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Large Scale Field Trial Results on Different Uplink Coordinated Multi-Point (CoMP) Concepts in an Urban Environment

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***Abstract*—Coordinated Multi-Point (CoMP) concepts such as multi-cell joint detection and transmission, promising large improvements in spectral efficiency and fairness, appears to be an effective option to combat inter-cell interference in mobile communications. One major drawback of uplink joint detection is the large additional backhaul required when compared to a non-cooperative system. Theoretical work has demonstrated how distributed interference subtraction can be used as a low backhaul option providing moderate CoMP gain. While a large amount of theoretical work has been carried out on this topic, and previous publications have shown that these schemes work in principle, the scenarios of urban deployment and the extent of capacity gains that can be achieved are still unclear. To this end, we compare potential rate gains through linear and non-linear uplink CoMP schemes for a large scale field trial setup wherein two mobile terminals have been moved through an urban test bed of 12 base stations located at UMTS sites in downtown Dresden.**

I. Introduction

Inter-cell interference is strongly limiting spectral efficiency in dense cellular systems. The occurring performance degradation especially for cell-edge users is identified as one of the major deficiencies of LTE Release 8 [1], demanding more sophisticated technical solutions for future releases. Some of the most promising proposals that are currently getting a lot of attention involve coordinated multi-point (CoMP) techniques for the up- and downlink. Theoretical analyses and simulations promise vast increases in spectral efficiency [2], [3], and currently available technology seems to be ready to support these ambitious concepts. Nonetheless, the challenges faced when bringing CoMP to the market have proven to be manifold. Prominent examples are the required synchronization of all cooperating entities in time and frequency [4], multi-cell channel estimation [5], and backhaul-efficient multi-cell signal processing [6], [7]. Even though significant progress has been made, the often isolated examination of certain problems is not sufficient to prove the maturity of ambitious CoMP concepts, and accurate models for system level simulations still need to be found and validated. Furthermore, industry players are cautious about innovations that require costly upgrades of the available cellular infrastructure. Thus, in order to make an impact on standardization, system complexity and performance needs to be assessed under real-world conditions, and simulation studies have to be accompanied by field trials that prove the maturity of a concept and provide reference data. These goals are driving forces behind various research activities world wide. Among these, in particular the German government founded project EASY-C [8] follows an integrated approach: identifying major obstacles, developing practical solutions, and showing realistic performance results for CoMP concepts supported by field trials.

In previous work [9], we presented measurement results for a cellular uplink with two terminals (UEs) and two cooperating base stations (BSs). We observed uplink cooperative detection; one BS forwards compressed receive signals to the other, which jointly decodes both UEs. The spectral efficiency could be increased by about 50 % through cooperation. The results presented in this publication provide evidence of the potential benefits of CoMP. However, the very limited scope of the observed scenario did not allow any reliable prediction of large scale performance. For this reason, an LTE-Advanced testbed was installed in downtown Dresden, a city with an infrastructure that is representative for urban scenarios in most of Europe. In this paper, we present field trial results for a setup of 12 BSs at 5 different sites. We show how CoMP gains that are achieved vary depending on the location of the UEs for different linear and non-linear detection schemes. In CoMP systems, we have the option to cancel interference of data streams that are decoded at different locations, which is possible when decoded data is exchanged among BSs. It was shown that this approach is potentially beneficial in terms of backhaul rate requirements when compared to a multi-cell joint detection approach that requires the exchange of quantized receive signals. A further topic of this paper is to investigate how large the cooperation size should be chosen.

In this paper, we only consider single antenna BSs. Even though the scenario with two (cross-polarized) antennas per BS is certainly more common, the single antenna BS case is interesting, as it resembles a scenario where the number of overall UE and BS antennas is equal if two BSs cooperate. Thus, the results obtained can be used to predict the gains in CoMP setups where multiple cooperating BSs serve two UEs per cell on the same resource, or where UEs with two transmit antennas each are employed. We refer to [10, Section 13.2] for a field trial evaluation of a setup with double antenna BSs.

