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Lei Cao, Jinyun Zhang, Norio Kanno

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Multi-user Cooperative Communications with Relay-Coding for uplink IMT-advanced 4G Systems

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***Abstract*—Adoption of relay stations has been commonly accepted as a key technique for future IMT-advanced 4G systems to improve the link performance. While study in relay systems is often carried out for individual users independently, in this paper, we present a design termed as relay-based multi-user cooperative communication specifically for the uplink of 4G systems. In this system, data streams from multiple users are coded at the relay with an invertible matrix in finite field. These coded data, with information of one user being spread into other data streams, are forwarded by the RS to the base station (BS). The relayed data received at the BS will work together with those received through the direct links between mobile stations (MS) and BS to implement a cooperative process. This is carried out using a turbo decoding process that alternates the decoding between a multi-user decoder and a number of single-user decoders. It is shown through the simulations that the decoding converges within two or three iterations, yet indeed provides significant gains compared with a reference relay system where each user is processed individually.**

***Index Terms*—IMT-advanced 4G systems, Relay, Multi-user cooperative communications, turbo decoding.**

I. Introduction

The IMT-advanced is the latest 4G wireless communication concept from ITU with many ambitious technical goals [1]. A very challenge requirement, among others, is the uplink peak spectrum efficiency of 15 bps/Hz and throughput as high as possible in the cell edge. Among the enabling techniques being considered, a consensus from different companies is the use of relay stations where the cooperative communications can be applied to improve the link performance.

In cooperative communications, two groups of links including MS-BS and MS-RS-BS are used to create a virtual MIMO system. A popular approach is that the cooperation, considering multiple paths, is for one user at a time. Recently, there were some work being proposed to consider data aggregation for two users. In [2], a scenario shown in Fig. 1 was studied where the RS with decode-and-forward (DF) ability relays "$a \oplus b$" instead of symbols "a" and "b" individually, where $\oplus$ is the operation of "XOR". It was shown that the performance can be improved given the same spectrum efficiency. An extension considering noisy MS-RS links is studied in [3] where the soft information was relayed with analog modulation. Discussion on equivalent BSC channels with the same setup was presented in [4]. Basically, these work were part of the effort shifting the application of network coding [5] in wired network into wireless communications. Despite interesting results reported in these papers, it is recognized that further research effort is demanded for a broad range of issues. For example, the assumption of the same channel quality in RS-BS and MS-BS links in some research might not be appropriate for a practical system. Comparison with a reference system equipped with full optimal maximal ratio combining (MRC) diversity has not been considered in [2]–[4]. The direct link between the MSs and BS is often weaker than the link between RS and BS. Therefore, it might be also desired that the source data of different users should be completely recovered from the relayed data in the case where the RS-BS link is good enough but the MS-BS links do not function well. This situation is evidenced in the current uplink of IEEE 802.16j where the MS-BS links are not considered when a relay is used. This self-recovery feature is not held in existing systems. Furthermore, under the assumption of mobiles being uniformly distributed in a cell, there are in fact many mobiles near the cell edge. Therefore, it can be conceived that multiple users (i.e., MSs) may communicate with one relay simultaneously and the number of such MSs may also vary time to time.

Taking the above issues into account, we present in this paper a new relay-based multi-user cooperative communication design for uplink in IMT 4G systems. In section II, a type of relay coding matrices is presented with the requirements of full rank in the finite field and maximum information spreading. In section III, symbol detection based on log-likelihood ratio (LLR) is then compared between the proposed system and a reference system with the MRC diversity. In section IV, a decoding process with turbo principle is developed that alternates between a multi-user decoder and a group of single-user decoders. Some simulation results are presented in section V to illustrate the performance improvement. Section VI concludes this paper and point out some potentials of this design.

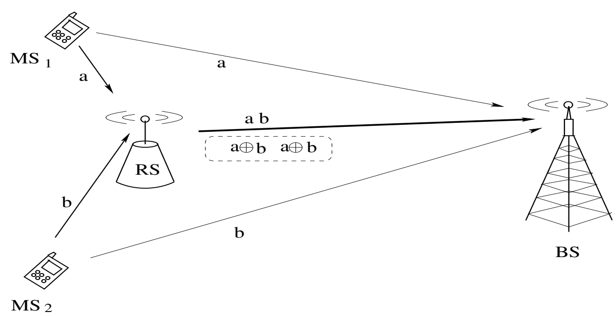

Fig. 1. XOR of decoded a and b for relaying.

