Two-way Relaying for 5G Systems

Comparison of Network Coding and MIMO Techniques

Karolina Ratajczak, Krzysztof Bakowski, Krzysztof Wesolowski
Chair of Wireless Communications
Poznan University of Technology
Poznan, Poland

***Abstract*—This paper studies the two-way wireless relaying with multiple antennas at the nodes, where data transfer takes place between the base station (BS) and the mobile station (MS) with the help of the relay station (RS). We consider the decode-and-forward protocol which is divided into two phases: Multiple Access phase and Broadcast phase. The main focus of this work is on the broadcast phase during which two data blocks received by the RS have to be sent to the BS and MS using the same channel resources. It may be achieved by incorporating network coding, where the binary sum of two data blocks is broadcast to both end nodes. In this paper, we demonstrate that when multiple antennas are available at the transmitter and receiver, applying network coding is not the optimal solution. We present a novel approach that exploits the MU-MIMO scheme and together with the proposed SVD precoding algorithm and interference cancellation receiver, provides a significant performance improvement. In the proposed scheme, we assume full channel state information at the transmitter (CSIT), which in a time division duplex (TDD) system may be obtained by exploiting the reciprocity of the wireless channel. The performance of the considered scenario is analyzed and verified through multi-link level simulations.**

Keywords*— *two-way relaying; network coding; MU-MIMO; precoding

I. Introduction

The exponential growth in mobile data traffic – typical estimates give an approximately 1000x increase over the next decade – requires an adequate response from the world's wireless communication researchers. Since current 4G technology will not be capable of carrying this rapid increase in data consumption, the attention of the research community is shifting towards what will be the next set of innovations in wireless communication technologies which will refer to 5G technologies. Beyond 2020, when the 5^{th} generation is expected to be rolled out, wireless devices with on-board high gain antennas will be installed on many vehicles. The vehicles will provide a dynamic network of data hotspots (relays) that can provide the functionality of dynamic and nomadic hotspots access points [19]. In this paper, the concept of vehicular hotspots is considered, where MS is communicating with the BS via RS mounted on the parked vehicle.

The two-way communication channel, where two nodes simultaneously transmit signal to each other, was first studied by Shannon in [13]. Recently, a two-way relay channel that incorporates network coding, has come into focus. Network coding was introduced in the seminal paper by Alswede [14] and emerged as a promising transmission technology, the key idea of which is to ask the intermediate node to mix the messages it received, and forward the mixture to several destinations simultaneously. The combination of network coding with the MIMO technique was considered in [1, 15, 16, 17, 18]. Assuming a binary symmetric relay channel, it was shown that bidirectional relaying with MIMO-NC performs equivalently to 2x2 V-BLAST MIMO and a 2x1 Alamouti MISO in multiple access phase and broadcasting phase, respectively [18]. In [16] and [17] the optimal precoding design for amplify-and-forward network coding (AF-NC) is presented. In [15], a decode-and-forward network coding (DNF-NC) scheme is proposed for MIMO multiple access relaying channels. A DNF-NC scheme with Virtual MIMO technique in the multiple access phase and network coding in the broadcast phase is considered in [1]. In this paper, we start with extending this scheme to the case when multiple antennas are available at each station during the broadcast phase. With that assumption, simple, single antenna network coding is extended to MISO and MIMO configuration. We further investigate broadcast phase coding strategies and propose a MU-MIMO based scheme that, together with the interference cancellation receiver, can outperform multiple antenna network coding in which transmit diversity and receive diversity techniques are applied. Performance of the MU-MIMO approach has been verified for several well-known linear precoding algorithms, such as zero forcing (ZF) or block diagonalization (BD), as well as for the SVD precoding algorithm proposed in this paper.

The rest of this paper is organized as follows. In Section II, we describe the system setup. Section III illustrates the multiple access phase. Typical MIMO-OFDM receivers, which jointly detect OFDMA (Orthogonal Frequency Division Multiple Access) and SC-FDMA (Single-Carrier Frequency Division Multiple Access) signals are derived. In Section IV, we go over the broadcast phase, describe the network coding scenario and motivate the proposed MU-MIMO based solution. Link level simulation results are provided in Section V. Section VI concludes the paper.

