System-level simulation results of UMTS networks with smart antennas

RAMÓN MARTÍNEZ-RODRÍGUEZ-OSORIO, LEANDRO DE-HARO-ARIET
Dpt. Señales, Sistemas y Radiocomunicaciones.
Universidad Politécnica de Madrid
ETSI de Telecomunicación. Ciudad Universitaria s/n. 28040 Madrid
SPAIN

Abstract - In the near future, an enormous increase in traffic will be experienced in mobile communication networks due to the introduction of new high bit rate data and multimedia services. Smart antenna systems are recognized as one of the most promising technologies for allocating the capacity demand when employed instead of conventional sector antennas. Network operators need to estimate the actual performance gain that can be achieved with a smart antenna system. This paper presents a technique to introduce smart adaptive antenna schemes in system level simulations based on the statistical performance gain computed in link-level simulations. Results in a typical deployment scenario quantify throughput increases with smart antennas of up to 87 % over conventional sector antennas.

Key-Words: - Beamforming; digital cellular systems; network planning; smart antennas; wideband code division multiple access (WCDMA).

1 Introduction

Third-generation (3G) mobile communications systems offer higher data rate services and quality of service performance than second-generation systems (2G) [1]. In contrast to 2G systems, 3G networks will be characterized by a multiservice environment that will have an impact not only on the access technology but also on the provision of services according to the customers expectations [2]. The demand of these new services over the following years is expected to increase significantly thanks to the worldwide penetration level of mobile telephony. Therefore, network operators will need to find and implement advanced technical solutions to allocate the excess system capacity and increase the spectrum efficiency of wireless cellular networks in the near future.

Smart antennas are to be one of the emerging technologies that will contribute to enhance the capacity of new 3G mobile communications systems. Unlike conventional sector antennas, smart antennas operating as beamformers act as spatial filters that can separate spectrally and temporally overlapping signals from multiple mobile units located in different angular positions [3]. Operational benefits that can be achieved with the deployment of smart antennas in cellular networks can be summarized as follows: coverage extension, increased capacity, reduced transmit power, support of value added-services, more efficient power control, smart system planning, link budget balancing and handover [4].

In the particular case of code division multiple access (CDMA) systems, all subscribers transmit simultaneously within the same wideband radio channel, so that the amount of co-channel interference is significantly increased. Thanks to their interference cancellation properties, smart antennas are specially suited to increase the spectrum efficiency of interference limited systems, such as wideband CDMA (WCDMA).

Despite the advantages achieved in terms of coverage extension and capacity increase, the deployment of smart antenna systems is not a reality. During the last decades, smart antennas have been widely studied from a signal processing perspective, and a number of beamforming algorithms, channel estimation techniques and receiver structures have been proposed [5]. The performance achieved with a smart antenna system is usually obtained through extensive link-level simulations that test the proposed beamforming algorithm in canonical scenarios that rarely appear in practical cellular deployments. These link level results, which should be analyzed statistically, are usually averaged so that the actual performance is misleading.

Nevertheless, smart antennas have an impact not only on the receiver structure and algorithms, but also on the system level aspects, such as network planning (analysis of coverage, capacity and interference) and radio network management (power control, handover, call admission control) [6]. To the best authors' knowledge, the integration and impact of smart antenna technology on existing and future cellular networks have not been covered up to now. This is in part because the introduction of smart antenna schemes in a system level simulator is not an easy task.

The main difficulty that appears to introduce a smart antenna scheme in a system level simulator is that, in contrast to conventional sector antennas, the radiation pattern is not known a priori. Moreover, it depends on a number of variables: beamforming algorithm, spatial user distribution, demanded service and features of the propagation channel. Therefore, the calculation of performance gain in terms of the signal-to-interference plus noise ratio (SINR) is not straightforward in the system level.

Traditionally, the introduction of smart antennas in the system level simulation is based on untrue hypothesis, especially incorrect in the case of adaptive antennas. In [7], the smart antenna pattern is approximated with a stepped function, without taking into account the dynamic nature of the beamforming process. In [8] the antenna array pattern is approximated by a fixed pulse function and analytical results for the outage probability in a CDMA system are obtained with spatially white noise; this way, the performance achieved by an adaptive antenna system in a mixed service scenario is not evaluated. In other works, either smart antennas are modelled as spatial filters with fixed predefined antenna diagrams such as the flat-topped pattern of [9] or it is assumed that the gain provided by the smart antenna as compared to a sector antenna can be approximated by the number of elements of the antenna array [10]. Finally, it is worth mentioning that existing system level studies makes use of multibeam antennas [11], [12] or, in case adaptive antennas are included, the beamforming vector is assumed to be known a priori without any calculation [13].

