Data Detection for MIMO Broadcasting System with Decode-and-Forward Cooperation

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***Abstract*—We consider the data detection in a multiple-input multiple-output (MIMO) broadcasting system where the source simultaneously transmits multiple data streams to single-antenna receivers. To detect multiple data streams, conventional MIMO techniques require the receivers to have multiple receive antennas, the number of which is greater than or equal to the number of transmit antennas. However, user cooperation can be applied to combat this limitation. In this paper, we propose a user decode-and-forward (DF) cooperation scheme and the corresponding detection method. The transmission consists of two phases: source broadcasting and the user cooperation. During the user cooperation phase, a selected leader in the cooperation group collects the detections from the other users. The leader then obtains its final detection by using *maximum likelihood* (ML) criteria and broadcasts the results to all the other users in the cooperation group. Through simulations we show that the average symbol error performance of the proposed cooperation scheme are affected by several factors including the cooperation group size, the number of users activated for transmission and the length of the cooperation phase. With moderately large group size, the proposed system can potentially outperform the conventional system whose number of receive antennas are equal to the number of transmit antennas.**

***Index Terms*—Cooperative detection, broadcasting, MIMO, decode-and-forward, cooperation, maximum likelihood detection**

I. Introduction

The MIMO communication system has been intensely studied in recent years due to its tremendous improvement in data rate and capacity [1], [2]. The widely studied architectures in MIMO include space-time-coding (STC) and MIMO with spatial-multiplexing (SM). In MIMO with STC, the reliability of the communication system is improved by designing codes to exploit the spatial and temporal domains [3]– [6]. In MIMO with SM, high data rate can be provided by transmitting independent data streams simultaneously on multiple antennas. With multiple antennas in the MIMO system, the data detection is complicated and various linear or non-linear detectors have been widely studied [7]– [10]. It is commonly practiced in the existing studies to assume that the number of receive antennas is equal to or more than the number of transmit antennas. The general conception is that, when the receive antennas is fewer than the transmit antennas, the data detection is not feasible. However, in a practical mobile communication system, mobile users often have fewer antennas then the base station (BS) does, and thus the aforementioned decoders cannot be directly applied.

Recent research works [11]– [13] attempt to combat the problem of insufficient user antennas in the MIMO system and increase the capacity. The technique is to exploit the cooperation diversity [14], where each user shares its antenna with other partners to transmit and decode the data. In more recent research, the distributed coding and decoding techniques via cooperation are proposed and analyzed [15], [16], [17]. These studies consider the frameworks where cooperative nodes do not decode the data but simply amplify and forward the data. The works assume that the full channel state information (CSI) can be shared among the cooperative nodes with the aid of the cooperation channels. However, the feedback error through the cooperation channels may degrade the system performance.

In this paper, we consider the user cooperative data detection in a MIMO broadcasting system. Particularly we focus on a non-coded SM system where the base station are equipped with multiple antennas and each user has a single antenna. The system is similar to that in [16], without the cooperation channels for the users to exchange their CSIs. In other words, the users have no knowledge of the channels which are not linked to themselves. In our assumed settings, the practicality of the system is improved since the exchange and storage of CSIs among users impose extra burden to an individual user when the system has a large number of users. We provide a transmission structure for user cooperation in such a system and the structure can be extended to systems with multiple-antenna users and systems with coding.

In the proposed structure, a transmission frame is divided into two phases, i.e., the source broadcasting phase and the user cooperation phase. After receiving the signal from the source broadcasting phase, the users obtain their initial detections and enter the cooperation phase. The cooperation phase is divided into two parts. During the first part of the cooperation phase, the users transmit their detections to a leader and the leader updates its detection. In the second part of the cooperation phase, the leader broadcasts the results to the users. We evaluate the proposed scheme using the average symbol error rate (SER) of an individual user. Simulation results show that the proposed scheme, under sufficient cooperative users, outperforms non-cooperative systems with multiple receive antennas.

