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Montecarlo Simulation Applied to Measurement of the Impact of the Smart Antenna Technology in Digital Cellular Systems

Simulación montecarlo aplicada a la medición del impacto de la tecnología de antenas inteligentes en sistemas celulares digitales

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Abstract

The smart antenna technology has received increasing interest due to its capability for improving the performance of wireless radio systems. In this work, we studied the throughput maximization in a digital cellular system when a smart antenna array is implemented. We focus, in the study of the downlink of a 3G cellular system and consider a packet data direct-sequence code division, multiple access (DS-CDMA). Our methodology is based on the Montecarlo simulation technique, and it is used to show that it is possible to obtain a significant increment in the throughput of the system due to the switched beam smart antenna array. From our results we conclude that it is feasible to consider the application of this technology in 4G environments.

Keywords:

- smart antenna
- Montecarlo simulation and
- Digital Cellular System

Resumen

La tecnología de antenas inteligentes ha sido de gran interés debido a su capacidad para mejorar el desempeño de los sistemas inalámbricos. En este trabajo, estudiamos la mejora del desempeño en el sistema digital celular cuando se utiliza un arreglo de antenas inteligentes. Nos enfocamos además, en el estudio del enlace de bajada de un sistema celular 3G y consideramos un esquema de acceso múltiple de paquetes de datos de secuencia directa (DS-CDMA). Nuestra metodología está basada en la técnica de simulación Montecarlo y se usa para mostrar que es posible obtener un incremento significativo en el desempeño del sistema debido al arreglo de antenas inteligentes. De nuestros resultados concluimos que es posible considerar la aplicación de esta tecnología en ambientes 4G.

Descriptores:

- *antenas Inteligentes*
- *simulación Montecarlo*
- *sistema celular digital*

Introduction

The adoption of smart antenna techniques in future wireless systems is expected to have a significant impact on the efficient use of the spectrum, the minimization of the cost of establishing new wireless networks, the optimization of service quality, and realization of transparent operation across wireless networks. Adaptive antennas have been used for decades in areas such as radars, satellite communications, remote sensing, and direction finding, to name a few. Each of these applications is associated with its own unique set of challenges, such as the channel in which the system operates, the propagation environment, sources of interference, and noise or jamming. In addition, the end goal for which the adaptive antenna is used affects the selection of the type of array, size, adaptive algorithms, and integration with other system components (Alexiou and Haardt, 2004; Liberti and Rapaport, 1999).

Current mobile communications systems employ sectorization to reduce interference and increase capacity. Cells are broken into three or six sectors, with dedicated antennas and RF paths. Increasing the amount of sectorization reduces the interference seen by the desired signal. One drawback of current sectorization techniques is that its efficiency decreases as the number of sectors increase, due to the antenna pattern overlap. Furthermore, increasing the number of sectors increases the handoffs in the mobile experiences while moving across the cell. Smart antennas offer a more efficient way to reduce interference in mobile communications systems, through the use of narrow beams directed toward clusters of users, while at the same time steering nulls toward interfering users. With a narrow-beam directed toward a desired user, some interferers that would have seen in the 120° sector antenna, will be outside of the beam-width of the array (Herscovici, 2001).

Achieving peak data rates specified in each standard in a real system remains very unlikely because it would require an unloaded system serving a single user to be extremely close to the base station. This leads to two questions: Why the increased interest in the smart antennas?, and how are they being considered as a viable technology for applications such as mobile telecommunications? As we know, operators are faced with increasing capacity demands for both voice and data services. Although various 3G technologies offer higher data rates and double voice capacity compared with their 2G counterparts, their actual performance is still susceptible to interference, and adverse channel conditions created by multipath propagation and system loading. As such, smart antennas techniques can complement 3G system and improve their performance by alleviating and reducing the degradation caused by the aforementioned factors. In fact, because of their nature, technologies such as HSDPA and 1xEV-DO can greatly benefit from smart antennas since any improvement in the SIR experienced by the users would directly translate to better throughput for individual users as well as increased sector throughput that can support higher capacities (Liberti and Rapaport, 1999; Herscovici, 2001; Bender *et al*., 2000) A new generation of mobile technology is marked by a significant advance in functionality (Etoh, 2005; Yavuz *et al*., 2006). Smart antennas techniques can complement the new generation systems by improving their performance.

