PERFORMANCE OF MULTIMEDIA SERVICES IN WCDMA SYSTEM WITH INTELLIGENT ANTENNAS(1)

Vicente A. de Sousa Jr. *Francisco R. P. Cavalcanti* *Carlos H. M. Lima*
vicente@dee.ufc.br *rod@dee.ufc.br* *carlosml@dee.ufc.br*

Universidade Federal do Ceará - Campus do Pici - CT/DEE/UFC, CP 6001, Fortaleza-CE, Brasil

ABSTRACT

The major purpose of this contribution is to analyze a VSG-WCDMA (variable spreading gain wideband code division multiple access) system in the reverse link with multiple rate services. The multi-rate VSG technique can be implemented with different quality of service (QoS) targets and distinct activity factors. A system-level simulation approach is employed where we consider three smart antenna strategies: switched fixed beams, spatial matched filter and fully adaptive antennas. Gains in average signal-to-interference ratio (SIR) are then evaluated. Distinct user scenarios are defined based on bit rate and user spatial distribution. The system-level model takes into account imperfect power control, multiple cellular environment and a realistic antenna element radiation pattern.

1. INTRODUCTION

Aiming the third generation of mobile communications several enabling technologies offer different trade-offs between performance and complexity when trying to meet requirements of increased capacity and data rates on the wireless channel. One of the major technological trends at this moment is towards wide band code division multiple access in order to meet 3rd generation (3G) objectives [1].

Besides the multiple access technology itself, other supporting alternatives may be considered. The deployment of microcells is a widely accepted technique for alleviating the traffic in areas with high densities of subscribers. However, the implementation of this technique may require system redesign, base stations installation, relocation and replacement. Those requirements may also lead to significant additional costs.

Sectorization and spatial diversity are already widely employed techniques in second generation wireless systems. These can be considered very basic forms of spatial signal processing. Another approach, namely the improved spatial signal processing capabilities offered by smart antennas, fulfills the enhanced performance requirements of 3G systems.

Smart antennas are now recognized as a viable option for increased capacity, data rate and coverage in wireless systems [2, 3].

This paper focuses on a system-level simulation of a WCDMA mobile communication network in the reverse link where smart antennas are employed for increased performance of multimedia services. The performance of different smart antennas concepts are appraised and compared.

Multiple rate services in CDMA systems are enabled by following two main approaches: multiple or single code transmission schemes. In a multi-code scheme, additional parallel codes are allocated as the data rate increases, namely, a high data stream is split into low-rate streams that are spread by distinct short codes with the same chip rate and combined signals are added together before the parallel transmission [4]. Alternatively, a single-code transmission scheme, also known as variable spreading gain (VSG), may be used where one spreading code is assigned for each user and different bit rates are achieved by varying its processing gain inversely proportional to the desired information bit rate. The latter technique is employed in this paper.

We look upon three distinct classes of services: speech users, low data rate users and high data rate users. The system behavior is evaluated in simulations performed in a multiple cellular environment.

The users are spatially distributed in two distinct ways. In the first one, we uniformly locate an average number of users over each cell site sector. In the second approach, we also represent a hot spot (large user concentration in a restricted region) to model, for instance, a shopping mall scenario.

The remainder of this paper is organized as follows. In section 2, we present the system model for system-level simulations. In section 3, we briefly review the smart antennas strategies in focus. In section 4, we analyze the simulation results, and, in section 5, we conclude this contribution with final remarks and perspectives.

2. SYSTEM-LEVEL SIMULATION MODEL

The simulator models a WCDMA system with multiple cells. Each cell site is composed of three hexagonal sectors. Two interferer layers are considered as can be seen in fig. 1.

For system-level evaluation, path loss and shadowing are the considered channel manifestations such that the obtained results express the system behavior in an average sense with respect to fast fading. In this case, the received power in a base station (BS) can be expressed as:

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$$P_r(r) = P_T.r^{-n}.10^{\left(X_\sigma/10\right)} \qquad (1)$$

where r is the transmitter-to-receiver separation distance, n is the Path Loss exponent, X_σ is a zero-mean Gaussian distributed random variable with standard deviation σ_{dB} which describes the shadowing effects and P_T is the transmitted signal power.