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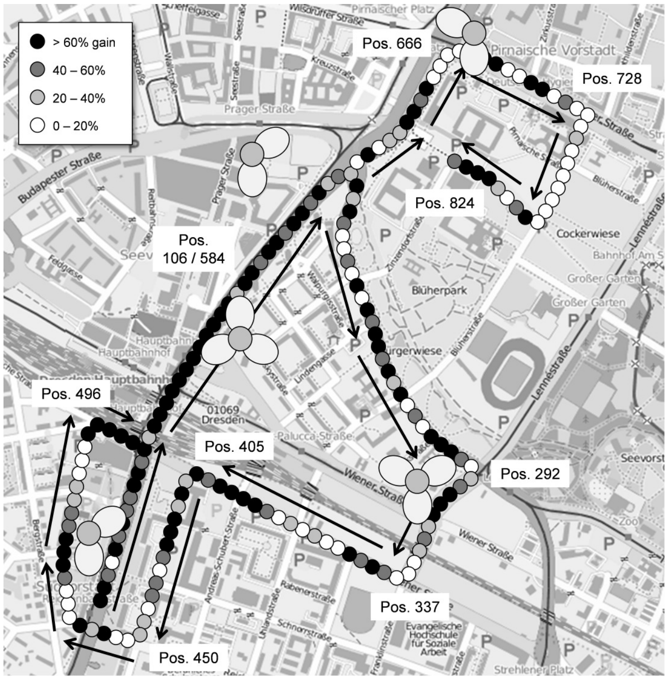

Fig. 1: Field trial setup and measurement trajectory, indicating the spectral efficiency gain of a joint detection of 2 UEs by 3 BSs using SIC vs. non-cooperative detection with SIC. Map data © OpenStreetMap & contributors, CC-BY-SA.

The rest of the paper is organized as follows. In Section II, we provide an overview of our measurement setup. The signal processing architecture including linear and nonlinear cooperative as well as non-cooperative detection is addressed in Section III. The field trial results are presented in Section IV, and the paper is concluded in Section V.

II. Measurement Setup

As shown in Figure 1, the measurement setup consists of twelve BSs deployed at a total of five current UMTS sites in downtown Dresden. The inter site distance varies in the range from 350 to 600 m and the antenna height from 15 – 35 m. The BSs are synchronized through GPS fed reference normals, and sites are connected through microwave links. Each BS is equipped with $N_{\text{bs}} = 1$ directional antenna (70 degrees half-power beamwidth and 14 dBi gain). The UEs — employing one omnidirectional antenna each — transmit using OFDM and a sequence of different modulation and coding schemes (MCSs), as discussed in detail later. The UEs are carried on a measurement bus, and antennas are assembled outside the bus in 1.2 m distance and placed 2 m above ground. Both UEs are scheduled to transmit on the same resource in time and frequency. The current implementation of the testbed does not have any handover functionality. Thus, in order to allow for an uninterrupted trial, downlink control information such as uplink grants are sent from an additional BS, which is carried on the measurement bus as well. The receive signals of all other BSs are recorded for offline evaluation, which facilitates the investigation of different linear and nonlinear detection schemes for the same recorded signals. Clearly, the focus of this approach is on physical layer evaluation. Various transmission parameters are listed in Table I.

Carrier frequency	2.53 GHz
System bandwidth	20 MHz
Resource blocks (PRBs)	30
No. of sub-carriers per PRB	12
Transmit Power	18 dBm
Quantization resolution	12 bit per real dim.

TABLE I: Transmission parameters

III. Signal Processing Architecture

In the next subsections, we will briefly explain the general signal processing steps performed in our architecture. For a more thorough discussion, we refer to [9].

A. Synchronization

The carrier frequency of all BSs is synchronized by using GPS fed reference normals. As shown in [11], remaining synchronization errors can be neglected in the uplink. On the UE side, the frequency offset is pre-compensated using downlink reference signals. Compared to the sub-carrier spacing, the remaining frequency offset of about 200 Hz is small enough for inter-subcarrier interference to be disregarded. The common phase error (CPE) is taken into account by an appropriate interpolation of channel estimates.

B. Channel and Noise Covariance Estimation

The channel is estimated by a pilot based approach using LTE pilot positions. Interference between pilot symbols of different UEs is avoided by a code orthogonal design using Frank-Zadoff-Chu sequences. Due to a spreading factor of two, the channel is estimated for every second sub-carrier in frequency domain. To estimate the channel for all other sub-carriers, time and frequency interpolation are carried out separately. Note that in the following model, the estimated channel links inherently contain the transmit power. The noise covariance is estimated based on the channel estimates. In particular, we exploit the autocorrelation properties of the estimated channel to separate its noise and signal components and determine one noise variance estimate per BS.

