Multi-Rate Joint CDMA and SDMA Multiuser Detection with Parallel Interference Cancellation

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ABSTRACT

This paper describes a novel performance evaluation technique of a Multi-rate combined Code Division Multiple Access (CDMA) and Space Division Multiple Access (SDMA) multiuser receiver. Single sector in a cell adopts combined CDMA and SDMA system, and accommodates an arbitrary K number of users transmitting their data using different rates, according to a predetermined minimum required Quality of Service (QOS) is considered. The Bit Error Rate (BER) expressions of the Uij user (j-th user in the i-th class rate (media)) have been derived in exact form. Parallel Interference Canceller (PIC) is adopted as a suboptimum multiuser detector. The system performance of different number of antenna elements is investigated. Moreover, comparison between Combined CDMA and SDMA with and without PIC canceller is also presented. Finally, the system performance for both pure CDMA and combined CDMA and SDMA systems is studied. The obtained results show that the BER is improved with the increasing number of antenna elements. Also, the system capacity of a combined CDMA and SDMA system is improved compared to the pure CDMA system. Finally, the system capacity of a combined CDMA and SDMA system with PIC is noticeably improved compared to the one without PIC (conventional multiuser receiver).

***Keywords**: Multi-Rate, Wireless CDMA, SDMA, Multiuser Detection (MUD), parallel Interference Cancellation (PIC).*

1. INTRODUCTION

The demand for capacity in wireless communication capacity is growing. Not only the number of mobile subscribers but also the requirements of multi-rate users become an important issue to adopt in the new wireless communication systems. Usually multi-rate heterogeneous users refer to those transmitting using different media. Relying to multimedia system requirement, each medium has its own data rate and quality constraints. In order to meet the requirements under the limited frequency spectrum, it is an important issue to use the limited bandwidth spectrum in more efficient manner.

Multiple access technique were developed to enhance the capacity of a wireless communication system, by enabling more than one user to utilize the same channel resources simultaneously, such as Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). In CDMA two major problems limit the system performance, Near-far problem and Multiple Access Interference (MAI). Efficient power control can be used to overcome the near-far effect, while MAI interference can be partially mitigated using some cancellation at the receivers [1]. To overcome MAI along with some others problems in wireless communication, researchers started to look for new multiple access method, with more degree of freedom.

Space Division Multiple Access (SDMA) was proposed to increase orthogonallity between users. The basic principle of SDMA is to exploits the spatial diversity of multiple users transmitting at the same time and frequency to increase the number of users who can be using the system simultaneously, mobile users can be distinguished by their locations relative to the base station and specified by the Angle of Arrival (AOA) [2]. A smart antenna array at the base station is used to exploit this spatial diversity for both uplink and downlink with the mobile user using a handset with a conventional antenna [3]. Single narrow beam is generated and radiated toward each mobile user with maximum gain and null can be preceded to the other interferer users (see Fig. 1, (a)). However, the generated beams can be narrower by increasing the number of antenna elements; thus, more degree of orthogonallity can be maintained [4]. Due to the high mobility of the mobile users, interferers cannot be completely nulled: So, MAI interference due to the side loops affects the detection performance of the desired user as shown in Fig. 1 (b).

In combined CDMA and SDMA system [5] users are distinguished not only by spatial or code signature. Instead combination of these two signatures is assigned to each user.

In this case, semi-orthogonal codes are assigned to users located close to each other, and the same codes can be reassigned (reused) to other users located far away with different spatial signature, in such a way, the channel resources (spreading codes) are contained on the base station in a central pool, and when new user want to communicate, then according to his AOA the most optimal spreading code is assigned to that user, in which the maximum joint orthogonality (spatial and code signatures orthogonality) can be obtained. However, the detection performance is still limited due to the side lobes generated by narrow beams. This interference put a limit to the system capacity, means, increasing number of users within a system results the increased amount of interference, which reduce the reliability of detecting signal from the user under consideration. This problem leads to study the Multiuser Detection in the combined CDMA and SDMA system with interference canceller, in order to improve the system performance, hence, to accommodate all growing users' demand.

In this paper, multiuser detection suboptimum receiver is investigated to employ and install in Base Station (BS) receiver of the combined CDMA and SDMA system. The suboptimum one provides better performance over the conventional detector and less complexity than the optimal one [6]. Parallel Interference Canceller (PIC), Successive Interference Canceller (SIC), and Zero-Forcing Decision-Feedback (ZF-DF) receivers are classified to be suboptimum non-linear receivers [1].

