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Performance analysis of space-time transmit diversity techniques for multi-antenna WCDMA systems

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Abstract: Several space-time coding based transmit diversity techniques for wideband code division multiple access (WCDMA) systems with four transmitter antennas are investigated. Performances of the rake receivers are analyzed and compared with those of the multi-antenna receive diversity techniques. Theoretical analysis shows that the multi-antenna transmit diversity techniques provide considerable performance gain at the mobile receiver in the wireless channel with less inherent multipath diversity, especially the G_4 coding based scheme. Compared with the multi-antenna receive diversity techniques with the same diversity order, the transmit diversity techniques introduce much more multi-access plus multipath interference and require measures of interference suppression in the multi-user environments.

Key words: multi-antenna; transmit diversity; space-time coding; wideband code division multiple access (WCDMA)

Diversity is an effective technique to combat fading and improve the link and system performance in wireless communication systems. Among various techniques, transmit diversity has received considerable attention recently[1]. Since the multiple antennas are actually mounted at the base stations, transmit diversity can improve the downlink performance and be beneficial to all the mobile stations in the cell, whereas receive diversity (RD) benefits the uplink performance.

The transmit diversity techniques proposed by the wideband code division multiple access (WCDMA) standard is for two antennas at the base station transmitter and can be classified as the open loop mode and the closed loop mode[2-4]. The distinction is that the open loop system employs space-time block coding at the transmitter and has no knowledge of the channel at the transmitter. The closed loop system has some knowledge of the channel at the transmitter by implementing a feedback path from the receiver to the transmitter. The diversity techniques employing more than two antennas at the base stations are promising for future wireless systems due to their capacity for providing much greater performance gain[1]. Several space-time coding transmit diversity schemes for four transmit antennas have been proposed and their performances in the WCDMA systems need further demonstration and comparison. This paper intends to investigate the performances of space-time block coding based open loop transmit diversity techniques in the case of four antennas at the base station transmitter and compare them with those of the multi-antenna receive diversity techniques.

1 System Model

We consider a transmission on the downlink of a WCDMA based system with four widely spaced antennas located at the transmitter of the base station and one antenna at the receiver of the mobile handset. The system block diagram supporting the space-time coding based transmit diversity techniques is shown in Fig.1. The transmit diversity techniques differ in their space-time encoders. Channel coding and interleaving are done as in the non-diversity mode.

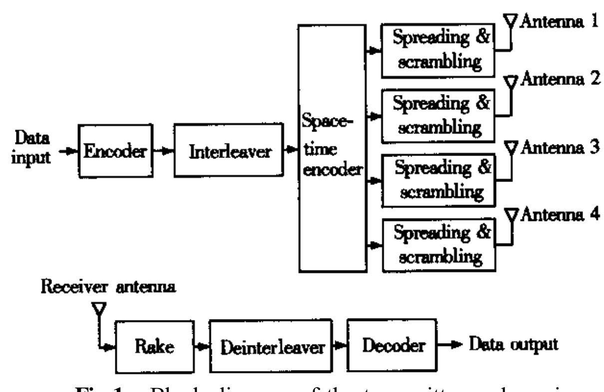

Fig.1 Block diagram of the transmitter and receiver

The transmitted signals propagate through a multipath frequency selective channel, which is modeled as tapped delay lines. A rake-type architecture is required for reception to collect the

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signal energy from the separable multipaths[5]. The received signals can be written as

$$r(t) = \sum_{i=1}^{4}\sum_{l=1}^{L} h_{il}(t)s_i(t-\tau_{il}) + n(t) \tag{1}$$

where $s_i(t)$ is the transmitted signal from the i-th transmitter antenna, $h_{il}(t)$ is the independent complex-Gaussian fading coefficient of the l-th multipath of the i-th transmitter antenna, having Rayleigh distributed amplitude and uniformly distributed phase, τ_{il} is the relative delay of the separable multipath component, and $n(t)$ is the additive white Gaussian noise with zero-mean and two-sided power spectral density equal to $N_0/2$. The multipath channel is assumed to remain stationary across p consecutive symbols.

$$h_{il}(t) = h_{il}(t+T_b) = \cdots = h_{il}(t+(p-1)T_b) = h_{il}$$
$$i = 1, \cdots, 4; l = 1, \cdots, L \tag{2}$$

In the following part of the paper, we use (n, m) to denote a wideband system with n transmitter antennas and m receiver antennas for simplicity.

