

# Evaluation of Link-Level Performance Improvements by using Smart Antennas for the TD-CDMA based UTRA TDD Mobile Radio System

Gerald Lehmann<sup>1</sup>, Christina Gessner<sup>1</sup>, Martin Haardt<sup>2</sup>

<sup>1</sup>SIEMENS AG, D-13623 Berlin, Germany, <sup>2</sup>SIEMENS AG, D-81359 Munich, Germany

E-mail: Gerald.Lehmann@icn.siemens.de, Christina.Gessner@icn.siemens.de, Martin.Haardt@icn.siemens.de

## Abstract

*For Third Generation mobile radio systems like the TD-CDMA based UTRA TDD mode the use of smart antenna technology promises a substantial performance improvement on the up- and the downlink. The Third Generation mobile radio system UTRA with the TDD mode, which utilizes a combined CDMA and TDMA multiple access scheme, has been specified in the Third Generation Partnership Project (3GPP). At the end of last year the release 99 of the specification has been published.*

*The use of smart antennas at the base station reduces interference in two ways: On the uplink the intercell interference can be suppressed. The estimated spatial information about the users and interferers can then be used for beamforming on the downlink, which significantly reduces the interference also in this direction. Especially for terminals with a rake-receiver-structure a major performance improvement can be observed because of the intracell interference reduction. These performance improvements are expressed in concrete results derived from link-level simulations using the described technology and simulation environment.*

**Keywords** - UTRA TDD, smart antenna, beamforming

## 1 Introduction

The UTRA (UMTS Terrestrial Radio Access) TDD mode, specified in the Third Generation Partnership Project (3GPP), uses a combined time and code division multiple access scheme. This mode is well-suited for applications with higher data rates (up to 2 Mbps) and for asymmetric traffic like Internet access because of the flexible assignment of timeslots to either downlink (DL) or uplink (UL). It is proposed that Multi-User-Detection (MUD) should be applied. Joint-Detection (JD) is capable to eliminate intracell interference, i.e., the interference caused by other users in the same timeslot and cell, with a reasonable effort and complexity. A more detailed

description of the UTRA TDD mode can be found in [1] and also in 3GPP standardization documents [4].

The fact that uplink (UL) and downlink (DL) are operating on the same frequency facilitates the use of adaptive antennas for UTRA TDD. For this case a reciprocity of the spatial covariance matrices of UL and DL can be approximately assumed. This means that the estimated spatial covariance matrix obtained on uplink can be used for the beamforming on downlink.

For the evaluation of the performance improvement a link-level simulation environment, which is compliant to the release 99 UTRA TDD specification, was adapted to smart antenna simulations. A ray tracing channel model with spatial information was applied. The joint detection algorithm was extended to a joint-space-time algorithm, which estimates the spatial covariance matrix of the interference.

Chapter 2 gives an overview of the structure and the benefits of the smart antenna technology for this series of simulations for TDD. This chapter also includes a description of the used channel model.

Chapter 3 lists all relevant simulation assumptions, shows the obtained simulation results followed by a discussion of the results. This also includes a comparison with the case, where no adaptive antennas are used.

This paper ends with a conclusion which can be found in chapter 4.

## 2 Overview of the smart antenna implementation

The implementation of the smart antenna technology in the UTRA TDD simulation environment can be divided in four parts: The antenna configuration at the base station, the spatial channel model, the extended detection and equalizer technology at the receiver side and the beamforming on downlink. Figure 1 illustrates the structure of the antenna at the basestation with M single antenna elements. Figure 2 shows the simplified receiver structure for the uplink.

