Coverage and Capacity of WCDMA Systems with Beam Steering Antennas

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Abstract— **The goal of this contribution is to discuss the benefits of beam steering antennas on Downlink Dedicated Channels (DCHs) of the WCDMA-FDD system regarding coverage and capacity aspects. Our studies are based on a software tool ($WIDE_{SIM}$ - WCDMA Downlink Dynamic System Level Simulator), which performs slot-based dynamic simulations of the WCDMA radio access network on the forward link direction. Multicell environment and user mobility are taken into account, aiming a combined evaluation of Radio Resource Management (RRM) and smart antenna strategies. The RRM algorithms implemented in the simulator are: power-based Call Admission Control, Power Allocation, Power Control (open loop and inner loop) and Soft(er) Handover.**

I. INTRODUCTION

The population of wireless communications consumers is growing worldwide. Mobile communications players are starting to provide voice and multimedia service successfully and, as the number of mobile subscribers continues to grow, coverage and capacity problems are arising due to the limited available frequency spectrum. Consequently, methods of enhancing existing and future cellular networks must be studied and implemented.

In WCDMA systems, the main limiting factor is the interference, since users share the same spectrum simultaneously. In this context, the soft capacity can be enhanced by means of interference reduction strategies such as Smart Antennas (SA) and efficient Radio Resource Management (RRM) algorithms.

Nowadays, smart antennas have been deployed in some high capacity wireless networks. This antenna technology is an alternative to increase system coverage (rural areas) and capacity (dense urban areas) without cellular re-planning. Furthermore, smart antennas play a key role in WCDMA systems because they allow Multiple Access Interference (MAI) cancellation. Besides inherent interference reduction capability, smart antennas enable operators to manage and distribute traffic loading more effectively, becoming a promising solution to cope with the increased data traffic flow and the presence of hot spots.

The importance of Radio Resource Management (RRM) grows strongly as mobile communications evolve into next generation cellular networks. More efficient utilization of the radio spectrum plays such an important role because spectrum is simultaneously a very scarce and widely shared resource. In the forward direction of WCDMA systems, another limiting factor is the base station power which is a limited physical resource. In this context, an efficient power allocation and management can be translated in capacity improvements, as long as it can provide interference reduction and base station power consumption optimization.

In this article, an UMTS WCDMA-FDD radio network is assessed in the forward direction, focusing on the fact that the mutualism between RRM algorithms and smart antennas can substantially increase the coverage and capacity of 3G systems.

The remainder of this paper is organized as follows. Firstly, we describe the simulation models and assumptions of this study presenting the $WIDE_{SIM}$ simulation tool. Afterwards, the RRM techniques considered are presented as well as the proposed advanced antenna strategy. In the following, we present performance results and, finally, we draw some conclusions and further research perspectives.

II. SIMULATION TOOL - $WIDE_{SIM}$

In order to perform a complete dynamic system level evaluation of the UMTS WCDMA-FDD system, a simulation tool named $WIDE_{SIM}$ (WCDMA Downlink Dynamic System Level Simulator) was projected. This simulator, which was implemented using C++ object oriented programming language, was used to analyze the proposed algorithms to enhance system coverage and capacity considering dedicated channels in the forward link direction.

A. Radio Network Modelling

The macrocell grid is composed of 16 cell sites, each composed of three hexagonal sectors with radius equal to 1.5 Km. In order to make sure that border effects on interference calculations are avoided, a wraparound technique was used.

Our radio channel modelling is strongly based on 3GPP recommendations [1]. The $WIDE_{SIM}$ dynamic simulator models the three following channel manifestations: Path Loss, Slow Fading (shadowing) and Fast Fading.

Different descriptive equations are provided for path loss calculation as a function of distance. Our deployment model is characterized by large cells and high transmit power, in

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accordance with [1]. The path loss equation considered in the simulations is depicted in Eq. 1.

$$L = 128.1 + 37.6\log(R) \qquad [dB] \tag{1}$$

where R is the mobile to base station separation distance.

A 2D Gaussian distributed distance correlated shadowing is utilized following [2]. A tapped-delay line model is employed to model the multipath fading characteristics of the envelope of the channel. This model is specified by an amount of taps, delays relative to the first tap and correspondent attenuations relative to the average power of the strongest tap.

B. User Behavior Modelling

$WIDE_{SIM}$ is capable of assessing the 3rd generation WCDMA-FDD network for conversational and interactive service classes. We chose these service classes to represent both the classical voice service (Real Time - RT) and the WWW browsing service (Non-Real Time - NRT). However, only conversational users are considered in this article.

