FREE SPACE EXPERIMENTS WITH MIMO UMTS HIGH SPEED DOWNLINK PACKET ACCESS

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Abstract

The HSDPA (High Speed Downlink Packet Access) mode of UMTS provides high data rates to the user. In this contribution comparisons, based on free space measurements, between SISO (Single Input Single Output) HSDPA and MIMO (Multiple Input Multiple Output) HSDPA are shown. For two transmit antennas the STTD (Space-Time Transmit Diversity) mode of UMTS is used to increase the diversity order of the transmission. Measurements with four transmit antennas are carried out incorporating the DSTTD-SGRC (Double Space-Time Transmit Diversity with Sub-Group Rate Control) proposal of MERL (Mitsubishi Electric Research Laboratories). Besides of the comparison of the various HSDPA schemes, this paper focuses on the setup of the radio frequency frontend and its requirements for MIMO transmissions.

1 Introduction

Since the theoretical work of Foschini, Gans [1], and Telatar [2] it is known that the use of multiple antennas at the transmitter and receiver can substantially increase the capacity and reliability of a wireless link. Today, more than ten years later, several standardization workgroups are considering MIMO techniques as mandatory for their next generation systems. One of these workgroups is the 3GPP (Third Generation Partnership Project) which is responsible for UMTS standardization. In Release'99 of the UMTS standard a so-called STTD (Space-Time Transmit Diversity) mode is specified mandatory for the UE (User Equipment) receiver. This STTD mode incorporates Alamouti coding [3] at the transmitter, thus achieving a diversity order of two. However, this STTD mode is not a "true" MIMO transmission since it only requires two transmit antennas and one receive antenna. The use of multiple antennas at both transmitter and receiver side is expected to be standardized as an extension of the HSDPA mode. Currently, HSDPA channels are incorporated into the networks by UMTS providers. These channels increase the available data rate to the UE by using HARQ (Hybrid Automatic Retransmission Request) combining, fast scheduling, and 16-QAM modulation in addition to QPSK. The SISO HSDPA mode achieves data rates up to 14.4 Mbit/s per cell. These data rates shall be further increased by MIMO proposals for more than two transmit antennas that have already been submitted to the 3GPP by several companies [4]. Since it is not obvious which proposal is the best in terms of data throughput and implementation complexity, a careful evaluation has to be performed. One corporate proposal is DSTTD-SGRC (Double Space-Time Transmit Diversity with Sub-Group Rate Control) which will be evaluated and compared to STTD and SISO HSDPA in this contribution. Our evaluation is performed by free space transmission experiments that reveal both the block error rate and the system throughput.

The measurement results are obtained with our MIMO testbed described in [5, 6, 7]. All measurements were carried out inside the laboratory, i.e. with flat fading MIMO channels. Small scale fading was achieved by moving the receive antennas by means of an xy positioning table. By moving the whole table itself, large scale fading and different propagation scenarios (LOS - Line Of Sight, NLOS - Non Line Of Sight) can be investigated.

The paper is organized as follows. In Section 2 the radio frequency frontend and the xy positioning table are explained. The transmitter and receiver for SISO, STTD, and DSTTD are described in Section 3. Measurement results are shown in Section 4. Finally, Section 5 reports conclusions.

2 Setup of the Radio Frequency Frontend

The testbed (Figure 1) is designed to enable flexible testing of various MIMO modulation schemes. The radio transmission hardware is exchanging IF (Intermediate Frequency) signals with a transmitter and a receiver host computer. These computers use fast D/A and A/D converter modules interfaced by MATLAB to generate and receive the IF signals [5]. Complex baseband signal samples are interchanged with a measurement PC via the LAN. This PC processes the received signal samples by applying the receiver algorithms implemented in MATLAB. The testbed also offers the possibility of real-time processing by the use of fast FPGAs (Field Programmable Gate Arrays). Since this work focuses on a comparison between various HSDPA schemes and not on real-time implementation, the sophisticated receiver structures were implemented in MATLAB only.

