Performance of Two-Hop Communication Links Employing Various Relay Processing Schemes

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***Abstract*—The error performance of a two-hop communication link (THCL) supported by a cluster of relay nodes (RNs) is investigated. The THCL includes one source node (SN) and one destination node (DN). The SN sends information to the DN via a cluster of RNs. At the RNs, signals received from the SN are processed based on one of the three relay processing schemes. The three relay processing schemes considered include the distributed relay processing, maximal-ratio combining (MRC)-assisted relay processing and the majority vote and equal-gain combining (MV-EGC) aided relay processing. For the MRC-assisted and MV-EGC aided relay processing schemes, information exchange among the RNs is supported by a local information exchange network, within which communicates are based on the principles of direct-sequence code-division multiple-access (DS-CDMA). In this contribution, the bit error rate (BER) performance of the THCLs is investigated and compared, when assuming that the first and second hops of the THCLs experience flat Rayleigh fading and that the communications within the local information exchange network conflict only Gaussian noise. We address the impact of the energy consumed for RNs' cooperation on the achievable BER performance of the THCLs. Our studies demonstrate that, when the energy spent for cooperation is taken into account, cooperation among the RNs may impose a big trade-off on the achievable BER performance of the THCLs.**

I. Introduction

In recent years, cooperative communications have drawn a lot of attention and received intensive research. It has widely been recognized that cooperative communications will play more and more important roles in wireless communications of the future generations [1–4]. Specifically, in the relay-assisted wireless communications systems, clusters of distributed mobile nodes may be employed for attaining cooperative diversity, in order to enhance the reliability of communications [5–7]. The relay diversity schemes have been investigated in the context of various relay protocols, which include amplify-and-forward (AF), decode-and-forward (DF), compress-and-forward (CF), etc., [5–8]. In most of the references concerning cooperative diversity, a typical assumption is that cooperation among the relay nodes (RNs) is ideal, without requiring any energy for information exchange among the RNs. However, this assumption in impractical.

Against this background, in this contribution, we study and compare three types of relay processing schemes in association with two-hop communication links (THCLs). We assume that a THCL consists of one source node (SN) and one destination node (DN), which cannot communicate directly. Instead, the SN sends information to the DN via a cluster of RNs that are close to each other. Therefore, sending signals from the SN to the DN requires two hops, SN to RNs and RNs to DN. At the RNs, the signals received from the SN may be processed in a distributed way or jointly via relay cooperation. Specifically, in this contribution, three types of relay processing schemes are considered. The first one is named as the distributed relay processing, which does not require information exchange among the RNs. The second one is termed as the maximal-ratio combining (MRC)-assisted relay processing, which requires exchange of both the channel information as well as the data information of all the RNs. Finally, the third one is referred to as the majority vote and equal-gain combining (MV-EGC) aided relay processing, which requires to exchange the data information, but not the channel information, of all the RNs. In both the MRC-assisted and the MV-EGC aided relay processing schemes, information exchange is implemented via a local information exchange network governed by one information exchange centra unit (IECU), and in the local network the communications are based on the principles of direct-sequence code-division multiple-access (DS-CDMA). Explicitly, for the three schemes considered, the distributed relay processing has the lowest complexity, while the MRC-assisted relay processing has the highest complexity.

In this paper, the bit error rate (BER) performance of the THCLs is investigated by assuming that both the first and second hops experience flat Rayleigh fading, while the communications within the local information exchange network are only disturbed by Gaussian noise. The BER performance of the THCLs associated with the three types relay processing schemes is investigated and compared, when various scenarios are considered. From our performance results we are implied that cooperation among the RNs imposes a big trade-off on the achievable BER performance of the THCLs. Specifically, when under the ideal assumption that cooperation spends no energy, which is explicitly not true in practice, the MRC-assisted relay processing is the best of the three in terms of the BER, and significantly outperform the distributed relay processing. However, when energy consumption for the RNs' cooperation is taken into account, the distributed relay processing may achieve a better BER performance than the MRC-assisted relay processing, even under the assumption that the communications in the local information exchange network are highly reliable.

The rest of the paper is organized as follows. Section II considers the system model. In Section III, the three relay processing schemes are described. Section IV demonstrates the performance results and provides some discussion. Finally, in Section V, conclusions are summarized.

