BER Performance of a Smart Antenna System for IS-95 CDMA

Salman Durrani[†]and Marek E. Bialkowski[†,††]

[†]School of ITEE, The University of Queensland, Brisbane, Australia.
[††]Dept. of ECE, National University of Singapore, Singapore.
Email: {dsalman, Bialkowski}@ieee.org

I   Introduction

CDMA systems are commonly deployed for second and third generation wireless systems. Due to the fact that in CDMA systems all users communicate simultaneously in the same frequency band, Multiple Access Interference (MAI) is a major cause of transmission impairment. Additionally, the ever present multipath fading significantly degrades the uplink (or reverse link) performance. In order to reduce MAI and avoid adverse effects of multipath, the use of smart antenna systems is postulated [1]. Many authors use the mean bit error rate ($\overline{BER}$) as a figure of merit in determining the performance of smart antennas and their respective algorithms [2] [3]. However, the $\overline{BER}$ does not provide a true reflection of the system performance. Furthermore the performance of practical CDMA systems is usually characterised by the frame bit error rate (BER_f). System engineers like to know how often BER_f, averaged over the ensemble of channel parameters and Direction of Arrival (DOA), exceeds a given threshold. This is known as outage probability. The main contribution of the work in this paper is that we relate the frame bit error rate to outage probability and then analyse the outage performance (P_{out}) of the smart antenna system for CDMA as a function of the number of users, number of antenna elements, doppler frequency and noise levels. These results are derived via simulation of the reverse link of an IS-95 CDMA system.

The paper is organised as follows. In Section II, we present the simulation methodology and define the new figures of merit used to investigate the performance of smart antennas. Section III contains the simulation results and discussion. Finally, summary and conclusions are presented in Section IV.

II   System Model

Block diagram of the investigated smart antenna system is shown in Fig. 1. We evaluate its performance by means of Monte Carlo simulations that are run over 5000 frames for each value of the variable of interest (E_b/N_o or K or N). All the K users are modelled according to the IS-95 CDMA reverse link frame format [4]. The main parameters of the simulation model are summarised in Table 1. The channel model considered is a double spike ($L = 2$), equal strength Rayleigh fading multipaths per user respectively in Additive White Gaussian Noise (AWGN) with the maximum Doppler frequency of $f_D = 100$ Hz, which corresponds to a fast vehicular case, and a constant path delay $\tau = 5T_c$. Angle spread is assumed zero for simplicity. This model is valid for suburban areas. The base station uses a uniform linear array of N omni-directional antenna elements to receive the signal. The mutual coupling between antenna elements is ignored due to the fact that its inclusion only negligibly affects interference rejection capability of a smart antenna system [5]. The smart antenna weight vector adaptation is assumed to be perfect i.e. the weight vector is assumed to match perfectly with the array response vector. As a result, the simulation results are regarded as an upper bound of the performance of a practical system. The following figures of merit are used to study the performance of smart antennas: (i) $\overline{BER}$, defined as the ratio of total number of bit errors to the total number of bits simulated, (ii) BER_f, defined as

the ratio of number of bit errors in a frame to the number of bits/frame. The BER_f is dependent on the particular value of fading amplitude α and DOA θ present during the frame (iii) Outage Probability P_{out}, defined as the probability that BER_f exceeds a given BER threshold (BER_{th}), averaged over the ensemble of channel parameters and DOA of the multiple users. This is given by the following integration:

$$
\begin{aligned}
P_{out} &= \int_{-\pi/2}^{\pi/2} \int_0^{\infty} Pr(BER_f \geq BER_{th}) \, d\alpha \, d\theta \\
&= \int_{-\pi/2}^{\pi/2} \int_0^{\infty} \int_{BER_{th}}^{\infty} p_{BER_f}(BER_f)\big|_{\alpha,\theta} \, p_{\alpha}(\alpha) \, p_{\theta}(\theta) \, d(BER_f) \, d\alpha \, d\theta \quad (1)
\end{aligned}
$$

where, $p_{BER_f}(BER_f)\big|_{\alpha,\theta}$ is the probability density function (pdf) of the BER_f conditioned over α and θ, $p_{\alpha}(\alpha)$ is the Rayleigh pdf and $p_{\theta}(\theta)$ is a uniform pdf of the DOA. The averaging over the ensemble of channel parameters and DOA is done by running the simulations for 5000 frames. To ensure averaging over fading, the fading generators are run continuously over the 5000 frames. To ensure averaging over DOA's, the DOA of the desired user is linearly increased or decreased with $0.01°$ per snapshot, while the DOA of interferers is randomly selected. We have also confirmed via Chi square test [6] that 5000 frames are adequate for average value to be obtained.