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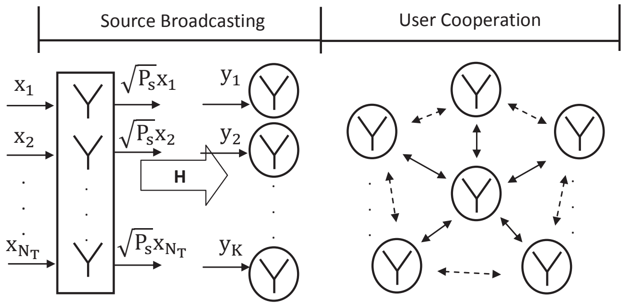

Fig. 1. System model. The transmission is divided into two phases: the source broadcasting phase and the user cooperation phase. The matrix $\mathbf{H} = [\mathbf{h}_1^T\ \mathbf{h}_2^T\ \cdots\ \mathbf{h}_K^T]^T$ is the channel matrix between the source and the K users.

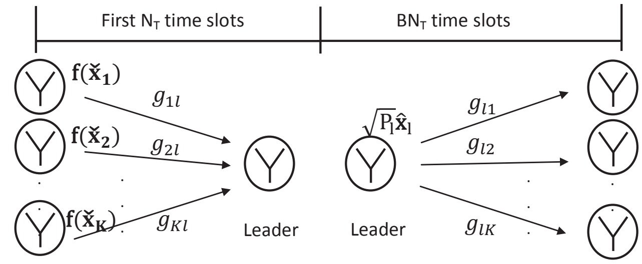

Fig. 2. The proposed user DF cooperation scheme, where the transmission is divided into two parts: users transmit their initial detection to the leader in the first N_T time slots and the leader broadcasts its detection to the users in the following BN_T time slots. The vector $\mathbf{f}(\check{\mathbf{x}}_i)$ is the forwarded symbol vector from the ith user to the leader l

This paper is organized as follows. Section II introduces the data broadcasting system model with a multiple-antenna source. Section III proposes a user cooperation scheme in temporally divided transmission and the corresponding signal detection. Section IV demonstrates the simulated SER performance of the proposed scheme. Section V concludes this work.

Notations: Vectors are written as boldface lower-case letters and matrices as boldface capitals. Sets are written in italic capitals. $\mathbb{C}$ represents the complex number set and $\mathbb{N}$ represents the positive integer set. The operation $(\cdot)^T$ represents the matrix transpose. The expression $diag(\cdot)$ is the operator that forms a diagonal matrix from its vector argument.

II. System Model

We consider a broadcasting system shown in Fig. 1. The source is equipped with N_T antennas and each user is equipped with a single antenna. We assume that each user has full receive channel state information (CSI) on itself but has no knowledge on the other users' CSI. The transmission is divided into two phases: the source broadcasting phase and the user cooperation phase. In the source broadcasting phase, the source node broadcasts simultaneously its N_T data streams to the K users. We assume that there is no coding applied at the source. The received signal at the ith user can be expressed as

$$y_i = \mathbf{h}_i \sqrt{P_S}\mathbf{x} + n_i,\ i = 1...K, \tag{1}$$

where $\mathbf{h}_i \in \mathbb{C}^{1\times N_T}$ is the channel vector of the ith user, whose elements are modeled as independently and identically distributed (i.i.d.) complex Gaussian random variables with zero mean and variance σ_h^2. The quantity P_S is the transmit power constraint of each transmit antenna at the source. The vector $\mathbf{x} \in S^{N_T\times 1}$ is the data symbol vector of the source and the set S denotes the modulation constellation set with cardinality of M. The average symbol energy of the symbols in S is normalized to unity. The quantity $n_i \in \mathbb{C}$ is the additive white Gaussian noise (AWGN) of the ith user with zero mean and variance σ_n^2.

In the user cooperation phase, each user forward the received signal with proper power scaling to the other users or attempts to obtain an initial detection of the source data and then forwards the detection. The former forwarding scheme is often called amplify-and-forward (AF), while the latter scheme is referred to as the decode-and-forward (DF). In the following, we consider DF users in our proposed scheme. The ith user obtains its initial detection by applying the ML criteria on eq. 1, which gives

$$\check{\mathbf{x}}_i = \underset{\mathbf{x}\in S^{N_T}}{\operatorname{argmin}} ||y_i - \mathbf{h}_i\sqrt{P_S}\mathbf{x}||^2. \tag{2}$$