II. System Models

The two-hop communication link (THCL) to be studied is shown in Fig. 1, where information is transmitted from the SN to the DN with the aid of a cluster of L number of RNs. The RNs are either the distributed relays without cooperation or the cooperative relays, which share each other's information with the aid of a so-called information exchange control unit (IECU), as seen in Fig. 1. In this contribution, we assume that each of the communication terminals, including the SN, RNs, DN, IECU, employs one antenna for receiving and transmission. The L RNs are assumed to be close to each other and, when they are cooperative relays, the IECU seats in the middle of L RNs and has a small distance from any of the RNs. Furthermore, we assume that the IECU can only communicate with the RNs, and cannot receive signals from the SN or transmit signals to the DN. When distributed RNs

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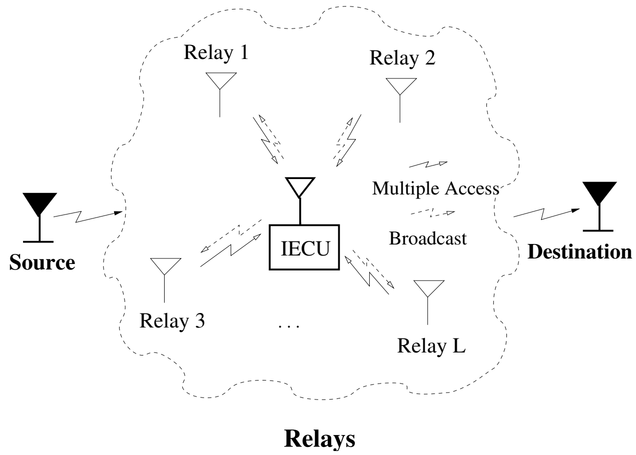

Fig. 1. Schematic of the Two-Hop Communication Link

are used, the THCL transmits signals in two steps: (a) SN transmits, RNs receive and (b) RNs transmit, DN receives. By contrast, when cooperative RNs are employed, the THCL is operated in four phases: (a) SN transmits, RNs receive; (b) RNs decode the received signals and send them to the IECU; (c) IECU makes the final decision of the information transmitted by the SN and broadcasts the decision to the RNs; (d) RNs detect and send the detected signals to the DN.

For the sake of comparison, the total transmission power of a symbol is constraint to P, regardless of the distributed RNs or cooperative RNs, or of the number of RNs used. Specifically, given that the total transmission power per symbol is $P = 1$, the power used by the first hop, information exchange among the RNs and the second hop are expressed as α_1, α_2, α_3, respectively, where $\alpha_1 + \alpha_2 + \alpha_3 = 1$. Furthermore, when cooperative RNs are employed, the power spent for transmitting signals from the RNs to the IECU and that required by the IECU to broadcast its decision to the RNs are the same of $\alpha_2/2$. In the considered THCL, we assume that the cluster of RNs are far away from both the SN and the DN. Correspondingly, we assume that the channels of the first hop and the second hop experience independent identically distributed (iid) flat Rayleigh fading. The RNs are assumed to employ the channel knowledge of both the first hop and the second hop. By contrast, we assume that the channels between the RNs and the IECU are additive white Gaussian noise (AWGN) channels, since we assumed that the RNs are very close to the IECU. Additionally, when the cooperative RNs are used, we assume that the communication between the RNs and the IECU is based on the principles of DS-CDMA.

With the aid of the above assumptions, below we describe the operations of the THCL in detail. Firstly, after the SN transmits a symbol expressed as x, which is assumed to satisfy $E[x] = 0$ and $E[|x|^2] = 1$, the received signals by the L RNs can be expressed in vector form as

$$\boldsymbol{y}_r = \sqrt{\alpha_1}\boldsymbol{h}_{sr}x + \boldsymbol{n}_r \tag{1}$$