C. Channel Equalization

If residual synchronization errors are neglected, and if we assume a flat fading channel on each sub-carrier of bandwidth $\Delta F = 15$ kHz, the received signal of each symbol on a single sub-carrier of the OFDM system at BS m can be stated as

$$y_m = h_{m,1}x_1 + h_{m,2}x_2 + n_m, \qquad (1)$$

where $y_m \in \mathbb{C}$ is the signal received by BS m, $h_{m,n} \in \mathbb{C}$ denotes the channel gain from UE n to BS m, $x_n \in \mathbb{C}$ is a symbol transmitted by UE n, and $n_m \in \mathbb{C}$ denotes additive, uncorrelated noise of covariance $E\{n_m n_m^H\} = \sigma_m^2$. The channel vectors include UE transmit power, hence $E\{x_n x_n^H\} = 1$.

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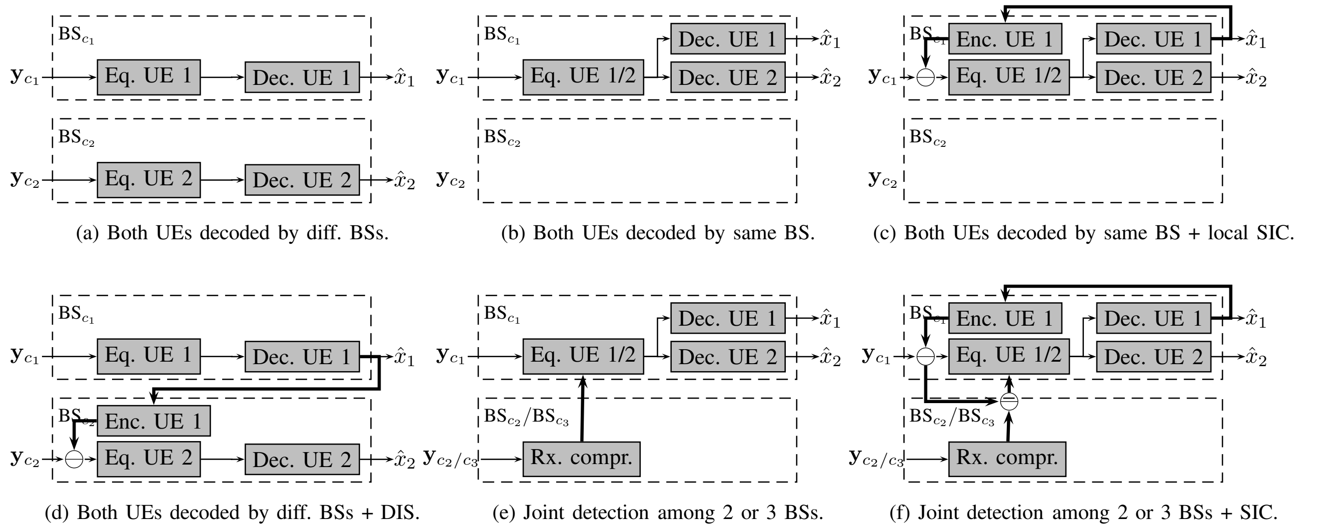

(a) Both UEs decoded by diff. BSs. (b) Both UEs decoded by same BS. (c) Both UEs decoded by same BS + local SIC.

(d) Both UEs decoded by diff. BSs + DIS. (e) Joint detection among 2 or 3 BSs. (f) Joint detection among 2 or 3 BSs + SIC.

Fig. 2: Signal processing setup for various exemplary detection and cooperation schemes.

The set of BSs that form a cooperation cluster is denoted by $\mathcal{C}$ with elements $\{c_1 \dots c_C\}$, where the cooperation cluster size is denoted by $C = |\mathcal{C}|$. The corresponding transmission model for the cluster is given by

$$\mathbf{y}_{\mathcal{C}} = \begin{bmatrix} h_{c_1,1} & h_{c_1,2} \\ \vdots & \vdots \\ h_{c_C,1} & h_{c_C,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_{\mathcal{C}}, \qquad (2)$$

where $\mathbf{y}_{\mathcal{C}} \in \mathbb{C}^{[C \times 1]}$ are the signals received by the C antennas of the cluster.

The signal processing architecture enables a variety of equalization schemes, of which the following examples are illustrated in Fig. 2:

- Both UEs can be decoded individually by their assigned BS (see Fig. 2a).
- Both UEs can be decoded by the same BS, possibly using successive interference cancelation (SIC, see Fig. 2c).
- Both UEs can be decoded individually by their assigned BSs, but one BS forwards decoded data bits to another for distributed interference subtraction (DIS), see Fig. 2d).
- One or two BSs forward all received signals to another BS, where both UEs are decoded jointly. This can be done via linear equalization (see Fig. 2e), or using SIC (JD+SIC) (see Figure 2f).

