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On Reduced-Complexity Variants to The Double Space-Time Transmit Diversity Proposal for UMTS

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Abstract— **In this paper the throughput performance of the DSTTD (Double Space-Time Transmit Diversity) proposal that is under consideration for the MIMO extension of UMTS HSDPA (High Speed Downlink Packet Access) is investigated in realistic environments. We introduce slight modifications to the DSTTD proposal to reduce the complexity of the transmitter as well as the receiver. Furthermore, this modified DSTTD scheme only uses one acknowledge signal instead of two, reducing the signalling effort at only minor performance loss. The modified DSTTD scheme is compared to the original DSTTD proposal by means of throughput simulations in uncorrelated and spatially correlated flat fading MIMO channels. From our simulation results we conclude several important design criteria.**

I. Introduction

The HSDPA (High Speed Downlink Packet Access) channels of UMTS provide data rates up to 14.4 Mbit/s and are currently incorporated into the networks by providers. The high data rate of HSDPA is achieved by fast acknowledging, Hybrid ARQ, and adaptive modulation and coding. In a next step these data rates, as well as the spectral efficiency of the overall system, will be further increased by the use of MIMO (Multiple-Input Multiple-Output) techniques [1], [2]. For this purpose eight different corporate proposals were submitted to the 3GPP and are summarized in the technical report 25.876 [3]. All these proposals are using four transmit antennas at the Node B and at least two receive antennas at the user equipment. By using a 6 bit CQI (Channel Quality Indicator) value, the modulation and coding is adapted to the actual channel realization. The MIMO proposals differ in the actual meaning of the CQI feedback information and the space-time coding used. Therefore, simple uncoded BER simulations are not sufficient for a meaningful comparison of the proposals, and detailed throughput comparisons are necessary.

In the original DSTTD proposal, two data streams (also denoted as subgroups) are independently Turbo coded and interleaved. Both data streams are also individually protected by CRC (Cyclic Redundancy Check) bits allowing for acknowledging the subgroups independently. Unfortunately, these independent acknowledge signals demand for changes in the uplink HS-DPCCH (High Speed Dedicated Physical Common Control Channel) defined in [4]. If only one acknowledge signal can be used for DSTTD, the uplink control channel could remain the same as in SISO HSDPA. Therefore, it is important to know the impact of joint acknowledging both subgroups on the system throughput.

All simulation results presented in Section IV were obtained with a UMTS Release 5 HSDPA simulator [5] which was extended by the DSTTD mode for MIMO throughput simulations. The UMTS Release 5 HSDPA simulator was originally intended for analyzing various receivers on complying with the performance requirements specified in [6]. Since the performance requirements are always given at certain HS-PDSCH E_c/I_{or} (chip energy of the data stream over total radiated energy) values, our simulations were also performed over HS-PDSCH E_c/I_{or}.

The paper is organized as follows. In Section II we give an overview about the original DSTTD proposal and its drawbacks. A modified DSTTD scheme is presented in Section III, improving the original scheme in terms of complexity. Section IV presents throughput results for spatially uncorrelated and correlated flat fading MIMO channels. Finally, conclusions are reported in Section V.

II. Original DSTTD Scheme

The DSTTD scheme proposed by MERL (Mitsubishi Electric Research Laboratories) for the MIMO extension of UMTS HSDPA was implemented according to [3]. This section gives a short overview about the original scheme and its drawbacks that will be resolved by the modified DSTTD scheme presented in the next section.

A. DSTTD transmitter

The original DSTTD transmitter splits the HS-PDSCH (High-Speed Physical Downlink Shared Channel) bitstream into two subgroups which are coded separately. Depending on the channel quality, the symbol constellation (QPSK or 16-QAM) and the coding rate is selected. The adaptive coding rate is achieved by performing puncturing and bit stuffing on the output bits of the rate 1/3 Turbo encoder.

After symbol mapping, Alamouti coding [7] is performed on each subgroup to add transmit diversity. The four resulting symbol streams are demultiplexed onto several physical channels (i.e. different channelization codes) and scrambled by the scrambling sequence assigned to the Node B.