In this contribution, we present the principles for developing a system level simulator including smart antennas to analyze the impact of spatial filtering on network aspects such as the capacity increase and the range extension. The proposed system-level simulation approach makes use of link level results, so that a link-to-system level interface is defined to avoid additional simplifications in the system level analysis. The interface definition that we propose takes into account the statistical performance gain achieved with the smart antenna system and the dynamic behaviour of the iterative beamforming process.

The contribution is organized as follows. Section II presents the link-to-system level interface that we propose to include link level simulation results in the system level. Section III shows both link and system level simulation results for different smart antenna schemes. Finally, the conclusions of the paper are drawn in section IV.

2 Definition of a Link-to-System Level Simulation Interface

The performance of a network scenario with many base stations is evaluated by means of a simulator which combines both link and system level aspects [14]. The complexity of such a single simulator (in terms of memory requirements and processing time) including both simulation levels from the transmitted waveforms and impulse responses of the propagation channel to the radio resource managements algorithms in the multitier network would be far too high. Either we should include some simplifying hypothesis in the simulation process or the simulation time along with the required hardware would be unaffordable.

As a solution, the use of separate link and system level simulators is preferred [15]. This approach reduces the complexity of a unique simulator while maintaining realistic system-level performance figures starting from link-level result, but an appropriate definition for the link-to-system interface is required to export link level results to the system level.

Link-level analysis follows a Monte Carlo simulation approach to study the performance of single radio links, including signal processing algorithms, such as channel estimation methods, demodulation techniques and beamforming algorithms. Therefore, detailed and accurate representations for the signal and the radio propagation channel are required. As the signal processing techniques operate on the samples of the signal, the temporal resolution of link level simulations is very high, with a sampling rate higher than the chip rate for CDMA systems. The number of users is kept below some limit given by the computational load of the simulation, and all of them are distributed within one sector. Intercell interference is modeled by Gaussian noise.

Link-level performance results are usually given in terms of the bit error rate and the frame error rate for a given transmitter and receiver structures and propagation environment. However, in order to study the performance obtained with smart antenna systems, SINR values are to be provided. Moreover, we take the SINR increase compared to a sector antenna (ΔSINR) as the key parameter to quantify the improvement achieved with a smart antenna.

On the other hand, system-level simulations aim at evaluating radio resource management procedures such as power control, handover, call admission and congestion control, packet scheduling, etc.. Therefore, the simulator does not require details of the transmission chain at the chip or bit level, but the simulated real time will be on the order of some tens of seconds. A complete system-level simulator should include a multi cell network deployment, different cell types (macro, micro or pico cells), traffic models, quality of service parameters, user mobility, etc. Typical system-level results are cell capacity, throughput per cell, cell loading, and best server maps. If smart antennas are included in the simulation, other parameters such as the range extension or transmit power reduction are also of interest.

From the above paragraphs, it is clear that separate link and system level simulations are required. The next step is then the definition of an appropriate interface between both simulation levels. The interface should define an adequate format to export the link-level information to the system-level simulator while maintaining the reliability of the radio link results.

Traditionally, the results obtained at link level are reported in the system level simulator in the form of look-up tables (LUTs). These tables relate a set of initial conditions (mean carrier-to-interference ratio level, channel coding parameters, terminal speed, cell type) with a quality metric (number of erroneous bits, block error rate). However, if smart antennas are included in the radio link simulations, other input parameters should be taken into account: beamforming algorithm, spatial distribution, service type, and any other variables having an impact on the performance provided by the smart antenna system.

In the context of adaptive antennas, the antenna pattern cannot be used to characterize the coverage or interference rejection performance due to the iterative nature of the beamforming techniques, which are based on the dynamic reconfiguration of the antenna diagram. Because of that, in our analysis we consider the ΔSINR information obtained via extensive link-level simulations as the most relevant parameter to characterize the performance of a smart antenna system.

