A Novel Very Low-Complexity Asymmetrical Relay Selection and Association for Multi-User Multi-Relay MIMO Uplink

Gayathri B[1] | Anitha K[2]

[1,2] Department of ECE, Prasad V Potluri Siddhartha Institute of Technology, Kanuru, Vijayawada.

ABSTRACT

In this paper, First we study joint user-relay selection and association in multi-user multi-relay cooperative wireless relay uplinks with multi-antenna nodes. For non-regenerative and altruistic relays we propose a low-complexity joint scheme, which simultaneously selects multiple relays and users for cooperation as well as assigns the selected users to different selected relays for service. This project proposes a new differential encoding and decoding process for D-DSTC systems with two relays. The proposed method is robust against synchronization errors and does not require any channel information at the destination. Moreover, the maximum possible diversity and symbol-by-symbol decoding are attained. Simulation results are provided to show the performance of the proposed method for various synchronization errors and the fact that our algorithm is not sensitive to synchronization error. The favorable performance and low-complexity of the proposed scheme make it very attractive for possible implementation in emerging broadband wireless relay networks (e.g., LTE-Advanced).

KEYWORDS: *Multiuser MIMO, MIMO relaying, relay selection, user scheduling, user-relay selection and association.*

I. Introduction

The use of multi-antenna relays has emerged as a very promising technique for combating fading, enhancing throughput and extending coverage in emerging wireless broad- band networks (e.g., LTE-Advanced). However, practical wire- less relay networks are delay sensitive due to two or more hops required to convey information from the source to the destination. Although prone to noise and interference enhancement, amplify-and-forward (AF) relays are simpler, hence more attractive than decode-and-forward (DF) ones [1], [2]. Quite recently, the possibility of leveraging the spatial dimensions of multi-antenna AF relays to pre-cancel interference from unintended sources before forwarding the useful signals to the destination has been investigated [3], [4].

In practical multi-user multi-relay systems, not all nodes are able (or allowed) to cooperate during data transmission. Selecting subsets of advantageous relays and users simultaneously for cooperation and communication will not only enhance the system performance by leveraging the inherent cooperative and multiuser diversity in the network, but also reduce signaling overhead and complexity. In order to have any practical relevance, user-relay selection and/or association schemes must be of acceptable complexity and fit within a small fraction of the coherence time of the channel.

Relay selection and user scheduling have been separately and extensively reported in the literature. For example, relay selection was studied in [5], [6] for networks with the same type of relays (e.g., AF or DF) and in [7] for networks with different types of relays (e.g., AF and DF). Similarly, user-scheduling in MIMO networks employing zero-forcing beam forming has been studied in [8]. Recently, 2-step single-user single-relay selection schemes in which the user with the best channel is selected in the first step, while the relay with the best channel to the selected user is selected in the 2nd step, for networks with single-antenna nodes have been studied [7], [9], [10]. However, transceiver nodes are envisaged to have multiple antennas in the emerging wireless broadband networks [2]. Most recently, user- relay association (i.e., no selection) in a multi-user multi-relay MIMO cellular network has been investigated [4].In this work, our goal is to design very low-complexity Asymmetrical relay and user selection scheme in order to enhance the system performance by leveraging the inherent multiuser and cooperative diversities in multi-user multi-relay wireless networks. In particular, we propose a novel joint sub-optimal scheme, which simultaneously selects multiple relays and users for coopera- tion, as well as assigns the selected users to selected relays for service. That is, three different tasks (i.e., relay selection, user selection/scheduling, user-relay selection and association) are performed concurrently. The proposed scheme utilizes only the Frobenius norms of the MIMO channel matrices between the nodes (i.e., partial instead of full channel state information (CSI) is needed), and hence it is more practical and easy to implement.1 Compared with a scheme with neither user-relay selection nor user-relay association and another with user-relay association, but no user-relay selection, the proposed scheme offers superior performance.

The paper is organized as follows. We present the system model in Section II. Section III details the proposed relay selection and association scheme. Simulation results are presented in Section IV. Section V concludes the paper.