Table 1: Main parameters of the simulation

Chip time	$T_c = \frac{1}{1228800}$ s	Modulation	OQPSK
Carrier frequency	900 MHz	Frame length	20 ms
Base Station synchronisation	Asynchronous operation	Spreading Codes	Long code and I and Q sequences
Power Control	Ideal	Channel Coding	No
Oversampling factor	$Q = 4$	Pulse shaping	No
Antenna Geometry	Uniform Linear Array	Antenna distance	$d = \lambda/2$
BER threshold	$BER_{th} = 10^{-3}$	Bits/frame	576
Direction of Arrival	$-\pi/2 \leq \theta \leq \pi/2$	User motion	$0.01°$ per snapshot

III   Results & Discussion

We start our results and discussion for the case of a single user. These are followed by a multiuser case.

Mean Bit Error Rate vs. Number of antennas

The BER results for a single user with $L = 2$ paths ($M = 64$-ary orthogonal modulation with non-coherent detection) for a single antenna (conventional case) are well known [4] and are used as reference. It is apparent that there is no MAI in the case of one user.

Fig. 2 shows the plot of mean BER ($\overline{BER}$) versus E_b/N_o for the case of a single user for different number of antennas. We see that for the conventional case, the simulation results show good agreement with the theory. Fig. 2 illustrates the performance gain in E_b/N_o achieved by the use of smart antenna combining. We define the **smart antenna gain** as the reduction in E_b/N_o relative to the conventional case at a given BER. The smart antenna gain from simulations is found to follow the well known linear relationship in array processing of Signal to Noise Ratio (SNR) gain versus N [3] i.e. the reduction in E_b/N_o is equal to $10\log 10(N)$. Thus smart antenna can be used for either increasing the coverage or improving capacity or both. Also as seen in Fig. 2, the mean BER decreases as the number of antennas increases. Therefore in addition to the capacity and coverage improvement, smart antennas also offer an improvement in system performance measured in terms of reduction in $\overline{BER}$.

Outage Probability vs. Number of antennas

Fig. 3 shows the plot of Outage Probability (P_{out}) vs. number of antenna elements for a single user under three different noise conditions ($E_b/N_o = 0, 10$ and 15 dB respectively) for $f_D = 100$ Hz. We see that for all the simulated cases P_{out} improves as E_b/N_o increases. In addition P_{out} also shows an exponential improvement as N increases. As seen in Fig. 3, when only one user is present in the system, the most significant improvement in P_{out} occurs when the array size is increased up to 4 elements.

Fig. 4 shows the plot of P_{out} versus N for a single user with $E_b/N_o = 10$ dB for the following three cases:- (i) uncorrelated fading, (ii) $f_D = 100$ Hz which corresponds to a fast vehicular channel and (iii) $f_D = 10$ Hz which corresponds to a pedestrian channel. From Fig. 4, we see that uncorrelated fading results in higher outage than the corresponding correlated cases. i.e. vehicular channel shows higher outage than pedestrian channel, e.g. from the figure for $N = 4$, the vehicular channel outage is roughly 4 times the pedestrian channel outage. For $E_b/N_o = 15$ dB, there is little improvement in P_{out} as N increases from 4 to 8 for pedestrian channel.

Mean BER and Outage Probability vs. Number of users

All the results presented earlier were for a single user. In commercial systems there are typically 20 users/sector (for IS-95). Fig. 5 shows how $\overline{BER}$ varies with number of users K for $E_b/N_o = 10$ dB and may be used to determine P_{out} as system load increases. This figure also shows the effect of varying the number of users on Outage Probability. In the range simulated, P_{out} shows a linear increase with the number of users. We can, however, expect that at some large value of K, when the system is heavily dominated by Multiple Access Interference (MAI), P_{out} will become asymptotic at value of 1.

IV   Conclusions

In this paper, we have reported on the BER and outage analysis of a smart antenna system for reverse link of IS-95 CDMA. We have defined new figures of merit for smart antennas (smart antenna gain and outage probability). Simulation results have been presented showing how these figures of merit, and additionally the mean BER, vary with the number of antennas (N) and number of users under different channel conditions. It has been found that significant improvement in outage occurs in the range $1 \leq N \leq 4$. When N increases from 4 to 8, the outage probability reduction is not significant, especially for pedestrian channels. This observation is of value in the planning of smart antenna structures for urban areas. The reported results assume perfect adaptation. Effect of imperfect adaptation is the goal of future work.

References

[1] J. C. Liberti and T. S. Rappaport, *Smart antennas for wireless communications : IS-95 and third generation CDMA applications*, Prentice Hall PTR, 1999.

[2] S. Choi and D. Yun, "Design of Adaptive Antenna Array for Tracking the Source of Maximum Power and its Application to CDMA Mobile Communications," *IEEE Transactions on Antennas and Propagation*, vol. 45, pp. 1393-1404, 1997.

[3] Yoo S. Song and Hyuck M. Kwon, "Analysis of a Simple Smart Antenna for CDMA Wireless Communications," *IEEE Vehicular Technology Conference,* Houston, Texas, pp. 254-258, May 16-20, 1999.

[4] J. Lee and L. E. Miller, *CDMA Systems Engineering Handbook.* Artech House, 1998.