In the sequel, we will refer to the option of either letting both UEs be decoded by different BSs (see Fig. 2a) or jointly and linearly by one BS (see Fig. 2b) as *non-coop., linear* detection. If local SIC is enabled in addition (see Fig. 2c), then we refer to this as *non-coop., SIC* detection.

Equalization itself depends on the detection and cooperation scheme observed. Clearly, whenever local equalization is performed, then the BS can do nothing but correct the scaling and phase rotation of the symbols as introduced by the channel. In the case of joint detection, an MMSE filter is used, which depends on whether interference subtraction (i.e. through SIC) has been performed in advance. If UE n is to be detected jointly, and still subject to the interference from UE $\bar{n} \neq n$, the biased MMSE filter for a particular sub-carrier is given as

$$\mathbf{G}^{[n]}_{\text{biased}} = \hat{\mathbf{h}}^H_{\mathcal{C},n}\left(\hat{\mathbf{h}}_{\mathcal{C},n}\hat{\mathbf{h}}^H_{\mathcal{C},n} + \hat{\mathbf{h}}_{\mathcal{C},\bar{n}}\hat{\mathbf{h}}^H_{\mathcal{C},\bar{n}} + \text{diag}\left(\left[\hat{\sigma}^2_{c_1}\mathbf{I} \cdots \hat{\sigma}^2_{c_C}\mathbf{I}\right]\right)\right)^{-1}, \qquad (3)$$

where $\hat{\mathbf{h}}_{\mathcal{C},n} = \left[\hat{h}^T_{c_1,n} \quad \cdots \quad \hat{h}^T_{c_C,n}\right]^T$, and $\hat{\sigma}^2_m$ are estimates of the noise. If interference of the other UE has already been canceled, the filter from (3) changes to

$$\mathbf{G}^{[n]}_{\text{SIC,biased}} = \hat{\mathbf{h}}^H_{\mathcal{C},n}\left(\hat{\mathbf{h}}_{\mathcal{C},n}\hat{\mathbf{h}}^H_{\mathcal{C},n} + \text{diag}\left[\hat{\sigma}^2_{c_1} \ \cdots \ \hat{\sigma}^2_{c_C}\right]\right)^{-1}. \qquad (4)$$

In order to avoid an increased bit error probability for higher order modulation schemes, the bias has to be removed from all previously stated filters, i.e. we apply

$$\mathbf{G} = \left(\Delta\left(\mathbf{G}_{\text{biased}}\right)\right)^{-1}\mathbf{G}_{\text{biased}}, \qquad (5)$$

where $\Delta(\mathbf{G})$ sets all off-diagonal elements of $\mathbf{G}$ to zero.

D. Soft Demodulation and Decoding

After equalization, signal-to-interference-and-noise ratios (SINRs) are estimated via an error vector magnitude approach [12], followed by soft demodulation. The demodulator output is fed into an LTE Rel. 8 compliant decoding chain using the codes listed in Table II. Each codeword spans one transmit time interval (TTI) in time domain and 30 physical resource blocks (PRBs) in frequency domain. Decoding success is determined through an outer CRC-code.

IV. Field Trial Results

The route traversed by the measurement car is depicted in Figure 1. It has a total length of 7.5 km and passes through different surroundings, such as an underpass, apartment buildings, a train station, and open spaces like parking areas. Part of the trajectory is followed twice to see whether results are reproducible, which is indeed the fact when observing the results

