x),\cdots,z_n(k,iN_x+N_x-1))^{\mathrm{T}}$, which is circularly symmetric complex Gaussian distributed with variance N_0.

3. TF-DST MODULATION AND DETECTION SCHEME

The method proposed in Ref. [6], in which OFDM is concatenated with double differential space-time coding (DDST), is an effective way to oppress time-selective and frequency-selective fading. In DDST-OFDM system, DDST is introduced in consecutive OFDM symbols and the fading component of frequency-domain channel response $\tilde{H}_{mn}(k)$ is assumed to be constant during three consecutive OFDM symbols, i.e. it needs three OFDM symbols to detect one information symbol. In this paper, a novel time-frequency differential space-time modulation scheme is proposed for multi-antenna OFDM system. The new modulation scheme adopts differential modulation in