Performance Evaluation of Opportunistic Beamforming with SINR Prediction for HSDPA

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Abstract—In this paper, Opportunistic Beamforming for HSDPA is considered. Opportunistic Beamforming can jointly increase the system throughput and the quality of service in multiuser communication systems with Proportional-Fair Scheduling, since with this beamforming scheme a user experiences more fading peaks in a given period of time. However, the existence of an SINR feedback delay from the user to the base station degrades the performance in such a system rapidly due to outdated and thus mismatched SINR information. Here, the prediction of the SINR in the base station is proposed with a predictor structure that is matched to the beamforming process.

I. INTRODUCTION

In this work, the downlink of an HSDPA system is considered, where multiple users are being scheduled in a TDMA fashion. The capacity of such a system can be increased compared to the point-to-point case if information about the instantaneous signal-to-interference-plus-noise ratio (SINR) of every user is available in the base station. In such a case, so-called channel aware scheduling may be employed, where in every time slot a user with favorable fading conditions is selected for transmission. Since the channel of this user is relatively strong, a transmission scheme with higher spectral efficiency may be selected via adaptive modulation and coding (AMC), thus increasing the overall system capacity. For base stations featuring multiple antennas, the authors in [1] propose a very simple scheme to increase the throughput even further: A beam is formed without any knowledge about the position of the users into a random direction, so that users that happen to be inside the main lobe of the beam receive a beamforming gain. The direction of the beam is changed every time slot, so that every user benefits from the beam every once in a while. For a large number of users, this relatively simple so-called Opportunistic Beamforming can reach the same throughput as coherent beamforming (cf. [1]), while only requiring instantaneous SINR information as opposed to the full instantaneous channel vector for coherent beamforming. In realistic systems, information about the channel quality cannot be instantaneous but is outdated to some degree. Firstly, the SINR estimation in the receiver takes some time, and secondly, the user has to wait for the next channel allocation to report his SINR to the base station. To still be able to use the SINR information for channel-aware scheduling and AMC mode selection, the authors in [1] propose not to change the beamforming vector too much within this time span. As this is in contrast to the original purpose of increasing the channel dynamics, other ways of reducing the effect of outdated SINR information have been devised. In [3] the complete physical channel vector is tracked in the base station, using a low-rate feedback of received data from the users. With an estimate of the instantaneous channel, beamforming vectors could be chosen freely, but the increase in uplink signaling load is disadvantageous especially in cases with many users. In [8], a predictive scheduler in the base station is considered. Results were given for a scenario without beamforming if knowledge of the complex-valued channel coefficient is available. This represents double the necessary feedback compared to real-valued SINR feedback. While the increase in throughput was remarkable, the necessary number of predictor coefficients was relatively high.

Another possibility is the prediction of the SINR in the mobile (cf. [5]). This requires information about the underlying statistics of the effective channel and thus about the beamforming process, which requires the base station to maintain the process for a longer period of time. Also, complex calculations in the user equipment should be avoided because of energy consumption and device cost reasons.

This paper picks up the work from [2], where the SINR prediction for a generic signal model was shown. In this paper, the applicability of a SINR prediction for Opportunistic Beamforming in the context of HSDPA is being considered. HSDPA provides channel quality information in the base station by means of CQI (channel quality indicator) feedback. This feedback can be used to predict the actual SINR at the mobile at the scheduling time. The SINR prediction will be facilitated with an RLS adaptive filter with a very low number of coefficients.

The structure of this document is as follows: After the introduction in Section 1, Section 2 describes the signal model. Section 3 introduces the prediction algorithm. Section 4 analyzes the performance of the predictor in terms of system throughput and Section 5 concludes the document.

II. SYSTEM MODEL

A. Basic Simulation Methodology

A standard cell layout consisting of a hexagonal grid is assumed, where each hexagon represents a cell. The simulator
operates at transmission time interval (TTI) level, which is the scheduling time interval in HSDPA. The system level simulator employs an actual value interface (AVI), which maps the current SINR, modulation alphabet and code rate to the block error rate (BLER) and originates from [11]. When HARQ is also taken into account, the resulting throughput as a function of SINR and adaptive modulation and code rate (AMC) scheme is shown in Figure 1, which constitutes the link-level/system-level interface.

