Performance Evaluation of Space-Time Spreading and Orthogonal Transmit Diversity*

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Abstract: Space-time spreading (STS) and orthogonal transmit diversity (OTD) are two transmit diversity schemes proposed by cdma2000 standard. In this paper, performance comparison analysis of the two transmits diversity schemes in multipath channel under multiuser situation are carried out. Link level simulation in forward link cdma2000 is performed in IMT-2000 channel. Performance analysis and simulation results show that the performance improvement provided by STS over OTD decreases as the increase of propagation path number and decrease of the user number.

Key words: space-time spreading, orthogonal transmit diversity, cdma2000

Transmit diversity is an effective technique to combat slow fading in mobile communication systems. In current cdma2000 standard, space-time spreading (STS) and orthogonal transmit diversity (OTD) are considered as two transmit diversity schemes[1] to achieve diversity gain.

STS is firstly proposed by Papadias[2], and then is adopted by cdma2000 standard. It can offer substantial performance gain compared with the transmission by single antenna. OTD proposed by Weerackody[3] is also used by cdma2000 standard. In Ref.[4], performance of STS and OTD is evaluated for forward link cdma2000 by simulation. However, the simulation is only carried out for single user under flat fading and two equal power Rayleigh channels.

In this paper, we carry out the performance comparison analysis of STS and OTD for multiuser under multipath fading environment. The performance of the two transmit diversity schemes are also evaluated in forward link cdma2000 under COSSAP design environment. The channel used in the simulation is standard channel A in Ref. [5].

Just before the finish of this paper, we notice that the theoretical analysis of STS is presented in detail in Ref. [6] recently. The difference between our work and Ref. [6] is that multiuser is considered in our paper and simulation guided by cdma2000 standard is performed.

The remainder of paper is organized as follows. The system model is presented in section 1. Section 2 carries out the performance comparison analysis. The link level simulation is described in section 3. We finalize the paper with the conclusion in section 4.

1 System Model

In this section, we set up the system model of synchronous forward link cdma2000. Two transmitting and one receiving antennas are considered. The baseband diagram of transmitter structure for the kth traffic channel ($k = 1,2,\cdots,K$; users are called as traffic channel in cdma2000) is depicted in Fig.1. The data of the traffic channel, which has been encoded by a convoltional encoder and interleaved, is sent into symbol mapper to create QPSK symbol. Two QPSK symbols $d_k^{(n)}$, $d_k^{(n+1)}$ are sent into transmit diversity encoder once to achieve STS or OTD. The output is spread by one Walsh codes and one complex PN

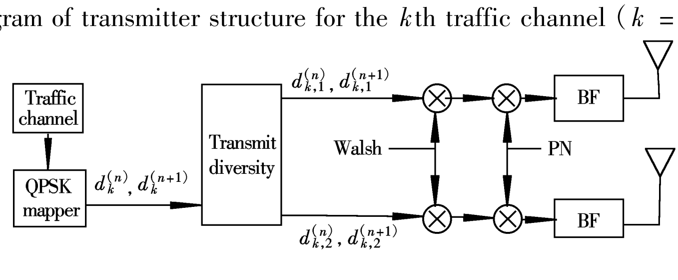

Fig.1 The baseband diagram of transmitter structure for the kth traffic channel

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sequences, followed by baseband filtering, and sent out at two antennas respectively. Two transmit antennas, which have equal average power, are sufficiently spaced apart in order to ensure that the signals transmitted from the two antennas are not correlated. The baseband signal of the kth traffic channel transmitted from the jth antenna $(j = 1,2)$ can be written as

$$x_{k,j}(t) = \sum_{n=-\infty}^{\infty} A_k d_{k,j}^{(n)} s_k(t - nT_s) \tag{1}$$

where $A_k = \sqrt{E_k/2}$, E_k is the energy of per symbol; $d_{k,j}^{(n)}$ is QPSK symbol after transmit diversity encoder; T_s is the symbol interval; $s_k(t) = \sum_{m=0}^{M-1} w_k(m)p(m)\psi(t - mT_c)$ is the energy normalized signature waveform (i.e. $\int_0^{T_s} s_k^2(t)\mathrm{d}t = 1$), where $w_k(m)$ is a Walsh function and $p(m)$ is the complex PN sequence for the base station used, $\psi(t)$ is a normalized chip waveform of duration $T_c = T_s/M$; M is the processing gain. Two pilot channels are assigned for two transmitting antennas to perform the channel estimation.

The channel is a frequency selective Rayleigh fading model. The impulse response of the jth antenna at lth $(1 \leqslant l \leqslant L)$ path can be modeled as

$$h_{k,j,l}(t) = g_{k,j,l}(t)\delta(t - \tau_{k,l}) \tag{2}$$

where the amplitude of complex path gain $g_{k,j,l}(t)$ is Rayleigh distributed; the phase of $g_{k,j,l}(t)$ is uniformly distribution over the interval $[-\pi,\pi)$; $\delta(\cdot)$ is Kronecker delta function; $\tau_{k,l}$ is the propagation time delay. It is reasonable that $\tau_{k,l}$ is the same for the two transmitting antennas.