In this work we analyze the benefit of the smart antennas in CDMA2000 1xEV-DO systems in terms of the throughput of the data network or the maximum achievable data transmission rate; in a sense that any improvement in the SIR experienced by the users would directly translate to better throughput for individual users as well as increased sector throughput that can support higher capacities (Herscovici, 2001; Bender *et al*., 2000).

We evaluate the throughput in the forward link of a system configuration which consists of 37 macrocells. The base stations are located in the center position and the use of three sectored antennas is assumed. The mobile users are uniformly distributed within the cells. The performance of the system has been measured in terms of a Monte Carlo simulation implemented in MATLAB. The Monte Carlo simulation methodology is a type of simulation that relies on repeated random sampling and statistical analysis to compute the results (Raychaudhuri, 2008; Zhuang and Lin, 2007). This method of simulation is very closely related to random experiments, experiments for which the specific result is not known in advance. In this context, Monte Carlo simulation can be considered as a methodical way of doing so-called what-if analysis where we use mathematical models to describe the interactions in a system using mathematical expressions. These models typically depend on a number of input parameters, which when processed through the mathematical formulas in the model, results in one or more outputs.

This work is organized as follows. In the next section, we present the operation of the CDMA2000 1xEV-DO system. In the third section we evaluate the performance of the CDMA2000 1xEV-DO system. The numerical results are presented in the fourth section. The last section provides our conclusions and remarks.

CDMA2000 1xEV-DO System

As we can see in Table 1, different technologies support different peak data rates. The peak rate is the maximum transmission speed which an individual user may experience under ideal conditions (i.e., it only affects the user experience). Data throughput on the other hand, is a far more important metric for performance. Thus, the user throughput is the average data rate a user may experience. Table I compares different peak data rates and throughput for different 3G technologies (Liberti and Rapaport, 1999).

The CDMA2000 family of standards is a wideband spread spectrum radio interface that uses CDMA technology to meet the objectives of 3G systems while maintaining backward compatibility with IS-95 based systems. This means that mobile handsets designed according to the IS-95 standard are capable to operate in a CDMA2000 system and vice versa. The first component of the CDMA2000 standard is called 1x radio transmission technology (1xRTT) because it uses an RF carrier of 1.25 MHz just like IS-95 based systems, hence the 1x, is also referred to as spreading rate (SR) 1. The key benefits of the 1xRTT technology standardized under the name of IS-2000 compared with IS-95A/B standards can be summarized as follows: Better forward error correction (FEC), fast forward link power control mechanism and multimedia services and improved data services support (Liberti and Rapaport, 1999).

The current 3G operators in Japan and Korea as well as in the United States are already experiencing great success with their data services. The 1xEV-DO standard is optimized for wireless high speed packet data services (Liberti and Rapaport, 1999; Esteves *et al*., 2003; Wonsuk *et al*., 2001);. Because of the typical asymmetric characteristics of the IP traffic, the downlink is the most critical of the two links (Bender *et al*., 2000; Esteves *et al*., 2003). Thus several techniques were introduced in 1xEV-DO to optimize the downlink throughput. Time-division-multiplexed (TDM) waveform, power control and a variety of modulation schemes, including QPSK, 8 PSK and 16 QAM as well as coding rates that best match the fading channel, are defined in what is commonly called adaptive modulation and coding techniques (Yavuz and Paranchych, 2003; Yonghoon and Youngnam, 2002)

Forward Link Performance.

In the CDMA2000 1xEV-DO system when the transmission rate of user i is R_i and the bandwidth is given by W_C, the energy to interference ratio requirement is given by

$$\gamma = \left(\frac{E_b}{I_0}\right)_i = \frac{W_C}{R_i} SIR_i \tag{1}$$

where SIR_i is the signal to interference ratio requirement. If we consider QPSK modulation and the transmission rate as a function of the processing gain, the maximum achievable transmission rate for the user i, which we define as throughput, can be written as (Yonghoon and Youngnam, 2002; Ulukus and Greenstain, 2000).