The following notations are used in the paper. Lowercase boldface letters and uppercase boldface letters denote vectors

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and matrices, respectively. $(\cdot)^T$ and $(\cdot)^H$ denote the transpose and the conjugate transpose. $\|\cdot\|$ denotes the Frobenius norm. $|\cdot|$ denotes the absolute value. $Tr(\cdot)$ denotes the trace, $diag(\cdot)$ denotes diagonal matrix and $det(\cdot)$ a matrix determinant.

II. System Model

In this paper, we consider the two-way relaying system, as shown in Fig. 1 that comprises one relay node (RS), such that the mobile station (MS) and the base station (BS) can communicate through the relay. Moreover, the system may be considered as an LTE-like system in which two different access methods such as SC-FDMA and OFDMA are applied in UL and DL, respectively. In the traditional solution of two-way relaying, four time slots are needed in TDD mode to exchange data blocks between two stations. In the considered scenario, the number of slots is reduced to two. These time slots are the multiple access slot and broadcast slot.

In the multiple access time slot, the MS transmits its data in the SC-FDMA format to the RS, whereas the BS concurrently transmits its own data blocks in the OFDMA format. Both stations use the same time and frequency resources during transmission. The RS jointly detects both data blocks using the MIMO (Multiple Input Multiple Output) technique, performs soft-decoding of received codewords and finds information blocks transmitted by the MS and BS. In the broadcast phase, the encoded modulo-2 sum of these two messages is transmitted by the RS in the OFDMA format, using the same resources as previously [1].

Fig. 2 presents an alternative realization of the broadcast phase that utilizes the MU-MIMO technique. In the considered MU-MIMO scenario, the RS communicates with the BS and MS simultaneously, through the same radio resources. The signal transmitted from the relay station is the sum of $\mathbf{x}_{BS}$ and $\mathbf{x}_{MS}$ multiplied by corresponding precoding matrices $\mathbf{W}_{BS}$ and $\mathbf{W}_{MS}$. In this paper we compare different precoding approaches and propose a solution that together with interference cancellation receiver can outperform traditional modulo-2 based network coding, in the case when multiple antennas are available at the transmitting node, as well as at the receiving nodes.

Let us assume one BS, one RS and one MS user with $N_{T_{BS}}$, $N_{T_{RS}}$, $N_{T_{MS}}$ transmit antennas and $N_{R_{BS}}$, $N_{R_{RS}}$, $N_{R_{MS}}$ receive antennas respectively. Furthermore, we assume that the MIMO

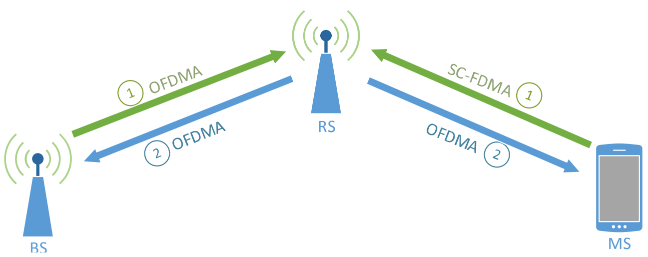

Fig. 1. Two-way relaying system with application of MIMO and Network Coding in RS

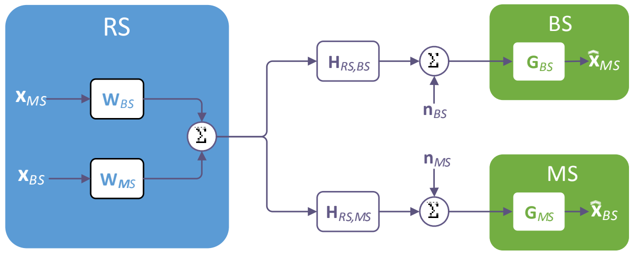

Fig. 2. Two-way relaying system with MU-MIMO in broadcast phase

channel between node A and node B is perfectly known at the receiving node, and may be described by $N_{R_B} \times N_{T_A}$ channel matrix $\mathbf{H}_{B,A}$.

III. Multiple Access Phase

In the multiple access phase, we assume that BS and MS have at least one transmit antenna and RS has at least two receive antennas. In order to make full use of MIMO spatial multiplexing and to decrease the number of required time slots, Virtual MIMO has been adopted. In this configuration the BS generates a signal in the OFDMA mode, whereas the MS transmits its signal in the SC-FDMA mode as shown in Fig. 3. Recall that the simulated system is based on the LTE standard in which OFDMA and SC-FDMA are multiple access schemes used in the downlink and uplink, respectively [2].