2 Receiver Algorithm and Performance Analysis

2.1 Space-time code proposed by Tarokh, et al

The space-time encoder shown in Fig. 1 can be described by a matrix. The space-time codes for four transmit antennas, which are orthogonal and enable the diversity order of four at the receiver, are proposed by Tarokh, et al. and shown as[6]

$$\boldsymbol{G}_4 = \begin{bmatrix} d_1 & d_2 & d_3 & d_4 \\ -d_2 & d_1 & -d_4 & d_3 \\ -d_3 & d_4 & d_1 & -d_2 \\ -d_4 & -d_3 & d_2 & d_1 \\ d_1^* & d_2^* & d_3^* & d_4^* \\ -d_2^* & d_1^* & -d_4^* & d_3^* \\ -d_3^* & d_4^* & d_1^* & -d_2^* \\ -d_4^* & -d_3^* & d_2^* & d_1^* \end{bmatrix}_{p\times 4} \tag{3}$$

$$\boldsymbol{H}_4 = \begin{bmatrix} d_1 & d_2 & \frac{d_3}{\sqrt{2}} & \frac{d_3}{\sqrt{2}} \\ -d_2^* & d_1^* & \frac{d_3}{\sqrt{2}} & -\frac{d_3}{\sqrt{2}} \\ \frac{d_3^*}{\sqrt{2}} & \frac{d_3^*}{\sqrt{2}} & \frac{-d_1-d_1^*+d_2-d_2^*}{2} & \frac{-d_2-d_2^*+d_1-d_1^*}{2} \\ \frac{d_3^*}{\sqrt{2}} & -\frac{d_3^*}{\sqrt{2}} & \frac{d_2+d_2^*+d_1-d_1^*}{2} & -\frac{d_1+d_1^*+d_2-d_2^*}{2} \end{bmatrix}_{p\times 4} \tag{4}$$

where the columns denote the signals transmitted from different antennas. As can be seen from Eqs. (3) and (4), the data rate is 1/2 for G_4 with $p = 8$ and is 3/4 for H_4 with $p = 4$.

In the case of the G_4 coding based transmit diversity scheme, the received signals of the l-th multipath, after being despread at the receiver, can be written as

$$\boldsymbol{r}_{l,G_4} = \sqrt{\frac{\varepsilon_k}{4}}\boldsymbol{G}_4\boldsymbol{h}_l + \boldsymbol{z}_{l,G_4} \tag{5}$$

where $\boldsymbol{r}_{l,G_4} = \{r_1, r_2, r_3, r_4, r_5, r_6, r_7, r_8\}^T$ comprises eight consecutive received symbols, ε_k is the k-th symbol energy transmitted, 1/4 makes the transmitter power constant, $\boldsymbol{h}_l = \{h_{1l}, h_{2l}, h_{3l}, h_{4l}\}^T$ is the l-th multipath channel coefficient vector, and $\boldsymbol{z}_{l,G_4}$ is the noise plus interference vector after the operation of despreading. The combinable decision vector in the l-th finger of the rake receiver for the transmitted symbols is given as

$$\{\tilde{d}_{1l}, \tilde{d}_{2l}, \tilde{d}_{3l}, \tilde{d}_{4l}\}^T_{G_4} = \sqrt{\frac{\varepsilon_k}{4}}\cdot 2(|h_{1l}|^2 + |h_{2l}|^2 + |h_{3l}|^2 + |h_{4l}|^2)\{d_1, d_2, d_3, d_4\}^T_{G_4} + \boldsymbol{z}'_{l,G_4} \tag{6}$$

where $\boldsymbol{z}'_{l,G_4}$ is the noise plus interference vector after the linear combination.