The received signal of the mobile station is

$$r(t) = \sum_{n=-\infty}^{\infty}\sum_{k=1}^{K}\sum_{j=1}^{2}\sum_{l=1}^{L} A_k d_{k,j}^{(n)} g_{k,j,l}(t) s_k(t - nT_s - \tau_{k,l}) + n(t) \tag{3}$$

where $n(t)$ is complex AWGN. The baseband diagram of receiver is shown in Fig.2. If we consider the beginning

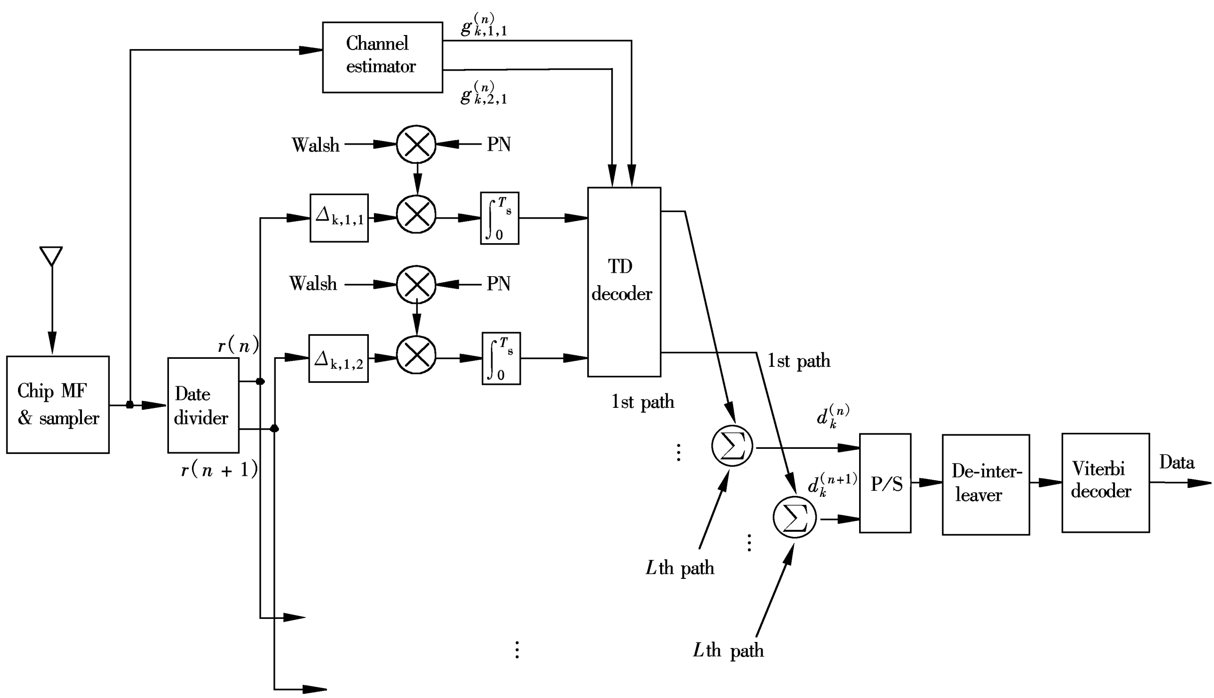

Fig.2 The baseband diagram of receiver

time of sampling is at the beginning of nth symbol at lth path, the discrete output of the chip match filter and sampler for nth symbol is modeled as

$$\boldsymbol{r}_l^{(n)} = \boldsymbol{S}_l \sum_{j=1}^{2} \boldsymbol{G}_j \boldsymbol{A} \boldsymbol{d}_j^{(n)} + \boldsymbol{I}_l^{(n)} + \boldsymbol{N} \tag{4}$$

where $\boldsymbol{r}_l^{(n)} = [r(T_c(nM + \Delta_{k,l})), \cdots, r(T_c(nM + \Delta_{k,l} + M))]^{\mathrm{T}} \in C^M$, $\Delta_{k,l} = [\tau_{k,l}/T_c]$ ($[x]$ is the smallest integer, which is greater than or equal to x, assuming that $\Delta_{k,1} \leqslant \cdots \leqslant \Delta_{k,l} \leqslant \cdots \leqslant \Delta_{k,L}$); the superscript T denotes transpose; $\boldsymbol{S}_l = [\boldsymbol{s}_{1,1}, \cdots, \boldsymbol{s}_{1,L}, \cdots, \boldsymbol{s}_{K,1}, \cdots, \boldsymbol{s}_{K,L}] \in R^{M \times KL}$ is the sample spreading sequence matrix, where

$$\boldsymbol{s}_{k,l'} = \begin{cases} [\, s_k(T_c(\Delta_{k,l} - \Delta_{k,l'} + 1)) \cdots s_k(T_c M), 0^{\mathrm{T}}_{(\Delta_{k,l} - \Delta_{k,l'}) \times 1}]^{\mathrm{T}} & \text{if } l' < l \\ [\, s_k(T_c) \cdots s_k(T_c M)]^{\mathrm{T}} & \text{if } l' = l \\ [\, 0^{\mathrm{T}}_{(\Delta_{k,l'} - \Delta_{k,l}) \times 1}, s_k(T_c) \cdots s_k(T_c(M - \Delta_{k,l'} + \Delta_{k,l}))]^{\mathrm{T}} & \text{if } l' > l \end{cases} \tag{5}$$

