Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

Enhanced cooperative packet retransmission employing joint cooperative diversity and symbol mapping diversity*

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Received Nov. 23, 2007; revision accepted Feb. 22, 2008

Abstract: A joint cooperation diversity and symbol mapping diversity (SMD) strategy is proposed for cooperative packet retransmission system with high-order modulation such as 16QAM. Substantial SER/BER (symbol error rate/bit error rate) gains result from multiple packet transmissions over independent paths and distinct bit-to-symbol mappings for each packet transmission. The SER/BER performance of relay assisted retransmission system is analyzed. Simulation results show that the joint-diversity strategy can provide more BER gains than other relaying strategies (i.e., decode-and-forward and constellation rearrangement relaying strategies) when no relay makes a decision error; but if some relays make decision errors, the joint-diversity strategy outperforms other relaying strategies only when the relays are closer to the source than to the destination.

Key words: Cooperative retransmission, Hybrid automatic repeat request (HARQ), Cooperative diversity, Symbol mapping diversity (SMD)
doi:10.1631/jzus.A0720076 **Document code:** A **CLC number:** TN929.5; TN911

INTRODUCTION

Communications over wireless channels suffer from fading induced by multipath propagation, which causes a random fluctuation at the received signal level. The effects of fading can be combated by transmitting and processing independent copies of the same signal, i.e., diversity. The most well-known forms of diversity are temporal diversity, spatial diversity and frequency diversity (Sendonaris *et al.*, 2003a; 2003b). Hybrid automatic repeat request (HARQ) has been studied as a temporal diversity mechanism, which is categorized into two classes: type I HARQ and type II HARQ. In type I HARQ, received packets with uncorrectable errors are discarded. In type II HARQ, these packets are stored and combined with subsequent retransmissions (Gidlund and Ahag, 2004; Gidlund, 2005; 2007; Zhang *et al.*, 2005). Cooperation diversity occurs as a new form of spatial diversity and soon becomes a popular approach to combating the fading induced by multipath propagation, which allows single-antenna terminals in a multiuser environment to share their physical resources to help one another to transmit information. Decode-and-forward (DF) and amplify-and-forward (AF) have been proposed as two basic relaying strategies (Laneman and Wornell, 2003; Laneman *et al.*, 2004). Especially when the source-destination link keeps in deep fade over several continuous slots, relays assisted retransmission can play an important role and type II HARQ is incorporated in cooperative retransmissions (Dianati *et al.*, 2006; Hong and Scaglione, 2006; Jia *et al.*, 2006; Rizvi, 2006; Scaglione *et al.*, 2006; Stankovic *et al.*, 2006; Joo *et al.*, 2007).

* Project supported by the National Natural Science Foundation of China (No. 60372107), the Natural Science Fund for Higher Education of Jiangsu Province, China (No. 06KJA51001), and the Natural Science Fund of the Science and Technology Department of Jiangsu Province, China (No. BK2007729)

Diversity among retransmissions still can be improved through some other approaches at the physical layer. For the systems with high-order modulation, e.g., high speed downlink packet access system, constellation rearrangement (CR) is proposed to average the bit reliabilities after retransmissions by changing the mapping of consecutive bits onto the symbol (Panasonic, 2001a; 2001b). The cases of parallel AWGN and fading channels have been extensively studied (Miyoshi *et al.*, 2002; 2006; Wengerter *et al.*, 2004; Benjillali *et al.*, 2006). And the existing implementations of CR are all done under the fixed mapping rule, i.e., Gray-mapping rule. Different from CR, symbol mapping diversity (SMD) can enhance the diversity by varying the bit-to-symbol mapping rules for each packet transmission and achieve more SER/BER (symbol error rate/bit error rate) gains after retransmission (Samra *et al.*, 2003; 2005; Samra and Ding, 2006a; 2006b).

Even though these initial works have already posed important milestones, showing the potential benefits of diversity in packet retransmission, much research still has to be done to gain insight into this promising technology. It is proposed that the effect of collaborative transmit diversity can be improved through employing CR in the system with multilevel pulse amplitude modulation (M-PAM) (Khormuji and Larsson, 2007). Different diversity strategies or the combination of them can also be selected to improve system performances. As a form of spatial diversity, cooperative diversity can be easily combined with other diversity. We have done some initial work to exploit more BER gains by joint use of cooperation diversity and SMD with high-order 2D modulation. It is confirmed that the performance of joint diversity is better than that of single diversity (Ji and Zheng, 2007). All these papers are the main inspiration sources for our work.