According to Eq. (6), the instantaneous bit signal-to-noise ratio (SNR) at the output of the rake receiver for the G_4 coding based transmit diversity technique can be given as

$$\gamma_{G_4} = \frac{\sum_{l=1}^{L}(|h_{1l}(m)|^2 + |h_{2l}(m)|^2 + |h_{3l}(m)|^2 + |h_{4l}(m)|^2)}{2N_0/\varepsilon_k + \upsilon_{\xi,G_4}} \tag{7}$$

where $\upsilon_{\xi,G_4} = \sigma^2_{\xi,G_4}T_b/\varepsilon_k$, σ^2_{ξ,G_4} is the variance of the multi-access interference plus multipath interference.

For performance analysis in this paper, a uniformly multipath intensity profile is assumed for the multipath fading channel. The probability density function of γ_{G_4} can be given as[7]

$$f_\gamma(\gamma_{G_4}) = \frac{1}{(4L-1)!\,\bar{\gamma}^{4L}_{l,G_4}}\gamma^{4L}_{G_4}\exp\left(-\frac{\gamma_{G_4}}{\bar{\gamma}_{l,G_4}}\right) \tag{8}$$

where $\bar{\gamma}_{l,G_4} = \sigma_l^2/(2N_0/\varepsilon_k + \upsilon_{\xi,G_4})$ is the averaged SNR of the l-th multipath, σ_l^2 is the averaged power of the l-th multipath. Therefore, the average bit error rates (BERs) of the rake receiver for G_4, denoted as P_{G_4}, can be obtained as

$$P_{G_4} = E\left[\frac{1}{2}\mathrm{erfc}(\sqrt{\gamma_{G_4}})\right] = \left[\frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_{l,G_4}}{1+\bar{\gamma}_{l,G_4}}}\right)\right]^{4L}\times \sum_{l=1}^{4L}\binom{4L-1+l}{l}\left[\frac{1}{2}\left(1+\sqrt{\frac{\bar{\gamma}_{l,G_4}}{1+\bar{\gamma}_{l,G_4}}}\right)\right]^{l} \tag{9}$$

For the H_4 coding based transmit diversity scheme, the combinable signal in the l-th finger of the rake receiver for the transmitted symbols can be given as

$$\{\tilde{d}_{1l}, \tilde{d}_{2l}, \tilde{d}_{3l}, \tilde{d}_{4l}\}_{H_4}^{T} = \sqrt{\frac{\varepsilon_k}{4}}(|h_{1l}|^2 + |h_{2l}|^2 + |h_{3l}|^2 + |h_{4l}|^2) \cdot \{d_1, d_2, d_3, d_4\}_{H_4}^{T} + z'_{l, H_4} \tag{10}$$

where z'_{l, H_4} is the noise plus interference vector after the linear combination. And the instantaneous output bit SNRs of the rake receivers for H_4 can be given as

$$\gamma_{H_4} = \frac{\frac{1}{4}\sum_{l=1}^{L}(|h_{1l}(m)|^2 + |h_{2l}(m)|^2 + |h_{3l}(m)|^2 + |h_{4l}(m)|^2)}{2N_0/\varepsilon_k + v_{\xi, H_4}} \tag{11}$$

where $v_{\xi, H_4} = \sigma^2_{\xi, H_4} T_b/\varepsilon_k$, σ^2_{ξ, H_4} denotes the variance of multi-access interference and multipath interference.

The average BERs of the rake receiver for H_4, denoted as P_{H_4}, can be given as

$$P_{H_4} = E\left[\frac{1}{2}\mathrm{erfc}(\sqrt{\gamma_{H_4}})\right] = \left[\frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_{l, H_4}}{1 + \bar{\gamma}_{l, H_4}}}\right)\right]^{4L} \times \sum_{l=1}^{4L}\binom{4L - 1 + l}{l}\left[\frac{1}{2}\left(1 + \sqrt{\frac{\bar{\gamma}_{l, H_4}}{1 + \bar{\gamma}_{l, H_4}}}\right)\right]^{l} \tag{12}$$

where $\bar{\gamma}_{l, H_4} = (\sigma_l^2/4)/(2N_0/\varepsilon_k + v_{\xi, H_4})$.

