Power Control Imperfection in CDMA Systems with Adaptive Antennas

Karol HRUDKAY, Vladimír WIESER
Dept. of Telecommunications
University of Žilina
Veľký diel, 010 26 Žilina
Slovak Republic

hrudkay@fel.utc.sk, wieser@fel.utc.sk

Abstract

This paper deals with a simulation of cellular CDMA system using base station adaptive antennas. The model assumes two tiers area, four types of antennas, lognormal shadowing corresponding to three types of environments and perfect power control or two values of power control error, respectively. The capacity of system in up-link is evaluated by a number of mobile stations with higher signal to interference ratio than threshold with given outage probability.

Keywords

CDMA, cellular, adaptive antennas, shadowing, power control, capacity

1. Introduction

It was shown that CDMA (Code Division Multiple Access) systems based on spread spectrum techniques are effective in mitigating of two main limitations of mobile cellular communication systems, namely multipath fading and co-channel interference. Both these undesirable phenomena can be suppressed because of wideband nature of spread spectrum signals. The main utilisation in mobile systems has found direct sequence CDMA (DS/CDMA) systems. Such asynchronous systems using non-orthogonal pseudonoise (PN) sequences are sensitive to near-far problem and they are interference limited. It means that any action leading to interference level reduction in the cellular system leads directly to the capacity increasing, i.e. higher number of users per cell can operate in the system [1, 5].

2. Cellular Mobile Systems with Adaptive Antennas

In traditional cellular system the base station (BS) radiates the signal in all directions, in order to cover the entire area of the cell. This entails both a waste of power and the transmission in the direction where no mobile stations are to reach, of signal which is seen as interfering for co-channel cell, i.e. the cell using the same group of radio channels. In receptions, the antenna picks up signals coming from all directions, incl. interference and noise.

Systems with adaptive antennas are based on deriving and exploiting information about the spatial position of mobile stations (MSs). The radiation pattern of the BS, both in transmission and reception, is adapted to each different MS position to obtain the highest gain in the direction of the MS. Radiation nulls shall be positioned in directions of interfering MSs. The reciprocal scheme is used in transmission. This process is known as spatial filtering.

Apart from the possibility of capacity increase, systems with adaptive antennas can exploit their higher gain to extend cell size or, on the other hand, to reduce transmitting power and improve performance under multipath fading conditions. All changes required to deploy adaptive antennas are limited only to base stations.

3. CDMA Systems

The CDMA technique uses spread spectrum signals sharing the same band in each point of territory by all users. Especially, in the DS/CDMA system, each user employs a personal signal spread code whereby signals relating to the other users are separated in reception. Each piece of information is multiplied by this personal code at much higher frequency in order to produce a broadband signal. The spreading of information signal is evaluated by processing gain G defined as transmission bandwidth B_t to information signal bandwidth B_i ratio:

$$G = B_t / B_i \, . \tag{1}$$

Since all MSs share the same band, the number of potential interfering stations is very high, certainly higher than the number of antennas in the array, i.e. the number of degrees of freedom of the adaptive system. As a consequence, the behavior of the radiation pattern cannot be the null steering type, but instead, the main beam is simply pointed in the direction of desired MS (Fig. 1).

In both links, the up-link (mobile-to-base, MS-BS) and down-link (base-to-mobile, BS-MS), the *C/I* ratio (the ratio of power of desired user signal to power of all interfering user signals), being dependent on the random positions of the MSs and on the randomness of radio environment, needs to be evaluated on a statistical basis. Cumulative distribution function of the *C/I* ratios is possible to determine as the not exceeded *C/I* ratio (C/I_{th}) at the probability Q and is the function of number of users N, that is:

$$Q = P(\tfrac{C}{I} \le \tfrac{C}{I}\Big|_{th}) \,. \qquad (2)$$

To assess the system capacity, i.e. the maximum number of users that the system can serve, the relationship between C/I and E_b/N_0 is used [2]:

$$\frac{E_b}{N_0} = G \cdot \frac{C}{I} \qquad (3)$$

where E_b/N_0 is the energy per bit to noise spectral density ratio. Assuming the minimum value of E_b/N_0 to have a good quality level in term of Bit Error Rate (BER), the equations (2), (3) provide, at a given outage probability, the maximum number of the MSs (as a function of G), that can be locked to the reference BS at the same quality level.

