Orthogonal Space-time Spreading Transmit Diversity

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Abstract- In this paper, a new 2-antenna transmit diversity, called orthogonal space-time spreading transmit diversity (OSTSTD) combined with time diversity transmission, is proposed. At the transmitter, N data symbols to be transmitted are spread using N different orthogonal space-time spreading codes (each represented by N-by-N matrix) and are transmitted from two transmit antennas after adding different time delays. At the receiver, 2-step space-time despreading is carried out to recover the N transmitted data symbols. The first step recovers the N orthogonal channels by taking the correlation between the received space-time spread signal and time-domain spreading sequences. The second step recovers the N transmitted data symbols using minimum mean square error (MMSE) despreading. The average bit error rate (BER) performance in a Rayleigh fading channel is evaluated by computer simulation. It is confirmed that the OSTSTD provides better BER performance than the Alamouti's space-time transmit diversity (STTD) at the cost of transmission time delay.
Keywords- Transmit diversity, space-time spreading, fading channel.

1. Introduction

In mobile radio communications, the transmitted signal is scattered by many obstacles located between a transmitter and a receiver, thereby creating a multipath channel and severely degrading the transmission performance [1]. Multiple diversity antennas at a transmitter and/or a receiver can be used to reduce the adverse effect of multipath fading. Receive antenna diversity has been successfully used in practical systems. However, recently, transmit antenna diversity has been gaining a much attention since the use of transmit diversity at a base station alleviates the complexity problem of mobile receivers [2]. The transmit diversity technique employing orthogonal space-time block code (STBC) is well-known [3-5]. Especially, the Alamouti's space-time transmit diversity (STTD) [3] has a simple coding and decoding algorithm and provides the full transmission rate. In STTD, the data modulated symbol sequence to be transmitted is space-time block coded and transmitted from two spatially separated antennas. At the receiver, a simple decoding operation is applied to achieve the 2-branch maximal ratio combining (MRC) effect but with 3dB power penalty. Also, the transmit diversity technique based on space-time spreading (STS) was proposed for code division multiple access (CDMA) systems [6]. Although the STS using binary phase shift keying (BPSK) works even with four and eight transmit antennas, the STS using quadrature PSK (QPSK) can offer the full diversity gain and full transmission rate only for the two transmit antenna case [6].

In this paper, we combine space-time spreading and time diversity transmission to exploit the time-selective fading and propose orthogonal space-time spreading transmit diversity (OSTSTD). In Sect. 2, orthogonal space-time spreading and despreading based on minimum mean square error (MMSE) criterion are presented. Sect. 3 evaluates by computer simulation the achievable bit error rate (BER) performance in a Rayleigh fading channel to show that better BER performance can be obtained than Alamouti's STTD. Sect. 4 concludes the paper.

2. OSTSTD

Figure 1 illustrates the transmission system model of OSTSTD with two transmit antennas and M_r received antennas.

2.1 Orthogonal space-time spreading codes

Orthogonal $N\times N$ space-time spreading codes $\mathbf{C}_n^{(N)}, n=0\sim N-1,$ are constructed using the $N\times N$ -Hadamard matrix $\mathbf{H}^{(N)}$. The element $c_n^{(N)}(m,t)=\pm1$ of $\mathbf{C}_n^{(N)}$ at the m-th row and t-th column is generated as [7]

$$c_n^{(N)}(m,t)=h^{(N)}(m,t)h^{(N)}(n,m)\,, (1)$$

where $h^{(N)}(m,t)=\pm1$ is the element of $\mathbf{H}^{(N)}$ at the m-th row and t-th column. $h^{(N)}(m,t)$ (or $h^{(N)}(n,m)$) is used for orthogonal temporal (or spatial)-spreading of the transmitted data. To acquire a better understanding of orthogonal space-time spreading codes, the four-by-four case is shown below:

$$\mathbf{C}_0^{(4)}=\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}\mathbf{C}_1^{(4)}=\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&1&-1&-1\\-1&1&1&-1\end{bmatrix},\ (2)$$
$$\mathbf{C}_2^{(4)}=\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\-1&-1&1&1\\-1&1&1&-1\end{bmatrix}\mathbf{C}_3^{(4)}=\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\-1&-1&1&1\\1&-1&-1&1\end{bmatrix}$$

