

POLARISATION DEPENDENT MIMO GAINS ON MULTIUSER DOWNLINK OFDMA WITH A 3GPP LTE AIR INTERFACE IN TYPICAL URBAN OUTDOOR SCENARIOS

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ABSTRACT

Recent studies on spatial multiplexing gain based on antenna polarisation diversity are mostly based on channel measurements or theoretical propagation models. The advantage of using XPD cross-polarised antennas in cellular MIMO-OFDM systems is that XPD antennas save costs and space achieved by a more compact antenna design. The throughput performance is generally considered to be similar to co-polarised antennas with pre-coding. In this paper we show the achievable gains of using cross-polarised antennas as compared to co-polarised antennas at the base station. These cross-polarised antennas are used for adaptive MIMO transmission for typical outdoor scenarios. Our results are based on real-time multi-user (MU) multi-antenna capacity measurements taken with a MIMO-OFDMA system with parameters close to the current 3G-Long-Term-Evolution (LTE) standard. Downlink transmission is considered in a single-cell outdoor scenario. We demonstrate the significant effect of polarisation on the overall system performance, especially on user sum rates when fairness scheduling in OFDMA is applied.

1. INTRODUCTION

Existing cellular infrastructure currently offers cross-polarised antennas at the base station. These antennas are mainly used for diversity combining in the uplink. Recent outdoor measurements indicate that there exists a second strong singular value in the downlink if we exploit cross-polarisation discrimination (XPD) at both the terminal and the base station [1]. This second spatial degree of freedom can be used for spatial multiplexing [2, 3, 4, 5] to increase the system throughput which is also termed as polarisation multiplexing [6].

In this paper, we investigate the impact of polarisation multiplexing in a realistic outdoor environment. We performed LTE test-bed measurements in Berlin using XPD antennas cross-polarised and co-polarised antennas at the base station.

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This real-time measurement data is used for analysis in this paper. Our contributions are as follows.

First, we evaluate the received power statistics and the measured outdoor channel capacity. We illustrate the user sum rate gains with XPD antennas in contrast to co-polarised antennas. The results show that XPD antennas provide good gains at high SNR in LOS channels. The setup consisted of two co-located users moving along a track. Finally, we investigate the scheduler performance in a distributed scenario with randomised user positions. We investigate this in an offline simulation by using real-time measurement data which is then used as input for a scheduler. We compare different scheduling strategies, especially if user fairness is applied and show the offset to the maximum achievable throughput in the scenario. The simulation scenario consists of evenly distributed users moving along a track and fully randomised user positions. Our goal is show the impact of XPD antennas in such a practical scenario when OFDMA scheduling is applied.

2. TEST BED PARAMETERS

The parameter set for the PHY implementation was chosen according to working assumptions in the LTE study item in November 2005. The frequency used was 2.6 GHz with 1200 sub-carriers in 20 MHz bandwidth. The MCS levels for adaptive modulation were QPSK, 16- and 64-QAM. The smallest resource assigned by the BS scheduler is a resource block (RB) which contains 25 sub-carriers on the frequency axis. 7 OFDM symbols form a transmission time interval (TTI) and 20 consecutive TTIs form a radio frame of 10 ms. A full description of the parameter set can be found in [7].

3. FUNCTIONAL DESCRIPTION OF PHY AND MAC

3.1. PHY Layer

The PHY Layer of the MIMO-OFDMA test-bed includes synchronisation, channel estimation, signal separation and basic features of link adaptation. This was implemented similar to

the 1 Gbit/s experiment [8]. For the measurements, we implemented a closed-loop MIMO system in the following way. The user equipment (UE) reports the channel quality information (CQI) to the base station (BS) via a dedicated feedback link. The UE also computes the best spatial mode, whether to transmit with a single stream (SS) or dual stream (DS), and reports it to the BS. These calculations are done for every frequency resource block (RB), as defined in [9]. The CQI feedback is then taken as input for the BS scheduler at the MAC layer. The feedback rate is 9.6 Kbps and the transmit power spectrum is flat.