Out of $N_S < N$ potentially used subcarriers, where N is the size of the FFT block in the modulator, the same M subcarriers are applied in both links. Assuming that the RS has two receive antennas and is able to select N samples of signals received from both transmission ends belonging to the same OFDMA/SC-FDMA symbol (i.e. owing to timing synchronization the relative delay between symbols received from BS and MS does not exceed a fraction of the cyclic prefix), and assuming frequency synchronization of both signals, we may write down the following equation for the signal at the output of two OFDM demodulators in RS [1]:

$$\begin{bmatrix} \mathbf{y}_{RS_1} \\ \mathbf{y}_{RS_2} \end{bmatrix} = \begin{bmatrix} diag(\mathbf{H}_{RS_1,BS}) & diag(\mathbf{H}_{RS_1,MS}) \\ diag(\mathbf{H}_{RS_2,BS}) & diag(\mathbf{H}_{RS_2,MS}) \end{bmatrix} \cdot \begin{bmatrix} \mathbf{x}_{BS} \\ \mathbf{x}_{MS} \end{bmatrix} + \begin{bmatrix} \mathbf{n}_{RS_1} \\ \mathbf{n}_{RS_2} \end{bmatrix} \quad (1)$$

where $\mathbf{y}_{RS_1}$ and $\mathbf{y}_{RS_2}$ are the sample blocks at M subcarrier outputs of FFT demodulators for the first and second RS antenna, respectively. The matrices $\mathbf{H}_{RS_i,BS}$ and $\mathbf{H}_{RS_i,MS}$ are channel matrices for the link between BS/MS and RS, seen on the output of the i-th FFT demodulator. $\mathbf{x}'_{MS}$ and $\mathbf{x}_{BS}$ are M-element data blocks transmitted by the MS and BS, respectively. Since the MS transmits its data in the SC-FDMA mode, the data block is a subject of FFT transform which is

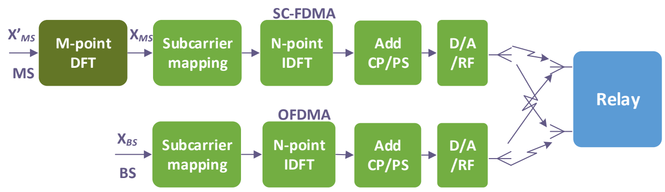

Fig. 3. MIMO system configuration in the multiple access time slot

expressed by the multiplication of the data block $\mathbf{x}_{MS}$ by the FFT matrix $\mathbf{F}_M$. Therefore, the data block transmitted by the MS may be expressed as

$$\mathbf{x}'_{MS} = \mathbf{F}_M \mathbf{x}_{MS} \tag{2}$$

Typical receivers in a MIMO-OFDM system may be categorized with their signal processing styles, e.g. they may be non-linear or linear. A linear receiver operating according to the zero-forcing (ZF) or minimum mean square error (MMSE) criterion applies a linear filter on received data blocks to separate the transmitted data streams, and then to decode each stream independently. The ZF solution of equation (1) applied in each subcarrier of the MIMO-OFDM system is given as

$$\begin{bmatrix} \tilde{x}_{BS} \\ \tilde{x}_{MS} \end{bmatrix} = \left[\mathbf{H}_{RS}^{\mathrm{H}} \mathbf{H}_{RS}\right]^{-1} \mathbf{H}_{RS}^{\mathrm{H}} \cdot \begin{bmatrix} y_{RS_1} \\ y_{RS2} \end{bmatrix} \tag{3}$$

whereas the MMSE solution is

$$\begin{bmatrix} \tilde{x}_{BS} \\ \tilde{x}_{MS} \end{bmatrix} = \left[\mathbf{H}_{RS}^{\mathrm{H}} \mathbf{H}_{RS} + \sigma \mathbf{I}_{N_T}\right]^{-1} \mathbf{H}_{RS}^{\mathrm{H}} \cdot \begin{bmatrix} y_{RS_1} \\ y_{RS2} \end{bmatrix} \tag{4}$$

where σ is the noise variance, $N_T = N_{T_{BS}} + N_{T_{MS}}$ and

$$\mathbf{H}_{RS} = \begin{bmatrix} h_{11} & \cdots & h_{1N_T} \\ \vdots & \ddots & \vdots \\ h_{N_R 1} & \cdots & h_{N_R N_T} \end{bmatrix} \tag{5}$$

IV. Broadcast Phase

During the second phase of two-way relaying, the decoded information blocks received by the RS from both end stations are broadcast in the OFDMA mode to the MS and BS using the same time and frequency resources as in the multiple access phase. Although the BS typically receives signals in the SC-FDMA mode, it must be able to receive OFDMA signals as well, which is not a problem due to the similarities between both access schemes. In the proposed system, savings in the transmission time resources during the broadcast phase may be achieved in two ways: by simple network coding in the network layer or, in the case of multiple antenna transmission, by performing MU-MIMO on separated signal streams for BS and MS. Both methods will be presented in this section.

