복호 후 전달 릴레이 선택을 이용한 적응형 협력 기법의 BER 성능분석

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BER Performance Analysis for Adaptive Cooperation Scheme with Decode-and-Forward Relay-Selection

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요 약

본 논문에서는 기존의 협력 기법보다 뛰어난 성능과 주파수 효율을 얻을 수 있는 다중 릴레이 노드를 이용한 새로운 적응형 협력기법을 제안한다. 릴레이 선택은 K개의 릴레이 중 가장 뛰어난 채널 상태를 가진 잠재적 릴레이를 선택하는데 이용된다. 소스와 목적지, 소스와 릴레이, 릴레이와 목적지사이 채널의 순시 신호 대 잡음 비를 고려하여 적응형 협력 또는 비 협력 여부를 결정한다. 본 논문에서 제안하는 적응형 프로토콜은 만일, 직접 통신의 채널 상태가 복호 후 전달 기법보다 양호하다면 소스는 가용한 전력으로 목적지로 신호를 전달하며, 그렇지 않다면 소스는 저전력으로 모든 릴레이에게 신호를 브로드캐스트하며, 릴레이의 올바른 복호를 가정할 시 릴레이는 신호를 복호한 후 다시 목적지로 전송하게 된다. 그리고 소스는 남은 전력으로 신호를 전송한다. 본 논문에서는 우선 확률적 계산을 통해 주파수 효율성을 보이며, 릴레이 선택을 통한 적응형 협력 기법의 BER성능 분석을 한다. 최종적으로 수식적 결과를 통해 본 논문에서 제안하는 기법의 성능 향상을 검증한다.

Key Words : BER Performance, Cooperative Diversity, Decode and Forward, Relay Selection

ABSTRACT

In this paper, we propose a new adaptive cooperation scheme with multi-relay nodes which achieves higher performance and spectral efficiency than that of some conventional cooperative schemes. The relay-selection is applied to choose the most potential relay among K ones. Afterward, the instantaneous signal-to-noise ratio (SNR) differences between S-D, S-R and R-D channels are considered for adaptive selection between the direct and the cooperation transmission strategy. In the proposed adaptive protocol, if the direct link is of high quality, the source will transmit to destination directly with all power consumption. Otherwise, the source broadcasts the signal with a lower power and requires the help of the chosen relay if it decodes correctly, else the source will transmit again with remaining power. Firstly, the spectral efficiency is derived by calculating the probability of each mode. Subsequently, the BER performance for the adaptive cooperation scheme is analyzed by considering each event that one of K relays is selected and then making the summation of all. Finally, the numerical results are presented to confirm the performance enhancement offered by the proposed schemes.

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Ⅰ. 서 론

Diversity techniques have been developed in order to combat fading on wireless channels and improve the reliability of the received message. Recently, cooperation has been proposed as a new mean to obtain "space-time" or "cooperative" diversity[1]-[2]. Different nodes in the network cooperate in order to form a virtual MIMO system and exploit space-time diversity even if their hardware constraints do not allow them to support several antennas. Many cooperative protocols have been proposed[3]-[6] which can be classified in three main families: decode and forward (DF), amplify and forward (AF) and compress and forward (CF).

In this paper, we are interested in the first family which is the more natural ones and studied most due to their simplicity. It just requires a symbol processing; this strategy consists in decoding the received signals at the relays and then forwarding them. However, most of the schemes in literature, the cooperation always occurs. This may waste bandwidth and power allocated to the relay if the relay fails to decode the source information. Moreover, relaying is also not needed if the direct channel, between the source (S) and the destination (D), is of high quality. In[5], cooperation is decided by considering the difference in instantaneous SNR between the S-D and S-R channels, applied to DF schemes and two equal phases. In general, the relative quality differences between the three channels: S-R, S-D, and R-D should be considered in selection of cooperation strategies.

Additionally, to achieve the higher diversity we would like to focus on the DF multi- node schemes in which the transmission from the source to the destination is helped by the collection of relays. In some conventional works, the destination waits to receive all the re-transmitted signals from the potential relays and then uses various combining techniques [12]-[13] (i.e. MRC, SC…) to decode the information. Conversely, killing the time to collect all the signals is not a good choice. Thus, there are various protocols, which named relay-selection, proposed to choose the best relay among a group of available relays. Such as, in[10], Laneman et. al. use distributed-timer technique to choose the best path from the source to destination. In another way[5], author proposes to choose the best relay depending on its geographic position, based on the graphic random forwarding (GeRaF) protocols proposed in[11]. With these techniques, we can save the time, the bandwidth but also get the roughly performance.