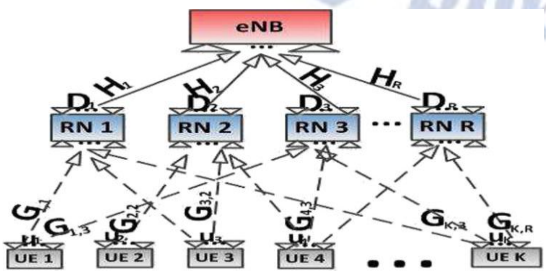

Fig. 1. A single-cell multiuser MIMO relay uplink(MARC)

The following notation is used. Boldface upper-case letters denote matrices, while boldface lower-case letters denote vectors. AH and _A_F respectively denote the Hermitian transpose and Frobenius norm of matrix A. A [I,j] is the ith row and jth column element of matrix A, while diag{. . .} is a diagonal matrix, whose diagonal elements are its arguments. |S| is the cardinality of the set S. E denotes the expectation operator. For random variables, x~CN (μ, σ^2) means that x is a circularly symmetric complex Gaussian random variable with mean μ and variance σ^2, while i.i.d. stands for independent and identically distributed.

II. Proposed Method

In this section, we propose a method for combating the synchronization error in the above system. The method combines differential encoding and decoding with an OFDM approach and is referred to as Differential OFDM (D-OFDM) DSTC. To establish the notation, first a brief review of OFDM systems is provided.

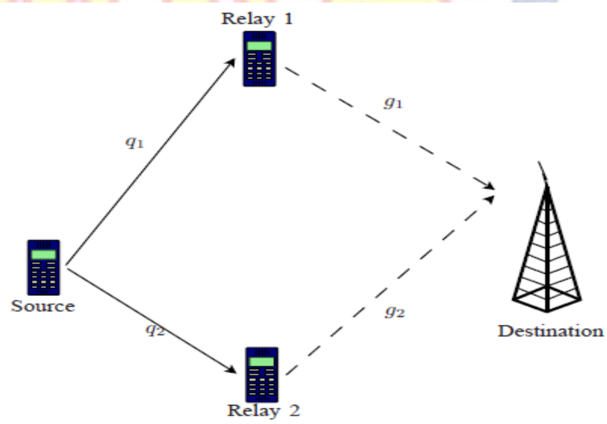

Fig. 2. Cooperative network under consideration, Source communicates with Destination through two relays.

A. OFDM System

Frequency selective channels are usually modeled with finite impulse response (FIR) filters in the base-band. The channel output is the convolution of the channel impulse response and input sequence which leads to ISI. OFDM is a low complexity approach to deal with the ISI encountered in frequency-selective channels as explained in the following. Let $\{x[n]\}$, $n = 0,\dots,N-1$ represent the data symbols of length N and $\{h_0,\dots,h_{L-1}\}$ represent the discrete time channel of length L. The N-point IDFT defined as $X[m] = IDFT\{x[n]\} = 1/\sqrt{N}\sum_{n=0}^{N-1} x[n]\exp(j2\pi mn/N)$, is applied to obtain sequence $\{X[m]\}$, $m = 0,\ldots,N-1$. Next, a cyclic prefix is appended to the beginning of sequence $\{X[N-L],\ldots,X[N-1],X[0],\ldots,X[N-1]\}$ and the result is injected to the channel. Let us assume that the additive noise is zero. The channel output sequence, after

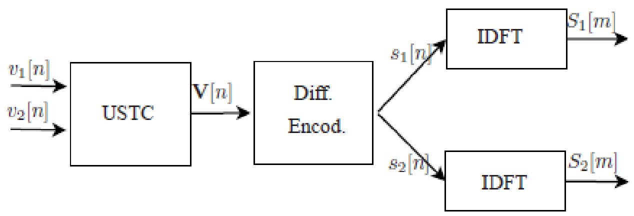

Fig. 3. Encoding process at Source

removing the first L received symbols, is $Y[m] = h_1 \otimes X[m]$, $m = 0,\ldots,N-1$. Now, the N-point DFT defined as $y[n] = DFT\{Y[m]\} = 1/\sqrt{N}\sum_{m=0}^{N-1} Y[m]\exp(-j2\pi mn/N)$ is applied to obtain $y[n] = H[n]x[n]$, $n = 0,\ldots,N-1$

where $H[n] = \sum_{l=0}^{L-1} h_1 \exp(-j2\pi \ln/N)$. Using OFDM, the ISI is removed and the L-tap frequency-selective channel is converted to N parallel flat-fading channels. In the next section, the proposed method is described in detail.

