Algorithms for Flexible Multistandard Array Processing: FDD Mode of UTRA

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Abstract

Results of link level simulations for the evaluation of adaptive antennas in the FDD mode of UTRA are presented. Two families of algorithms were initially considered, the basic difference between them being their robustness against directional interfering sources. It is shown that time-reference beamforming algorithms suffer from severe beampattern distortion effects when providing high bit rate services. This causes harsh performance degradation in terms of output raw BER, especially at high output SINR levels. These effects are basically caused by the uplink multiplexation of the traffic channel, which is seen by the base station as a powerful interfering source coming from the direction of arrival of the desired user.

1. Introduction

The first aim of the work presented herein was to evaluate the convenience of array-processing interference cancelling schemes in typical W-CDMA scenarios. The actual performance of such architectures will depend strongly on both the spatial distribution and temporal structure of the transmitted signals. Since analytical modelling of these effects becomes an arduous task, a first approximation to the problem by means of extensive simulations seemed most appropriate.

Two families of algorithms were initially considered, the basic difference between them being their robustness against directional interfering sources. The algorithms of the first family resorted to the assumption of temporally and spatially white interference and represented the optimum alternative in these circumstances. The algorithms of the second family acted as interference nulling schemes aimed at maximising the Signal to Interference plus Noise Ratio (SINR) at the input of a sequence detector. Two distinct schemes were established as representatives for each family and their performance was evaluated in presence of some illustrative interfering scenarios.

The evaluation work was carried out following FRAMES recommendations described in [3]. Hence, the "Actual Value Interface" (AVI) was chosen as a proper connection between link-level and system-level simulations. The main purpose of this approach was to take into account the fast radio resource management algorithms, as well as other low time resolution aspects of the system, such as changing interference conditions or power control tracking of the fading channel. The technique establishes that 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.

2. Algorithms under Test

Uplink Algorithms under Test

The first scheme under consideration, henceforth referred to as *V-Rake Receiver* (Figure 1), was chosen as representative for algorithms which do not take into account the presence of directional interfering sources. The scheme can basically be shown to be the optimum detector from a maximum-likelihood point of view when dealing with Additive Gaussian White Noise channels. Assuming that noise and interference can be considered omnidirectional, i.e. uncorrelated both in temporal and spatial domains, the optimal signal prior to detection becomes equal to the combination of outputs of different Rake Receivers matched to the channel temporal impulse response measured in each antenna.

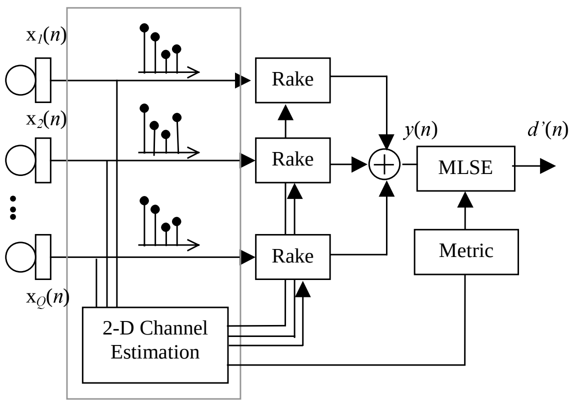

Figure 1. Vectorial Rake Receiver.

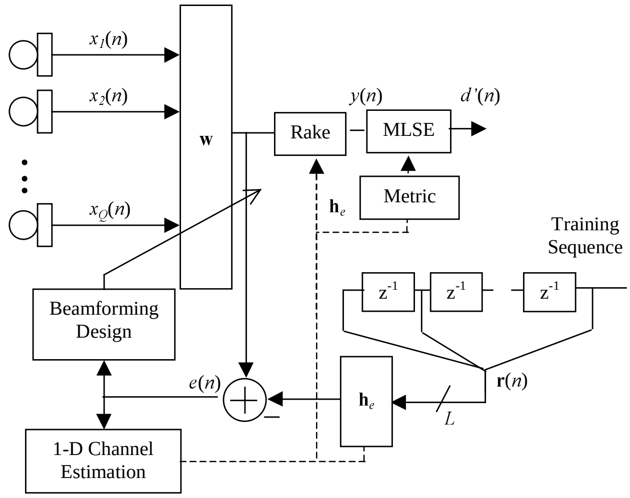

Figure 2. Matched Desired Impulse Response Receiver.

