Interference Management for WCDMA Systems Using SINR-Based Soft Handover and Smart Antennas

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***Abstract*— This contribution intends to analyze an hierarchical cell structure with a hot spot embedded in a WCDMA macrocellular system. Particular attention is paid to the impact of the introduction of smart antennas in this context. We propose a new approach to attain fair resource distribution in an hierarchical cell structure using a system-level simulation approach. We employ an enhanced SINR-based Soft Handover (SHO) algorithm to take proper decisions, intending suitable resource management between macrocell and microcell layers in order to guarantee predefined QoS requirements. The analysis is evaluated in the reverse direction and utilizes a modified selection combined SHO procedure to attain the performance gains. Smart antennas benefit of interference reduction is also addressed when users are interchanged between different cell layers.**

***Keywords*— WCDMA, Soft(er) Handover, Hierarchical Cell Structure, Smart Antennas.**

I. INTRODUCTION

IN 3G emerging systems, Radio Resource Management (RRM) techniques perform a remarkable expedient. These procedures dynamically tune the network performance and behavior towards desired values. RRM algorithms have a strong impact on the overall network capacity and Quality Of Service (QoS). Proper design of these techniques corresponds to a major challenge in mobile communications, since they play decisive role in system fulfillment determination.

In this article, an UMTS WCDMA-FDD radio network will be assessed in the reverse direction, focusing on hierarchical cell structures. We evaluate how the soft handover schemes and smart antennas alternatives impinge over the radio network fulfillment in order to keep the system SINR (Signal-to-Interference plus Noise Ratio) on the acceptable levels. This analysis is accomplished by means of a semi-static simulation tool implemented using C++ Object Oriented Programming language.

The adoption of RRM strategies is the natural way to provide an acceptable QoS and to maximize the system capacity in a 3G communication system. When considering WCDMA as the terrestrial radio access of the UMTS, the main limiting factor for system capacity is the interference, since all users share the whole spectrum at the same time. Since WCDMA systems presents soft capacity, the proper management of the interference issue by means of efficient radio resource management can provide better utilization of the air interface allowing maximization of system capacity. Any reduction in the interference can be translated into capacity gains. In an Hierarchical Cell Structure (HCS) where the spectrum is also shared between the macro and microcell layers, the interference management may provide remarkable improvements to the system. In particular we address the situation when a traffic hot spot is embedded in a macrocellular system.

The handover (HO) procedure is an essential feature in mobile communication systems. The hard handover is a break-before-make phenomenon, where a Mobile Station (MS) releases its connection with the previous Base Station (BS), before establishing a new connection with the new serving cell. In Soft(er) Handover (SHO) based systems, such as WCDMA, a MS maintains a seamless connection with each one of the BS inside its Active Set (AS), where each new link is set before releasing the old one.

The well-known benefit of SHO schemes is the macrodiversity gain, allowing fading margin improvement, so higher capacity in the reverse direction is achieved. HO schemes can also be utilized in order to shrink the coverage area of overloaded cells transferring the poor link users to less loaded surrounding cells.

Smart antenna is another enhanced feature applicable to 3G systems in which users can take advantage of its well-known interference reduction capability.

Our work is motivated by previous results attained in [1], where three main approaches were presented to deal with traffic hot spot areas: the placement of a microcell antenna near the hot spot area, the adoption of smart antennas at the macrocell site and the combined solution of these two alternatives. While the adoption of either a dedicated microcell or a smart antenna system generated capacity gains, the combined solution did not present the best overall results [1].

This paper proposes and evaluates an algorithm that tries to maximize the gain obtained by this combined solution. It aims to manage the SINR of the users initially connected to the microcell site by estimating the macrocell smart antenna gain.

The remainder of this contribution is organized as follows. Firstly, we describe the system model implemented in our

This work is supported by a grant from Ericsson of Brazil - Research Branch under ERBB/UFC.07 Technical Cooperation Contract.

simulation tool in Section II. In the following, Section III, the proposed RRM algorithm is described. Finally, we present performance results and draw some conclusions in Sections IV and V, respectively.

II. SIMULATION TOOL

The WCDMA simulator, which was developed using the C++ object-oriented programming language, focuses on semi-static multi-cellular system-level simulations of a WCDMA-FDD mobile communication radio access network in the reverse link. The simulator models a WCDMA system with multiple macrocells. Each cell site is composed of three hexagonal sectors. A microcell site is comprised of just one hexagonal sector covering the Hot Spot (HS) area. Two macrocell interferer layers are considered.

