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FIELD TRIAL RESULTS FOR LTE-ADVANCED CONCEPTS

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ABSTRACT

Coordinated Multi-Point transmission and relaying are two likely candidates for the upcoming LTE-Advanced standard as both are able to satisfy the ever increasing demands for ubiquitous services with higher data rates. In this paper, we present field trial results for both techniques and discuss the most challenging problems during the implementation process in the EASY-C testbed in downtown Dresden.

Index Terms— Cooperative systems, relaying, testbed, LTE-Advanced, field trial

1. INTRODUCTION

Next generation mobile communication systems such as LTE aim at ubiquitously providing very high data rates and fairness both outdoors and indoors. While LTE is currently deployed in Asian countries and is planned to go online in year 2011 in Europe and USA, its successor LTE-Advanced (LTE-A) is already under development. Two prominent key concepts of LTE-A are coordinated multi-point (CoMP) transmission [1] and *relaying* [2]. The former exploits inter-cell interference and the latter increases the density of radio access points in order to provide coverage in otherwise shadowed areas.

At 2009 IEEE International Conference on Communications the worldwide first CoMP downlink setup was demonstrated by the German research project EASY-C. Within this project a testbed has been deployed, which covers major parts of downtown Dresden (Germany). Thus, this project implements and evaluates LTE-A concepts in a real environment, which covers two of the most challenging problems: inter-cell interference in urban areas and high-rate indoor coverage.

In this paper, we introduce the basic concepts of CoMP downlink transmission and relaying in the uplink. Then, we describe the field trial setup using the EASY-C testbed, and based on this, we present results for downlink CoMP and uplink relaying. These results are then evaluated and major implementation challenges are discussed.

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2. CONCEPTS FOR LTE-ADVANCED

Among the most serious difficulties in current and future mobile communications systems is the mitigation or avoidance of inter-cell interference. Therefore, future mobile communication systems are likely to use CoMP approaches as well as relaying, which are explained in the following.

2.1. Cooperative Multi-Point

CoMP transmission combines multiple, physically separated base stations to one cluster, which then act as one virtual antenna array (VAA). Within such a VAA techniques can be applied, which were introduced in the context of the MIMO broadcast channel [3]. This implies very stringent requirements on the deployed hardware such as perfect synchronization within the VAA, channel state information (CSI) of the compound channel between base stations and mobile terminals, and the availability of user data at all base stations.

Using CoMP transmission, interference is exploited instead of avoiding it in order to improve the spectral efficiency. Additionally, since in a CoMP based system all time-frequency resources are used in all involved cells, we achieve full resource reuse. This offers more degrees of freedom for cell planning and simplifies the deployment optimization, which has been crucial to avoid inter-cell interference. CoMP transmission techniques can be divided into linear and non-linear approaches. Non-linear approaches such as Dirty-Paper Coding (DPC) [4] provide higher performance gains but are more complex and require significantly more implementation efforts. By contrast, linear precoders are simpler to implement and still provide significant performance gains. In this paper, we concentrate on linear precoding and apply a fixed-SNR MMSE-filter to one block of 14 OFDM symbols and 6 subcarriers, which has been explained in further detail in [5].

2.2. Relaying

Relaying divides a conventional single-hop system in multiple hops, which improves the channel quality on the individual links, provides a more homogeneous receive-power dis-

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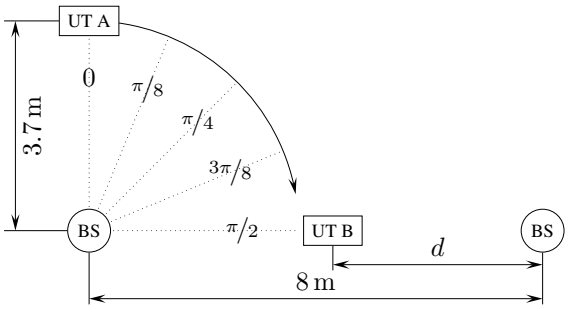


Fig. 1. Setup for CoMP downlink transmission where UT B is placed at $d = \{1.8\,\mathrm{m}, 3.7\,\mathrm{m}, 5.5\,\mathrm{m}\}$.

tribution, and offers more degrees of freedom for scheduling [6]. However, a cheap relay has to cope with the half-duplex constraint, which implies that it can either transmit or listen but not both on the same particular time-frequency resource. We can distinguish two major groups of relays: analog and digital relays. While the former amplifies the received signal, the latter decodes it and forwards a reencoded sequence. Furthermore, digital relays do not suffer from an enhanced noise level and provide more scheduling opportunities.