The second algorithm under consideration (Figure 2) was the so-called *Matched Desired Impulse Response MDIR Receiver* [4][10]. This narrowband beamforming architecture seeks to maximise the Signal to Interference plus Noise Ratio (SINR) at the input of a sequence detector (MLSE). To this end, the algorithm makes use of the training sequence transmitted through the DPCCH of the user of interest in order to obtain the optimum beamforming in terms of maximum output SINR.

The scheme can be shown to constitute the maximum likelihood detector under a twofold approximation: 1) temporal whiteness of interfering sources and 2) invariance of the users' spatial signature in observation periods shorter than the delay spread of the channel (see [5,6] for details). The approximation of temporal whiteness of the interfering sources can be clearly justified by the wide-band nature of the WCDMA signal. As for the temporal invariability hypothesis, it is backed up by results of measurement campaigns conducted within the SUNBEAM project [9].

It is finally worth noting that the architecture clearly resembles a classical time-reference beamformer (TRB) scheme. In fact, the classical TRB approach is obtained from the MDIR receiver when a channel length of L=1 tap is assumed. This way, the beamforming scheme under evaluation constitutes a generalisation of classical TRB techniques.

Downlink Algorithms under Test

The design of transmitting arrays to spatially distribute the different radio communication signals through an array of antennas may be basically taken on from two points of view. One can design the beamformer weights to provide the maximum array response towards the angular direction of the desired user, taking no account of the users that our transmission may interfere (Downlink Phased Array DPA scheme); or, contrarily, one can design the beampattern in an attempt to minimise the interference towards other mobile stations while simultaneously maximising the transmitted power towards the user of interest [2] (Downlink Beamforming with Null Steering DBNS scheme).

The DPA algorithm uses an estimation of the desired user's uplink spatial signature vector and directly applies it as downlink beamformer. The second scheme (DBNS architecture), constitutes the optimum solution in terms of SINR at the mobile station input disregarding the existence of intercell interference. It can be shown that the weight vector that maximises this ratio is equal to the solution obtained by the MDIR receiver, now applied to the downlink of the radio communications system.

3. Configuration of the Simulations

The presented array-processing algorithms were simulated on a linear equally spaced array of 8 antennas, in which the interelement separation was set to half wavelength at the carrier frequency (1950 MHz). All mobile angular locations were arbitrarily set by a uniform random variable within [-60,60] degrees, i.e. 120 degrees sectorisation was assumed.

All signals, adopting the W-CDMA modulation schemes described in [11], were transmitted through frequency-selective mobile radio channels, modelled with tapped delay lines of time-varying coefficients. Particularly, the models referred to as *Outdoor to Indoor and Pedestrian (A)* and *Vehicular (A)* in [8] were considered for the generation of the channel frequency selectivity.

The Doppler and angular dispersions experimented by each channel tap were simulated by means of a narrowband channel model inferred from the experimental measurement campaigns conducted within the TSUNAMI II and SUNBEAM projects [9]. According to this work, 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 was generated as a Poisson random variable with mean 50 rays and a constant spread factor of 8 degrees was chosen for all users and scenarios.

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.

4. Simulation Results

Two interfering scenarios were simulated for each power delay profile model, one with a single dominating HBR interference and another with five. Apart from the array beamforming algorithms presented in section 2, a single-sensor Rake receiver (uplink) and a single-sensor transmitter (downlink) were considered for comparison purposes.