$\boldsymbol{G}_j = \mathrm{diag}[\boldsymbol{g}_{1,j}, \cdots, \boldsymbol{g}_{K,j}, \cdots, \boldsymbol{g}_{K,j}] \in C^{KL \times K}$ is the channel response matrix with $\boldsymbol{g}_{k,j} = [g^{(n)}_{k,j,1} \cdots g^{(n)}_{k,j,L}]^{\mathrm{T}} \in C^L$; $\boldsymbol{A} = \mathrm{diag}[A_1 \cdots A_K] \in R^{K \times K}$; $\boldsymbol{d}_j^{(n)} = [d^{(n)}_{1,j} \cdots d^{(n)}_{K,j}]^{\mathrm{T}} \in \Xi^K$ is the data vector of nth symbol with modulation symbol alphabet Ξ after transmit diversity encoding; $\boldsymbol{N} \in C^M$ is the channel noise vector with variance $N_0/2$. The intersymbol interference $\boldsymbol{I}_l^{(n)}$ can be written as

$$\boldsymbol{I}_l^{(n)} = \boldsymbol{S}'_1 \sum_{j=1}^{2} \boldsymbol{G}_j \boldsymbol{A} \boldsymbol{d}_j^{(n+1)} + \boldsymbol{S}''_1 \sum_{j=1}^{2} \boldsymbol{G}_j \boldsymbol{A} \boldsymbol{d}_j^{(n+1)} \tag{6}$$

where

$$\boldsymbol{S}'_1 = [\, s'_{1,1}, \cdots, s'_{1,l-1}, 0^{\mathrm{T}}_{(L-l+1) \times M}, \cdots, s'_{K,1}, \cdots, s'_{K,l-1}, 0^{\mathrm{T}}_{(L-l+1) \times M}] \in R^{M \times KL}$$
$$\boldsymbol{s}'_{k,l'} = [\, 0^{\mathrm{T}}_{(M - \Delta_{k,l} - \Delta_{k,l'}) \times 1}, s_k(T_c), \cdots, s_k(T_c(\Delta_{k,l} - \Delta_{k,l'}))]^{\mathrm{T}}$$
$$\boldsymbol{S}''_1 = [\, 0^{\mathrm{T}}_{l \times M}, \boldsymbol{s}''_{1,l+1}, \cdots, \boldsymbol{s}''_{1,L}, 0^{\mathrm{T}}_{(L \times M)}, \boldsymbol{s}''_{K,l+1}, \cdots, \boldsymbol{s}'_{K,L}] \in R^{M \times KL}$$
$$\boldsymbol{s}''_{k,l'} = [\, \boldsymbol{s}''_k(T_c(M - \Delta_{k,l'} + \Delta_{k,l} + 1)), \cdots, \boldsymbol{s}''_k(T_c M), 0^{\mathrm{T}}_{(M - \Delta k, l + \Delta k, l') \times 1}]^{\mathrm{T}}$$

The receiving signals are processed by a Rake receiver with transmit diversity decoder. The soft outputs are de-interleaved and Viterbi decoded.

2 Performance Comparison Analysis

In this section, we carry out the performance comparison analysis of OTD and STS. In this paper, the scheme of OTD and STS is the same as the scheme in Ref.[1].

2.1 Performance analysis of OTD

The block diagram of OTD is shown in Fig.3. The transmitted symbols of the nth and $(n+1)$th symbol can be shown in the matrix form as follows:

$$\begin{bmatrix} d_k^{(n)} & d_k^{(n+1)} \\ d_k^{(n)} & -d_k^{(n+1)} \end{bmatrix} \tag{7}$$

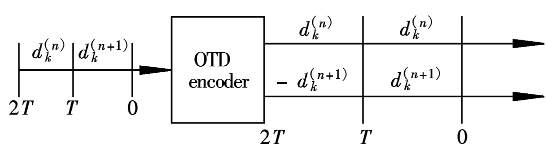

Fig.3 The block diagram of orthogonal transmit diversity

The first and second rows denote the signal transmitted for two consecutive QPSK symbols; different columns denote signals transmitting from different antennas.