On the other hand, average ΔSINR values are not enough to fully characterize the performance gain achieved with adaptive antennas as these results present a great variance which depends on a number of parameters: spatial user distribution, service profile and beamforming algorithm.

Therefore, the LUT must contain the complete statistical characterization of the ΔSINR gain. As the most appropriate format, we propose the use of cumulative distribution functions (CDFs) of the ΔSINR for each specific scenario, so that there will be a different CDF for each spatial user distribution, demanded service, and beamforming scheme.

The corresponding CDFs are used in the system simulator to generate the actual ΔSINR gains via the inverse transform method [16]. The procedure is applied for uplink and downlink. As shown in Fig. 1, we use the inverse transform method to the corresponding CDF to extract the ΔSINR gains to be used in the system simulator for transmit power calculations and interference analysis.

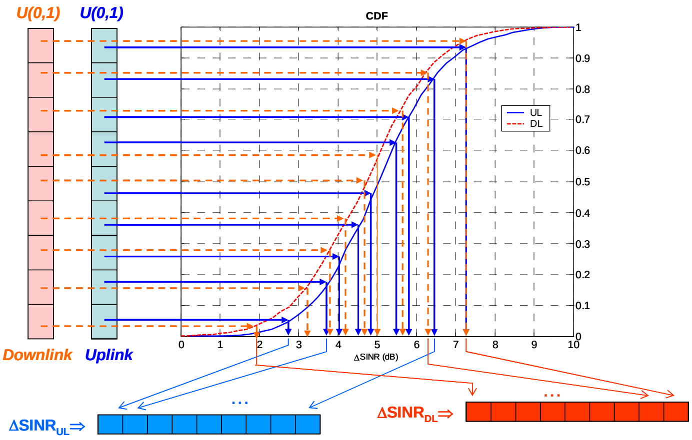


Figure 1. Use of look-up tables in the system level simulator based on the CDFs of the ΔSINR.

Consequently, the next three steps must be fulfilled to define the link-to-system level interface: 1) characterize and model the scenario (spatial user distribution, service profiles, spatio-temporal channel model) and beamforming algorithm; 2) execute extensive Monte Carlo link-level simulations to obtain the ΔSINR gain for every user in the scenario, and 3) compute the CDF for the ΔSINR for each algorithm and service profile pair in uplink and downlink directions.

3 Simulation Results

In this section, we present link and system level performance results based on the simulation technique described above. We consider a scenario with a mix of speech and data services, including low bit rate (LBR) and high bit rate (HBR) users. In the simulations, users are uniformly spatially distributed in the service area.

Monte Carlo link level simulations have been performed for a single 120º sector with 60 uniformly distributed pedestrian users (3 km/h). The percentages for the traffic classes are 50, 30 and 20 % of speech (12.2 kbit/s), LBR (64 kbit/s) and HBR (144 kbit/s) users, respectively, with corresponding spreading factors of 64, 16 and 8. Power is perfectly controlled by the base station. Each user transmits a 10 ms radio frame with a chip rate of 3.84 Mchip/s. Modulation and spreading processes have been modelled according to 3GPP specifications [17]. 100 trials with a duration of one 10 ms radio frame each have been made, with random spatial distributions. We consider a uniform linear array with four antenna elements, spaced half a wavelength in the UL frequency. Three smart antenna schemes have been studied:

- Switched-beam antenna (SWBA) with four fixed beams serving the 120º sector, where the beams cross at 4 dB points [18]; the active beam for each user is selected according to the maximum received power criterion;
- Adaptive beamforming based on the Minimum Mean Squared Error (MMSE) criterion; the Normalized Least Mean Square (NLMS) has been used to compute weights [19];
- Adaptive beamforming based on the maximum SNR criterion using the linearized power method (LPM) [20].

Adaptive antennas under the control of NLMS and LPM algorithms update beamforming weights each time a pilot bit is received, i.e. 10/150 ms, and the ΔSINR is computed on a slot-by-slot basis. Downlink (DL) weights are estimated from the uplink (UL) information under the hypothesis that the power azimuth spectrum in UL and DL are approximately identical for the frequency duplex distance of WCDMA [21]. Conventional sector antennas are modeled as having a -3 dB beamwidth of 65 degrees.