where $\boldsymbol{y}_r = [y_{r_1}, y_{r_2}, \ldots, y_{r_L}]^T$ collects the observations obtained by the L RNs, $\boldsymbol{h}_{sr} = [h_{sr_1}, h_{sr_2}, \ldots, h_{sr_L}]^T$ contains the corresponding gains of the channels from the SN to the L RNs, where $\{h_{sr_i}\}$ obey the complex Gaussian distribution with zero mean and unit variance. In (1), $\boldsymbol{n}_r = [n_{r_1}, n_{r_2}, \ldots, n_{r_L}]^T$ is an L-length noise vector, each element of which obeys the Gaussian distribution with zero mean and a variance of $2\sigma^2$, where $\sigma^2 = 1/(2\bar{\gamma}_s)$ with $\bar{\gamma}_s$ denoting the average signal-to-noise ratio (SNR) per symbol. Explictly, from (1) we can know that the average SNR of the first hop is $\gamma_{sr} = \alpha_1\bar{\gamma}_s$.

Based on (1), the RNs carry out some processing, which will be detailed in Section III. Let us express $\tilde{\boldsymbol{y}}_r$ the results after the relay processing. Then, the RNs forward $\tilde{\boldsymbol{y}}_r$ to DN. Correspondingly, the received signals at the DN can be written as

$$y_d = \sum_{i=1}^{L} \sqrt{\alpha_3} h_{r_i d}\, \tilde{y}_{r_i} + n_d \tag{2}$$

where $h_{r_i d}$ represents the channel gain between the ith RN and the DN, which obeys the complex Gaussian distribution with zero mean and a variance of 0.5 per dimension, while n_d is the Gaussian noise with zero mean and a variance of $2\sigma^2$. Based on (2), we can know that the average SNR from the ith RN to the DN is $\gamma_{r_i d} = \alpha_3 E[|\tilde{y}_{r_i}|^2]\bar{\gamma}_s$, where $i = 1, 2, \ldots, L$. Let us now consider in detail the processing at the RNs.

III. Relay Processing

In this paper, three types of relay processing are considered, which are the distributed relay processing, maximal-ratio combining (MRC)-assisted relay processing as well as the majority vote and equal-gain combining (MV-EGC) aided relay processing.

A. *Distributed Relay Processing*

When the THCL employs the distributed RNs, the RNs simply forward their decisions about the symbol transmitted by the SN. Specifically, let the symbols detected by the RNs be expressed as $\{x_{r_i}\}$. Then, after carrying out the preprocessing using the channel knowledge of the second hop, the ith RN obtains

$$\tilde{y}_{r_i} = \frac{1}{\sqrt{L}} \frac{h^*_{r_i d}}{\sqrt{|h_{r_i d}|^2}} x_{r_i}, \quad i = 1, 2, \ldots, L \tag{3}$$

which is forwarded to the DN. Hence, when substituting (3) into (2), we obtain

$$\begin{aligned} y_d &= \sum_{i=1}^{L} \sqrt{\alpha_3} h_{r_i d} \frac{1}{\sqrt{L}} \frac{h^*_{r_i d}}{\sqrt{|h_{r_i d}|^2}} x_{r_i} + n_d \\ &= \sum_{i=1}^{L} \frac{\sqrt{\alpha_3}|h_{r_i d}|}{\sqrt{L}} x_{r_i} + n_d \end{aligned} \tag{4}$$

Note that, in the above equations, $x_{r_i} = x$, when the detection of the ith RN is correct. Otherwise, $x_{r_i} \neq x$, if the detection of the ith RN is incorrect. In other words, $\{x_{r_i}\}$ in (4) may take different values, which make the analysis of the error performance of the THCL very difficult.

From the above description, we can realize that, in order to implement the distributed relay processing, a RN requires the knowledge of the channel from the SN to this RN as well as of the channel from this RN to the DN.

B. *Maximal-Ratio Combining Assisted Relay Processing*

The MRC-assisted relay processing is for the THCL supported by the cluster of cooperative relays, which exchange information with the aid of the IECU, as seen in Fig. 1. At the IECU, signals received from the RNs are combined based on the MRC principles. Furthermore, the signals transmitted by the RNs to the DN are also preprocessed based on the MRC principles. In detail, the relay processing can be described as follows.