There have been several works focused on multiuser receivers with MAI cancellers under Gaussian approximation of other user's interference [7-9], i.e., the total MAI from other users is considered as a summation of infinite number of random variables. However, the validity of Gaussian approximation depends on the number of users, wherein, for small number of users, the reliability of such approximation is decreased [10]. Therefore, the multiuser receiver is analyzed under the effects of other user's interference (hereinafter, we call it exact analysis) in more close form. The effect of MAI can be mitigated by considering a multiuser detection strategy, in which the receiver jointly detects all the incoming signals from all users. Hence the PIC receiver is best suited and adopted here.

The paper is organized as follows. The next section describes the system model of multi-rate combined CDMA and SDMA followed by multi-rate multiuser receiver, multi-rate receiver without PIC, multi-rate receiver with PIC, pure CDMA system performance, Numerical results and finally the conclusion.

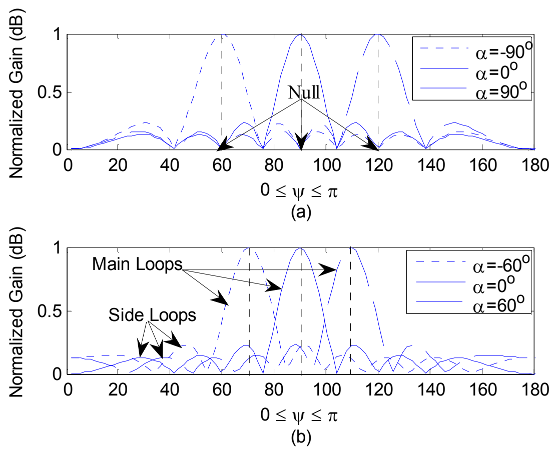

Figure 1: Smart Antenna Radiation Patterns: (a) Orthogonal Patterns with Null interference, (b) Non orthogonal Patterns with side loop Interference

2. SYSTEM MODEL OF MULTI-RATE COMBINED CDMA AND SDMA

Figure 2 shows a single sector in a cell adopting Combined CDMA and SDMA system operating in a synchronous mode and consisting of N classes of users, the i-th class includes an arbitrary u_i number of users those transmit their signals with equal power (P_i), spreading factor (G_i) and data rate (R_i). For a total of K heterogeneous users given by, $K=\sum_{i=1}^{N} u_i$,each user is assigned a unique signature code to carry out spreading of the transmitted signal, and spatial signature to differentiate users according to their Angle of Arrival (AOA) at the base station receiver. The composite received signal from all users, $r(\psi_o,t)$ is given by

$$r(\psi_o,t)=\sum_{i=1}^{N}\sum_{j=1}^{u_i}\sqrt{P_i}\,b_{ij}(t)C_{ij}(t)V_{ij}(\psi_o)+\eta(t) \tag{1}$$

where P_i, $b_{ij}, C_{ij}(t), V_{ij}(\psi_o)$ and $\eta(t)$are the signal power, transmitted BPSK bits, signature sequence, spatial signature in terms of antenna radiation pattern gain at AOA equal to ψ_o and Gaussian Noise (AWGN) respectively. $V_{ij}(\psi_o)$ is given by [11]:

$$V_{ij}(\psi_o)=\frac{1}{N_e}\left|\frac{\sin N_e(\pi L\cos\psi_o+\alpha/2)}{\sin(\pi L\cos\psi_o+\alpha/2)}\right| \tag{2}$$

Where, N_e is the total number of antenna elements, and L is the inter-element spacing constant and it is given as 0.5 for half wavelength ($d=\frac{\lambda}{2}$) spacing, α is the phase shift between different users.