For system-level evaluation, the propagation channel follows a path loss/shadowing model where the received power is based on a vehicular test environment with a spatially correlated log-normal fluctuation [2]. Fast fading is assumed averaged out by means of diversity (spatial, Rake reception, etc.). The 2D correlated shadowing model used in this report is similar to that presented in [3]. In simulations, the reference system uses the typical sectored antenna radiation pattern, according to [2].

The system is assessed considering two distinct service classes: Speech Service (SPC) at 15 Kbps and High Data Rate (HDR) at 384 Kbps. The WCDMA system simulator main parameters are based on the UTRA-FDD standard specification with a 3.84 Mcps chip rate [4], [5].

The analysis considers sets of system configurations where the users may be active or not depending on the activity factor. This birth-and-death process is applied independently in each BS. The activity factors are 0.4 for SPC users and 0.7 for HDR users. The latter factor characterizes intense data transfer applications. We considered the target values of SINR for the service classes as SINR = 5.1dB for SPC users and 0.9dB for HDR users, according to [6]. These are typical values used in performance measurement of static Additive White Gaussian Noise (AWGN) environments.

The simulation scenario comprises 70% of SPC users and 30% of HDR users uniformly located over the entire system. In this approach, we focus on the specific case of an hierarchical cell structure with a Hot Spot embedded in it. The microcell user density is 100-fold the macrocell one, although the same number of users is placed over each sector area. The system performance is assessed by means of SINR distribution of the users located inside the target sector of the central BS, which embraces the Hot Spot area.

III. RADIO RESOURCE MANAGEMENT

A. Power Control Algorithms

The Full Gain Compensation (FGC) PC algorithm is evaluated in this work. In the uplink, power control techniques aim to achieve efficient MS power setting.

The FGC PC scheme is a distributed signal strength based power control algorithm. It depends only on the corresponding radio link channel manifestations such as path loss and shadowing between the MS and its serving base station. The MS transmission power is updated in order to compensate the propagation losses and guarantee the required level of the correspondent user service class at the base station receiver front-end. The FGC PC algorithm is based on the Open Loop Power Control algorithm, which is described in [4]. After FGC employment and considering the reference antenna gain, the transmitted signal power of the ith MS fitted in the kth service class and connected to the jth base station can be expressed as in Eq. 1.

$$P_{T_{i,j,k}} = \frac{P_{\mathrm{Req}_{j,k}} \cdot r_{i,j}^{n}}{10^{\left(X_{\sigma_{i,j}}/10\right)} \cdot G_{REF_{i,j}}(\theta_{i,j})} 10^{\left(X_{IPC}/10\right)} \quad (1)$$

where $P_{\mathrm{Req}_{j,k}}$ is the jth base station received signal power required by the kth service class; $G_{REF_{i,j}}(\theta_{i,j})$ is the antenna gain of the ith UE with respect to the jth base station for its $\theta_{i,j}$ direction of arrival (DOA); $r_{i,j}$ is the jth base station to ith UE separation distance and $r_{i,j}^{n}$ represents the path loss effects; n is the path loss exponent; X_{IPC} and $X_{\sigma_{i,j}}$ are zero-mean Gaussian distributed random variables with standard deviations σ_{IPC} and σ_{dB}, respectively; the former models imperfect power control, while the latter describes the shadowing effects for the i,j path.

B. Smart Antenna Algorithms

Smart antenna architectures are employed to combat multiple access interference from intra-cell 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) and employ Wiener's optimum linear solution to determine the array weights [7].

In the following, we review the two smart antenna strategies considered in this work. An overview about smart antennas and their application in wireless systems may be found, for instance, in [8], [9].

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 an array of narrower multiple beams in pre-established positions inward each cell site sector for the reference-sectored antenna. 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 Direction of Arrival while null out interfering DOAs.

C. SINR Soft(er) Handover (SSHO) Algorithm

The main objective of this algorithm is to manage the system resources in such a way that minimal complexity is added to network without demanding additional hardware resources, supposing that the smart antennas and the microcell site are already installed. The possible benefits are that the users may have a better link quality or even the system may increase its capacity.