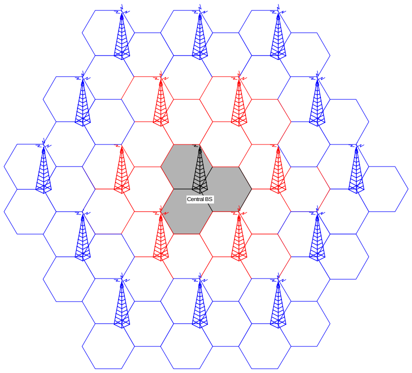


Figure 1: Two Interferer Layers in Multicellular CDMA Environment.

In simulations the reference system uses the typical sectored antenna radiation pattern shown in fig. 2, in agreement to [5].

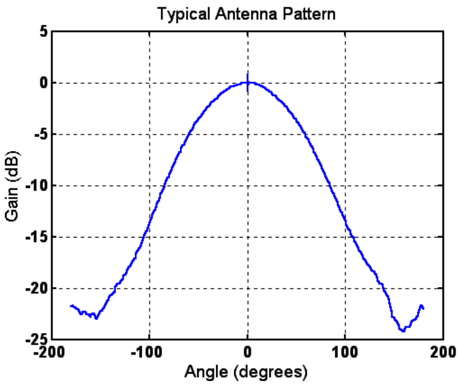


Figure 2: Typical Antenna Pattern.

The connection between the ith mobile and its own BS is achieved selecting the highest $P_r(r_{i,j}).G_{REF}(\theta_{i,j})$ value, where $P_r(r_{i,j})$ is the received power given by (1) and $G_{REF}(\theta_{i,j})$ is the antenna gain of the ith user with respect to the jth BS for its $\theta_{i,j}$ direction of arrival (DOA) relative to the jth BS.

Data is collected from one sector of the central BS where the SIR is measured taking into account inter and intra-cellular interference. Eq. 2 expresses the interference of that the ith mobile connected to the jth BS causes at the central cell site after power control is performed (see fig. 3):

$$\mathrm{I}_{i,j} = P_{Ti}\frac{r_{i,0}^{-n}.10^{\left(X_\sigma/10\right)}.G_{REF_{i,0}}(\theta_{i,0})}{r_{i,j}^{-n}.10^{\left(X_\sigma/10\right)}.G_{REF_{i,j}}(\theta_{i,j})}.10^{\left(X_{IPC}/10\right)} \qquad (2)$$

where P_{Ti} is the ith mobile transmitted signal power and $r_{i,j}$ is the jth BS to ith mobile separation distance. X_{IPC} is a zero-mean Gaussian distributed random variable, with standard deviation σ_{IPC}, which models imperfect power control.

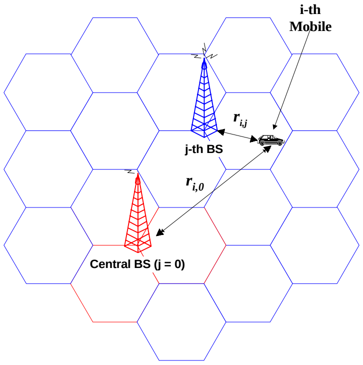


Figure 3: Interference Model: The mobile connected to the jth base station causes intra-cell interference to central base station.

After smart antennas have been added to the central base station, the interference caused the ith mobile connected to the jth BS at the central cell site is modified and becomes:

$$\mathrm{I}'_{i,j} = \mathrm{I}_{i,j}.G_{SMART}(\theta_{i,0}) \qquad (3)$$

where $G_{SMART}(\theta_{i,0})$ is the specific smart antenna scheme gain performed in the central base station for the ith mobile.