B. MMSE-SIC Receiver

The original DSTTD proposal also includes a suggestion for the space-time receiver, the so-called MMSE-SIC (Mini-

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mum Mean Squared Error with Successive Interference Cancelation) receiver. The first task of the MMSE-SIC receiver is to determine the decoding order of the two subgroups. In [8] a decoding order was proposed which takes into account the SIR and different coding and modulation of both subgroups. The decoding order in [8] is decided by

$$\frac{h_1^2}{\mathrm{TBS}_1} \underset{\mathrm{SG2}}{\overset{\mathrm{SG1}}{\gtrless}} \frac{h_2^2}{\mathrm{TBS}_2}, \tag{1}$$

where h_k^2 is the gain of the MIMO channel matrix seen by the k-th subgroup. The Transport Block Size (TBS) is the number of information bits transmitted within one subframe. Note that this decision is based on the energy per information bit in each subgroup. In the following we assume without loss of generality that the first subgroup is detected first, i.e. the first subgroup has the higher SIR.

When the decoding order is decided, a linear MMSE receiver calculates estimations for the transmit symbols of the first subgroup. Theses symbols are then soft demapped to LLR (Log Likelihood Ratio) values that are further processed in a Turbo decoder. After the decoding operation, the bitstream is treated like in the transmitter, i.e. coded, interleaved, and mapped to symbols. The reconstructed transmit symbols are then multiplied by the estimated channel matrix and subtracted from the received symbols to perform the interference cancelation. After interference cancelation, the remaining symbols of the second subgroup can be easily detected by a standard Alamouti receiver [7].

Reference [8] showed that the MMSE-SIC receiver performs very well in uncorrelated MIMO channels and achieves about 94% of the ML (Maximum Likelihood) throughput at high SNR values. Unfortunately, the original DSTTD scheme and the MMSE-SIC receiver incorporate the following drawbacks:

1) Due to the successive Turbo decoding a large decoding delay is incorporated in the receiver.
2) Two Turbo decoders are needed for decoding a continuous DSTTD data stream.
3) Two acknowledge signals are needed in the uplink control channel. The transmission of the second ACK signal requires a change in the structure of the control channel which, of course, should be avoided if possible. Note, that the two ACK signals can be easily combined to a single ACK signal by a logical AND-operation. This scheme was also investigated and will be referred as *"original DSTTD with one ACK signal"* in the throughput simulations.

III. Modified DSTTD Scheme

In this section we present a modified DSTTD scheme compensating for the above mentioned drawbacks of the original DSTTD scheme.

A. Modified DSTTD Transmitter

In contrast to the original DSTTD proposal, the serial to parallel converter is shifted after the Turbo Coder. This has the advantage that only one Turbo coder is needed in the transmitter and, more importantly, only one Turbo decoder is needed in the UE (User Equipment) to comply with the strict timing requirements for the ACK signal. After serial to parallel conversion of the coded bits, separate rate matching and interleaving is performed for the two subgroups to account for the adaptive coding in the DSTTD proposal. The advantage of the joint coding is a lower transmitter and receiver complexity since only one Turbo coder and decoder has to be implemented. However, due to the joint coding and the joint cyclic redundancy check, both subgroups cannot be acknowledged separately anymore. Therefore, we would expect a loss in throughput for this scheme. In Section IV we will see that jointly acknowledging both subgroups has only a moderate impact on the system throughput.

B. Modified DSTTD Receiver

Because of the joint channel coding of both subgroups in the modified DSTTD transmitter, the original DSTTD receiver has to be modified. Instead of performing the interference cancelation with symbols reconstructed from the decoded bit stream, the receiver for the modified DSTTD scheme performs the interference cancelation with hard decision values of the soft symbols obtained after the linear MMSE receiver. This process is depicted in Fig. 1. Since the interference cancelation is now performed before the decoding operation, a slightly different SIR has to be evaluated to reveal the decoding order of the subgroups. In our simulations we used the following SIR estimate:

$$\frac{h_1^2}{(\mathrm{Bits/Symbol})_1} \underset{\mathrm{SG2}}{\overset{\mathrm{SG1}}{\gtrless}} \frac{h_2^2}{(\mathrm{Bits/Symbol})_2}. \tag{2}$$

Note, that in contrast to (1), (2) implements a comparison of the coded bit energies.