In this paper, we take decision errors at relays into consideration and extend our study to cooperative packet retransmission systems. In short, the idea is to detect the source information bits at the relays and then retransmit them over independent paths after remapping. The bit-to-symbol mapping rules for each packet transmission are distinct from each other. The specific contributions of our paper are as follows:

(1) We propose to use the joint-diversity strategy to improve the link reliability of a cooperative retransmission system, which is the combination of temporal diversity and spatial diversity. However, most of the existing works, e.g. (Dianati *et al*., 2006; Hong and Scaglione, 2006; Jia *et al*., 2006; Rizvi, 2006; Scaglione *et al*., 2006; Stankovic *et al*., 2006; Joo *et al*., 2007), only deal with the application of CR to temporal/frequency diversity.

(2) We use the SMD relaying strategy in cooperative networks with high-order non-binary linear modulation, which extends the work of (Khormuji and Larsson, 2007) which only deals with 1D low-order modulation.

(3) We derive the detector at the destination and analyze the performance of the relay assisted retransmission which takes the quality of the source-relay link into consideration. The maximum BER gains are analyzed in the multi-relay assisted retransmission. The proposed scheme can provide more BER gains than other relaying strategies when no relay makes a decision error. When some relays make decision errors and the relays are closer to the source than to the destination, the proposed scheme still outperforms other relaying strategies with only a small increase in receiver complexity.

SYSTEM MODEL

Consider a wireless communication network with one source, M relays and one destination. The relays are located between the source and the destination and all distances are normalized by the distance between the source and the destination. Each user in the network has only one antenna, which cannot be used for transmission and reception simultaneously, so all the users communicate in the half-duplex mode.

The cooperative retransmission system model is depicted in Fig.1. The transmission link between any two users is modeled as a quasi-static channel which captures the effects of both path loss and frequency nonselective fading,

$$a_{ij} = h_{ij} \big/ d_{ij}^{\alpha/2}, \quad i \neq j, \\ i \in \{s, r_1, r_2, \cdots, r_M\},\ j \in \{r_1, r_2, \cdots, r_M, d\}, \tag{1}$$

where h_{ij} are channel coefficients between nodes i and j which are modeled as mutually independent and Rayleigh distributed random variances, and d_{ij} denotes the distance between nodes i and j. Path loss exponent α can be determined according to a preferred path loss model, typically $2\le\alpha\le4$. For free space $\alpha=2$, and in dense urban areas $\alpha\approx4$ (Khormuji and Larsson, 2007). Some additional assumptions are made on the receiver noises, which are modeled as zero-mean, mutually and temporally independent, Gaussian random variables with variances $N_0/2$. The average received signal-to-noise ratio (SNR) is denoted as $\gamma_{ij}=E_s/(N_0 d_{ij}^{\alpha})$, where E_s is the average transmitted energy per symbol.

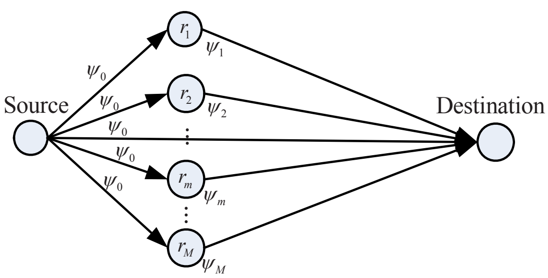


Fig.1 Cooperative retransmission system model

COOPERATIVE RETRANSMISSION SCHEME WITH JOINT DIVERSITY

Cooperative retransmission protocol

For a packet of bits, consecutive groups of bits are assigned to symbols via a symbol mapping function ψ:{0, 1, …, $|C|-1$}$\rightarrow C$ (Samra *et al.*, 2005), where C is a set of real- or complex-valued points that represents the points of a signal constellation, e.g., 16QAM and 16PSK. During the nth slot, a label s is mapped to the symbol $S_0[n]$ and then transmitted by the source, where $S_0[n]=\psi_0[s]$ and $\psi_0[\cdot]$ is the mapping function at the source.