Here, in order to achieve these advantages which mentioned previously, we propose a new strategy named adaptive cooperation with relay-selection for the scheme multi- relay nodes in which the DF protocols can be applied whenever the direct link is not good. With this scheme, we can save the time and the bandwidth while its performance is higher than the conventional ones. Firstly, the most potential relay will be selected based on the instantaneous SNR of the channels between it and two end terminals: the source and the destination. This optimal relay is the one which has the maximum instantaneous value of the relay metric, which is denoted as equivalent SNRs, as in[9]. The selection decision can be achieved by the destination after collecting all the channel coefficients or through setting a timer as in[10]. Then by using the instantaneous SNR as the performance measure, the source checks whether the direct path or the relay path is better, then choose the higher SNR path for the transmission with the help of the chosen relay if it needs to cooperate. We also apply the re-transmission at the source when the relay fails to decode the signal to achieve an enhanced performance.

Through mathematical analysis, we study about the proposed scheme by investigating the spectral efficiency and the bit-error-rate performance. To get the spectral efficiency, we derive the probability of each mode. Afterward, with the notation that the spectral efficiency of the cooperation mode is a half of that of direct transmission mode we can get the average efficiency of the scheme. Subsequently, to obtain the BER performance, initially, we consider the event that a relay is the most potential one. Then we calculate the end-to-end performance by getting the summation of all scheme's routine in each event. To conclude, we will use the Monte-Carlo simulations to confirm the results of the mathematical analysis.

The rest of this paper is organized as follows. Section 2 presents the system model of the adaptive cooperative relay-selection scheme with decoded and forward. Next, the spectral efficiency and the BER performance of the scheme will be investigated in Section 3 and Section 4. Section 5 illustrates Monte- Carlo simulation and the numerical results. Finally, the paper is concluded in Section 6.

Ⅱ. System models

We consider an adaptive cooperative wireless network where the information is transmitted from a source S to a destination D with the assistance of K DF relays R_k ($k=1\cdots K$) as shown in Fig.1. Each terminal is equipped with single-antenna transceiver and operates in a half-duplex mode using the same frequency slot over slow frequency -flat Rayleigh fading channels, i.e.,the instantaneous channel coefficients are constant during a symbol transmission block (include two phases) but change independently to the next one. Here, we denote a_{SD}, a_{R_kD} and a_{SR_k} as the independent channel gains for the source-to-destination (S-D) link, the source-to-kth relay (S-Rk) link and the kth relay- to-destination (Rk-D) link, correspondingly. Let $\gamma_0=|a_{SD}|^2$, $\gamma_{1k}=|a_{SR_k}|^2$ and $\gamma_{2k}=|a_{R_kD}|^2$ represent the S-D, S-Rk and Rk-D SNRs. As a result γ_0, γ_{1k} and γ_{2k} are modeled as i.n.d. exponential random variables with means $1/\Omega_0$, $1/\Omega_{1k}$ and $1/\Omega_{2k}$, respectively.

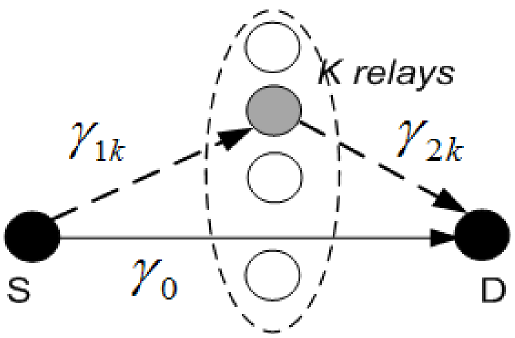

Fig. 1. Adaptive cooperative scheme with K relays
그림 1. K개의 릴레이를 가진 적응형 협력 기법 모델

The basic idea of the proposed scheme is that select the most potential relay among the K relays to cooperate with the source, if it needs to cooperate. Here, we address two main questions: "*How to choose the best relay?*" and "*How does the source cooperate with this relay?*". The rationale behind this protocol is that there is no need for the relay to cooperate with the system if the direct link (S-D), is of high quality. In addition, the source picks up an optimal relay to collaborate with in case it needs help.