Multipath fading is modeled as having two paths with relative amplitudes and delays of [0, -10 dB] and [0, 976 ns], respectively (25.104 specification [17]). For pedestrian users (3 km/h), the maximum Doppler shift is 5.56 Hz at a carrier frequency of 2 GHz. According to empirical measurements, the azimuth spectrum in the base station antenna array is modeled as a Laplacian law, along with a Gaussian distribution for the directions of arrival around the mean angular position of the user [22]. The angular spread is taken to be 10º.

Table 1 shows the average ΔSINR for the different service profiles. Comparing the results of the algorithms under study, it is clear that NLMS and SWBA schemes outperform the LPM beamforming in this scenario. Moreover, DL results are slightly degraded as compared to UL due to the frequency separation in both links because of the frequency dependent antenna array response.

Figure 2 shows the CDF of the ΔSINR for speech and HBR users in UL. It is clear that NLMS and SWBA schemes outperform LPM algorithm. From the curves, it can be concluded that LPM results present a greater variance than NLMS and SWBA. Moreover, although the average ΔSINR is 1.44 dB for speech users using the LPM algorithm in UL, in 27 % of the situations its performance is inferior to that of a sector antenna. This fact means that the average ΔSINR is not enough to characterize the performance that can be obtained with an adaptive antenna.

Table 1. Average ΔSINR gains for NLMS, SWBA and LPM.

Service profile	Average ΔSINR (dB)					
	Uplink (UL)			Downlink (DL)		
	NLMS	SWBA	LPM	NLMS	SWBA	LPM
Speech	5.70	4.54	1.44	4.98	4.21	1.59
LBR	5.53	4.45	2.69	5.18	4.32	2.78
HBR	5.49	4.42	2.62	5.09	4.32	2.56

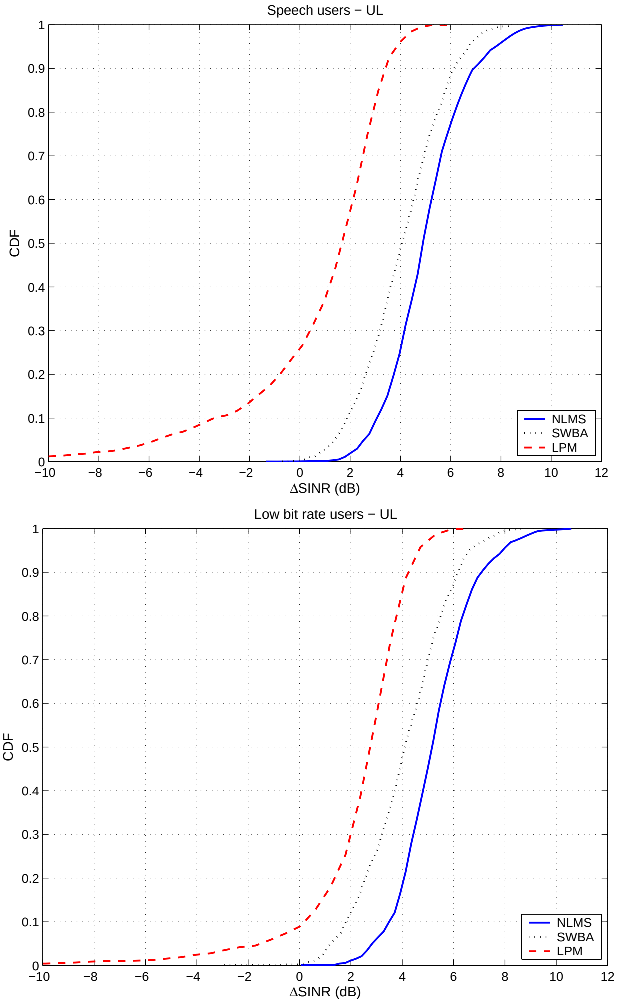


Figure 2. CDFs of ΔSINR for speech (top) and LBR (bottom) users.