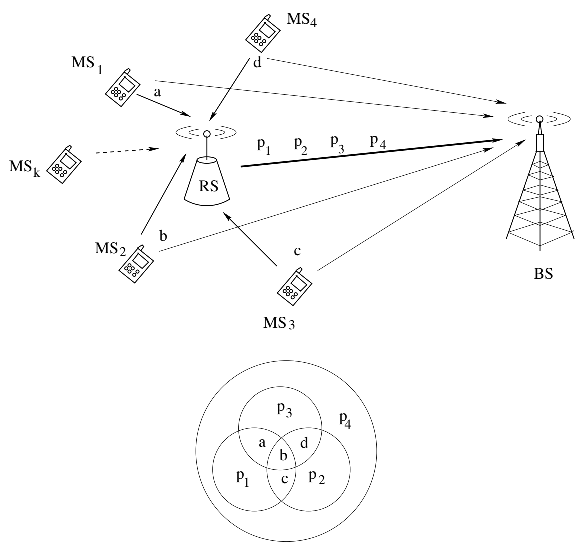

Fig. 2. An example of proposed system

II. Proposed System and Relay Coding Matrix

Without loss of generality, the proposed system was shown in Fig. 2 where there are four users (MSs) joining the cooperation. Instead of transmitting original information a, b, c, d, we transmit their combinations p_1, p_2, p_3, p_4 shown in the lower part of Fig. 2. For example, $p_1 = a \oplus b \oplus c$. Once the MSs being coded at the relay have the same modulation constellation, this coding operation may be the "addition" operation in an appropriate finite field $GF(2^m)$ where m is the number of bits per symbol. If MSs are using different types of modulation, the coding at the relay can always be reduced to the "addition" in the binary finite field $GF(2)$. For simplicity, we assume the BPSK modulation for all MSs in this paper.

There are many ways, such as random network coding and linear block codes, can be employed for the coding at RS. In our system, we consider this coding based on the requirements in rank and information spreading. First, we require that the relay outputs are linearly independent. Therefore, these coded data, if perfectly decoded at the BS, can recover the original information of different users completely, without information from the MS-BS links. As a result, a coding matrix should be of full rank in the finite field. The number of this type of matrices with size of $K \times K$ is $\prod_{i=0}^{K-1}(2^K - 2^i)$, which can be obtained by sequentially selecting a non-zero row vector that is not the linear combination of previous rows. This number should be further divided by a factor $K!$ if we do not distinguish matrices with row-permutations. Second, we expect to secure a spreading gain by spreading information of one user to multiple output streams in RS. Therefore, in a general case when data are also received from the direct MS-BS links, they can work with those relay-coded data to provide a decoding gain.

Let $\mathbf{U}^T = \{u_1^t, u_2^t, \ldots, u_K^t\}$ be symbols from K MSs that are received and decoded at the RS at time t. The relay output will be $\mathbf{P} = \mathbf{AU}$, where $\mathbf{A} = \{a_{i,j}\}$ is a $K \times K$ coding matrix and $a_{i,j} \in \{0, 1\}$. In order to give the maximum spreading, we can set each row of $\mathbf{A}$ with all "1"s except one "0", which results in K different rows. In addition, "$\mathbf{A}$" needs to be invertible (i.e., of full rank) in the finite field. From mathematical induction, it can be easily seen that A designed as above is in full rank only when K is an even number. To make A invertible for odd values of K, we can simply set one row, such as the 1st row, to be all "1"'s. Verification, again, can be readily obtained from the mathematical induction. Therefore, the matrices used are as follows.

$$A_{Keven} = \begin{bmatrix} 1 & \cdots & 1 & 0 \\ 0 & 1 & \cdots & 1 \\ 1 & 0 & \cdots & 1 \\ 1 & \cdots & 0 & 1 \end{bmatrix}, A_{Kodd} = \begin{bmatrix} 1 & \cdots & 1 & 1 \\ 0 & 1 & \cdots & 1 \\ 1 & 0 & \cdots & 1 \\ 1 & \cdots & 0 & 1 \end{bmatrix}. \quad (1)$$

It is interesting to recognize that the above design for $K = 4$ used in Fig. 2 is exactly the extended-Hamming (8,4,4) code. It also needs to note that $K = 2$ is a special case which has two "1"s in one row and one "1" in the other, in order to have both information spreading and full rank.