Firstly, among K relays, the best relay will be chosen based on the instantaneous SNR of the relay channels. According to[9], the dual-hop $S\to R_k\to D$ channel can be modeled as an equivalent single hop with the output SNR γ_{eq_k} can be approximated in the high SNR regime as

$$\gamma_{eq_k}=\min\{\gamma_{1k},\gamma_{2k}\} \quad (1)$$

Thus, in order to get the better result which achieved by the cooperation, the relay links with the highest equivalent SNR is selected (e.g., selected using distributed timers[10]). Then the instantaneous SNR of the relay link through the best relay can be given by

$$\gamma_R=\max\{\gamma_k\} \quad (2)$$

Without loss of generality, we let i^{th} relay is the chosen relay. After determining the best one, the K-relay scheme now is considered as a simple scheme with one source, one destination and one relay.

The transmission protocol can be described as shown in the Fig.2, the source selects cooperation or non-cooperation at the beginning of each time-slot based on the ratio γ_0/γ_{eq_i}. The cooperation between source and the relay takes place according to the scheme in [8] with one relay. Due to the qualities of the channels, the source directly transmits to the destination when $\Phi^D=\{\gamma_0 \geq \gamma_{eq_i}\}$ happens and cooperates with the relay when $\Phi^D=\{\gamma_0 < \gamma_{eq_i}\}$ happens.

Note that, it is assumed that the channels are reciprocal as in the Time Division Duplex (TDD) mode, hence, the source knows its S-R and S-D instantaneous channels gain γ_{1i} and γ_0. Moreover, the source does not require the destination to feedback the value of the R-D channel gain γ_{2i} at the beginning of each time slot. Instead, the destination only sends one bit that indicates whether the event $\{\gamma_0/\gamma_{2i} \geq 1\}$ happens or not. Therefore, the overhead for feedback information from the destination to the source is negligible.

Hence, in the first phase, the source can know whether the event Φ^D or the event Φ^R happens, and decide to choose the better scheme for transmitting the signal to the destination in each case as follow. If $\gamma_0 \geq \gamma_{eq_i}$ happens, the source decides to employ direct transmission with the total transmitted power of scheme. The received symbol at the destination can be modeled as

$$y_D^{\Phi^D} = \sqrt{P}a_{SD}s + n_{SD} \tag{3}$$

where P is the total transmitted power, s is the transmitted symbol of the source, n_{SD} is an additive noise. This mode is denoted by the direct-transmission (DT) mode.

If $\gamma_0 < \gamma_{eq_i}$, the relay-cooperation (RC) mode, the relay will join in the cooperation transmission from the source to the destination based on the quality of its received symbol. This mode can be described as follows. In the first time slot, the source broadcasts its symbol to both destination and relay. The received symbols at the destination and the relay can be modeled as

$$y_{D,1}^{\Phi^R} = \sqrt{P_1}a_{SD}s + n_{D,1} \tag{4}$$

$$y_R^{\Phi^R} = \sqrt{P_1}a_{SR_i}s + n_{SR_i} \tag{5}$$

where P_1 is the source transmitted power in the first time slot, $n_{D,1}$ and n_{SR_i} are additive noises.

In the second time slot, if the relay decodes its received symbol correctly, it retransmits the decoded symbol to the destination. Otherwise, it informs to the source to transmit once more. Due to mathematical analysis, we assume that the relay can decide whether the symbol is decoded correctly or not, perfectly. In the real application, that can be achieved by using Cyclic Redundancy Check code to check the signal, or comparing the SNR with a threshold. Hence, the received symbol at the destination in the second time slot can be written as

$$y_{D,2}^{\Phi^R} = \sqrt{P_2}\widetilde{a_D}s + n_{D,2} \tag{6}$$

where $\tilde{a}=a_{R_iD}$ if the relay decodes the symbol correctly and forwards its symbol, otherwise, $\tilde{a}=a_{SD}$, the source transmits again. P_2 is the transmitted power of the relay or source in the time slot two with $P_1+P_2=P$ and $n_{D,2}$ is an additive noise. The noise terms n_{SD}, n_{SR_i}, $n_{D,1}$ and $n_{D,2}$ are modeled as zero-mean, complex

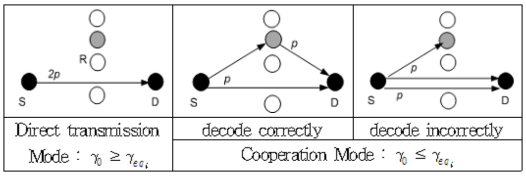

Fig 2. Adaptive cooperative transmission protocols
그림 2. 적응형 협력 전송 프로토콜

Gaussian random variables with variance N_0. Afterward, the destination combines two received signals within two time slots by using Maximum Ratio Combining (MRC)[12] technique to decode the information.