Spatial channel modeling at the system-level is based on an idealized DOA knowledge, based solely on the mobile position on the cell grid. This scenario can be representative of a macrocellular system with small angle spread. For a description of robust DOA estimation methods see [6].

Our analysis is based on independent trials where the mobiles are randomly located obeying the same probability over the whole network. The simulation is semi-static in the sense that there is no mobile motion involved but performance is calculated over several uncorrelated location sets. As a consequence, no handoffs are modeled.

2.1 Traffic Model

The system is assessed considering three distinct service classes: speech service (SPC) at 15 Kbps; low data rate (LDR) at 32 Kbps; high data rate (HDR) at 144 Kbps. The WCDMA system main parameters are a 3.84 Mcps chip rate and BPSK modulation, similar to, e.g., the UTRA-FDD specification [1, 7, 8].

The analysis considers sets of system configurations where the users may be active or not depending on the activity factor. The activity factors assumed presently are 0.4 for SPC users, 0.7 for LDR users and 1.0 for HDR users. The latter two factors represent intense data transfer applications such as file-transfer protocol or constant bit-rate videoconference.

Our QoS measure on uplink is a signal-to-interference ratio (SIR) expressed as the bit energy-to-interference density ratio (Eb/Io). Rake receiving, spatial diversity and multi-user detection techniques allow us to estimate a value of SIR=5dB as sufficient to provide a satisfactory raw Bit Error Rate (BER) on the order of 10^{-3} [9]. Further channel coding should bring the BER to the required acceptable level. We use this value of SIR to specify outage probabilities and to optimize power allocation for all service classes. Notice that different QoS requirements could have been specified for each service class.

For the ith class, the target SIR is expressed as follows considering that perfect power control is achieved and additive noise is negligible when compared to the overall interference:

$$\gamma_{\mathbf{i}} = \frac{G_{pi}}{(N_i - 1)\alpha_i + \sum_{\substack{\mathbf{j=1} \\ \mathbf{j \neq i}}}^{c} \alpha_j N_j \frac{P_j}{P_i} + I_{EXT}} \tag{4}$$

where G_{Pi} is the processing gain, N_i is the average number of users, α_i is the user activity factor, P_i is the received power of the ith class and c is the number of service classes. The 1st and 2nd terms in the denominator represent inner central cell interference. I_{EXT} is the central cell site external interference. This interference is the same for all users in the central cell.

In multimedia CDMA systems, power allocation is an important issue. In this paper we follow the method presented in [10] where power is allocated trying to preserve the prescribed quality of service of each service class. This power allocation scheme is based on the processing gain, QoS and activity factor of each service class as follows:

$$\frac{P_i}{P_j} = \frac{G_{pj}/\gamma_j - \alpha_j}{G_{pi}/\gamma_i - \alpha_i} \tag{5}$$

where P_i is the ith service class power, γ_i is the signal-to-interference threshold (E_b/I_o) required by the ith service class and α_i is the i-th service class activity factor. Other power allocation criteria for heterogeneous traffic in CDMA systems can be found in, e.g., [11, 12].

The received power of voice users is normalized to one and used as the reference power level. SPC users are characterized by a processing gain equal to 256. The lowest spreading gain for HDR service is 27. We neglect additional multiuser or intersymbol interference that may arise from the reduced spreading gain through the use of advanced techniques such as multiuser detection and equalization.

2.2 Spatial User Distribution

We randomly locate an average number of users ranging from 5 to 15 over each cell site sector. Initially, the users are placed uniformly over the entire network modeling a median behavior. After that, we model a hot spot concentrating all BS data users inside a small region within the 1st sector.

2.3 Scenario Definitions

The simulation scenarios comprise both specific user distributions and user service classes that are considered together or separately. In the scenario definitions we follow the suggestions in [13].

Reference Speech: we consider speech users uniformly distributed over the whole cellular network.

Suburban Scenario: in this scenario we consider 70% of speech users and 30% of LDR users uniformly located over the entire system.