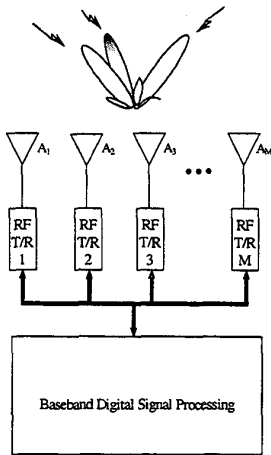


Figure 1 Base station antenna structure

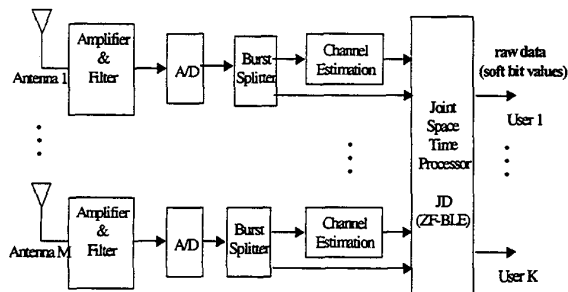


Figure 2 Simplified receiver structure in UL

## 2.1 Antenna configuration

For the series of simulations presented here a Uniform Circular Array (UCA) with eight antenna elements was used. The distance between the elements is  $0.5 \lambda$  and the radius  $R$  is equal to  $0.6533 \lambda$ . Figure 3 illustrates the antenna configuration.

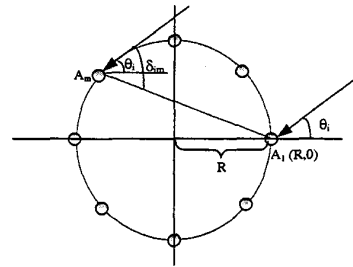


Figure 3 Eight-element circular antenna array

## 2.2 Channel model

To model the channel a deterministic ray-tracing channel model was used. This model allows a flexible configuration of the number and position of the scatterers, the antenna configuration and the movement of the mobile. For this series of simulations a macro cell was assumed. In macro cell areas, the angular spread is typically expected to be 5-10 degrees. Therefore, the scatterer distribution has to be modeled accordingly, and an angular spread of 7 degrees was chosen as shown in figure 4. If several users are simulated, they are assumed to be distributed uniformly within the cell. This means that the angular distance from user to user is  $90^\circ$  in case of four users and  $45^\circ$  in case of eight users.

For each user 4 scatterer clusters are assigned with a different number of randomly distributed scatterers where each cluster causes a 'tap' in the channel impulse response. Each scatterer cluster is also assigned a different weighting factor. This ensures that the corresponding taps have sufficient energy to be resolved. The total number of scatterers for one user is 1500. There is no line-of-sight (LOS) path.

For these simulations only two dimensional scenarios are considered. However, an extension of the scatterer distribution to three dimensional coordinates did not pose any problems and did not provide a noticeable performance difference.

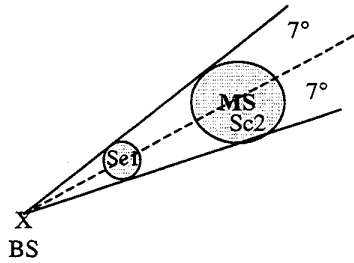


Figure 4 Basic layout of the channel model for one user (only two scatterer clusters Sc1 & Sc2 are indicated)

As it is commonly defined for macro channel environments, the mobile speed is 120 km/h. The mobile is moving on a circle with an averaged distance of 500 m to the base station.

As described, this channel model is designed to be very flexible. Thus any cell layout can be modeled but on the other hand it is very computation power consuming and time consuming due to its deterministic nature.

### 2.3 JSTP-Processing

The purpose of the joint space time processing is to obtain spatial covariance matrices which can be directly used for the calculation of the beamforming weights needed for the the downlink.

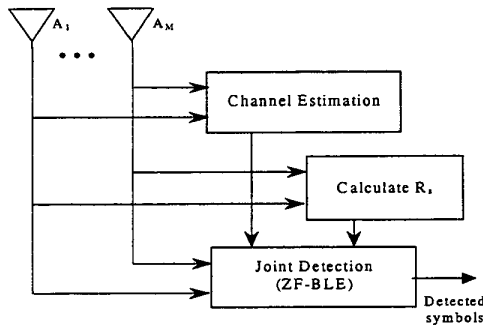


Figure 5 Basic structure of the JSTP processing

The spatial covariance matrix of the interference  $\mathbf{R}_S$  is computed by estimating the spatial covariance matrix of the complete received signal  $\mathbf{R}_{SIN}$  and by subtracting the estimated spatial covariance matrices  $\mathbf{R}_s^{(k)}$  of the intracell users (i.e., the users that are going to be detected in the joint detector). The joint detector eliminates the greatest portion of the intracell interference, therefore the