![Figure 1. SINR-Throughput mapping for 31 AMC modes assuming chase combining with up to three retransmissions](image)

The resulting throughput for the AMC mode 25 is highlighted in Figure 1 for convenience to show the effect of the HARQ on the throughput.

### B. Model for the HSDPA concept

The high speed physical downlink shared channel (HS-PDSCH), which is the data channel in HSDPA, receives a fixed amount of the total transmit power. The remaining power is used for other channel types such as synchronization and pilot channels. The spreading factor for the HS-PDSCH is 16. A number of user equipments (UEs) is scheduled simultaneously in different beams and inter-symbol interference (ISI) because of multipath propagation. Table I lists the various quantities of the signal model. The thermal noise power is labeled by $N$ and the intercell interference power is modeled as a location dependent constant, which has been determined through extensive link-level simulations involving six rings of cells around the cell of interest. Figure 2 shows a contour plot of the ratio between the total intercell interference power and the total long term averaged signal power in dB.

### C. Signal Model

The SINR is calculated for every UE in every TTI and is then fed back to the base station. The base station receives this SINR feedback with a feedback delay and decides the AMC format. The achieved throughput depends on the actual instantaneous SINR and the selected AMC mode. The UEs are assumed to have a rake receiver with maximum ratio combining of the $L$ fingers. With a similar signal model as in [6], the SINR for a UE $i$ on beam $j$ at time $k$ is given as:

$$\gamma_{i,j}(k) = \sum_{l=1}^{L} \gamma_{i,j,l}(k),$$

where the terms

$$\gamma_{i,j,l}(k) = \frac{S_{i,j,l}(k)}{N + I_{i,j,l}^{\text{intr}}(k) + I_{i,j,l}^{\text{inter}}(k)}$$

denote the SINR at the output of rake finger $l$. The quantities

$$S_{i,j,l}(k) = \varepsilon \cdot F_S \cdot P_{TX}^{\text{total}} \cdot |w_j^H h_{i,l}(k)|^2$$

$$I_{i,j,l}^{\text{intr}}(k) = \sum_{d=1}^{N_B} \sum_{k=1}^{D} \frac{P_{TX}^{\text{total}} \cdot |w_j^H h_{i,d}(k)|^2}{P_{TX}^{\text{total}} \cdot |w_j^H h_{i,d}(k)|^2}$$

denote the signal and intracell interference power, respectively, where the latter includes both multiple access interference (MAI) because of the $N_B$ different beams and inter-symbol interference (ISI) because of multipath propagation. Table I lists the various quantities of the signal model. The thermal noise power is labeled by $N$ and the intercell interference power is modeled as a location dependent constant, which has been determined through extensive link-level simulations involving six rings of cells around the cell of interest. Figure 2 shows a contour plot of the ratio between the total intercell interference power and the total long term averaged signal power in dB.

### D. Beamforming Pattern

In Section IV, we investigate the performance for phased-array beamforming, which is proposed in [1] and [7] for spatially highly correlated scenarios such as outdoor macrocell.
Phased-Array Beamforming is described by a beamforming vector
\[
\mathbf{w}_\phi = \frac{1}{\sqrt{N_B}} \left( e^{j2\pi \frac{d}{\lambda} \sin \phi}, \ldots, e^{j2\pi (N_B - 1) \frac{d}{\lambda} \sin \phi} \right)^T,
\]
where \( \phi \) is the direction of the main lobe of the beam with respect to the broadside direction, \( d \) is the distance between adjacent antenna elements and \( \lambda \) is the carrier wavelength.

In this contribution an SDMA approach is considered. The total sector of 120° is divided into \( N_B \) subsectors of equal size \( \Delta S \). The angle of beam \( j \) is assumed to increase linearly in time
\[
\phi_j(k) = \phi_{0,j} + \Delta \phi \cdot k
\]
as long as \( \phi_j \) is contained inside the part of the cell that is associated with the beam \( j \), i.e. inside
\[
S_j = [-60° + (j - 1) \Delta S, -60° + j \Delta S],
\]
and begins at \(-60° + (j - 1) \Delta S\) again if the angle would leave this interval. The quantity \( \Delta \phi \) is called the angle increment.

The whole beamforming process can thus be understood as a grid of \( N_B \) beams from \( N_T \) antennas, which is rotated to scan the whole cell.