A. Network Coding

At the beginning of the broadcast phase, the RS determines the binary sum (XOR) of information bit blocks. Subsequently the codeword is calculated in the turbo code encoder and its bits are mapped onto data symbols of an appropriate number of the OFDM symbols. The RS broadcasts the produced OFDM symbols in the OFDMA mode to the BS and MS, which receive the transmitted signals, decode it using the decoder of the applied turbo code and, as a result, determine the modulo-2 sum of the BS and MS information blocks. Having their own information blocks stored in their buffers, both stations are able to determine the other station's information block by modulo-2 summing the decoded block with the own one.

Since the RS inherently uses at least two antennas in the multiple access phase, they may be applied in the broadcast phase to perform transmit diversity as well. Depending on the capabilities of the MS and BS participating in the two-way relaying process, both MISO (Multiple Input Single Output) and MIMO configurations have been considered (two or four transmit antennas, one or two receive antennas). For two transmit antennas, pure SFBC was used. SFBC is a frequency-domain version of the well-known Space-Time Block Codes (STBCs), also known as Alamouti codes [3]. For four transmit antennas the combination of SFBC and FSTD (Frequency Switched Transmit Diversity) was used [4]. In the case of multiple receive antennas, the receiver combined the signals from N_R antennas by aligning the beamforming vector with the channel, via so-called Maximum Ratio Combining (MRC).

B. MU-MIMO

The optimal way of communicating over the MIMO channel involves a channel-dependent precoder that performs both transmit beamforming and power allocation across the transmitted streams. Let us consider a set of $P = NT$ symbols to be sent over the channel. The symbols are separated into N streams (or layers) of T symbols each. Stream i consists of symbols $[x_{i,1}, x_{i,2}, ..., x_{i,T}]$. Thus, the transmitted signal may be noted as

$$\mathbf{Y} = \mathbf{WPX} \tag{6}$$

where

$$X = \begin{pmatrix} x_{1,1} & x_{1,2} & \dots & x_{1,T} \\ \vdots & \vdots & & \vdots \\ x_{N,1} & x_{N,2} & \dots & x_{N,T} \end{pmatrix} \tag{7}$$

$\mathbf{W}$ is an $N \times N$ transmit beamforming matrix, and $\mathbf{P}$ is an $N \times N$ diagonal power allocation matrix with $\sqrt{p_i}$ as its i-th diagonal element, where p_i is the power allocated to the i-th stream. For this model, the information-theoretic capacity of the MIMO channel in bps/Hz may be obtained as [4, 9]

$$C_{MIMO} = \log_2 det(\mathbf{I} + \rho \mathbf{HWP}^2 \mathbf{W}^{\mathrm{H}} \mathbf{H}^{\mathrm{H}}) \tag{8}$$

where ρ is the so-called transmit SNR, given by the ratio of the transmit power over the noise power. The optimal (capacity-maximizing) precoder **WP** in equation (8) is obtained through the concatenation of *singular vector beamforming* and *waterfilling power allocation*.

The MIMO channel of user k may be decomposed by the singular value decomposition (SVD) as

$$\mathbf{H}_k = \mathbf{U}_k \Sigma_k \mathbf{V}_k^{\mathrm{H}} \tag{9}$$

If we apply $\mathbf{W}_k = [\mathbf{V}_k]_1$ to precode data for user k, where $[\mathbf{V}_k]_1$ denotes the first column of $\mathbf{V}_k$, we obtain the maximal precoding gains as follows [10]

$$\begin{aligned} \|\mathbf{H}_k \mathbf{W}_k\|_2 &= \|\mathbf{H}_k [\mathbf{V}_k]_1\|_2 = \sqrt{(\mathbf{H}_k [\mathbf{V}_k]_1)^{\mathrm{H}} (\mathbf{H}_k [\mathbf{V}_k]_1)} \\ &= \sqrt{(\lambda_k^{\max} [\mathbf{U}_k]_1)^{\mathrm{H}} (\lambda_k^{\max} [\mathbf{U}_k]_1)} = \lambda_k^{\max} \end{aligned} \tag{10}$$

where $[\mathbf{U}_k]_1$ denotes the first column of unitary matrix $\mathbf{U}_k$, and $\lambda_k^{\max}$ denotes the maximal singular value of $\mathbf{H}_k$.