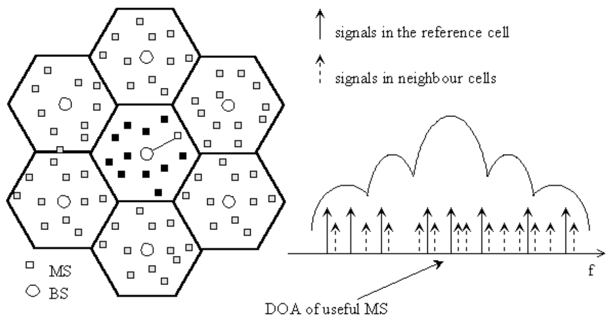

Fig. 1 Radiation pattern adaptation for CDMA system

When MS is close to a BS, the interference can mask the received signals at BS so that the signal from a far-end MS is unable to be received by BS at the same time. For reducing near-end to far-end interference, the reverse-link power control is used. The forward-link power control is used to reduce the necessary interference outside its own cell boundary.

4. Simulation Model

A regular cellular layout with all the BSs spaced by the same distance and equipped with either omnidirectional or directional / adaptive antennas is considered. Taking into account shadowing effect, the path loss is assumed to be proportional to $r^{\gamma}10^{-\xi/10}$, where r is the transmitter-to-receiver distance, γ represents the propagation factor and ξ, expressed in dB, is the random Gaussian variable with zero mean and standard deviation σ. The particular MS is locked to the BS for which the received power is maximal.

Propagation factor γ	Standard deviation σ [dB]	Environment
3	6	Rural
4	8	Macrocell
5	10	Urban

Tab. 1 Simulated environments

The area of the first two tiers of interfering cells, i.e. 18 cells is assumed. For adequate performance the required BER is 10^{-3} which corresponds to E_b/N_0 of 7 dB [1]. The processing gain G is chosen to be 256. Further, perfect power control or two values of power control error (1dB and 3dB) are assumed, respectively.

	Model	Directivity D
a	Omnidirectional	1 / (0 dB)
b	Sectorized (120°)	3,0 / (4,8 dB)
c	Flat-topped (30°/-6dB)	3,2 / (5,1 dB)
d	Adaptive antenna (30°/-20 dB)	6,1 / (7,8 dB)

Tab. 2 Antenna models

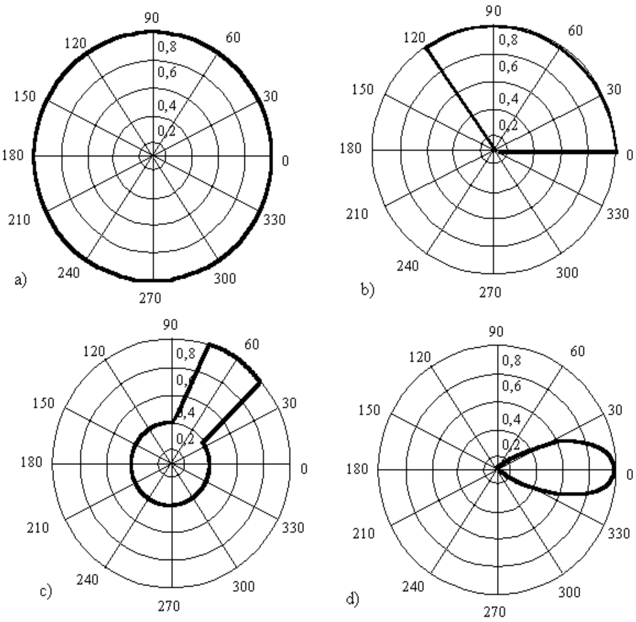

Fig. 2 Antenna patterns

Finally, three types of environment are supposed (Tab. 1) and four types of antenna models. To compare effects among various antenna types, Fig. 2(a) shows standard omnidirectional pattern that models those used in traditional mobile cellular systems. The second configuration in Fig. 2(b) uses 120° sectorized antenna at the BS. The third base station antenna configuration shown in Fig 3(c) is "flat-topped" beam pattern. The main beam is 30° wide with uniform gain in the main lobe. Side lobes are modelled by the uniform side lobe gain 6 dB bellow the main beam gain. The fourth antenna pattern represents phased array antenna which radiation pattern is approximated as a parabola in power with constant backside gain as follows (Fig. 2(d)) [4]:

$$G(\Theta) = \begin{cases} 1-2.(\frac{\Theta}{BW})^2, & |\Theta| \le \sqrt{0,495}.BW \\ 0,01 & elsewhere \end{cases} \qquad (7)$$

where Θis the elevation angle and BW is the 3-dB antenna beamwidth. On the assumption that BW=30° the directivity of this beam is 7.8 dB.

Capacity of the system is then evaluated as the number of MSs that can be served by system when the C/I

exceeds the threshold (from 3 follows that $C/I\,|_{th}$ = -17 dB) value during more than 90% of time, i.e. the outage probability is 0.1.