Once the RNs obtain the observations of $\boldsymbol{y}_r$, as shown in (1), each of the RNs normalizes its observation and then forwards it to the IECU based on the principles of DS-CDMA. Therefore, the observations obtained at the IECU can be represented as

$$\boldsymbol{y}_{cu} = \sqrt{\frac{\alpha_2}{2L}}\boldsymbol{H}\boldsymbol{s}_r + \boldsymbol{n}_{cu} = \sqrt{\frac{\alpha_2}{2L}}\,\boldsymbol{C}\boldsymbol{A}\boldsymbol{s}_r + \boldsymbol{n}_{cu} \tag{5}$$

where $\boldsymbol{H} = \boldsymbol{C}\boldsymbol{A}$, $\boldsymbol{s}_r = [s_{r_1}, s_{r_2}, \ldots, s_{r_L}]^T$ with s_{r_i} denoting the normalized observation of the ith RN, which can be expressed as $s_{r_i} = y_{r_i}/\sqrt{|h_{sr_i}|^2 + 2\sigma^2}$. In (5), $\boldsymbol{y}_{cu}$ is an N-length vector, when a spreading factor of N is assumed for the DS-CDMA, $\boldsymbol{C} = [\boldsymbol{c}_1, \boldsymbol{c}_2, \ldots, \boldsymbol{c}_L]$ is an $(N \times L)$ matrix containing the spreading sequences assigned to the L RNs, where $\boldsymbol{c}_i$ satisfies $||\boldsymbol{c}_i||^2 = 1$, while $\boldsymbol{A} = \text{diag}\{a_1, a_2, \ldots, a_L\}$, where $a_i = \exp(j\theta_i)$ with θ_i denoting the phases due to carrier modulation and channel in the context of the ith RN. Furthermore, in (5), $\boldsymbol{n}_{cu} = [n_{cu_1}, n_{cu_2}, \ldots, n_{cu_N}]^T$, where the element n_{cu_i} obeys the Gaussian distribution with zero mean and a variance of $2\sigma_{cu}^2$, where $\sigma_{cu}^2 = 1/(2\bar{\gamma}_s\beta)$ and β is the parameter used for setting the noise variance at IECU, in comparison with that at the RNs and DN. Note that, it can be shown that the SNR of the DS-CDMA channels is $\gamma_{ma} = \alpha_2\bar{\gamma}_s\beta/(2L)$, where the term of $2L$ is due to the fact that the total power of α_2 is used for both multiple-access and broadcast as well as for L RNs.

Having obtained $\boldsymbol{y}_{cu}$ as shown in (5), the IECU first carries out the de-spreading, which can be expressed as

$$\bar{\boldsymbol{y}}_{cu} = \boldsymbol{H}^H\boldsymbol{y}_{cu} = \sqrt{\frac{\alpha_2}{2L}}\boldsymbol{A}^H\boldsymbol{C}^T\boldsymbol{C}\boldsymbol{A}\boldsymbol{s}_r + \bar{\boldsymbol{n}}_{cu} \tag{6}$$

where $\bar{\boldsymbol{n}}_{cu} = \boldsymbol{A}^H\boldsymbol{C}^T\boldsymbol{n}_{cu}$. Then, the MRC is operated to form the final decision variable, which is expressed as

$$z_{cu} = \sum_{i=1}^{L} h_{sr_i}^*\bar{y}_{cu_i} \tag{7}$$

Upon substituting $\bar{y}_{cu_i}$ from (6) as well as using the relationship between s_{r_i} and y_{r_i}, we obtain

$$\begin{aligned} z_{cu} =& \sum_{i=1}^{L}\sqrt{\frac{\alpha_1\alpha_2}{2L}}\frac{|h_{sr_i}|^2}{\sqrt{|h_{sr_i}|^2 + 2\sigma^2}}x \\ &+ \sum_{i=1}^{L}\sqrt{\frac{\alpha_1\alpha_2}{2L}}\frac{h_{sr_i}^*}{\sqrt{|h_{sr_i}|^2 + 2\sigma^2}}n_{r_i} + \sum_{i=1}^{L}h_{sr_i}^*\bar{n}_{cu_i} \end{aligned} \tag{8}$$