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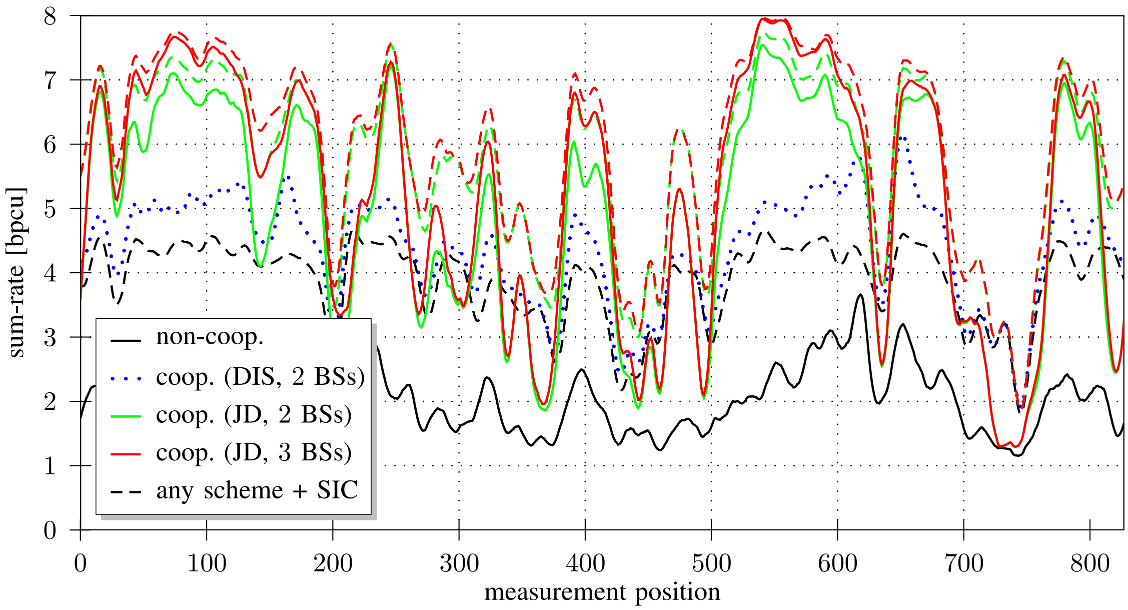

Fig. 3: Achieved sum-rates for considered cooperation and detection schemes along the measurement trajectory.

MCS#	Mod. scheme	Code rate	Peak rate	Bit per channel use
1	4QAM	3/16	1.30 Mbps	0.375
2	4QAM	1/2	3.46 Mbps	1
3	16QAM	2/5	5.62 Mbps	1.60
4	16QAM	4/7	7.99 Mbps	2.29
5	16QAM	2/3	9.29 Mbps	2.66
6	16QAM	3/4	10.6 Mbps	3.00
7	16QAM	6/7	12.3 Mbps	3.43
8	16QAM	99/100	14 Mbps	3.96

TABLE II: Modulation schemes and code rates used for transmission, assuming turbo codes as used in LTE Rel. 8.

around measurement positions 106 and 584 in later figures. The car traveled at an average speed of about 7 km/h during measurements. The UEs continuously transmitted codewords, each spanning 1 TTI (1 ms) switching cyclically between the MCSs given in Table II. Given that the channel does not change significantly during the time it takes to loop through all MCS, we can determine the instantaneous rate of the UEs that would be achieved under the assumption of optimal link adaptation. Due to limited memory capacity, we are not able to store all the received signals at the BSs continuously. Instead, the BSs synchronously capture their received signal for a duration that is long enough for several iterations through all MCSs to obtain robust statistics of achievable rates for a small scale area. Thus, we determine the rate (per position) that leads to the largest successful throughput on average, which is denoted as $r_{k,p}$ for UE k and position p. Even though both UEs transmit using the same MCS, we are able to determine the highest rate MCSs that are possible for each UE individually when SIC is used, because the transmitted codeword is known under field trial conditions. Thus, we are able to determine the highest rate MCS that was successfully transmitted either with or without prior SIC (genie SIC receiver) and, assuming the channel did not change significantly during one loop through all MCSs, we can apply the decoding order that achieves the highest sum-rate. One receive signal dump was generated every 5 s for a total of $P = 824$ measurement positions, to observe large-scale effects.

In principle, we are able to investigate the performance if a UE were decoded by any arbitrary cluster of BSs due to offline evaluation. However, to reduce the evaluation complexity, for each transmitted codeword, the BSs that are considered for the decoding of the UE and a particular codeword are determined by a minimum pathloss criterion. Regarding multi-cell joint detection (JD), we consider cases where either two or three BSs, which are again heuristically chosen based on pathloss criteria, cooperate. In all the plots in this section, we show only sum-rate results, i.e. we compute the sum of the UE rates ($r_{\mathrm{sum},p} = r_{1,p} + r_{2,p}$) at each position.

The achieved sum-rates for all investigated detection schemes are shown in Figure 3. We use the terminology introduced in Figure 2. Since the focus of this observation is on large-scale effects, we smoothed out small-scale variations of measured rates using a moving average filter with a length of 10 positions. We can see that non-cooperative, linear detection typically yields a sum-rate of 1.5-3 bits per channel use (bpcu), i.e. both UEs are able to transmit successfully with QPSK and a low rate. The sum-rate is then substantially increased to about 4 bpcu on average if local SIC is applied, i.e. if both UEs are decoded by the same BS successively. Further rate increases are achieved with distributed interference subtraction (DIS), as then both UEs can be decoded at the best suitable BS, but still one UE can profit from interference cancelation. Applying joint detection among 2 or 3 BSs finally brings us into a sum-rate regime of up to 6-8 bpcu, i.e. close to twice the rate of the maximum MCS supported. We can see, however, that the gain of going from 2 to 3 cooperating cells is rather limited - an aspect we will discuss further later.