[5] S. Durrani, M. E. Bialkowski and J. Janapsatya, "Effect of mutual coupling on the interference rejection capabilities of a linear array antenna," *Proc. Asia Pacific Microwave Conference*, vol. 2, Kyoto, Japan, pp. 1095-1098, November 19-22, 2002.

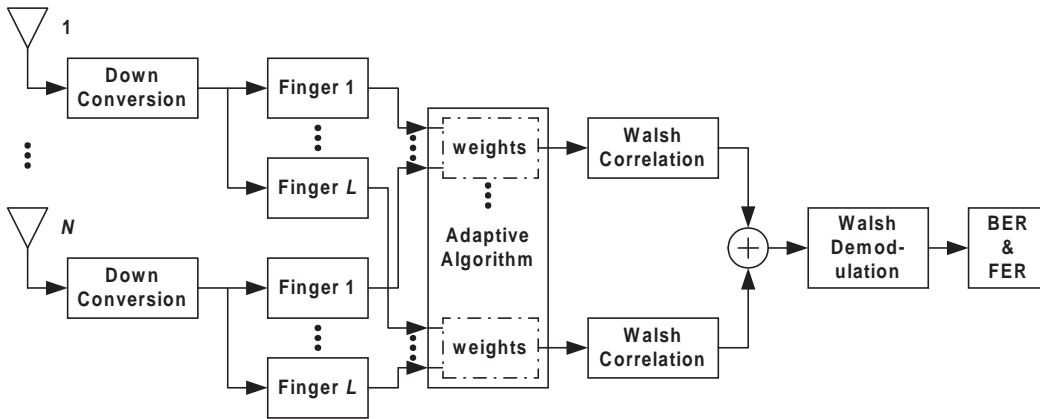[6] E. Kreyszig, *Advanced Engineering Mathematics.* John Wiley, 8th ed., 1999.

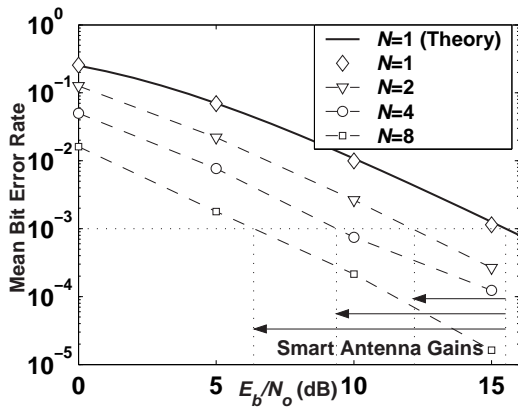Figure 1: The block diagram of the receiver incorporating the smart antenna for the CDMA reverse link.

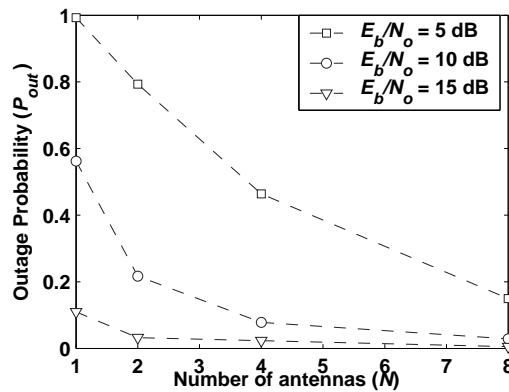Figure 2: Mean BER versus E_b/N_o for single user for various number of antenna elements.

Figure 3: Outage probability P_{out} versus number of antennas N for a single user for different E_b/N_o ($f_D = 100Hz$).
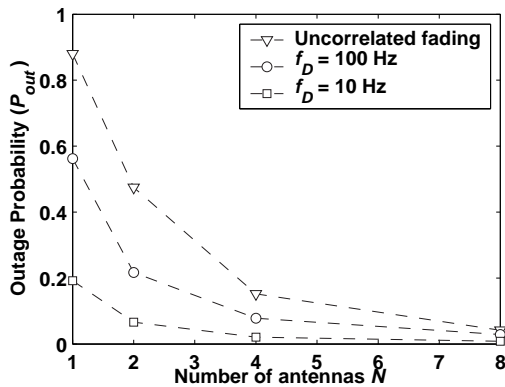

Figure 4: Outage probability P_{out} versus number of antennas N for a single user for different f_D ($E_b/N_o = 10$ dB).
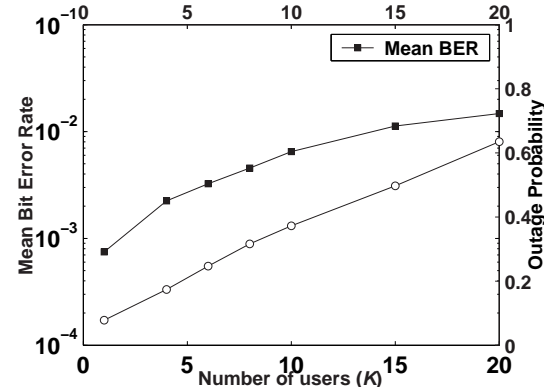

Figure 5: Mean BER and Outage Probability respectively versus Number of users K for $N = 4$ smart antenna array.