Table 1. 3G Technologies Comparisons

Technology	Carrier Bandwidth /Spectrum (MHz)	Downlink Peak Data Rate(Kbps)	Average User Throughput (Kbps)
CDMA20001x	1.25/1.25	153.6	60-80
CDMA2000 1xEV-DO Rev. 0	1.25/1.25	2458	300-500
WCDMA	3.85/5	384	220-320
HSDPA	3.84-/-5	14400	550-1100

$$R_i = \begin{cases} \dfrac{W_C}{\gamma} SIR_i & SIR_i < 2\gamma \\ 2W_C & SIR_i \geq 2\gamma \end{cases} \tag{2}$$

For the CDMA2000 1xEV-DO system, the signal to interference ratio is given by

$$SIR_i = \frac{G\left(\varphi_{0,i}\right) / 10^{\varsigma_{0,i}/10} r_{0,i}^{\mu}}{\sum_{k=1}^{N_{BS}} G\left(\varphi_{k,i}\right) / 10^{\varsigma_{k,i}/10} r_{k,i}^{\mu}} \tag{3}$$

where $G(\varphi_{0,i})$ is the antenna gain relative to the i-th user respect to the 0-th base station, $G(\varphi_{k,i})$ is the antenna gain relative to the i-th user with respect to the k-th base station $10^{\varsigma_{k,i}/10} r_{k,i}^{\mu}$ models the propagation losses given by the product of the μ-th power of the $r_{k,i}$ distance between the CDMA2000 1xEV-DO interest user in the 0-th base station and the k-th base station, and a log-normal component which represents the shadowing losses and whose characteristic Gaussian random variable, $\zeta_{k,i}$, has zero mean and standard deviation Δ. The $10^{\varsigma_{k,j}/10} r_{k,j}^{\mu}$ models the propagation losses given by the product of the μ-th power of the $r_{k,j}$ distance between the j-th user and its k-th power control base station and a log-normal component which represents the shadowing losses. N_{BS} is the number of interfering base stations.

In the previous equation the antenna gain is approximated by a parabolic function in the main beam and by a constant average for the side-lobe. Therefore, the antenna gain can be expressed as (Ramakrishna and Holtzman, 1998; Castañeda y Lara, 2008).

$$G\left(\phi_{k,j}\right) = \begin{cases} 1 - \dfrac{1-q}{\theta^2} \phi_{k,j}{}^2 & \left|\phi_{k,j}\right| \leq \sqrt{\dfrac{1-p}{1-q}}\theta \\ p & \left|\phi_{k,j}\right| > \sqrt{\dfrac{1-p}{1-q}}\theta \end{cases} \tag{4}$$

where ϕ is the angle between the desired user and the direction of the maximum gain of the antenna, q represents the antenna gain level (normalized to the maximum gain) at different θ sector crossover from the maximum gain direction and p represents the average normalized gain level for the side-lobe. The nominal values chosen in our evaluations for q and p were –4 and –15 dB respectively. This corresponds to a typical cellular sector antenna with 3-dB horizontal beam width around 100-110°.

Numerical results

A Monte Carlo simulation of discrete events was carried out in a cellular CDMA2000 1xEV-DO system. We evaluated the performance in terms of the throughput given by the equation (2), where the SIR is calculated in the scenario proposed in Figure 1. In addition we