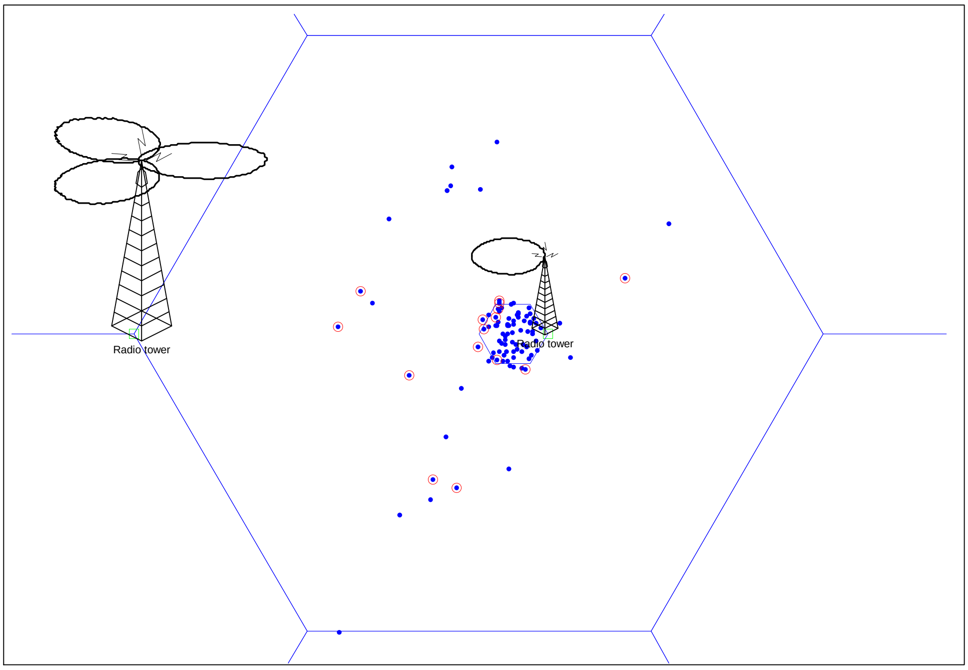

Fig. 1. Illustration of the Reassignment Procedure for the Privileged Users .

The transmission power of each user is based on the FGC PC, in that the transmission power intends to compensate for the path gain (shadowing and path loss). In a conventional approach, the cell assignment is made based on the minimum calculated transmission power.

Using the proposed algorithm, the link between the users that are initially connected to the microcell, have their SINR calculated relative to the central macrocell site. The real decision mechanism of the connection is the SINR value, as long as it provides a better link quality. It can result in a better performance because the path gain difference of the supposed microcell users can be compensated by the smart antenna gain.

Fig. 1 gives a qualitative idea of the reassignment achieved by the proposed algorithm. On the one hand, the points indicate those users initially connected to the microcell site. On the other hand, the circles point out those users reassigned to the macrocell site, according to the algorithm decisions.

Our proposal intends a better utilization of network resources, namely, the proper interchanging of load between macrocell and microcell antenna (two different layers sharing the same carrier band). In our previous work [1] we have evaluated the performance of several smart antennas algorithms in order to maximize the proper utilization of network resources intending better performance results.

In this way, a 3G intrinsic functionality can be used in order to provide the desired output. We consider the selection combining SHO alternative, where the decision criterion is based on the SINR exhibited by a given user. Then, even if a mobile station presents a lower path gain to a specific base station, the BS with better link quality (in terms of SINR values) will be selected. This procedure is applicable between the central macro and microcell antennas only (where we get all of our performance measures).

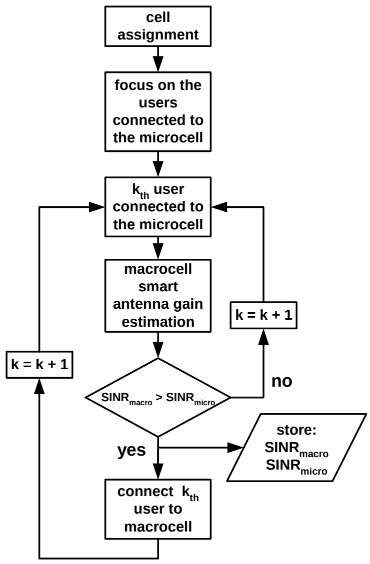

Fig. 2. SINR Soft(er) Handover Flowchart.

Indeed, the SHO algorithm is easily implemented, as can be seen from Fig. 2. Firstly, the SINR of microcell users is calculated. Secondly, a rough estimation of the probable SINR is attained, when the link of the same user is now estimated considering the macrocell antenna. It must be clear that through this estimative all benefits of a new connection are taken into consideration (i.e. the profit of interference reduction achieved by smart antennas). It is worth to notice that the pre-established transmitted power is kept in the same value. This procedure is intended to privilege those microcell users poorly served and probably in outage situation, which are eventually compromizing the overall system performance.