Urban Scenario: we assess the cellular network considering 50% of speech users, 30% of LDR users and 20% of HDR users.

Dense Urban Scenario: in this situation the system is evaluated as in the urban scenario but with all data users of the central BS sector concentrated in a hot spot.

3. SMART ANTENNA REVIEW

Smart antenna architectures are employed to combat multiple access interference – MAI (user capacity limiting factor) from intra- and inter-cell mobiles in CDMA systems. Smart antennas comprise an array of antenna elements that digitally process the received signals in order to achieve beam steering.

We use a uniform linear array (ULA) with 4 or 8 antenna elements and employ Wiener's optimum linear solution to determine the array weights [14]. Weights determination is based on the assumption of a planar wave arrival over the azimuth. This way, the spatial component of propagation channel depends on the user's DOA θ only.

In the following we review the three smart antenna strategies considered in this paper. An overview about smart antennas and their application in wireless systems may be found, for instance, in [3, 6].

Switched Multiple Fixed Beams (FB) is the simplest smart antenna technique used in this paper. In order to implement this method it is necessary to substitute the reference sectored antenna by an array of narrower multiple beams in pre-established positions inward each cell site sector. The best beam is selected according to the user position in order to give the highest power. The pitfall of this architecture occurs when the angular position of the user is in-between two beams where the array gain is lower (fig.4).

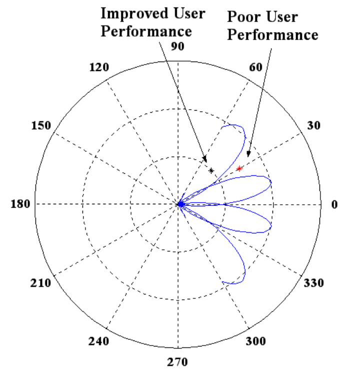


Figure 4: Fixed Beam Scheme.

Spatial Matched Filter (MF) steers a beam toward the desired user. The steered beam is generated according to user DOA regardless of the position of the interferers (fig.5).

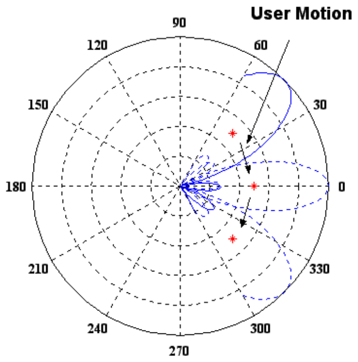


Figure 5: Matched Filter Scheme.

Adaptive Antennas (AA) are the most sophisticated smart antenna scheme treated here. Adaptive antennas generate a steered beam towards the desired user according to its DOA while nulls out interfering DOAs. The relative power levels are also taken into account (figure 6).

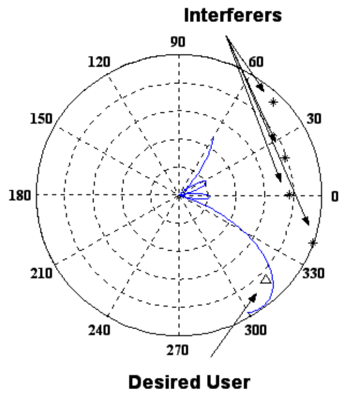


Figure 6: Adaptive Antennas Scheme.

Practical implementation of these architectures may range from conventional fixed beamshaping techniques to shophisticated digital beamforming techniques based on adaptive signal processing [15].

4. PERFORMANCE RESULTS

Performance results consist of the average SIR per user in a central base station sector. The average SIR behavior of the central base station is representative for the whole system in the reverse link of a homogeneous network. In the following results, a 4-element array is employed in all smart antenna architectures. Other parameters include path-loss exponent n=4, shadowing standard deviation σ_{dB} = 8 dB and power control imperfection standard deviation σ_{IPC} = 2 dB.

