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Effect of Transmit and Receive Antenna Configuration on the Throughput of MIMO UMTS Downlink

Christian Mehlführer, Sebastian Caban, Markus Rupp, and Arpad L. Scholtz
Institute of Communications and Radio-Frequency Engineering
Vienna University of Technology
Gusshausstrasse 25/389, A-1040 Vienna, Austria
Email: chmehl@nt.tuwien.ac.at
Web: http://www.nt.tuwien.ac.at/rapid_prototyping

***Abstract*— In this contribution, throughput measurements of DSTTD-SGRC (Double Space Time Transmit Diversity with Sub Group Rate Control), a candidate for the MIMO extension of UMTS, are presented. The system throughput is compared for feasible transmit and receive antenna arrays. Emphasis is placed on a quad inverted-F antenna which is a realistic receive antenna array that could be built into a mobile phone. The size of this array incorporating four individual antennas is only $34\times34\,\mathrm{mm}^2$. Although due to the small size high spatial correlation between the antennas might be expected, the measurements show that the quad inverted-F antenna performs very well. The throughput is comparable to a linear array with an antenna spacing of $0.5\,\lambda$.**

I. INTRODUCTION

The theoretical work of Foschini, Gans [1], and Telatar [2] showed that the use of multiple antennas at the transmitter and at the receiver can substantially increase the capacity and reliability of a wireless link. Now, a couple of years later, many workgroups are considering MIMO techniques in their standardization processes. One of these workgroups is the 3GPP (3rd Generation Partnership Project), which considers to use MIMO in the next generation of UMTS HSDPA (High Speed Downlink Packet Access). Several corporate proposals for this MIMO extension have been submitted to the 3GPP and are summarized in the Technical Report 25.876 [3]. Many simulations of the proposed MIMO systems have been performed to predict the performance in the UMTS network [4], [5]. Other publications, like [6] or [7], deal with the implementation of antenna arrays for future mobile terminals, but the investigations are limited to an electromagnetic point of view (i.e. measurements of input matching, gain pattern). Such investigations have the disadvantage that they do not directly show the effect on the throughput achieved by the mobile terminal. It is therefore unknown if it is feasible to build multiple antennas into a mobile handset.

In this contribution the throughput performance of the DSTTD-SGRC (Double Space Time Transmit Diversity with Sub Group Rate Control) proposal [3] is measured using several representative transmit and receive antenna arrays. The measurements were carried out with our MIMO testbed, previously described in [8], [9].

The paper is organized as follows. In Section II, the linear antenna arrays and the quad inverted-F antenna used for the measurements are described in detail. The radio frequency hardware and the measurement setup are explained in Section III. In Section IV, the results of the throughput measurements are presented. Finally, Section V reports our conclusions.

II. ANTENNA CONFIGURATIONS

In the following we discuss the antenna configurations used for our measurements.

A. Linear Arrays

Three different linear antenna arrays were used. These arrays consist of four $\lambda/4$ monopoles mounted on an aluminum ground plane. The antenna spacings and the dimensions of the arrays are illustrated in Figures 1, 2, and 3.

Figures 1 and 2 show linear arrays with equal antenna spacing of $0.5\,\lambda$ and $1.8\,\lambda$, respectively. We will refer to these antennas as the close-spaced and the wide-spaced array throughout the paper. Due to the smaller spacing of the close-spaced array the spatial correlation between the elements is higher and the performance is expected to degrade.

In DSTTD-SGRC two independent data streams are transmitted. Both data streams are Alamouti coded using two transmit antennas each. Reference [5] found for DSTTD-SGRC and for a fixed maximum dimension of the transmit antenna array that antennas belonging to the same data stream should be placed close to each other to increase the system throughput. This unequal spacing increases the spatial correlation within one data stream, but decreases the correlation between the different data streams. Such an antenna array is depicted in Fig. 3. It has the same overall size as the wide-spaced array.

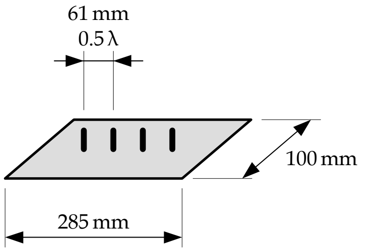

Fig. 1: Close-spaced linear antenna array with $\lambda/4$ monopoles.