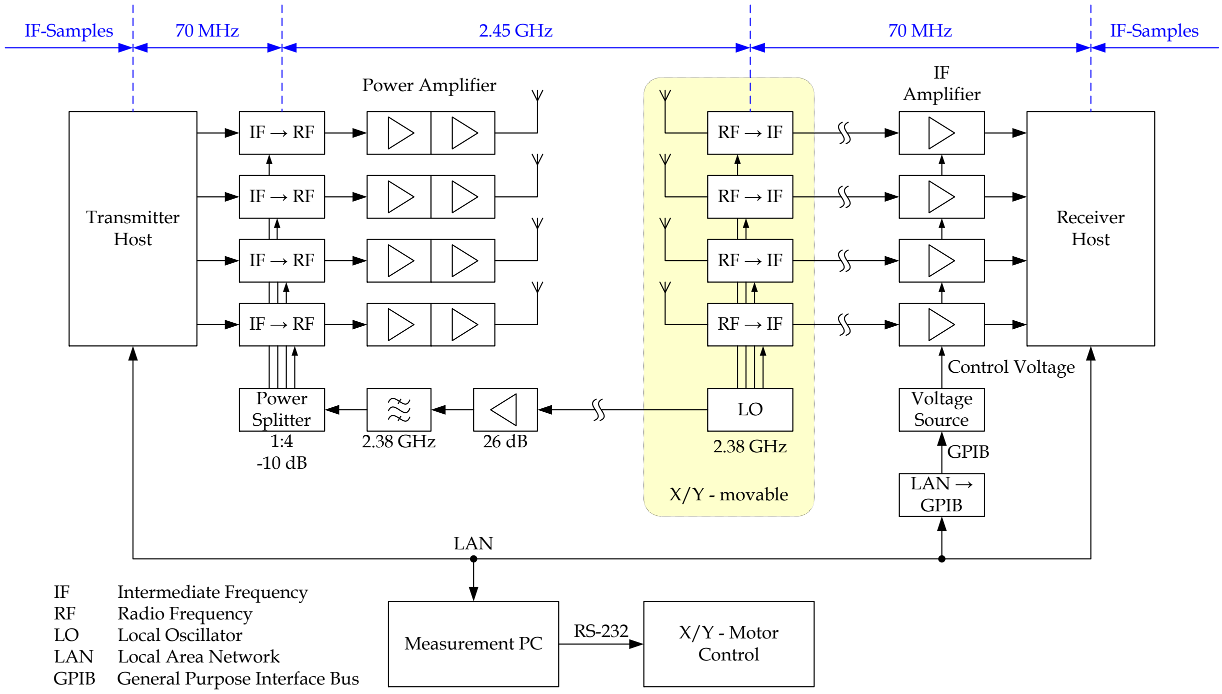

Fig. 1: Block diagram of the MIMO testbed.

Intermediate Frequency	70 MHz
Radio Frequency	2.45 GHz
Bandwidth of RF Frontend	20 MHz
Transmit power per antenna	17 dBm
IF amplifier gain	4 - 94 dB
Maximum supported signal bandwidth	6.25 MHz
Number of transmitter channels	4
Number of receiver channels	4

Table 1: Testbed parameters.

2.1 RF Transmitter

The radio frequency hardware basically consists of four parallel signal paths. In the transmitter, the IF signals (center frequency 70 MHz, maximum bandwidth 20 MHz) provided by the transmitter host are converted to 2.45 GHz. The peak output power of each of the succeeding amplifiers is 23 dBm at the 1 dB compression point. Due to the high peak-to-average power ratio of the CDMA signals, the achievable average output power is below 23 dBm. Fig. 2 shows the measured output spectrum of one power amplifier. The maximum achievable output power was determined by increasing the signal amplitude until nonlinear distortion products just reached the UMTS spectral mask [8]. Therewith, a mean output power of 17 dBm was obtained.