Ⅲ. Spectral efficiency

In this section, we obtain the probability of the direct transmission and the relay cooperation modes. And then based on these probabilities we calculate the average spectral efficiency of this proposed scheme.

Since γ_{1k} and γ_{2k} are exponentially distributed random variables with means $1/\Omega_{1k}$ and $1/\Omega_{2k}$, respectively, it is easy to see from (1) that γ_{eq_k} is also an exponentially distributed random variable with hazard rate $\alpha_k = \Omega_{1k} + \Omega_{2k}$[14]. Then, considering i^{th} relay, with the certain value of γ_{1i} and γ_{2i}, we have the probability that it is the chosen relay is performed as

$$\begin{aligned}\Pr{}_i\left(\gamma_{eq_i}\right) &= \Pr\left[\bigcap_{k=1,\neq i}^{K}\left(\gamma_{eq_k} < \gamma_{eq_i}\right)\right] \\ &= \prod_{k=1,\neq i}^{K} F_{\gamma_{eq_k}}\left(\gamma_{eq_i}\right) = \prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{eq_i}}\right) \\ &= 1+\sum_{k=1}^{K}(-1)^k \sum_{\substack{n_1,\dots,n_k=1,\neq i \\ n_1<n_2<\dots<n_k}}^{K} e^{-\beta_{ik}\gamma_{eq_i}}\end{aligned} \tag{7}$$

where $\beta_{ik} = \sum_{l=1}^{k}\alpha_{n_l}$.

With a certain value of γ_0, the probability of RC mode can be given by

$$\begin{aligned}\Pr\left(\Phi^R,\gamma_0\right) &= \sum_{i=1}^{K}\Pr{}_i\left(\gamma_{eq_i}\right)\Pr\left(\gamma_0 < \gamma_{eq_i}\right) \\ &= \sum_{i=1}^{K}\int_{\gamma_0}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{eq_i}}\right) f_{\gamma_{eq_i}}\left(\gamma_{eq_i}\right)d\gamma_{eq_i}\end{aligned} \tag{8}$$

Each element of the sum above is an integral of variable γ_{eq_i} which is denoted as the minimum value of γ_{1i} and γ_{2i}. Thus, in order to calculate these integrals we consider two cases $\{\gamma_{1i} < \gamma_{2i}, \gamma_{eq_i} = \gamma_{1i}\}$ and $\{\gamma_{1i} > \gamma_{2i}, \gamma_{eq_i} = \gamma_{2i}\}$ as

$$\begin{aligned}H_i &= \int_{\gamma_0}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{eq_i}}\right) f_{\gamma_{eq_i}}\left(\gamma_{eq_i}\right)d\gamma_{eq_i} \\ &= \int_{\gamma_0}^{\infty}\int_{\gamma_{1i}}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{1i}}\right) f_{\gamma_{2i}}(\gamma_{2i}) f_{\gamma_{1i}}(\gamma_{1i})d\gamma_{2i}d\gamma_{1i} \\ &+ \int_{\gamma_0}^{\infty}\int_{\gamma_{2i}}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{2i}}\right) f_{\gamma_{1i}}(\gamma_{1i}) f_{\gamma_{2i}}(\gamma_{2i})d\gamma_{1i}d\gamma_{2i}\end{aligned} \tag{9}$$

According to Appendix (A.1,2) we get the desired result as

$$H_i = e^{-\alpha_i\gamma_0} + \sum_{k=1}^{K-1}(-1)^k \sum_{\substack{n_1,\dots,n_k=1,\neq i \\ n_1<n_2<\dots<n_k}}^{K} \frac{\alpha_i e^{-(\alpha_i+\beta_{ik})\gamma_0}}{\alpha_i+\beta_{ik}} \tag{10}$$

Substituting (10) into (8) and simplifying the equation we have

$$\begin{aligned}\Pr\left(\Phi^R,\gamma_0\right) &= \sum_{i=1}^{K}(-1)^{i-1}\sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_k}}^{K} e^{-\beta_i\gamma_0} \\ &= 1-\prod_{i=1}^{K}\left(1-e^{-\alpha_i\gamma_0}\right)\end{aligned} \tag{11}$$

where $\beta_i = \sum_{l=1}^{i}\alpha_{n_l}$.