Based on z_{cu}, the IECU can detect for the symbol transmitted by the SN. Let the detected symbol be expressed as $\hat{x}$. Then, the IECU broadcasts it to the L RNs. When assuming that the BC channels are Gaussian channels, the received signals by the RNs can be expressed as

$$\hat{y}_{r_i} = \sqrt{\frac{\alpha_2}{2L}}\hat{x} + \hat{n}_{r_i}, \;\; i = 1, 2, \ldots, L \tag{9}$$

where $\hat{n}_{r_i}$ denotes the Gaussian noise of the ith BC channel, which has zero mean and a variance of $\sigma_{cu}^2 = 1/(2\bar{\gamma}_s\beta)$ per dimension. From (9) we can readily know that the SNR of the BC channels is given by $\gamma_{bc} = \sqrt{\alpha_2/2}\bar{\gamma}_s\beta$. With the aid of $\{\hat{y}_{r_i}\}$, the RNs make their decisions about the symbol transmitted by the IECU. Let the symbol detected by the ith RN be expressed as x_{r_i}.

Finally, the L RNs send their detected symbols $\{x_{r_i}\}$ to the DN based on the MRC principles, which can be represented as

$$\tilde{y}_{r_i} = \frac{\sqrt{\alpha_3}h_{r_id}^*}{\sqrt{\sum_{i=1}^{L}|h_{r_id}|^2}}\,x_{r_i}, \;\; i = 1, 2, \ldots, L \tag{10}$$

Consequently, at the DN, the decision variable for detecting the symbol x transmitted by the SN can be expressed as

$$\begin{aligned} y_d &= \sum_{i=1}^{L} h_{r_id}\tilde{y}_{r_i} + n_d \\ &= \sum_{i=1}^{L}\frac{\sqrt{\alpha_3}|h_{r_id}|^2}{\sqrt{\sum_{i=1}^{L}|h_{r_id}|^2}}\,x_{r_i} + n_d \end{aligned} \tag{11}$$

In comparison with the distributed relay processing, as described in Section III-A, the MRC-assisted relay processing has much higher complexity. According to (8), we can know that, in order to implement the MRC at the IECU, the IECU requires the channel knowledge of all the L channels from the SN to the L RNs. According to (10), implementing the MRC-based preprocessing for the second hop, a RN requires to employ the channel knowledge of all the L channels from the L RNs to the DN.

C. Majority Vote and Equal Gain Combining Aided Relay Processing

In order to reduce the complexity of the MRC-assisted relay processing, in this section we propose a so-called MV-EGC aided relay processing. In this relay processing scheme, the IECU detects the symbol transmitted by the SN based on the majority vote, which does not require the knowledge of the channels from the SN to the L RNs. Furthermore, for the second hop, the RNs carry out their preprocessing in a distributed way as the distributed relay processing analyzed in Section III-A. Therefore, each of the RNs only needs to know the channel related itself. Hence, the complexity may be significantly reduced, in comparison with the MRC-assisted relay processing scheme considered in Section III-B.

In more detail, in the context of the MV-EGC aided relay processing, after the ith RN receives y_{r_i}, which is given in (1), it carries out the hard-detection. Let the ith estimate to the symbol transmitted by the SN be expressed as s_{r_i}. Then, the RNs transmit their estimates to the IECU based on the principles of the DS-CDMA and, correspondingly, the received observations at the IECU can be written as

$$\boldsymbol{y}_{cu} = \sqrt{\frac{\alpha_2}{2L}}\boldsymbol{C}\boldsymbol{A}\boldsymbol{s}_r + \boldsymbol{n}_{cu} \tag{12}$$

where the matrices and vectors have the same explanation as those in (5), but $\boldsymbol{s} = [s_{r_1}, s_{r_2}, \cdots, s_{r_L}]^T$ with $\{s_{r_i}\}$ being the hard decision symbols.

Based on $\boldsymbol{y}_{cu}$, the IECU detects the symbols $\{s_{r_i}\}$ transmitted by the L RNs. Let the detected symbols be expressed as $\{\hat{s}_{r_i}\}$. Then, the IECU carries out the majority vote and the symbol presented most times is taken as the estimate of the symbol transmitted by the SN. Let this symbol be expressed by $\hat{x}$. This symbol is then sent back to the L RNs by the IECU via the broadcast channels using the same principles as that described in Section III-B. From the broadcast channels, the RNs can detect the symbol $\hat{x}$ transmitted by the IECU. Let the detected symbols be expressed as $\{x_{r_i}\}$. Then, the RNs carry out the preprocessing based on the EGC principles, as described in Section III-A, and send the preprocessed signals to the DN via the second hop. Finally, the decision variable obtained at the DN can be expressed as (4), based on which the symbol transmitted by the SN can be detected.