The actual sum-rate gains in percent between different

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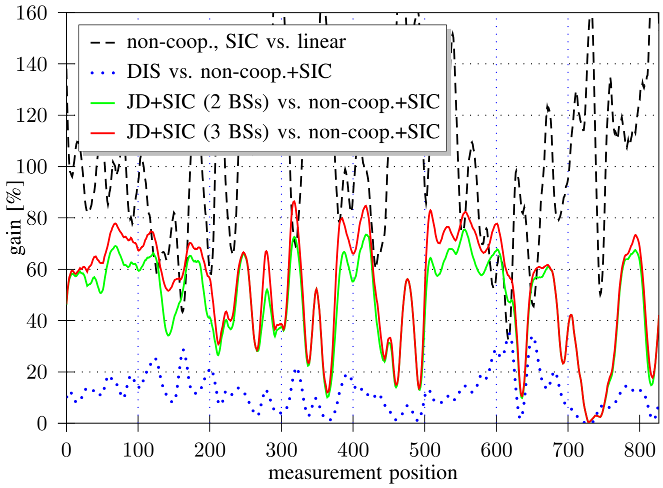

Fig. 4: Relative gains between pairs of compared schemes.

tuples of detection and cooperation schemes are shown in Figure 4. First of all, we can see the massive gains obtained through applying local SIC, which are on average about 100%. The gain of DIS-based cooperation compared to local DIS is typically between 10 and 20%, but in same cases more than 30%. The gains of applying multi-cell joint detection (in all cases with SIC and compared to a SIC baseline) are between 20 and 80%. However, the difference in gain between DIS and JD has to be put into perspective with the very different backhaul capacity requirements of these two schemes. In this field trial, the backhaul rate required for the use of DIS was 1 bpcu on average or 2.5 Mbit/s (considering the 30 used PRBs), which is quite low when compared to 24 or 48 bpcu (12 bits per I/Q dimension and antenna), leading to 121 or 242 Mbit/s required for JD among 2 or 3 BSs, respectively. Note that we did not consider compression of received signals (i.e. the signals forwarded to the decoding BS have the same bit resolution the ADC uses), which would allow reducing backhaul under similar performance.

One must further note that the fairly small gain from DIS is due to the fact that the UEs were always co-located. In future field trials, we will also consider UEs with a considerable spacing in order to obtain more asymmetrical interference scenarios, where it is known that DIS concepts become highly interesting. This was shown, e.g., in simulations in [7], as well as in previous small-scale field trials [13].

As expected, the achieved average rates vary as the UEs are moved through the test bed, attesting that fairness is a challenging issue in a cellular system. However, if the achieved rates are observed more closely, we see that low rate events are improved by using cooperation in most cases. A measure that is often used to evaluate fairness in networks is the Jain's index, which is defined as

$$\text{fairness} = \left(\sum_{P} \sum_{K} r_{k,p} \right)^2 \Bigg/ \left(PK \sum_{P} \sum_{K} r_{k,p}^2 \right). \quad (6)$$

The Jain's index can take values between $\frac{1}{PK}$ (minimum fairness) and 1 (maximum fairness). It is usually used to evaluate fairness among many users over a period of time, but since we only observe two UEs and do not consider scheduling, we compute fairness over the measurement positions. Hence, the index reflects the achievable rate distribution over the measurement area. We see that fairness is already increased strongly by using local SIC, as shown in Table III, even though we use sum-rate as a criterion for choosing the SIC order. The reason is simply that the option of locally decoding both UEs with SIC strongly improves the average sum-rate, while its variance over measurement positions remains more or less the same. However, using SIC will always lead to the fact that the UE decoded last may obtain a much better rate than the first one, so that fairness among the two UEs is bad. This is the reason why JD in conjunction with SIC leads to a further significant fairness improvement. In this case, the UEs can already be spatially separated quite well due to the additional degree of freedom at the receiver side, and SIC can still improve rates, but does not require trading one UE's rate against the other to the extent that was the case for non-cooperative detection at one single antenna.