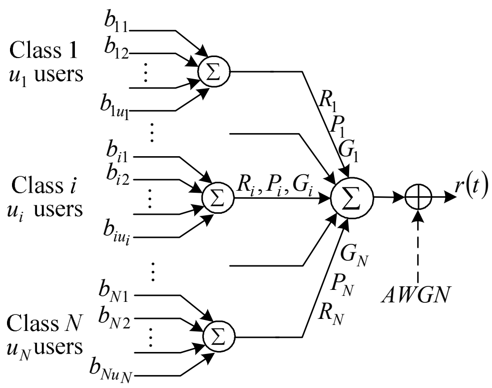

Figure 2: Multi-Rate Transmitter and channel

3. MULTI-RATE MULTIUSER RECEIVER

In this section, heterogeneous users with different data rates are considered. The total K number of users distributed into N classes, each with different specifications and (QOS). Figure 3, Depicts the multi-rate scenario considering three classes of users specified by low, medium and high data rate classes and denoted by R_l, R_m and R_h respectively. It is seen from Figure 3 that the bit duration of the low rate users is 2 times the medium rate users and 4 times the high rate user bit duration, i.e., $T_l = 2T_m = 4T_h$, or equivalently, $R_h = 2R_m = 4R_l$, where, T_l, T_m, T_h and R_l, R_m, R_h, are the bit duration and the data rate of the low, medium and high rate users respectively. T_c and R_c are the chip duration and chip rate respectively.

Recall (1), and without loss of generality, it is assumed that the *ij*-th user is the user under consideration, where, *ij*-th user is the *j*-th user, who belongs to the *i*-th class. Then the correlator output of the *ij*-th desired user can be written as:

$$\begin{aligned} y_{ij} &= \sqrt{P_i}\, b_{ij} T_{b_i} \\ &+ \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1} \sqrt{P_i}\, b_{il}\, \rho_{il,ij} V_{i,l}(\psi_{i,j}) T_{b_i} \\ &+ \sum_{\substack{k=0 \\ k\neq i}}^{N-1} \sum_{l=0}^{u_k-1} \sqrt{P_k}\, b_{kl}\, \rho_{kl,ij} V_{k,l}(\psi_{i,j}) T_{b_i} \qquad (3) \\ &+ \eta_{ij}(t) \\ &= S_{ij} + I_{ij}^{i} + I_{ij}^{N-1} + \eta_{ij} \end{aligned}$$

Where, the first and last terms are the desired signal and the AWGN noise respectively, second term represent the interference from users of the same class (*i*-th class, contain u_i users) with normalized crosscorrelation $\rho_{il,ij}$ given by,

$$\rho_{il,ij} = \int_{(n-1)T_{b_i}}^{nT_{b_i}} C_{il}(t) C_{ij}(t)\, dt\,, \qquad (4)$$

and the third term represent the Interference generated by the other users belongs to other classes (*N-1* classes, each contain u_n users) with normalized crosscorrelation specified by $\rho_{kl,ij}$. In this case, the normalized crosscorrelation is performed between two different users each belongs to different class. Thus there are two possibilities as follow:

1. $T_{b_i} < T_{b_k}$ and 2. $T_{b_i} > T_{b_k}$

Where T_{b_i} and T_{b_k} are the bit duration associated to the *i*-th and *k*-th class respectively, which will be investigated in the following subsections.

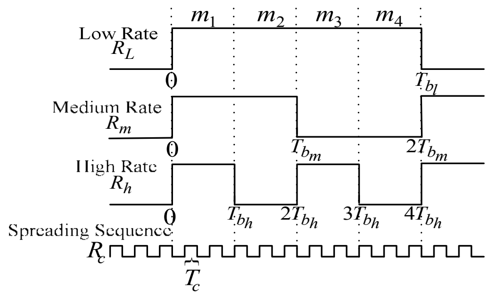

Figure 3:Multi-Rate Transmission Model.

3.1. Case 1 $\left(T_{b_i} < T_{b_k}\right)$

For $T_{b_i} < T_{b_k}$ (or equivalently, $\left(T_{b_h} < T_{b_l}\right)$ in Fig.3.), and since the desired users belong to the *i*-th class, the partial crosscorrelation function (when the desired user data rate is higher than that of the interferer user) in the *m*-th subinterval of the low rate class can be written as:

$$\rho_{kl,ij}^{H} = \frac{1}{G_i} \sum_{p=1}^{G_i} C_p^{(i,j)} C_{p+(m-1)G_i}^{(k,l)} \qquad (5)$$

Where, G_i represent the *i*-th class spreading factor and given by,

$$G_i = \frac{T_{b_i}}{T_c}\,, \qquad (6)$$

m=1,2,…,M is a subinterval of the *k*-th class bit duration, with interval duration equal to the *i*-th class bit duration, and the total number of the subintervals (M) is given as,

$$M = \frac{T_{b_l}}{T_{b_h}}\,. \qquad (7)$$

3.2. Case 2 $\left(T_{b_i} > T_{b_k}\right)$

On the other hand, consider that the desired user bit duration is higher than that of the interferer user or equivalently, desired user data rate is lower than that of the interferer user $\left(R_i < R_k\right)$. In this case the crosscorrelation will be repeated between the *n*-th interfering bit and the *m*-th subinterval of the *n*-th desired bit for all values of m. Thus, it can be written

$$\rho^{L}_{kl,ij} = \frac{1}{G_i}\sum_{m=1}^{M}\sum_{p=1}^{G_k} C^{(i,j)}_{p+(m-1)G_k}\, C^{(k,l)}_{p} \qquad (8)$$