B. Differential OFDM DSTC

Using Eq. (5), the effect of synchronization error is modeled by a frequency-selective channel with two taps and the OFDM method is utilized to remove the ISI. Similar to the conventional method, a two-phase transmission process is employed. However, instead of two symbols, a sequence of symbols will be transmitted during each phase. In Phase I, Source encodes data information as depicted in Fig. 4 and transmits $2N$ symbols to the relays. Then, the relays apply a special configuration, append $2L$ symbols and transmit $2(N+L)$ symbols to Destination in Phase II. Finally, Destination removes the $2L$ symbols and decodes the $2N$ symbols. Transmission of $2N$ symbols from Source to Destination in two phases is referred to as "one block transmission", indexed by $k \in Z$. The description of each step is described in detail as follows. Let us consider $2N$ data symbols, to be transmitted from Source to Destination, into sequences $\{v_1[n]\}, \{v_2[n]\}$, $n = 1,\ldots,N$ of length N. The two sequences are then encoded to USTC matrices based on (1) to obtain $\{V[n]\}$, $n = 1,\ldots,N$. Next, matrices $\{V[n]\}$ are differentially encoded as

$$s[n]^{(k)} = V[n]^{(k)}\, s[n]^{(k-1)} = \begin{bmatrix} s_1[n] \\ s_2[n] \end{bmatrix}$$

$$s[n]^{(0)} = [1 \quad 0]^t, \quad n = 0,\ldots,N-1, \tag{9}$$

To obtain sequence,

s $\{s_1[n]\}^{(k)}, \{s_2[n]\}^{(k)}$, $n = 0,\ldots,N-1$ of length N. From now on, for simplicity of notations, the block-index (k) is omitted.

Then, the N-point IDFT is applied to $\{s_1[n]\}, \{s_2[n]\}$ sequences to obtain $S_1[m] = IDFT\{s_1[n]\}$ and $S_2[m] = IDFT\{s_2[n]\}$, $m = 0,\ldots,N-1$. The obtained sequences $S_1[m]$ and $S_2[m]$ are then transmitted consecutively from Source to the relays over two sub-blocks, in Phase I.

The received signals at the relays for $m = 0,\ldots,N-1$ are expressed as

$$R_{ij}[m] = \sqrt{2P_0}\, q_i S_j[m] + Z_{ij}[m], \quad i, j = 1, 2 \tag{10}$$

Where $Z_{ij}[m] \sim CN(0, N_0)$ are the noise elements at Relay i and sub-block j. The received signals at Relays 1 and 2 for $m = 0, \dots, N-1$ are configured as

The received signals at Relays 1 and 2 for $m = 0, \dots, N-1$ are configured as

$$\begin{aligned} X_{1j}[m] &= A R_{1j}[m], \quad j = 1, 2, \\ X_{21}[m] &= -A \mathring{R}_{22}^{*}[m], \\ X_{22}[m] &= A \mathring{R}_{21}^{*}[m], \end{aligned} \tag{11}$$

Where A is the amplification factor and $\mathring{R}_{2j}[m]$ is the circular time-reversal [15] of $R_{2j}[m]$ defined as

$$\mathring{R}_{2j}[m] = \begin{cases} R_{2j}[0], & m = 0 \\ R_{2j}[N-m], & otherwise. \end{cases} \tag{12}$$

Before transmission, the last L symbols of sequences $\{X_{ij}[m]\}, i, j = 1, 2$ are appended to their beginnings as the cyclic prefix to obtain

$$\{X_{ij}[N-L], \dots, X_{ij}[N-1], \dots, X_{ij}[N-1]\}$$

with length $N + L$. Here, L is the cyclic prefix length determined based on the amount of delay between the received signals from both relays and will be discussed shortly.

In Phase II, Relay 1 transmits sequences $\{X_{11}[m]\}$ and $\{X_{12}[m]\}$, while Relay 2 transmits $\{X_{21}[m]\}$ and $\{X_{22}[m]\}$, for $m = -L, \dots, ., \dots, N-1$, during two consecutive sub blocks or $2(N+L)$ symbols, to Destination.