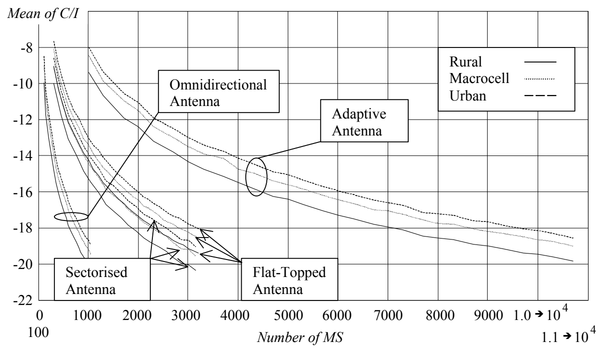

Fig. 3 Mean value of C/I vs. number of MS in the system – perfect power control

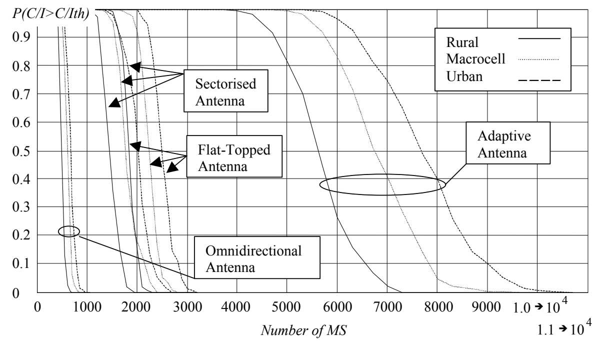

Fig. 4 Probability P(C/I>C/I_{th}) vs. number of MS in the system – perfect power control

5. Results

5.1 Perfect Power Control

Results of simulation corresponding to perfect power control (PPC) are shown in Fig. 3 and Fig. 4 and give relation between the mean value of *C*/*I* expressed in dB and outage probability as a function of number of MSs in the system.

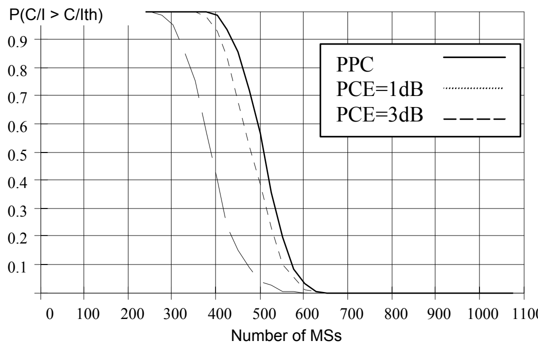

Fig. 5 Probability P(C/I>C/I_{th}) vs. number of MSs (rural environment, omidirectional antenna)

5.2 Power Control Error

Examples of simulation results considering power control error (PCE) 1 dB or 3 dB are shown in the following figures.

Fig. 5 and 6 show capacity loss caused by power control error and an increasing capacity caused by impact of different environments. Further, next figures (Fig. 7, 8 and 9) reflect an effect of using different antennas. A progress of C/I ratio for particular environments and types of antenna is analogous to that is seen in Fig. 3.

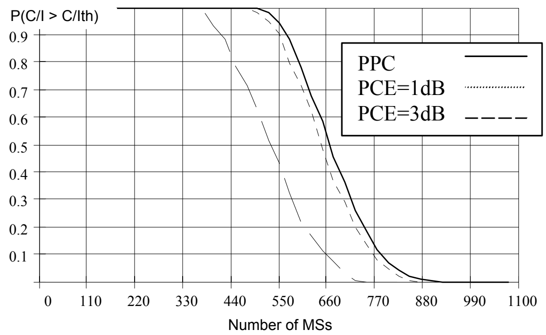

Fig. 6 Probability P(C/I>C/I_{th}) vs. number of MSs (urban environment, omnidirectional antenna)

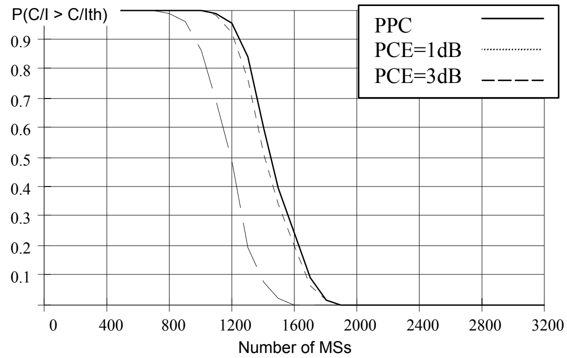

Fig. 7 Probability P(C/I>C/I_{th}) vs. number of MSs (rural environment, sectorized antenna)