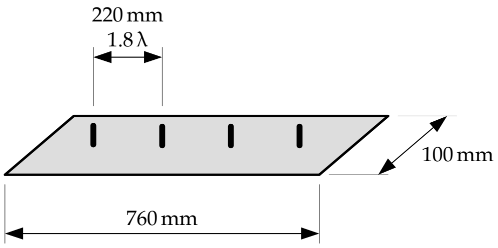

Fig. 2: Wide-spaced linear antenna array with $\lambda/4$ monopoles.

B. *Quad Inverted-F Antenna*

For our experiments, the inverted-F antenna (also known as L antenna), thoroughly investigated in [10] and [11], was quadrupled on a $34 \times 34\,\text{mm}^2$ shielding box that could, in a final product, contain the radio frequency hardware. This array will be referenced as quad inverted-F antenna throughout the paper. The dimensions of one F antenna are given in Fig. 4, and a picture of the whole antenna showing the numbering of the antenna elements is presented in Fig. 5. This numbering will be used in Section IV when comparing the throughput for different numbers of receive antennas.

The magnitudes of the S-parameters of the quad inverted-F antenna are given in Fig. 6 and Table I. The input matching and the decoupling of the antenna elements is about -15 dB at the operating frequency of 2.45 GHz. The bandwidth for -10 dB input matching is about 100 MHz. Reference [10] introduced some modifications to the inverted-F antenna that increase the antenna bandwidth by at least 50 %. This antenna can therefore perfectly be adapted to support the total UMTS frequency band (i.e. uplink and downlink).

TABLE I: S-parameters of the quad inv.-F antenna.

	1	2	3	4
1	-15.8 dB	-14.6 dB	-18.3 dB	-14.6 dB
2	-	-14.1 dB	-14.6 dB	-17.4 dB
3	-	-	-17.3 dB	-12.4 dB
4	-	-	-	-18.3 dB

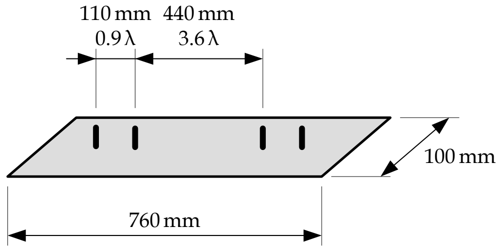

Fig. 3: Linear antenna array with $\lambda/4$ monopoles and unequal antenna spacing.

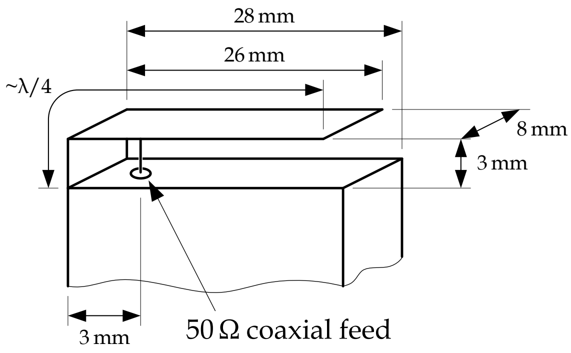

Fig. 4: One quarter of the quad inverted F antenna for 2.45 GHz.

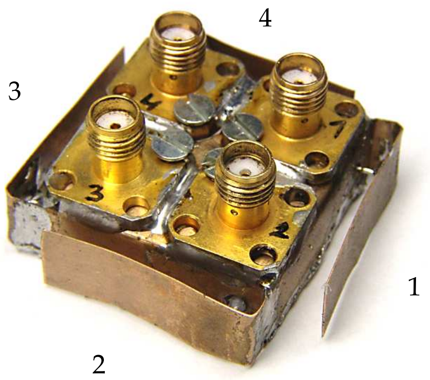

Fig. 5: Picture of the whole quad inverted F antenna showing the numbering of the antenna elements.

III. MEASUREMENT SETUP

The measurements were carried out in the 2.45 GHz ISM (Industrial, Scientific, and Medical) frequency band. This frequency band was chosen for the experiments because it is very close to the UMTS frequencies with similar wave propagation. The measurement results obtained are thus representative for UMTS.