2.2 STTD-OTD

The space-time coding based transmit diversity-orthogonal transmit diversity (STTD-OTD) scheme is compatible with STTD for two transmitter antennas, which is adopted by WCDMA standard in 3G systems. The corresponding space-time code matrix can be describe as

$$\boldsymbol{C}_4 = \begin{bmatrix} d_1 & d_2 & d_1 & d_2 \\ -d_2^* & d_1^* & -d_2^* & d_1^* \\ d_3 & d_4 & -d_3 & -d_4 \\ -d_4^* & d_3^* & d_4^* & -d_3^* \end{bmatrix}_{4\times4} \tag{13}$$

As can be seen from Eq.(13), the data rate is 1. At the receiver, the received signals of the l-th multipath, after being despread, can be written in a vector as

$$\boldsymbol{r}_{l, C_4} = \sqrt{\frac{\varepsilon_k}{4}}\boldsymbol{C}_4\boldsymbol{h}_l + \boldsymbol{z}_{l, C_4} \tag{14}$$

where $\boldsymbol{r}_{l, C_4} = \{r_1, r_2, r_3, r_4\}^T$ comprises the consecutive received symbols, $\boldsymbol{h}_l = \{h_{1l}, h_{2l}, h_{3l}, h_{4l}\}^T$ is the l-th channel coefficient vector, and z_{l, C_4} is the vector of noise plus interference after the operation of despreading.

The combinable signal can be obtained by the linear operation on the despreaded signal $\boldsymbol{r}_{l, C_4}$ as follows:

$$\begin{bmatrix} \tilde{d}_{1l} & \tilde{d}_{2l} \\ \tilde{d}_{3l} & \tilde{d}_{4l} \end{bmatrix} = \sqrt{\frac{\varepsilon_k}{4}} \cdot 2(|h_{1l}|^2 + |h_{2l}|^2 + |h_{3l}|^2 + |h_{4l}|^2)\begin{bmatrix} d_{1l} & d_{2l} \\ d_{3l} & d_{4l} \end{bmatrix} + \boldsymbol{Z}'_{l, C_4} \tag{15}$$

where $\boldsymbol{Z}'_{l, C_4}$ is the noise plus interference vector after the above linear combination.

According to Eq.(15), the instantaneous bit SNR for d_1, d_2 and d_3, d_4 at the output of the rake receiver can be given respectively as follows:

$$\gamma_{S\_OTD} = \frac{\sum_{l=1}^{L}(|h_{1l}(m)|^2 + |h_{2l}(m)|^2)}{2N_0/\varepsilon_k + v_{\xi, S\_OTD}} \tag{16}$$

$$\gamma'_{S\_OTD} = \frac{\sum_{l=1}^{L}(|h_{3l}(m)|^2 + |h_{4l}(m)|^2)}{2N_0/\varepsilon_k + v_{\xi, S\_OTD}} \tag{17}$$

where $v_{\xi, S\_OTD} = \sigma^2_{\xi, S\_OTD} T_b/\varepsilon_k$, σ^2_{ξ, S_OTD} is the variance of the multi-access interference plus multipath interference.

Similar to the derivation in section 2.1, the average BERs of the rake receivers for STTD-OTD, denoted as P_{S_OTD}, can be given as

$$P_{S\_OTD} = E\left[\frac{1}{2}\mathrm{erfc}(\sqrt{\gamma_{S\_OTD}})\right] = \left[\frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_{l, S\_OTD}}{1 + \bar{\gamma}_{l, S\_OTD}}}\right)\right]^{2L} \times \sum_{l=1}^{2L}\binom{2L - 1 + l}{l}\left[\frac{1}{2}\left(1 + \sqrt{\frac{\bar{\gamma}_{l, S\_OTD}}{1 + \bar{\gamma}_{l, S\_OTD}}}\right)\right]^{l} \tag{18}$$

where $\bar{\gamma}_{l, S\_OTD} = \sigma_l^2/(2N_0/\varepsilon_k + v_{\xi, S\_OTD})$.