It is noted that eq. 2 can be obtained via exhaustive search (brute force ML) or via some reduced complexity ML detections for rank deficient MIMO systems. The detection error of the ith user in this phase can be expressed as

$$\begin{aligned}\tilde{\mathbf{x}}_i &= \check{\mathbf{x}}_i - \mathbf{x} \\ &= [(\check{x}_{1,i} - x_1)\ (\check{x}_{2,i} - x_2)\cdots(\check{x}_{N_T,i} - x_{N_T})]^T \\ &= [\tilde{x}_{1,i}\ \tilde{x}_{2,i}\cdots\tilde{x}_{N_t,i}]^T.\end{aligned} \tag{3}$$

The result of eq. 2 is a rough detection with high error probability due to severe interference among the data streams. The interference can not be resolved with the mere use of ML criteria on eq. 1. However, the rough detections can be forwarded to a pre-selected leader l and refine its detection. The leader then can broadcast the refined detection to the users. Detailed cooperation phase is described in the following section.

III. Proposed User Cooperation: Time Division Transmission

In this section, we propose a time division cooperation scheme as shown in Fig. 2. The corresponding data detection is also derived. After receiving the signals at the end of the source broadcasting phase, the users form a cooperation group and randomly select one leader from the group member. Then the user cooperation phase is divided into $(1 + B)N_T$ time slots, where the parameter $B \in \mathbb{N}$ is choosen based on the retransmission scheme applied at the leader. In the first N_T time slots, the users transmits the detections of the source data to the leader. The leader receives the signals and re-detects the source data. In the remaining BN_T time slots, the leader broadcasts its re-detection to all the other users. In the following, we denote the channel from the ith user to the leader as g_{il} and assume that it remains constant during each N_T time slots of the cooperation phase.

For each data symbol x_j, the L active users are selected from the cooperation group in time slot j and the selected users transmit the corresponding detections. The selection algorithm can be based on the reliability of individual data symbols or the overall data symbol vector. In our scheme, we choose the users with the L largest channel gain $h_{i,j}$ for the data x_j into the cooperation. The D_j denotes the index set of the users that are activated for forwarding the detections of x_j. The transmitted symbol of ith user at the jth time slot of the cooperation phase can be written as

$$f_j(i) = \begin{cases} e^{-j\theta_{il}}\sqrt{P_i}\check{x}_{j,i}, & \text{if } i \in D_j, \\ 0, & \text{if } i \notin D_j. \end{cases} \tag{4}$$

where $\theta_{il} = \angle g_{il}$ is the phase of the channel between the ith user and the leader. The quantity P_i is the transmit power constraint at the ith user. The symbol $\check{x}_{j,i}$ is the initial detection of jth data symbol at the ith user. The symbol vector forwarded from the ith user to the leader l is $\mathbf{f}(\check{\mathbf{x}}_\mathbf{i}) = [f_1(i)\ f_2(i)\ \cdots\ f_{N_T}(i)]$. It is to note that, when we have $L = K - 1$, all the users are activated to forward their initial detections to the leader, except for the leader itself. This setting simplifies the required cooperation protocols since no further signaling is required for indicating the active users. A user transmits its detection as long as it is not selected as the leader.

The received signal at the leader node at time slot j of the cooperation phase can be expressed as

$$y_{j,l} = \sum_{i=1}^{K} g_{il} f_j(i) + w_j, \tag{5}$$

where l is the index of the leader and the quantity w_j is the AWGN of the leader at time slot j with zero mean and variance σ_w^2.

At the end of the first N_T time slots, the leader has $\mathbf{y}_l = [y_{1,l}\ y_{2,l}\ \cdots\ y_{N_t,l}]^T$. Together with the leader's received signal at the source broadcasting phase, we rewrite the received signals in the vector form as

$$\mathbf{y}_L = \begin{bmatrix} y_l \\ \mathbf{y}_l \end{bmatrix} = \begin{bmatrix} \mathbf{h}_l\sqrt{P_S} \\ \mathbf{G} \end{bmatrix} \mathbf{x} + \begin{bmatrix} n_l \\ \mathbf{n} \end{bmatrix} = \mathbf{G}_L\mathbf{x} + \mathbf{n_L}, \tag{6}$$

where $\mathrm{G} = \mathrm{diag}([g_1, g_2, \cdots, g_{N_T}])$ is the effective gain matrix of the received signal at the first N_T time slots in the cooperation phase. The diagonal elements g_j may be represented as