In this paper we consider two types of digital relays: a simple relay implementation, which uses the same encoding scheme on both hops and a more complex, which is able to use different encoding schemes on both hops. A complex relay does not require to use the same amount of resources on both hops but it requires a separate rate adaptation on each hop in comparison to a simple relay where we transmit on both hops with the same rate. While CoMP is an effective way to counteract inter-cell interference, relaying provides a cost-efficient way to improve indoor coverage using indoor relay nodes, which are evaluated in this paper.

3. FIELD TRIAL SETUP

This paper utilizes an experimentation system, which is based on OFDM and closely aligned to the PHY parameters of the 3GPP LTE standard. Our system is able to implement both CoMP downlink transmission as well as relaying uplink transmission using the same EASY-C equipment. The realized trials employed user terminals (UT) with $0\,\mathrm{dBm}$ transmit power, and a relay node (RN) and base stations (BS) with $10\,\mathrm{dBm}$ transmit power each. Both UT and RN have a noise power density of $-123\,\mathrm{dBm/Hz}$. RN and BS use two receive antennas each, and UT and RN use one transmit antenna each.

3.1. Cooperative Multi-Point

The analyzed CoMP downlink transmission has been implemented using an indoor laboratory setup, which is illustrated in Fig. 1. In this setup, UT A experiences different cell-edge scenarios while it is moved around its BS such that the link towards the interfering BS improves and interference increases. By contrast, UT B is moved on a line between both BSs in order to obtain varying scenarios between very high signal-to-interference ratio (SIR) (cell center) and very low SIR (cell edge). Hence, we consider overall 15 different measurement setups and for each the individual antenna positions were changed to reflect different fading situations.

In our implementation, both base stations use a common GPS based reference clock to guarantee coherent local oscillators and (frame) timing at the transmitters. We further employ a decentralized processing approach where both UTs broadcast their CSI to both BSs using frequency orthogonal feedback channels in the UL. Each BS then uses the compound channel matrix to determine the precoding matrices. This method requires more feedback overhead but avoids the necessity of a low-latency and high-rate backhaul between both base stations. Each user terminal returns four channel coefficients per resource block (14 OFDM symbols times 12 subcarriers) and link between each BS antenna and UT antenna, which are linearly quantized using $16\,\mathrm{Bit}$ per complex dimension. Furthermore, each user terminal feeds back the estimated signal-to-interference-and-noise ratio (SINR). Both feedback information is transmitted using a standard LTE uplink data channel, which is completely occupied by the CSI feedback. This work does not consider the trade-off between the achieved uplink and downlink rate but concentrates on the maximum improvement using the methods introduced in [5]. The feedback delay is about $0.5\,\mathrm{s}$ due to an intermediate Matlab feedback processing chain and therefore requires rather static channel conditions during one measurement. Using the same channel situations, we compare in Section 4 space-time block-coding (STBC) (only CSI at the receiver), local beamforming (BF) (without interference-awareness), and CoMP transmission.

3.2. Relaying

Relaying is able to provide significant gains in terms of achievable rates for both cell edge and indoor users [7]. In this paper we concentrate on indoor coverage extension and rate improvement for indoor users. For this we investigate the performance of relaying in the setup illustrated in Fig. 2, where triangles indicate the measurement trajectory of the UT. One trajectory is along the corridor (solid line) and one trajectory within office rooms (dashed) in order to compare two different indoor scenarios. In both setups all doors and windows were closed in order to demonstrate a worst case for relaying since no line-of-sight (LOS) between UT and RN occurred. At each point, we took multiple measurements with different modulation and coding schemes (MCS). Each uses a turbo-encoder as defined in [8] and either QPSK modulation with code rates $1/10$, $1/3$, and $2/3$, or 16-QAM modulation with code rates $1/2$, $2/3$, $7/8$, and 0.9939. The relay node has been placed indoors close to the window (at about $8\,\mathrm{m}$ above street