Then, we can get the probability of DT mode with a certain value of γ_0 as

$$\begin{aligned}&\Pr\left(\Phi^D,\gamma_0\right) = 1-\Pr\left(\Phi^R,\gamma_0\right) \\ &= 1-\sum_{i=1}^{K}(-1)^{i-1}\sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_k}}^{K} e^{-\beta_i\gamma_0} = \prod_{i=1}^{K}\left(1-e^{-\alpha_i\gamma_0}\right)\end{aligned} \tag{12}$$

By averaging (11) and (12) over γ_0 the probabilities of two modes can be achieved as

$$\begin{aligned}\Pr\left(\Phi^R\right) &= \int_0^{\infty}\Pr\left(\Phi^R,\gamma_0\right) f_{\gamma_0}(\gamma_0)d\gamma_0 \\ &= \int_0^{\infty}\Omega_0 e^{-\Omega_0\gamma_0}\sum_{i=1}^{K}(-1)^{i-1}\sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_i}}^{K} e^{-\beta_i\gamma_0} \\ &= \sum_{i=1}^{K}(-1)^{i-1}\sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_i}}^{K}\frac{\Omega_0}{\Omega_0+\beta_i}\end{aligned} \tag{13}$$

$$\Pr(\Phi^D) = 1 - \Pr(\Phi^R) = 1 - \sum_{i=1}^{K} (-1)^{i-1} \sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_i}}^{K} \frac{\Omega_0}{\Omega_0+\beta_i} \quad (14)$$

Let r denotes the spectral efficiency of the DT, so the spectral efficiency of the RC mode is r/2 (using two time slots). Hence, the expected spectral efficiency of our proposed scheme can be defined as the average efficiency viewed in a long-term perspective, is expressed as

$$\tilde{r} = \Pr(\Phi^D) r + \Pr(\Phi^R)\frac{r}{2} = \left[2 - \sum_{i=1}^{K}(-1)^{i-1} \sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_i}}^{K} \frac{\Omega_0}{\Omega_0+\beta_i}\right]\frac{r}{2} \quad (15)$$

Ⅳ. BER performance analysis

To calculate the BER of our proposed scheme, we consider BER of each mode. The end-to-end BER of this scheme can be written as

$$P_e(\gamma) = P_e(\gamma_{\Phi^D}|\Phi^D)\Pr(\Phi^D) + P_e(\gamma_{\Phi^R}|\Phi^D)\Pr(\Phi^D) = P_e^{\Phi^D} + P_e^{\Phi^R} \quad (16)$$

where $P_e^{\Phi^D} = P_e(\gamma_{\Phi^D}|\Phi^D)\Pr(\Phi^D)$ denotes the BER of the DT mode and $P_e^{\Phi^R} = P_e(\gamma_{\Phi^R}|\Phi^R)\Pr(\Phi^R)$ presents the RC mode BER. Thus, to calculate the total bit error rate, we consider the BER of each mode separately.

4.1 Direct transmission mode

For the DT mode, the instantaneous signal-to-noise (SNR) of the received signal at the destination is

$$\gamma_{\Phi^D} = P\gamma_0 / N_0 \quad (17)$$

In this paper, we use the BPSK modulation for transmission scheme so the conditional DT BER can be given by

$$P_e(\gamma_{\Phi^D}|\Phi^D,\gamma_0) = \frac{1}{\pi}\int_0^{\pi/2} e^{-\frac{\gamma_{\Phi^D}}{\sin^2\theta}} d\theta = \frac{1}{\pi}\int_0^{\pi/2} e^{-\frac{P\gamma_0}{N_0\sin^2\theta}} d\theta \quad (18)$$

By averaging (18) over γ_0 we can get the BER of the DT mode as (Appendix B.1)

$$P_e^{\Phi^D} = P_e(\gamma_{\Phi^D}|\Phi^D)\Pr(\Phi^D) = \int_0^\infty P_e(\gamma_{\Phi^D}|\Phi^D,\gamma_0)\Pr(\Phi^D,\gamma_0) f_{\gamma_0}(\gamma_0)d\gamma_0 = B_0\left(1, \frac{P}{\Omega_0 N_0}\right) - \sum_{i=1}^{K}(-1)^{i-1}\sum_{\substack{n_1,\dots,n_i=1 \\ n_1<\dots<n_i}}^{K} B_0\left(1+\frac{\beta_i}{\Omega_0}, \frac{P}{\Omega_0 N_0}\right) \quad (19)$$

where

$$B_0(x,y) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} \frac{\sin^2\theta d\theta}{x sin^2\theta + y} = \frac{1-\sqrt{y/(x+y)}}{2x}$$

4.2 Relay cooperation mode

For the RC mode, it is obvious that there are two cases happening at relay: correctly decode and incorrectly decode at the relay.