spatial covariance matrix  $\mathbf{R}_I^{(k)} = \mathbf{R}_I$  only contains contributions from interfering co-channel mobiles from other cells. A more detailed description of the algorithm is given in [6].

### 2.4 Adaptive beamforming (downlink)

The purpose of adaptive beamforming is to modify the beam pattern in order to enhance the reception of the desired code at the mobile, while simultaneously suppressing interfering signals through complex weight selection. In other words this means there are pointing beams in the direction of the desired user which minimize the energy transmitted in direction of interfering sources. In addition adaptive beamforming reduces multipath fading because of the decreased number of multipath signals (paths) due to the used narrow beams.

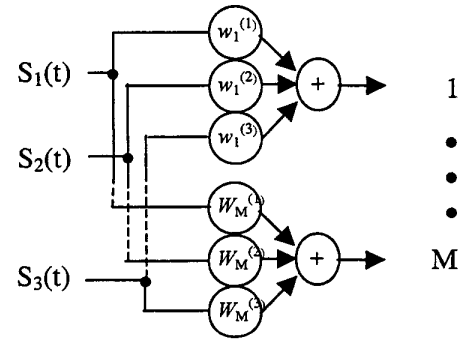


Figure 6 Beamforming principle

The elements of the complex beamforming weights vector  $\mathbf{w}^{(k)}$  for the  $k$ th user are illustrated in figure 6. Here, the different user-specific signals to be transmitted are denoted as  $s_k(t)$  for  $k = 1 \dots 3$ .

For the calculation of the optimal beamforming weights different criteria can be applied, which can be found in [2].

The three possible criteria are

- 1) Minimum Mean-Square Error
- 2) Maximum Signal-to-Interference Ratio
- 3) Minimum Variance

The maximization of the SIR was chosen as criterion for the adaptation of the beamforming weights.

$$SIR = \frac{\mathbf{w}^{(k)H} \mathbf{R}_s^{(k)} \mathbf{w}^{(k)}}{\mathbf{w}^{(k)H} \mathbf{R}_I^{(k)} \mathbf{w}^{(k)}} \quad (1)$$

where  $\mathbf{R}_s^{(k)} = E\{\mathbf{s}^{(k)}\mathbf{s}^{(k)H}\}$  is the spatial covariance matrix of the  $k$ th user estimated on downlink and  $\mathbf{R}_j^{(k)} = E\{\mathbf{u}^{(k)}\mathbf{u}^{(k)H}\}$  is the spatial covariance matrix of the interferers also estimated on downlink. The maximization of equation (1) is a joint eigenproblem, its solution can be found in the literature [2].

### 3 Simulation environment & results

This simulation series consists of three major cases. For all cases a comparison between an environment without and with adaptive antennas at the base station is made.

1. Uplink (UL), JSTP applied at receiver side
2. Downlink (DL), JD applied at receiver side
3. Downlink (DL), Rake receiver structure

Parameter	Explanation/Assumption
Chip rate	3.84 Mcps
Duration of TDMA frame	10 ms
time slots per frame	15
Number of samples per chip	1 sample per chip
Numerical precision	Floating point simulations
Burst structure	Burst structure #1 (long midamble, 512 chips), code specific midamble
Spreading codes	SF = 16 for all codes, each user has one code, cell scrambling code #0
Other physical layer parameters	as specified in 3GPP standardization documents (release 99) for the high chip rate TDD mode
Intercell interference	Modelled as Gaussian noise
Channel Estimation	Non-ideal, Joint channel estimator according to [5], based on correlation
Power control	Not applied
MUD-receiver (uplink & downlink)	Joint-detecter (JD) using the zero-forcing block linear equalizer (ZF-BLE), ideal code detection
RAKE-receiver (downlink, if indicated)	Max. 4 RAKE fingers

Table 1 General simulation parameters

It should be noted that in case of the uplink the performance is an average value of the performances of all detected users. This is contrary to the downlink, where only one user can be regarded in one simulation run because of the optimized beamforming pattern in the direction of that one user.