IV. Performance Results

In this section, we provide a range of simulation results, in order to demonstrate the achievable error performance of the relay processing schemes considered in this contribution. For all the error

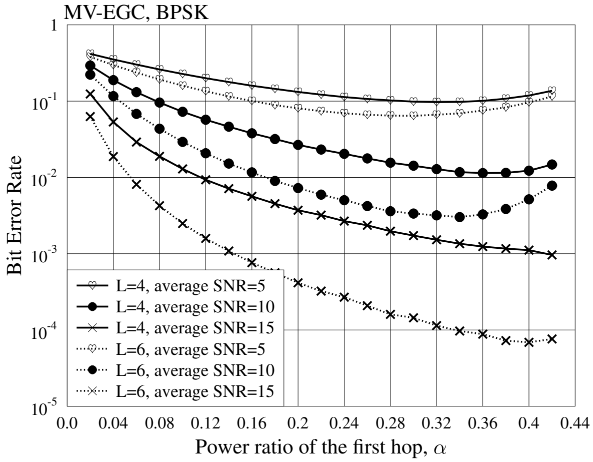

Fig. 2. Effect of power-allocation on the BER performance of the THCL with MV-EGC aided relay processing, where $\alpha_1 = \alpha_3 = \alpha$, $\beta = 10$ and BPSK baseband modulation are assumed.

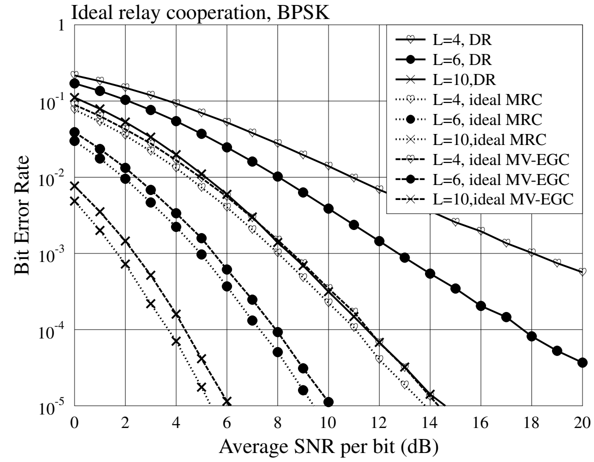

Fig. 4. BER performance of the THCLs with ideal relay cooperation, where $\alpha_1 = \alpha_3 = 1/2$ and BPSK baseband modulation are assumed, when both the first and second hops experience flat Rayleigh fading.

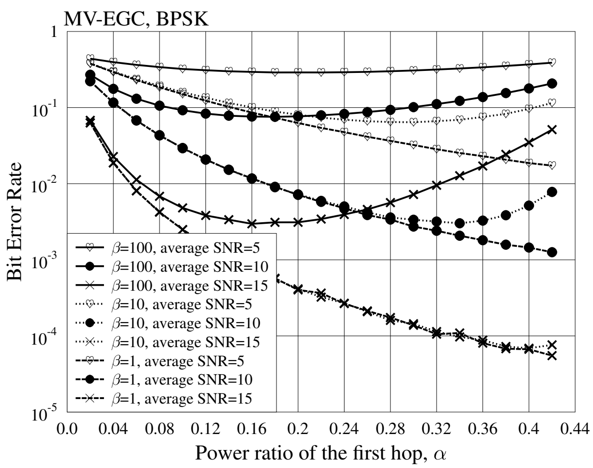

Fig. 3. Effect of power-allocation on the BER performance of the THCL with MV-EGC aided relay processing, where $\alpha_1 = \alpha_3 = \alpha$, $L = 6$ and BPSK baseband modulation are assumed.