4.2.1 Incorrectly decode at the chosen relay

If the relay cannot decode the received signal successfully, the source transmits twice in two time slot. Here, we assume that the channel coefficient is constant within a frame; hence, the instantaneous SNR of the received signal at the destination can be written as

$$\gamma_{\Phi^R}^{inc} = (P_1\gamma_0 + P_2\gamma_0)/N_0 = P\gamma_{0/N_0} \quad (20)$$

In this case, the instantaneous SNR is same with the DT mode (17). However, we calculate the bit-error-rate based on the conditionals of each case; therefore, the achieved BER results are different.

Here, the probability of the incorrectly case is the error probability of the transmission from the source to the relay, so we have

$$P_{e,inc}^{\Phi^R} = P_e\left(\gamma_{\Phi^R}^{inc}|\Phi^R\right)P_e\left(\gamma_{SR}|\Phi^R\right)\Pr\left(\Phi^R\right) = \sum_{i=1}^{K}\int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{inc}|\Phi^R,\gamma_{\Phi^R}^{inc}\right)\Pr_i\left(\gamma_{eq_i}\right)P_e\left(\gamma_{1i}|\Phi^R\right)f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right)d\hat{\gamma}_i \quad (21)$$

where γ_{SR} deputizes for the instantaneous SNR of the channel between the source and the selected relay, $\hat{\gamma}_i$ present for three variables γ_0, γ_{1i}, γ_{2i} with the definition areas as $\hat{\gamma}_i = [\gamma_0,\gamma_1,\gamma_2|0<\gamma_0<\infty,\gamma_0<\gamma_{1i}<\infty,\gamma_0<\gamma_{2i}<\infty]$ and $f_{\hat{\gamma}_i}(\hat{\gamma}_i) = f_{\gamma_0}(\gamma_0)f_{\gamma_{1i}}(\gamma_{1i})f_{\gamma_{2i}}(\gamma_{2i})$.

By averaging each element of the sum in equation (21) over $\hat{\gamma}_i$ we can get the result as (according to Appendix C.1-5)

$$P_{e,inc}^{\Phi^R} = \sum_{i=1}^{K} P_{e,inc}^{\Phi^R,i} = \sum_{i=1}^{K}\left[\begin{array}{l} B_1\left(\Omega_{1i},\Omega_{2i},0,0\right)+\sum_{k=1}^{K-1}(-1)^k \\ \sum_{\substack{n_1,\dots,n_k=1,\neq i \\ n_1<\dots<n_k}}^{K} B_1\left(\Omega_{1i},\Omega_{2i},\beta_{ik},0\right)\end{array}\right] \quad (22)$$

where the function B_1 is determined as

$$B_1\left(\Omega_{1i},\Omega_{2i},\beta_{ik},a\right) = \frac{1}{\pi^2}\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}} \frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\Omega_{1i}}\frac{\Omega_{2i}}{\frac{aP_2}{N_0\sin^2\theta_1}+\Omega_{2i}} \times\frac{\frac{P_1}{N_0\sin^2\theta_2}+\frac{aP_2}{N_0\sin^2\theta_1}+\Omega_{1i}+\Omega_{2i}}{\frac{P_1}{N_0\sin^2\theta}+\frac{aP_2}{N_0\sin^2\theta_1}+\beta_{ik}+\Omega_{1i}+\Omega_{2i}} \times\frac{\Omega_0 d\theta_1 d\theta_2}{\frac{P_1}{N_0\sin^2\theta}+\frac{aP_2}{N_0\sin^2\theta_1}+\beta_{ik}+\Omega_{1i}+\Omega_{2i}+\Omega_0} \quad (23)$$

4.2.2 Correctly decode at the chosen relay

If the relay decodes correctly, it will forward its re-encoded symbol in the second time slot. Thus, the instantaneous SNR of the received signal at the destination can be given as

$$\gamma_{\Phi^R}^{co} = \left(P_1\gamma_0+P_2\gamma_{RD}\right)/N_0 \quad (24)$$

where γ_{RD} presents for the instantaneous SNR of the channel between selected relay and the destination.