An important issue when transmitting four signals at once is to avoid crosstalk between the transmit channels. The high signal power at the antennas (4×17 dBm) yields strong electromagnetic fields in the area where the transmission equipment is located. In particular, the high gain that is introduced

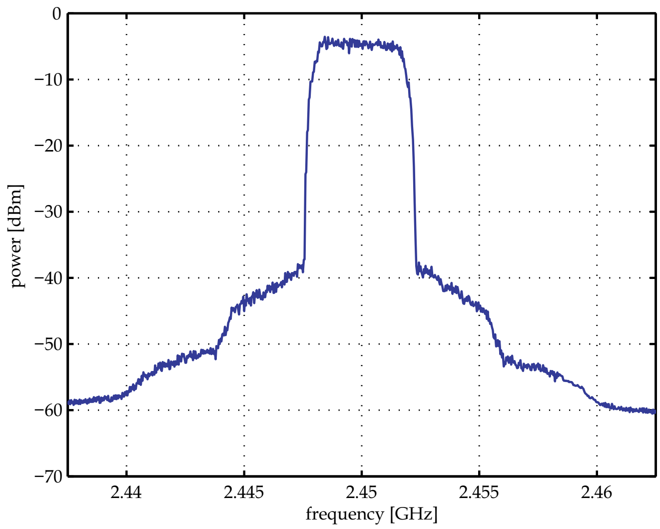

Fig. 2: Measured output spectrum of the power amplifier (resolution bandwidth 30 kHz; video bandwidth 30 Hz).

by the upconverter and the two stage power amplifier brings small signals that intrude into housings at a formidable level. To avoid this, all casings were sealed with copper foil shielding tape. Furthermore, the mixer circuits are equipped with band-pass filters at the inputs and outputs to reduce interference with signals picked up along cables or through the LO. With these measures a channel separation of more than 40 dB could be achieved.

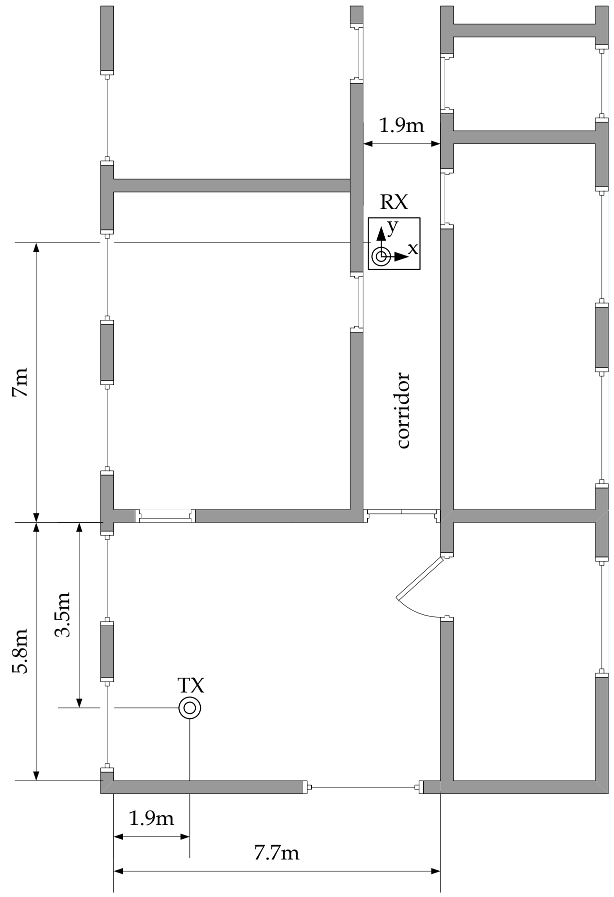

Fig. 3: Floor plan of the laboratory with positions of TX array and RX array on xy positioning table.