Due to the broadcast nature of the radio channel, both the destination and the relays can listen to the transmitted data in the first slot. If no error exists after the reception of the transmitted data packet, an acknowledgment will be sent back to confirm the successful communication. Otherwise, if errors remain there (possibly after error correction), a request for retransmission is made to the transmitter and the system enters a cooperative retransmission epoch (CTE). During the CTE, the relays will assist the source in retransmitting the data packet. The destination node will send a control bit to all nodes to indicate the beginning of a CTE and will continue sending this bit until the CTE is over. The relays retransmit the copies of initially packets received at slot n one by one, so CTE of this protocol is composed of M slots, i.e., slots $n+1$, $n+2$,…, $n+m$, …, $n+M$.

In the nth slot, the received base band signals at the mth relay (y_{sm}) and at the destination (y_{sd}) are given by

$$y_{sd}[n]=a_{sd}S_0[n]+z_{sd}[n], \tag{2}$$

$$y_{sm}[n]=a_{sm}S_0[n]+z_{sm}[n],\ \ 1\le m\le M, \tag{3}$$

where $z_{sd}[n]$ denotes the noise between the source and the destination and $z_{sm}[n]$ denotes the noise between the source and the mth relay at slot n.

Symbol mapping and retransmission at the relays

In the conventional cooperative communication system, two fundamental relaying strategies are provided at the relays, i.e., AF and DF. However, neither AF/DF nor CR relaying strategy will change the symbol mapping rule. In our 'joint-diversity' system, the SMD technique allows the bit-to-symbol mapping to be re-designed for each relaying packet. The mapping function used by M relays are defined as $\psi_1[\cdot]$, $\psi_2[\cdot]$, …, $\psi_M[\cdot]$. The remapped symbols at M relays are $S_1[n]$, $S_2[n]$, …, $S_m[n]$, …, $S_M[n]$, where $S_m[n]=\psi_m[\psi_0^{-1}[S_0[n]]]$ and $1\le m\le M$. M relays will forward the copies of the source packet to the destination at subsequent time slots through M independent paths. The sample obtained by the destination node during CTE is

$$y_{md}[n+m]=a_{md}S_m[n+m]+z_{md}[n+m], \tag{4}$$

where $S_m[n+m]=S_m[n]$, $1\le m\le M$ and $z_{md}[n+m]$ denotes the noise between the mth relay and the destination at slot $n+m$.

Receiver design

Given the mappings ψ_0, ψ_1, …, ψ_M, the destination combines all the samples from the source and M relays according to the maximum-ratio combining (MRC) rule and then decides label s transmitted:

$$\min_{s=0,1,\ldots,|C|-1}\alpha_{M+1}[s]. \tag{5}$$

$\alpha_{M+1}[s]$ in Eq.(5) can be gained through iterative operations (Samra *et al.*, 2005):

$$\beta_{M+1}[s]=\sum_{m=1}^{M}\left|y_{md}-\hat{a}_{md}S_m[n+m]\right|^2$$
$$=\left|y_{Md}-\hat{a}_{Md}(\psi_M[s])\right|^2+\sum_{m=1}^{M-1}\left|y_{md}-\hat{a}_{md}(\psi_m[s])\right|^2$$
$$=\left|y_{Md}-\hat{a}_{Md}(\psi_M[s])\right|^2+\beta_M[s], \quad (6)$$

$$\alpha_{M+1}[s]=\beta_{M+1}[s]+\left|y_{sd}-\hat{a}_{sd}S_0[n]\right|^2$$
$$=\beta_{M+1}[s]+\left|y_{sd}-\hat{a}_{sd}(\psi_0[s])\right|^2, \quad (7)$$

where $\hat{a}_{sd}=a_{sd}$ and $\hat{a}_{md}=a_{md}$ when the channel state information (CSI) can be estimated perfectly.