TABLE III: Fairness and gain of the compared schemes.

Decoder	Fairness (Jain's index)	Gain w.r.t. non-coop. (linear)	Gain w.r.t. non-coop. (SIC)	back. rate [bpcu]
non-coop. (linear)	0.69	0%	−51%	0
non-coop. (SIC)	0.83	104.0%	0%	0
coop. (DIS, 2 BSs)	0.84	124%	9%	≈ 1
coop. (JD, 2 BSs)	0.83	142%	18%	24
coop. (JD+SIC, 2 BSs)	0.91	198%	45%	24
coop. (JD, 3 BSs)	0.84	160%	27%	48
coop. (JD+SIC, 3 BSs)	0.91	209%	51%	48

Table III further summerizes the relative performance gains of the compared schemes, where we use non-cooperative detection with or without SIC as two baselines. The relative gain of using JD among three BSs with SIC compared to non-cooperative detection with SIC is also illustrated along the trajectory in Fig. 1. Clearly, cooperation gains are largest at cell-edges. Having a commercial usage of uplink CoMP in mind, it is interesting to see that some cases of strong cooperation gain can be obtained with inter-sector cooperation at the same site, where proprietary and inexpensive solutions are thinkable (see, e.g., the measured gains around position 292 in Figure 1).

Finally, we show cumulative distribution functions (CDFs) of the achieved sum-rates in Figure 5, which support the previous observations. Though the schemes local SIC and DIS appear to be fairer than joint linear detection (as the CDFs are steeper), one has to keep in mind that the CDFs are calculated over sum-rates, i.e. these reflect fairness over measurement positions, but not among the two UEs. For the overall fairness, the before mentioned Jain's index is hence the better measure. We can further see that the achieved sum-rates in the case of joint detection are often close to 8 bpcu, which is the current limit of our system (2 UEs transmitting with 16-QAM at a rate close to one), thereby suggesting that 64-QAM should also be

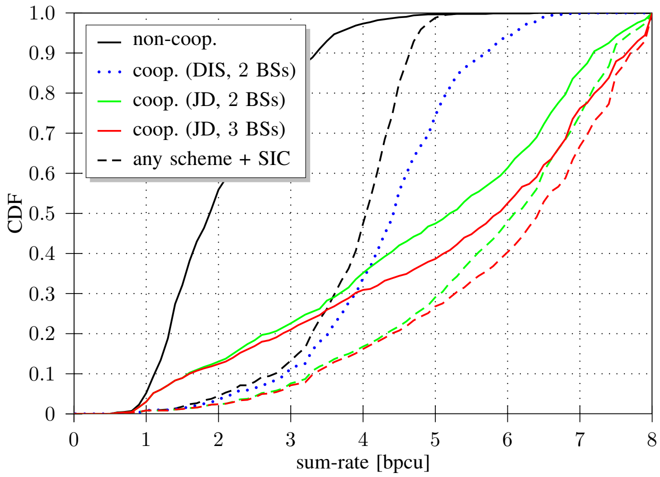

Fig. 5: CDF of sum-rates observed on the measurement route.

used in the LTE-Advanced uplink.

While the results presented here already provide a good insight into the potential of non-linear detection and multi-cell cooperative signal processing, one must point out that the results can not yet be fully generalized, due to the fact that

- only the case of 1 UE and 1 BS antenna is considered.
- UEs are located in close vicinity and with fixed distance.
- no interference is considered.
- the number of MCS is limited (no 64-QAM).

Clearly, the gain through cooperation decreases strongly if, e.g., two receive antennas per BS are considered, as pointed out in [10, Section 13.2], as then the two UEs can already be spatially separated very well through local MMSE filtering. But as mentioned at the beginning of this paper, we believe that the assumption of single-antenna BSs is quite interesting to predict the gain in cooperation constellations where the number of UE and BS antennas are equal in general. This would for example be the case if multi-antenna terminals are used, or if each BS serves as many UEs on the same resource as it has receive antennas. If the two UEs are placed at larger distances, we expect the DIS cooperation strategy to be more relevant, as discussed before.

If, however, in future field trials interferers are added to the setup, one can expect larger cooperation gains in general, as then the non-cooperative performance will deteriorate, while cooperative schemes will enable a better spatial separation of desired signals and interference, and the obtained array gain will play a more important role. If a larger number of UEs is considered for being served cooperatively, we also expect a stronger benefit of increasing the cooperation size to 3 for joint detection, as tuples of only two cooperating BSs will typically not be able to capture all dominant interferers [14].