Based on (4) and (7), we can write signal during two consecutive symbols as follows:

$$\begin{bmatrix} \boldsymbol{r}_l^{(n)} \\ \boldsymbol{r}_l^{(n+1)} \end{bmatrix} = \begin{bmatrix} \boldsymbol{S}_l \boldsymbol{G}_1 \boldsymbol{A} \boldsymbol{d}^{(n)} + \boldsymbol{S}_l \boldsymbol{G}_2 \boldsymbol{A} \boldsymbol{d}^{(n+1)} + \boldsymbol{I}^{(n)} + \boldsymbol{N}_1 \\ \boldsymbol{S}_l \boldsymbol{G}_1 \boldsymbol{A} \boldsymbol{d}^{(n)} - \boldsymbol{S}_l \boldsymbol{G}_2 \boldsymbol{A} \boldsymbol{d}^{(n+1)} + \boldsymbol{I}^{(n+1)} + \boldsymbol{N}_2 \end{bmatrix} \tag{8}$$

where $\boldsymbol{d}^{(n)} = [d_1^{(n)} \cdots d_K^{(n)}]^{\mathrm{T}}$. If we consider double length Walsh code as one Walsh code ($M = 128$), the two consecutive symbols can be modeled as

$$\tilde{\boldsymbol{r}}_l^{(n)} = \boldsymbol{S}_{1,l} \boldsymbol{G}_1 \boldsymbol{A} \boldsymbol{d}^{(n)} + \boldsymbol{S}_{2,l} \boldsymbol{G}_2 \boldsymbol{A} \boldsymbol{d}^{(n+1)} + \tilde{\boldsymbol{I}}_l^{(n)} + \widetilde{\boldsymbol{N}} \tag{9}$$

where $\boldsymbol{S}_{1,l} = [\boldsymbol{S}_l \quad \boldsymbol{S}_l]^{\mathrm{T}}, \boldsymbol{S}_{2,l} = [\boldsymbol{S}_l \quad -\boldsymbol{S}_l]^{\mathrm{T}}, \tilde{\boldsymbol{I}}_l^{(n)} = [\boldsymbol{I}_l^{(n)} \quad \boldsymbol{I}_l^{(n+1)}]^{\mathrm{T}}, \boldsymbol{N} = [\boldsymbol{N}_1 \quad \boldsymbol{N}_2]^{\mathrm{T}}$.

After de-spreading and coherent detecting in Rake receiver, the combining output of L paths for the kth traffic channel is shown as

$$\begin{bmatrix} \tilde{d}_k^{(n)} \\ \tilde{d}_k^{(n+1)} \end{bmatrix} = \sum_{l=1}^{L} \begin{bmatrix} (\boldsymbol{s}_{k,1,l} g^{(n)}_{k,1,l})^* \\ (\boldsymbol{s}_{k,2,l} g^{(n)}_{k,2,l})^* \end{bmatrix} \tilde{\boldsymbol{r}}_l^{(n)} = \begin{bmatrix} 2 \sum_{l=1}^{L} | g^{(n)}_{k,1,l} |^2 A_k d_k^{(n)} \\ 2 \sum_{l=1}^{L} | g^{(n)}_{k,2,l} |^2 A_k d_k^{(n+1)} \end{bmatrix} +$$

$$\sum_{l=1}^{L}\begin{bmatrix}(\boldsymbol{s}_{k,1,l}g_{k,1,l}^{(n)})^{*}\\(\boldsymbol{s}_{k,2,l}g_{k,2,l}^{(n)})^{*}\end{bmatrix}\sum_{j=1}^{2}\widetilde{\boldsymbol{S}}_{j,l}\widetilde{\boldsymbol{G}}_{j}\boldsymbol{A}\boldsymbol{d}^{(n+j-1)}+\sum_{l=1}^{L}\begin{bmatrix}(\boldsymbol{s}_{k,1,l}g_{k,1,l}^{(n)})^{*}\\(\boldsymbol{s}_{k,2,l}g_{k,2,l}^{(n)})^{*}\end{bmatrix}\widetilde{\boldsymbol{I}}_{l}^{(n)}+$$

$$\sum_{l=1}^{L}\begin{bmatrix}(\boldsymbol{s}_{k,1,l}g_{k,1,l}^{(n)})^{*}\\(\boldsymbol{s}_{k,2,l}g_{k,2,l}^{(n)})^{*}\end{bmatrix}\widetilde{\boldsymbol{N}}=\begin{bmatrix}2\sum_{l=1}^{L}|g_{k,1,l}^{(n)}|^{2}A_{k}d_{k}^{(n)}\\2\sum_{l=1}^{L}|g_{k,2,l}^{(n)}|^{2}A_{k}d_{k}^{(n+1)}\end{bmatrix}+\begin{bmatrix}\widetilde{\boldsymbol{U}}_{l,1}^{(n)}\\\widetilde{\boldsymbol{U}}_{l,2}^{(n)}\end{bmatrix}+\begin{bmatrix}\widetilde{\widetilde{\boldsymbol{I}}}_{l,1}^{(n)}\\\widetilde{\widetilde{\boldsymbol{I}}}_{l,2}^{(n)}\end{bmatrix}+\begin{bmatrix}\widetilde{\widetilde{\boldsymbol{N}}}_{1}\\\widetilde{\widetilde{\boldsymbol{N}}}_{2}\end{bmatrix}\tag{10}$$