3.2. MAC Layer

At the MAC layer, frequency dependent multi-user scheduling is implemented for every time slot. In principle, frequency dependent scheduling allows us to fully exploit the resources in a broadband OFDMA system. This is done by allocating resource blocks (RB) independently to users with better spectral efficiency. The proportional fair scheduling (PFS) algorithm [10] additionally incorporates a fairness utility function. The PFS keeps track on the average rate $R_u^j(t)$ of each user u on resource j over a fixed window $t_c = 1280$ ms, where 10 ms is the duration of a radio frame. $Q_u^j(t)$ is the supportable sum rate of user u on a specific resource block j while $R_u^j(t)$ is considered as the long-term rate on resource j . We will drop the time index t for convenience. The proportional fair scheduler will select the user \hat{u} in time slot t for the resource j such that:

$$\hat{u} = \arg \max_u \left\{ \frac{Q_u^j}{R_u^j} \right\} \quad (1)$$

The PFS has to be modified to include spatial mode selection for single and dual stream transmission. This is done by calculating the maximum supportable rate over all available spatial transmission modes, where dual stream transmission is automatically selected if available. It is also possible to run different MCS on both antennas in dual stream transmission mode. This allows to transport different rates Q_u^j on each antenna.

In **Eq. 1**, Q_u^j is updated for every resource block (RB). The number of available resource blocks per antenna is 48. Let \mathbf{w} be a negative exponential smoothing vector of length t_c normalised to 1 and $\hat{\mathbf{Q}}_u^j$ be a vector containing all Q_u^j 's over the time window t_c . The long-term rate R_u^j for user u in each time step t is then calculated by

$$R_u^j = \mathbf{w}^T \hat{\mathbf{Q}}_u^j. \quad (2)$$

The smoothing vector \mathbf{w} in **Eq. 2** allows a weighting of the average user rate in the past in such a way that older user rates have less influence on the user selection process for a resource block.

For comparison we implemented a round-robin TDMA and max-rate OFDMA scheduler. The round-robin TDMA

scheduler allocates all resource blocks to only one user in each time slot and is considered as a *fair* scheduling strategy. In contrast, a max-rate OFDMA scheduler allocates a RB to the best user without regarding fairness criteria and will try to optimise the system throughput for RB j according to:

$$\hat{u} = \arg \max_u \{Q_u^j\} \quad (3)$$

4. MEASUREMENT SCENARIO

4.1. Scenario Description

For the downlink we used 2 transmit antennas at the BS and 2 receive antennas at the UE. Two sets of measurements were performed. One with cross-polarised antennas ($+45^\circ / -45^\circ$) at the BS, and the other with co-polarised antenna elements (each $+45^\circ$). The co-polarised measurements were taken without precoding. At the UE, cross-polarised antennas were used in all measurements. The two co-polarised antennas at the BS were placed on top of each other with an antenna spacing of 10λ . This was to ensure uncorrelated transmit signals. The same antennas were used in the cross-polarised measurement. The BS antennas had a downtilt of 12° . The UE antennas were separated by about 1 meter facing different directions.

4.2. Co-Located Users

The measurement was done with 1 base station (BS) and 2 user equipments (UEs). The two UEs were synchronised to the BS. There was no interference from other BSs. The scenario was a typical urban scenario with a mixture of LOS and NLOS and multipath propagation between buildings. The BS antenna was placed on top of the building of the Heinrich-Hertz-Institut (HHI) at a height of 60 m. Two UEs were placed in a car which was moved at pedestrian speed through the campus of the Technische Universität Berlin. Thus, both UEs were co-located during the measurement. The measurement track is depicted in **Fig. 1**. The colour-code corresponds to the received power along the track with 2x2 MIMO and cross-polarised antennas at the BS and both UEs. The received power ranged from -45 to -75 dbm. The signal degradation caused by reflection on some of the buildings on the campus can be seen in this figure. The longest distance between BS and UE was approximately 250 m. The maximum achievable throughput at -45 dbm with 2x2 MIMO was 157 Mbps.

4.3. Channel Statistics

Fig. 2 shows the received power statistics for each UE for the measurement using co- and XPD cross-polarised antennas at the BS. The plot shows the same channel characteristics for all measurements and UEs. This figure clarifies that the received power measured at the UE is independent of the po-

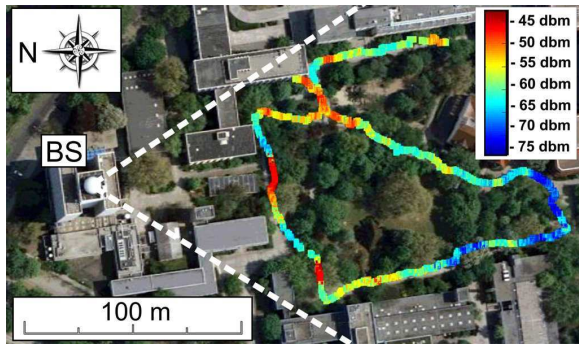


Fig. 1. Received Power on the Measurement Track

larisation used at the BS. The mean received power at the UE was -58.2 dBm with a variance of 21.3 dBm.