Uplink results are depicted in terms of raw (uncoded) BER in Figure 3 and Figure 4. Although simulations took into account a high range of LBR power (reflected in the Eb/No ratio), only results with Eb/No=10dB are presented herein. Note that the BER is always expressed as a function of the instantaneous Eb/Io per sensor (i.e., received by a single antenna and measured within an actualisation period of the fast power control). Thanks to that, a conventional planning tool can directly use these results and therefore disregard the existence of adaptive antennas.

Comparing the performance of the proposed algorithms, the MDIR receiver generally attains the best results in terms of required Eb/No and Eb/Io for a particular raw BER in the range of interest (usually from 10^{-2} to 10^{-1} for raw BER). This is a logical result, since neither the V-Rake algorithm nor its single-sensor counterpart take into consideration the presence of interference, which has a most detrimental effect on the receiver performance.

Note however that when the power of the interferers increases, the BER for the beamforming algorithm (MDIR) tends to reach a lower bound regardless of the scenario. This behaviour is basically caused by the multiplexation of the traffic channel over the desired user's data stream. This traffic channel is seen by the base station as a new interfering component coming from the direction of arrival of the desired user. Thus, at high Eb/No the system cannot avoid trying to null out the contribution from the desired user instead of enhancing it. This causes the generation of nulls around the main lobe of the beampattern, giving rise to a global distortion of the array response.

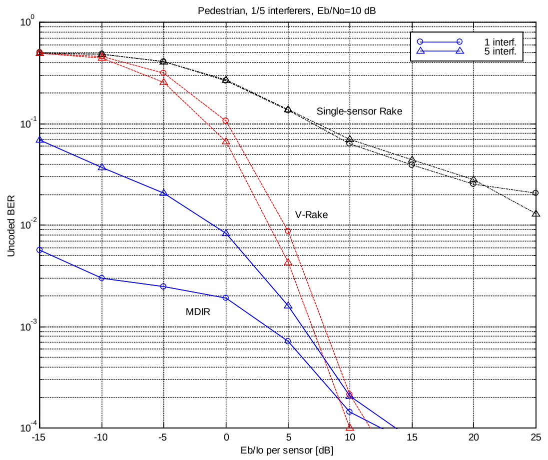

Figure 3. Uplink results for the Pedestrian Channel Model.

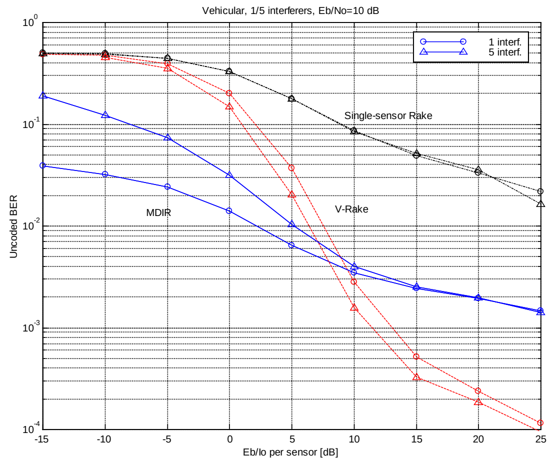

Figure 4. Uplink results for the Vehicular Channel Model.

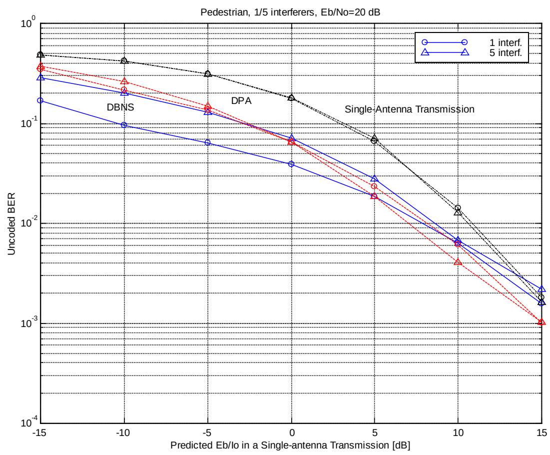

Figure 5. Downlink results for the Pedestrian Model.

