Super Orthogonal Differential Space-Time Trellis Coding and Decoding

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***Abstract*— In this paper, a differential space-time trellis-coded scheme based on super orthogonal space-time trellis codes (SOSTTC) is proposed. Based on its trellis structure, a low-complexity suboptimal differential decoder using the per-survival processing technique (PSP) is developed. In slow fading channels, it can approach the performance of SOSTTC with coherent decoding. Furthermore, an adaptive receiver is presented for time-varying channels, in which no training data is needed. Simulation results show that our scheme can achieve a good performance in both slow fading and time-varying fading channels with a reasonable complexity.**

I. Introduction

In multiple antenna systems, channel estimation becomes more complicated than that in single antenna systems. In order to avoid channel estimation, differential unitary space-time modulation (DUSTM) was proposed by Hughes [2] and Hochwald and Sweldens [3] independently, where unitary space-time codes with group structures were constructed. In [1], a differential space-time block code (DSTBC) based on Alamouti's scheme with PSK modulation was proposed and it has a fast maximum-likelihood (ML) decoding. More recently, trellis-coded DUSTM schemes (TC-DUSTM) were studied in [9] where trellis coded modulation (TCM) was combined with DUSTM to achieve a better coding gain. However, the decoding complexity of TC-DUSTM grows exponentially with the number of transmit antennas due to its inner unitary group codes.

In this paper, we propose a differential space-time trellis-coded scheme based on the lately proposed SOSTTC [4], [5], [6] for space-time coded systems with coherent detection. It achieves full diversity and has a better performance than DSTBC does in Rayleigh flat fading channels. A suboptimal differential decoder, which combines decision feedback differential detection (DF-DD) with Viterbi algorithm using the PSP technique, is developed. Due to the orthogonal structure of SOSTTC, the branch metric calculation can be done in a symbol-wise like way, which means our scheme has a lower decoding complexity compared with TC-DUSTM when the transmission rate is high. It can approach the performance of the coherent decoding in slow fading channels and the performance loss is negligible when the frame length is large. Moreover, we propose an adaptive receiver for time-varying fading channels. It does not need the training symbols or the channel statistics. Simulation results show that our proposed schemes can provide a good performance with modest complexity in both slow fading channels and time-varying fading channels.

In what follows, $\boldsymbol{c}^H$, $\boldsymbol{c}^T$, $\|\boldsymbol{c}\|$,$\boldsymbol{c}^{-1}$, tr$\{\boldsymbol{c}\}$ and det$\{\boldsymbol{c}\}$ refer to the complex conjugate transpose, transpose, Frobenius norm, the inverse, the trace and the determinant of the matrix $\boldsymbol{c}$, respectively. $\Re\{c\}$, $|c|$ and c^* denote the real part, the complex modulus and the complex conjugate of a complex number c. $E\{c\}$ denotes the expectation of the random variable c. $\mathbf{I}_k$, $\mathbf{1}_k$ and $\mathbf{0}_{m,n}$ denote a k by k identity matrix, a k by k all one matrix and a m by n zero matrix, respectively.

II. System Model

For simplicity, we consider a wireless communication system with two transmit and one receive antennas that operates in a Rayleigh flat fading environment. The extension to systems with more transmit antennas is trivial. Let $s_m(t)$ be the transmitted complex symbol from the m-th transmit antenna at time t with $E\{|s_m(t)|^2\} = 0.5$. Let $h_m(t)$ be the fading coefficient of the channel between the m-th transmit antenna and the receive antenna. We assume $h_m(t)$ is a zero-mean complex Gaussian random variable with variance 0.5 per dimension and $h_m(t)$ is independent in the space domain. In this paper, we consider two channel models. One is slow fading in which we assume that $h_m(t)$ keeps constant in each transmission frame and it changes independently from frame to frame. Another model is time-varying in which we take the effects of Doppler frequency shift and carrier frequency offset (CFO) into account. Based on Jakes' model, the autocorrelation function $r_{h_m}(\tau)$ can be written as:

$$r_{h_m}(\tau) = E\{h_m^*(t)h_m(t+\tau)\} = \exp(j2\pi f_o T_s \tau) J_0(2\pi f_d T_s \tau), \tag{1}$$

where $\tau = 0, 1, 2, \ldots,$ and f_d, f_o and T_s refer to the maximum Doppler frequency shift, the CFO and the symbol interval length, respectively. J_0 is the zeroth order Bessel function. We can drop the index m from $r_{h_m}(\tau)$ and rewrite it as $r_h(\tau)$ because it is the same for $m = 1, 2$. Then, the received signal at time t can be written as:

$$y_t = \sqrt{\rho}\sum_{m=1}^{2} h_m(t)s_m(t) + w_t,\ t = 1, 2, \ldots, \tag{2}$$

where w_t is a complex additive white Gaussian noise with variance 0.5 per dimension and ρ is the signal-to-noise ratio (SNR) at the receiver.