At Destination, without loss of generality, let us assume that the received signal from Relay 2 is $(dT_S + \tau)$ seconds delayed with respect to that of Relay 1, where d is an integer number and $0 \le \tau \le T_S$. Thus, to avoid ISI, the cyclic-prefix length is determined as $L > d$. If the delay, as shown in Fig. 2, is less than one symbol duration, $L = 1$ is enough. In practice the relays do not need to know the delay and, based on the propagation environment, the maximum value of d in the network can be estimated and used to determine the cyclic prefix length.

In this case, the received signals during two sub-blocks, after removing the first L symbols, can be expressed as

$$\begin{aligned} Y_1[m] &= g_1 X_{11}[m] + g_{20} X_{21}[m-d] + g_{21} X_{21}[m-1-d] + W_1[m] \\ &= g_1 X_{11}[m] + (g_2[m] \otimes X_{21}[m-d]) + W_1[m], \ m = 0, \dots, N-1 \end{aligned} \tag{13}$$

$$\begin{aligned} Y_2[m] &= g_1 X_{12}[m] + g_{20} X_{22}[m-d] + g_{21} X_{22}[m-1-d] + W_2[m] \\ &= g_1 X_{12}[m] + (g_2[m] \otimes X_{22}[m-d]) + W_2[m], \ m = 0, \dots, N-1 \end{aligned} \tag{14}$$

Where $g_2[m] = \sum_{l=0}^{1} g_{21} \delta[m-l]$.

By substituting (11) and (10) into the above equations, one obtains, for $m = 0, \dots, N-1$

Where sequences $\mathring{S}_j[m]$ and $\mathring{Z}_{2j}[m]$ are the circular time reversal of sequences $S_j[m]$ and $Z_{2j}[m]$, respectively, as defined in (12).

$h_1 = q_1 g_1$, $h_2[m] = \sum_{l=0}^{1} h_{21} \delta[m-l]$, $h_{20} = q_2^{*} g_{20}$, $h_{21} = q_2^{*} g_{21}$ and as defined in Section II.

By taking the N-point DFT of $Y_1[m]$, $Y_2[m]$ sequences and the properties of circular time-reversal1 sequences, for $n = 0, \dots, N-1$, one derives

$$\begin{aligned} y_1[n] &= A\sqrt{2P_0}\left(h_1 s_1[n] - H_2[n] s_2^{*}[n]\right) + \tilde{w}_1[n], \\ y_2[n] &= A\sqrt{2P_0}\left(h_1 s_2[n] + H_2[n] s_1^{*}[n]\right) + \tilde{w}_2[n], \end{aligned} \tag{17}$$

With

$$\begin{aligned}
&H_2[n]=q_2^* G_2[n],\\
&G_2[n]=\left(g_{20}+g_{21}e^{-j2\pi d/N}\right),\\
&\tilde{w}_1[n]=A\left(g_1 z_{11}[n]-G_2[n]z_{22}^*[n]\right)+w_1[n],\\
&\tilde{w}_2[n]=A\left(g_1 z_{12}[n]+G_2[n]z_{21}^*[n]\right)+w_2[n],\\
&z_{11}[n]=DFT\{Z_{11}[m]\},\ \ z_{22}[n]=DFT\{Z_{22}[m]\},\\
&z_{12}[n]=DFT\{Z_{12}[m]\},\ \ z_{21}[n]=DFT\{Z_{21}[m]\},\\
&w_1[n]=DFT\{W_1[m]\},\ \ w_2[n]=DFT\{W_2[m]\}.
\end{aligned} \tag{18}$$

The received signals for the block-index (k), $y[n]^{(k)}=\left[y_1[n] \quad y_2[n]\right]^t$, in the matrix form, for $0 \le n \le N-1$, can be expressed as

$$y[n]^{(k)}=A\sqrt{2P_0}\begin{bmatrix} s_1[n] & -s_2^*[n] \\ s_2[n] & s_1^*[n]\end{bmatrix}\begin{bmatrix} h_1 \\ H_2[n]\end{bmatrix}+\begin{bmatrix}\tilde{w}_1[n] \\ \tilde{w}_2[n]\end{bmatrix} \tag{19}$$