N data symbols are spread using N different orthogonal space-time spreading codes $\{\mathbf{C}_n^{(N)};n=0\sim N-1\}$ and are transmitted from two transmit antennas after adding different time delays. Note that there is no bandwidth expansion and that N orthogonal spatial channels, over

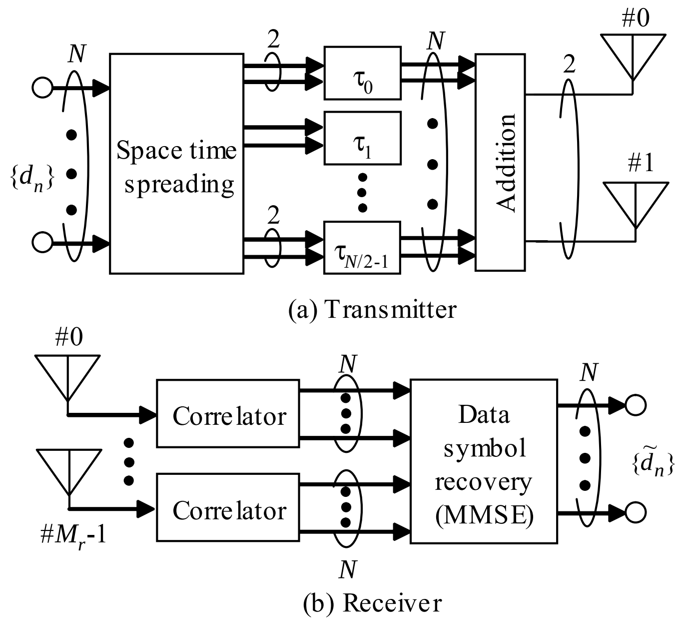


Fig. 1 Transmission system model of OSTSTD.

which each data symbol is spread, are constructed using time diversity transmission from two transmit antennas. The $2i$ (or $2i$+1)-th row corresponds to the 0 (or 1)-th transmit antenna.

2.2 Spreading and despreading

Discrete time representation of the space-time spread signal is used. Below, we consider the time interval of $T=NT_s$ for the transmission of N data symbols in parallel, where T_s is the data symbol duration. The space-time spread signal sequence of length N in time is represented by $\{c_n^{(N)}(m,t);t=0\sim N-1\}$ for the transmission of the nth data symbol d_n. The space-time spread signal $s(m,t)$ is expressed in the equivalent lowpass representation as

$$s(m,t)=\sqrt{2S/N}\sum_{n=0}^{N-1}d_n c_n^{(N)}(m,t) \quad (3)$$

for m and t=0~N-1, where S is the total transmit power. Orthogonal space-time spreading codes have the property that any two rows taken from either the same spreading code or a different spreading code are orthogonal to each other, i.e.,

$$(1/N)\sum_{l=0}^{N-1}h^{(N)}(m,t)h^{(N)}(m',t)=0 \quad \text{if } m\neq m', \quad (4)$$

This allows simple recovery of the N transmitted symbols using the well-known MMSE despreading [8].