The 2.45 GHz band is also used by WLAN (Wireless Local Area Network) devices. Since it was not possible to disable all WLAN routers near to the receive

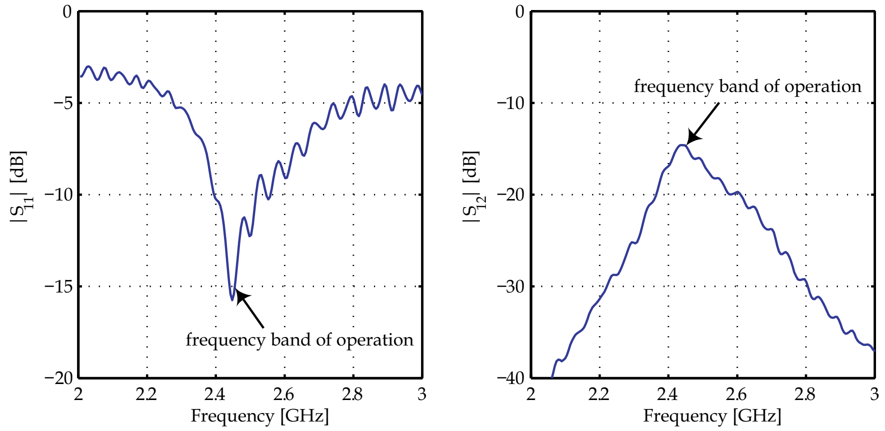

Fig. 6: Magnitudes of selected S-parameters of the inverted-F antenna (matched at 2.45 GHz).

antenna, interference occurred at a small number of transmitted subframes. This interference was approximately the same for all antenna array configurations and therefore did not hinder a fair comparison between the different antenna arrays. It should be noted that interference would also occur in a real UMTS system (although it would be inter-cell interference from other base stations), therefore the experimental results get even more realistic.

The transmit and receive antenna arrays were located inside a building in an NLOS (Non Line of Sight) scenario. The receive antenna array was moved by means of a cross-slide arrangement to obtain 400 different MIMO channel realizations. An area of $2\lambda \times 2\lambda$ with a step size of 0.1λ was covered by the antenna positions. This small area ensures that only small-scale fading occurs.

A detailed description of the measurement setup and the radio frequency frontend can be found in [12].

IV. MEASUREMENT RESULTS

For the measurements a fixed CQI (Channel Quality Indicator) value of zero was selected [3]. This CQI value corresponds to the transmission of two independent data streams with code rate 3/4. After mapping to a 16-QAM symbol alphabet the two symbol streams are Alamouti coded, generating the symbols for the four transmit antennas. These symbol streams are then multiplexed onto the physical channel by using the same two orthogonal spreading codes of length 16 for every transmit antenna. Note that the assignment of more spreading codes would linearly increase the data throughput since flat fading was observed during the indoor measurements, i.e. no multiple access interference occurred. An overview of the measurement parameters is given in Tables II and III. During the measurements the HS-PDSCH (High Speed Physical Downlink Shared Channel) E_c/I_{or}, i.e. energy of the data chip stream over total available transmitter energy, was varied to obtain measurements for different signal to noise ratios at the receiver.

TABLE II: Common measurement parameters.

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

TABLE III: DSTTD measurement parameters.

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	

A. Throughput vs. Number of Receive Antennas

The measured system throughput with the linear array with unequal spacing as transmit antenna array is depicted in Fig. 7 for different number of receive antennas. The dashed and solid lines represent the close-spaced linear array and the quad inverted-F antenna array as receive antenna, respectively.

The measurement in Fig. 7 shows clearly that the quad inverted-F antenna performs approximately like the close-spaced linear antenna array although the size is much smaller. We observe furthermore that the use of three instead of two receive antennas dramatically increases the throughput, whereas the use of four instead of three receive antennas only marginally influences the performance. It can therefore be concluded that the optimum number of receive antennas (in terms of performance and complexity) for DSTTD-SGRC is three.

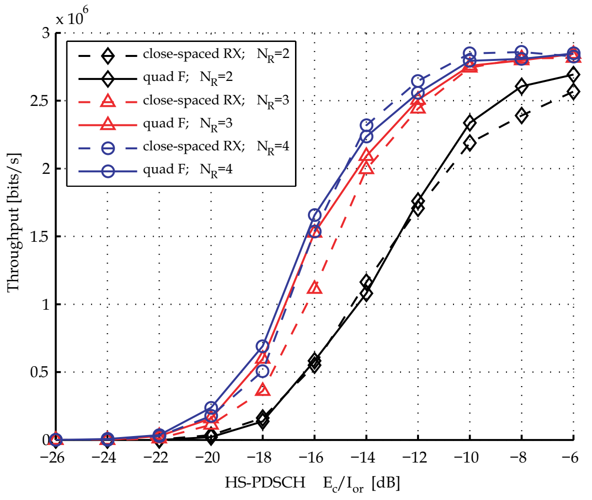

Fig. 7: Throughput measurement for varying number of receive antennas N_R.