III. A Differential Space-Time Coding Based on SOSTTC

As shown in [2][3], when the conventional differential decoder is used, the design criteria for differential unitary space-time codes are the same as those for systems with coherent decoding, i.e., the rank criterion and diversity product criterion. The differential scheme can use the existing space-time codes that are for coherent systems directly. This motivates the work in this paper. In this section, we propose a differential trellis-coded scheme based on the recently proposed SOSTTC design to achieve a better performance.

The encoder structure is similar to DSTBC and the only difference is that a SOSTTC is used before the differential encoding. Here, the transmission frame includes N_f space-time blocks, i.e. $2N_f$ symbol transmissions. The first transmitted space-time block S_0 acts as a reference signal and it carries no information. At time $2t+1$, $t = 1, 2, 3 \cdots, N_f - 1$, a block of $2b$ information bits arrive at the encoder and are input into the SOSTTC encoder. The SOSTTC encoder generates a 2 by 2 information matrix $\mathbf{V}_t$ based on its trellis structure and the current state k, which has the following form:

$$\mathbf{V}_t = \mathbf{C}_t(c_{2t+1}, c_{2t+2})\mathbf{R}(\theta_k) = \begin{bmatrix} c_{2t+1} & c_{2t+2} \\ -c_{2t+2}^* & c_{2t+1}^* \end{bmatrix} \begin{bmatrix} e^{j\theta_k} & 0 \\ 0 & 1 \end{bmatrix}$$

where c_{2t+1} and c_{2t+2} are two information symbols from the 2^b-PSK constellation Υ with $|c_{2t+i}|^2 = 0.5$, $i = 1, 2$ and θ_k is the rotation angle associated with the trellis state k that belongs to the set Θ. We can choose Θ such that the entries of $\mathbf{V}_t$ are also from the constellation Υ [4]. After the SOSTTC encoding, the information matrix $\mathbf{V}_t$ is then input to the differential encoder to obtain a transmitted signal matrix $\mathbf{S}_t$ and

$$\mathbf{S}_t = \mathbf{V}_t\mathbf{S}_{t-1}. \tag{3}$$

The m-th ($m = 1, 2$) row of $\mathbf{S}_t$ is transmitted at time $2t+m$ and the n-th ($n = 1, 2$) column of $\mathbf{S}_t$ is transmitted from the n-th antenna. All the design criteria for SOSTTC with coherent detection and the proposed SOSTTC schemes in [4],[5] and [6] can be used directly in our design. These criteria can guarantee our scheme to achieve full diversity and a good performance. More details can be found in [4],[5] and [6].

In this paper, we assume that the channels are constant in each space-time code block, i.e. $h_m(2t + 1) = h_m(2t + 2)$, but may change from block to block. This assumption is usually acceptable for most wireless communication systems. Then, at the receiver, the received signal block $\mathbf{Y}_t = [y_{2t+1}\ y_{2t+2}]^T$ in the t-th space-time block at time $2t + 1$ and $2t + 2$ can be written as:

$$\mathbf{Y}_t = \sqrt{\rho}\mathbf{S}_t\mathbf{H}_t + \mathbf{W}_t \tag{4}$$

where $\mathbf{H}_t \triangleq [h_1(2t+1)\ h_2(2t+1)]^T$ and $\mathbf{W}_t \triangleq [w_{2t+1}\ w_{2t+2}]^T$ is an additive Gaussian noise vector with $E\{\mathbf{W}_t\mathbf{W}_t^H\} = \mathbf{I}_2$. Let $\mathbf{R}_{\overrightarrow{\mathbf{H}}}$ be the autocorrelation matrix of $[h_1(1)\ h_1(3)\ h_1(5)\cdots h_1(2N_f-1)]^T$. The entries of $\mathbf{R}_{\overrightarrow{\mathbf{H}}}$ are given as: $\mathbf{R}_{\overrightarrow{\mathbf{H}}}[m, n] = r_h(2(m-n))$ where $r_h(t)$ is the autocorrelation function of each channel coefficient, which is defined in (1). Denote