The signals $s(m,t)$'s with m=2i and 2i+1 to be transmitted are added the same time delay $\tau_i=iDN$, where D denotes the time delay separation. Then, N/2 space-time spread signals with m=2i are added for i=0~N/2-1and those with m=2i+1 are also added for i=0~N/2-1 to produce two spread signal sequences, $\bar{s}_0(t)$ and $\bar{s}_1(t)$, for transmission from two transmit antennas, respectively, where

$$\bar{s}_{m_t}(t)=\sum_{i=0}^{N/2-1}s(2i+m_t,t-\tau_i) \quad \text{for } m_t=0,1. \quad (5)$$

M_r receive antennas are used at the receiver. The complex-valued propagation channel gain experienced between the m_t-th transmit antenna and the m_r-th received antenna is represented by $\xi_{m_t,m_r}(t)$ with the ensemble average of $\left|\xi_{m_t,m_r}(t)\right|^2$ being unity for all m_t and m_r (m_t=0~1 and m_r=0~M_r-1). The received signal on the m_r-th receive antenna at time t can be represented as

$$r_{m_r}(t)=\sum_{m_t=0}^{1}\xi_{m_t,m_r}(t)\bar{s}_{m_t}(t)+\eta(t) \quad (6)$$

for t=0~N-1, where $\eta(t)$ is the additive white Gaussian noise (AWGN) process with zero mean and a variance of N_0/T_s with N_0 being the AWGN power spectrum density.

Space-time despreading of N transmitted data symbols consists of two steps. The first step recovers the m-th channel by taking the correlation between $\{r_{m_r}(t);t=0\sim N-1\}$ and $\{h^{(N)}(m,t);\ t=0\sim N-1\}$. Using Eq. (6), we obtain

$$\tilde{r}_{m_r}(m)=(1/N)\sum_{t=0}^{N-1}r_{m_r}(t+\tau_{\lfloor m/2\rfloor})h^{(N)}(m,t) \quad (7)$$

for m=0~N-1. The second step recovers the decision variable $\tilde{d}_n$ for the transmitted n-th data symbol using MMSE:

$$\tilde{d}_n=(1/N)\sum_{m=0}^{N-1}\left(\sum_{m_r=0}^{M_r-1}w_{m_r}(m)\tilde{r}_{m_r}(m)\right)h^{(N)}(n,m), \quad (8)$$

where

$$w_{m_r}(m)=\frac{\hat{\xi}^*_{m_r}(m)}{\sum_{m_r=0}^{M_r-1}\left|\hat{\xi}_{m_r}(m)\right|^2+\left(\frac{E_s}{N_0}\right)^{-1}} \quad (9)$$

is the MMSE weight [9] with E_s/N_0 being the average symbol energy-to-AWGN power spectrum density ratio and

$$\hat{\xi}_{m_r}(m)=\begin{cases}\xi_{0,m_r}(m) & \text{if } m=\text{even}\\ \xi_{1,m_r}(m) & \text{if } m=\text{odd}\end{cases}. \quad (10)$$

3. Computer Simulation

Table 1 shows the simulation condition. QPSK data

Table 1 Simulation condition.

Data modulation	QPSK
Orthogonal code	Walsh-Hadamard code
No. of transmit antennas	2
Propagation channel model	Rayleigh fading
No. of receive antennas	M_r=1, 2, 4
Channel estimation	Ideal