In this paper, although we assume that the relay correctly decodes the data from MSs, the correctly decoding of a specific MS is not required. As long as the relay has correctly decoded data from a number of MSs, it can put them into cooperation through the coding in the RS with an appropriate K (such as 4 here). The MSs in the next packet or time slot can be different from the MSs in the current packet. As assumed in the research in this area, direct links and relay links are separated in either time slots or channel frequency so that synchronization is not considered as an issue here. In addition, the indices of cooperated MSs are included in the head of relayed packets and received at the BS.

III. Information Spreading and Diversity

We set the reference system as a typical DF-based relay system that the relay decodes data for each MS and then re-encoded with the same code and send to the BS. In such scenario, there are two copies of data at the BS for each user, one from MS-BS link directly and the other from the RS. The optimal symbol detection is the diversity technique with MRC. For the proposed system shown in Fig. 2 with four MSs using the RS simultaneously, the data from multiple MSs are coded in the relay using the extended-Hamming (8,4,4) code, i.e., simple multiplication through the matrix A with $K = 4$. It still has the same spectrum efficiency with the reference system so that we can focus on the performance only. It is also possible to code different number of MSs with different linear codes and transmit either all or part of the coded data in order to obtain various trade-off between the performance and bandwidth.

For the system example considered here, intuitively, each symbol of one particular MS will be transmitted four times (in different forms) instead of twice in the reference system. For example, "a" is embedded in p_1, p_3, p_4 in addition to the one through direction link. However, data from some different users are "mixed" together in the relay to use the same transmission power which is used by a single user symbol in the reference system. The former feature is beneficial in terms of information spreading but the latter characteristic appears a minus due to the share of transmit power. Therefore, the first issue to be clarified is whether the net gain is positive for the proposed multi-user cooperative communication. We consider this through the log-likelihood ratio of each symbol conditioned on received data.

A. LLR of the Reference System

For a transmitted BPSK symbol u_k from the k-th MS, $k = 1, \ldots, K$, in the reference system, each u_k will be sent to the BS through two paths experiencing different fading. Suppose that we have received two copies $y_{k,i} = a_{k,i}u_k + n_{k,i}$, $i = 1, 2$, where $a_{k,i}$ is the independent fading factor and $n_{k,i} \sim \mathcal{N}(0, \sigma_{k,i}^2)$ determines the average SNR at BS from each link. Then, we can calculate the conditional LLR

$$
\begin{aligned}
L(u_k|y_{k,1}, y_2) &= \ln \frac{P(u_k = +1|y_{k,1}, y_{k,2})}{P(u_k = -1|y_{k,1}, y_{k,2})} \\
= L(u_k) + \ln \frac{P(y_{k,1}|u_k = +1)}{P(y_{k,1}|u_k = -1)} &+ \ln \frac{P(y_{k,2}|u_k = +1)}{P(y_{k,2}|u_k = -1)} \\
&= L(u_k) + L_c^{(k,1)} y_{k,1} + L_c^{(k,2)} y_{k,2}
\end{aligned} \tag{2}
$$

where

$$
L(u_k) = \ln \frac{P(u_k = +1)}{P(u_k = -1)} \tag{3}
$$

which is often termed as the *a priori* information of $u_k, k = 1, \ldots, K$; $L_c^{(k,i)} = 2a_{k,i}/\sigma_{k,i}^2, \quad i = 1, 2$. Then $u_k = +1$ (or -1) when $L(u_k|y_{k,1}, y_{k,2}) \geq 0$ (or < 0). $L(u_k) = 0$ when the *a priori* information of u_k is not available at the BS. It should be noted that equation (2) when $L(u_k) = 0$ is exactly the MRC which is the optimal diversity process with two receiving copies.