V. Conclusions and Outlook

In this paper, large-scale field trial results for different uplink CoMP schemes were presented, where two UEs were moved through an urban cellular test bed with a total of twelve BSs. Compared to non-cooperative linear detection, local SIC already increases average spectral efficiency by about 104%. On top of this, distributed interference subtraction (DIS) can yield another 9% gain, at the price of a (very limited extent of) backhaul capacity. If a much larger extent of backhaul capacity is invested into multi-cell joint detection among 2 or 3 cells, further gains of about 40% can be obtained on average. Clearly, these gains are most visible at cell-edges, where these can rise up to 80%. The results emphasize the strong value of multi-cell cooperation in mobile communications, and show that DIS can indeed be a low-backhaul complement to joint detection. Future field trials shall focus on the impact of different UE distances, different BS antenna configurations and compression schemes for more backhaul-efficient joint detection.

Acknowledgement

We would like to thank our project partners for a very fruitful collaboration, and the German Ministry for Education and Research (BMBF) for the partial funding of EASY-C. This work would not have been possible without valuable support from Ainoa Navarro Caldevilla, Sven-Einar Breuer, Vincent Kotzsch, Fabian Diehm, Joachim Heft, Matthias Pötschke, André Zoch, and Eckhard Ohlmer.

References

[1] W. McCoy, "Overview of 3GPP LTE Physical Layer: White Paper by Dr. Wes McCoy," *White Paper*, 2007.
[2] P. Marsch, S. Khattak, and G. Fettweis, "A Framework for Determining Realistic Capacity Bounds for Distributed Antenna Systems," in *Proc. of the IEEE Information Theory Workshop (ITW'06)*, Oct. 2006.
[3] S. Venkatesan, "Coordinating base stations for greater uplink spectral efficiency in a cellular network," in *Proc. of the Personal, Indoor and Mobile Radio Communications Conference (PIMRC'07)*, Sept. 2007.
[4] M. Schellmann and V. Jungnickel, "Multiple CFOs in OFDM-SDMA Uplink: Interference Analysis and Compensation," *EURASIP Journal on Wireless Communications and Networking*, 2009.
[5] L. Maniatis, T. Weber, A. Sklavos, and Y. Liu, "Pilots for joint channel estimation in multi-user OFDM mobile radio systems," in *ISSSTA*, 2002.
[6] P. Marsch and G. Fettweis, "A Framework for Optimizing the Uplink Performance of Distributed Antenna Systems under a Constrained Backhaul," in *Proc. of the IEEE Intern. Conf. on Communications (ICC'07)*, June 2007.
[7] ——, "On Uplink Network MIMO under a Constrained Backhaul and Imperfect Channel Knowledge," in *Proc. of the IEEE International Conference on Communications (ICC'09)*, June 2009.
[8] R. Irmer, H.-P. Mayer, A. Weber, V. Braun, M. Schmidt, M. Ohm, N. Ahr, A. Zoch, C. Jandura, P. Marsch, and G. Fettweis, "Multisite field trial for LTE and advanced concepts," *IEEE Comm. Mag.*, 2009.
[9] M. Grieger, P. Marsch, Z. Rong, and G. Fettweis, "Field Trial Results for a Coordinated Multi-Point (CoMP) Uplink in Cellular Systems," in *International ITG Workshop on Smart Antennas 2010*, Feb. 2010.
[10] P. Marsch and G. Fettweis (editors), *Coordinated Multi-Point in Mobile Communications - From Theory To Practice*. Cambridge University Press, 2011.
[11] V. Jungnickel, T. Wirth, M. Schellmann, T. Haustein, and W. Zirwas, "Synchronization of cooperative base stations," in *IEEE Int. Symp. on Wireless Comms. Systems (ISWCS'08)*, Oct. 2008.
[12] R. Shafik, S. Rahman, R. Islam, and N. Ashraf, "On the error vector magnitude as a performance metric and comparative analysis," in *Proc. of the International Conference on Emerging Technologies (ICET'06)*.
[13] P. Marsch, M. Grieger, and G. Fettweis, "Field trial results on different uplink coordinated Multi-Point (CoMP) concepts in cellular systems," in *IEEE Global Comms. Conf. (GLOBECOM'10)*, 2010.
[14] P. Marsch and G. Fettweis, "A Decentralized Optimization Approach to Backhaul-Constrained Distributed Antenna Systems," in *IST Mobile and Wireless Communications Summit (IST'07)*, July 2007.