Field Trial Results on Uplink Joint Detection for Moving Relays

Michael Grieger, Gerhard Fettweis
Technische Universität Dresden,
Vodafone Chair Mobile Communications Systems,
Email: {michael.grieger, fettweis}@ifn.et.tu-dresden.de

***Abstract*—Public transportation vehicles are natural hotspots of wireless communication demand. Potentially, multiple users in the vehicle will compete for scarce spectral resources. At the same time, the direct link of users in the vehicle to the base stations might be rather week due to a high indoor-outdoor penetration loss. A potential solution to these this is the use of multi-antenna relays with antennas outside the vehicle for communication with the base stations and inside the vehicle for communication with the users. In order to increase the throughput on the base station - relay link, especially at cell edges, coordinated signal processing of multiple base stations could be used. In this work, we explore the performance of this approach in an uplink large-scale field trial of a multi-antenna transmitter carried on a measurement bus in an urban cellular environment. For this setup we show achievable data rates using linear and non-linear detection and explore the gain of joint detection in cooperation clusters of up to three base stations.**

I. Introduction

Vehicles such as trams or buses constitute wireless communication hot-spots. In order to improve the connectivity of users on such vehicles, moving relay nodes could be deployed inside. This way the users benefit from short distances and quasi-static channels. The access points connect to the cellular network via relay links using antennas mounted outside of the vehicle (see e.g. [1]). These (moving) relay feeder links are the major bottlenecks of the transmission scheme. Thus, improving their performance and reliability is important to the success of the overall concept. Since vehicles provide sufficient space for placing multiple antennas, both measures could be improved using multi-antenna techniques which, potentially, allow for a drastic increase of throughput with the number of antennas. However, these performance gains can only be achieved entirely if the MIMO links between the relay and the associated base station (BS) are uncorrelated and the number of BS antennas is at least as large as the number of relay antennas. Both of these requirements will often not be met in practical systems. The number of antennas per BS is limited and they are placed in close vicinity, leading to correlated channel fading. Furthermore, it should be considered that spectral efficiency of today's cellular systems is often limited by inter-cell interference. Especially mobile users (resp. relays) that are located at cell edges will suffer from this effect. The resulting lack of fairness and quality of service is identified as one of the major deficiencies of LTE Release 8.

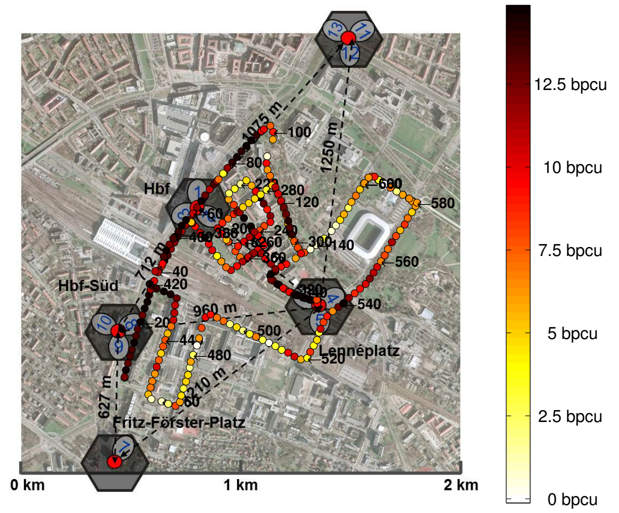


Fig. 1. Testbed Deployment and JD+SIC ($C = 3$) sum-rate of $K = 4$ Tx streams at measurement locations. Map data © Sandstein Neue Medien GmbH (http://stadtplan.dresden.de)

Potentially, these problems can be overcome using joint signal processing of BSs which exploit signal propagation across cells rather than treating it as noise. Theoretical analysis and simulations promise vast increases in spectral efficiency [2]–[4], and today's technology seems to be ready to support these concepts as previous field trial publications demonstrate [5], [6]. In this publication, we report the performance of a multi antenna moving relay feeder link observed in an extensive field trial of an urban scenario. We consider the uplink direction where the moving relay was transmitting up to four parallel data streams, and we compare different conventional and cooperative detection schemes. We also compare the performance of linear minimum mean square error (MMSE) detection and non-linear detection using successive interference cancellation (SIC).

In the sequel, the field trial setup is described in Section II, after which details on the signal processing architecture are provided in Section III. The field trial results are discussed in Section IV, followed by conclusions in Section V.