PERFORMANCE ANALYSIS

In the following section, we develop analytical expressions for SER/BER of the cooperative retransmission system. Due to the tediousness and cumbersomeness of the closed-form expression for the SER/BER, we utilize a general SER upper bound (Miyoshi *et al.*, 2002) in this paper, which is

$$\sum_{s=0}^{|C|-1}\sum_{\substack{k=0\\k\neq s}}^{|C|-1}Pr\{s\}Pr\{\alpha_{M+1}[k]<\alpha_{M+1}[s]\,|\,s\}, \quad (8)$$

where $Pr\{s\}$ denotes *a priori* probability that label s is transmitted. $Pr\{\alpha_{M+1}[k]<\alpha_{M+1}[s]|s\}$ denotes the pairwise error probability (PEP), i.e., the probability that label k is more likely than label s to be detected when label s is transmitted.

Further, the corresponding general BER upper bound can be expressed as

$$\sum_{s=0}^{|C|-1}\sum_{\substack{k=0\\k\neq s}}^{|C|-1}Pr\{s\}B[s,k]Pr\{\alpha_{M+1}[k]<\alpha_{M+1}[s]\,|\,s\}, \quad (9)$$

where

$$B[s,k]=\frac{\text{Number of different bits between } s \text{ and } k}{\log_2|C|} \quad (10)$$

is defined to account for the number of bit errors that result from a label misdetection. Obviously, it is vital to deal with PEP, which is associated with the channel condition and signal constellation.

Multi-relay assisted retransmission without decision errors

If multiple relays exist in the network, the maximum SER/BER enhancement through multiple retransmissions is conditioned on that all the source-relay links are perfect, which means no relays make a decision error, then PEP at the destination can be expressed as

$$E_h\left\{Q\left(\sqrt{\frac{1}{2\sigma_v^2}\sum_{m=0}^{M}\left|h_m\right|^2\left|d_m[s,k]\right|^2}\right)\right\}, \quad (11)$$

where $d_m[s, k]$ (m>0) denotes the distance between labels s and k during the mth retransmission, $d_0[s, k]$ denotes the distance between labels s and k during the first transmission, and h_m denotes the channel coefficient of a certain link at the mth transmission.

In conventional DF relaying, the relay uses the same constellation mapping as that the source uses, so $d_m[s, k]=d_0[s, k]$, m=1, 2, …, M. With regard to CR and SMD relaying, different bit-symbol mappings are employed during each retransmission, so the distances between the same symbol pair will be different during each retransmission. It is difficult to discriminate CR and SMD mathematically, so we will compare their impact on SER/BER according to their definitions in the following paragraphs.

Single-relay assisted retransmission with decision errors

In the single-relay assisted retransmission system, the SER at the destination can be written as a sum of two terms conditioned on the performance of relays:

$$Pe=(1-P_r)P_t+P_rP_x, \quad (12)$$

where P_r is the SER at the relay, P_t is the SER of retransmission diversity, and P_x is the SER at the destination when the relay makes a decision error.

Given source-relay link parameter a_{sr}, the SER at the relay can be expressed as

$$P_{\mathrm{r}|a_{\mathrm{sr}}}=1-\left(1-1.5Q\left(\sqrt{\frac{2}{5}\gamma_{\mathrm{sr}}\left|h_{\mathrm{sr}}\right|^{2}}\right)\right)^{2}, \tag{13}$$

$$P_{\mathrm{r}}=\int P_{\mathrm{r}|a_{\mathrm{sr}}}\,p(a_{\mathrm{sr}})\mathrm{d}a_{\mathrm{sr}}. \tag{14}$$

When the relay makes no decision error, the SER of retransmission diversity can also be obtained from the general SER upper bound, where PEP can be expressed as

$$E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}\sum_{m=0}^{1}\left|h_{m}\right|^{2}\left|d_{m}[s,k]\right|^{2}}\right)\right\}. \tag{15}$$

For DF relaying, Eq.(15) can be further expressed as

$$E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}\left(\left|h_{0}\right|^{2}+\left|h_{1}\right|^{2}\right)\left|d_{0}[s,k]\right|^{2}}\right)\right\}. \tag{16}$$

For CR and SMD relaying, Eq.(15) can be further expressed as

$$E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}\left(\left|h_{0}\right|^{2}\left|d_{0}[s,k]\right|^{2}+\left|h_{1}\right|^{2}\left|d_{1}[s,k]\right|^{2}\right)}\right)\right\}. \tag{17}$$

If we assume that both the relay and the destination only choose signal points in the proximity of the transmitted signal point, it is easy to show that $P_{\mathrm{x}}\approx 1$ for DF relaying, CR relaying and SMD relaying.