$$\mathbf{T} = -(\mathbf{R}_{\overrightarrow{\mathbf{H}}} + \frac{1}{\rho}\mathbf{I}_{N_f})^{-1} \tag{5}$$

where $\mathbf{T} \triangleq [t_{m,n}]$ is Hermitian. Then the ML detection becomes [7][10]:

$$\widehat{\overrightarrow{\mathbf{V}}} = \arg\max_{\overrightarrow{\mathbf{V}}} \Re\{\sum_{m=1}^{N_f-1}\sum_{n=0}^{m-1} t_{m+1,n+1}\mathbf{Y}_m^H(\prod_{l=0}^{m-n-1}\mathbf{V}_{m-l})\mathbf{Y}_n\} \tag{6}$$

where $\overrightarrow{\mathbf{V}} \triangleq [\mathbf{V}_1\ \mathbf{V}_2\cdots\mathbf{V}_{N_f-1}]$ is the information matrix vector we need to detect. One can see that the complexity of the ML decoding grows exponentially with the frame length N_f. It may be difficult to use ML decoding in a real system.

Instead of ML decoding, based on the trellis structure of SOSTTC, the Viterbi algorithm can be used to do decoding. Because there exist parallel branches on the SOSTTC trellis, the decoding is done in two steps [5]. The first step is to find a survivor branch for each state transition from the parallel branches attached with it. Then these survivor branches are used to represent the state transitions and the standard Viterbi algorithm can be used to find the survivor path. At each trellis stage, the conventional differential decoder can be used to calculate the branch metrics. Assume the fading coefficients keep constant in two consecutive space-time blocks, $\mathbf{H}_t = \mathbf{H}_{t-1}$, we can get:

$$\mathbf{Y}_t = \mathbf{V}_t\mathbf{Y}_{t-1} + \mathbf{W}_t - \mathbf{V}_t\mathbf{W}_{t-1} \tag{7}$$

where $\mathbf{Y}_{t-1}$ and $\mathbf{W}_{t-1}$ are the received signal block and the additive Gaussian noise vector in the $(t-1)$-th space-time block at time $2t-1$ and $2t$, respectively. Then, the branch metric can be defined as:

$$\lambda_t(\mathbf{V}_t) = \Re\{\mathbf{Y}_t^H\mathbf{V}_t\mathbf{Y}_{t-1}\}. \tag{8}$$

Because all the branches leaving from the same state are labelled with codewords from the same constituent code, which have the same rotation matrix $\mathbf{R}(\theta_k)$, branch metric calculations for all branches leaving from state k at trellis stage t can be simplified as

$$\lambda_t(\mathbf{V}_t) = f_{\theta_k,1}(c_{2t+1}) + f_{\theta_k,2}(c_{2t+2}), \tag{9}$$
$$f_{\theta_k,1}(c_{2t+1}) \triangleq \Re\{y_{2t+1}^*y_{\text{ref},k,2t+1}c_{2t+1} + y_{2t+2}^*y_{\text{ref},k,2t+2}c_{2t+1}^*\},$$
$$f_{\theta_k,2}(c_{2t+2}) \triangleq \Re\{y_{2t+1}^*y_{\text{ref},k,2t+2}c_{2t+2} - y_{2t+2}^*y_{\text{ref},k,2t+1}c_{2t+2}^*\},$$

where $\mathbf{Y}_{\text{ref},k,t} \triangleq [y_{\text{ref},k,2t+1}\ y_{\text{ref},k,2t+2}]^T = \mathbf{R}(\theta_k)\mathbf{Y}_{t-1}$. The survivor branch searching for the state transition from state s_1 to state s_2 can be done as

$$\hat{\mathbf{V}}_t = \arg\max_{(c_{2t+1},c_{2t+2})\in\Psi(s_1,s_2)}\{f_{\theta_{s_1},1}(c_{2t+1}) + f_{\theta_{s_1},2}(c_{2t+2})\}, \tag{10}$$