B. LLR of the Proposed System

This is in fact to find the LLR values of the systematic symbols in a block code but with different fading for different symbols. Let C be the set of all possible codewords generated in the relay and $\mathbf{u}$ is a specific codeword with u_k at position k. (N, K) is the code used in the relay. $\mathbf{y}$ is the received data. We can find

$$
\begin{aligned}
L(u_k|\mathbf{y}) &= \ln \frac{\sum_{\mathbf{u} \in C, u_k = +1} P(\mathbf{u}|\mathbf{y})}{\sum_{\mathbf{u} \in C, u_k = -1} P(\mathbf{u}|\mathbf{y})} \\
&= \ln \frac{\sum_{\mathbf{u} \in C, u_k = +1} \left(\prod_{j=1}^{N} p(y_j|u_j) \cdot \prod_{j=1}^{N} p(u_j) \right)}{\sum_{\mathbf{u} \in C, u_k = -1} \left(\prod_{j=1}^{N} p(y_j|u_j) \cdot \prod_{j=1}^{N} p(u_j) \right)} \\
&= \ln \frac{p(u_k = +1; y_k) \cdot \sum_{\mathbf{u} \in C, u_k = +1} \prod_{j=1, j \neq k}^{N} p(u_j, y_j)}{p(u_k = -1; y_k) \cdot \sum_{\mathbf{u} \in C, u_k = -1} \prod_{j=1, j \neq k}^{N} p(u_j, y_j)} \\
&= L(u_k) + L_c^{(k)} y_k \\
&+ \ln \frac{\sum_{\mathbf{u} \in C, u_k = +1} \Pi_{j=1, j \neq k}^{N} \exp(L(u_j; y_j) u_j / 2)}{\sum_{\mathbf{u} \in C, u_k = -1} \Pi_{j=1, j \neq k}^{N} \exp(L(u_j; y_j) u_j / 2)}
\end{aligned} \tag{4}
$$

where

$$
L(u_j; y_j) = L_c^{(j)} y_j + L(u_j), \quad 1 \leq j \leq N \tag{5}
$$

In this example, $K = 4$, $N = 8$ and $\mathbf{u} = \{u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8\} = \{a, b, c, d, p_1, p_2, p_3, p_4\}$. $L_c^{(j)} = 2a_j/\sigma_j^2, j = 1, \ldots, N$. In the above equations, a general case is considered where the *a priori* information of relay coded symbols $u_K, u_{K+1}, \ldots, u_{2K}$ is also included. If this part of information is not available independent of the source symbols, we can simply set $L(u_j) = 0$ for $j = K, \ldots, 2K$. Comparing to equation (2), the difference of equation (4) lies in the last term which contains information constrained by the code used in the RS.

As a result, we can simply compare the reference system and the proposed system by calculating the LLR of each information symbol based on equations (2)(4) and then conduct the threshold detection. For simplicity, we set all direct links from MSs to BS with the same SNR (SNR_d) and vary the SNR between the RS and BS (SNR_r) within a range. Fig. 5 show the simulation results for the detection BER in the block Rayleigh fading channels.

From this figure, first we can observe that when the direct link quality (MSs-BS) is moderate or high, such as SNR_d=8 dB and above in the figure, the proposed system has consistent performance improvement over the reference system. The higher the SNR_d, the larger the improvement is. It should be noted that this performance gain is obtained with a higher computational cost associated with equation (4) which, however, is considered practical due to its operating at the BS. Second, when the SNR_d is low, such as 3dB, both systems perform very similarly, due to the weak systematic part not being able to help enough in the LLR calculation.

Although we have the similar results by directly comparing the LLR values for two systems when SNR_d is small, the benefit of the proposed method has not been fully exploited yet. In fact, the proposed method also gives a mechanism to build up a turbo decoding process which could further provide some gain.