2.3 (1, 4) receive diversity

In this subsection, we will investigate the performance of the rake receiver when multi-antenna receive diversity is available. In the case of a WCDMA system with a single transmitter antenna and four receiver antennas, the instantaneous bit SNR at the output of the rake receiver can be obtained as

$$\gamma_{(1, 4)} = \frac{\sum_{l=1}^{L}\sum_{i=1}^{4}|h_{il}(m)|^2}{2N_0/\varepsilon_k + v_{\xi, (1, 4)}} \tag{19}$$

The average BERs of the rake receivers for four receiver antennas diversity, denoted as $P_{(1, 4)}$, is given as

$$P_{(1, 4)} = E\left[\frac{1}{2}\mathrm{erfc}(\sqrt{\gamma_{(1, 4)}})\right] = \left[\frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_{l, (1, 4)}}{1 + \bar{\gamma}_{l, (1, 4)}}}\right)\right]^{4L} \times$$

$$\sum_{l=1}^{4L}\binom{4L-1+l}{l}\left[\frac{1}{2}\left(1+\sqrt{\frac{\bar{\gamma}_{l,(1,4)}}{1+\bar{\gamma}_{l,(1,4)}}}\right)\right]^{l} \tag{20}$$

where $\bar{\gamma}_{l,(1,4)} = \sigma_l^2/(2N_0/\varepsilon_k + v_{\xi,(1,4)})$, $v_{\xi,(1,4)}$ reflects multi-access interference and multipath interference.

2.4 (2, 2) STTD transmit and receive diversity

In the case of a WCDMA system with two antennas at both the transmitter and the receiver, STTD can be employed at the transmitter. Therefore both transmit diversity and receive diversity gain can be attained with the diversity order of four. The instantaneous output bit SNR of the rake receiver, can be given as

$$\gamma_{(2,2)} = \frac{\frac{1}{2}\sum_{l=1}^{L}(|h_{11l}(m)|^2 + |h_{12l}(m)|^2 + |h_{21l}(m)|^2 + |h_{22l}(m)|^2)}{2N_0/\varepsilon_k + v_{\xi,(2,2)}} \tag{21}$$

The average BERs of the rake receivers for the transmit and receive diversity scheme, denoted as $P_{(2,2)}$, is given as

$$P_{(2,2)} = E\left[\frac{1}{2}\mathrm{erfc}(\sqrt{\gamma_{(2,2)}})\right] = \left[\frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_{l,(2,2)}}{1+\bar{\gamma}_{l,(2,2)}}}\right)\right]^{4L} \times$$

$$\sum_{l=1}^{4L}\binom{4L-1+l}{l}\left[\frac{1}{2}\left(1+\sqrt{\frac{\bar{\gamma}_{l,(2,2)}}{1+\bar{\gamma}_{l,(2,2)}}}\right)\right]^{l} \tag{22}$$

where $\bar{\gamma}_{l,(2,2)} = (\sigma_l^2/2)/(2N_0/\varepsilon_k + v_{\xi,(2,2)})$, $v_{\xi,(2,2)}$ reflects the multi-access and multipath interference.

3 Numerical Results and Discussion

Selected numerical results have been obtained to show the performances of the different diversity techniques for multi-antenna WCDMA systems. In order to provide a fair performance comparison, the total transmit power for the desired user's traffic channel is always fixed for a given E_b/N_0 level, no matter how many antennas are employed at the transmitter. Perfect power control, perfect channel estimation and Gaussian multi-access and multipath interference are assumed. The Gaussian approximation of the multi-access plus multipath interference for a (1, 1) WCDMA system is given as[8]

$$v_{\xi} = \frac{KL-1}{3N} \tag{23}$$

where K is the number of users in the cell, L is the number of resolvable multipaths, and N is the spreading factor of the data channel. Performance parameters for the different transmit schemes are shown in Tab.1.

Tab.1 Performance parameters for transmit diversity techniques

Transmit scheme	Performance		MAI v_{ξ}
	Diversity order	Averaged SNR of the l-th path	
(1, 1)	1	$\sigma_l^2/(2N_0/\varepsilon_k + v_{\xi,(1,1)})$	$(KL-1)/3N$
G_4	4	$\sigma_l^2/(2N_0/\varepsilon_k + v_{\xi,G_4})$	$(4KL-1)/3N$
H_4	4	$\sigma_l^2/(4(2N_0/\varepsilon_k + v_{\xi,H_4}))$	$(4KL-1)/3N$
STTD-OTD	2	$\sigma_l^2/(2N_0/\varepsilon_k + v_{\xi,S\_OTD})$	$(4KL-1)/3N$
(2, 2)STTD	4	$\sigma_l^2/(2(2N_0/\varepsilon_k + v_{\xi,(2,2)}))$	$(2KL-1)/3N$
(1, 4)RD	4	$\sigma_l^2/(2N_0/\varepsilon_k + v_{\xi,(1,4)})$	$(KL-1)/3N$

