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A Novel CDMA-BLAST Space-Time Code Scheme

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Abstract: This study proposes a novel CDMA BLAST (Bell Labs layered space-time) space-time code scheme used in forward link in a cellular CDMA system. Both scrambling code and orthogonal spreading code are employed to specify different transmit antennas and users, respectively. Since scrambling codes use pseudo-noise sequences providing excellent quality of auto and cross correlation proprieties, the proposed novel scheme can obtain considerable improvement of performance without sacrificing the precious code resources. The simulation results demonstrates the average BER of improved scheme decrease 10 dB for (2, 2) system with 4 users when Eb/N0 = 7 dB.

Key words: Bell Labs layered space-time (BLAST), space-time code, scrambling code, CDMA

INTRODUCTION

The next generation of wireless mobile communication will support multiple classes of traffic with different quality of service requirements such as data rate and bit error rate. Specially, high-speed packet data service will be an important application of future CDMA systems. The combination of space-domain techniques like Multiple Input Multiple Output (MIMO) and time-domain techniques like multiuser detection has been recommended for next generation CDMA systems to provide such services.

BLAST is a promising technique (Loyka and Gagnon, 2004; Foschini and Gans, 1998) for achieving high-speed services using multiple transmit antennas, multiple receive antennas and advanced signal processing at the receiver. Narrowband BLAST provides high data rates by transmitting independent substreams from multiple antennas, where each antenna transmits a single substream. Multiple antennas at the receiver allow the substreams to be separated based on their different spatial characteristics. If we consider a point-to-point system where the number of transmit antennas is M and the number of receive antennas is P, These conclusions have been demonstrated (Woliansky *et al*., 1998) that if P isn't less than M and if there is sufficient scattering in the channel so that the substream vectors are linearly independent, one can use the BLAST detection algorithm to demodulate the substreams based only on their spatial characteristics.

Previous BLAST investigations have been in the context of narrowband channels and point-to-point communications. In order to provide high speed packet data service based on the prevalent CDMA system, it is necessary to extend BLAST technique to CDMA system. In CDMA-BLAST system (Huang *et al*., 1999), user's data stream is demultiplexed into M substreams, either different code or same code can be used to spread each of the M substreams. If we use the same code, the substreams can be distinguished only by their spatial characteristics since the same codes don't aid the receiver in distinguishing among them. As an alternative spreading strategy, one could use different codes for each of the substreams. In this case, the substreams can be differentiated by their spatial characteristics and their codes. Because the number of orthogonal codes is limited by the spreading factor, the codes become a scarce resource as the number of user increases. Hence, while different-code transmission may provide better link level performance, the fact that it uses more codes means that the maximum achievable spectral efficiency is potentially less than that of same-code transmission (Huang *et al*., 1999).

Using either scheme, the fact that use of spreading code allows us to reuse the antennas since we can transmit multiple substreams from a single antenna using different codes. Therefore, for providing high-speed data services, these schemes can be used in the forward link (from the base station to the remotes) in a cellular CDMA system (Chizhik *et al*., 2000). Note that depending on the channel characteristics and the code transmission choice,

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there are potentially two types of multiaccess interference the detector contends with. For single desired substream of a given user, there is interference from the user's other substreams at other antennas and from all of the substreams of the other users (Narasimhan, 2003).

In this study, we assign one scrambling code per transmit antenna and one Orthogonal Variable Spreading Factor (OVSF) code per user. Scrambling codes are not orthogonal and don't spread signal bandwidth, but they have excellent quality of auto and cross correlation proprieties (Golden *et al*., 1999; Gore *et al*., 2002). Due to the excellent quality of scrambling codes, the novel scheme proposed in this study can obtain considerable improvement of link performance without sacrificing the precious code resources.

SYSTEM MODEL

At first, we assume a flat fading channel where the multipath components are ignored, the channel between each transmit and receive antenna pair can be characterized by a complex amplitude coefficient. Furthermore, we assume that transmit and receive antennas are sufficiently spaced so the channel coefficients are independent and we assume that they have normalized variance, sequentially, the Eq. 1 is true,

$$E\left(h^*_{m_1,p_1}h_{m_2,p_2}\right)=\begin{cases}0 & \text{if} \quad m_1\neq m_2 \quad \text{or} \quad p_1\neq p_2\\ 1 & \text{if} \quad m_1=m_2 \quad \text{and} \quad p_1=p_2\end{cases} \tag{1}$$

where, * denotes the complex conjugate. The channel is assumed to be fixed over the duration of the symbol and these channel coefficients are perfectly known at the receiver and synchronous receive is also assumed.