Call (voice) or session (WWW) requisitions are generated according to a Poisson process with arrival rate of λ. Regarding the conversational service class, the rate λ of a Poisson process is related to the offered traffic load, representing the average number of calls per time unit.

The traffic model for RT services is based on [3, 4]. We model an ON-OFF traffic pattern, with activity and silent periods being generated by an exponential distribution. The traffic model parameters are the mean value for call holding time (mean call duration = 120s), active (1s) and silence periods (1s).

A typical WWW browsing session, which consists of an application-based sequence of packet calls, is used for the interactive traffic modelling. During a packet call, several packets may be generated. In our model, a session represents the whole interactive user life. The WWW browsing traffic model used in the simulator was based on [1].

In the RLC/MAC modelling, each arriving packet is segmented into RLC blocks prior to transmission. Packet segmentation is modelled in accordance with the 3GPP standard [5], where we use the SDU fixed size paradigm. Interleaving is performed over a TTI. By means of link-to-system level mapping and random experiments, it is decided how many blocks are erroneously received. These corrupted blocks must be retransmitted using an Automatic Repeat Request (ARQ) protocol.

C. Mobility Models

Although both pedestrian and vehicular mobility classes are modelled in $WIDE_{SIM}$, only pedestrian users will be assessed in this paper. The mobility model consider that user speed is constant throughout the simulation, and also that it moves the same distance in each time slot. The decorrelation distance defines the point at which the user can change its direction.

The mobility model is the Brownian model [6]. It is assumed that the speed follows a truncated normal distribution with a mean of 3 km/h and a specific standard deviation, whose default value is 2 Km/h. In this case, the maximum and minimum speed values are 3 ± 2 km/h. The model is characterized by the following parameters:

- Mean speed value: 3 km/h
- Direction angle distribution: uniform over [0, 2π)
- Decorrelation distance: 5 m (time interval = 6s = 600 frames)

III. RADIO RESOURCE MANAGEMENT TECHNIQUES

In the forward link direction, where we concentrate our analysis, three functionalities are employed in order to achieve a suitable user Quality of Service (QoS) while maintaining an efficient system utilization: Call Admission Control/Power Allocation, Power Control and Site Selection Diversity Transmit. These functionalities take into account that the base station have limited transmission power. A specified percentage of this maximum power is reserved for the Primary Common Pilot Channel (P-CPICH), which plays a decisive role on the Open Loop Power Control and SHO algorithms. The RRM algorithms analyzed in this article are described in the next sub-sections.

A. Call Admission Control and Power Allocation

Our Call Admission Control handles all new incoming traffic. It checks whether a new voice or data connection can be admitted to the system based on base station power measurements. In WCDMA systems, it is essential to keep the transmission powers at a minimum level while ensuring adequate signal quality at the receiving end. Thus, the Power Allocation algorithm manages all power updates, accepting or rejecting a new power increase requisition from the Power Control algorithm and a base station adding/replacement in the user Active Set (AS) recommended by the SHO algorithm.

The CAC algorithm is essential in CDMA-based systems. The study of its interaction with other RRM algorithms is of utmost importance. Figures of merit such as call blocking, dropping and outage probability are directly dependent on the CAC performance.

When the user tries to initiate a call with the selected base station, this BS tries to use the initial power set by the Open Loop Power Control. If this initial power cannot be allocated and the BS has some power to offer, this difference is assigned to the mobile. If the current total traffic transmission power has already reached its maximum value, the user will be blocked. This strategy aims to maximize the utilization of the BS transmission power.

We consider that a mobile station is in outage when it stays with its SINR lower than 50% of the target SINR for more than 5 seconds. This outage situation characterizes a call dropping event.

B. Power Control

In a WCDMA system with users sharing the same frequency bandwidth and using the same base station limited-power, multiple access interference and power management are

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critical issues. In such systems, the performance of each user becomes poorer as the number of simultaneous users increases. Thus, power control is an essential technique to manage each user's interference to the communications links of the others.

Two power control functions are employed in order to achieve a suitable user transmit power: Open Loop Power control and Inner Loop (Fast Closed Loop) Power Control.

In the Open Loop Power Control procedure, the mobile estimates the propagation loss to the cells by means of a link quality measurement, which is the P-CPICH E_c/I_0, and reports it to the Radio Network Controller (RNC). We use a formulation presented in [7] which estimates the transmitted power considering the user QoS requirements.