The period length and the angle increment are related according to
\[
N_p = \left\lfloor \frac{120°}{N_B \Delta \phi} \right\rfloor.
\]
Since the beamforming process is periodic with period length \( N_p \), the resulting SINR is cyclostationary.

E. SINR Feedback

The UE \( i \) feeds SINR information back to the base station for exactly one beam \( B_i \). This is the beam that scans inside the subsector in which the UE is located. The feedback delay for SINR transmission is \( N_D \) time slots.

F. Scheduling

A scheduling decision is made according to the Multi-User Proportional-Fair Scheduling algorithm that was proposed in [13]. Here, among all users \( 1 \leq i \leq I \) the set of users \( U^* \) with
\[
U^* = \arg \max_{U} \sum_{i \in U} \frac{R_i(k)}{T_i(k)}
\]
is scheduled, where \( R_i(k) \) is the throughput of user \( i \). Every UE may only be scheduled on the beam \( B_i \) for which it sends SINR information to the base station.

The past throughput is calculated with an exponential averaging filter:
\[
T_i(k) = \begin{cases} (1 - \frac{1}{t_c})T_i(k) + \frac{1}{t_c} R_i(k), & i \in U^* \\ (1 - \frac{1}{t_c})T_i(k), & \text{else} \end{cases}
\]

The choice of the scheduler time constant \( t_c \) is crucial for the properties of the scheduler. This time constant describes how long a scheduling instant may be delayed for a particular user. Thus, if the scheduler time constant is high, users may be scheduled in channel peaks even if a long time passes between peaks. A high \( t_c \) is thus beneficial for throughput since scheduling occurs predominantly in good channel conditions but affects quality of service (QoS) negatively since the scheduling becomes irregular.

G. Simulation Parameters

A list of the default simulation parameters is given in Table II. The correlation of shadowing describes the correlation between the shadowing coefficients for signal power and intracell interference power on the one hand and intercell interference power on the other hand.
### TABLE II
**DEFAULT SIMULATION PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency</td>
<td>2 GHz</td>
</tr>
<tr>
<td>TTI duration</td>
<td>2 ms</td>
</tr>
<tr>
<td>Inter-site distance</td>
<td>2000 m</td>
</tr>
<tr>
<td>Sectorized</td>
<td>Yes</td>
</tr>
<tr>
<td>Sectorization pattern</td>
<td>-10 dB at 60°</td>
</tr>
<tr>
<td>HARQ</td>
<td>Chase-combining</td>
</tr>
<tr>
<td>Max. # of retransmissions</td>
<td>3</td>
</tr>
<tr>
<td>Transmit power</td>
<td>20 W</td>
</tr>
<tr>
<td>Power of the HS-PDSCH</td>
<td>16 W</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>17 dBi</td>
</tr>
<tr>
<td>Std of shadow fading</td>
<td>8 dB</td>
</tr>
<tr>
<td>Correlation of shadowing</td>
<td>0.3</td>
</tr>
<tr>
<td>Path loss exponent</td>
<td>3.76</td>
</tr>
<tr>
<td>Thermal noise power</td>
<td>-99 dBm</td>
</tr>
<tr>
<td>Number of UEs</td>
<td>10</td>
</tr>
<tr>
<td>Number of Rake fingers</td>
<td>4</td>
</tr>
<tr>
<td>User placement</td>
<td>uniform (cartesian)</td>
</tr>
<tr>
<td>User velocity</td>
<td>3 km/h</td>
</tr>
<tr>
<td>SINR feedback delay</td>
<td>2 TTI</td>
</tr>
<tr>
<td>Transmit antennas</td>
<td>4</td>
</tr>
<tr>
<td>Beams</td>
<td>2</td>
</tr>
<tr>
<td>Power angular density</td>
<td>Laplacian, 5° std. dev.</td>
</tr>
<tr>
<td>Doppler profile</td>
<td>Jakes spectrum</td>
</tr>
<tr>
<td>Channel power tap 1</td>
<td>0 dB</td>
</tr>
<tr>
<td>Channel power tap 2</td>
<td>-9.7 dB</td>
</tr>
<tr>
<td>Channel power tap 3</td>
<td>-19.2 dB</td>
</tr>
<tr>
<td>Channel power tap 4</td>
<td>-22.8 dB</td>
</tr>
</tbody>
</table>

The training of the RLS predictor can be done without additional signalling: The true SINR value that is predicted at time \( k \) is transmitted to the base station after \( N_D \) time slots. This can be used as the training data to enable the adaptation of the RLS predictor. The adaptation algorithm of the filter is summarized in Table III.