2.2 Channel Setup

The transmit and receive antennas are $\lambda/4$ monopole antennas arranged in a linear array configuration with spacing of $\lambda/2$. The spacing can be changed easily allowing for investigations of its influence on the MIMO channel and the performance of various transmission schemes.

Fig. 3 shows the floor plan of the building where the measurements were carried out. It can be seen that the transmitter and receiver are located in different rooms and are separated by walls and doors. Since there are a lot of scattering objects (e.g. measurement equipment, computers, cables, etc.) situated in these rooms, multipath propagation is enhanced. The experiment described in the following is perfectly suited to obtain meaningful results for indoor MIMO HSDPA. In outdoor communications the multipath propagation leads to inter symbol interference. If equalization is performed in the UE receiver, the results from the indoor scenario are also representative for the outdoor scenario.

To categorize the propagation properties, a channel sounding experiment was carried out prior to the MIMO measurements. Fig. 4 shows the SISO channel coefficient versus the receive antenna positions. The spacing between the positions is $\lambda/10$ and the area covered is $2\lambda \times 2\lambda$. An analysis of the channel coefficient statistics revealed a nearly perfect fit with a Rayleigh distribution. No dominating paths were observed.

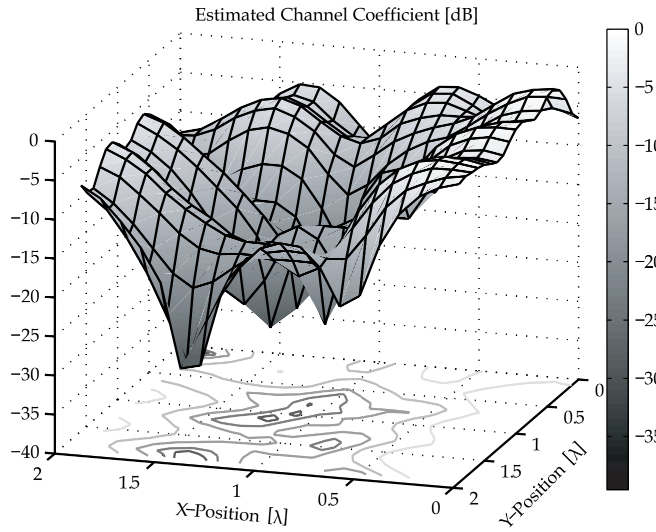

Fig. 4: Estimated channel coefficient of the measured SISO channel in an area of $2\lambda \times 2\lambda$ ($\lambda/10$ resolution).

2.3 RF Receiver

Fig. 5 shows the receive antenna array mounted on the xy positioning table. Absorber mats were used to minimize the influence of the metallic positioning table on the array characteristics.

The four signals picked up by the receive antennas are fairly weak and thus sensitive to noise. According to Fries formula, the first stage of the receiver chain has the most impact on the signal to noise ratio. The cables that lead the signals back to the receiver host would impair the noise figure by their attenuation (27.8 dB at 2.45 GHz). Therefore, it is essential that the downconverters are located as close as possible to the receive antennas. Besides this, the cable loss reduces to 3.6 dB at 70 MHz.

To benefit from the full dynamic range of the A/D converters, four adjustable gain amplifiers are foreseen. Each of these units offers a gain between 4 dB and 94 dB. The gain is adjusted via a GPIB (General Purpose Interface Bus) controlled voltage source. It is possible to adjust the input power of the A/D converter cards in an iterative process. The dynamic range of the A/D converter cards is about 84 dB (14 Bit) and thus sufficient to resolve weaker signals as well. Fast fading due to multipath propagation is not compensated by the IF-amplifiers.

3 HSDPA Baseband Processing

In this section the baseband processing of the various transmitters and receivers implemented is described. The STTD and DSTTD schemes are based on the SISO HSDPA scheme. Therefore, the SISO scheme will be explained in more detail before the MIMO systems are discussed.