Multi-relay assisted retransmission with decision errors

In the multi-relay assisted retransmission system, the SER/BER at the destination is conditioned on the performance of relays. The SER at the destination can be expressed as

$$Pe=\sum_{r=0}^{M}P_{M}^{r}Pe_{M+1}^{r}, \tag{18}$$

where P_{M}^{r} is the probability that r relays make decision errors in M-relay assisted retransmission system, Pe_{M+1}^{r} is the SER of retransmission diversity at the destination.

Here, we assume that all the relays have the same distance to the source. The SER over single source-relay links can be expressed as

$$P_{M}^{r}=C_{M}^{r}(1-P_{\mathrm{r}})^{M-r}P_{\mathrm{r}}^{r}, \tag{19}$$

where P_{r} is the SER at the relays. Given the source-relay link parameter a_{sr}, the SER at the relay can be expressed as Eqs.(13) and (14). Then Pe_{M+1}^{r} is the only term remaining in Eq.(18). According to the performance of relays, Pe_{M+1}^{r} are classed into three cases:

(1) If no relay makes a decision error, i.e., $P_{M}^{0}=C_{M}^{0}(1-P_{\mathrm{r}})^{M}P_{\mathrm{r}}^{0}=(1-P_{\mathrm{r}})^{M}$, the maximum SER/BER gains can be achieved from M retransmissions. Pe_{M+1}^{r} can be gained from the general upper bound, where PEP can be expressed as Eq.(11).

(2) If decision errors are made by the relays, SER gains from retransmission will be less than those in Case (1). Pe_{M+1}^{r} can still be gained from the general upper bound, where PEP can be bounded as

$$Pr\{\alpha_{M+1}[k]<\alpha_{M+1}[s]|s\}$$
$$=E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}(A+B)}\right)\right\}<E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}A}\right)\right\}, \tag{20}$$

where

$$A=\sum_{\substack{m=0\\ m\notin R_{\mathrm{e}}}}^{M}\left|h_{m}\right|^{2}\left|d_{m}[s,k]\right|^{2},\quad B=\sum_{\substack{m=0\\ m\in R_{\mathrm{e}}}}^{M}\left|h_{m}\right|^{2}\left|d_{m}[s_{\mathrm{e},m},k]\right|^{2}.$$

Suppose that when label s is transmitted, relay r_m makes a decision error; the detected label is denoted as $s_{\mathrm{e},m}$ and R_{e} denotes the set of relays that make decision errors.

(3) If all the relays make decision errors [the special case of Case (2)], the advantage of retransmissions cannot be taken by the destination, and Pe_{M+1}^{M} can still be gained from the general upper bound, where PEP can be bounded as

$$Pr\{\alpha_{M+1}[k]<\alpha_{M+1}[s]\,|\,s\}=E_{h}\left\{Q\left(\sqrt{\frac{1}{2\sigma_{v}^{2}}(A+B)}\right)\right\}$$

$$= E_h\left\{Q\left(\sqrt{\frac{1}{2\sigma_v^2}\left(|h_0|^2\left|d_0[s,k]\right|^2+\sum_{m=1}^{M}|h_m|^2\left|d_m[s_{e,m},k]\right|^2\right)}\right)\right\}$$

$$< E_h\left\{Q\left(\sqrt{\frac{1}{2\sigma_v^2}\left(|h_0|^2\left|d_0[s,k]\right|^2\right)}\right)\right\}\approx 1, \qquad (21)$$

where A and B are the same as those in Eq.(20).

In addition, the only modification to the cooperative communication system is the application of a unique symbol mapping to each retransmission in relay nodes; this computational cost is negligible. The overall increase in complexity from mapping diversity is very small.

SIMULATION RESULTS

The performances of conventional DF relaying, CR relaying and SMD relaying in cooperative retransmission systems are compared in this section.

The substantial differences among three relaying strategies lie in their design of the bit-to-symbol mapping, which can be seen from the constellations over every packet transmission.