II. Measurement Setup

The field trial testbed, deployed in downtown Dresden (Germany), is depicted in Figure 1. In total $N_{\text{BS}} = 13$ BSs located on five sites with up to three-fold sectorization are used for the measurements. Each BS is equipped with a two element, cross-polarized KATHREIN 80010541 antenna which has $58°$ horizontal and $6.1°$ vertical half power beam width. The angle between the boresight of antennas that belong to different BSs at one site is $\geq 120°$. The basic uplink physical layer parameters are used in close compliance with the 3GPP/LTE standard (see e.g. [7]). This concerns mainly the control and data signaling. However, as a major difference, we use orthogonal frequency division multiplexing (OFDM) instead of SC-FDMA in the uplink as well. Time and frequency synchronization of BSs, which is required for joint detection, is done through GPS fed reference normals. The remaining sampling time offset and carrier frequency offset is very low (a couple of samples, and few Hz respectively). Other general transmission parameters are stated in Table I.

A Volkswagen T4 measurement bus was used as a moving relay. The bus was equipped with a linear array of four dipole antennas that were positioned on the car roof in mutual distance of $3\lambda(\text{wavelengths}) = 35.6$ cm distance as shown in Figure 2. A metal sheet was used below the antennas in order to have an idealized local surrounding that is independent of the particular type of vehicle. While the antenna layout can certainly be optimized, we chose this configuration because it facilitates channel prediction beyond a couple μs if a predictor antenna concept is used as presented in [8]. During the field trial up to four data streams were transmitted on the same time and frequency resources. The superimposed signal is jointly received by *all* BSs which took snapshots of 80 ms (corresponds to 80 transmit time intervals (TTIs)) every 10 s. The signal processing at the receiving BS side was done offline as presented in the following section. The benefit of this approach is that it permits a comparison of multiple receiver algorithms using the same data set. On the downside, offline signal processing does not allow for real-time feedback which is useful for rate adaptation and hybrid ARQ. In order to enable the determination of realistic throughput results, the transmitter configuration was changed on a ms basis as follows: The number of streams that were transmitted was changed in intervals of 10 ms (corresponds to 10 TTIs). During this interval, 10 different codewords were transmitted, coding over all symbols of one TTI each. These 10 codewords were chosen to have different rates using different modulation and coding scheme (MCS) as listed in Table II. Given that the measurement bus was moving at a slow speed of about 5 km/h, different number transmission rates and data streams were tested within the channel coherence time. In total about 600 such measurements were taken in order to observe a large number of different transmission scenarios.

Fig. 2. Configuration of moving relay antennas on measurement bus. Metal plate is used to get homogeneous ground plane below the antennas

TABLE I
Transmission parameters.

BS distance	500-1100 m (see Figure 1)
BS antenna height	30 - 55 m
Tx antenna distance	$3\lambda = 35.6$ cm
Tx antenna height	1.8 m
Carrier frequency	2.53 GHz
Subcarrier bandwidth	15 kHz System bandwidth 20 MHz
Used PRBs	30 (5.4MHz)
Sub-carriers per PRB	12
Per antenna data transmit power	11 dBm
Quantization resolution	12 bit per real dim.

III. Signal Processing Architecture and Evaluation Concept

The basic signal processing steps were already presented in previous field trial publications such as [5], [6]. They include

- OFDM symbol timing and frequency synchronization
- demapping of reference and data symbols
- channel estimation
- noise variance estimation
- symbol equalization
- QAM symbol demapping and decoding

In this section we summarize these steps and focus on the most important aspects that will be further evaluated in Section IV.

a) OFDM Processing, Channel and Noise Estimation: After OFDM symbol synchronization, the cyclic prefix is removed and the received signals at all BSs are converted to the frequency domain using an FFT. As a next step, reference and data symbols are separated. In total 11 data OFDM symbols are transmitted in each TTI. In each OFDM symbol 30 physical resource block (PRB) are used for data transmission, resulting in 3960 QAM symbols per TTI/codeword. Channel estimation is performed based on reference symbols transmitted on the 4th and 11th OFDM symbols of each TTI. Since these resources are shared among all four streams using code orthogonal reference symbol patterns, there are 8 reference symbols per PRB and stream. Noise power is estimated on empty sub-carriers, and we obtain a signal-to-noise ratio estimate $\hat{\text{SNR}}_l^k$ per stream k and measurement location l by dividing the average channel power of each stream by the noise power. The (linear domain) average of these stream SNRs at each location is referred to as $\hat{\text{SNR}}_l = \frac{1}{K}\sum_{k=1}^{K} \hat{\text{SNR}}_l^k$.

TABLE II
MODULATION SCHEMES AND CODE RATES USED FOR TRANSMISSION.