Where, G_k represent the *k*-th class spreading factor and given by,

$$G_k = \frac{T_{b_k}}{T_c}\ , \qquad (9)$$

Now the normalized cross correlation $\rho_{kl,ij}$ in (3), using (5) and (8), is given by

$$\rho_{kl,ij} = \begin{cases} \rho^{H}_{kl,ij} & T_{b_i} < T_{b_k} \\ \rho^{L}_{kl,ij} & T_{b_i} > T_{b_k} \end{cases} \qquad (10)$$

4. MULTI-RATE RECEIVER WITHOUT PIC

Multiuser receiver without PIC canceller is considered here with the *ij*-th user as the desired user. If the receiver erroneously detects b_{ij}, i.e., $b_{ij} \neq \hat{b}_{ij}$, then the error probability $p^{c,m}_{ij}$ of the *ij*-th user using the conventional multi-rate receiver can be calculated as:

$$P^{c.m}_{ij} = P[b_{ij} \neq \hat{b}_{ij}] \qquad (11)$$

Due to equal probability and symmetry, we can simply assume that the transmitted bit is -1 then (11) can be written as

$$P^{c.m}_{ij} = P[y_{ij} > 0 \mid b_{ij} = -1] \qquad (12)$$

Under the assumption that the transmitted bits are independent and identically distributed (i.i.d.) and considering all the combinations from the interferer users then applying (3) in (12), then the BER formula of the *ij*-th user can be written as

$$P^{c,m}_{ij} = \left[\frac{1}{2^{K-1}} \sum_{e_{1,1}\in\{-1,+1\}}\cdots \sum_{\substack{e_{w,r}\in\{-1,+1\} \\ e_{w,r}\neq e_{i,j}}}\cdots \sum_{e_{N,U_n}\in\{-1,+1\}} Q\left(\frac{A}{\sigma}+\frac{B}{\sigma}+\frac{C}{\sigma}\right)\right] \qquad (13)$$

Where, *A, B* and *C* in (13) are given respectively as,

$$A = \sqrt{P_i}\,T_{b_i}\ , \qquad (14)$$

$$B = \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1} e_{\lfloor i,l \rfloor}\sqrt{P_i}\,\rho_{il,ij}V_{i,l}(\psi_{i,j})T_{b_i} \quad \text{and,} \qquad (15)$$

$$C = \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sum_{l=0}^{u_k-1} e_{\lfloor k,l \rfloor}\sqrt{P_k}\,\rho_{kl,ij}V_{k,l}(\psi_{i,j})T_{b_i} \qquad (16)$$

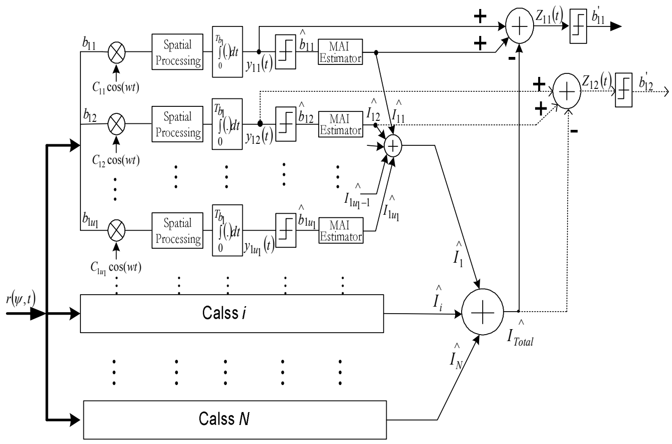

Figure 4: Combined CDMA and SDMA Multi-Rate Receiver.

5. MULTI-RATE RECEIVER WITH PIC

Fig.4 depicts the multi-rate multiuser receiver with PIC canceller. The algorithm for the PIC technique as shown in Fig.4 is as follows: 1-the receiver jointly detects the transmitted bits from all users. 2-Estimates the crosscorrelation values among them. 3-generates a replica of the estimation. 4-subtracts this replica from the composite received signal. In other words, the MAI overwhelm the desired signal is cancelled in parallel stages [12]. One stage PIC canceller is considered in this paper.

