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Performance Evaluation of Adaptive Antennas in UTRA

1. INTRODUCTION

This document introduces the performance evaluation activities for Adaptive Antennas in UTRA carried out in the context of the ACTS project SUNBEAM. There are a number of assumptions that were adopted related to user modeling in the link-level simulator as well as some difficulties that appeared when applying the Actual Value Interface between the link and system level simulator. The purpose of this document is to initiate discussion regarding these issues, and to outline tentative solutions to them.

2. USER MODELING ASPECTS

2.1 Power Angular Spectrum

Each sensor frequency-selective channel is modeled with a tapped delay line of time-varying coefficients. This approach leads to a straightforward procedure for channel generation, consisting in first obtaining the different narrow band channel taps and subsequently generating the filtered received signal.

In all simulation tests, the Doppler and angular dispersion associated with each mobile channel is created using a ray channel model inferred from the experimental measurement campaigns conducted within the TSUNAMI II and SUNBEAM projects [Pedersen97]. Basically, it is found that the Power Angular Spectrum (PAS) can be accurately described by a Laplacian function centered on the actual angular azimuth of the desired user. Besides, the distribution of the different ray azimuths is found to match a Gaussian PDF quite precisely, being the angular variance approximately equal to 1.38 times the Angular Spread of the PAS (Laplacian-shaped). The number of impinging wavefronts to be generated can be accurately modeled by a Poisson random variable with mean 50 rays.

In a practical implementation, a random number of rays is chosen for each channel simulation. Each wavefront is given a direction of arrival according to a Gaussian distribution, an expected power according to a Laplacian PAS and a Doppler frequency correction corresponding to a uniform distribution of the scatters surrounding the mobile station. In the simulations carried out in SUNBEAM a constant spread factor of 8 degrees was chosen for all users and scenarios. This approximation is expected to be precise enough for the Vehicular channel model only, since higher angular spreads might be required when simulating Indoor and Pedestrian deployments.

2.2 Power Control Mechanisms and Intercell Interferers in the TDD mode

Modeling intercell interferers becomes necessary when combining multi-user detection and adaptive antennas in the TDD mode. Since intracell users are jointly detected, users in other cells become the predominant source of interference. Additionally, beamforming performance is very sensitive to interferers' location and therefore, these can no longer be modeled as spatially-white noise.

Following UMTS 30.03, a carrier-level power control scheme is assumed. The slow-fading attenuation is regarded as a log-normally distributed random variable with standard deviation σ. For simplicity, it is further assumed that the slow-fading attenuation experienced by all users *as seen from their corresponding base station* (both BS_1 and BS_2 in Fig. 1) is perfectly compensated for. Additionally, and without loss of generality, Rayleigh fading and propagation path-loss are (temporary) disregarded.

In this situation and assuming ideal PC[1], the effective attenuation experienced by the signal transmitted by MS_2 as seen from BS_1 is the sum (actually, the difference) of two uncorrelated log-normal random variables with variances s_1^2 and s_2^2 respectively. Thus, the effective variance for the resulting random variable modeling the effective attenuation is equal to $s_1^2 + s_2^2$.

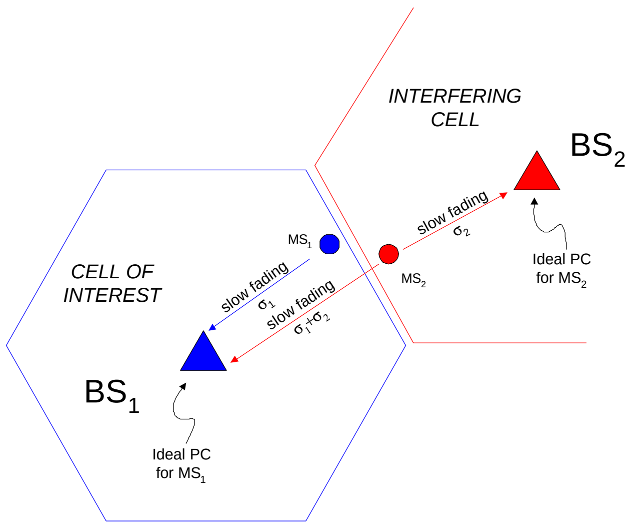

Fig. Error! Unknown switch argument.**:** Influence of power control on the slow fading experienced by intracell an intercell users.