IV. PERFORMANCE RESULTS

The simulation parameters are summarized in the table I.

TABLE I
SIMULATION PARAMETERS.

PARAMETERS	VALUE
Radio access	WCDMA – FDD
Chip rate	3.84 Mcps
Frequency band	5 MHz
Deployment model	HCS: tri-sectored cells with hexagonal sectors
2D correlated shadowing model	Mean: 0 dB Standard deviation: 10 dB, Decorrelation distance: 50 m
Maximum transmission power per mobile station	24 dBm
Traffic class activity factor	SPC: 40% HDR: 70%
User bit rates	SPC: 15kbps HDR: 384kbps
Eb/No required	SPC: 5.1 dB HDR: 0.9 dB
Number of antennas elements	4 elements in a linear array
Beamforming technology	Switched fixed beams and adaptive antennas

The simulation aims to assess the HCS structure fulfillment, while subject to different methods to increase capacity. The work was evaluated aiming coherent load distribution between macrocellular and microcellular layers, in order to take advantage of adequate network resource assignment, guaranteeing the pre-established QoS requirements. The system improvement will be assessed in terms of SINR curves. These performance quantities will be shown utilizing CDF and 10th percentile plots in order to aggregate results and facilitate the system analysis.

Figs. 3 and 4 draw the SINR CDF of the privileged SPC and HDR users (users that were reassigned to the macrocell) in the simulated HCS scenarios before and after the employment of the SSHO-SA proposed algorithm, respectively. The results depict the gains achieved with FB and AA smart antennas alternatives. It is clear the beneficial impact of the SSHO-SA procedure over the system. Those users poorly covered by microcell antennas are reassigned to the macrocell antenna and perceive less interference due to the interference cancellation achieved by smart antennas installed at the central macrocell site. The more enhanced the smart antenna scheme utilized,

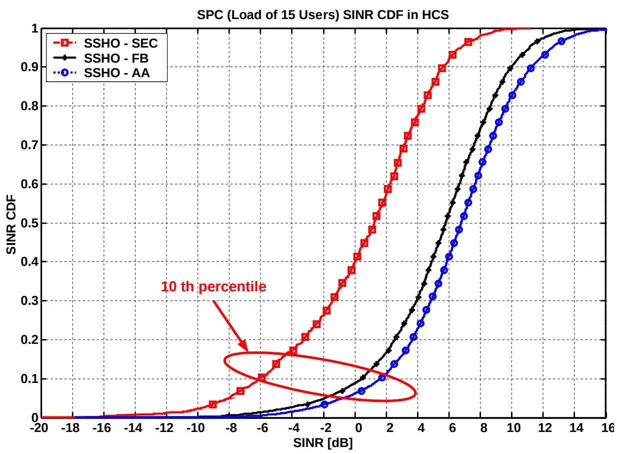

Fig. 3. Privileged SPC SINR CDF in Hierarchical Cell Structure with Smart Antenna considering a load of 15 users/sector.

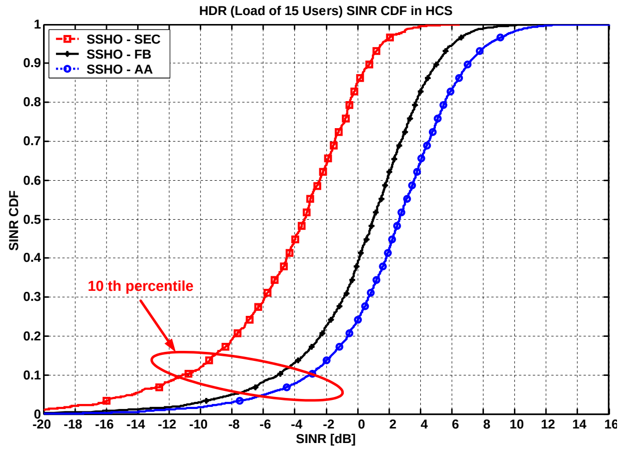

Fig. 4. Privileged HDR SINR CDF in Hierarchical Cell Structure with Smart Antenna considering a load of 15 users/sector.

the higher the gains achieved. It is worth to notice that users eventually in outage before utilization of the SSHO-SA procedure, are able to satisfy their QoS requirements (SINR target) after SSHO-SA employment.

The performance results presented by SPC users resembles that ones presented by HDR. Hereafter, only HDR users output results will be appraised.