Fig.2 shows the rake receiver BER performances in the single user environments with different multipath fading channels. As can be seen from the plot, the transmit diversity schemes provide considerable performance gain over the non-transmit diversity (NTD) schemes. Among all the transmit diversity schemes for four transmitter antennas, the G_4 space-time coding based transmit diversity scheme presents superior performance to the others, even to the (2, 2) STTD transmit and receive diversity scheme. However, the cost of the superior performance is a data rate of 1/2, while the data rate of H_4 code is 3/4 and the others have a full data rate of 1. Compared with STTD-OTD providing a diversity order of two, H_4 coding provides lower SNRs at the output of the rake

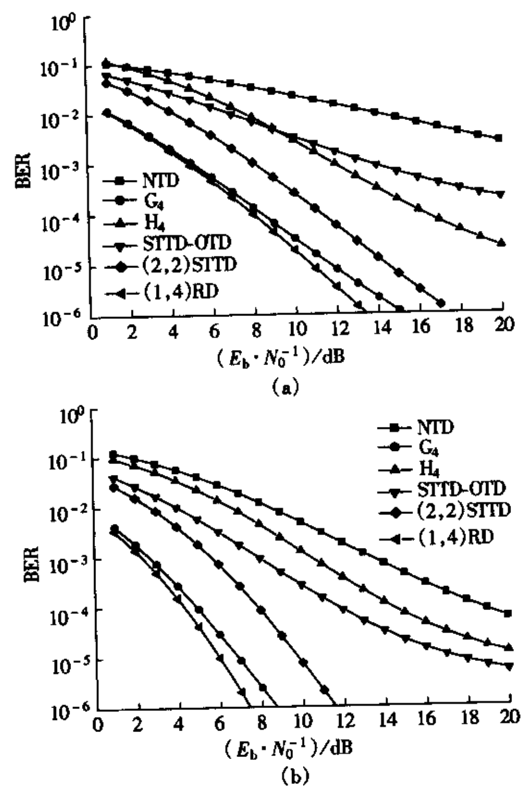

Fig.2 BER performances in the single user environments. (a) $L=1$, $K=1$; (b) $L=3$, $K=1$

receiver with a diversity order of four. Therefore the H_4 coding based scheme provides better performance than STTD-OTD at high SNRs in a single multipath channel, while it is inferior to STTD-OTD in a 3-multipth channel due to the increasing inherent multipath diversity. The performance of STTD-OTD is between those of G_4 coding and H_4 coding. It is obvious that (1, 4) receive diversity provides the best performance of all the diversity schemes.

Fig. 3 plots BER performances of the rake receivers in the multi-user environments with different multipath fading channels. As seen from the plot, the performance for all the transmit schemes deteriorates dramatically in the multi-user environments because of the increasing introduced interference. Worst of all, the rake receivers for H_4 and STTD-OTD based transmit diversity schemes cannot function normally. In some cases H_4 and STTD-OTD based transmit diversity schemes are even inferior to the non-diversity scheme. This shows that, in multi-user environments, some measures should be taken against multi-user interference at the receiver to ensure normal performance. However, similar to the cases in single-user environments, G_4 provides the best performance among all the transmit diversity techniques. The (1, 4) receive diversity technique is superior to all the schemes since it does not introduce any additional interference.