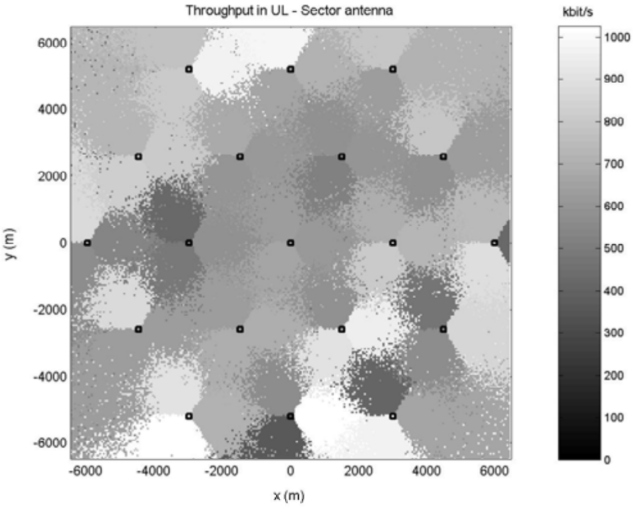
System level simulations are performed with a modified version of the NPSW simulator [23] that now includes smart antenna systems in the network planning process [24]. In WCDMA, the interference calculation is a crucial step in the radio network planning phase. In a mixed service scenario, different services have different processing gains and Eb/No specifications and thus different SINR requirements. Moreover, the inclusion of smart antennas in base station sites modifies the actual SINR values according to the statistical characterization obtained from link level simulations.

System level simulation follows an iterative process for UL and DL. In the UL iteration, mobile transmit powers are allocated until the interference level in the base stations converge. For each mobile-to-base station link, a ΔSINR value is assigned according to the technique proposed in the previous section, using the CDF of the particular demanded service, scenario and beamforming algorithm.

The target in the DL iteration is to assign the correct base station transmit power to each mobile station, including the effect of the smart antenna via the ΔSINR value from the corresponding CDF. Users are put to outage if the maximum transmit power is exceeded and also in the case that cell loading must be reduced.

A macrocellular network with 19 sites and 57 sectors is considered. The distance between adjacent sites is 3000 m. In the simulations, 3600 users are uniformly distributed within the region of interest, with a service distribution of 3000 speech users, 500 LBR users, and 100 HBR users.

Figure 3 compares the total throughput per cell in the UL direction when sector and adaptive antennas are installed in the sites. Using a beamforming scheme based on the NLMS algorithm, the throughput is increased by a factor of nearly two in most sectors as compared to a situation with sector antennas. This capacity increase comes from the fact that a lower number of users are put to outage when the adaptive antenna is used. As well, using a sector antenna HBR are more likely to be put out than voice users, making the throughput reduction more abrupt than with adaptive antennas.



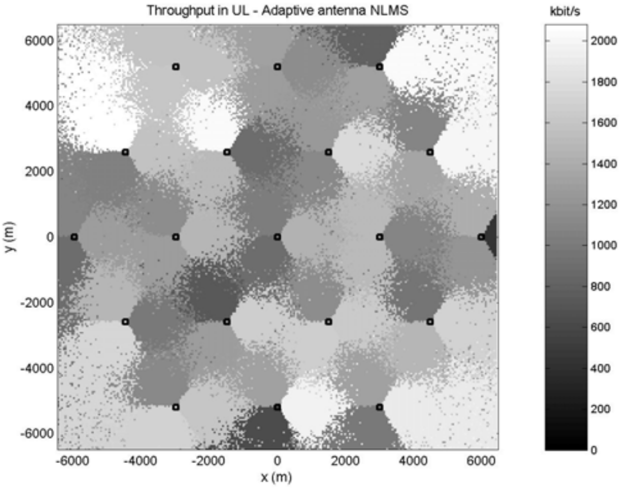


Figure 3. Map for the total throughput per cell for the sector (top) and NLMS-based adaptive (bottom) antennas.

4 Conclusion

In this paper, we have presented one technique to connect link and system level simulation levels that permits to quantify the performance gain achieved with smart antenna systems in cellular networks. Both simulation levels are needed to asses the performance of smart antenna systems. In contrast to other research works, the interface definition is not based on the average performance gain but on the complete statistical characterization of the ΔSINR gain achieved in the link level simulations.

System level simulation results have been presented to support the proposed simulation technique in a cellular network where base station sites are equipped with different smart antenna schemes. Results show that switched-beam antenna and NLMS based adaptive antenna systems outperform the results obtained with a sector antenna in a typical mixed service scenario. In contrast, the use of the LPM algorithm in the beamforming process gives similar results to that of the sector antenna in the scenario under study.

Finally, it is worth mentioning that the proposed simulation technique can be used by network operators to estimate the increase in the wireless network capacity achieved with a smart antenna scheme whereas incorporating advanced antenna systems in the initial dimensioning phase of the WCDMA radio network planning process.

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