The Inner Loop Power Control algorithm dynamically sets the power of the downlink DPCH (Dedicated Physical Channel). The UMTS Terrestrial Radio Access Network (UTRAN) adjusts the downlink traffic channel power accordingly, based on the received TPC (Transmit Power Control) commands. In each update interval (each slot) a SINR estimate is compared with a target SINR. If the estimate is greater than the target, the mobile station transmits the TPC command 'down' to the base station; otherwise the UE transmits the TPC command 'up' [8]. This algorithm is the basic UP/DOWN power control specified in 3GPPP standard [9]. We assume discrete power control steps of 1dB.

C. Soft(er) Handover

The Soft(er) Handover (SHO) implementation in $WIDE_{SIM}$ follows the UMTS proposal [10]. SHO allows easy provision of macro-diversity, since the same frequency band is shared among adjacent cell sites. However, one must also pay attention on the trade-off between macro-diversity and extra interference generated by the SHO branches on the forward direction link. In this way, Site Selection Diversity Transmit (SSDT) is utilized in this study, aiming to reduce the downlink interference among active users in the considered base stations. Using this strategy, only the best base station transmits to the mobile station during SHO. The primary BS in the active set transmits both Dedicated Physical Channel (DPDCH) and Dedicated Physical Control Channel (DPCCH), while the others SHO branches deactivate their DPDCHs.

The reporting events are the basic input of the SHO algorithm and the measurement quantity (triggering condition) considered is the P-CPICH E_c/I_0. This quantity is continuously monitored and furnish data to the events triggering [11]. We have utilized an admission control strategy intending to avoid overloaded situations by means of denying or admitting a new AS branch to a specific user. Thus, the CAC algorithm is intrinsically related to the SHO procedure. In this way, it is expected that the overall system QoS requirements are preserved by means of proper setting of thresholds before acceptance or refusal of a new connection. The admission control decisions is based on base station transmitted power [7, 12].

IV. STEERING BEAM ANTENNAS

A. Conception and Benefits

Smart antenna systems have received great attention over the last decade in terms of research and field trials to improve the performance of wireless mobile communication networks (see [13-16]). Basically, a smart antenna system combines multiple antenna elements with a signal-processing capability to optimize its radiation and/or reception pattern automatically in response to the signal environment.

Smart antenna architectures are employed to combat Multiple Access Interference (MAI) from intra- and inter-cell mobiles in WCDMA systems. This technology allows system coverage and/or capacity enhancement [15].

Fig. 1 shows that the coverage is more load-dependent on the downlink than the uplink. This happens because the total base station power is shared between the downlink users, while in uplink each additional user has its own power amplifier.

Although coverage and capacity are inherently coupled, if we improve one of them does not always mean that the other will be degraded. If a coverage enhancement technique is considered in the radio network planning phase, it is possible that both coverage and capacity improve simultaneously or that one improves with no effect upon the other. Fig. 1 draws the influence of the smart antenna technology in the system coverage/capacity curves. Smart antennas provide an E_b/N_0 gain to the user due to interference reduction. In this figure, we consider a theoretical gain proportional to the number of antenna array elements (Gain = 10.log(4) = 6.02 dB) [15].

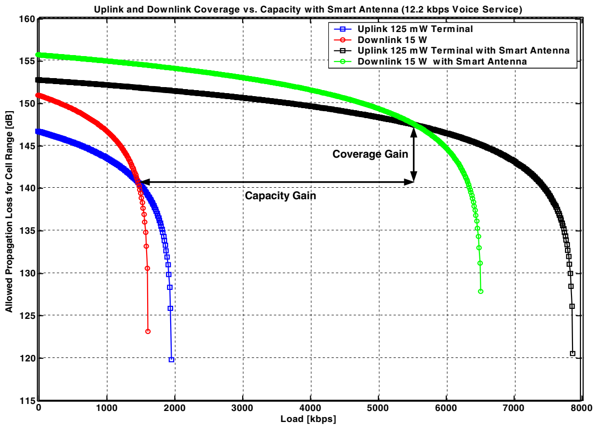

Fig. 1. Illustration of the Influence of the Smart Antenna Employment in the Uplink and Downlink Coverage and Capacity Curves (4 antenna elements).