Thus, precoding with the singular vector corresponding to the maximal singular value is the way to obtain good performance. However, in the case of multi-user transmission, when the MIMO channels of MU-MIMO users are nonorthogonal, applying a singular vector directly at the transmitter would significantly increase the CCI (Co-channel Interference), causing performance loss.

In the classic MU-MIMO scheme, for Gaussian MIMO broadcast channels, the capacity region may be achieved when Dirty Paper Coding (DPC) is applied [5]. Due to its high complexity, some suboptimal precoding techniques have emerged, such as Zero Forcing Beamforming (ZFBF) [6, 7], Minimum Mean Square Error (MMSE) [6], Block Diagonalization (BD) or Multi User Block Diagonalization Beamforming (MU-BFBF) [8]. The main goal of these precoding techniques is to remove the interference between the signals transmitted on the same resources and intended for different end points.

The ZFBF precoding matrix is expressed by the Moore-Penrose pseudoinverse of $\overline{\mathbf{H}} = [\mathbf{H}_{RS,BS}^{\mathrm{T}} \mid \mathbf{H}_{RS,MS}^{\mathrm{T}}]^{\mathrm{T}}$

$$\mathbf{W} = \overline{\mathbf{H}}^{\mathrm{H}}(\overline{\mathbf{H}}\overline{\mathbf{H}}^{\mathrm{H}})^{-1} \tag{11}$$

where precoding weights are the corresponding submatrices of $\mathbf{W} = [\mathbf{W}_{BS} \mid \mathbf{W}_{MS}]$.

When BD algorithm is applied, the precoding matrices $\mathbf{W}_{BS}$ and $\mathbf{W}_{MS}$ are chosen in such a way that $\mathbf{W}_{BS}$ lays in the null space of channel matrix $\mathbf{H}_{RS,MS}$ and $\mathbf{W}_{MS}$ lays in the null space of channel matrix $\mathbf{H}_{RS,BS}$ as follows

$$\mathbf{H}_{RS,BS} = \mathbf{U}_{BS}(\mathbf{\Lambda}_{BS} \mid \mathbf{0})(\mathbf{V}_{BS} \mid \mathbf{W}_{MS})^{\mathrm{H}} \tag{12}$$

$$\mathbf{H}_{RS,MS} = \mathbf{U}_{MS}(\mathbf{\Lambda}_{MS} \mid \mathbf{0})(\mathbf{V}_{MS} \mid \mathbf{W}_{BS})^{\mathrm{H}} \tag{13}$$

where $\mathbf{V}_{BS}$ and $\mathbf{V}_{MS}$ denote the right singular matrices corresponding to the non-zero singular values $\mathbf{\Lambda}_{BS}$ and $\mathbf{\Lambda}_{MS}$ respectively, while $\mathbf{W}_{BS}$ and $\mathbf{W}_{MS}$ correspond to zero singular values.

Just like in the BD algorithm, MU-BDBF eliminates intra-cell interferences using block diagonalization, but in comparison to BD it uses two beamforming matrices to precode one data stream. Precoding matrices may therefore be noted as

$$\mathbf{W}_{BS} = \mathbf{B}_{BS}\mathbf{D}_{BS} \tag{14}$$

$$\mathbf{W}_{MS} = \mathbf{B}_{MS}\mathbf{D}_{MS} \tag{15}$$

where $\mathbf{B}_{BS}$ and $\mathbf{B}_{MS}$ are used for interference cancellation, and $\mathbf{D}_{BS}$ and $\mathbf{D}_{MS}$ are applied for parallelizing and power allocation. While $\mathbf{B}_{BS}$ and $\mathbf{B}_{MS}$ are obtained in the same way as precoding matrices in the BD algorithm, $\mathbf{D}_{BS}$ and $\mathbf{D}_{MS}$ are calculated as follows [11]

$$\mathbf{H}_{RS,BS}\mathbf{B}_{BS} = \mathbf{U}_{BS}\mathbf{\Lambda}_{BS}\mathbf{D}_{BS}^{\mathrm{H}} \tag{16}$$

$$\mathbf{H}_{RS,MS}\mathbf{B}_{MS} = \mathbf{U}_{MS}\mathbf{\Lambda}_{MS}\mathbf{D}_{MS}^{\mathrm{H}} \tag{17}$$