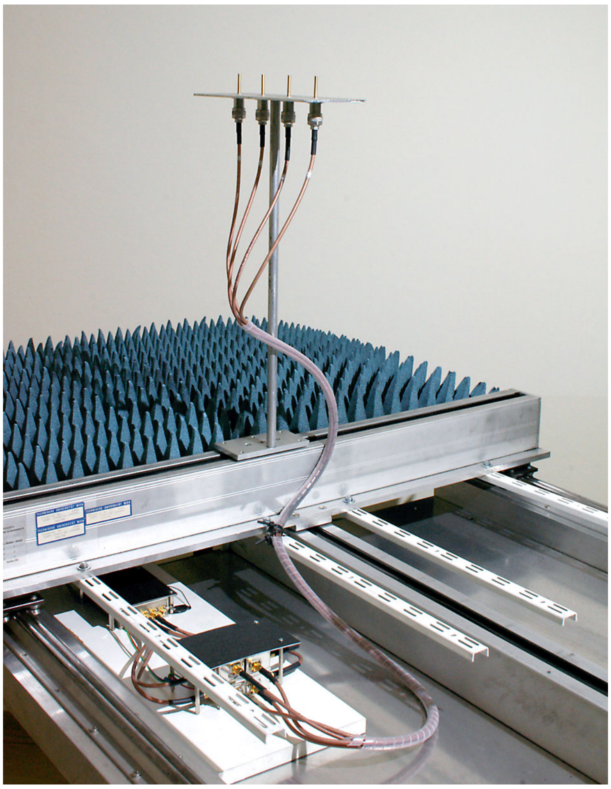

Fig. 5: The xy positioning table with receive antenna array, downconverter units, and local oscillator.

3.1 SISO

The SISO transmitter, completely implemented in MATLAB, generates HSPDA subframes as specified by the 3GPP [9]. It performs the following operations on randomly generated data bits:

- Add 24 CRC (Cyclic Redundancy Check) bits allowing for frame error detection in the receiver.
- Turbo coding with rate 1/3.
- Adaptive rate matching to the desired code rate which is determined by the CQI (Channel Quality Indicator) value.
- Adaptive symbol mapping (QPSK, 16-QAM), also determined by the CQI.
- Spreading with spreading factor 16.
- Scrambling with a specific Node B scrambling sequence.

After generating the HS-PDSCH (High Speed Physical Downlink Shared Channel) chipstream, the pilot and synchronization channels are added. These channels are used for channel estimation and synchronization (i.e. frame synchronization and symbol timing recovery) at the receiver. The resulting chip stream is then transmitted using a previously developed interface between MATLAB and the D/A converters [5].

After transmission, the MATLAB interface also provides the oversampled receive signal. This signal is then correlated with the synchronization channel to obtain the optimum sampling time instant. After decimation, the resulting synchronized chip stream is further processed.

The first stage of the digital baseband SISO HSDPA receiver is a matched filter. After the matched filter, all operations done in the transmitter are performed inversely (i.e. descrambling, despreading, demapping, decoding). By evaluating the CRC bits, the block error rate shown in the measurement results was determined.

Parameter	Value
$\mathrm{P-CPICH}\ E_c/I_{or}$	-10 dB
$\mathrm{SCH}\ E_c/I_{or}$	-12 dB
$\mathrm{P-CCPCH}\ E_c/I_{or}$	-12 dB
Channel coefficient estimation	least squares
Turbo decoding	max-log-MAP - 8 iterations
Retransmissions	none

Table 2: Common measurement parameters.

Parameter	Value
Modulation	16-QAM
Transport block size	2880
Coding rate	3/4
No. of channelization codes	2
Peak data rate	1.44 Mbps

Table 3: SISO and STTD measurement parameters.