$$g_j = \sum_{i\in D_j} |g_{il}|\sqrt{P_i}, j = 1 \cdots N_T. \tag{7}$$

The vector $\mathbf{n} \in \mathbb{C}^{N_T\times 1}$ represents the equivalent noise components, which consists of the detection error of the cooperation users and the thermal noise at the leader. With eq. 3, eq. 4 and eq. 5, the jth element of $\mathbf{n}$ can be expressed as

$$\begin{aligned} n_{j,l} &= \sum_{i\in D_j} |g_{il}|\sqrt{P_i}\tilde{x}_{j,i} + w_j \\ &= \sum_{i\in D_j} |g_{il}|\sqrt{P_i}(\check{x}_{j,i} - x_j) + w_j \end{aligned} \tag{8}$$

With eq. 6, the leader may obtain its re-detection of the source data with the ML criteria

$$\hat{\mathbf{x}}_l = \underset{\mathbf{x}\in S^{N_T}}{\text{argmin}}\, |\mathbf{y}_L - \mathbf{G}_L\mathbf{x}| \tag{9}$$

The detection error of the leader can be expressed as

$$\begin{aligned} \tilde{\mathbf{x}}_l &= \hat{\mathbf{x}}_l - \mathbf{x} \\ &= [(\hat{x}_{1,l} - x_1)\ (\hat{x}_{2,l} - x_2) \cdots (\hat{x}_{N_T,l} - x_{N_T})]^T \\ &= [\tilde{x}_{1,l}\ \tilde{x}_{2,l} \cdots \tilde{x}_{N_t,l}]^T \end{aligned} \tag{10}$$

After obtaining the re-detection, the leader broadcasts its result $\hat{\mathbf{x}}_l = [\hat{x}_{1,l}\ \hat{x}_{2,l} \cdots \hat{x}_{N_T,l}]$ to all the other users in the remaining BN_T time slots. The leader may apply different coding technique on its re-detection and transmit the results during this BN_T. However, for the conciseness of presentation, we only describe the situation where $B = 1$ and $B = 2$ as follows. When $B = 1$, for the ith user, the received signal in the following jth time slot is

$$y_{i,L,j}^{(1)} = g_{li}^{(1)}\sqrt{P_L}\hat{x}_{j,l} + n_{li,j}^{(1)}, \tag{11}$$

where $g_{li}^{(1)}$ represents the slow fading channel between the leader and the ith user. The quantity $n_{li,j}^{(1)}$ is the AWGN at the ith user with zero mean and variance σ_n^2. In the end of user cooperation phase, the ith user receives a total of $1 + N_T$ signals, including the signal received in the source broadcasting phase. We rewrite the received signals of the ith user in the vector form as

$$\mathbf{y}_i^{(1)} = \begin{bmatrix} y_i \\ \mathbf{y}_{i,L}^{(1)} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_i\sqrt{P_S} \\ \mathbf{G}_{i,L}^{(1)} \end{bmatrix} \mathbf{x} + \begin{bmatrix} n_i \\ \mathbf{n}_{i,L}^{(1)} \end{bmatrix} = \mathbf{G}_i^{(1)}\mathbf{x} + \mathbf{n}_i^{(1)}, \tag{12}$$

where $\mathbf{G}_{i,L}^{(1)}$ is an $N_T \times N_T$ diagonal matrix with all the diagonal elements being $g_{li}^{(1)}$ and all the off-diagonal elements equal to zero. The ith user then obtains its final detection of x using the ML criterion

$$\hat{\mathbf{x}}_{i,final} = \underset{\mathbf{x}\in S^{N_T}}{\text{argmin}}\, |\mathbf{y}_i^{(1)} - \mathbf{G}_i^{(1)}\mathbf{x}|. \tag{13}$$

For $B = 2$, we consider the case where the leader repeats the broadcasting in the third N_T time slots. Assuming that the channel between the leader and the ith user during the second broadcasting is $g_{li}^{(2)}$, then the received signal in the $(j+N_T)$th time slot can be expressed as

$$y_{i,L,j}^{(2)} = g_{li}^{(2)}\sqrt{P_L}\hat{x}_{j,l} + n_{li,j}^{(2)}, \tag{14}$$

where the quantity $n_{li,j}^{(2)}$ is the AWGN at the user with zero mean and variance σ_n^2.