It is pointed out that, for given g_1, g_2 the equivalent noise $\left[\tilde{w}_1[n] \quad \tilde{w}_2[n]\right]^t \sim CN\left(0,\sigma^2[N]I_2\right)$, where

$$\sigma^2[n]=N_0\left(1+A^2\left(|g_1|^2+|g_2|^2 c[n]\right)\right), \tag{20}$$

$$c[n]=\left|p(\tau)+p(T_S-\tau)e^{-j2\pi n/N}\right|^2. \tag{21}$$

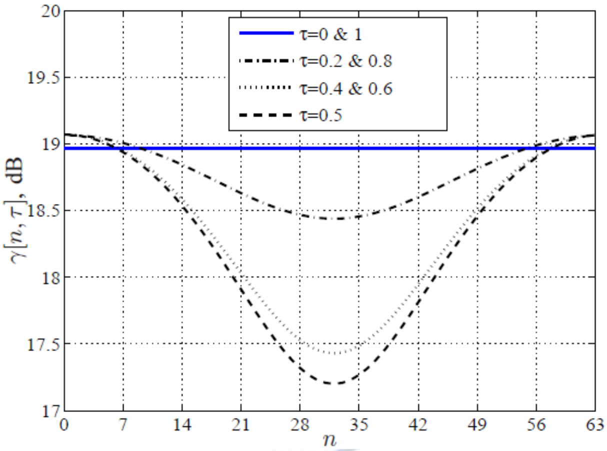

Fig. 4. Received SNR vs. n **and** τ **,**

$N=64,\ L=1,\ P/N_0 = 25dB$,

$P_0=P/2,\ P_r=P/4,\ |g_1|^2=|g_2|^2=1$.

Also, the received SNR per symbol, for given g_1, g_2 can be obtain as

$$\gamma[n,\tau]=\frac{A^2P_0\left(|g_1|^2+|g_2|^2 c[n]\right)}{N_0\left(1+A^2\left(|g_1|^2+|g_2|^2 c[n]\right)\right)} \tag{22}$$

With the raised-cosine filter defined in Section II, $p(\tau)=1$ and $p(T_S-\tau)=0$ for $\tau=0$ and hence $c[n]=1$. Thus, the noise variance and the received SNR of the proposed system are the same as that of the conventional D-DSTC for $\tau=0$. However, for $\tau \ne 0$ the average received SNR is a function of τ and n. To see this dependency, $\gamma[\tau,n]$ is plotted versus n and τ in Fig. 5, when $N=64$, $L=1$, P/N_0 = $25dB$, $P_0=P/2$, $P_r=P/4$, and for simplicity $|g_1|^2=|g_2|^2=1$. As can be seen, $\gamma[\tau,n]$ is symmetric around its minimum at $n=N/2-1$. Also, overall, $\gamma[\tau,n]$ decreases with increasing τ and reaches its minimum value at $\tau=0.5T_S$. Then it increases with increasing τ towards T_S such that $\gamma(\tau,n)=\gamma[T_S-\tau,n]$. This phenomenon yields the same average BER for symmetric values of τ around $0.5T_S$, as will be seen in the simulation results.

By writing (19) for two consecutive block-indexes (k), $(k-1)$, using (9) and assuming that h_1 and $H_2[n]$ are constant over two consecutive blocks, the differential decoding is applied for $n=0,\ldots,N-1$

$$\hat{v}_1[n],\hat{v}_2[n]=\arg\min_{v}\left\|y[n]^{(k)}-V[n]^{(k)}y[n]^{(k-1)}\right\| \tag{23}$$

to decode the $2N$ data symbols. Because of the orthogonality of $V[n]$, symbols $v_1[n], v_2[n]$ are decoded independently, without any knowledge of CSI or delay. It is easy to see that, due to the structure of Eq.(19), the desired diversity of two is achieved in this system.