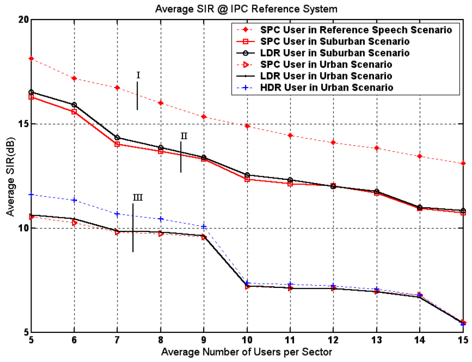


Figure 7: Average SIR for Reference Systems: (I) Reference Speech Scenario, (II) Suburban Scenario, (III) Urban Scenario.

Fig. 7 describes the performance of the reference (3-sectored) system. It can be seen that attaching additional services reduce system performance. We ascertain that going from Reference Speech scenario (I) to Suburban scenario (II) there is a degradation of approximately 2.7 dB and that going from Suburban scenario (II) to Urban Scenario (III) there is a degradation of 5.4 dB. We observed that at a load of 15 users per sector, about 18% of the connections in each service class did not meet the required SIR.

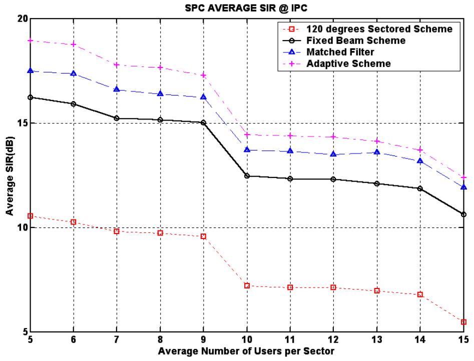


Figure 8: Average SIR for SPC users in Urban Scenario

In Figure 8 SPC user results for the three smart antenna concepts in an urban scenario are shown, while the LDR and HDR results are depicted in figures 9 and 10, respectively. A significant gain in average SIR is observed.

In those cases we observed that the outage significantly decreased. For the 15 users per sector load, about 2% with fixed beam and 0.14% with fully adaptive antennas of the connections in each service class did not meet the required minimum SIR (5 dB).

Figure 11 depicts the smart antenna gains relative to the reference sectored antenna system. The gain is proportional to the complexity of the antenna architecture, lower with fixed beams and highest with the fully adaptive solution. Results for 8 antenna element arrays are also shown, with the corresponding higher gains.

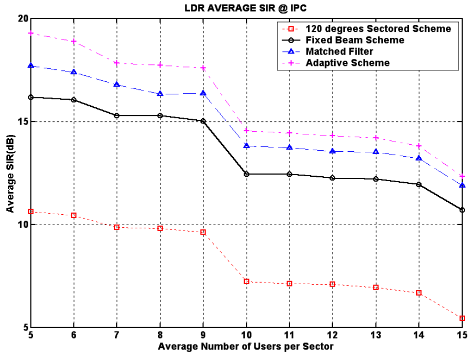


Figure 9: Average SIR for LDR users in Urban Scenario

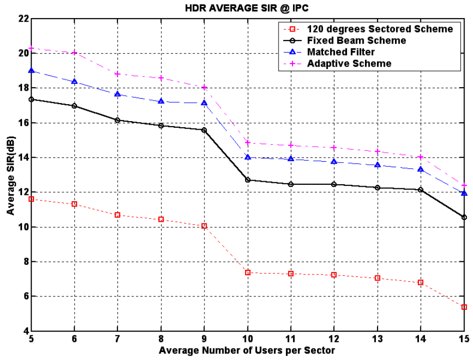
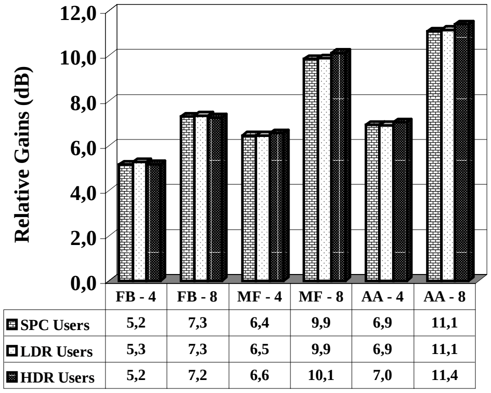


Figure 10: Average SIR for HDR users in Urban Scenario

In the following we analyze the performance for the dense urban scenario (hot spot). The hot spot has a radius that is 1/10th of the sector radius and is positioned in the center of the sector.