In summary, no slow-fading attenuation factor is used when simulating intracell users whereas an augmented standard deviation, $\sqrt{2}s$, is introduced to model users from other cells. Difference in the statistics for both types of interferers clearly affects algorithms' performance. For example, any spatial filtering scheme performs much better when interferers are scarce but powerful, i.e. there are few predominant interferers. The increase in the standard deviation associated to intercell interferers favors this extent.

2.3 Number of users, associated logical channels and spreading factors.

The configuration of users to be modeled at the link level is also a matter for discussion. Since all possible situations regarding the number of users, logical channels per user and spreading factors can not possibly be simulated with the link level platform, some representative cases have been selected.

Only two distinct types of users are defined: High Bit Rate (HBR) and Low Bit Rate (LBR) users. HBR users have a greater bandwidth demand so that they consequently make use of lower Spread Factors (SF) and higher transmitted powers (in order to achieve a target requirement on the Eb/(Io+No), *which is assumed constant and independent of the service being*

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[1] Power control discussion mainly applies to the TDD mode. Since this mode is primarily intended to adopt hard handover strategies, each individual service is associated at a given time to a *single* BS.

offered). Thus, the number of HBR users is expected to be lower than the number of LBR ones, even though their contribution to the overall interference in the scenario plays a more important role.

Ideally, tables of raw BER should take into account any Spreading Factor ranging from 4 to 256 for the FDD mode and from 1 to 16 for the TDD mode. In addition, link-level simulations should provide results accounting for all possible combinations of Spreading Factors among users, as well as number of logical channels assigned to each transmission. Since this looks unaffordable in practical simulation times, *the approximation of a unique spreading factor for all users*, approach taken in UTRA evaluations [EvalUTRA], seems the most appropriate alternative.

The number of channels assigned to each user in the FDD mode has a major impact on the simulation results. Increasing the number of logical channels used by each user does not only imply a higher level of simulated interfering power; it has also an important impact on the performance of the array beamforming algorithms to be simulated. As reported in ([Mestre99]) the traffic channels multiplexed with the control channel are seen by the base station as new interfering sources coming from the direction of arrival of the desired one. In consequence, whenever the power of the user of interest increases beyond 5-10 dB the beamforming algorithms tend to null out the contribution of the desired user instead of enhancing it. In addition, the more logical channels are used, the worse the consequences of this effect are. This fact should be taken into account in the FDD mode when trying to obtain link-level simulation results. Here, following ETSI specifications for the evaluation of UTRA [EvalUTRA], we propose to consider a constant number of logical channels for all users, which ultimately varies depending on the service under analysis.

2.4 Variable spreading factor and TDD

Several features in the TDD mode facilitate the use of Multi-User Detection (MUD) approaches. For example, a limited number of co-channel interferers per timeslot makes joint detection computationally feasible. Also, the use of short spreading sequences is appreciated since, otherwise, signatures would appear to be varying from symbol to symbol which is inherently more difficult to manage. However, both FDD and TDD modes include variable spreading factors in order to provide bit-rate granularity. Whereas single-user detection schemes may be used regardless of interferers' spreading factor, it is not the case when MUD is taken into consideration. Actually, making use of different spreading factors within the *same* timeslot would make harder the application of JD schemes where, initially, the same spreading factor is assumed for every user. This is the case, for example, in typical MUD schemes like the JD-MMSE detector [Jung95, Lupas89].

Consequently a *fixed spreading factor within each timeslot has been assumed* in the performance evaluation activities carried out in the project SUNBEAM.