In the contracting with sub-section above, the probability of the correctly case is the probability of successful transmission from the source to the relay, so we have

$$P_{e,co}^{\Phi^R} = P_e\left(\gamma_{\Phi^R}^{co}|\Phi^R\right)\left[1-P_e\left(\gamma_{SR}|\Phi^R\right)\right]\Pr\left(\Phi^R\right) = \sum_{i=1}^{K}\int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{co}|\Phi^R,\gamma_{\Phi^R}^{co}\right)\Pr_i\left(\gamma_{eq_i}\right) \times\left[1-P_e\left(\gamma_{1i}|\Phi^R\right)\right]f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right)d\hat{\gamma}_i \quad (25)$$

By averaging (25) over $\hat{\gamma}_i$ we can get the result as (Appendix D.1-5)

$$P_{e,co}^{\Phi^R} = M_1 - M_2 \quad (26)$$

where M_1 and M_2 are determined as

$$M_1 = \sum_{i=1}^{K}\left[\begin{array}{l} B_2\left(\Omega_{1i},\Omega_{2i},0\right)+\sum_{k=1}^{K-1}(-1)^k \\ \sum_{\substack{n_1,\dots,n_k=1,\neq i \\ n_1<\dots<n_k}}^{K} B_2\left(\Omega_{1i},\Omega_{2i},\beta_{ik}\right)\end{array}\right] \quad (27)$$

and

$$M_2 = \sum_{i=1}^{K}\left[\begin{array}{l} B_1\left(\Omega_{1i},\Omega_{2i},0,1\right)+\sum_{k=1}^{K-1}(-1)^k \\ \sum_{\substack{n_1,\dots,n_k=1,\neq i \\ n_1<\dots<n_k}}^{K} B_1\left(\Omega_{1i},\Omega_{2i},\beta_{ik},1\right)\end{array}\right] \quad (28)$$

with the function B_2 is defined as

$$B_2\left(\Omega_{1i},\Omega_{2i},\beta_{ik}\right) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} \frac{\Omega_{2i}}{\frac{P_2}{N_0\sin^2\theta}+\Omega_{2i}}\frac{\frac{P_2}{N_0\sin^2\theta}+\Omega_{1i}+\Omega_{2i}}{\frac{P_2}{N_0\sin^2\theta}+\beta_{ik}+\Omega_{1i}+\Omega_{2i}} \times\frac{\Omega_0}{\frac{P}{N_0\sin^2\theta}+\beta_{ik}+\Omega_{1i}+\Omega_{2i}+\Omega_0}d\theta \quad (29)$$

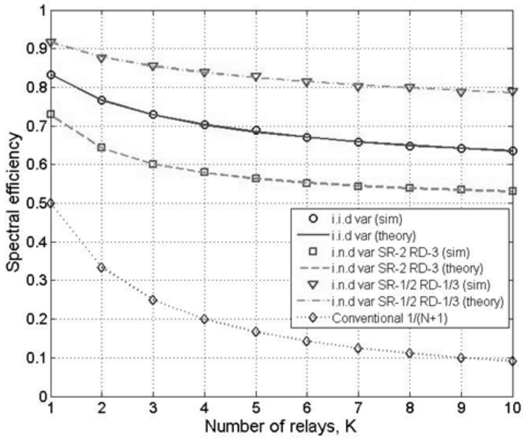

Fig 3. Spectrum efficiency versus the number of relays K
그림 3. 릴레이 개수 K 에 따른 스펙트럼 효율

Finally, the end-to-end BER of the scheme can be achieved by summation of (19), (22) and (26) as in (16)

$$P_e(\gamma) = P_e^{\Phi^D} + P_{e,inc}^{\Phi^R} + P_{e,co}^{\Phi^R} \tag{30}$$

Ⅴ. Numerical Results

In this section, we use the Monte-Carlo simulation to evaluate the performances of the different cooperation schemes in terms of their spectral efficiency and bit error probabilities. For a fair of comparison to direct transmission, equal power allocation is used, that is $P_1 = P_2 = P/2$.

5.1 Spectral efficiency

Fig. 3 depicts the spectral efficiency of the adaptive cooperation and the conventional cooperation schemes for the different numbers of relays. We plot both of simulation results and theoretical analysis in eqn. (15) over the independent and identically distributed (i.i.d) channel variances and also independent and not identically distributed (i.n.d) channel variances. For the i.i.d case, all the means of channel SNRs are set to 1, $\Omega_0 = \Omega_{1k} = \Omega_{2k} = 1$ with $k=1,\cdots;K$ and for the i.n.d cases, we change the means of SNRs of S-R channel Ω_{1k} to 2, 1/2 and that of R-D channel Ω_{2k} to 3, 1/3, respectively. Here, we consider that the spectral efficiencies of the DT and RC modes equal 1 symbol per channel use (SPCU) and $\frac{1}{2}$ SPCU, respectively. Due to Fig. 3, the spectral efficiency of the proposed scheme decreases down to $\frac{1}{2}$ as K rises. It can be explained that increasing the number of relays boosts the probability of exiting an optimal relay's link better than the direct link. So the probability of the DT mode lessens down to 0 and the average efficiency reaches to the spectral efficiency of RC mode as K goes to infinitive.