Here, we choose a retransmission system with 16QAM as an example and the number of retransmissions is three. Assume the initial bit sequence $i_1q_1i_2q_2$ is mapped to the constellation in the first line of Fig.2 under the Gray-mapping rule. In DF relaying strategy, no change is made on the bit-to-symbol mapping, so constellations over three subsequent retransmissions are the same as the constellation in the first line of Fig.2. In CR relaying strategy, logical inversion or position swapping is made on the bit sequence $i_1q_1i_2q_2$ in retransmissions, i.e., $i_1q_1\overline{i_2q_2}$, $i_2q_2i_1q_1$ and $i_2q_2\overline{i_1q_1}$. Though the constellations after CR are different, they still satisfy the Gray-mapping rule. With regard to SMD relaying, even the bit-to-symbol mapping rules are distinct over every packet transmission, which are obviously seen in other lines of Fig.2.

Some channel parameters are set as follows: the carrier frequency is 900 MHz, the sampling frequency is 3.6 GHz, and the vehicle speed is 20 m/s. Here, we consider the communication in free space, so the path loss exponent is set as α=2.

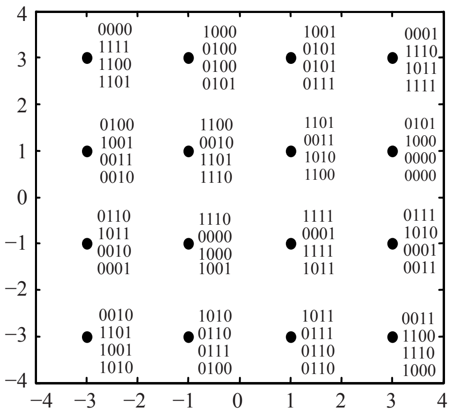


Fig.2 16QAM constellation with SMD

BER gains in multi-relay retransmission without decision errors

Fig.3 shows the BER in multi-relay assisted retransmission with no decision error when the single-hop average SNR varies from 0 dB to 14 dB. It is obvious that SMD can provide more BER gains than DF and CR relaying in multi-relay assisted retransmission. And DF and CR have similar BER performance. This is because the impact of the above methods on retransmission without decision errors lies in the distances between symbol pairs. In case of retransmitting copies of the initial Gray-mapped symbols with DF relaying, the variations in distances between symbols are greatly enlarged (Fig.4a).

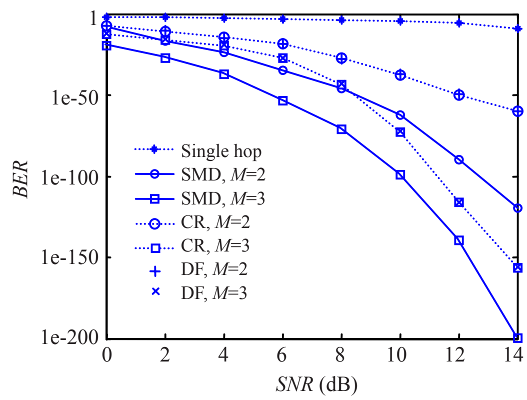


Fig.3 Comparison of BER in multi-relay system with no decision error

By rearranging the signal constellations for retransmissions (Panasonic, 2001a; 2001b), a small part of distances between symbol pairs is averaged. But the variations in distances between symbols remain biased (Fig.4b). So, DF and CR have similar BER. However, SMD performs an averaging of the distances between most symbols over the retransmissions (Fig.4c), so more BER gains can be achieved further. See details in the appendix.

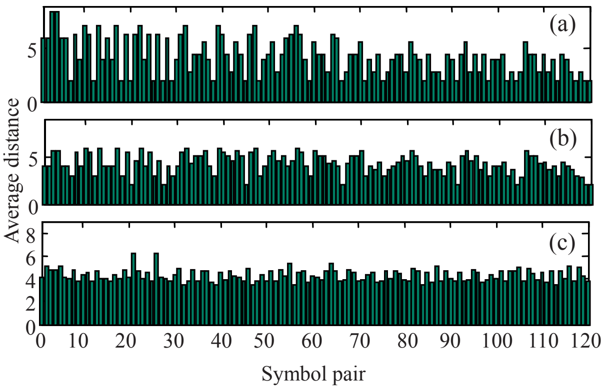


Fig.4 Average distance between symbol pairs. (a) Retransmission with DF; (b) Retransmission with CR; (c) Retransmission with SMD