3. PROVIDING AN INTERFACE BETWEEN LINK- AND SYSTEM-LEVEL SIMULATIONS

All system aspects such as user mobility, cell deployment, power control mechanisms, among others, should eventually be taken into account in order to assess spectrum and coverage efficiency. However, the complexity of a simulator including everything form transmitted waveforms to multi-cell network would be prohibitive. Therefore, separate link and system level simulators are needed[2]. System level simulation requires parameters such as C/I thresholds as input parameters. On the other hand, these parameters are outputs from the link-level simulation stage. However, it is not clear what kind of format is required for the link level simulation outputs from the point of view of the system level simulator. Actually, two different approaches exist, namely, *average value and actual value interfaces*.

3.1 Average Value Interface

An average value interface is the conventional way to interface link level simulations with system level simulations. The output of link level simulations when considering this interface consists in a curve of coded BER vs. mean C/I, averaged over a very long period (tens or hundreds of seconds) of time. By doing so, the effects from multipath fading, interleaving, power control, interference variation are taken intro account according to their averaged characteristics. Next, in system level simulations, a static snapshot C/I value is produced without multipath or fast fading characteristics. A fundamental difficulty arises: link and system level C/I values correspond to each other if and only if

- the system level simulation resolution is so low that the effects from interleaving, and fast fading can be assumed to be averaged out, and
- the fading, interleaving and interference characteristics are the same on the average as those assumed in the link level simulations.

Additionally, long average periods lead to the situation that radio resource management algorithms whose activation frequency is high (say above 10 Hz) have to be simulated in the link level. This includes, for instance, power control schemes that, in UMTS, take place at the burst rate (every 0.625 ms).

3.2 Actual Value Interface

The Actual Value Interface (AVI) [Hamal97] is chosen as the most appropriate connection between link and system level simulations for third generation system evaluation. The main purpose of this approach is to take into account the fast radio resource management algorithms, as well as other high time resolution aspects of the system, such as changing interference conditions or power control tracking of the fading channel. The technique establishes that the link level simulation results should be measured in a burst-by-burst basis so that the system simulator undertakes all coding and link level adaptation. Thanks to that, all radio resource management algorithms (having an activation period higher than burst duration) can be accurately simulated on the system level platform.

In principle, the link level simulator provides a set of two curves. One curve depicts the raw[3] BER versus in-burst C/I ratio measured for each burst within the interleaving block (Fig. 2). In the sequel this C/I ratio is referred to as *instantaneous* opposite to the *mean* C/I handled by average value-based approaches. Additionally, a second curve reflecting the relationship between raw BER and coded BER must be obtained (Fig. 3). For that purpose, raw BERs for all bursts within the interleaving period are collected and, after channel decoding and interleaving, coded BER is measured.

In the system level, the C/I ratio is measured for each burst within the interleaving block and is mapped to raw BER by using the raw BER vs. C/I curve. De-interleaving is modeled so that the

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[2] Actually, rough estimates for coverage efficiency could well be obtained on the basis of link level simulations only (see [EvalUTRA]) For that purpose, not only fast-fading but also slow fading and path-loss effects should be included in the link-level simulations.

[3] Before coding.

average raw BER within the interleaving block is calculated. Further, decoding is modeled by mapping the de-interleaved raw BER to the coded BER.

Ideally, raw vs. coded BER curve should be scenario-independent provided that after de-interleaving errors are uniformly distributed. Unfortunately, this is not always the case as pointed out by [Wigard96]. Hence, special attention should be paid to this fact throughout the evaluation procedure.

Fig. Error! Unknown switch argument.**:** Raw BER vs. Eb/Io for the FDD mode of UTRA for three specific detection algorithms, 1 or 8 sensors and 1 or 5 interferers.

Fig. Error! Unknown switch argument.**:** Coded vs. Raw BER curves for the Speech and Low-delay Constrained Data services in UTRA.