IV. Turbo Decoding Principle

A. Multi-user Decoding and Single-user Decoding

It is known that the channel coding is always employed in wireless communications. That it, symbols to be transmitted

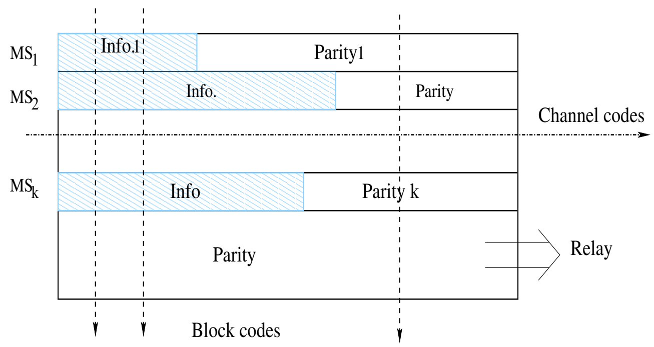

Fig. 3. Coding structure for single user and across multiple users

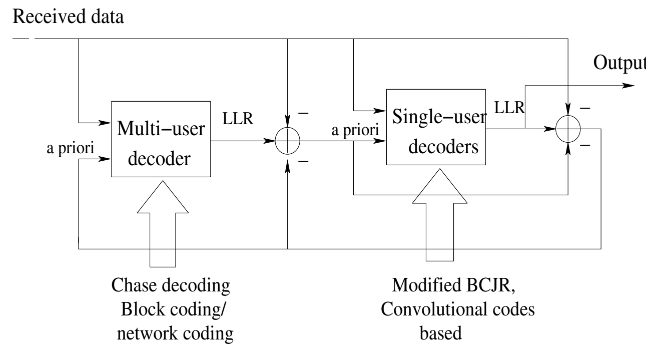

Fig. 4. Decoding structure for single users and across multiple users

from a MS to BS have already been coded. When the additional coding is introduced in the relay, the overall coding structure is shown in Fig. 3. This is in fact a product coding system. Let $\mathbf{u_i}, i = 1, \ldots, K$ be the source information of the ith MS. Then the coded data of K MSs are

$$Y = (\mathbf{y_1}, \mathbf{y_2}, \ldots, \mathbf{y_K})^T \tag{6}$$

where

$$\mathbf{y_i} = \mathbf{G_i}\mathbf{u_i}. \tag{7}$$

The relay coded data are

$$\mathbf{R} = (\mathbf{r_1}, \mathbf{r_2}, \ldots, \mathbf{r_K})^T = \mathbf{AY} \tag{8}$$

where sizes of $\mathbf{r_i}$, $\mathbf{y_i}$ $\mathbf{u_i}$ and $\mathbf{G_i}$ are $n\times1$, $n\times1$, $n_i\times1$ and $n\times n_i$ respectively. In the horizontal direction, coding is along each individual user. (n, n_i) is the code $\mathbf{G_i}$ of the ith MS which can be in any type defined in the standard specifications. In the vertical direction (i.e., in the RS), it is a block code or a network code across multiple users. Both $\mathbf{Y}$ and $\mathbf{R}$ will be listened by the BS. The final objective of the maximum likelihood decoding is to find an estimate of the information data $\hat{\mathbf{u}}_i, i = 1, \ldots, K$ which, after coding in both directions, have the shortest distance from the received data at the BS. This problem can be near-optimally solved by applying the turbo decoding principle. As shown in Fig. 3, it needs to be noted that in order to join the cooperative communication the coded packets of all MSs should be in the same length.

Since each source symbol joins two independent coding in two directions and can hence be decoded independently, for each symbol, starting from a zero *a priori* information, we can generate the extrinsic information from one decoder and use that as the new *a priori* information in the other decoder. This information exchange can continue with several iterations until no more improvement is observed. The decoding structure is illustrated in Fig. 4. This process bears the decoding principle of turbo codes but it should be noted that the information is exchanged between the decoding of a group of single users and the decoding of multiple users. Different codes with different rates can be used for different users (i.e., different MSs). Similarly, the number of users joining the cooperation can also vary from time to time. That is, the code and rate can change in different time slots (or packets) in the relay.