The following graphs show the required  $C/I$  for achieving a raw bit error rate (rawBER) of 5 % or 8 % over the number of users in one timeslot.

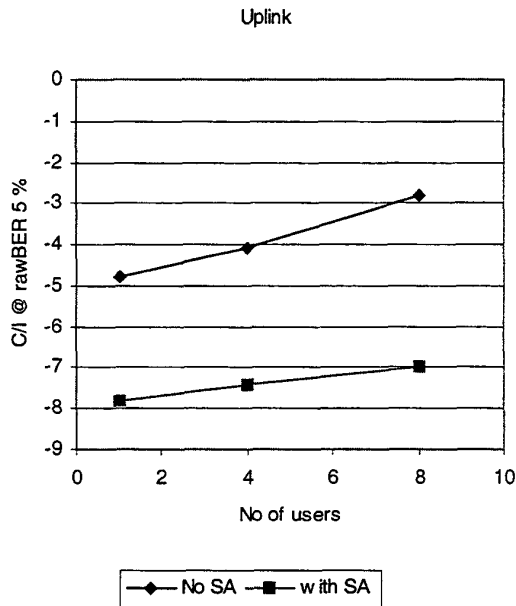


Figure 7  $C/I$  versus number of users (Uplink)

For the uplink case, where a joint detector at the receiver side is used, a basic reduction of the required  $C/I$  for one user can be observed due to the introduced receiving antenna diversity. With increasing number of users a slight increase of the required  $C/I$  can be seen, but due to the applied JSTP this increase is kept low. For eight users the performance difference is about 4.2 dB.

On the downlink with joint detection, it can be seen that the performance gain of the beamforming is relatively small. This is due to the fact that the intracell interference is almost cancelled by the JD and this is nearly independent from the distribution of the users within the cell. It should be noted that no real intercell interference is simulated. If interference to adjacent cells is simulated, smart antennas lead to a significant performance gain also on the downlink.

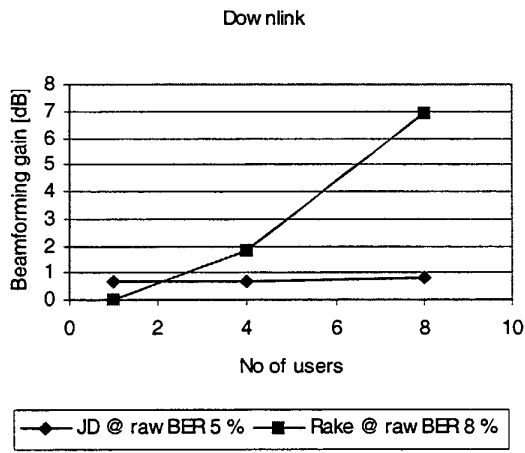


Figure 8 C/I versus number of users (Downlink)

The beamforming gain plotted in figure 8 as a function of the number of users is the C/I gain of an adaptive array antennas compared to an omnidirectional antenna.

In case of a rake receiver a great performance difference can be observed. Please note that the reference rawBER is set to 8 % because of the higher BER level when no smart antennas are applied. Intracell interference reduction can only be achieved by the beamforming in this case. The performance difference is more than 6 dB in case of eight users.

#### 4 Conclusion

The presented simulation results for a macro cell environment show a remarkable performance increase due the application of adaptive antennas on the uplink. It was shown that the use of beamforming on the DL is especially beneficial for Rake receiver based on the investigated interference scenarios. Future work will comprise the investigation of advanced intercell interference scenarios, where noticeable performance gains also for JD receivers on the DL can be expected.

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