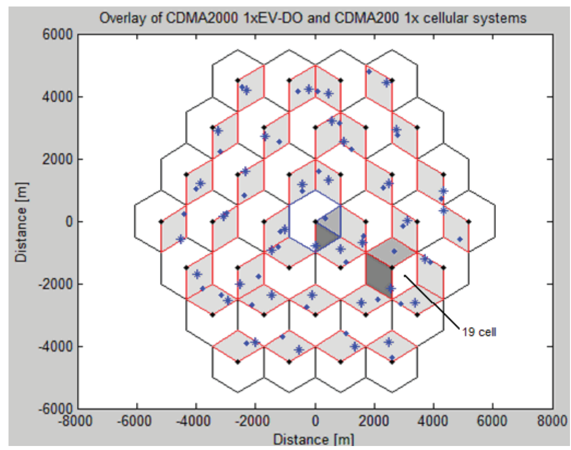

Figure 1. Macrocell CDMA1xEV-DO system scenario

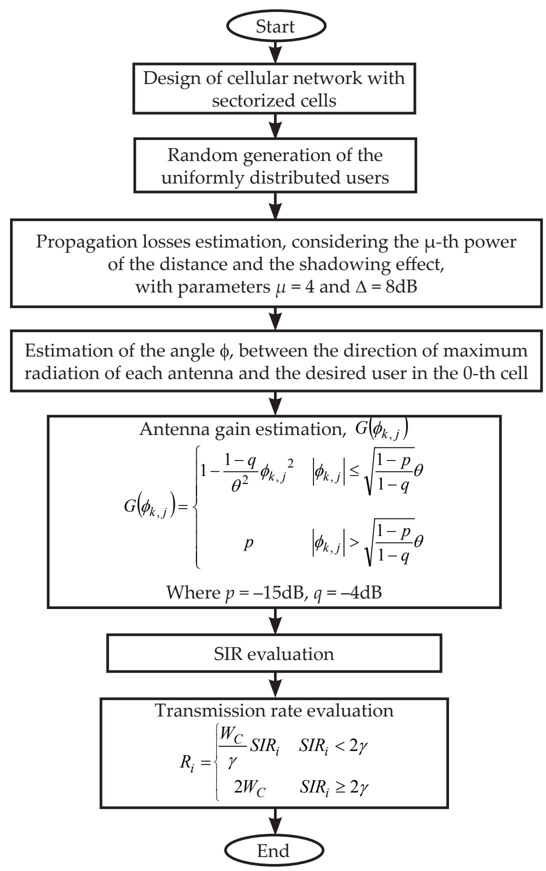

Figure 2. Dataflow of the Monte Carlo simulation

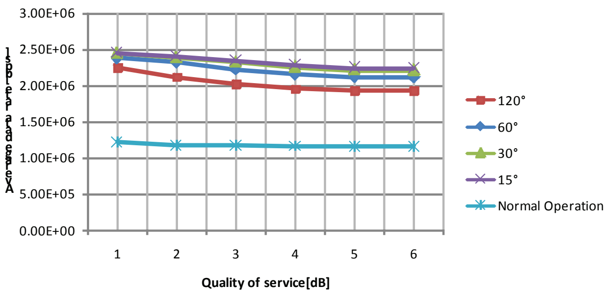

Figure 3. Throughput [bps] of the CDMA1xEV-DO system

assumed that Δ = 8dB, μ = 4, W_C = 1.2288 MHz and the cell size of 1 Km. In equation (3) we are considering that N_{BS} = 36 in a 37-cell system with one center cell and 36 interfering cells as we can see in Figure 1.

The development of the Monte Carlo simulation can be summarized by the dataflow in Figure 2.

Finally, Figure 3 shows the average data rate or maximum achievable data transmission rate of the CDMA2000 1xEV-DO system for different γ values and for different, θ, beam-width values.

Compared with the normal operation, in which the CDMA2000 1xEV-DO system does not implement smart antennas, we can observe that the throughput increases as the beam width of the antenna array decreases. From the results, when we consider for example a θ=15° we obtain a significantly improved data rate, approximately equal to 100% in comparison with the normal operation.

Conclusion

In this paper we developed a Monte Carlo simulation of discrete events to prove that it is possible to obtain a significant increment in the throughput of the 3G system due to the smart antenna array. Also, we can apply this technology to 4G generation systems to improve its performance. Smart antenna arrays provide an efficient mechanism to maximize the throughput of a CDMA2000 1xEV-DO system. In fact, results prove that the use of smart antennas in a CDMA cellular system can provide a 100% of data rate increment compared with the normal operation of the system. We are also leaving the basis for the analysis of this smart antenna technology in future wireless generations.

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