As shown in Fig.3, the total number of users distributed into several data rate groups (classes). To perform the detection process, PIC receiver estimate the MAI generated by the desired user class (*i*-th class) and other classes (*N-1*-th classes) which can be respectively given as:

$$\hat{I}^{i}_{ij} = \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1}\sqrt{P_i}\,\hat{b}_{il}\,\rho_{il,ij}V_{i,l}(\psi_{i,j})T_{b_i} \qquad (17)$$

$$\hat{I}^{N-1}_{ij} = \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sum_{l=0}^{u_k-1}\sqrt{P_k}\,\hat{b}_{kl}\,\rho_{kl,ij}V_{k,l}(\psi_{i,j})T_{b_i} \qquad (18)$$

then subtracting the estimated MAI in (17) and (18) from the composite signal in (3) to generate $Z_{i,j}$, which contains the desired signal, residual interference from all classes and the AWGN noise, is given by

$$\begin{aligned} Z_{i,j} = {} & \sqrt{P_i}b_{ij}T_{b_i} + \sqrt{P_i}\gamma_{i1}\rho_{i1,ij}V_{i,1}(\psi_{i,j})T_{b_i} + \ldots + \sqrt{P_i}\gamma_{i(u_i-1)}\rho_{i(u_i-1),ij}V_{i,(u_i-1)}(\psi_{i,j})T_{b_i} \\ & + \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sqrt{P_k}\gamma_{k1}\rho_{k1,ij}V_{k,1}(\psi_{i,j})T_{b_i} + \ldots + \sqrt{P_k}\gamma_{ku_k}\rho_{ku_k,ij}V_{k,u_k}(\psi_{i,j})T_{b_i} + \eta_{ij}(t) \end{aligned} \qquad (19)$$

Where, $\gamma_i = b_i - \hat{b}_i$. Applying (19) to threshold detection, the output desired bit from *ij*-th user is given by

$$b'_{ij} = \mathrm{sgn}\{Z_{i,j}(t)\} \qquad (20)$$

Assumes that the transmitted bit from *ij*-th user $\left(b_{ij}\right)$ is -1. The BER of the received bit b_i after PIC canceller can be expressed as

$$P_{ij}^{PIC,m} = \mathrm{P}\left(Z_{i,j} > 0 \middle| b_{ij} = \text{-}1\right) \tag{21}$$

Consider the values of $Z_{i,j}$ by taking all possible combinations on the received bit from *K*-1 interferer users, then applying (19), with the assumption that the BERs are equal for all users, (i.e., $P_{ij}^{c,m} = P^{c,m}$) and considering all the possible combinations with their relative probability of occurrence, the BER of the *ij*-th user after cancelling the effect of MAI from all users is given by

$$P_{\mathrm{ij}}^{\mathrm{PIC,m}} = \frac{1}{2^{K-1}}\left[\sum_{\substack{\left(b_{1,1},\ldots,b_{1,u_1},\ldots,b_{N,1},\ldots,b_{N,u_N} | b_{ij}\right) \\ \in\{-1,1\}^{NUn-1}}} \; \sum_{\substack{\left(\hat{b}_{1,1},\ldots,\hat{b}_{1,u_1},\ldots,\hat{b}_{N,1},\ldots,\hat{b}_{N,u_N}\right) \\ \in\{-1,1\}^{NUn-1}}} Q\left(\frac{A}{\sigma}+\frac{B}{\sigma}+\frac{C}{\sigma}\right)D\right] \tag{22}$$

Where, *A*, *B*, *C* and *D* are given respectively as:

$$A = \sqrt{P_i}\,T_{b_i}\,, \tag{23}$$

$$B = \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1} \sqrt{P_i}\,\gamma_{il}\,\rho_{il,ij}\,V_{il}\left(\psi_{ij}\right)T_{b_i}\,, \tag{24}$$

$$C = \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sum_{l=0}^{u_k-1} \sqrt{P_k}\,\gamma_{kl}\,\rho_{kl,ij}\,V_{k,l}\left(\psi_{i,j}\right)T_{b_i} \quad \text{and,} \tag{25}$$

$$D = \prod_{\substack{k=1,1 \\ k\neq ij}}^{N,U_n} P_{ij}^{c,m\;\frac{|\gamma_k|}{2}}\left(1 - P_{ij}^{c,m}\right)^{1-\frac{|\gamma_k|}{2}} \tag{26}$$

$P^{c,m}$ and $\left(1 - P^{c,m}\right)$ represent the BER and the correct estimation due to the matched filter receiver given in (13).