3.2 STTD

The SISO HSDPA mode can be extended to two transmit antennas by Alamouti coding [3] of the transmit symbols. This so-called STTD mode achieves a transmit diversity order of two, allowing for a more reliable data transmission. The receiver is again the matched filter receiver that multiplies the received symbols with the conjugated, transposed channel matrix.

3.3 DSTTD

The DSTTD scheme transmits two independent data streams on four transmit antennas. The input data is first separated into two subgroups and each subgroup is further processed like in the SISO scheme. After symbol mapping, Alamouti coding is performed on every subgroup individually. Thus, DSTTD basically implements two independent STTD schemes. The resulting symbol streams of the four transmit antennas are spread and

Parameter	Value	
CQI	0	
Modulation	16-QAM	
Subgroup	SG1	SG2
Transport block size	2880	2880
Coding rate	3/4	3/4
No. of channelization codes	2	
Peak data rate	2.88 Mbps	

Table 4: DSTTD measurement parameters.

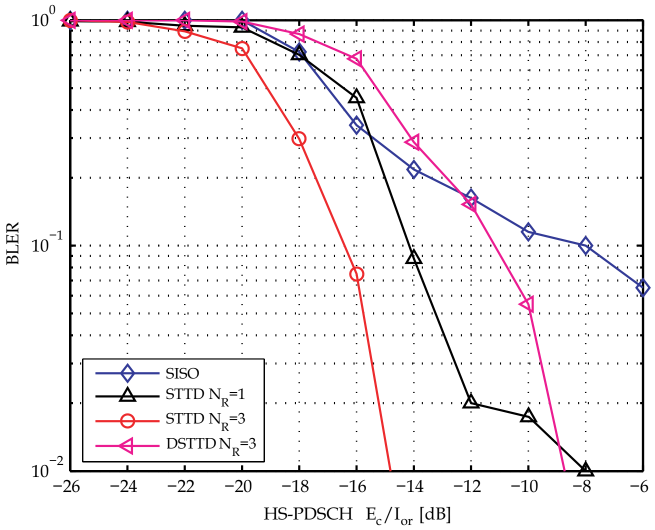

Fig. 6: SISO, STTD, and DSTTD BLER (Block Error Ratio) comparison.

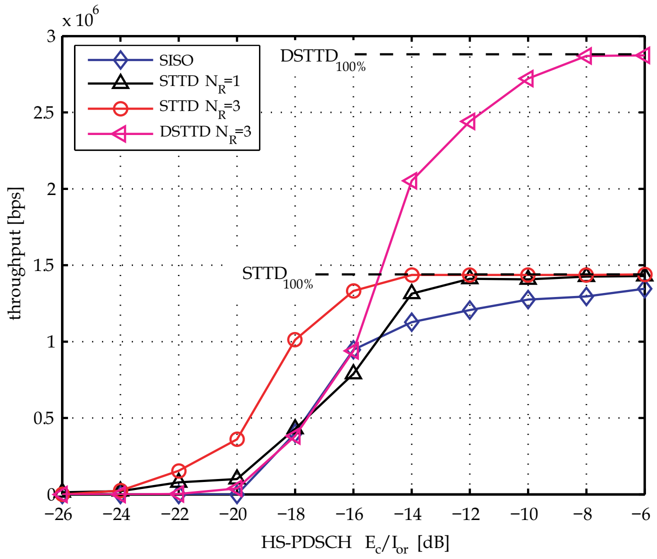

Fig. 7: SISO, STTD, and DSTTD throughput comparison.

scrambled with the same spreading and scrambling sequence. Since the UMTS standard does not specify pilot channels for four transmit antennas a novel pilot pattern presented in [10] was used.

The space-time receiver is an MMSE-SIC (Minimum Mean Squared Error with Successive Interference Cancelation) receiver. This receiver decodes the subgroup with higher SINR (Signal to Interference and Noise Ratio) first and performs the interference cancelation with error corrected symbols obtained from the Turbo decoder. A more detailed description of the receiver and the determination of the subgroup decoding order is given in [11].