where $\Psi(s_1, s_2)$ is the set of the possible values of (c_{2t+1}, c_{2t+2}) attached with the branches from state s_1 to s_2. In fact, (10) can be simplified into a symbol-wise like way [5], which means the decoding complexity is reduced greatly when the constellation size 2^b is large. Here, we can treat the branch metric calculation (8) as a coherent detection of the information matrix $\mathbf{V}_t$, which is transmitted through a known channel $\mathbf{Y}_{t-1}$. The noise power is doubled, as seen in (7) and the noise terms in different trellis stage now are correlated. However, we may assume they are uncorrelated and expect the performance loss is about 3dB compared to the coherent decoding. As we will see later, the simulation results prove our statements.

IV. Improved Decoders for Differential SOSTTC

In this section, we propose an improved low-complexity decoder for slow fading channels, which can compensate the 3dB performance loss. Furthermore, we give an adaptive decoder with RLS predictors for time-varying channels.

A. A Suboptimal Receiver for Slow Fading Channels

First, we can rewrite (6) as:

$$\widehat{\overrightarrow{\mathbf{V}}} = \arg\max_{\overrightarrow{\mathbf{V}}} \Re\{\sum_{m=1}^{N_f-1}\{\mathbf{Y}_m^H\mathbf{V}_m\mathbf{Y}_{\text{ref},m}\}\}, \tag{11}$$

$$\mathbf{Y}_{\text{ref},m} \triangleq \sum_{n=0}^{m-1} t_{m+1,n+1}\{(\prod_{l=1}^{m-n-1}\mathbf{V}_{m-l})\mathbf{Y}_n\}, \tag{12}$$

where, when $m - n - 1 = 0$, we define $\prod_{l=1}^{0}\mathbf{V}_{m-l} \triangleq \mathbf{I}_2$. Then, instead of using (8), we redefine the branch metric as:

$$\lambda_m(\mathbf{V}_m) = \Re\{\mathbf{Y}_m^H\mathbf{V}_m\mathbf{Y}_{\text{ref},m}\}. \tag{13}$$

When the channel is slow fading, then $\mathbf{R}_{\overrightarrow{\mathbf{H}}} = \mathbf{1}_{N_f}$ and from (5), we get $\mathbf{T} = -\rho\mathbf{I}_{N_f} + \frac{\rho^2}{1+N_f\rho}\mathbf{1}_{N_f}$. In this case, $t_{m+1,n+1}, 1 \le m \le N_f - 1, 0 \le n \le m-1$, are constant and can be omitted in (12). Thus, for slow fading channels, we can define $Y_{\text{ref},m}$ as

$$\mathbf{Y}_{\text{ref},m} \triangleq \sum_{n=0}^{m-1}(\prod_{l=1}^{m-n-1}\mathbf{V}_{m-l})\mathbf{Y}_n. \tag{14}$$

The problem is that $\mathbf{Y}_{\text{ref},m}$ is related to the unknown previous information matrices $\mathbf{V}_i, i = 1, 2, \cdots, m-1$. This can be solved by the PSP technique [8]. In our case, when we calculate the branch metrics for branches stemming from state k, at the trellis stage m, we use the tentative detected information matrix sequence $\widehat{\mathbf{V}}_{k,i}, i = 1, 2, \cdots, m-1$, associated with the survivor path of state k in (14) to calculate the reference vector $\mathbf{Y}_{\text{ref},k,m}$, i.e., $\mathbf{Y}_{\text{ref},k,m}$ is $\mathbf{Y}_{\text{ref},m}$ when $\mathbf{V}_{m-l}$ in (14) is replaced by $\widehat{\mathbf{V}}_{k,m-l}$. Now each survivor path (or state) has its own reference vector $\mathbf{Y}_{\text{ref},k,m}$. Using $\mathbf{Y}_{\text{ref},k,m}$, the branch metric λ_m of all branches stemming from state k can be obtained and the Viterbi algorithm of SOSTTC can be done.