Equation (4) shows the calculation of the extrinsic information. The calculation complexity may be tolerable for a small number of cooperative MSs in the relay but increases exponentially when more MSs join in. For large K values, the Chase-II algorithm in [6] may be applied as a good approximation method in the vertical directional decoding with reduced complexity.

It can be noted that when all the MSs are using the same channel code. The relayed data in the row direction are also in the same coding space because network coding along the column direction is a linear operation. Therefore, the relayed data can also be channel decoded horizontally if necessary.

B. Extrinsic Information for Parity Symbols

One important component in the decoding implementation of this system is the processing of the extrinsic information for parity symbols. This is because the relay coding is applied to all data in the horizontal direction in Fig. 3 including both systematic and parity information of each participating user. Since current industry standards in cellular systems still have a favor for convolutional codes and convolutional codes-based turbo codes, we proceed with convolutional codes without loss of generality to show the modification of the conventional BCJR maximum *a posteriori* probability (MAP) algorithm [7] for the calculation of LLR of the parity symbols. The general idea of providing extrinsic information for all coded data was first presented in [8] but without any implementation details. A specific example was presented in [9]. Actually, we can simply modify the existing “textbook” MAP algorithm based on the trellis for the same purpose.

We illustrate with a recursive systematic convolutional (RSC) code with rate of 1/2. Input to this single user decoder includes the *a priori* information of both systematic and parity bits generated from the multi-user decoder. For any trellis transition (s_{k-1}, s_k), there are two output bits (u_k^s and u_k^p). The conditional LLR for $u_k^p, k = 1, \ldots, M$ where M is the length of the information symbols in a packet, given the received data packet $\mathbf{y}$, is

$$\wedge(u_k^p) = L(u_k|\mathbf{y}) = \ln\left(\frac{P(u_k^p = +1|\mathbf{y})}{P(u_k^p = -1|\mathbf{y})}\right)$$

$$= \ln\left(\frac{\sum_{\substack{(s_{k-1},s_k)\\ \Rightarrow u_k^p=1}} \alpha_{k-1}(s_{k-1})\gamma_k(s_{k-1},s_k)\beta_k(s_k)}{\sum_{\substack{(s_{k-1},s_k)\\ \Rightarrow u_k^p=-1}} \alpha_{k-1}(s_{k-1})\gamma_k(s_{k-1},s_k)\beta_k(s_k)}\right) \quad (9)$$

$\alpha_k(\cdot)$ and $\beta_k(\cdot)$ can be obtained recursively as

$$\begin{cases} \alpha_k(s_k) = \sum_{s_{k-1}} \alpha_{k-1}(s_{k-1})\gamma_k(s_{k-1},s_k) \\ \alpha_0(s_0 = 1) = 1,\ \alpha_0(s_0 = s) = 0, \text{for}\, s \neq 1, \end{cases} \quad (10)$$

$$\begin{cases} \beta_{k-1}(s_{k-1}) = \sum_{s_k} \beta_k(s)\gamma_k(s_{k-1},s_k) \\ \beta_N(s_N) \text{ depends on the trellis termination condition.} \end{cases} \quad (11)$$

The term we first need to modify is $\gamma_k(s_{k-1}, s_k)$ which was calculated as,

$$\gamma_k(s_{k-1}, s_k) = P(\mathbf{y_k}|(s_{k-1}, s_k))P(s_k|s_{k-1}) \quad (12)$$

where $P(\mathbf{y_k}|(s_{k-1}, s_k))$ is the distance measurement between the received symbols $\mathbf{y_k}$ and the symbols associated with the transition from s_{k-1} to s_k. In conventional BCJR algorithm $P(s_k|s_{k-1})$ is the probability $P(u_k^s)$ coming from the *a priori* information and $P(u_k^p)$ is always set to 1/2. In our scenario, since $P(u_k^p)$ can be obtained from the multi-user decoder, we need to take this additional information into account. Therefore, the unnormalized probability can be simply set as $P(u_k^s)P(u_k^p)$ due to the independent additive noise on symbols. Normalization can be automatically completed with the same scaling factor in both numerator and denominator. When putting this back into equation (9), we can get