In the considered two-way relaying scenario, when MU-MIMO is applied in broadcast phase, a linear combination of two physical signals is transmitted by the RS. Codewords for the BS and MS are calculated separately in turbo code encoders and then multiplied by adequate precoding matrices. The sum of these codewords is mapped onto the resource grid. The resultant received signal vectors for the BS and MS are noted as follows

$$\mathbf{y}_{BS} = \mathbf{H}_{RS,BS}\overline{\mathbf{W}}_{BS}\mathbf{x}_{MS} + \underbrace{\mathbf{H}_{RS,BS}\overline{\mathbf{W}}_{MS}\mathbf{x}_{BS}}_{interference} + \mathbf{n}_{BS} \tag{18}$$

$$\mathbf{y}_{MS} = \mathbf{H}_{RS,MS}\overline{\mathbf{W}}_{MS}\mathbf{x}_{BS} + \underbrace{\mathbf{H}_{RS,MS}\overline{\mathbf{W}}_{BS}\mathbf{x}_{MS}}_{interference} + \mathbf{n}_{MS} \tag{19}$$

where $\overline{\mathbf{W}}_{BS} = \mathbf{W}_{BS}\mathbf{P}_{BS}$ and $\overline{\mathbf{W}}_{MS} = \mathbf{W}_{MS}\mathbf{P}_{MS}$ are the precoding matrices including the power control that may be expressed as

$$\mathbf{P} = diag(\mathbf{p})^{1/2} \tag{20}$$

where vector $\mathbf{p} = [p_1, \ldots, p_A]$ includes power loading coefficients. Under the assumption of equal power distribution across all users, each element $p_k = P / A\|\mathbf{w}_k\|^2$, $(k = 1, \ldots, A)$, where P is the total power constraint on the transmitted signal, and $\mathbf{w}_k$ is the k-th column of $\mathbf{W}$.

The interferences from multi-user transmission occurring in the received signal (according to equations (18) and (19)) in the BS and MS respectively, may be expressed as

$$\mathbf{I}_{BS} = \mathbf{H}_{RS,BS}\overline{\mathbf{W}}_{MS}\mathbf{x}_{BS} \tag{21}$$

$$\mathbf{I}_{MS} = \mathbf{H}_{RS,MS}\overline{\mathbf{W}}_{BS}\mathbf{x}_{MS} \tag{22}$$

We can see that interference is the product of three factors: the channel matrix, the data signal desired to another station, and its precoder. $\mathbf{x}_{BS}$ is the data block transmitted during the multiple access phase from BS to RS (for MS) whereas $\mathbf{x}_{MS}$ denotes the data block transmitted from MS to RS (for BS). Therefore, if during the previous phase $\mathbf{x}_{BS}$ and $\mathbf{x}_{MS}$ have been buffered by BS and MS, respectively, they are perfectly known in these nodes during the subsequent phase. Since the channel matrix is estimated at the receiver, the only unknown factor is the precoder. If the BS and MS were aware of precoding matrix applied for the other station by the RS, then multiuser interference could be completely removed at the receiving nodes and it would be not necessary to do it at the transmitter. Having that on mind, we propose new precoding algorithm for MU-MIMO transmission in which precoders are calculated according to singular value decomposition (SVD) of the channel matrix (equation (9)). With SVD precoding algorithm the RS performs optimal precoding for each constituent link between the RS and end nodes and transmits the sum of calculated that way codewords. Since SVD precoding algorithm does not remove the interference between transmitted streams all the cancellation must be performed at the receiving nodes. Required by the interference cancellation receiver information about applied for another station precoder should be then conveyed to all end stations. In order to reduce the feedback overhead, in the proposed SVD-based scheme, precoding matrices are chosen from a finite codebook [12] known to all stations, and only the indices of the optimal precoders (PMI – precoding matrix index) are send from the RS to the BS and MS. The SVD precoding matrices are then obtained as follows

$$\mathbf{W}_{BS} = \mathbf{F}_{PMI_{BS}} \tag{23}$$

$$\mathbf{W}_{MS} = \mathbf{F}_{PMI_{MS}} \tag{24}$$

where PMI_{BS} and PMI_{MS} $(PMI_{BS}, PMI_{MS} = 1, \ldots, C)$ are the precoding matrix indices calculated by the RS for the BS and MS, respectively, $\mathcal{F} = \{\mathbf{F}_1, \ldots, \mathbf{F}_C\}$ is the codebook with a finite set of precoding matrices.