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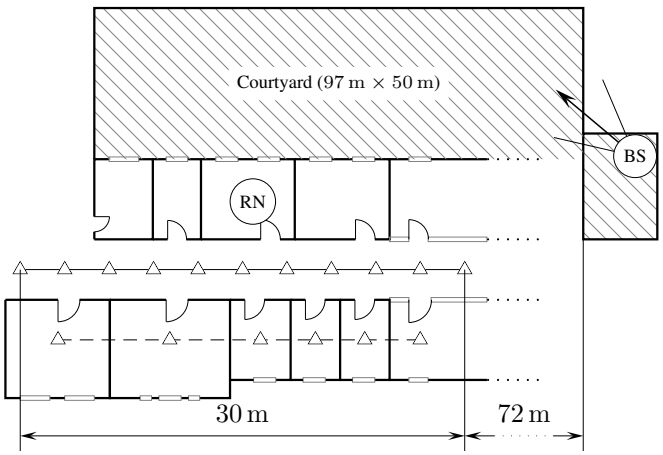


Fig. 2. Setup for relay uplink measurement.

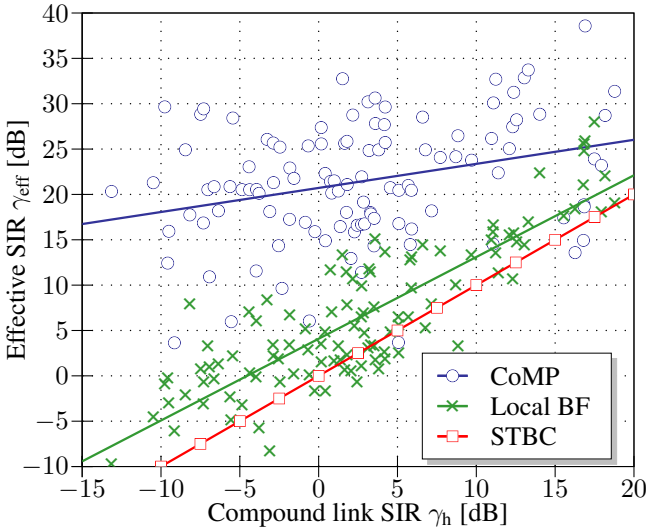


Fig. 3. Achieved SIR values using CoMP, local BF, and STBC for the downlink.

level). Furthermore, the BS has been placed on the rooftop of the same building 20 m above street level and uses a directive antenna with a 3dB half-beam-width of 60 degrees. Note that the BS is transmitting towards the center of a courtyard and therefore both RN and UT receive reflections from the opposite side of the courtyard and a direct transmission component, which has to pass through the roof.

4. PERFORMANCE RESULTS AND DISCUSSION

4.1. Cooperative Multi-Point

Fig. 3 shows the effective SIR values γ_{eff} for both UTs using CoMP, local BF, and STBC depending on the compound link SIR γ_{h} (all links were interference limited and therefore neglect the noise power). The latter is the sum of the received power from both antennas of the assigned BS over the received power from the interfering BS. By contrast, the effective SIR is the effectively achieved SIR after precoding and before signal detection and decoding. We compare CoMP with local BF where precoding is applied locally without interference-awareness. In addition, we compare CoMP with STBC, which does not require CSI at the transmitter and provides full diversity gain for a 2×1 antenna array, which is equivalent to the compound link SIR γ_{h}. In addition to actually measured effective SIR values (indicated by markers), Fig. 3 shows their linear regression in the logarithmic domain (indicated by solid lines), which indicates the performance trend but not necessarily implies a linear dependence.

Our measurements show significant performance gains of CoMP over both local BF and STBC. More specifically, CoMP provides on average about 20 dB higher γ_{eff} values than local BF. This benefit decreases for increasing link SIR values as CoMP already avoids interference at low SIR and therefore does not profit from decreased interference at high SIR as much as STBC which employs no interference-avoidance strategy. We can further see a gain of local BF over STBC. Depending on the instantaneous channel realization STBC might outperform local BF if either both antenna transmissions do not coherently superimpose or the interfering BS also directs its beam on the UT. However, on average local BF provides at least an array gain of 3 dB over STBC, which is reflected by our measurements.