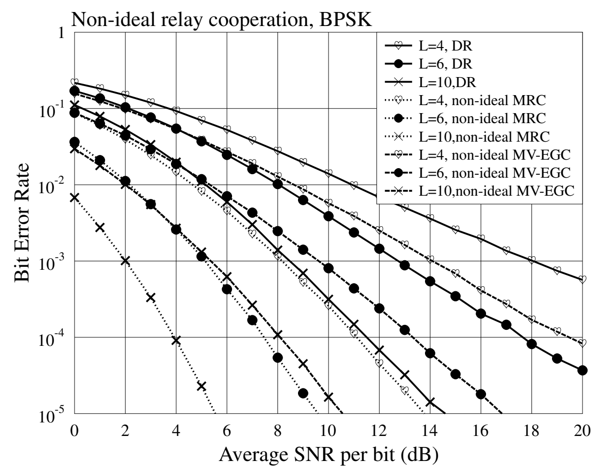

Fig. 5. BER performance of the THCLs with non-ideal relay cooperation, where $\alpha_1 = \alpha_3 = 1/2, \beta = 10$ and BPSK baseband modulation are assumed, when both the first and second hops experience flat Rayleigh fading.

performance results shown in this section, we assumed that the total power consumed for transmission of a symbol is $P = 1$. Furthermore, there is no fading considered in relay cooperation. In other words, the communication channels between the IECU and the L RNs were assumed to be the Gaussian channels.

As two examples, in Figs. 2 and 3, we investigate the effect of the power-allocation on the achievable BER performance of the THCLs employing the MV-EGC aided relay processing. As shown in the figure, we assumed that $\alpha_1 = \alpha_3 = \alpha$. Hence, $\alpha_2 = 1 - 2\alpha$. Furthermore, we assumed BPSK baseband modulation and that signals transmitted over the first and second hops experience Rayleigh fading, while information exchange among the RNs over Gaussian channels. From the results of Figs. 2 and 3, we can clearly observe that, when given the number of RNs, the value of SNR as well as the value of β, there exists a corresponding value for α, which yields the lowest BER. This means that optimum power-allocation is required for the THCL to achieve the best error performance. As seen in Figs. 2 and 3, the optimum value of α becomes larger, as the number of RNs or the average SNR, $\bar{\gamma}_s$, increases. This observation means that, when more number of RNs are employed or when the information exchange among the RNs becomes more reliable, more power should be allocated to the first and second hops of the THCL, in order to achieve better BER performance. In Fig. 3, we can see that the optimal value of α becomes smaller, as the value of β decreases, This implies that, when operated at the optimum point, the relay cooperation requires more power, as the information exchange channels become less reliable. Additionally, from both the figures we can see that the optimal value of α is around $\alpha = 0.2 \sim 0.4$, which means that the relay cooperation requires about $20\% \sim 60\%$ of the total power. Therefore, the relay cooperation requires to consume a substantial amount of energy, even when the information exchange channels are highly reliable.

In Figs. 4 and 5, we compare the BER performance of the THCLs employing respectively the three relay processing schemes considered in this paper. In the context of Fig. 4, we assumed the ideal relay cooperation, while in Fig. 5, we assumed the non-ideal cooperation. Here the ideal relay cooperation assumes that information exchange among the RNs is fully reliable, while the non-ideal relay cooperation assumes that information exchange among the RNs conflicts Gaussian noise. In

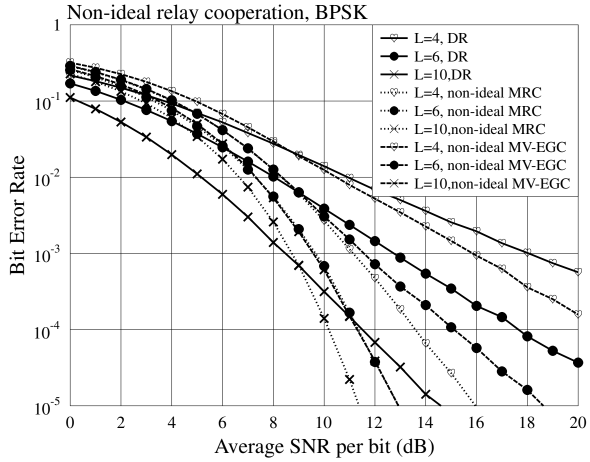

Fig. 6. BER performance of the THCLs with non-ideal relay cooperation, where $\alpha_1 = \alpha_2 = \alpha_3 = 1/3$, $\beta = 10$ and BPSK baseband modulation are assumed, when both the first and second hops experience flat Rayleigh fading.