6. PURE CDMA SYSTEM PERFORMANCE

In the previous sections, combined CDMA and SDMA is considered for the evaluation of BER performance. However, for pure CDMA system, the spatial signature is ignored, since the degree of orthogonallity in CDMA system only depends on the code properties.

Equations (13) and (22), represent the pure multi-rate CDMA system performance without and with PIC canceller respectively. In this case *B* and *C* in (13) for CDMA without PIC can be expressed as:

$$B = \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1} e_{\lfloor i,l\rfloor}\sqrt{P_i}\,\rho_{il,ij}\,T_{b_i} \tag{27}$$

$$C = \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sum_{l=0}^{u_k-1} e_{\lfloor k,l\rfloor}\sqrt{P_k}\,\rho_{kl,ij}\,T_{b_i} \tag{28}$$

respectively. Again and, *B* and *C* in (22) in case of pure CDMA system with PIC can be written as

$$B = \sum_{\substack{l=0 \\ l\neq j}}^{u_i-1} \sqrt{P_i}\,\gamma_{il}\,\rho_{il,ij}\,T_{b_i} \tag{29}$$

$$C = \sum_{\substack{k=0 \\ k\neq i}}^{N-1}\sum_{l=0}^{u_k-1} \sqrt{P_k}\,\gamma_{kl}\,\rho_{kl,ij}\,T_{b_i} \tag{30}$$

7. NUMERICAL RESULTS

The BER performance of a combined CDMA and SDMA system without PIC canceller applying different number of antenna elements is illustrated in Fig.5, as shown from the figure, the BER performance is improved with the increasing in the number of antenna elements, since the generated beams become narrower, and thus, more degree of interference from the other users can be mitigated. Moreover, it can be seen from the figure that the effect of adding 2 elements over 14 is less than that of adding 2 elements over 2 or 4 existing elements, which is because the value of the normalized gain become smaller when the number of elements is increased.

The system capacity of a multi-rate pure CDMA and combined CDMA and SDMA systems without PIC canceller are presented here. Figure.6. illustrates the BER vs. number of users at certain value of SNR and equal to 12.5 dB. Two classes of user are considered, high and low data rate users with high rate users power equal to two times the low rate users power, without loss of generality, it is assumed that the receiver is intended to detect an arbitrary user of the low rate class, the normalized crosscorrelation between each two different users are considered to be 0.1429 with a 7 chips gold code, the desired user is located at 90°, and the interferer users are randomly distributed with average normalized gain of the desired user beam towered the interfering users given by 0.2579 in the combined system. From Figure 6., it is clear that the BER is increased as the number of users is increased in both cases, in terms of system capacity, it can be seen from the figure that the combined system increase the system capacity over the pure CDMA system for any given certain quality. However, under the same assumptions of Figure 6, combined CDMA and SDMA multiuser receiver with and without PIC canceller is considered in Figure.7. As shown from the figure, PIC receiver improves the system capacity for the combined CDMA and SDMA system over the conventional one.

Moreover, the BER performance based on conventional receiver (without PIC) is intensively increased with the increasing on the number of users compared to the PIC receiver, in which, the BER slowly increased as the number of users is increased.

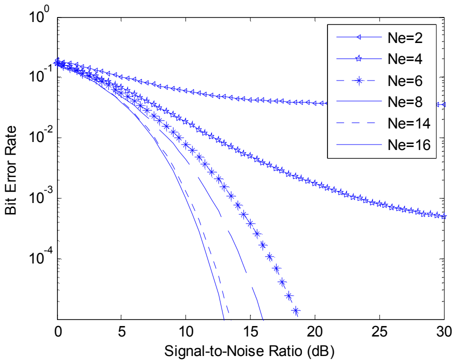

Figure 5: Combined CDMA and SDMA BER performance with different number of antenna elements.