B. $WIDE_{SIM}$ Modelling

The smart antenna strategy that is used in the $WIDE_{SIM}$ simulation tool is the spatial matched filter technique, due to its beam steering characteristic. Spatial matched filter steers a beam toward the desired user, according to its direction of arrival (DOA), regardless of the position of interfering users. Smart Antennas processing on forward link is a pre-processing procedure, i.e., the power transmitted by base station is affected by antenna array pattern prior to transmission and all system interference are reduced. This fact significantly impacts on the simulation modelling, because it is too hard to compute interference in this scenario.

Furthermore, smart antenna performance is closely related to the azimuth spread of the multipath propagation channel. Thus, we consider a smart antenna model that takes into account a Laplacian Power Azimuth Spectrum. This model includes impact of the RMS delay spread of the power delay profile, which is a stochastic quantity strongly correlated with the shadow fading component [17]. Additionally, we apply a non-uniform window function to suppress the sidelobes of the generated antenna array pattern at the expense of a broader mainlobe and a reduced gain [17].

V. PERFORMANCE RESULTS

In this section, we focus on capacity results for conversational users varying the offered traffic load. Results consist in CDF of the downlink base station transmission power, blocking and dropping probabilities and CDF of SINR and FEP per user. The results presented below have been obtained using a slot-based dynamic simulation of the pedestrian users following the mobility model explained in section II-C. The basic idea in these analysis is to verify the impact of interference increase on the performance metrics and emphasize expected benefits of the use of steering beam antennas in such system configurations. Table I summarizes the system parameters used in our investigation.

TABLE I

SIMULATION PARAMETERS.

Number of Tiers of Interfering Cells (wraparound)	1 layer
Chip Rate	3.84 Mcps
Conversational Data Rate	12.2 Kbps
Voice Radio Frame	20 ms
Minimum Required Downlink SINR	6.5 dB
FEP Target	1%
Sector Radius	1.2 km
Shadowing Standard Deviation (σ_{dB})	8 dB
Inter BS shadow correlation (ρ)	0.5
Shadowing de-Correlation Distance (d_{dec})	50 m
Total Base Station Power	20 W
Percentage of power for Common and Pilot Channels	25%
Power Control Step Size	1 dB
Power Control Error	0.5%
Active Set Length	3
Number of RAKE Fingers	3

Fig. 2 depicts the Cumulative Distribution Function (CDF) of the total traffic transmission power of the base stations for different offered loads. One can notice that the higher the offered load, and consequently the interference, the higher the utilization of the BS downlink power. As expected, the Call Admission Control and Power Allocation algorithms succeeded in maximizing the utilization of the BS transmission power. As a result, a higher number of users is admitted in the system and the interference level increases, yielding a low blocking probability and a high dropping probability. This fact can be seen in Figs. 3 and 4.

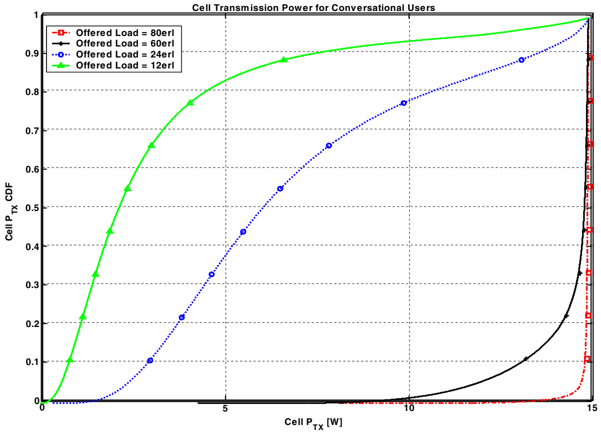

Fig. 2. Base Station Downlink Transmission Power.

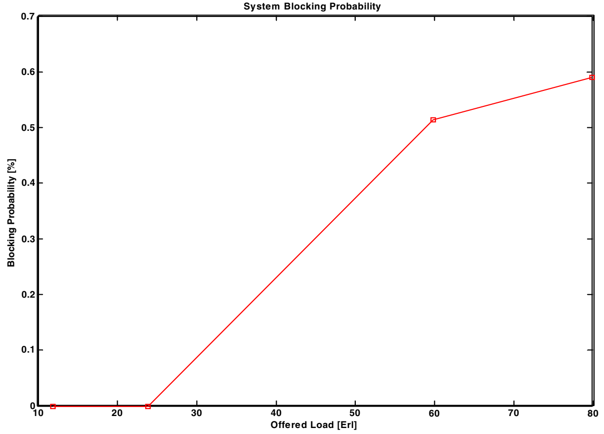

Fig. 3. System Blocking Probability.