After decoding the interference canceled receive symbols in a standard Alamouti receiver, both subgroups are soft demapped, deinterleaved, and inverse rate matched independently. Then the soft-bits of the two subgroups are parallel to serial converted facilitating joint Turbo decoding and further processing.

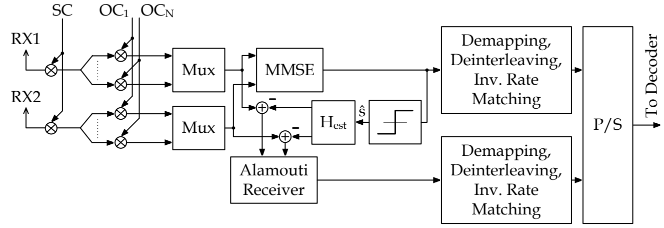

Fig. 1. Modified DSTTD receiver.

IV. Throughput Results

An overview of the simulation parameters used is given in Tables I and II. Table I shows the common simulation parameters of the HSDPA simulator. Reference [9] explains these parameters in detail.

TABLE I
COMMON SIMULATION PARAMETERS.

Parameter	Value
UE capability class	6
Max. no. of retransmissions	3
Combining	soft
RV coding sequence	{6,2,1,5}
$\mathrm{P-CPICH}\ E_c/I_{or}$	$-10\,\mathrm{dB}$
$\mathrm{SCH}\ E_c/I_{or}$	$-12\,\mathrm{dB}$
$\mathrm{P-CCPCH}\ E_c/I_{or}$	$-12\,\mathrm{dB}$
OCNS	on
$\hat{I}_{or}/I_{oc}$	15 dB
Channel coefficient estimation	least squares
Turbo decoding	max-log-MAP - 8 iterations

TABLE II
DSTTD SIMULATION PARAMETERS.

Parameter	Value	
CQI	2	
Modulation	16-QAM	
Subgroup	SG1	SG2
Transport Block Size	960 bits	1440 bits
Coding Rate	1 / 2	3 / 4
No. of OVSF Sequences per user	2	
Peak Data Rate	2.4 Mbps	

All simulations were performed for several HS-PDSCH E_c/I_{or} (chip energy of the data stream over total radiated energy) values. The $\hat{I}_{or}/I_{oc}$ ratio is defined at the UE and is the ratio between the mean energy received from the desired Node B and the mean interferer energy. We assumed an $\hat{I}_{or}/I_{oc} = 15\,\mathrm{dB}$ and modeled the interferers evolving from other basestations as additive white Gaussian noise. This assumption is feasible since the different basestations are using different scrambling sequences.

For all simulations we transmitted at a fixed CQI (Channel Quality Indicator) value of two, corresponding to a peak data rate of 2.4 Mbps when two channelization codes are assigned to the user.

A. DSTTD Throughput for Different Acknowledge Methods

The throughput curves for a spatially uncorrelated flat fading MIMO channel are illustrated in Fig. 2. At high HS-PDSCH E_c/I_{or} the three DSTTD schemes perform almost identically. At low HS-PDSCH E_c/I_{or} the modified DSTTD scheme with one acknowledge signal even outperforms the original DSTTD scheme with two acknowledge signals. This fact can be explained by the interference cancelation method. Since the original DSTTD scheme performs Turbo decoding and error correction before interference cancelation, it can happen at low E_c/I_{or} that additional bit errors are introduced on the bit stream resulting in error propagation and lower overall system throughput. However, as defined in [10] a CQI value shall be reported from the UE (User Equipment) to the Node B ensuring that the transport block error probability does not exceed 10 %. Therefore, we should compare the different DSTTD schemes at approximately 90% of the peak