MCS#	Mod. scheme	Code rate	Peak rate (Mbps)	Bit per channel use (bpcu)
1	4QAM	3/16	1.3	0.375
2	4QAM	1/2	3.46	1.0
3	4QAM	3/5	5.04	1.27
4	16QAM	2/5	5.62	1.6
5	16QAM	4/7	7.99	2.29
6	16QAM	3/4	10.6	3.0
7	16QAM	6/7	12.3	3.43
8	16QAM	98/100	15.6	3.94
9	64QAM	3/4	16.3	4.5
10	64QAM	7/8	18.72	5.25

b) Transmission Model: A couple of different detections schemes are compared in this paper. These are:

- conventional (conv.) linear MMSE detection where different streams are potentially decoded at different BSs.
- conv. non-linear detection of all streams at the same BS using SIC.
- joint detection (JD) of all streams in a cooperation cluster of C BS potentially using linear MMSE filters or SIC

In order to formalize these schemes, we neglect residual synchronization errors and assume a flat fading channel on each sub-carrier. In this case, the received signal of each symbol on a single OFDM sub-carrier at BS m can be stated as

$$\mathbf{y}_m = \sum_{k=1}^{K} \mathbf{h}_{m,k} x_k + \mathbf{n}_m, \tag{1}$$

where $\mathbf{y}_m \in \mathbb{C}^{[N_{\text{bs}} \times 1]}$ is the signal received by N_{bs} antennas of BS m, $\mathbf{h}_{m,k} \in \mathbb{C}^{[N_{\text{bs}} \times 1]}$ denotes the channel gain from Tx antenna k to BS m, $x_k \in \mathbb{C}$ is a symbol transmitted by Tx k. A total of K streams were transmitted, each at an individual antenna. The vector $\mathbf{n}_m \in \mathbb{C}^{[N_{\text{bs}} \times 1]}$ denotes noise that is assumed to be additive, uncorrelated Gaussian with covariance matrix $\sigma_m^2 \mathbf{I}$. Note that the channel vectors include transmit power due to the assumption of $E\{x_k x_k^H\} = 1$.

If cooperation is used, a set of BSs in a cooperation cluster forward their received signals to a joint receiver. The set of BSs that form a cooperation cluster is denoted by $\mathcal{C} = \{c_1 \dots c_C\}$ ($c_. \in 1 \dots N_{\text{BS}}$), where the cooperation cluster size is denoted by $C = |\mathcal{C}|$. The corresponding transmission model for the cluster is given by

$$\mathbf{y}_{\mathcal{C}} = \sum_{k=1}^{K} \begin{bmatrix} \mathbf{h}_{c_1,k} \\ \vdots \\ \mathbf{h}_{c_C,k} \end{bmatrix} x_k + \mathbf{n}_{\mathcal{C}}, \tag{2}$$

where $\mathbf{y}_{\mathcal{C}} \in \mathbb{C}^{[N_{\text{bs}} C \times 1]}$ are the signals received by the C antennas of the cluster, and $\mathbf{n}_{\mathcal{C}}$ is noise.

c) Linear Detection: If a linear MMSE filter is used for non-cooperative detection of stream k at BS m the filter matrix for a particular sub-carrier is given by

$$\mathbf{D}_{\text{biased}}^{[m,k]} = \hat{\mathbf{h}}_{m,k}^H \left(\sum_{\bar{k}=1}^{K} \hat{\mathbf{h}}_{m,\bar{k}} \hat{\mathbf{h}}_{m,\bar{k}}^H + \hat{\sigma}_m^2 \mathbf{I} \right)^{-1}, \tag{3}$$

where $\hat{\mathbf{h}}$ and $\hat{\sigma}_m^2$ are estimates of the channel and noise, respectively. If the received signals of all BSs in a cluster are available at a joint receiver, the biased MMSE filter for stream k is given by

$$\mathbf{D}_{\text{biased}}^{[\mathcal{C},k]} = \hat{\mathbf{h}}_{\mathcal{C},k}^H \left(\sum_{\bar{k}=1}^{K} \hat{\mathbf{h}}_{\mathcal{C},\bar{k}} \hat{\mathbf{h}}_{\mathcal{C},\bar{k}}^H + \Phi_{n_{\mathcal{C}} n_{\mathcal{C}}} \right)^{-1}, \tag{4}$$

where $\hat{\mathbf{h}}_{\mathcal{C},k} = \left[\hat{\mathbf{h}}_{c_1,k}^T \ \cdots \ \hat{\mathbf{h}}_{c_C,k}^T \right]^T$ and $\Phi_{\mathbf{n}_{\mathcal{C}} \mathbf{n}_{\mathcal{C}}} = \text{diag}\left[\text{diag}^{-1}\left(\sigma_{c_1}^2 \mathbf{I}\right) \cdots \text{diag}^{-1}\left(\sigma_{c_C}^2 \mathbf{I}\right) \right]$.