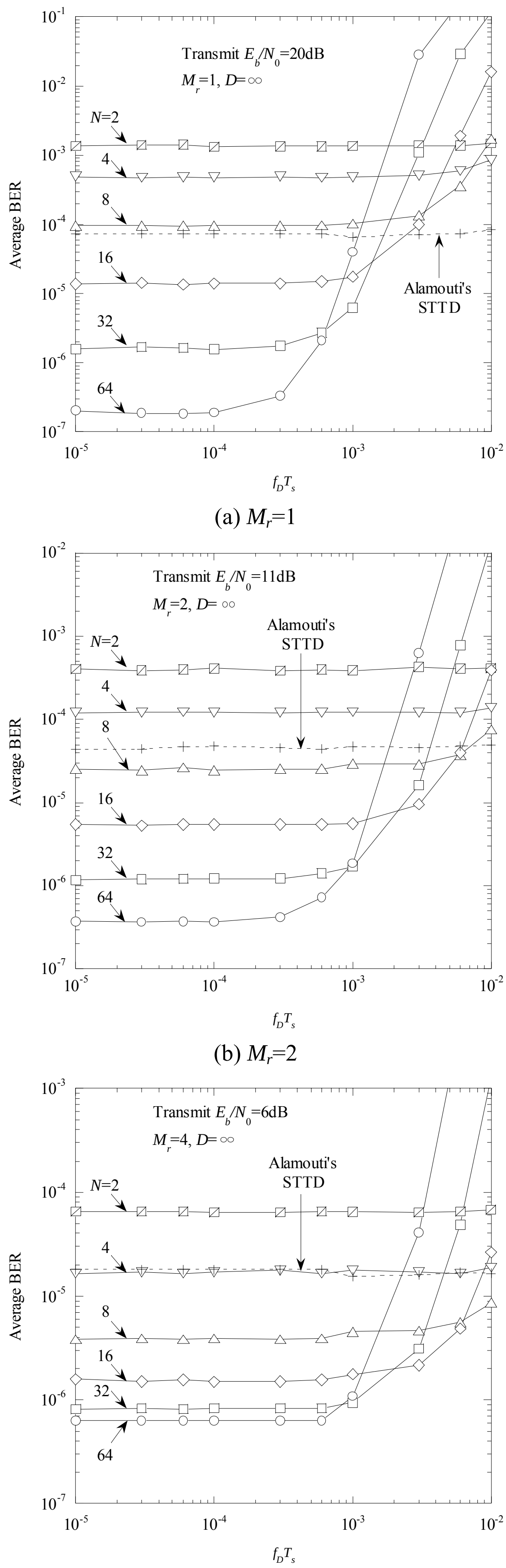
modulation is used. The propagation channels between two transmit antennas and M_r receive antennas are assumed to be characterized by independent Rayleigh fading processes. Channel estimation is assumed to be ideal.

In OSTSTD, N data symbols are spread spatially and temporally using time diversity transmission from two transmit antenna. As the space-time spreading code size N becomes larger, the achievable BER improves due to the time diversity effect. However, since we take the correlation between the received signals and time-domain spreading sequences at the receiver in order to separate the N orthogonal spatial channels, the use of the large space-time spreading code size causes the code orthogonality destruction in time if fading becomes faster. Hence, there is a tradeoff relationship between the time diversity effect and the code orthogonality in time.

First, we evaluate the effect of the space-time spreading code size N on the average BER performance. Figure 2 plots the simulated average BER performance of OSTSTD as a function of the normalized maximum Doppler frequency f_DT_s with N as a parameter, where $1/T_s$ denotes the transmission symbol rate. The time delay separation D between the adjacent space-time spread signals is assumed to be infinite. This implies that N perfect independent channels are constructed. As the space-time spreading code size N increases, the average BER performance significantly reduces for the slow fading channel case. For comparison, the BER achievable by the Alamouti's STTD is also plotted. OSTSTD using $N \geq 16$ for M_r=1, 2 and 4 outperforms the Alamouti's STTD in a low f_DT_s region. The BER starts to increase rapidly as f_DT_s increases beyond a certain value and becomes larger than that of STTD. This is because of the increased code orthogonality destruction in time. However, the value of f_DT_s at which the BER starts to increase becomes larger as M_r increases. Thus, the use of the receive diversity reception is always beneficial.

Figure 3 plots the average BER performances as a function of the total transmit E_b/N_0 (=0.5 E_s/N_0) with M_r as a parameter for the normalized maximum Doppler frequency f_DT_s=0.0006 (the corresponding mobile speed becomes approximately 50km/h for the carrier frequency of 5GHz and the transmission symbol rate of $1/T_s$=400ksps). The average BERs are plotted with M_r as a parameter. As D increases, the achievable average BER performance improves. When M_r=2 and D=20, the required total transmit E_b/N_0 for the average BER=10^{-6} is 12.8 and 11.2 dB for N=16 and 32, respectively. OSTSTD provides better BER performance than Alamouti's STTD. The diversity gain in the required average E_b/N_0 from Alamouti's STTD is as much as 2.9 and 4.4 dB for N=16 and 32, respectively.