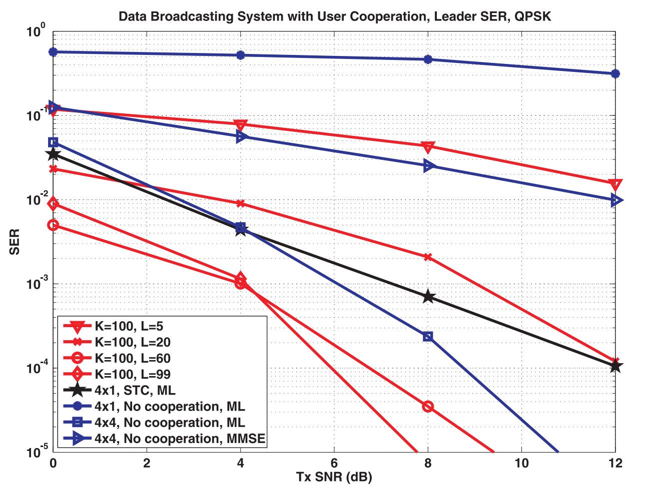

Fig. 3. The Leader SER performance with K = 100, QPSK and various L values.

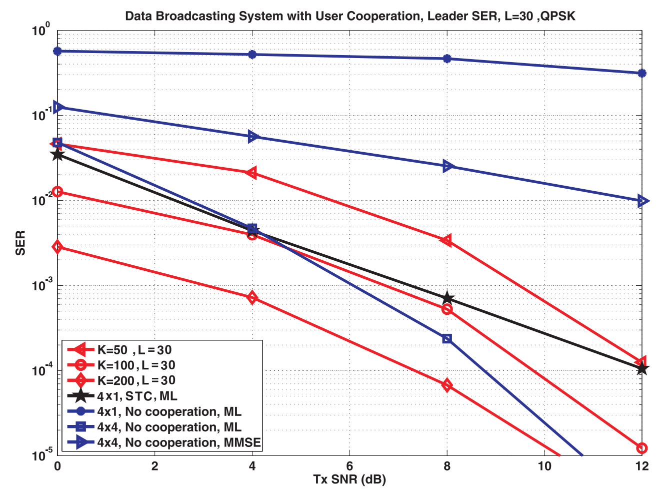

Fig. 4. The Leader SER performance with L = 30, QPSK and various K values.

With a similar derivation as in the case $B = 1$, the received signals at the ith user can be expressed as

$$\mathbf{y}_i^{(2)} = \begin{bmatrix} y_i \\ \mathbf{y}_{i,L}^{(1)} \\ \mathbf{y}_{i,L}^{(2)} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_i\sqrt{P_S} \\ \mathbf{G}_{i,L}^{(1)} \\ \mathbf{G}_{i,L}^{(2)} \end{bmatrix} \mathbf{x} + \begin{bmatrix} n_i \\ \mathbf{n}_{i,L}^{(1)} \\ \mathbf{n}_{i,L}^{(2)} \end{bmatrix} = \mathbf{G}_i^{(2)}\mathbf{x} + \mathbf{n}_i^{(2)}, \tag{15}$$

where $\mathbf{G}_{i,L}^{(2)}$ is an $N_T \times N_T$ diagonal matrix with all the diagonal elements being $g_{li}^{(2)}$ and all the off-diagonal elements being zero. The ML criteria can then be applied and the users obtain the final detections.

Remark1: In the proposed cooperation scheme, the transmission of the detected data symbols is illustrated as time-division-multiplexing (TDM). The transmission can also be frequency-division-multiplexing (FDM) or code-division-multiplexing (CDM). Regardless of the types of multiplex, the additional resource blocks are needed to avoid severe interference between the data streams inherent in the insufficient number of the users' antennas. These additional resource blocks imply additional spectrum use. However, in situations where the users are located in the geographical proximity, the ISM band is one of the options which reduce the extra resource cost.

Remark2: The final detection of the user is not limited to the ML criterion. Since the data streams are broadcasted by the leader continuously up to the the predefined number, the number of received signals is larger than the number of data streams. The data model can be equivalently converted to the conventional MIMO system. As a result, the linear or non-linear decoders in conventional MIMO systems can be possibly applied.