$$\wedge(u_k^p) = L(u_k^p) + L_c y_k^p +$$

$$\ln\left(\frac{\sum_{\substack{(s_{k-1},s_k)\\ \Rightarrow u_k^p=1}} \alpha_{k-1}(s_{k-1})\exp(\frac{x_k L(x_k)}{2} + \frac{L_c}{2}x_k y_k^s)\beta_k(s_k)}{\sum_{\substack{(s_{k-1},s_k)\\ \Rightarrow u_k^p=-1}} \alpha_{k-1}(s_{k-1})\exp(\frac{x_k L(x_k)}{2} + \frac{L_c}{2}x_k y_k^s)\beta_k(s_k)}\right) \quad (13)$$

where the last term is the extrinsic information generated for the parity bits in the single user decoding. It should be noted that the codewords summed in the numerator(or denominator) are those with bit "1" (or "-1") in the considered parity bit position.

V. Simulation Results

Theoretic BER analysis is difficult due to the turbo decoding involving different codes and number of users. We use simulation to test the performance. We use RSC code with generator $(7,5)_{oct}$ and rate 1/2 as the code for each MS for simplicity. Each link experiences different Rayleigh block fading. When $K = 4$, operation at RS is the (8,4,4) extended Hamming code. We first show in Fig. 5 the direct comparison for the results of threshold detection after LLR calculation. For $SNR_D = 8dB$, it shows improvement about $3dB$ or more for all RS-BS SNR cases. However, when $SNR_d = 3dB$, the two systems perform almost the same. We then consider the involvement of channel decoding and

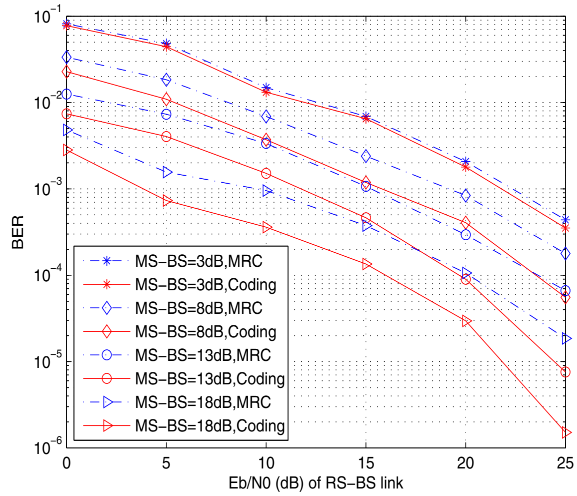

Fig. 5. BER comparison between MRC and relay coding.

for the case of SNR_D=3 dB where there is no improvement by comparing the LLR directly. The reference system carries out convolutional decoding after the MRC diversity, while the turbo decoding principle can be used for the proposed system. Fig. 6 shows the decoding performance of the proposed cooperative communication compared with the reference system. It demonstrates consistent improvement around 1-2 dB compared with the reference system when the MS-BS links are very weak ($SNR_D = 3dB$).

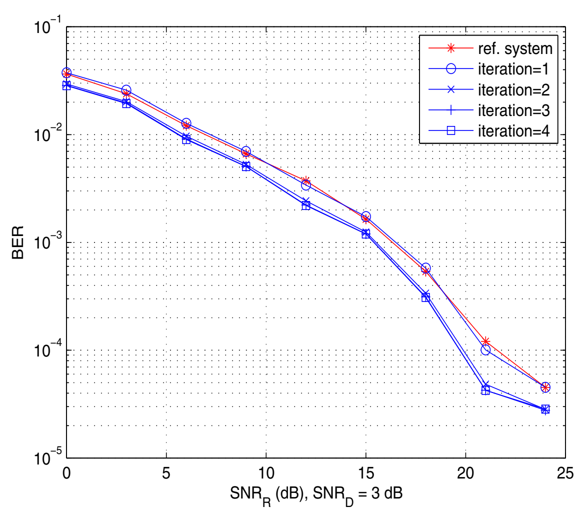

Fig. 6. BER Performance, SNR_D=3 dB, K=4

For SNR_D cases where the detection with information spread already outperforms MRC, the decoding gain is even higher. In Fig. 7, we show the performance when $SNR_D = 6dB$. Now the performance starts to improve from the first iteration. 2-3 dB improvement on average can be observed compared with the reference system.