In fact, the reference vector $\mathbf{Y}_{\text{ref},k,m}$ can be calculated in a recursive way:

$$\mathbf{Y}_{\text{ref},k,m} = \widehat{\mathbf{V}}_{k,m-1}\mathbf{Y}_{\text{ref},s_{k,m-1},m-1} + \mathbf{Y}_{m-1} \tag{15}$$

where $s_{k,m-1}$ is the state that the survivor path of state k (at the trellis stage m) goes through at the trellis stage $m-1$. And we let $\mathbf{Y}_{\text{ref},k,0} = \mathbf{0}_{2,1}$. From (15), one can see that at each trellis stage m, besides $\mathbf{Y}_m$, we only need to store $\mathbf{Y}_{\text{ref},k,m}$ for each state k. The extra storage requirement is low and the computation of $\mathbf{Y}_{\text{ref},k,m+1}$ is simple. Based on the above discussions, we arrive at the following suboptimal receiver for slow fading channels based on PSP, where N_s denotes the state number of SOSTTC trellis:

- Give the initial values to $\mathbf{Y}_{\text{ref},k,1}$, $\mathbf{Y}_{\text{ref},k,1} = \mathbf{Y}_0$, $k = 1,2\cdots,N_s$.
- At the trellis stage $m = 1,2,3,\cdots,N_f-1$,
  - For $k = 1,2,3,\cdots,N_s$, calculate the branch metric $\lambda_m(\mathbf{V}_m)$ for every branch stemming from state k at the trellis state m using (13). Search the survivor branch for each parallel branch set.
  - Using the survivor branches to represent the state transitions, do the standard Viterbi survivor path and state metric update operations.
  - For the state $k = 1,2,3,\cdots,N_s$ at trellis stage $m+1$, update the reference vector $\mathbf{Y}_{\text{ref},k,m+1}$ using (15).
- Standard Viterbi traceback operation.

Here we want to mention that the fast decoding in (10) still exists when we do the survivor branch searching operation in each parallel branch set. The only difference is that here, for different state k at the trellis stage m, we need to use different reference vector $\mathbf{Y}_{\text{ref},k,m}$. We refer this proposed scheme as NON-RLS decoder.

B. An Adaptive Receiver for Time-Varying Channels

When the channel is time-varying, $t_{m+1,n+1}$ in (6) are not constant. when we do the optimal ML decoding in (6), there is no easy way to get $t_{m+1,n+1}$. In this section, we propose an adaptive RLS receiver for time-varying channels.

We still define the branch metric as $\lambda_m(\mathbf{V}_m) = \Re\{\mathbf{Y}_m^H\mathbf{V}_m\mathbf{Y}_{\text{ref},k,m}\}$, but the reference vector $\mathbf{Y}_{\text{ref},k,m}$ becomes:

$$\mathbf{Y}_{\text{ref},k,m} = \sum_{n=0}^{m-1} t_{m+1,n+1}\{(\prod_{l=1}^{m-n-1}\widehat{\mathbf{V}}_{k,m-l})\mathbf{Y}_n\} \tag{16}$$

and we need to estimate $t_{m+1,n+1}$. In order to reduce the complexity, we calculate $\mathbf{Y}_{\text{ref},k,m}$ only based on N recently received signal blocks and let $t_{m+1,n+1} = 0$, for $n = 0,1,\cdots,m-N-1$. Then we only need to estimate N parameters $t_{m+1,n+1}$, $n = m-N,\cdots,m-1$, where N is called as the decision feedback length. We can think of them as coefficients of an adaptive predictor and incorporate N_s RLS predictors into the Viterbi algorithms to estimate them. Every state has its own RLS predictor to track channel variance. Denote $\hat{t}_{k,m,n}$ as the estimation of $t_{m+1,m-n+1}$, $n = 1,\cdots,N$ at state k. Then we can rewrite (16) as

$$\mathbf{Y}_{\text{ref},k,m} = \sum_{n=1}^{N}\hat{t}_{k,m,n}\{(\prod_{l=1}^{n-1}\widehat{\mathbf{V}}_{k,m-l})\mathbf{Y}_{m-n}\} \tag{17}$$

After the Viterbi decoder finishes the survivor path and state metric update operation, RLS predictors use the tentative decision results of each survivor path to update the estimation of $\hat{t}_{k,m,n}$. Following [7], we choose the RLS cost function (for all k) as:

$$J_k[m] \triangleq \sum_{\xi=1}^{m}\omega^{m-\xi}\|\mathbf{Y}_m - \sum_{n=1}^{N}\hat{t}_{k,m,n}\{(\prod_{l=0}^{n-1}\widehat{\mathbf{V}}_{k,m-l})\mathbf{Y}_{m-n}\}\|^2 \tag{18}$$

where $\omega, 0 < \omega \leq 1$, denotes the forgetting factor. The proposed adaptive decoder is summarized as bellow:

- Give the initial values for $\hat{t}_{k,1,n}$, $k = 1,2\cdots,N_s$,
  $\hat{t}_{k,1,n} = \{ \begin{array}{ll} 1, & n=1, \\ 0, & n = 2,3,\cdots,N. \end{array}$
- At the trellis stage $m = 1,2,3,\cdots,N_f-1$,
  - For $k = 1,2,3,\cdots,N_s$, calculate the reference vector $\mathbf{Y}_{\text{ref},k,m}$ using $\hat{t}_{k,m,n}$. Then calculate the branch metric $\lambda_m(\mathbf{V}_m)$ for all branches stemming from state k at the trellis state m using (13). Search the survivor branch for each parallel branch set.
  - Using the survivor branches to represent the state transitions, do the standard Viterbi survivor path and state metric update operations.
  - For state $k = 1,2,3,\cdots,N_s$ at trellis stage $m+1$, update the RLS output as:
    Denote $\hat{\mathbf{T}}_{k,m}$=$[\hat{t}_{k,m,1}\hat{t}_{k,m,2}\cdots\hat{t}_{k,m,N}]^T$, which is a N by 1 vector. $\hat{\mathbf{U}}_{k,m} = [\widehat{\mathbf{V}}_{k,m}\mathbf{Y}_{m-1},\ \widehat{\mathbf{V}}_{k,m}\widehat{\mathbf{V}}_{k,m-1}\mathbf{Y}_{m-2},\cdots,(\prod_{l=0}^{N-1}\widehat{\mathbf{V}}_{k,m-l})\mathbf{Y}_{m-N}]^T$, which is an N by 2 matrix. The RLS algorithm is: for each state k at the trellis stage $m+1$

$$\mathbf{\Gamma}_{k,m+1} = [I_2 + \omega^{-1}\hat{\mathbf{U}}^H_{s_{m,k},m}\mathbf{P}_{s_{m,k},m}\hat{\mathbf{U}}_{s_{m,k},m}]^{-1}$$
$$\mathbf{\Lambda}_{k,m+1} = \omega^{-1}\mathbf{P}_{s_{m,k},m}\hat{\mathbf{U}}_{s_{m,k},m}\mathbf{\Gamma}_{k,m+1}$$
$$\alpha_{k,m+1} = \mathbf{Y}_m - \hat{\mathbf{T}}^H_{s_{m,k},m}\hat{\mathbf{U}}_{s_{m,k},m}$$
$$\hat{\mathbf{T}}_{k,m+1} = \hat{\mathbf{T}}_{s_{m,k},m} + \mathbf{\Lambda}_{k,m+1}\alpha^H_{k,m+1}$$
$$\hat{\mathbf{P}}_{k,m+1} = \omega^{-1}\mathbf{P}_{s_{m,k},m} - \omega^{-1}\mathbf{\Lambda}_{k,m+1}\hat{\mathbf{U}}^H_{s_{m,k},m}\mathbf{P}_{s_{m,k},m}$$

    with the initial conditions $\hat{\mathbf{P}}_{k,1} = \delta_x\mathbf{I}_N$ where δ_x is a constant parameter.
- Standard Viterbi traceback operation.

With the RLS predictors, the matrix inversion operation is avoided and it does not need any channel fading statistics or the SNR information. It is easy to see that we still can do survivor branch searching in symbol-wise like way in each parallel branch set. Therefore, the complexity is reduced. We refer this adaptive decoder as RLS decoder.

V. Simulation Results

The simulated system has two transmit antennas and one receive antenna. Each frame consists of $N_f = 65$ space-time blocks. The SOSTTC scheme we used is a four-state QPSK SOSTTC from [4], whose rate is 2bits/channel use. Its set-partitioning and trellis structure are given in Fig.3 and Fig.5 of [4]. The time varying channels are generated as $h_m(t) = \exp(j2\pi f_o t)\alpha_m(t)$ where $\alpha_m(t)$ is generated based on Jakes' model. The simulated channels vary inside each space-time block although we assume it is not changed in each block.