MU-MIMO may be viewed as network coding performed on signal samples, rather than on binary blocks. Applying such coding directly in the physical layer enables the choice of different data blocks sizes and modulation schemes by the BS and MS during the multiple access phase. This provides flexibility in applying transmission parameters to the source stations, which fit best to current channel conditions.

V. Simulation Results

In this section, the performance of the multiple antenna NC scheme together with the proposed MU-MIMO transmission protocol will be evaluated by means of link-level simulations. Two-way relaying in the system with basic features of the LTE system was modelled. The most important simulation parameters are presented in Table I.

TABLE I. Simulation parameters

Parameter	Value
Bandwidth	1.4 MHz
Transport block size	600
Duplex	TDD
Radio Channel	EPA 5Hz, ETU 70Hz
Channel estimation	Ideal
Number of frames	500
Modulation	QPSK
Channel coding	Turbo coder, rate 1/3

For the multiple access phase, two antenna setups were considered. The first one with one transmit antenna at BS and MS and two receive antennas at RS, and the second one with two transmit antennas at BS and MS and four receive antennas at RS. The performance of the system in this phase in terms of BLER (Block Error Rate) in the function of transmit SNR (Signal-to-Noise Ratio) for two channel models is shown in Fig. 4. It is evident that for the given channel models and assumed system configuration, the performance of the signal in the SC-FDMA format is worse than of the signal in the OFDMA format.

The broadcast phase performance analysis is presented in Figures 5-7. Fig. 5 compares the BLER performance of network coding applied in the broadcast phase in different antenna setups. With the increasing number of transmit and receive antennas the probability of block errors decreases, as expected. The best results are achieved in the configuration with $N_{T_{RS}} = 4$, $N_{R_{BS}} = 2$ and $N_{R_{MS}} = 2$.

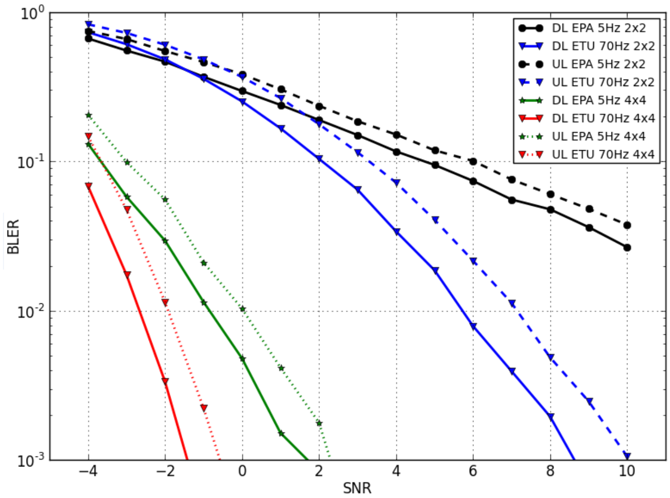

Fig. 4. Multiple access phase

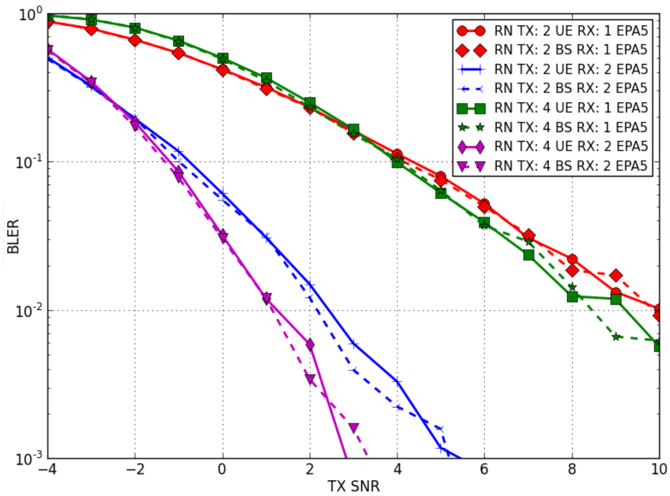

Fig. 5. NC in broadcast phase, EPA 5 Hz, different antenna configurations

Fig. 6 shows the BLER performance of the MU-MIMO scheme for different precoding algorithms. Two versions of SVD precoding algorithm are presented (referred to as FULL and LIMITED). Whereas in the first version the BS and MS have full knowledge of the precoding matrices calculated by the RS, in the second one precoding matrices are chosen from the codebook. From the simulation results, it is clear that the proposed MU-MIMO scheme with SVD precoding and interference cancellation receiver outperforms the BD, MU-BDBF and the ZFBF algorithms.