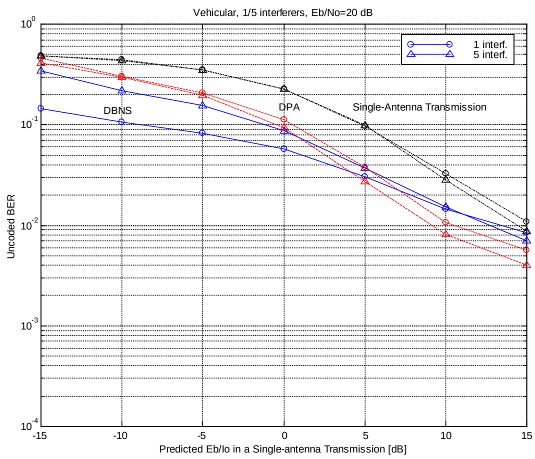

Figure 6. Downlink results for the Vehicular Model.

Figures 5 and 6 present downlink performance curves for an input Eb/No (at the mobile station) fixed to 20dB. Results are presented in terms of raw (uncoded) BER as a function of the instantaneous values of Eb/No and Eb/Io that a standard system simulation tool would predict in the mobile station location presuming that a single-antenna transmitter is used. The simulated HBR users were all supposed to be allocated within a cell and, as a consequence, inter-cell interference was modelled as omnidireccional Gaussian noise.

Comparing the results obtained with downlink array processing algorithms with those obtained for the uplink, it is clear that the former show severe performance degradation, essentially due to the uncorrelation between uplink and downlink realisations of the mobile radio channel. Surprisingly, it can be observed that the DLB algorithm outperforms the DBNS scheme for values of the instantaneous Eb/Io above 5-8 dB. Once again, this behaviour is basically motivated by a poor estimation of both the global covariance matrix and particularly the desired signal spatial signature. This latter estimation may be precise enough to properly point at the desired mobile, but not so reliable to avoid the desired signal suppression when a maximum SINR strategy is adopted.

A deeper insight into the behaviour of the implemented beamformer can be gained following the Wax's analytical approach presented in [12]. Let us assume that only one high bit rate user is present in the scenario. According to [12] and assuming an infinite sample size, the maximum output *SINR* that a beamformer using the only DPCCH reference can achieve may be approximated by:

$$SINR \approx \frac{P_{DPCCH} |\mathbf{s}_1|^2}{\alpha_n^2 + P_{DPDCH} |\mathbf{s}_1|^2}$$

with $\mathbf{s}_1$ the user's generalised steering vector[1] and P_{DPDCH}, P_{DPCCH} and α_n^2 denoting the input power of the Dedicated Data Channel, Dedicated Control Channel and Gaussian white noise respectively. As expected, in absence of Traffic Channel (P_{DPDCH} =0) the SINR at the beamformer output becomes equal to the optimal one and therefore proportional to the input power. Note however that when the traffic channel is activated the output *SINR* can no longer sustain its optimum values, and instead this ratio levels off as the desired source input power (P_{DPCCH} +P_{DPDCH}) increases.

Users making use of High Bit Rate (HBR) services (low SF) will have to transmit with a higher power than the Low Bit Rate (LBR) users in order to fulfil the same Eb/No and Eb/Io requirements at the base station input. So, the higher the bit rates, the worse the beamformer performance will be. As a conclusion, HBR users will be the most likely to suffer from the harsh degradation introduced by this beampattern distortion effect.

5. Robust beamforming for HBR users

This section outlines a valid solution to the beampattern distortion effect caused by the muliplexation of the traffic channels over the modulated data stream. Bearing in mind that valid algorithms should take into account the presence of not only known (DPCCH) but also unknown (DPDCH) data, semi-blind techniques naturally come forth as valid candidates to tackle with the problem [1]. Even though the use of these approaches has been so far restricted to the equalisation of mobile radio channels, the scope of their possibilities may be extended far beyond.