III. SIMULATION RESULTS

In this section the relay network in Fig. 1 is simulated in various scenarios. Through these simulations, the effectiveness of the proposed method against synchronization error is

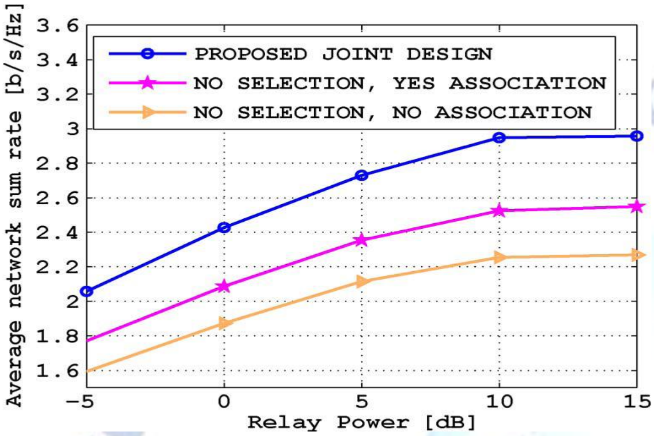

Fig. 5. Average sum rate of a MARC with *PU* = 0 dB, *MB* = 6, *MR* = 6, *N* = 2, *R* = 3, *Rt* = 6, *K* = 3, and *Kt* = 5.d as

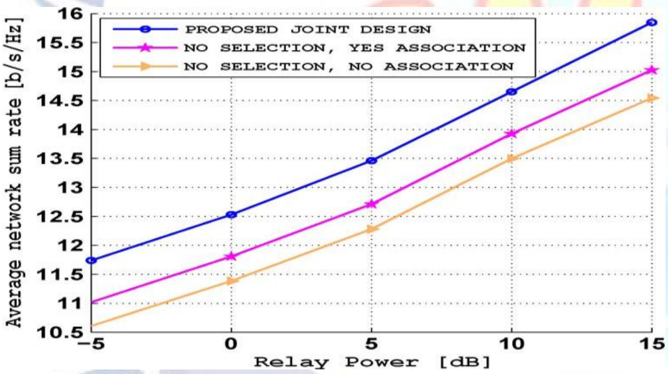

Fig. 6. Average sum rate of a MARC with *PU* = 20 dB, = 6,*MR* = 6, *N* = 2, *R* = 3, *Rt* = 6, *K* = 3, and *Kt* = 5.

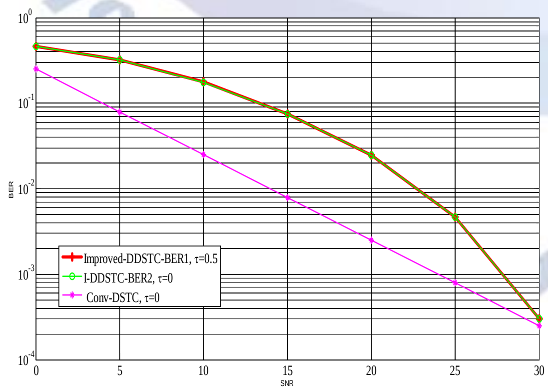

Fig. 7. Simulation for BER of D-OFDM DSTC (proposed method, $N=64$, $L=1$,), D-DSTC [6], and coherent DSTC [3] using BPSK for various values of delays.

Illustrated and compared with conventional D-DSTC [6] and coherent DSTC [3].

The channel coefficients q_1, q_2, g_1, g_2, are assumed to be static during each OFDM block and change from block to block according to the Jakes' model with the normalized Doppler frequency of $f_D T_S = 10^{-3}$. The simulation method of [16] is used to generate the channel coefficients. BPSK modulation is used to convert information bits into symbols. Also, $N=64$, point DFT and IDFT with a cyclic prefix length of $L=1$, are employed in the simulation. The system is simulated for various amounts of delay $\tau = (0, 0.2, 0.4, 0.6, 0.8, 1)T_S$ and $T_S = 1$.

Fig. 6 depicts the BER results of the D-OFDM DSTC system versus P/N_0 , where P is the total power in the network. For comparison purposes, the BER results of the conventional D-DSTC system [6] are also added to the figure for various values of τ . Moreover, the BER curve of coherent DSTC [3] with perfect synchronization $\tau = 0$ is plotted as a benchmark.