IV. Simulation Results

In this section, we present the simulation results of the proposed cooperation scheme. For comparison, four non-cooperation systems are also presented: a single-antenna user with ML detection, a four-antenna user with MMSE and a

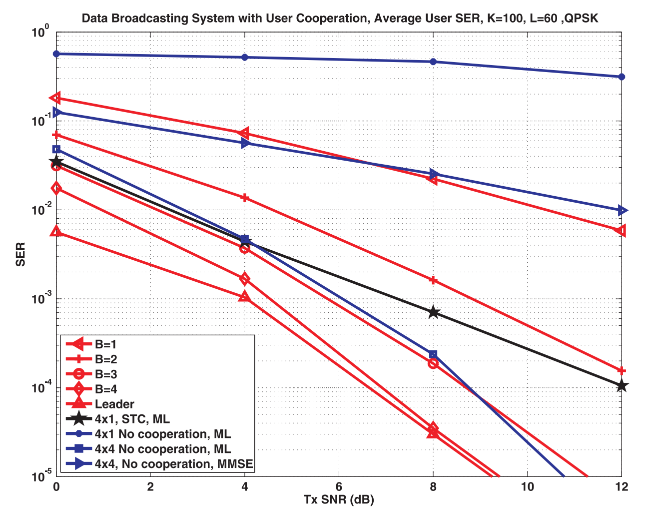

Fig. 5. The average user SER performance with K = 100, L=60 and QPSK. The value B represents the repetitions of the leader's broadcasting.

four-antenna user with ML detection and a single-antenna system with STC [4]. In the following simulations, we use an individual user's average SER as our performance metric. The SER is averaged over the $N_T = 4$ data streams. We use QPSK in the simulations. The channel gains are realized as i.i.d. complex Gaussian random variables with zero mean and variance $\sigma_h^2 = 1 = \sigma_g^2$. The AWGNs at the users are i.i.d. complex Gaussian with zero mean and variance $\sigma_n^2 = 1$. The transmission power of the source and the users are set as $P_s = P_i = 2P_b$ and the signal-to-noise ratio (SNR) is defined as P_b/σ_n^2.

Figure 3 shows the leader's average SERs under different numbers of active cooperation users. The total number of the user is $K = 100$. As observed in Fig. 3, with the increase of the number of active cooperation user L, the effective signal strength at the leader increases and thus reduces the average SER. However, we notice that when L continues to increase, the performance slightly degrades in the low SNR region. This phenomenon comes from the fact that in low SNR region, most users obtain incorrect initial detections after the source broadcasting phase. Particularly for the users having deep fade, their initial detections are very erroneously away from the correct data; the detection errors are large. If these users are selected and activated in the cooperation, their detection errors contributes more to the equivalent noise than to the effective signal. From eq. 8, we can see that if we have more active users, i.e., the larger the size of D_j, the error accumulates more quickly and the equivalent noise is larger. As a result, the SER in the low SNR region slightly degrades. When the SNR increases, the detection error is smaller and thus the joint of these users makes contribution to the effective signal and provides performance improvements. We also notice that for the system to outperform the conventional $4\text{x}4$ non-cooperation systems, we need roughly 60 active users in the cooperation when $K = 100$.

Figure 4 shows the leader's average SERs under different numbers of total users. The active cooperation user number is $L = 30$. As we can see from the figure, when the number of total user K doubles, the SER performance is improved by roughly 6 dB. With more users, the probability of having high channel gains is increased and thus the effective signal strength is enhanced. This implies that the cooperation can be more effective when there are more users in the cooperation group. To obtain the same transmission quality, fewer active users are needed when the total number of the user is large enough. For those non-active users, they do not spend extra power on current transmission and can switch to listen to the current symbol, which can improve its own final detection.

Figure 5 shows the user's average SERs for different repetitions of leader's broadcasting in the cooperation phase. The dark lines represent user's average SERs under different B values. The red line is the leader's SER. We have totally $K = 100$ users and $L = 60$ active users in this simulation. As we can see from the figure, the increase of B provides diversity gain. Also, the user's average SER approaches the leader's SER as B increases.