The comparison of network coding and MU-MIMO with codebook-based SVD precoding algorithm is presented in Fig. 7. The link from RS to BS is denoted as UL and the one from RS to MS as DL. It can be seen that the network coding performance is worse than the performance of the proposed SVD algorithm in the case of four transmit antennas. For two transmit antennas, NC performs better than MU-MIMO. The complexity of MU-MIMO scheme is higher than NC, but still realizable in practical implementations.

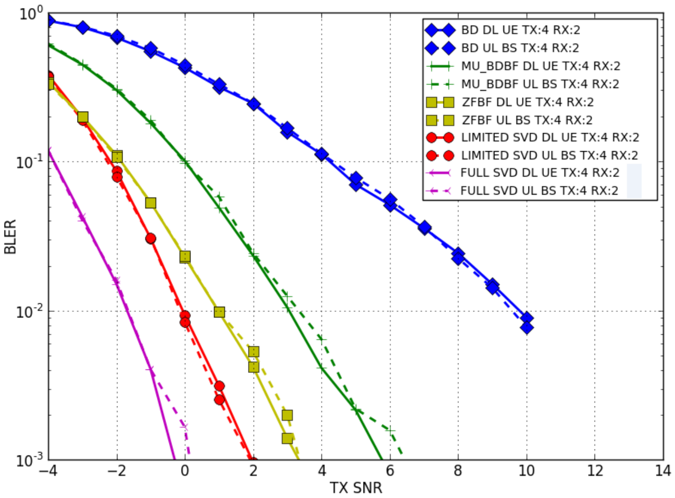

Fig. 6. MU-MIMO in broadcast phase, precoding algorithms comparison, EPA 5Hz, 4x2 antenna configuration, DL – link between RS and MS, UL – link between RS and BS

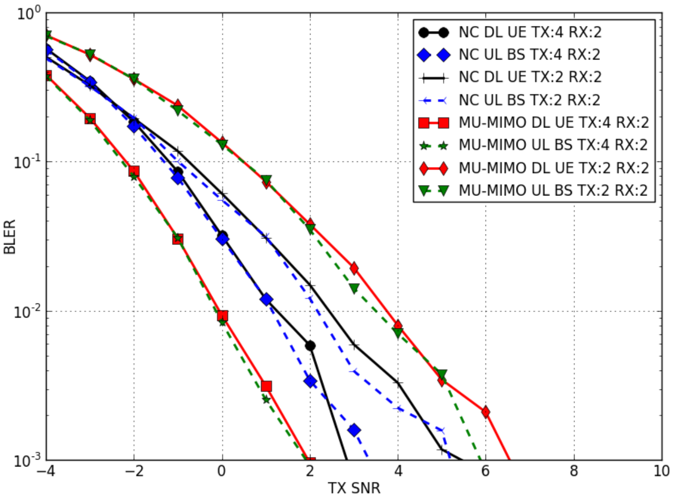

Fig. 7. Comparison of multiple antenna NC and MU-MIMO scheme (EPA 5 Hz, 4x2, limited scenario)

VI. CONCLUSIONS

The paper considers how the availability of multiple antennas may be exploited in the broadcast phase of a two-way relaying scenario. A new MU-MIMO transmission protocol has been proposed. The performed simulations have proven that the MU-MIMO method can obtain better performance in comparison to the network coding scheme, however, further investigations are necessary. They may include different antenna setups, modulation schemes and propagation scenarios (Doppler frequency and relay/terminals velocities). Investigations should be also performed via system-level simulations. The proposed algorithm enables different transport block sizes and modulation schemes to be chosen by BS and MS during multiple access phase, because data blocks are mixed by RS on the physical layer level. Thanks to this feature, transmission parameters can be matched more effectively to current radio channel conditions.

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