Conventional CDMA-BLAST scheme: The conventional CDMA-BLAST transmission is achieved by transmitting different substreams over different antennas using the same code. For M antennas and K users, the transmitted signals are:

$$t_m=\left(s_1b_{m,1}+s_2b_{m,2}+\cdots+s_kb_{m,k}+\cdots+s_Kb_{m,K}\right)/\sqrt{M} \tag{2}$$

where, $m\in[1,2,...,M]$, $k\in[1,2,...,M]$, t_m is the transmitted signals from mth transmit antenna, s_k is the orthogonal spreading code of kth user (normalized to unit energy over the symbol period) and $b_{m,k}$ is the data symbol of from mth transmit antenna and kth user. The signal amplitudes are normalized by $1/\sqrt{M}$ so the total transmit power is fixed. The KM data substreams are each spread by a length N code and transmitted out of M transmit antennas, the spectral efficiency is 16CM/N bps/Hz, where C is the number of bit per symbol of the signaling constellation and N is the spreading factor. For a given symbol period, the baseband received signal at the pth antenna of a mobile station is a complex N dimensional vector:

$$r_p=\sum_{m=1}^{M}Ah_{m,p}t_m+n_p \qquad p=1\cdots P \tag{3}$$

where, A is the amplitude which is a function of path loss and shadow fading, $h_{m,p}$ is the complex Gaussian random variable which represents the channel between the mth transmitter and pth receiver antenna, t_m is the signal from the mth transmitter and n_p is the complex additive white Gaussian noise vector with covariance σ^2I_N. Using BLAST transmission according to Eq. 2, the received signals for P antenna receiver can be stacked to yield:

$$\begin{bmatrix}r_1\\ M\\ r_P\end{bmatrix}=\sum_{k=1}^{K}\begin{bmatrix}s_k & & & \\ & s_k & & \\ & & O & \\ & & & s_k\end{bmatrix}\begin{bmatrix}h_{1,1} & h_{1,2} & \Lambda & h_{1,M}\\ h_{2,1} & h_{2,2} & \Lambda & h_{2,M}\\ M & M & O & \\ h_{P,1} & h_{1,2} & & h_{P,M}\end{bmatrix}\begin{bmatrix}b_{1,k}\\ b_{2,k}\\ M\\ b_{M,k}\end{bmatrix}+n \tag{4}$$

An improved CDMA-BLAST scheme: Based on conventional scheme mentioned above, scrambling code can be applied to suppress the interference without sacrificing codes or spectral efficiency. This improved BLAST transmission is achieved by transmitting different substreams over different antennas using the same spreading code and different scrambling codes. In other words, the scrambling code is used to distinguish the transmit antennas and spreading code is used to distinguish different users. For M = 2 antennas, the transmitted signals are:

$$t_m=\text{diag}(v_m)\left(s_1b_{m,1}+s_2b_{m,2}+\cdots+s_Kb_{m,K}\right)/\sqrt{M} \tag{5}$$

where, v_m denoted scrambling code of mth transmitter. With M transmit antennas, the spectral efficiency is still 16CM/N bps/Hz. Using improved transmission scheme according to Eq. 5, the received signals for P antenna receiver can be stacked to yield. In Eq. 6, where $q_{k,m}=s_kv_m$ is the combination between the orthogonal spreading code s_k of kth user and scrambling code v_m of mth transmitting antenna. In other words, it means the spreading code sequence multiply by corresponding element of scrambling code sequence.

$$\begin{bmatrix} r_1 \\ r_2 \\ M \\ r_P \end{bmatrix} = \sum_{k=1}^{K} \mathrm{diag}(\begin{bmatrix} q_{k,1} & q_{k,2} & \Lambda & q_{k,M} \\ q_{k,1} & q_{k,2} & \Lambda & q_{k,M} \\ & \Lambda & & \\ q_{k,1} & q_{k,2} & \Lambda & q_{k,M} \end{bmatrix}^T) \begin{bmatrix} \mathrm{diag}(h_{1,1} & h_{2,1} & \Lambda & h_{M,1}) \\ \mathrm{diag}(h_{1,2} & h_{2,2} & \Lambda & h_{M,2}) \\ & M & & \\ \mathrm{diag}(h_{1,P} & h_{2,P} & \Lambda & h_{M,P}) \end{bmatrix} \begin{bmatrix} b_{1,k} \\ b_{2,k} \\ M \\ b_{M,k} \end{bmatrix} + n \quad (6)$$