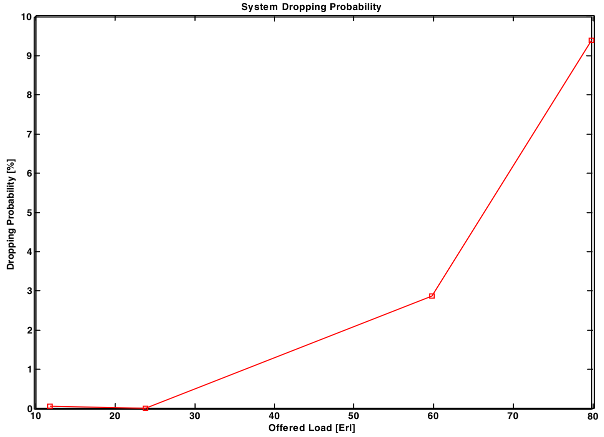

Fig. 4. System Dropping Probability.

Fig. 5 depicts the achieved SINR CDF for different offered loads considered in the voice traffic scenario. The slope of the curves can be seen as an indicative of the proper execution of the power control algorithm, as the great part of the captured SINR values stays around the target value. The small fluctuations arise from the fixed adjustment of the transmit power as a function of the power control step size suggested by the standard. Another expected result, which is evidenced by the curves, is the degradation of the system performance following the increment of the offered load.

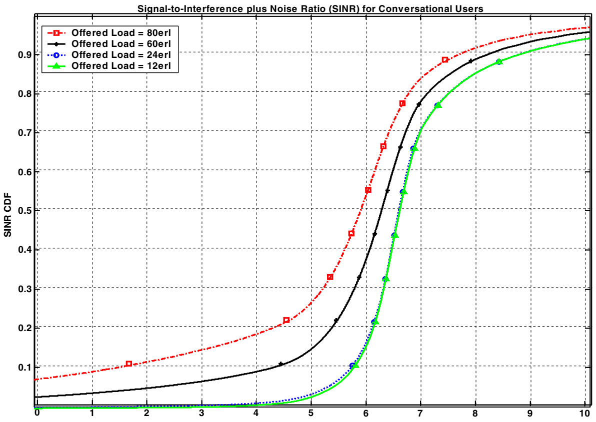

Fig. 5. Signal to Interference plus Noise Ratio (SINR).

Fig. 6 aims to present system performance, in terms of Frame Erasure Probability (FEP) values, take into consideration distinct offered loads. In order to evaluate conversational service class performance, the average SINR per TTI is mapped into a FEP by means of link-to-system level curves every voice frame period of 20ms. In this way as can one expect the FEP values follows the SINR CDF behavior, namely, higher loads (corresponds to lower inter-arrival time among calls) impinges negatively over the system resulting in worse performance, fact which is expressed by higher FEP values.

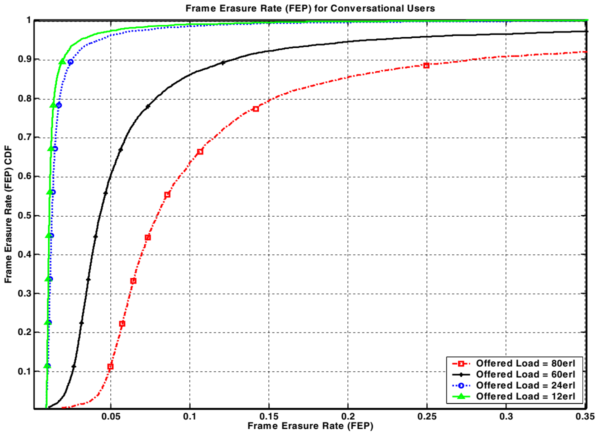

Fig. 6. Frame Erasure Probability (FEP) for Conversational Service Class.

VI. PERSPECTIVES AND FURTHER INVESTIGATIONS

This contribution intended to assess coverage and capacity aspects of a WCDMA system considering downlink dedicated channels and indicate expected benefits of the employment of beam steering antennas. It was suggested that not only could advanced antenna systems be used to decrease the dropping probability of systems with high utilization of the base stations' transmission power but they could bring the SINR 10th percentile and FEP 90th percentile for high offered loads to acceptable levels as well.

Further investigations will englobe more detailed analysis of the dynamic influence of smart antennas on a mixed scenario with conversational and interactive service classes.

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