BER gains in single-relay assisted retransmission with decision errors

Fig.5 gives the BER performance of single-relay assisted retransmission. It is easy to see that SMD relaying outperforms DF and CR relaying when d_{sr}/d_{sd}=0.1~0.4 for 0 dB average *SNR* (Fig.5a) and d_{sr}/d_{sd}=0.1~0.3 for 10 dB average *SNR* (Fig.5b). It is because the BER on the source-relay link is low when the relay is nearer to the source, and thus the advantage of SMD can be greatly shown. When d_{sr}/d_{sd}=0.15 (Fig.5a) and d_{sr}/d_{sd}=0.2 (Fig.5b), SMD provides the best BER performance. As d_{sr}/d_{sd} increases, BER gains provided by diversity decrease. When d_{sr}/d_{sd}>0.4 (Fig.5a) and d_{sr}/d_{sd}>0.3 (Fig.5b), the BER performance of SMD is similar to that of DF and CR, because as the source-relay link becomes poor, more decision errors occur at the relay and SMD does not provide as much extra protection. The BER performance of CR and DF is almost the same, because only one node acts as the relay and the bit-to-symbol mapping is under the same mapping rule, so diversity of CR relaying is not very obvious.

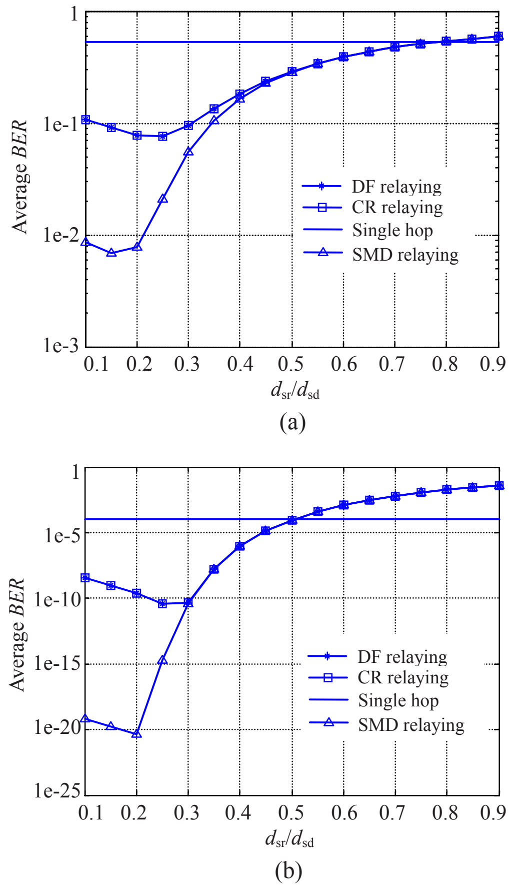
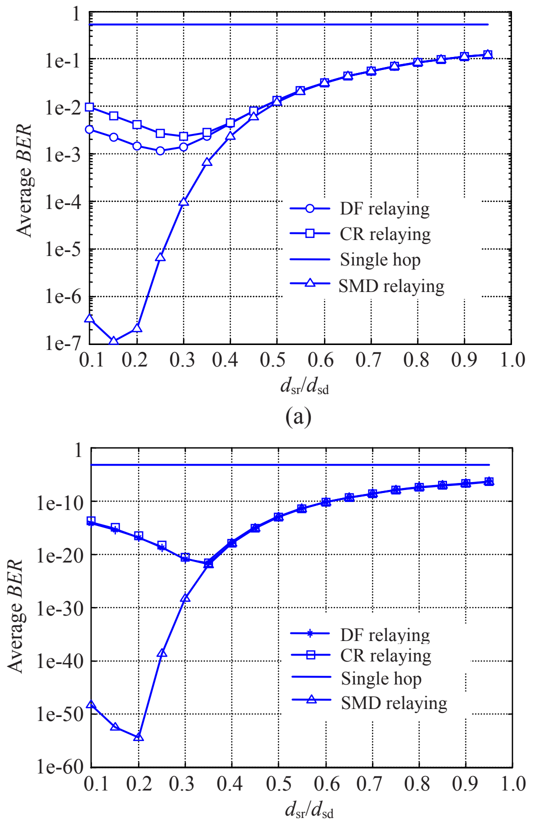


Fig.5 Comparison of BER performance in single-relay retransmission with decision errors. (a) Single-hop average *SNR*=0 dB; (b) Single-hop average *SNR*=10 dB