Fig.1 shows the performance of different decoding schemes in slow fading channels. One can see that our differential SOSTTC scheme with conventional differential decoding has about 1.5dB performance gain at FER of 0.01 over the DSTBC and 16-state TC-DUSTM [9] with conventional decoding. Obviously, a well known 3dB performance loss of the conventional differential decoding is there. At FER of 0.01, the performance loss is about 3.3dB, which is worse than 3dB. This is mainly caused by the correlation of the noise terms in different trellis stages. If the proposed NON-RLS scheme is used, we can approach the performance of coherent decoding. There is only about 0.4dB performance loss at FER of 0.01. The proposed RLS decoding scheme with the decision feedback length $N = 3$ also has a very good performance and its performance loss at FER of 0.01 is about 1.6dB compared with coherent detection. Fig.2 demonstrates the sensitivity of each scheme to CFO. In this simulation, the SNR is fixed to 20dB and three decoding schemes are simulated with different normalized CFO (f_oT_s). One can see that, when CFO is small, say $f_oT_s < 0.001$, the NON-RLS decoder works well because the noise is mainly from the receiver. On the other hand, when $f_oT_s > 0.001$, the performance of the NON-RLS degrades greatly. However, the performances of RLS and the conventional decoder are almost unchanged when $f_oT_s < 0.007$. The RLS is the most robust scheme against CFO among the others shown in Fig.2. Fig.3 shows the performances of the proposed schemes in time-varying channels with different Doppler frequency shifts. Again, NON-RLS scheme is more sensitive to the channel variance caused by Doppler frequency shifts than the other two are. The RLS decoder always has a better performance than the conventional differential decoder. The performance analysis and more simulation results can be found in [11].

VI. Conclusions

In this paper, a differential space-time trellis-coded scheme based on SOSTTC is proposed. It can provide a better coding gain than DSTBC. For slow fading channels, a suboptimal low complexity decoding algorithm based on the PSP technique is developed. It can approach the performance of coherent detection when the frame length is large. For time-varying channels, a bank of RLS predictors are incorporated into the Viterbi decoder to track to the channel variances. The simulation results show this scheme works well in both slow fading channels and time-varying channels.

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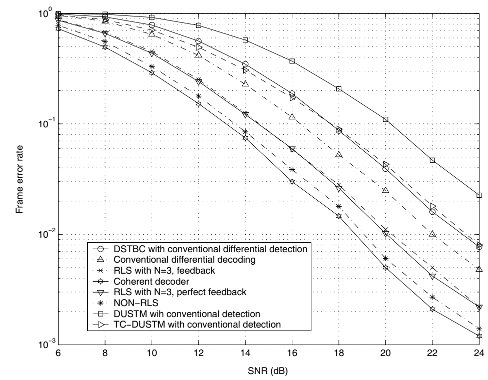

Fig. 1. Simulation results under a slow fading channel.

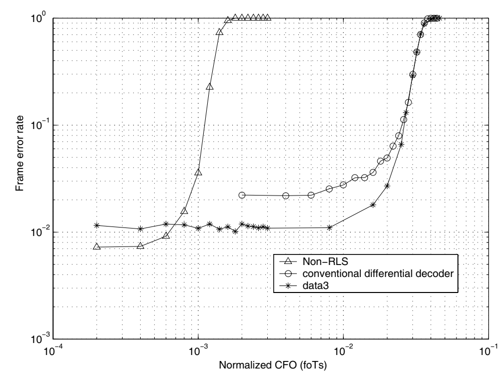

Fig. 2. Simulation results under a time-varying channel with various CFO.

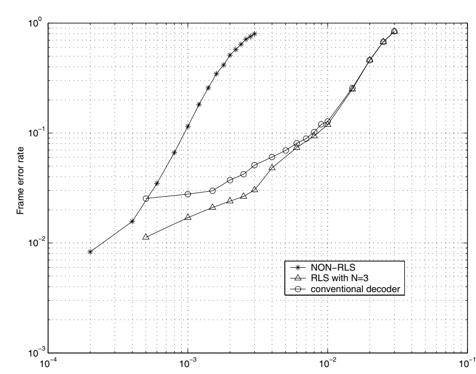

Fig. 3. Simulation results under a time-varying channel with various Doppler frequency shift.