From the simulations, we show that the proposed cooperative detection can outperform the non-cooperative systems with multiple receive antennas, when the cooperation size is moderately large with proper detection algorithms. We also observed the following properties. First, in our proposed scheme, the leader's SER is affected by the cooperation group size and the number of active users. Second, the leader's SER is the bound of the system performance. As a result, selection of a good leader or multiple leaders may be one of the possible options to enhance the system performance.

V. Conclusion

In this paper, we considered a data broadcasting MIMO system where the source is equipped with multiple transmit antennas and the users are equipped with only a single antenna. We considered a two-phase transmission structure for the users to cooperate and detect the spatial-multiplexed data streams from the source. In the first phase, the source broadcasts the data to all the users. In the second phase, we proposed to divide the user cooperation into two parts. In the first part, the active user transmits their initial detections to the leader. Then in the second part, the leader broadcasts its re-detection to all the other users. Simulation results show that the cooperation performance is affected by the size of cooperation group, the number of active users and the cooperation length. To be comparable to the conventional system whose number of receive antennas is equal to the number of transmit antennas, the extra resource blocks in time, frequency or code domain are adopted to accommodate the multiple data streams. One option to obtain the extra resource block is to use the ISM band. Related issues, including the selection of the leader and the active users, the detection algorithm for imperfect CSI, and the design of cooperation protocols are open for future studies.

References

[1] I. E. Telatar, "Capacity of multi-antenna Gaussian channels," *Bell Labs Technical Memorandum*, 1995.

[2] G.Foschini, "Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas," *Bell Labs Tech. J.*, vol. 1, no. 2, 1996

[3] S. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE J. Select. Areas Commun.*, vol. 16, pp. 1451–1458, Oct. 1998.

[4] M. Rupp and C. F. Mecklenbräuker, "On extended Alamouti schemes for space-time coding," *Proc. WPMC*, pp. 115–119, Honolulu, Oct. 2002.

[5] L. Zheng and D. N. C. Tse, "Diversity and multiplexing: a fundamental tradeoff in multipleantenna channels," *IEEE Trans. Inf. Theory*, vol. 49, pp. 1073–1096, May 2003.

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

[7] A. Klein, G. Kaleh and P. Baier, "Zero forcing and minimum mean-square-error equalization for multiuser detection in code-division multiple-access channels" *lEEE Trans. Veh. Technol.*, vo1. 45, pp. 276–287, May 1996

[8] P. W. Wolniansky, G. I. Foschini, G. D. Golden and R. A. Valenzuela, "V-BLAST: an architecture for realizing very high data rates over the rich-scattering wireless channel," Invited paper in *Proc. ISSSE-98*, Pisa, pp. 295–300, Italy, 1998.

[9] A. Bhargave, R.J.P. de Figueiredo and T. Eltoft, "A detection algorithm for the V-BLAST system," *IEEE GLOBECOM'01*, vol. 1, pp. 494–498, November 2001.

[10] H. Lee, B. Lee, and I. Lee, "Iterative detection and decoding with improved V-BLAST for MIMO-OFDM systems," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 3, pp. 504–513, Mar. 2006.

[11] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity-part I: system description," *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[12] A. Nosratinia, T. Hunter, and A. Hedayat, "Cooperative communication in wireless networks," *IEEE Commun. Mag.*, vol. 42, no. 10, pp. 74–80, Oct. 2004.

[13] N. Jindal, "MIMO broadcast channels with finite rate feedback," in *Proc. IEEE GLOBECOM*, pp. 1520–1524, Nov. 2005

[14] A. Sendonaris, E. Erkip, and B. Aazhang, "Increasing uplink capacity via user cooperation diversity," in *Proc. IEEE Int. Symp. Information Theory*, Cambridge, MA, Aug. 1998.

[15] R. Dabora and S. D. Servetto, "Broadcast channels with cooperating decoders," *IEEE Trans. Inf. Theory*, vol. 52, no. 12, pp. 5438–5454, 2006.

[16] H. Kwon and J. M. Cioffi, "Multi-user MISO broadcast channel with user-cooperating decoder," in *IEEE VTC 2008-Fall*, Calgary, Canada, Sep. 2008.

[17] W. Choi, D. I. Kim, and B.-H. Kim, "Adaptive multi-node incremental relaying for hybrid-ARQ in AF relay networks," *IEEE Trans. Wireless. Commun.*, vol. 9, no. 2, pp. 505–511, Feb. 2010.