d) SIC Detection: Multiple algorithms for the cancellation of inter-stream interference after successful detection of each individual stream exist of which we use hard SIC. The concept requires successful decoding prior to cancellation of interference. Thus, a decoding order $\mathcal{O} = \{o_1, \dots, o_K\}$ has to be defined which we chose according to the order of the $\hat{\text{SNR}}_l^k$: the stream with the largest SNR is decoded first, followed by the stream with the second largest SNR etc. In case of conventional detection, the detection filters for all subsequent streams are given by

$$\mathbf{D}_{\text{SIC,biased}}^{[m',o_k]} = \hat{\mathbf{h}}_{m',o_k}^H \left(\sum_{\bar{k}>k} \hat{\mathbf{h}}_{m',o_{\bar{k}}} \hat{\mathbf{h}}_{m',o_{\bar{k}}}^H + \hat{\sigma}_{m'}^2 \mathbf{I} \right)^{-1}. \tag{5}$$

Note that all streams are detected at the same BS m' in this case. Equivalently, the filters for JD are given by

$$\mathbf{D}_{\text{SIC,biased}}^{[\mathcal{C},o_k]} = \hat{\mathbf{h}}_{\mathcal{C},o_k}^H \left(\sum_{\bar{k}>k} \hat{\mathbf{h}}_{\mathcal{C},o_{\bar{k}}} \hat{\mathbf{h}}_{\mathcal{C},o_{\bar{k}}}^H + \Phi_{\mathbf{n}_{\mathcal{C}} \mathbf{n}_{\mathcal{C}}} \right)^{-1}. \tag{6}$$

Note that all detection filters stated previously are biased. To avoid demapping errors for higher order modulation schemes, the bias has to be removed from all stated filters by applying $\mathbf{D}^{[\cdot]} = (\Delta(\mathbf{D}_{\text{biased}} \hat{\mathbf{h}}_{\cdot}))^{-1} \mathbf{D}_{\text{biased}}$, where $\Delta(\mathbf{A})$ sets all off-diagonal elements of matrix $\mathbf{A}$ to zero

e) Decoding: After equalization, signal-to-interference-plus-noise ratios (SINRs) are estimated per stream via an error vector magnitude approach. Since the transmit symbols are known (under field trial conditions), we obtain an accurate estimate of $\hat{\text{SINR}}_l^{K,k}$ per location l and stream k. The following steps are soft demodulation and decoding by an LTE Rel. 8 compliant decoding chain.

IV. FIELD TRIAL RESULTS

The route traversed by the measurement , traveling at a speed of about 5 km/h, is depicted in Figure 1. It passes through surroundings of very different building morphology. Measurements at the BSs were taken synchronously every 10 s at a total of 600 measurement locations. The field trial was done in the uplink of the moving relay - BS feeder link. Thus, the moving relay was transmitting and the BS receiving. In order to test different transmitter configurations, the relay was configured to switch the number of Tx streams ($K = 1, 2, 3, 4$) as described in Section II. The Tx streams were transmitted

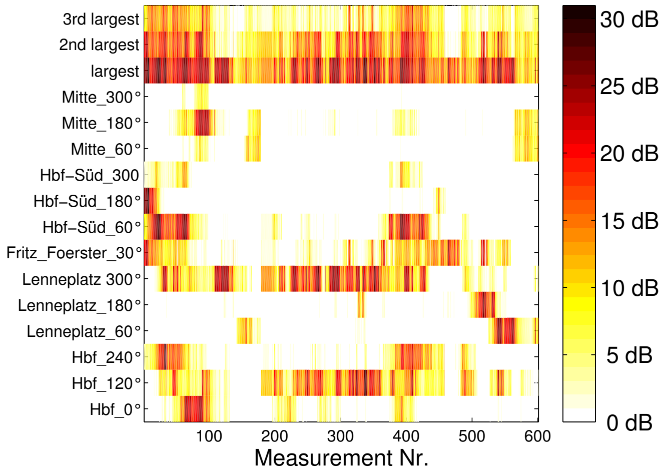


Fig. 3. Average per stream $\hat{\mathrm{SNR}}_l$ achieved at all BSs of the test bed during the complete field trial

at neighboring antennas, such that the antenna spacing for all stream combinations was always 3λ (see Figure 2).

As a first result, Figure 3 shows the average stream $\hat{\mathrm{SNR}}_l$ measured at all 13 BSs in the testbed. The figure also indicates the three largest $\hat{\mathrm{SNR}}_l$ that was measured at any BS. We see that typically a good link to the moving relay was often established to multiple BSs, while it was only seen by one or two BSs at some locations. Good links to multiple BSs are problematic in a conventional system with independent BSs because the received power at all non-serving cells is interfering with potential other users. In a cooperative system, however, signal propagation across cell boarder is exploited by joint signal processing.