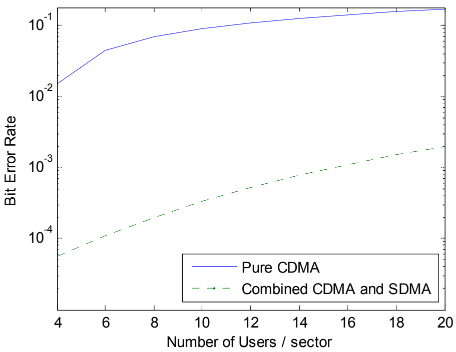

Figure 6: System Capacity of Pure CDMA and Combined CDMA and SDMA systems without PIC

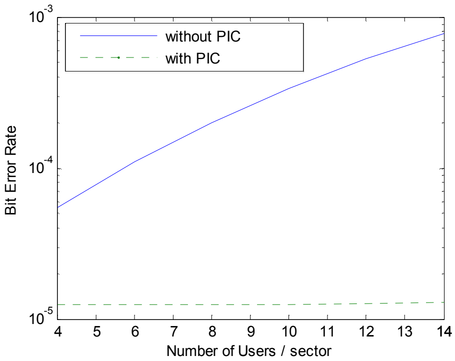

Figure 7: System Capacity of Combined CDMA and SDMA with and without PIC canceller

8. CONCLUSION

In this paper, the performance of a CDMA multiuser detection receiver with and without PIC canceller is investigated. The analytical model of the BER has been derived to evaluate the system performance. The system performance for various number of antenna elements has been investigated. The comparison between pure CDMA and combined CDMA and SDMA systems is illustrated. Moreover, comparison between system performance with and without PIC canceller of a combined system is studied. The results show that the BER is noticeably reduced with the increasing on the number of antenna elements. The system capacity of a combined CDMA and SDMA system is improved compared to the pure CDMA system. The PIC greatly increases the system capacity over the conventional receiver. Finally, the receiver with PIC canceller shows its superiority over the conventional one hence it is very useful to optimize CDMA system performance in terms of BER and capacity.

REFERENCES

[1] S. Moshavi, “Multi-user detection for DS-CDMA Communications”, *IEEE Comm. Magaz.*, pp. 124-136, Oct. 1996.

[2] Ung, C, Johnston, R.H , “A space division multiple access receiver ” , *IEEE International Symposium, Antennas and Propagation Society*, vol. 1, pp.422 - 425, 8-13 July 2001.

[3] Cheng Shuangmei, Li Jianhua, Yin Ying and Xu Zezhong, “A novel method for performance analysis of SDMA”, *Vehicular Technology Conference, VTC2004, IEEE 60th*. Volume 6, pp:4180 – 4184, 26-29 Sept. 2004

[4] Flavio Muratore, *UMTS Mobile Communications for the Future,* John Wiley & Sons Ltd, England, 2001.

[5] Chee Kyun Ng, M. Ismail, B.M. Ali, S. Khatun and S.S. Jamuar, “Impact of Inter-Cell Interference on Capacity in the Joint Multiple Access (CDMA and SDMA) System”, *Asia-Pacific Conference on Communications Proceedings*, pp. 435-439, 3 - 5 October 2005.

[6] S. Verdu, “Minimum probability of error for asynchronous Gaussian multiple-access channels”, *IEEE Trans. Inform. Theory*., vol. IT-32, pp.85-96, Jan. 1986.

[7] V. D. Remco, A.D. Hofst, and J. K. Marten, “Improving the Performance of Third Generation Wireless Communication System”, Applied Probability Trust, 17 November 2004.

[8] L. Trichard, J. Evans and I. Collings, “Large System Analysis of Linear Multistage Parallel Interference Cancellation”, *IEEE Trans. on Comm*., vol. 50, No. 11, Jan. 2002.

[9] N. Hamad and T. Hashimoto, “Receiver Link Capacity of a Wireless Multimedia CDMA System with Transmission Power Control and CCI Canceller”, *IEICE Trans. Fundamentals*., vol. E82-A, No. 12, Dec. 1999.

[10] M. Landolsi and W. Stark, “On the Accuracy of Gaussian Approximation in the Error Analysis of DS-CDMA with OQPSK Modulation ”, *IEEE Trans. on Comm*., vol. 50, No. 12, Dec. 2002.

[11] N.N. Rao, *Elements of Engineering Electromagnetics*, sixth edition, pp. 675-724, Prentice Hall, Inc., 2004.

[12] H. Poor and S. Verdu, “Single-User Detectors for Multiuser Channels”, *IEEE Trans. on Comm*., vol. 36, No. 1, Jan. 1988.