BER gains in multi-relay assisted retransmission with decision errors

Fig.6 gives the BER performance of multi-relay assisted retransmission, where *M*=3. In this subsection, the number of relays increases, so the retransmission diversity is enhanced. It is easy to see that SMD relaying outperforms DF and CR relaying when d_{sr}/d_{sd}=0.1~0.5 (Fig.6a) and d_{sr}/d_{sd}=0.1~0.35 (Fig.6b). When d_{sr}/d_{sd}=0.15 (Fig.6a) and d_{sr}/d_{sd}=0.2 (Fig.6b), SMD provides the best BER performance. As d_{sr}/d_{sd} increases further, BER gains provided by diversity also decrease. When d_{sr}/d_{sd}>0.5 (Fig.6a) and d_{sr}/d_{sd} >0.35 (Fig.6b), the BER performance of CR and SMD strategies is also similar to that of DF. This is because as d_{sr}/d_{sd} increases further, SER at relays increases correspondingly. The re-design of bit-to-symbol mappings in CR and SMD cannot play a part in enhancing BER gains.



(b)

Fig.6 Comparison of BER performance in three-relay retransmission with decision errors. (a) Single-hop average *SNR*=0 dB; (b) Single-hop average *SNR*=10 dB

CONCLUSION

We investigate a joint cooperation diversity and SMD strategy in cooperative packet retransmission systems with high-order modulations. Its impact on SER/BER is investigated and compared with other existing technologies. When no decision error occurs at relays, the joint-diversity scheme can provide the best BER performance in multi-relay assisted retransmission. But its performance is limited when there is a decision error at relays. If decision errors do occur, the joint-diversity scheme can only provide the best BER performance as the relays are closer to the source than to the destination.

In the future, we will address further improvement in the joint-diversity scheme. Additionally, we will compare the performance of this scheme in packet retransmission system with that of various modulations and combine the scheme with space-time coding.

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APPENDIX

To simplify the analysis, assume $Pr\{s\}$=1/16 for all labels. Let

$$x_{s,k}=\sqrt{\sum_{m=0}^{M}|h_m|^2|d_m[s,k]|^2}, \qquad \text{(A1)}$$

then PEP in Eq.(11) can be simply expressed as $g(x_{s,k})$, where $g(\cdot)$ denotes the functional relationship between PEP and $x_{s,k}$. And the SER upper bound in Eq.(8) can be expressed as

$$\frac{1}{16}\sum_{s=0}^{15}\sum_{\substack{k=0\\k\neq s}}^{15}g(x_{s,k}). \qquad \text{(A2)}$$

Given m,

$$\sum_{s=0}^{15}\sum_{\substack{k=0\\k\neq s}}^{15}|d_m[s,k]| \qquad \text{(A3)}$$

is constant. Correspondingly,

$$\sum_{s=0}^{15}\sum_{\substack{k=0\\k\neq s}}^{15}x_{s,k}=\sqrt{\sum_{m=0}^{M}|h_m|^2}\sum_{s=0}^{15}\sum_{\substack{k=0\\k\neq s}}^{15}|d_m[s,k]| \qquad \text{(A4)}$$

is also constant.

According to the general conclusion of the conditional extremum problem, when and only when all $x_{s,k}$ are the same, $\frac{1}{16}\sum_{s=0}^{15}\sum_{k=0,k\neq s}^{15}g(x_{s,k})$ achieves the minimum.

Then according to the property of the continuous function, if $\min f(x_1, x_2, \ldots, x_n)=f(x_0, x_0, \ldots, x_0)$ and $(x_1, x_2, \ldots, x_n)\rightarrow f(x_0, x_0, \ldots, x_0)$, it will be concluded that $f(x_1, x_2, \ldots, x_n)\rightarrow f(x_0, x_0, \ldots, x_0)$.

The average distances between symbol pairs after three retransmissions are shown in Fig.4. Compared with DF (see Fig.4a) and CR (see Fig.4b), it is obvious that SMD performs an averaging of the distances between most symbol pairs over the retransmissions (see Fig.4c) through remapping with different mapping rules, so its SER/BER is the closest to the minimum of SER/BER upper bound and more SER/BER gains can be achieved further.