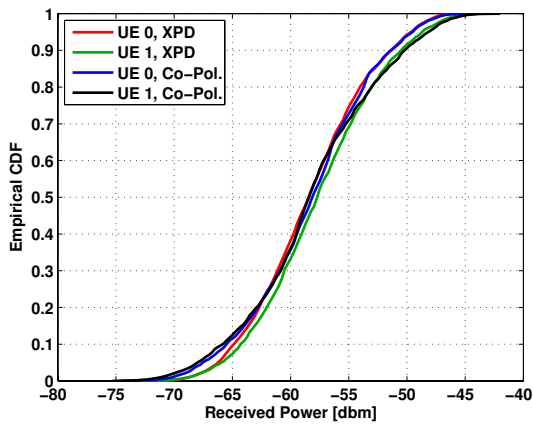


Fig. 2. Channel Variations: Received Power

4.4. Results: Sum Rates

Next, we will take a look at the achievable sum rates in the measurement scenario which is shown in Fig. 3. We compare the statistics for proportional fair scheduling (PFS) with round-robin TDMA and max-rate scheduling. XPD antennas with the same scheduling strategy clearly outperform co-polarised antennas in all cases. XPD antennas with OFDMA proportional fair scheduling (PFS) gives a sum rate gain of approximately 16.5 Mbps. We also compare the performance of the proportional fair OFDMA scheduler to the performance of round-robin TDMA. OFDMA seems to be a clearly better strategy even for correlated feedback if the UEs have LOS to the BS. The gap between TDMA and OFDMA is 9 Mbps with XPD antennas. This results from the fact that RBs are exclusively assigned per OFDM symbol to one UE in TDMA

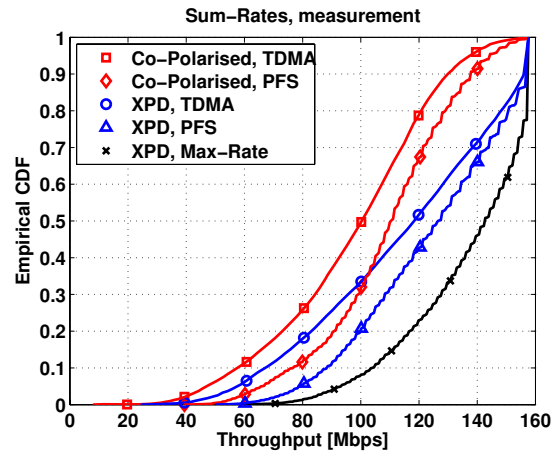


Fig. 3. Sum Rates, 2 co-located UEs

Table 1. Measured Polarisation and Multi-User Gains

MCS and Spatial Mode	A	B	C	D
No Allocation	3 %	0 %	0 %	0 %
Single Stream	24 %	8 %	8 %	2 %
Dual Stream QPSK	0 %	0 %	2 %	2 %
Dual Stream 16-QAM	50 %	58 %	20 %	16 %
Dual Stream 64-QAM	23 %	33 %	70 %	80 %

mode. In this case, RBs suffering from a bad channel condition are left unassigned. In case of OFDMA scheduling, these RBs can be assigned to the other UE. This shows that a lot can be gained from multi-user diversity in LTE systems. For completeness, we also show the achievable rates with the max-rate scheduler and XPD antennas. The fairness gap between max-rate and PFS for the median is 14 Mbps. The mean achievable sum rate with the max-rate scheduler is 143 Mbps. The max-rate scheduler statistic can be considered as an upper bound for the sum rate in this urban scenario.

We decouple the multi-user gains and polarisation gains in Table 1 and show the percentage of allocated resources with single and dual stream. In addition, for dual stream transmission, we show the modulation and coding schema used during the transmission. Column A and B are the scheduler input and scheduler output for the co-polarised measurement. Column C and D show the scheduler input and scheduler output for the XPD cross-polarised antenna case. The scheduler input is the MCS and spatial mode request taken from 2 UEs. The scheduler output list is the MCS and spatial mode list decided by the scheduler. From A, C to B, D we can see the multi-user gain resulting from multi-user scheduling. From A, B to C, D we see the polarisation multiplexing gains.