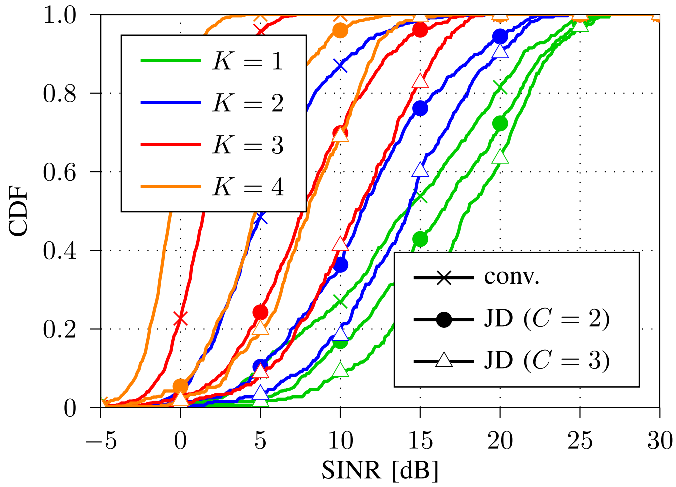
At each location the BSs with the best SNRs were chosen for detection. In the conventional case one BS was detecting each particular streams while C strongest BSs were forwarding their received signal to a joint decoder in the cooperative case. In order to assess the detection performance, we observe the cumulative distribution function (CDF) of SINR values measured after detection for different transmitter and receiver configurations. Figure 4(a) shows the SINRs that were achieved by linear MMSE detection at a single BS (conv.) or by JD. If $K > 1$, we do not distinguish between the SINR of the different streams and a single CDF curve comprises the achieved SINRs of any stream. The green curves correspond to a single stream transmission ($K = 1$). Since there is no inter-stream interference, the SINR values are largest for this transmitter configuration. Compared to conventional detection, JD yields an array gain because of maximum ratio combining of received signals through MMSE filtering. Increasing the number of Tx streams reduces the SINR for all receiver schemes. The decrease is most severe, however, for conventional detection. Even in the case of $K = 2$ streams, the SINR for conventional detection is strongly reduced because the links between the two Tx and the two receiver (Rx) antennas (of the BS) are highly correlated which reduces MIMO equalization performance. Note that conventional receiver processing (as it is understood herein) includes the option that different streams are decoded at different BSs which can be beneficial at the cell edge as a kind of soft handover. SINR values for JD degrade less severely because the MMSE filter makes use of the larger number of Rx streams that are less correlated. Figure 4(b) shows the SINR CDF for the same Tx and Rx configurations with the difference that inter-stream interference was canceled successively as described in Section III. For example, in the case of $K = 2$ Tx streams, the stream with the highest measured $\hat{\mathrm{SNR}}_l^k$ was detected first. Thus, this stream was still interfered by the other stream. After decoding and interference cancellation the other stream was detected facing only remaining interference due to channel estimation errors. The benefit of this approach can be clearly seen as the SINR for all numbers of Tx streams move much closer.

The previous results show that there is a large variation of SINR values while the relay is moving along the measurement route. In order to achieve robust communication and large throughput at the same time, the transmitter should adapt modulation and coding to the channel conditions. Unfortunately, this is not possible for offline evaluation, as used in this field trial. To determine achievable transmission rates for each channel we exploit that the channel coherence time is long enough for transmitting codewords with different MCS and number of Tx streams under very similar channel conditions. In particular, we transmit with a fixed number of Tx streams for 10 ms and switch in this interval through 10 MCS as listed in Table II. For each number of Tx streams and receiver configurations, the maximum achievable rate per stream $r_{K,k,l}^{\textit{Rx config}}$ (highest rate MCS) is determined, emulating a perfect rate adaptation. The total achieved rate of the moving relay is then given by

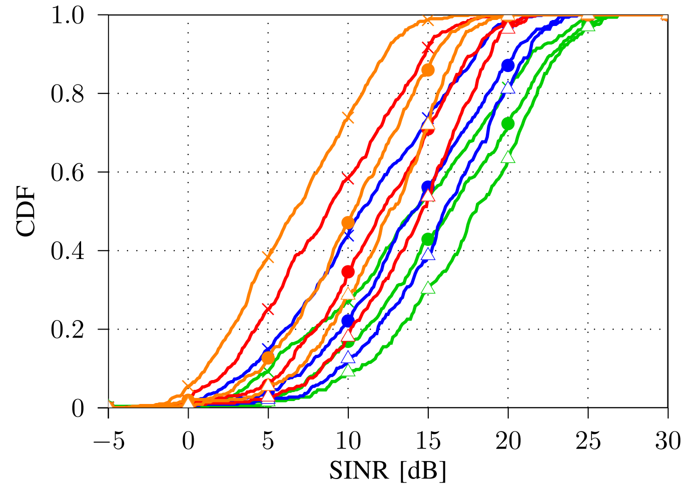
$$r_{K,l}^{\textit{Rx config}} = \sum_{k=1}^{K} r_{K,k,l}^{\textit{Rx config}}. \quad (7)$$

When SIC is used, we are able to determine the optimal MCS for each stream, and thus the rate $r_{K,l}^{\textit{Rx config, SIC}}$, because the transmitted codeword is known under field trial conditions. Thus, we can determine the MCS providing the highest rate that is successfully decoded either with or without prior SIC, applying a decoding order of highest SNR first. While this approach leads to reasonable results, and has the particular benefit that different Tx and Rx configurations are compared for the same measurement data respectively channels, the field trial is subject to the following assumptions and limitations:

- hybrid automatic repeat request (HARQ) is not considered (but also not necessary because emulated perfect rate adaptation is possible using offline signal processing).
- No background interference has been considered and, thus, no interference floor is visible.
- No power control is used which emphasizes the benefit of SIC because the sum capacity of the multiple access channel is achieved at full transmit power of all streams.