There is an average SIR reduction of data users in the Dense Urban Scenario as compared with the Urban Scenario (fig. 12). The lower relative gain provided by smart antennas to data users is due to limited spatial resolution obtained by the 4 element array. This way, the relative performance of the three smart antenna strategies is similar and the spatial matched filter scheme shows almost the same performance of the fixed beam scheme (the latter is not shown in fig. 12).

On the other hand, when we analyze the performance of SPC users, which are not concentrated within the hot spot, the average SIR is almost unchanged when compared to the urban scenario, as show in fig. 13. For those users, smart antennas are extremely beneficial since the high-powered data rate interferers will be more easily nulled out due to their spatial concentration. The fully adaptive solution brings significant gains for voice users in this scenario.



	FB - 4	FB - 8	MF - 4	MF - 8	AA - 4	AA - 8
▩ SPC Users	5,2	7,3	6,4	9,9	6,9	11,1
☐ LDR Users	5,3	7,3	6,5	9,9	6,9	11,1
■ HDR Users	5,2	7,2	6,6	10,1	7,0	11,4

Figure 11: Relative SIR Gains for 15 users/sector in Urban Scenario for 4 and 8 antenna elements.

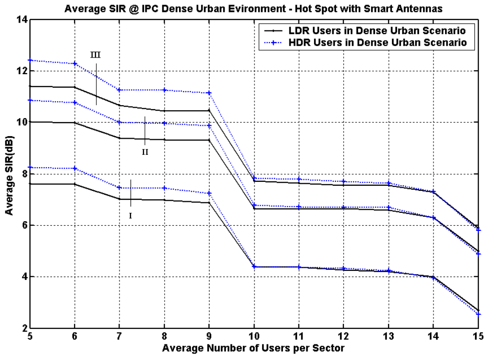


Figure 12: Average SIR in Dense Urban Scenario. (I): 120 degrees Sectored Scheme; (II) Spatial Matched Filter Scheme; (III) Adaptive Smart Antennas Scheme.

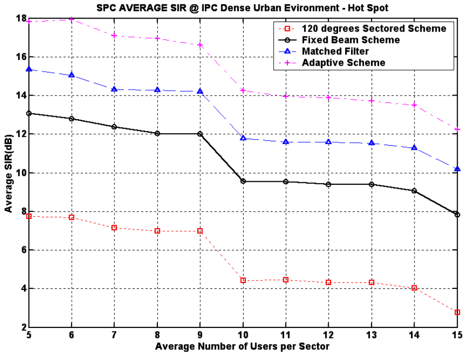


Figure 13: Average SIR for SPC users in Dense Urban Scenario

5. CONCLUSIONS

WCDMA system-level simulations have shown that the overall system performance and capacity can be increased using smart antennas. A comparison among three smart antennas architectures shows that the expected performance-complexity trade-off is verified. Gains on average SIR on the order of 4-7 dB with 4 element and 7-11 dB with 8 element arrays were verified relative to a conventional sectored system and depending on the complexity of each architecture.

Smart antennas can not only overcome but also revert the SIR degradation that occurs due to the introduction of high-data rate services therefore turning its combination with variable spreading gain a promising technique for multimedia services in WCDMA systems.

We also observed that in areas with dense concentration of data users, while the smart antenna techniques suffered from a reduced relative SIR gain for those users, the performance of the remaining users not present in that specific hot spot is greatly enhanced.

The continuation of this work includes the downlink evaluation as well as consideration of the multi-code alternative for achieving multiple bit rate services.

6. REFERENCES

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