For a periodic beamforming process as e.g. described by (4) and (5), the SINR is not stationary but cyclostationary. We propose in this case to utilize \( N_p \) different adaptive predictors, where each predictor corresponds to one state in the beamforming cycle, as e.g. discussed in [9]. Each predictor is used exactly once per beamforming cycle and also the training is done only once per predictor per cycle. If the RLS filter needs \( N_f \) training SINR values, the total training duration is then \( N_f \) beamforming cycles consisting of \( N_p \) beamforming states each.

### IV. PERFORMANCE ANALYSIS

In this section, the cell throughput is investigated with and without prediction of the actual SINR. Furthermore, the throughput with knowledge of the instantaneous SINR is also given to serve as an upper bound. Figure 3 depicts the achievable system throughput as a function of the angle increment \( \Delta \phi \), if a scheduler time constant of \( t_c = 50 \) TTI is assumed. The dash-dotted line without markers represents the throughput with perfect knowledge of the instantaneous SINR, i.e. with \( N_D = 0 \). Here, an increase in system throughput can be observed for increasing values of \( \Delta \phi \). This can be attributed to the increase in channel dynamics, highlighting the potential benefit of Opportunistic Beamforming.

The solid line without markers displays the system performance for the case of no prediction of SINR in the base station, i.e. the reported SINR is treated as if it was instantaneous. The throughput increases with an angle increment of up to \( \Delta \phi = 1^\circ \) because of increased channel dynamics. A clear degradation is visible for increasing values of \( \Delta \phi \) larger than \( 1^\circ \), which is due to the fact that the SINR report becomes more unreliable the higher the angular velocity of the beam is. In scenarios where QoS constraints demand users to be scheduled every few time slots, the angular velocity has to be chosen relatively high, so that the beam points to each user within a short period of time. Thus, in scenarios like these, employing Opportunistic Beamforming without SINR prediction leads to
a harsh performance loss due to outdated SINR feedback.

The solid line with circular markers shows the performance of the RLS adaptive filter of length $N_F = 3$ and a training length of 50 beamforming cycles. The throughput increases up to an angle increment of $\Delta \phi = 2^\circ$ and decreases afterwards. However, the overall achieved throughput is clearly increased compared to the case without prediction for all values of the angle increment regarded here. The maximum throughput with prediction at $\Delta \phi = 2^\circ$ represents an increase of about 15% compared to the maximum throughput without prediction occurring at $\Delta \phi = 1^\circ$.

The dash-dotted line with circular markers shows the performance if 10 beamforming cycles are used for the adaptation. Even though the throughput is not as high as with 50 cycles, the increase compared to the case without prediction is still remarkable. Here, the maximum throughput is also achieved with $\Delta \phi = 2^\circ$.

The solid and dash-dotted lines with cross markers shows the performance of the RLS adaptive filter with only $N_F = 1$ filter coefficient and a training length of 50 and 10 beamforming cycles, respectively. A throughput increase is observable predominantly for higher values of the angle increment.

Even though the adaptation of the predictor coefficients can be carried out throughout the whole transmission, the restriction to a finite training duration of $N_t$ cycles was made to show the performance if the adaptation is switched off at some point of time to reduce the computational load and to give an impression of the ability of the predictor to track changing long-term signal statistics.

The regarded range of the number of UEs.

V. CONCLUSION

In this paper it was shown that while an increase in channel dynamics e.g. by Opportunistic Beamforming can increase the system throughput, care must be taken not to increase the channel dynamics too much. In order to overcome the limit on the beamforming speed that is caused by an SINR feedback delay, the prediction of the SINR in the base station using an adaptive filter was proposed. The filter structure is matched to the beamforming process in that a separate predictor is used for every state in the periodic beamforming process. The possible gains by this predictor structure were demonstrated in the context of HSDPA, using the relatively low number of only one and three predictor coefficients. On the one hand, the maximally achievable throughput was shown to increase with SINR prediction. On the other hand, this maximally achievable throughput was obtained at a higher angular speed of the beamforming process, indicating that users do not have to wait as long to benefit from the beam, which affects QoS positively.

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REFERENCES