where * denotes conjugate; $\boldsymbol{s}_{k,1,l}=[\boldsymbol{s}_{k,l}\quad \boldsymbol{s}_{k,l}]^{\mathrm{T}}$, $\boldsymbol{s}_{k,2,l}=[\boldsymbol{s}_{k,l}\quad -\boldsymbol{s}_{k,l}]^{\mathrm{T}}$, $\boldsymbol{s}_{k,l}$ is defined in (5) when $l'=l$. $\widetilde{\boldsymbol{U}}_{l,1}^{(n)}$, $\widetilde{\boldsymbol{U}}_{l,2}^{(n)}$ is the residual interference term including $(L-1)$ self-interference term due to multiple propagation path and the suppressed multiple access interference. The definitions of $\widetilde{\boldsymbol{S}}_{j,l}$, $\widetilde{\boldsymbol{G}}_{j}$ are similar to (9), where the components of kth traffic channel at lth path are discarded. A common assumption used to simplify the analysis is to assume that $\widetilde{\boldsymbol{U}}_{l,1}^{(n)}$, $\widetilde{\boldsymbol{U}}_{l,2}^{(n)}$, $\widetilde{\widetilde{\boldsymbol{I}}}_{l,1}^{(n)}$, $\widetilde{\widetilde{\boldsymbol{I}}}_{l,2}^{(n)}$ is Gaussian random variable with variance $\sigma_{U1}^{\mathrm{OTD}}$, $\sigma_{U2}^{\mathrm{OTD}}$, $\sigma_{I1}^{\mathrm{OTD}}$, $\sigma_{I2}^{\mathrm{OTD}}$. The first term in (10) is the desired signal and the last term is the zero mean Guassian random variable due to the AWGN.

Based on the mean and variance of the decision of $\widetilde{d}_{k}^{(n)}$, $\widetilde{d}_{k}^{(n+1)}$, the overall SINR of the combined outputs of all the paths is

$$\gamma_{d_{k}^{(n)}}^{\mathrm{OTD}}=\frac{2\sum_{l=1}^{L}|g_{k,1,l}^{(n)}|^{2}}{\dfrac{N_{0}}{E_{k}}+\sigma_{U1}^{\mathrm{OTD}}+\sigma_{I1}^{\mathrm{OTD}}}\tag{11}$$

$$\gamma_{d_{k}^{(n+1)}}^{\mathrm{OTD}}=\frac{2\sum_{l=1}^{L}|g_{k,2,l}^{(n)}|^{2}}{\dfrac{N_{0}}{E_{k}}+\sigma_{U2}^{\mathrm{OTD}}+\sigma_{I2}^{\mathrm{OTD}}}\tag{12}$$

Assuming that path gain is constant during $2P(P\geqslant 1)$ symbols. (Because of the convolutional encoder and interleaver, the system performance becomes better as the fading becomes faster). For the time $n, n+2, \cdots$, the symbol sequences $\boldsymbol{d}_{k}=[d_{k}^{(n)}\ d_{k}^{(n+2)}\ \cdots\ d_{k}^{(n+2p-2)}]^{\mathrm{T}}$ are sent out and deciding out symbol sequences is $\hat{\boldsymbol{d}}_{k}=[\hat{d}_{k}^{(n)}\ \hat{d}_{k}^{(n+2)}\ \cdots\ \hat{d}_{k}^{(n+2p-2)}]^{\mathrm{T}}$ under maximum-likelihood decoding. The processing is the same for the time $n+1, n+3$. The upper bound on the pairwise error probability (PEP) is approximated by[7]

$$P(\boldsymbol{d}_{k}\rightarrow\hat{\boldsymbol{d}}_{k}\,|\,g_{k,1,l}^{(n)})\leqslant\exp\left[-\frac{\gamma_{d_{k}^{(n)}}^{\mathrm{OTD}}}{8}|\boldsymbol{d}_{k}-\hat{\boldsymbol{d}}_{k}|^{2}\right]\tag{13}$$

Under the Rayleigh fading channel, $g_{k,1,l}^{(n)}$ can be modeled as independent samples of a complex Gaussian random variable 0.5 per dimension for different k, j and l, the probability density function of $|g_{k,j,l}^{(n)}|$ is

$$p(|g_{k,1,l}^{(n)}|)=2|g_{k,1,l}^{(n)}|\exp(-|g_{k,1,l}^{(n)}|^{2})\tag{14}$$

By averaging (14) over (15), we can give

$$P(\boldsymbol{d}_{k}\rightarrow\hat{\boldsymbol{d}}_{k})\leqslant\left[1+\frac{|\boldsymbol{d}_{k}-\hat{\boldsymbol{d}}_{k}|^{2}}{4\left(\dfrac{N_{0}}{E_{k}}+\sigma_{U1}^{\mathrm{OTD}}+\sigma_{I1}^{\mathrm{OTD}}\right)}\right]^{-L}\tag{15}$$