As shown in the figure, the performance of the conventional D-DSTC system is severely degraded for $\tau > 0.2$ and an error floor appears in the BER curves. On the other hand, the proposed method is able to deliver the desired performance for all values of the delays. As explained in Section III, the BER curves are symmetric around $\tau = 0.5T_S$. Hence the BER curves of $\tau = 0.2T_S$ and $\tau = 0.8T_S$ and of $\tau = 0.4T_S$ and $\tau = 0.6T_S$ are the same. Moreover, the BER curves of $\tau = 0, T_S$ of the proposed method are similar to that of the conventional D-DSTC with $\tau = 0$, as expected. A performance difference of around 3 dB is seen between coherent DSTC with perfect synchronization and that of D-OFDM DSTC.

IV. CONCLUSION

In our paper we studied the joint user-relay selection and association in a MIMO multiple access relay channel (MARC). Since collecting channel information is challenging, synchronization error is also inevitable in distributed space-time relay networks. Hence, in this paper a method was proposed that does not require any channel information and is very robust against synchronization error. The method combines differential encoding and decoding with an OFDM-based approach to circumvent channel estimation and deal with synchronization error. It was shown through simulations that the method works well for various synchronization error values.

References

[1] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, cooperative diversity in wireless networks: Efficient protocols and outage behavior," vol. 50, no. 12, pp. 3062 – 3080, Dec. 2004.

[2] J. N. Laneman and G. W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks," vol. 49, no. 10, pp. 2415 – 2425, Oct. 2003.

[3] Y. Jing and H. Jafarkhani, "Using orthogonal and quasi-orthogonal designs in wireless relay networks," *IEEE Trans. Inform. Theory*, vol. 53, no. 11, pp. 4106–4118, Nov. 2007.

[4] Y. Jing and B. Hassibi, "Distributed space-time coding in wireless relay networks," *IEEE Trans. Commun.*, vol. 5, no. 12, pp. 3524 –3536, Dec. 2006.

[5] P.A.Anghel and M. Kaveh, "On the performance of distributed spacetime coding systems with one and two non-regenerative relays," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 3, pp. 682 – 692, Mar. 2006.

[6] Y. Jing and H. Jafarkhani, "Distributed differential space-time coding for wireless relay networks," *IEEE Trans. Commun.*, vol. 56, no. 7, pp. 1092 –1100, Jul. 2008.

[7] G. Wang, Y. Zhang, and M. Amin, "Differential distributed spacetime modulation for cooperative networks," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 11, pp. 3097 –3108, Nov. 2006.

[8] Wang, Y. Yao, and G. B. Giannakis, "Non-coherent distributed spacetime processing for multiuser cooperative transmissions," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 12, pp. 3339 –3343, Dec. 2006.

[9] S. Wei, D. L. Goeckel, and M. C. Valenti, "Asynchronous cooperative diversity," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 6, pp. 1547– 1557, Jun. 2006.

[10] Y. Mei, Y. Hua, A. Swami, and B. Daneshrad, "Combating synchronization errors in cooperative relays," in *IEEE Proceedings. Int. Conf. on Acoust., Speach and Signal Proc.,(ICASSP)*, Mar. 2005, vol. 3, pp. 369–372 Vol. 3.

[11] S. Barghi and H. Jafarkhani, "Exploiting asynchronous amplify-and forward relays to enhance the performance of IEEE 802.11 networks," *IEEE/ACM Trans. Network.*, vol. PP, no. 99, pp. 1– 12, 2014, to appear.

[12] F. C. Zheng, A. G. Burr, and S. Olafsson, "Pic detector for distributed space-time block coding under imperfect synchronisation," *Electronics Letters*, vol. 43, no. 10, pp. 580–581, May 2007.

[13] Z. Li and X. Xia, "A simple Alamouti space-time transmission scheme for asynchronous cooperative systems," *IEEE Signal Process. Letters*, vol. 14, no. 11, pp. 804–807, Nov. 2007.

[14] U. Madhow, *Fundamentals of digital communication*, vol. 518, Cambridge University Press New York, USA, 2008.

[15] B. Porat, *A course in digital signal processing*, vol. 1, Wiley New York, 1997.

[16] Y. R. Zheng and C. Xiao, "Improved models for the generation of multiple uncorrelated Rayleigh fading waveforms," *IEEE Commun. Letters*, vol. 6, no. 6, pp. 256 –258, Jun. 2002. 46, june 2013.