Finally, we show how the fading rate impacts the BER



(a) M_r=1

(b) M_r=2

(c) M_r=4

Fig. 2 Effect of space-time spreading code size N.

performance of OSTSTD with the finite value of D. The average BERs are plotted with D as a parameter in Fig. 4. We see that at the cost of the transmission time delay, the BER performance of OSTSTD can be made superior, by properly setting the time delay, to the Alamouti's STTD.

4. Conclusion

In this paper, orthogonal space-time spreading transmit diversity (OSTSTD) combined with time diversity transmission was proposed. 2-step space-time despreading based on MMSE criterion was presented to recover the transmitted data symbols spread over a number of independent channels constructed by orthogonal spreading and time diversity transmission. The average BER performance achievable with the proposed OSTSTD in a Rayleigh fading channel was evaluated by computer simulation. It was confirmed that, by properly setting the time delay, the OSTSTD provides the BER performance superior to Alamouti's STTD at the cost of the transmission time delay. When M_r=2, D=20 and f_DT_s=0.0006, the diversity gain in the required average E_b/N_0 from Alamouti's STTD was found to be as much as 2.9 and 4.4 dB for N=16 and 32, respectively.

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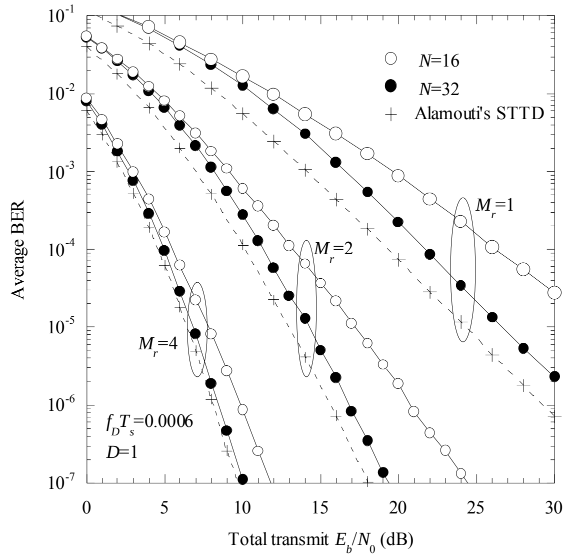
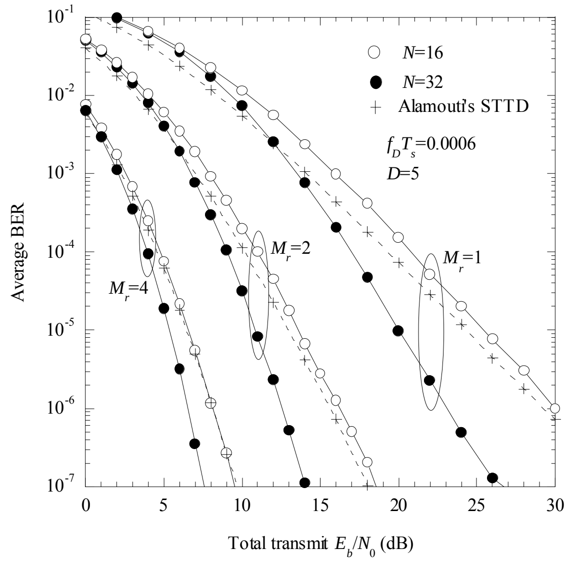
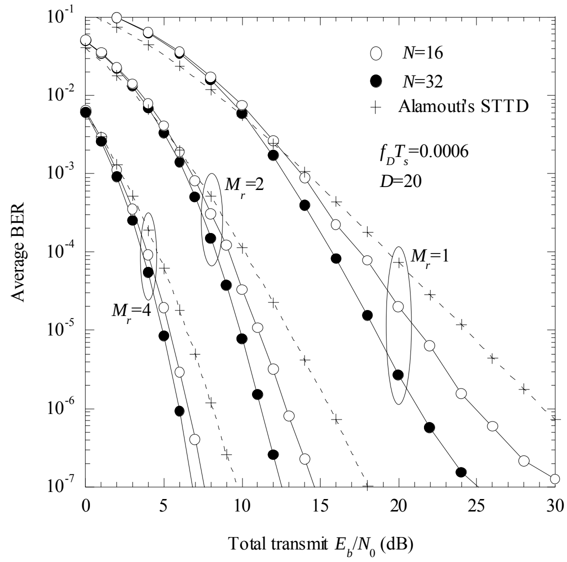