It can also be observed that the decoding converges after

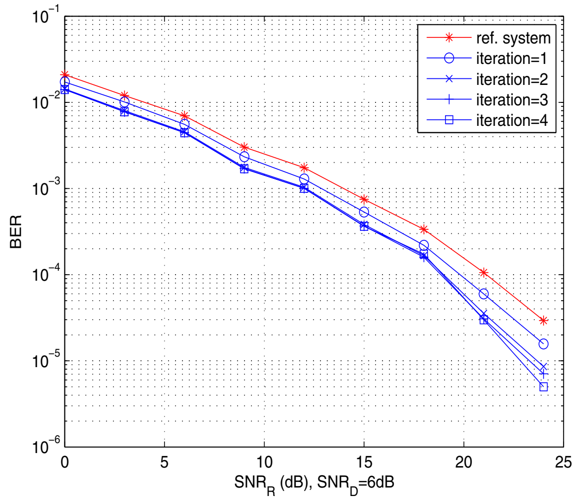

Fig. 7. BER Performance, SNR_D=6 dB, K=4

only a few iterations (2 or 3 in general). This is because the coding in the vertical direction (i.e., at the relay) is for a small value of K. Hence the correlation between the extrinsic information in this direction occurs very quickly, which is unlike the conventional turbo channel coding where each component code is applied to all source information symbols. As a result, we can stop the turbo decoding after the 2nd iteration to reduce the decoding complexity.

In Fig. 8, we also tested cooperation cases of 3 users and 6 users respectively. A higher gain is observed with more number of users in cooperation due to the larger K in the relay code. However, it needs to note that more users increases the computational complexity in equation (4) greatly. Therefore, a simplified decoding algorithm such as Chase-II algorithm should be used for the multi-user decoder.

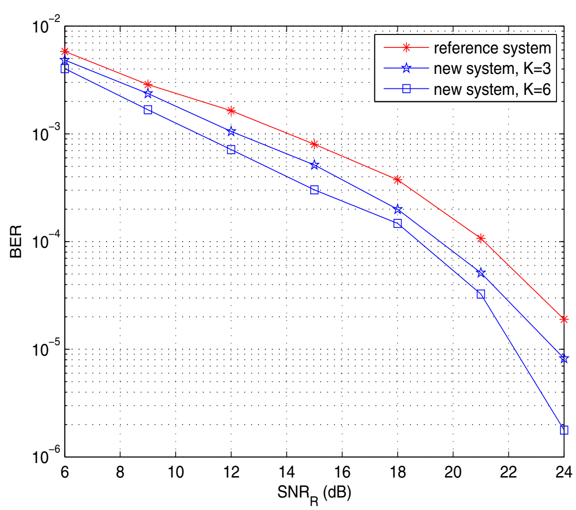

Fig. 8. BER Performance comparison, reference system and new system with $K = 3$ and $K = 6$

VI. Discussions and Conclusions

In this paper, a new design for the Relay-based cooperative communication is presented, which is specifically appropriate for future uplink LTE-advanced 4G systems. It uses the information spreading so that a type of "multiple user coding/diversity" gain can be obtained with a turbo-like decoding which alternates between a number of single-user decoders and a multi-user decoder. A type of coding matrices at the relay, some implementation details and simulations results have been provided. The proposed system has shown promising performance improvement over the system without multi-user cooperation. Furthermore, within this design, we can also note some further interesting research issues. One is the design of optimal matrix A, although it has been shown [10] that simple and weak codes might be good component codes in the setting of turbo decoding. Another interesting potential is for Hybrid ARQ. A feature of (8,4,4) code is that when two symbols, each from a different user, are wrong, correctly retransmission of one may correct both errors because the 1-error-correction capability of the code. Therefore, this system may lead to a new HARQ strategy that retransmission of one user's data could correct the errors in the data of other users in a previous transmission.

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