Fig. 5 intends to show the system behavior of HDR users concerning different traffic loads in the whole system. The relative performance shown at lower loads remains practically unchanged at higher loads, confirming the robustness of the proposed algorithm. This figure is depicted gathering together the microcell users and macrocell ones. It presents the overall system fulfillment certificating the advantage of using the SSHO-SA procedure beneficiating not only the privileged users but also to the complete network. The microcell users are not directly benefited by the interference reduction of the macrocell smart antenna. Since the whole user population inside the target sector is considered in this analysis, the gain is diminished when compered to fig. 4. However, the advantage of using the proposed algorithm can be still perceived.

The percentage of the privileged users, which are reassigned after execution of the proposed SSHO-SA algorithm, relative to the total number of microcell users (for different loads) can be seen from table II.

TABLE II
PERCENTAGE OF PRIVILEGED USERS.

PRIVILEGED MICROCELL USERS			
Load (Users/sector)	Percentage (%)		
	Sectored Antennas	Switched Fixed Beams	Adaptive Antennas
5	2.36	11.63	15.32
15	8.34	23.93	31.74
25	12.86	29.75	37.89

V. CONCLUSIONS

The use of the proposed algorithm, in which privileged microcell users are switched to the macrocell in order to take

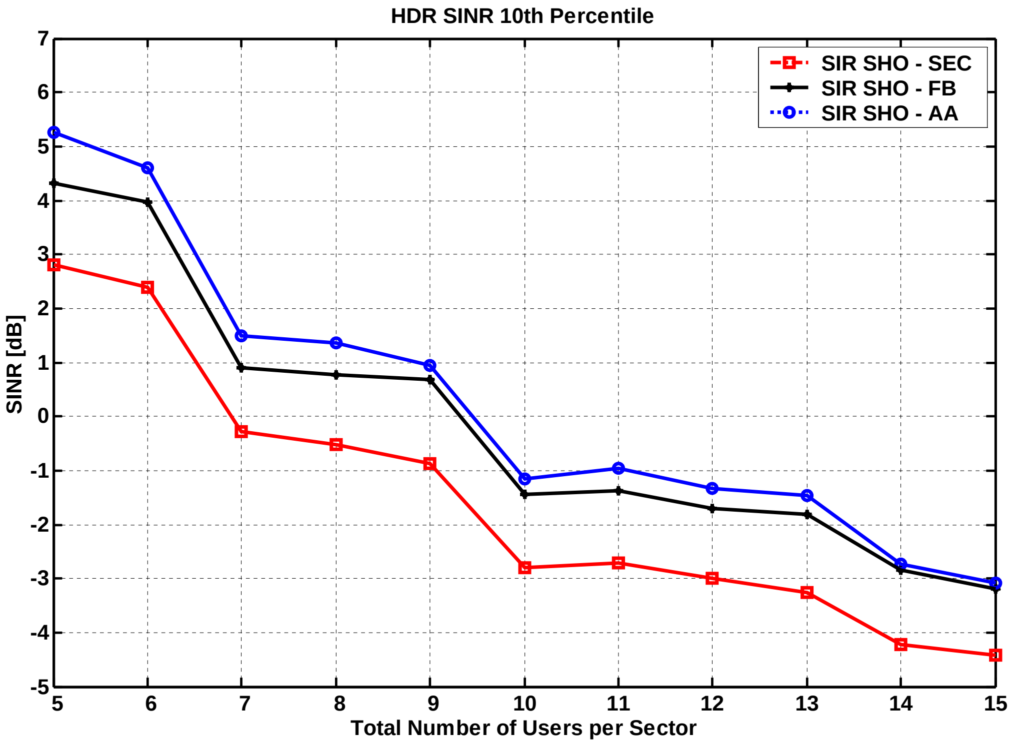

Fig. 5. HDR SINR 10th percentile in Hierarchical Cell Structure with Smart Antenna considering a load of 5 up to 15 users/sector.

advantage of the smart antenna gain, results in remarkable gains to the privileged users (microcell users poorly covered), since they have their link quality substantially improved by the smart antennas. In the uplink approach, there is no harmful impact to another users. Although there is a change of connection (serving cell), the reallocated users continue to transmit with the same power, keeping the same interference profile in the system.

The combined use of smart antennas together with the SINR-based SHO scheme in the HCS structure allows system improvement. The overall network presents better SINR values after SSHO-SA algorithm utilization. Indeed, some microcell users affected by the employment of the algorithm avoid an outage situation satisfying their QoS requirements (meeting their SINR target).

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