At high signal to noise rate, the frame error rate (FER) is decided by the PEP achieving d_{free}(the free Euclidean distance of transmitting symbols and decision output symbols). Then the upper bound on FER is

$$P_{F}^{\mathrm{OTD}}<\left[1+\frac{d_{\mathrm{free}}^{2}}{4\left(\dfrac{N_{0}}{E_{k}}+\sigma_{U1}^{\mathrm{OTD}}+\sigma_{I1}^{\mathrm{OTD}}\right)}\right]^{-L}\tag{16}$$

2.2 Performance analysis of STS

The block diagram of STS is shown in Fig.4. The transmitted symbols of the nth and $(n+1)$th symbol can be described by the matrix form as follows:

$$\frac{\sqrt{2}}{2}\begin{bmatrix} d_k^{(n)} - d_k^{(n+1)^*} & d_k^{(n+1)} - d_k^{(n)^*} \\ d_k^{(n)} + d_k^{(n+1)^*} & d_k^{(n+1)} + d_k^{(n)^*} \end{bmatrix} \tag{17}$$

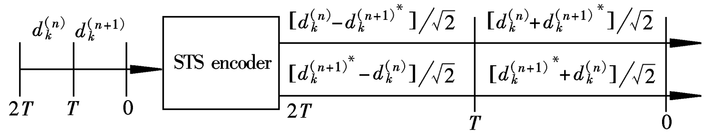

Fig. 4 The block diagram of space-time spreading

If we consider double length Walsh code as one Walsh code ($M = 128$), the signal received during two consecutive symbols can be modeled as

$$\tilde{\boldsymbol{r}}_l^{(n)} = (\boldsymbol{S}_{1,l}\boldsymbol{G}_1\boldsymbol{A}\boldsymbol{d}^{(n)} + \boldsymbol{S}_{2,l}\boldsymbol{G}_1\boldsymbol{A}\boldsymbol{d}_2^{(n+1)^*}) + (\boldsymbol{S}_{1,l}\boldsymbol{G}_2\boldsymbol{A}\boldsymbol{d}^{(n+1)} - \boldsymbol{S}_{2,l}\boldsymbol{G}_2\boldsymbol{A}\boldsymbol{d}^{(n)^*}) + \tilde{\boldsymbol{I}}_l^{(n)} + \tilde{\boldsymbol{N}} \tag{18}$$

where $\boldsymbol{S}_{1,l} = \frac{\sqrt{2}}{2}[\boldsymbol{S}_l \quad \boldsymbol{S}_l]^{\mathrm{T}}$, $\boldsymbol{S}_{2,l} = \frac{\sqrt{2}}{2}[\boldsymbol{S}_l \quad -\boldsymbol{S}_l]^{\mathrm{T}}$, $\tilde{\boldsymbol{I}}_l^{(n)} = [\boldsymbol{I}_l^{(n)} \quad \boldsymbol{I}_l^{(n+1)}]^{\mathrm{T}}$, $\boldsymbol{N} = [\boldsymbol{N}_1 \quad \boldsymbol{N}_2]^{\mathrm{T}}$. The coefficient $\frac{\sqrt{2}}{2}$ is to ensure that the total transmitting energy per symbol is the same as that of OTD. The combining output of Rake receiver is

$$\begin{bmatrix} \tilde{d}_k^{(n)} \\ \tilde{d}_k^{(n+1)} \end{bmatrix} = \sum_{l=1}^{L}\begin{bmatrix} (\boldsymbol{s}_{k,1,l}g_{k,1,l}^{(n)})^* \boldsymbol{r}_l^{(n)} - \boldsymbol{r}_l^{(n)*}(\boldsymbol{s}_{k,2,l}g_{k,2,l}^{(n)}) \\ (\boldsymbol{s}_{k,1,l}\boldsymbol{g}_{k,2,l}^{(n)})^* \boldsymbol{r}_l^{(n)} + \boldsymbol{r}_l^{(n)*}(\boldsymbol{s}_{k,2,l}g_{k,1,l}^{(n)}) \end{bmatrix} =$$
$$\begin{bmatrix} \sum_{l=1}^{L}(|g_{k,1,l}^{(n)}|^2 + |g_{k,2,l}^{(n)}|^2)A_k d_k^{(n)} \\ \sum_{l=1}^{L}(|g_{k,1,l}^{(n)}|^2 + |g_{k,2,l}^{(n)}|^2)A_k d_k^{(n+1)} \end{bmatrix} + \begin{bmatrix} \tilde{\boldsymbol{U}}_{l,1}^{(n)} \\ \tilde{\boldsymbol{U}}_{l,2}^{(n)} \end{bmatrix} + \begin{bmatrix} \approx{\boldsymbol{I}}_{l,1}^{(n)} \\ \approx{\boldsymbol{I}}_{l,2}^{(n)} \end{bmatrix} + \begin{bmatrix} \approx{\boldsymbol{N}}_1 \\ \approx{\boldsymbol{N}}_2 \end{bmatrix} \tag{19}$$