SYSTEM ANALYSIS

Here, we analyze the Signal to Interference Ratio (SIR) at both schemes. For simplicity, we ignore the effect of noise and divide the analysis into two steps. First, we deduce the SIR presentation at special case and then generalize these conclusions. We assume that the number of users is K = 2, the number of transmit antennas is M = 2, the number of receive antennas is P = 2 and desired symbol is b_1. The space-time matched filter output of conventional scheme (Huang and Viswanathan, 2000) is:

$$\begin{bmatrix} h_1^H \\ h_2^H \end{bmatrix} \begin{bmatrix} s_1^H r_1 \\ s_1^H r_2 \end{bmatrix} = \begin{bmatrix} \|h_1\|^2 & h_1^H h_2 \\ h_2^H h_1 & \|h_2\|^2 \end{bmatrix} b + n' \quad (7)$$

where, $h_1 = [h_{11}\ h_{12}]^T$ and $h_2 = [h_{21}\ h_{22}]^T$. $h_{m,p}$ is zero-mean complex Gaussian random variable with unit variance. The signal power is $\|\mathbf{h}_1^H \mathbf{h}_1 b_1\|^2$ and the corresponding interference item is $\mathbf{h}_1^H \mathbf{h}_2 b_2 = (h_{11}h_{21} + h_{12}h_{22})b_2$. Similarly, the space-time matched filter output of improved scheme is obtained; in Eq. 8. The signal power is $\|\mathbf{h}_1\|^2 \|\mathbf{q}_{11}\|^2$ and the corresponding interference includes three items

$$\begin{bmatrix} h_{11} & \\ & h_{21} \\ h_{12} & \\ & h_{22} \end{bmatrix}^H \begin{bmatrix} \mathbf{q}_{1,1} & \mathbf{q}_{1,2} & & \\ & & \mathbf{q}_{1,1} & \mathbf{q}_{,12} \end{bmatrix}^H \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \end{bmatrix}$$

$$= \begin{bmatrix} \|\mathbf{h}_1\|^2 \|\mathbf{q}_{1,1}\|^2 & \mathbf{h}_1^H \mathbf{h}_2 \mathbf{q}_{1,1}^H \mathbf{q}_{1,2} \\ \mathbf{h}_2^H \mathbf{h}_1 \mathbf{q}_{1,2}^H \mathbf{q}_{1,1} & \|\mathbf{h}_2\|^2 \|\mathbf{q}_{1,2}\|^2 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} \|\mathbf{h}_1\|^2 \mathbf{q}_{1,1}^H \mathbf{q}_{2,1} & \mathbf{h}_1^H \mathbf{h}_2 \mathbf{q}_{1,1}^H \mathbf{q}_{2,2} \\ \mathbf{h}_2^H \mathbf{h}_1 \mathbf{q}_{1,2}^H \mathbf{q}_{2,1} & \|\mathbf{h}_2\|^2 \mathbf{q}_{1,2}^H \mathbf{q}_{2,2} \end{bmatrix} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix} + n' \quad (8)$$

$$\underbrace{\mathbf{h}_1^H \mathbf{h}_2 \mathbf{q}_{1,1}^H \mathbf{q}_{1,2} b_2}_{A} + \underbrace{\|\mathbf{h}_1\|^2 \mathbf{q}_{1,1}^H \mathbf{q}_{2,1} b_3}_{B} + \underbrace{\mathbf{h}_1^H \mathbf{h}_2 \mathbf{q}_{1,1}^H \mathbf{q}_{2,2} b_4}_{C} \quad (9)$$

Item A denotes interference from different antennas of the identical user, Item B denotes interference from different users at the identical antenna and Item C denotes interference from different antennas of the different users. Although the interference items of improved scheme seem more than it of conventional one, the fact power may be smaller due to the excellent auto and cross correlation proprieties of scrambling code. According to the Monte-Carlo simulation, the statistic value of three items can be obtained. Sequentially, we extend these analyses to general case with K users, M transmit antennas and P receive antennas. The SIR of conventional scheme is:

$$\gamma_1 = \frac{1}{(M-1)} \quad (10)$$

The SIR of improved scheme is:

$$\gamma_2 = \frac{1}{A(M-1) + B(K-1) + C(K-1)(M-1)} \quad (11)$$

where, A = 0.0058, B = 2.33×10^{-35}, C = 0.0039. One can substitute A, B and C to Eq. 10, 11 and let $\gamma_1 = \gamma_2$, then get the approximate critical value $\tilde{K} \cong 253$. Obviously, the interference of conventional scheme depends on M, while the interference of improved one depends on MK. In other words, the performances of both scheme decrease as M increase and the performance of improved scheme decrease as K increase, while the performance of conventional keep steady. Therefore, the link performance of improved scheme is superior to conventional one only when the number of users is less than 253. The improved scheme is preferable in the system with fewer users.