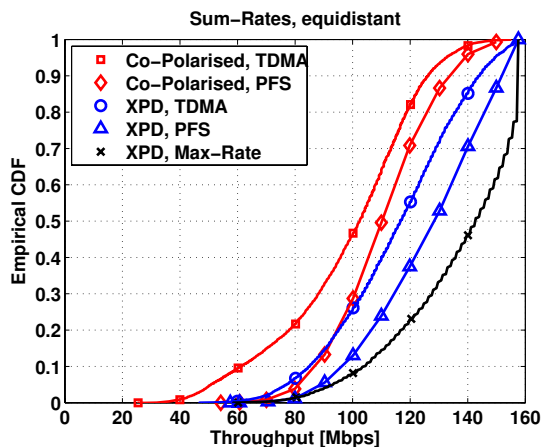


Fig. 4. Sum Rates, 2 equidistant UEs

5. SIMULATION SCENARIO

5.1. Scenario - Randomised Users

The two UEs in the measurement scenario provide correlated input data at the scheduler. This is due to the fact that both UEs are almost located at the same position during the measurement. This causes similar path-loss at both UEs in the same time step. Thus, the scheduler receives correlated CQI feedback from both UEs. To overcome this problem and provide path-loss diversity in a more realistic urban scenario, we implemented an off-line simulation with multiple users in a second scenario. We used the recorded real-time channel measurement data as well as the recorded CQI feedback from the UEs from the measurement as scheduler input in the simulation. We implemented two different positioning algorithms in the simulation for locating the UEs in the simulation scenario. The first algorithm locates UEs equidistantly along the track and makes them move a fixed step size along the measurement track. This will provide pathloss diversity. This was done to see polarisation performance in a realistic scenario. The second algorithm fully randomises UE positions by drawing their positions from a uniform distribution in each time step. This is used to show upper bounds, e.g. maximum multi-user gain, in the simulation setup.

5.2. Results: Sum Rates

In Fig. 4, we show the statistics of the sum rates for 2 UEs which have been put equidistantly on the measurement track. The median sum rates are similar to the sum rates achieved in the co-located scenario from the measurement. We can see the shorter tails towards lower sum rates when compared to Fig. 3. This shows the diversity gain of uncorrelated CQI-feedback already seen with 2 UEs.

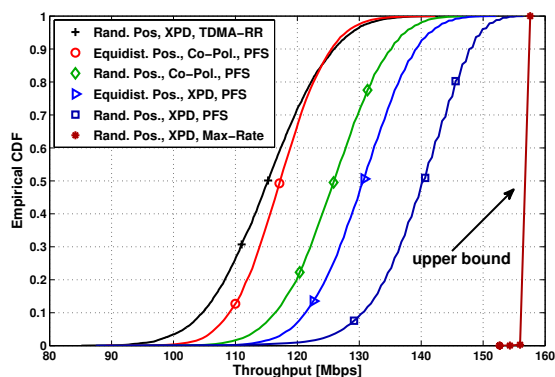


Fig. 5. Sum Rates, 15 UEs

Next, we increase the number of UEs from 2 to 15 UEs. The statistic for this scenario is shown in Fig. 5. Here, we compare the sum rate of equidistantly located UEs with the totally randomised UEs and different scheduling strategies and polarisation multiplexing. Again, XPD cross-polarised antennas outperform co-polarised antennas in all cases. The lower bound is given by round-robin TDMA scheduling with cross-polarised antennas which yields a loss of 45 Mbps as compared to the upper bound, achieved with max-rate scheduler and cross-polarised antennas. With PFS we achieve a gain of approximately 15 Mbps as compared to TDMA scheduling while still fulfilling long-term fairness constraints. The gain grows to 25 Mbps if we approximate many UEs in the scenario by full randomisation of user positions.

6. CONCLUSION

The paper demonstrates achievable MIMO gains using XPD cross-polarised antennas at the base station in different multi-user scenarios. This was done using real-time measurement taken with a LTE-like MIMO-OFDMA test-bed and simulations based on measurement data. Thereby, we also show the sum rate gains of OFDMA scheduling over TDMA and compare the results to the upper bound provided by the max-rate scheduler. Furthermore, we compare cross-polarised with co-polarised antennas for fair OFDMA scheduling. XPD antennas outperform co-polarised antennas in all cases. We increase the number of users to show the gaps between the different scheduling strategies with and without polarisation multiplexing.

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