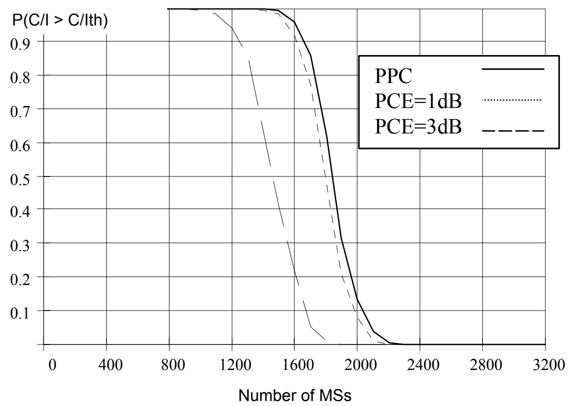

Fig. 8 Probability P(C/I>C/I_{th}) vs. number of MSs (rural environment, flat-topped antenna)

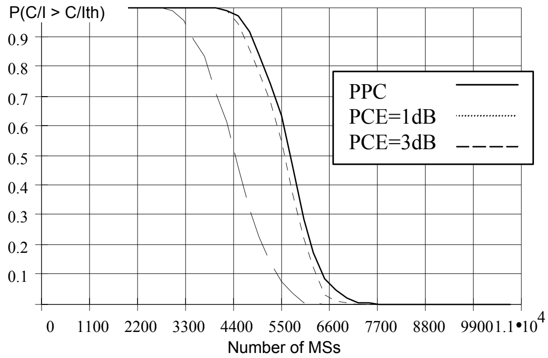

Fig. 9 Probability $P(C/I>C/I_{th})$ vs. number of MSs (rural environment, adaptive antenna)

Following conclusions can be done as the basis of detailed analysis of obtained data for all possible cases. The using of sectorised antennas provides triple capacity in comparison with omnidirectional antennas. A gain of using flat-topped antennas is approximately quadruple and capacity with using adaptive antenna is higher more than eleven times. The power control error 1 dB causes capacity loss approximately 4 %, but error 3 dB brings capacity loss more than 25%. Also the influence of type of environment is not negligible. In comparison with environment with γ=3 (rural), the capacity for γ=4 (typical macrocell) is higher about 20%, the capacity for γ=5 (urban) is higher more than 30%.

6. Conclusion

Adaptive antennas represent a possibility to improve performance of cellular systems. It is evident that capacity is affected by environment – the higher propagation factor the higher capacity. Systems with adaptive antennas with relatively modest requirements to beamwidth provide high increasing of capacity to compare with systems with omnidirectional antenna. The increasing of capacity is manifold. On the other hand, it has appeared that capacity loss caused by power control error 1 dB is not considerable, but higher power control error causes loss of capacity up to 1/3.

References

[1] GILHOUSEN, K. S. et al. On the Capacity of a Cellular CDMA System. IEEE Transaction on Vehicular Technology. 1991, vol. 40, no. 2, pp. 303-312.

[2] PROAKIS, J. G. Digital Communications. 3rd. ed. McGraw-Hill, 1995.

[3] LIBERTI, J. C.; RAPPAPORT, T. S. Analytical Results for Capacity Improvement in CDMA. IEEE Transaction on Vehicular Technology. 1994, vol. 43, no. 3, pp. 680-690.

[4] KAJIWARA, A. Effects of Cell Size, Directional Antenna, Diversity, and Shadowing on Indoor Radio CDMA Capacity. IEEE Transaction on Vehicular Technology. Feb.1997, pp. 265-275.

[5] WIESER, V., HRUDKAY, K. Mutual Interference Models for CDMA Mobile Communication Networks. This issue.

[6] HRUDKAY, K., DÚHA, J. Simulation of a Cellular CDMA System with Adaptive Antennas. In Proceedings of the 10th International Conference Radioelektronika 2000. Bratislava (Slovak Republic), 2000.

About Authors...

Vladimír WIESER was born in Puchov in 1954. He received the M.S. degree in electrical engineering and communication from the Military Academy Brno, Czech Republic, in 1978 and Ph.D. degree from the Military Academy Liptovsky Mikulas in 1996. Since 2001 he works as Ass. Prof. at the Telecommunication Dept., University of Zilina, Slovak Republic. His research includes mobile communication networks, especially power and rate adaptation, radio resource management.

Karol HRUDKAY was born in Mikusovce in 1971. In 1995 he received his M.S. degree of electrical engineering from the University of Zilina, Slovak Republic. He works as senior lecturer in the Dept. of Telecommunication, University of Zilina, Slovak Republic. His research includes mobile communication networks, smart antennas and digital radio-communications.