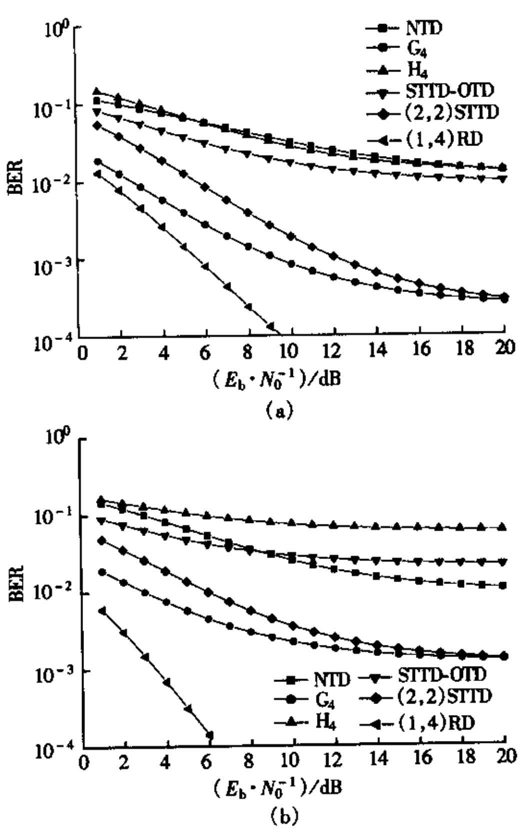

Fig.3 BER performances in the multi-user environments. (a) $L=1, K=10$; (b) $L=3, K=10$

4 Conclusion

In general, multi-antenna transmit diversity techniques provide considerable performance gain at the mobile receiver in the wireless channel with less inherent multipath diversity. Among the space-time block coding based transmit diversity schemes for four transmitter antennas WCDMA systems, the G_4 coding based scheme provides the best performance, even better than that of the (2, 2) STTD scheme. The H_4 coding based scheme is inferior and even inferior to STTD-OTD in multi-user environments. STTD-OTD coding provides a performance between those of G_4 coding and H_4 coding with diversity orders of two and full data rates. Compared with the multi-antenna receive diversity techniques with the same diversity order, the transmit diversity techniques introduce much more multi-access plus multipath interference and require measures of interference suppression in multi-user environments.

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多天线 WCDMA 系统空时发送分集技术的性能分析

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摘要: 研究了 WCDMA 系统 4 发送天线时可能存在的几种空时编码发送分集技术, 给出了各自的 rake 接收模型并研究了在衰落信道中的接收性能, 同时也与多天线的接收分集技术做了比较. 理论分析表明:在分集级数少的移动信道中, 各种多天线发送分集技术提供了很大的接收增益, 尤其是 G_4 编码方案; 在多用户环境下, 与同级数的接收分集技术相比, 发送分集由于引入了多径及多用户干扰而需要在接收端采用干扰抑制技术.

关键词: 多天线; 发送分集; 空时编码; WCDMA

中图分类号: TN929.533

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13.56MHz NFC/RFID 线圈天线设计培训课程套装

套装包含 4 门视频培训课程，培训将 13.56MHz 线圈天线设计原理和仿真设计实践相结合，全面系统地讲解了 13.56MHz 线圈天线的工作原理、设计方法、设计考量以及使用 HFSS 和 CST 仿真分析线圈天线的具体操作，同时还介绍了 13.56MHz 线圈天线匹配电路的设计和调试。通过该套课程的学习，可以帮助您快速学习掌握 13.56MHz 线圈天线及其匹配电路的原理、设计和调试…

详情浏览：http://www.edatop.com/peixun/antenna/116.html

关于易迪拓培训：

易迪拓培训(www.edatop.com)由数名来自于研发第一线的资深工程师发起成立，一直致力和专注于微波、射频、天线设计研发人才的培养；后于 2006 年整合合并微波 EDA 网(www.mweda.com)，现已发展成为国内最大的微波射频和天线设计人才培养基地，成功推出多套微波射频以及天线设计经典培训课程和 ADS、HFSS 等专业软件使用培训课程，广受客户好评；并先后与人民邮电出版社、电子工业出版社合作出版了多本专业图书，帮助数万名工程师提升了专业技术能力。客户遍布中兴通讯、研通高频、埃威航电、国人通信等多家国内知名公司，以及台湾工业技术研究院、永业科技、全一电子等多家台湾地区企业。

我们的课程优势：

※ 成立于 2004 年，10 多年丰富的行业经验

※ 一直专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 视频课程、既能达到了现场培训的效果，又能免除您舟车劳顿的辛苦，学习工作两不误

※ 经验丰富的一线资深工程师主讲，结合实际工程案例，直观、实用、易学

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