(a) linear MMSE Detection



(b) linear MMSE detection +SIC

Fig. 4. SINR CDF for different number of Tx streams ($K = 1, 2, 3, 4$) and receiver schemes.

The field trial setup is suitable to investigate moving relay feeder link performance in a realistic moving relay environment. However, we do not touch problems that arise from mobility of the relay, such as handover and channel estimation/prediction which, in the uplink, are vital for link adaptation. In particular, very good rate adaptation of all schemes is important when SIC is used because errors of a stream early in the decoding order propagate because interference cannot be canceled as expected by the rate adaptation algorithm. The accuracy of rate adaptation depends on the accuracy of channel and interference information. Joint scheduling of BSs has the potential to increase the control of interference [9]. At the same time, it introduces delays because channel information has to be forwarded over the backhaul network. This delay, on the other hand, reduces the accuracy of channel information which out-dates quickly for mobile users. However, there are concepts for accurate channel prediction for vehicles that travel at a constant velocity for the prediction horizon of a couple of ms. In this case, channel measurement of antennas placed in the front of a linear antenna array are used to predict the channel of the ones behind as presented in [8]. The applicability of this concept was the main motivation to place the relay antennas on a line in the direction of travel in a moderate distance of 3λ.

After detection we are interested in the throughput that was achieved throughout the field trial which is shown in Figure 5 for linear detection of a different numbers of streams. Looking at the performance of conventional detection first (green curves), we see that mostly (65% of the measurements) the transmission of a single data stream ($K = 1$) achieved the highest rates, measured in bit per channel use (bpcu) (which is equivalent to bits/s/Hz if overhead is neglected). As listed in Table III, 3.45 bpcu were achieved on average for this scheme. Switching between different number of transmit streams can be beneficial, e.g. between location 0 and 25, but would only provide small additional gains, mostly under very good channel conditions for which the rate of single stream transmission is limited by the limited choice of MCSs, allowing a maximum rate of 5.2 bpcu. Provided an optimal switching between different numbers of streams would be used (line named opt. in Table III), an average rate of 3.79 bpcu was achieved. Looking at the sum rate CDF in Figure 7(a) we arrive at the same conclusion. Increasing the number of streams even further is certainly detrimental as two Rx antennas per BS are not sufficient to spatially separate these streams, resulting in very low stream SINRs as already observed in Figure 4(a). For linear JD of $C = 2$ BSs, the transmission of $K = 2$ or $K = 3$ streams was typically the best choice. The average rate of 5.2 bpcu was the same in both cases. For an optimal selection of K at each location the average rate was 5.96 bpcu. The relative transmit time of each Tx stream number would have been 18%, 35%, 36%, and 10% for $K = 1, 2, 3, 4$ respectively. For $C = 3$, the transmission of $K = 3$ streams was optimal in 36% of the measurements and achieved the highest average rate of 6.10 bpcu. Optimal switching would have achieved 6.87 bpcu.

The picture is different for SIC reception as shown in Figure 6 and Figure 7(b). Now, the transmission of four streams achieved very large rates for any BS configuration, slightly outperformed by the transmission of three streams only for conv. reception. For cooperation cluster sizes of $C = 3$ even stream number adaptation gave only marginal gains while the transmission of four streams was optimal at over 70% of the measurement locations. We can observe in Figure 6 and Figure 1 that very high rates are possible at certain locations which is interesting for deployment of fixed relays as well. Fixed relays can be placed at selected locations where we see sum rates of up to 16 bpcu. This result is also very interesting for the downlink. Even though the results of this paper cannot be directly applied to this case, they indicate strong gains for joint transmission as well. And the use of joint transmission is very interesting for fixed relays due to rather