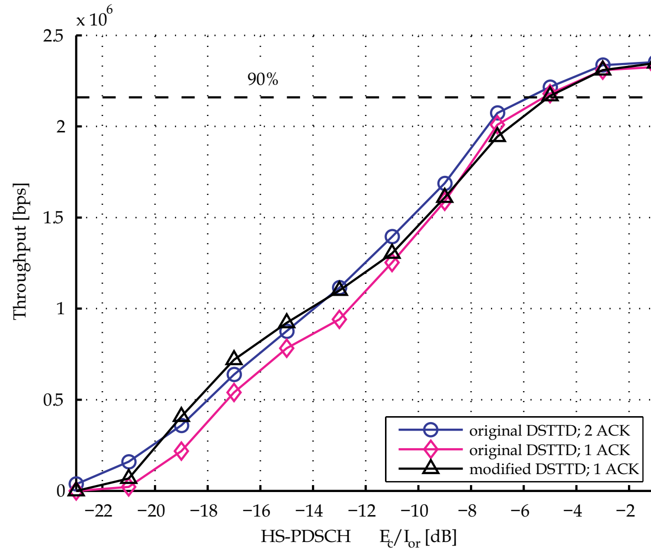

Fig. 2. Throughput comparison of the original DSTTD proposal and the modified DSTTD proposals in a spatially uncorrelated MIMO channel.

throughput. When comparing the original proposal with two ACK signals to the modified DSTTD at this 90% peak throughput, we observe a slight advantage of the original scheme of 0.7 dB in E_c/I_{or}.

B. DSTTD Throughput in Correlated Channels

Reference [11] showed that the DSTTD code suffers from high spatial correlation. Since the user equipment in mobile communication systems is typically very small, strongly correlated channels have to be expected. To investigate the influence of spatial correlation on the throughput, the MIMO channel was modeled by a simple Kronecker model. Realizations of the channel matrix $\mathbf{H}$ were obtained from

$$\mathbf{H} = \mathbf{R}_r^{\frac{1}{2}} \cdot \mathbf{U} \cdot (\mathbf{R}_t^{\frac{1}{2}})^T, \tag{3}$$

with the receive and transmit correlation matrices $\mathbf{R}_r$ and $\mathbf{R}_t$, and a matrix $\mathbf{U}$ with i.i.d. complex Gaussian entries. The correlation matrices for the 4×2 system were chosen as

$$\mathbf{R}_r = \begin{bmatrix} 1 & \rho_r \\ \rho_r & 1 \end{bmatrix}, \tag{4}$$

$$\mathbf{R}_t^{(1)} = \begin{bmatrix} 1 & \rho_t & \rho_t^2 & \rho_t^3 \\ \rho_t & 1 & \rho_t & \rho_t^2 \\ \rho_t^2 & \rho_t & 1 & \rho_t \\ \rho_t^3 & \rho_t^2 & \rho_t & 1 \end{bmatrix}, \tag{5}$$

$$\mathbf{R}_t^{(2)} = \begin{bmatrix} 1 & \rho_t & 0 & 0 \\ \rho_t & 1 & 0 & 0 \\ 0 & 0 & 1 & \rho_t \\ 0 & 0 & \rho_t & 1 \end{bmatrix}. \tag{6}$$

The transmit correlation matrix $\mathbf{R}_t^{(1)}$ corresponds to an antenna configuration where all antennas are placed on a linear array with equal spacing, whereas $\mathbf{R}_t^{(2)}$ corresponds to a configuration where the antennas of one subgroup are close to each other and antennas of different subgroups are well separated in space.

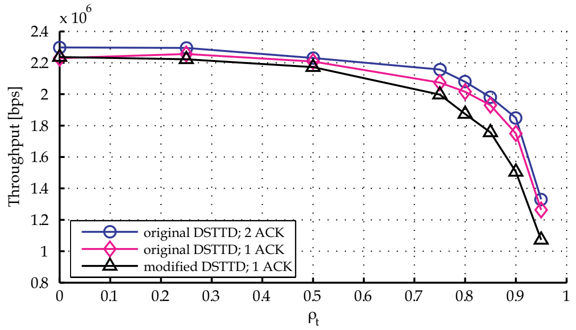

Fig. 3. Throughput performance of DSTTD depending on the transmit correlation (E_c/I_{or}=-4 dB, correlation matrix $\mathbf{R}_t^{(1)}$, and $\rho_r = 0$).