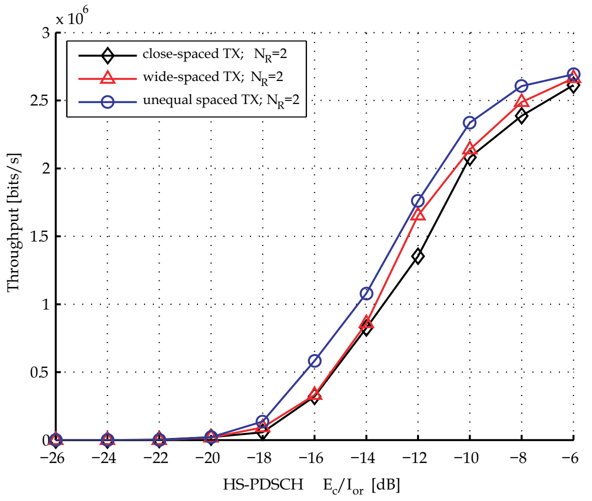

Fig. 8: Throughput measurement for different transmit antenna arrays.

B. *Throughput of Different Transmit Antenna Arrays*

The throughput for the three different linear transmit antenna arrays is depicted in Fig. 8. As receive antenna array the quad inverted-F antenna was used in this experiment. We observe that the wide-spaced antenna array outperforms the close-spaced array by about 0.5 to 1 dB, at the cost of nearly four times the antenna size. An additional 1 dB can be gained by the non equal spacing proposed in [5].

C. *Throughput of Quad Inverted-F Antenna*

To reduce hardware complexity, the number of antennas at the mobile should be kept at the minimum required. Therefore, we investigated which receive antennas shall be used for reception and which elements could be omitted. Fig. 9 shows the throughput when two antenna elements of the quad inverted-F antenna are used. In the region of interest (slightly below the maximum throughput at approximately HS-PDSCH E_c/I_{or}=-8 dB) all receive antenna combinations yield nearly the same throughput. It makes therefore no difference which two of the four elements of the quad inverted-F antenna are used for reception.

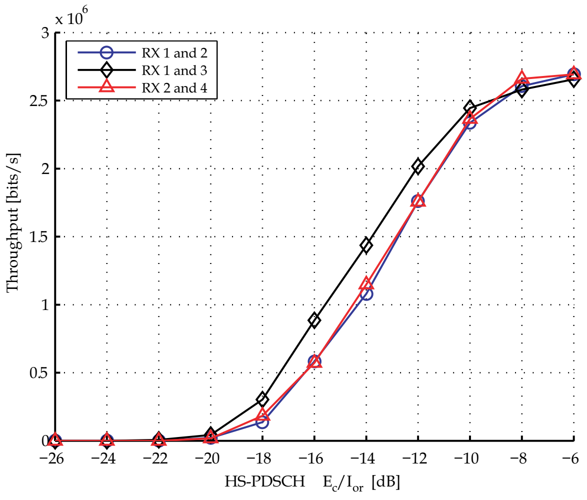

Fig. 9: Throughput when two elements of the quad inverted-F antenna are used for reception.

V. CONCLUSIONS

Throughput measurements of the DSTTD-SGRC proposal for MIMO UMTS high speed downlink packet access have been presented for different transmit and receive antenna arrays. The measurements show that the quad inverted-F antenna is perfectly suited as an internal MIMO antenna of a mobile terminal and it performs approximately like a linear antenna array with $0.5\,\lambda$ spacing. When using three elements of the quad inverted-F antenna, an optimum tradeoff between handset complexity and performance is achieved. Additionally, it was shown that a linear transmit antenna array with non equal spacing outperforms an array with equal spacing. When using not all elements of the quad inverted-F antenna, it can be chosen arbitrarily which elements are built into the mobile terminal.

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