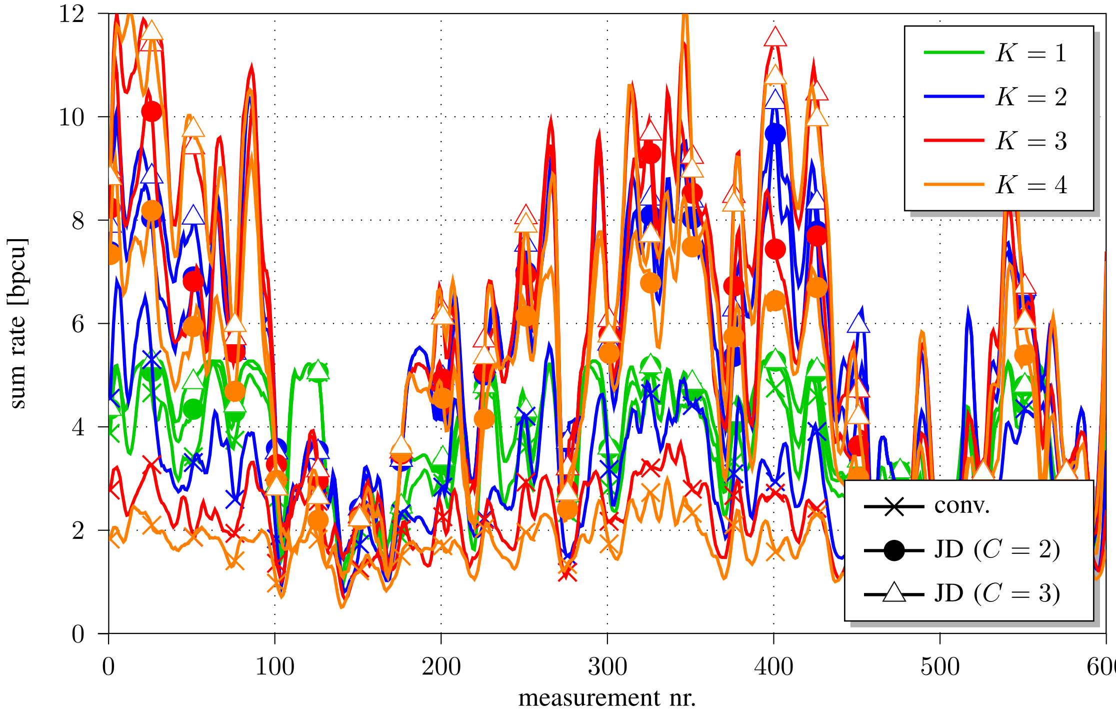


Fig. 5. Achieved rates for linear conventional and joint detection with cooperation cluster sizes $C = 2$ and $C = 3$ of $K = 1, 2, 3, 4$ streams along the measurement route.