SIMULATION RESULTS

Here, we compare the link performance between the existed scheme and improved one proposed in this study. At first, we assume that the transmit data use the same spreading factor N = 256 and operate with the same BPSK modulation and the total transmit power of each user is fixed to 1. Present benchmark for comparison channel is flat Rayleigh fading and the channel coefficients keep static over one symbol period and it is independent between the transmissions of each set of substreams. Then, we compare the performance between conventional and improved scheme, in terms of average BER versus such parameters as E_b/N_0, the number of transmit antenna M, the number of receive antenna P and the number of user K.

Figure 1 show the effect of E_b/N_0 on the link level performance for M = P = 2 and K = 4. Obviously the improved scheme has better performance than the conventional one in terms of average BER duo to the excellent quality of scrambling codes. We notice that there is almost 10 dB loss in BER compared to conventional scheme at E_b/N_0 of 7 dB.

Figure 2 shows the compare result between two schemes at different M and P, the horizontal axis is the number of receiver antenna, the vertical axis is the average BER, these conclusions as follow can be obtained. For fixed E_b/N_0, the larger the number of transmitter M, the worse the performance since more interference from other transmitter is introduced. The larger the number of receiver antennas P, the better the performance since more

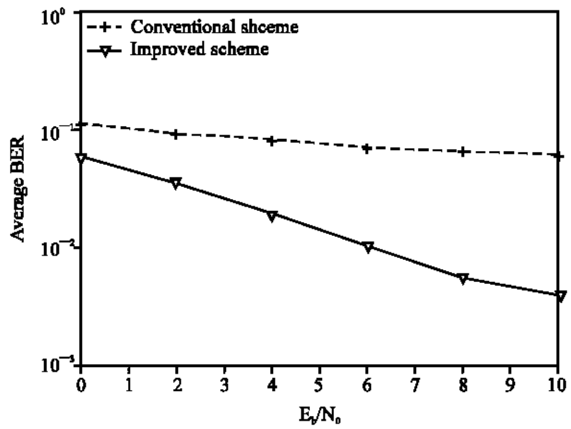

Fig. 1: Average BER versus E_b/N_0

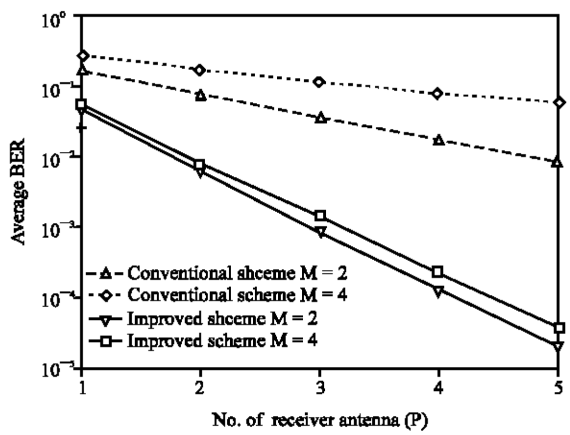

Fig. 2: Average BER versus P parameterized by M

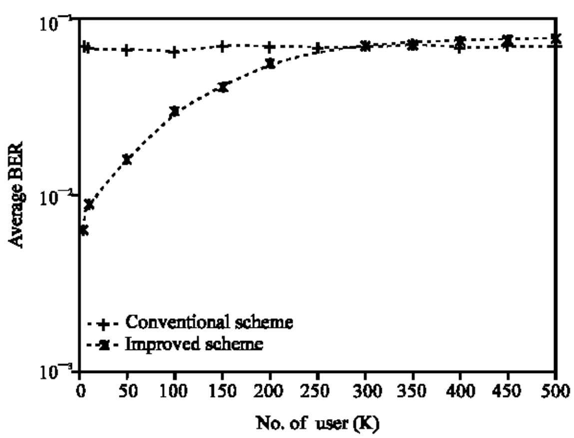

Fig. 3: Average BER versus K

received signals can be used to obtain larger diversity gain. In each case, the link level performance of improved scheme is superior to the conventional scheme obviously.

Figure 3 present the effect of the number of users on the link level performance for fixed M = P = 2 and E_b/N_0 = 7. The improved scheme always keeps advantage over conventional one when K is smaller than 253, but the predominance vanishes with an increasing number of users gradually. This result is in accordance with analyses as before.

CONCLUSIONS

This study presents a novel CDMA-BLAST space time code scheme based on scrambling code. We assign one scrambling code per transmit antenna and one OVSF code per user. Due to the scrambling codes using pseudo-noise sequences with excellent quality of auto and cross correlation proprieties, the proposed novel scheme can obtain considerable improvement of link performance without sacrificing the precious code resources. Compared to conventional scheme, the average BER of improved scheme decrease 10 dB for (2,2) system with 4 users when E_b/N_0 = 7 dB, but these advantages vanish when the number of user is more than 253, which are demonstrated by means of both theory analyses and simulations.

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