4 Measurement Results

This section provides block error rate and throughput measurements of SISO, STTD, and DSTTD HSDPA transmissions. An overview of the measurement parameters is given in Tables 2, 3, and 4. The measurements were performed with varying HS-PDSCH (High Speed Physical Downlink Shared Channel) E_c/I_{or} (energy of the data chip stream over totally available transmitter energy). The E_c/I_{or} value basically is the amount of energy that is assigned to the user.

Fig. 6 shows the measured BLER (Block Error Rate) for the different HSDPA schemes. In [12] 3GPP specifies a BLER of 10 % as target for the CQI (Channel Quality Indicator) reporting. When using this BLER value for comparisons between the different schemes we observe that STTD ($N_R = 1$) outperforms SISO by about 6 dB. STTD also needs about 2 dB less E_c/I_{or} than DSTTD to achieve 10 % BLER. Note, that the peak data rate of STTD is only half the one of DSTTD. Because of the non equal data rates of the MIMO schemes, a fair comparison should be drawn in terms of throughput to account for different peak data rates. Such a throughput comparison is shown in Fig. 7. We observe that STTD with $N_R = 1$ performs almost as well as the SISO system for $E_c/I_{or} < -15$ dB, but achieves its peak data rate of 1.4 Mbit/s at 6 dB less E_c/I_{or}.

Fig. 8 shows a throughput comparison of DSTTD for different numbers of receive antennas. A significant gain of 4 dB between the three and the two receive antenna scheme was measured. The third receive antenna favors the channel matrix to be of full rank, thus increasing the data throughput. A fourth receive antenna on the other hand does not significantly (approx. 1 dB E_c/I_{or} gain) change the throughput which is explained by the small antenna spacing of $\lambda/2$.

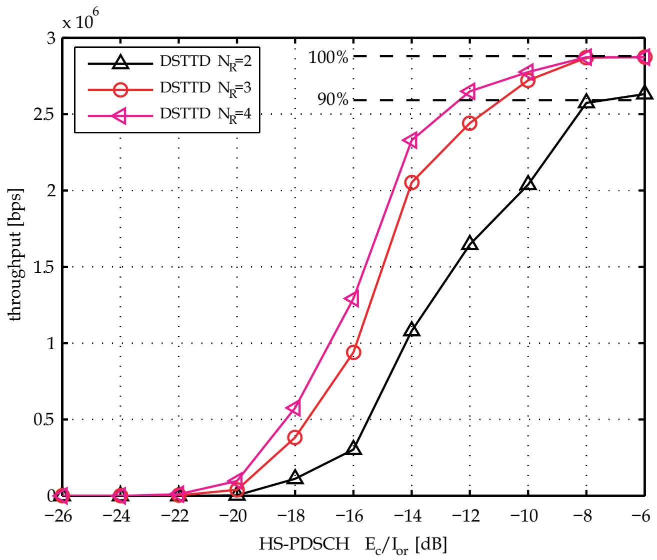

Fig. 8: DSTTD throughput for different numbers of receive antennas.

5 Conclusions

Indoor measurements for SISO and MIMO HSDPA were presented. The capabilities and important design criteria of the MIMO testbed were discussed. Measurements revealed for DSTTD that three antennas should be used at the receiver striking an optimum tradeoff between data throughput and receiver complexity. It was furthermore shown that the DSTTD scheme works very well in indoor scenarios with an antenna spacing of $\lambda/2$. More measurements have to be performed to investigate the dependence of the transmit and receive antenna array dimensions on the system throughput.

Acknowledgments

This work has been funded by the Christian Doppler Laboratory for Design Methodology of Signal Processing Algorithms as well as **K***plus*, Infineon Technologies and the ARC Seibersdorf Research GmbH (ARCS) through the ftw. Project C9.

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