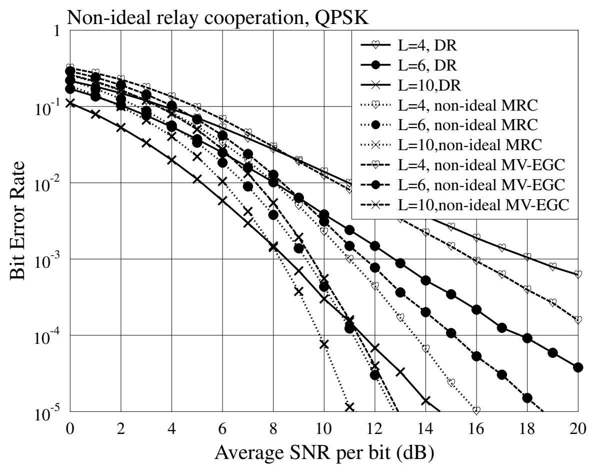

Fig. 7. BER performance of the THCLs with non-ideal relay cooperation, where $\alpha_1 = \alpha_2 = \alpha_3 = 1/3$, $\beta = 10$ and QPSK baseband modulation are assumed, when both the first and second hops experience flat Rayleigh fading.

both the figures, we assumed that the cooperation did not consume the energy for data transmission, and half of the power was used for supporting the first hop and the other half was used for supporting the second hop. From the results of Figs. 4 and 5 we can observe that, for a given value of L, the MRC-assisted relay processing is capable of achieving the best BER performance, while the distributed relay (DR) processing yields the worst BER performance. When the ideal relay cooperation is employed, the BER performance achieved by the MV-EGC aided relay processing is close to that achieved by the MRC-assisted relay processing. However, when the non-ideal relay cooperation is assumed, the MV-EGC aided relay processing may be significantly outperformed by the MRC-assisted relay processing.

Finally, in Figs. 6 and 7, we compare the BER performance of the THCLs with non-ideal relay cooperation, when the relay cooperation is assumed to consume a part of the total power. Specifically, we assumed that $\alpha_1 = \alpha_2 = \alpha_3 = 1/3$ and the Gaussian channels for information exchange had the SNR, which was 10 dB ($= 10\log_{10}\beta$) higher than the average SNR of $\bar{\gamma}_s$. In comparison with Figs. 4 and 5, the results of Figs. 6 and 7 demonstrate that the BER performance of the THCLs degrades significantly, after the energy consumed by the RNs is taken into account. As seen in Figs. 6 and 7, when the SNR is relatively lower, both the MRC-assisted and the MV-EGC aided relay processing schemes may be outperformed by the distributed relay processing scheme, which demands much lower complexity than the other two. When comparing the MRC-assisted relay processing with the MV-EGC aided relay processing, we can observe that the MRC-assisted relay processing always outperforms the MV-EGC aided relay processing. However, we should realize that the MRC-assisted relay processing requires higher complexity than the MV-EGC aided relay processing.

V. Conclusions

In this contribution, we have investigated the performance of the relay-assisted THCLs under the assumption that resources are required for relay cooperations. Specifically, three types of relay processing schemes have been studied, which are the distributed relay processing, MRC-assisted relay processing and the MV-EGC aided relay processing. While the distributed relay processing does not require information exchange among the RNs, the other two schemes do. This information exchange procedure consumes energy, resulting in that the BER performance of the THCLs degrades significantly, in comparison with the ideal scenarios, which assume no energy consumption for relay cooperations. When the energy consumed by the RNs is taken into account, our performance results show that the distributed relay processing scheme may achieve a better BER performance than the MRC-assisted and MV-EGC aided relay processing schemes, although these two schemes have much higher complexity than the distributed relay processing. Furthermore, we should realize that information exchange among the RNs not only requires bandwidth but also introduces extra delay.

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