We consider a Conditioned Maximum Likelihood approach to the problem; thus, unknown data and noise are assumed deterministic and Gaussian-distributed parameters respectively. Maximisation of the corresponding log-likelihood function directly leads to a three-stage iterative procedure aimed to consecutively estimate the unknown data stream, the one-dimensional channel vector and the beamformer weights. The interested reader is referred to [7], where extensive details of the procedure may be found.

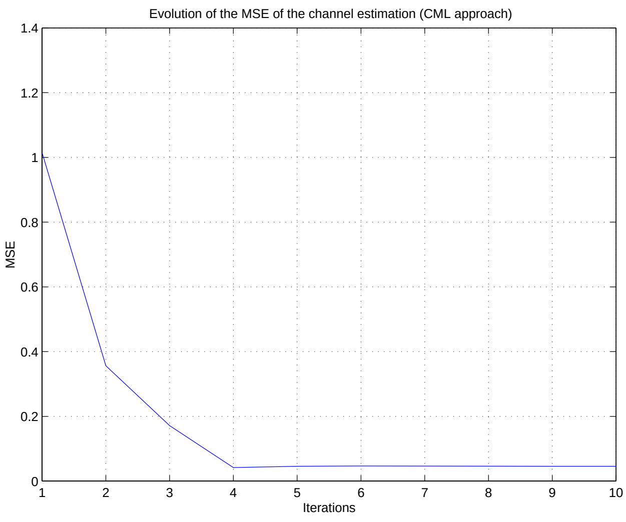

Figure 7. Evolution of the channel estimation Mean Squared Error.

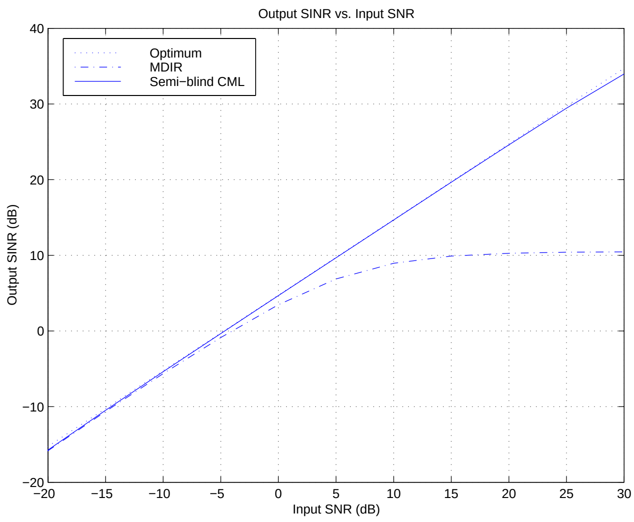

Figure 8. Evolution of the SINR at the output of the beamformer as the users' power increases.

[1] Note that a narrowband model is assumed in this formulation.

Simulations indicate that, in practice, 3-4 iterations are sufficient to guarantee global convergence of the algorithm. This is illustrated in Figure 7, where we have represented the mean squared error between the estimated channel and the actual one in an scenario with one interfering source and a Vehicular-120 channel model.

In Figure 8 we depict the signal to noise plus interference ratio achieved by the classical time-reference scheme (MDIR) and the semi-blind CML scheme proposed in this paper. In the simulation, the power of the two users present in the scenario ranged from –20 to 30 dB with respect to the noise floor. It is seen how the proposed scheme is capable of achieving high output SINR values (very close to the optimum) regardless of the users' power.

6. Conclusions

This paper has presented some link-level simulation results for the uplink and downlink of the current UTRA-FDD standard definition. Results show that application of classical time-reference beamforming techniques encounters severe performance problems when operating at high input power levels. A beampattern distortion effect, principally induced by the multiplexed traffic channel, has been shown to be the ultimate responsible for the performance degradation. Finally, semi-blind techniques are put forward as valid architectures to take into account the presence of the auto-interfering channel. Performance results of these techniques will be further addressed in [7].

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