Among the observed problems during the implementation process, numerical stability turned out to be one of the most challenging. The described hardware uses a 12 Bit fixed-point implementation, which limits the dynamic range and the ability to handle very asymmetrically conditioned propagation scenarios. Our implementation uses a recursive matrix-inversion algorithm, where sub-matrices of the compound channel matrix are recursively processed and in each recursion an additional user is added. Beside its ability to cope with numerically instable situations, it is also more flexible regarding the number of user terminals and provides the possibility to use a single software implementation for any number of users [5]. To estimate the effective channel, the LTE pilot scheme has been modified by adding spatial stream specific pilots, which are precoded in the same way as user data. In this way, the UT can estimate both the actual channel and the effective channel including precoding. The former is fed back to the transmitter to compute the precoding matrices and the latter is used by the terminal to detect data symbols.

4.2. Relaying

Fig. 4 shows the achieved rates for the relay setup described in Section 3. The achieved rates already reveal that relaying provides significant performance gains for most positions, where the direct link does not provide sufficient performance figures. More specifically, in the corridor scenario relaying

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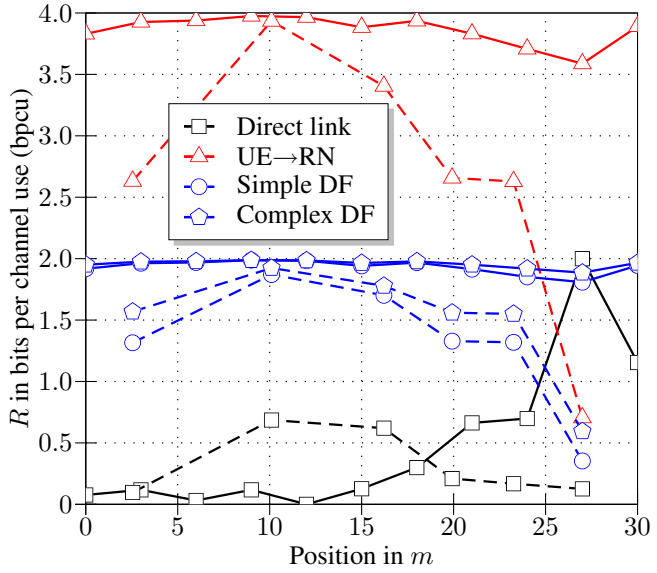


Fig. 4. Achieved rates using an indoor relay in the corridor scenario (solid lines) and the office scenario (dashed lines).

provides about $2\,\mathrm{bpcu}$ constantly while a direct transmission can only provide about $0.1\,\mathrm{bpcu}$ to $0.5\,\mathrm{bpcu}$ at most measurement points. In the office scenario, relaying provides at most measurement points about $1.5-2\,\mathrm{bpcu}$ and direct transmission provides about $0.1-0.5\,\mathrm{bpcu}$. Hence, relaying can significantly outperform direct transmission in both corridor and office scenario. Even though the transmission power at the user terminal was chosen very low ($0\,\mathrm{dBm}$) and all windows and doors were closed, the source-to-relay link is of such high quality that in most cases the highest MCS was supported. Therefore, the limiting factor in this scenario is rather the number of MCS than the provided channel quality. This underlines that relaying both improves the performance and reduces the required user terminal power.

We can further observe, that relaying not only improves the data rates close to the RN but also at the opposite side of the corridor. This implies that one relay suffices to cover most parts of this side of the building in order to provide the required high data rate services. This is not possible with conventional techniques or CoMP transmission without deploying additional base stations. Furthermore, the relaying performance is more constant than with conventional transmission. Using a smart relay we are able to further improve the performance and to more flexibly schedule resources.

Among the most challenging problems during the implementation process of half-duplex relaying is the co-channel interference of the source-to-relay link and the relay-to-destination link. We chose FDD to orthogonalized both hops as TDD requires not only a time synchronization but demands for more sophisticated scheduling algorithms and signaling structures, which go beyond the PHY oriented scope of our paper. Even though both carrier frequencies in the FDD system were separated by about $50\,\mathrm{MHz}$ and several duplex filters were used to separate both paths, the relay receiver-path suffered from a strong interference caused by the relay transmitter-path. Hence, the implemented FDD mode demanded for a physical separation of both antennas using shielding material or for a digital compensation.

5. CONCLUSIONS AND OUTLOOK

This paper discussed field trial results for CoMP downlink transmission and indoor relaying. Our results prove that relaying significantly improves the service quality for indoor users and that CoMP can alleviate the interference effects and can exploit a coherent transmission of multiple base stations in a real world setup. Our future work aims at testbed integration of both concepts in one system, where multiple relay nodes and CoMP transmission are jointly exploited.

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