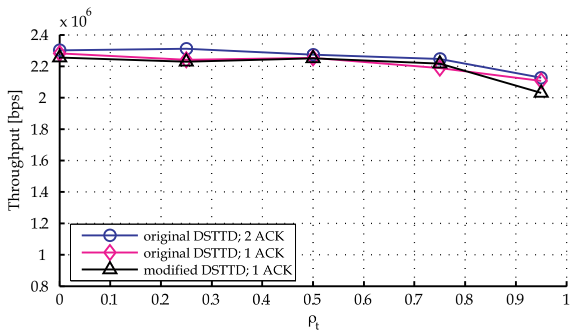

Fig. 4. Throughput performance of DSTTD depending on the transmit correlation (E_c/I_{or}=-4 dB, correlation matrix $\mathbf{R}_t^{(2)}$, and $\rho_r = 0$).

TX correlation for $\mathbf{R}_t^{(1)}$

The throughput for equally spaced transmit antennas is shown in Fig. 3. Up to a transmit correlation of $\rho_t = 0.75$ we notice only small degradations in the system throughput.

TX correlation for $\mathbf{R}_t^{(2)}$

Fig. 4 depicts the throughput dependent on the transmit correlation ρ_t and correlation matrix $\mathbf{R}_t^{(2)}$. We can observe that due to separation of the subgroup antennas, the throughput becomes nearly independent of the correlation factor. Therefore, we can conclude an optimized transmit antenna configuration for the DSTTD scheme. Antennas of different subgroups should be separated in space as good as possible, whereas antennas belonging to the same subgroup can be spaced near to each other without performance loss. When the size of the MIMO antenna is limited, a performance enhancement can be achieved by moving the inner antennas towards the outer antennas, as shown in Fig. 5.

RX correlation

The throughput for different values of the RX correlation factor ρ_r is illustrated in Fig. 6. We observe only moderate throughput loss up to an RX correlation of about 0.7. When

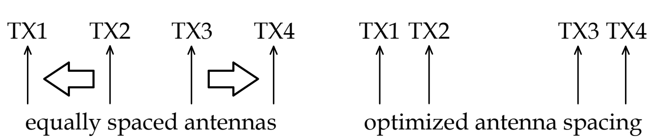

Fig. 5. Antenna spacing optimization for DSTTD (subgroup one is transmitted over TX1 and TX2, subgroup two is transmitted over TX3 and TX4).

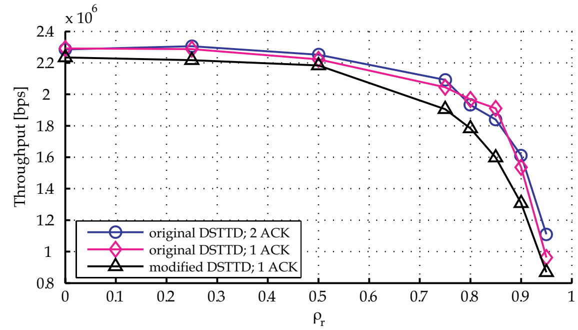

Fig. 6. Throughput performance of DSTTD depending on the receive correlation (E_c/I_{or}=-4 dB and $\rho_t = 0$).

the correlation exceeds 0.8 a dramatic loss in throughput occurs. Therefore, one design goal for the user equipment antennas is to obtain a spatial correlation factor that is smaller than 0.7.

V. Conclusions

A slightly modified DSTTD-SGRC proposal that greatly reduces the complexity of the user equipment was presented. In throughput simulations, it was shown that these modifications only cost minor loss in system throughput militating in favor of the modifications. Additionally, the throughput simulations for spatially correlated MIMO channels revealed design criteria for the transmit and receive antennas.

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