(a) D=1

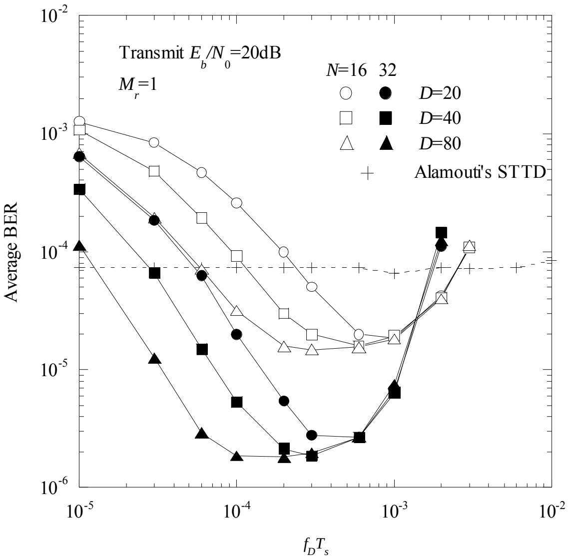


(b) D=5

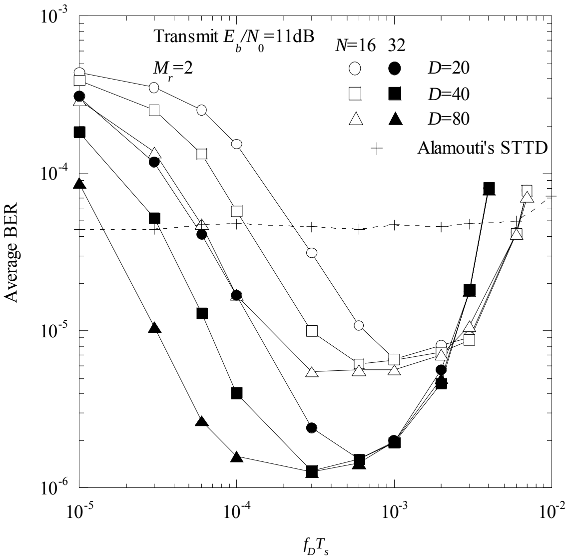


(c) D=20

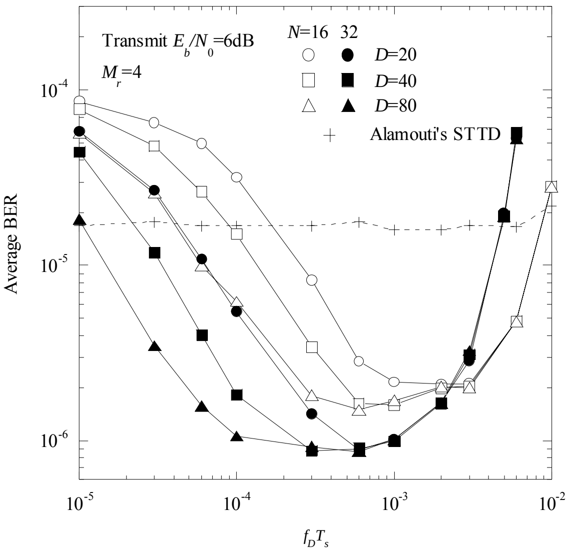
Fig. 3 Average BER performance.



(a) M_r=1



(b) M_r=2



(c) M_r=4

Fig. 4 Effect of fading rate.