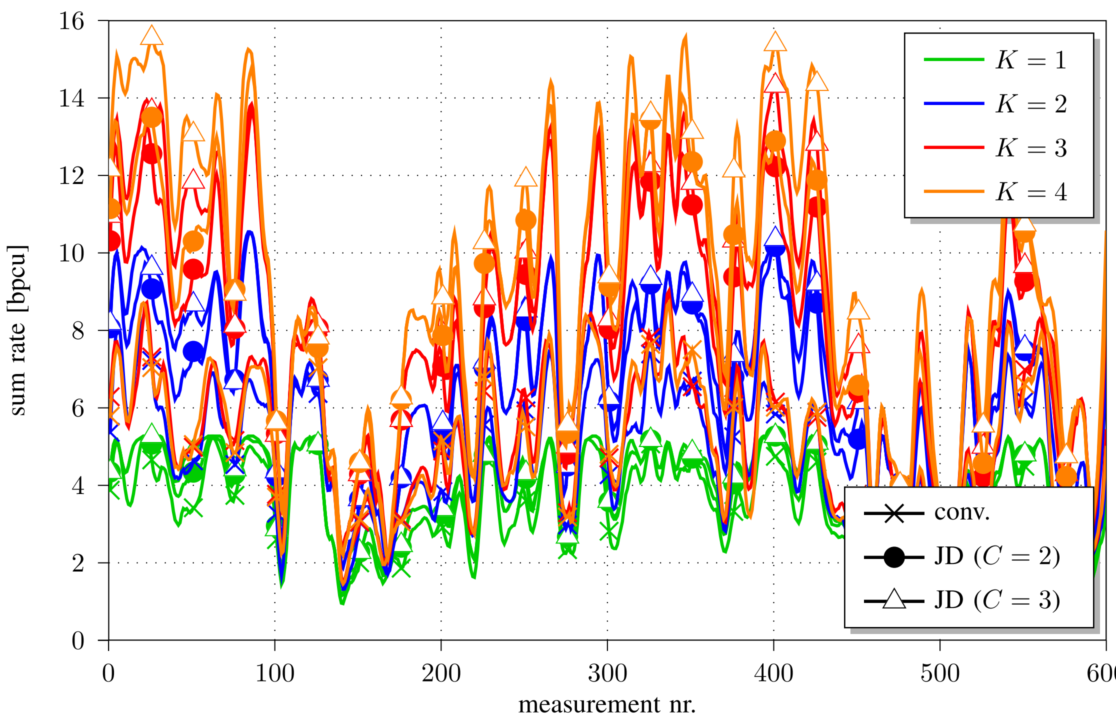
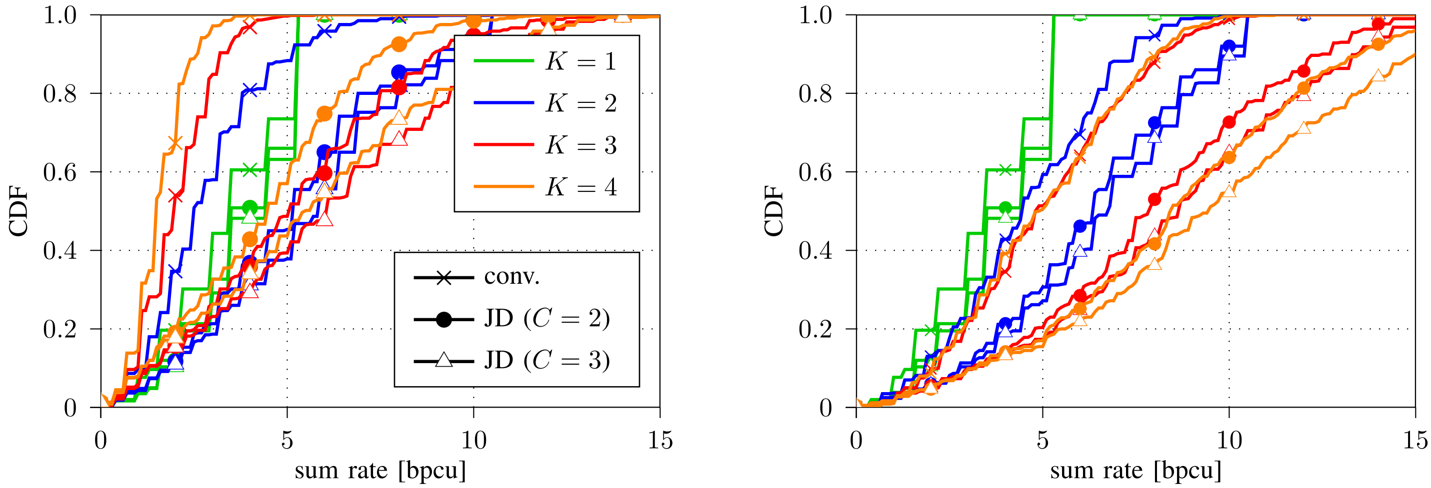


Fig. 6. Achieved rates for MMSE-SIC conventional and joint detection with cooperation cluster sizes $C = 2$ and $C = 3$ of $K = 1, 2, 3, 4$ streams along the measurement route.



(a) linear MMSE Detection

(b) linear MMSE detection +SIC

Fig. 7. Rate CDF for different number of Tx streams ($K = 1, 2, 3, 4$).

TABLE III
AVERAGE SUM RATES FOR LINEAR MMSE AND MMSE-SIC DETECTION AND A DIFFERENT NUMBER K OF TX STREAMS. THE LINE NAMED OPT. IS FOR OPTIMAL SWITCHING BETWEEN DIFFERENT NUMBER OF TX STREAMS.

K	conv. [bpcu] SIC off / SIC on	JD ($C = 2$) [bpcu] SIC off / SIC on	JD ($C = 3$) [bpcu] SIC off / SIC on
1	3.45 / 3.45	3.81 / 3.81	3.90 /3.90
2	2.92 / 4.65	5.22 / 6.30	5.60 / 6.62
3	2.09 / 5.10	5.21 / 7.88	6.10 / 8.50
4	1.62 / 5.00	4.44 / 8.53	5.80 / 9.40
opt.	3.79 / 5.50	5.96 / 8.73	6.87 / 9.58

static channel conditions of fixed wireless links which allow accurate precoding at rather low channel feedback rates.

V. CONCLUSIONS

We have investigated the performance of multi-antenna transmission for a moving relay feeder uplink in an urban cellular field trial. The evaluation included conventional detection of data streams at individual base stations as well as cooperative joint detection. We have seen that the data rates of conventional detection are limited because of the small number of receive antennas and also because of correlated channel fading which hinders spatial multiplexing. During the field trial the moving relay transmitted using a different number of up to four antennas (streams). The transmission of a few streams was typically the best choice without the use of successive interference cancellation (SIC). More streams were transmitted beneficially if SIC was used. We have seen strong average gains of joint detection throughout the field trial. For particular locations up to 16 bpcu were transmitted for cooperation cluster sizes of three base stations. While this result shows the benefit of joint signal processing on the relay feeder link in general, we have seen an average performance gain through joint detection of about 100% comparing conventional detection with JD of three BSs.

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