where $\boldsymbol{s}_{k,1,l} = \frac{\sqrt{2}}{2}[\boldsymbol{s}_{k,l} \quad \boldsymbol{s}_{k,l}]^{\mathrm{T}}$, $\boldsymbol{s}_{k,2,l} = \frac{\sqrt{2}}{2}[\boldsymbol{s}_{k,l} \quad -\boldsymbol{s}_{k,l}]^{\mathrm{T}}$, $\boldsymbol{s}_{k,l}$ is defined in (5) when $l' = l$. The overall SINR of the combined outputs of all the paths is

$$\gamma_{d_k^{(n)}}^{\mathrm{STS}} = \frac{\sum_{l=1}^{L}(|g_{k,1,l}^{(n)}|^2 + |g_{k,2,l}^{(n)}|^2)}{\frac{N_0}{E_k} + \sigma_{U1}^{\mathrm{STS}} + \sigma_{I1}^{\mathrm{STS}}} \tag{20}$$

$$\gamma_{d_k^{(n+1)}}^{\mathrm{STS}} = \frac{\sum_{l=1}^{L}(|g_{k,1,l}^{(n)}|^2 + |g_{k,2,l}^{(n)}|^2)}{\frac{N_0}{E_k} + \sigma_{U2}^{\mathrm{STS}} + \sigma_{I2}^{\mathrm{STS}}} \tag{21}$$

The upper bound on FER of STS is obtained by the same the processing of OTD.

$$P_{\mathrm{F}}^{\mathrm{STS}} < \left[1 + \frac{d_{\mathrm{free}}^2}{8\left(\frac{N_0}{E_k} + \sigma_{U1}^{\mathrm{STS}} + \sigma_{I1}^{\mathrm{STS}}\right)}\right]^{-2L} \tag{22}$$

It can be seen from Eqs.(11), (12),(21) and (22) that two path gains are used by STS, while OTD just uses one path gain. So, higher diversity gain can be obtained in STS.

The performance bound is shown in Fig.5. The condition is: one path or two equal power fading paths for each antenna; the time delay of the second path is one chip; $M = 64$; $\sigma_{U1}^{\mathrm{OTD}} = \sigma_{U1}^{\mathrm{STS}} = \frac{2KL - 1}{3M}$[8], $\sigma_{I1}^{\mathrm{OTD}} = \sigma_{I1}^{\mathrm{STS}} = \left(2\sum_{l'=1}^{l-1}\Delta_{k,j,l'}\right)\Big/(ML)$. The rate of the convolutional code is 1/4. The constraint length is 9. The generator in octal is (765,671,513,473)[1]. From the bound in Fig.5, we can see that STS outperform OTD under the same transmitting power. Furthermore, it can be seen from Fig.5(a) that at 10^{-2} FER, STS offers 5 dB over OTD under $L = 1$ and 3 dB under $L = 2$. It also can be seen from Fig.5(b) that at 10^{-2} FER, STS offers 4 dB over OTD under $K = 10$ and 7 dB under $K = 30$. Therefore, compared with OTD, the performance improvement of STS is reduced as the number of propagation path increases and the number of traffic channel decreases.

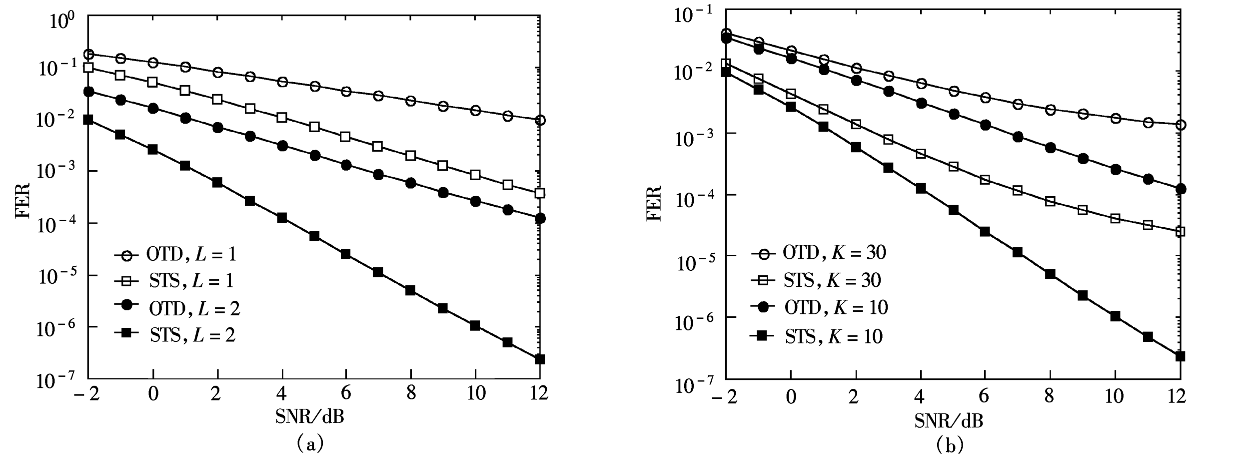

Fig.5 Performance comparison of frame error rate. (a) $K = 1; L = 1,2$; (b) $L = 2; K = 10,30$