4. AVI-RELATED ISSUES

4.1 Extension to systems deploying adaptive antennas

As originally conceived, the AVI was not designed to be used in conjunction with multi-antenna receivers. Consequently, no angular information (i.e. DOAs) is present in the interface but only E_b/I_o, the number of intracell users and the number of codes assigned to each user in a timeslot [EvalUTRA]. It is clear, though, that performance of adaptive antenna-based algorithms highly depends on angle of arrival information as well.

One possible approach is to assume that the link-system level interface is used unchanged, thus angular information must be averaged out at the link level. However, the increased accuracy in performance prediction provided by the Actual Value Interface (contrary to the Average Value Interface) is mainly due to the lack of averaging, which implies that DOA averaging should be avoided as well. However, including DOA information for every active user (either intracell o intercell) poses a major problem. Since constructing look-up tables for every combination of DOAs is computationally unfeasible, some type of discretization (i.e. assuming the DOA for every user to be within a range) could be devised. Nevertheless, splitting up cell sectors in a very low number of subsector (say 3) is still very costly for a moderate number of users. For example, for a total number of 8+2=10 users, 3^{10} different look-up tables should be constructed for every service under consideration.

In conclusion, *angular averaging is assumed when evaluating AA with the AVI.*

4.2 Channel estimation and link-level simulation duration.

Another matter under discussion, both for uplink and downlink transmission, is the procedure for channel estimation. Many algorithms developed for adaptive antenna operation require estimation of the two dimensional spatio-temporal channel prior to beamformer design. This estimate is known to be more sensitive to estimation errors than traditional temporal *only* channel estimation. This implies that more than one timeslot is usually required in order to provide an *averaged* channel estimation. When a reduced number of timeslots is used, the variance of the beamformer weights design is high. Conversely, excessive averaging can provide more stable estimates but introduces an intrinsic bias due to the Doppler variation.

Additionally, the averaging period for channel estimation should be shorter than the link-level simulation step which, in turn, is chosen according to the AVI. The fact that these periods are relatively short reverts in remarkable performance losses, especially in low Doppler scenarios.

In practice, the duration of the time step at the link level simulation is driven by the changing nature of the interference in the scenario. Whenever the interference situation is varying very fast (as it is the case in the TDD mode and in the FDD mode operating with non-real time packet services) low time steps of 0.625 ms should be considered. Contrarily, should interference conditions not be varying rapidly (as it is the case in switched circuit real-time services in the FDD mode), the time resolution restriction may be relaxed. This way, larger resolution steps may be used (i.e. 10 ms) which, in turn, reverts in a lower-complexity system-level simulation platform.

4.3 Look-up tables for coded BER computation

Complexity vs. performance trade-off leading to algorithm selection should be evaluated for the desired operating point (see Fig. 2). In order to meet QoS requirements, UTRA receivers must guarantee *coded* BER to be above a specific threshold for more than 95% of the frames. Aiming to establish a correspondence between coded and uncoded error rates, look-up tables as those illustrated in Figure 3 are to be computed. In the FDD mode of UTRA, Speech service is protected by a K=1/3 convolutional code only (upper curve). Low-delay Constrained Data (LCD) service is defined with an additional outer Reed-Solomon coding block [UMTS 30.03, EvalUTRA]. Taking into account that thresholds for these services are set to 10^{-3} and 10^{-6} respectively, a raw BER of approximately $9{,}5\cdot10^{-2}$ should be attained throughout the interleaving period.

Fig. Error! Unknown switch argument.**:** Coded vs. raw BER curves for speech (left) and LCD (right) services in the FDD mode of UTRA. Curves labeled as 'std' depict performance in the absence of rate matching mechanisms (either puncturing or bit repetition).

Nevertheless, when different puncturing and bit-repetition schemes are applied to match actual channel rates to those of different services, curves may differ significantly (Fig. 4). When considering a worst-case situation (higher percentage of bits being punctured like in LCD384UL, not displayed) the operating point should be set at $7 \cdot 10^{-2}$ raw BER.

Equivalent results can be derived for the TDD mode of UTRA as soon as details on the coding, interleaving and rate-matching schemes are released.

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6. ACKNOWLEDGEMENTS

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