3 Simulation

In this section, we test the performance of STS and OTD in forward link cdma2000 under indoor and vehicle environments. The link level simulation is carried out under COSSAP. The main simulation parameter is: two transmitting antennas and one receiving antenna; carrier frequency 1.9 GHz; symbol rate 9.6 kbit/s; PN chip rate 1.228 8 MHz; Walsh length 64; QPSK modulation; frame size 20 ms; code symbol repetition 1; traffic channel is forward fundamental channel; channel code is RC3 (1/4 rate convolutional code with additional puncturing for overlay of reverse-link power control information at a rate of 4/48). We consider power control is ideal in the simulation. The power of pilot channel is the same as that of one traffic channel. All traffic channels have equal power and transmission is synchronous. (In this case, multiple access interference is caused by the traffic channels on different propagation paths). The number of Rake finger is 3. Fading channel model used in the simulation is shown in Tab.1.

Tab.1 Fading channel model for channel A[5]

Pedestrian		Vehicular	
Relative delay/ns	Average power/dB	Relative delay/ns	Average power /dB
0	0	0	0
110	− 9.7	310	− 1.0
190	− 19.2	710	− 9.0
410	− 22.8	1 090	− 10.0
		1 730	− 15.5
		2 510	− 20.0

The simulation results for 5 traffic channels at 3 km/h are shown in Fig.6(a). In the case of pedestrian speed, the length of channel estimation window is 1 024 chips.

The simulation results for 5 traffic channels at 120 km/h are shown in Fig.6(b). The length of channel estimation window is 512 chips at vehicular speed. Higher speed needs shorter length of channel estimation window because the path gain is assumed to be constant during one channel estimation window.

The simulation results for 20 traffic channels at 120 km/h are shown in Fig.6(c).

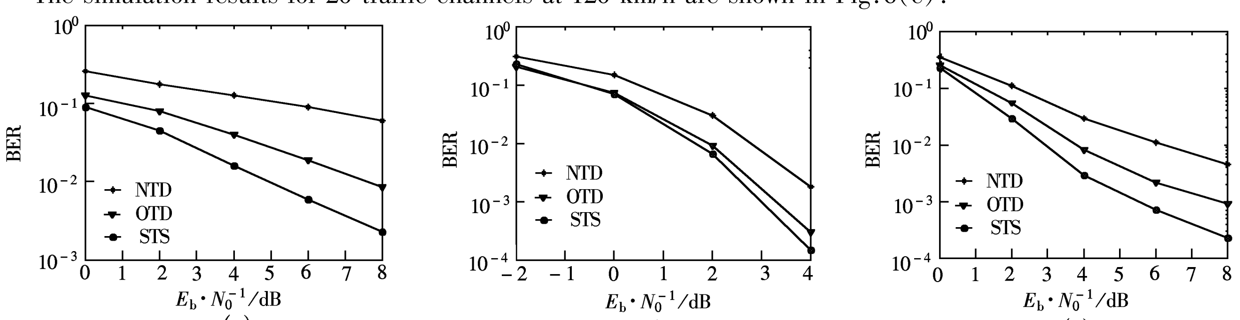

Fig.6 Performance comparison of transmit diversity schemes in cdma2000. (a) 3 km/h, 5 traffic channels; (b) 120 km/h, 5 traffic channels; (c) 120 km/h, 20 traffic channels

From the results, we can see that STS outperform OTD and OTD outperform NTD (no transmit diversity) under the same transmitting power at different conditions.

We also can see from Fig.6(a) and Fig.6(b) that at 10^{-2} BER, STS outperform OTD 2.4 dB at pedestrian speed and down to 0.3 dB at vehicular speed when the number of traffic channels is same. Under the same fading environment, it can be seen from Fig.6(b) and Fig.6(c) that at 10^{-2} BER, STS outperform OTD 0.3 dB when the number of traffic channel is 5 and up to 0.8 dB when the number of traffic channel is 20. It can be seen that the analysis results accord with the simulation results.

4 Conclusion

Performance analysis and simulation results show that STS outperforms OTD under the same transmitting power. The value of the performance improvement is reduced with the increase of propagation path and decrease of the number of traffic channels.

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空时扩频与正交发射分集的性能评估

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摘　要　空时扩频(STS)及正交发射分集(OTD)是 cdma2000 标准提出的 2 种发射分集方案.本文在多径信道及多用户条件下对 2 种方案进行了性能比较分析.在 IMT-2000 标准信道下进行了链路级仿真.性能分析及仿真结果表明 STS 相对于 OTD 的性能增益随着传播路径的增加及用户数的降低而减少.

关键词　空时扩频,正交发射分集,cdma2000
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