Moreover, we can see that the spectral efficiency curve for case $\Omega_{1k} = 2$ and $\Omega_{2k} = 3$ is below the i.i.d one. Here, these variance values present for the event that the relay links are better than the direct one, so the spectral efficiency is low owing to easily choosing a relay to cooperate with the source. On the contrary, with $\Omega_{1k} = 1/2$ and $\Omega_{2k} = 1/3$, it means that the direct link is better, so the results are higher than the others. Additionally, the spectral efficiency of the conventional cooperative schemes, $R_{conv} = 1/(K+1)$ SPCU, is plotted to show the significant increase in spectral efficiency of the proposed relay-selection cooperative scenario over the conventional cooperative scheme.

5.2 BER performance

Firstly, we compare the BER performance simulation and numerical results of the scheme with some difference numbers of relays to confirm the mathematical analysis results. Subsequently, we compare our scheme with some conventional DF schemes. Afterward, we concentrate on the scheme with one relay. We will evaluate the BER performance of the proposed scheme with the exact BER of DT, the simulate BER of AF scheme[7] and the adaptive scheme in [5]. We also consider the results with the i.i.d channel-variances case and the i.n.d cases.

Fig. 4 illustrates the BERs versus P/N_0 of the proposed scheme with some difference numbers of

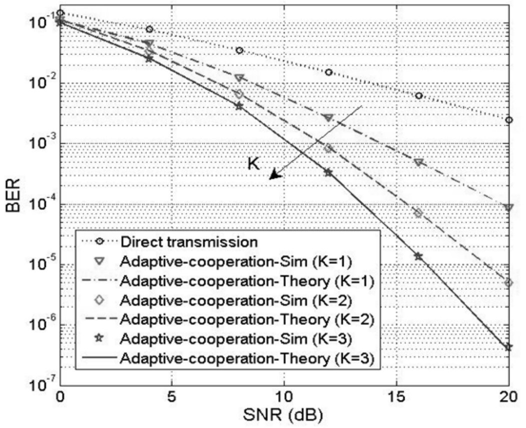

Fig 4. Bit-error-rate of the adaptive cooperative scheme relay-selection with K relays
그림 4. K 릴레이에서 적응형 협력통신의 릴레이 선택 비트 오류 확률

relays (K=1, 2, 3) in the i.i.d case $\Omega_0 = \Omega_{1k} = \Omega_{2k} = 1$. The figure shows that the simulation and numerical results exactly match together and the scheme performs better as the number of relays increases.

In the Fig. 5, the BER performances of DF relaying which the MRC[13] and SC diversity combining techniques are used at the destination and the proposed scheme are plotted with number of relays is 3 (K=3). According to this figure, we can see that, beside achieving higher spectral efficiency, as in Fig. 3, our proposed scheme's BER performance is superior than these conventional scenarios. In the comparison, ours outperforms about 3dB to the SC scheme and 0.5dB to the MRC scheme. Specially, at low SNR, the proposed scheme is more better (roughly 4dB, 1dB over the SC and MRC schemes, respectively).

In the Fig. 6, focusing on the scheme with one relay illustrates the BERs of various

cooperative schemes: DT, AF, Adaptive schemes in [5] (AC [5]) and our proposed scheme (NACR). Here, we consider the i.i.d case. In comparing with AF scheme and the scheme in [5], the simulation results shows that the proposed scheme can achieve full diversity and outperform those. Fig. 6 also demonstrates that our scheme provides a performance gain of about 0.5dB over the scheme in [5] and 1.3dB over the AF scheme in all range of SNRs.

Fig. 7 illustrates the BERs of the proposed scheme and the scheme in [5] over i.n.d channels with the relations among these variances perform as $\Omega_0 = M\Omega_{SR} = \Omega_{RD}/M = 1$. Here, we would like to consider the case, the channel from relay to destination is worse than the others. We can see that, according to the increasing of M, at the low SNR, our scheme can outperform the scheme in [5] more, i.e. over 1dB. Here, since we

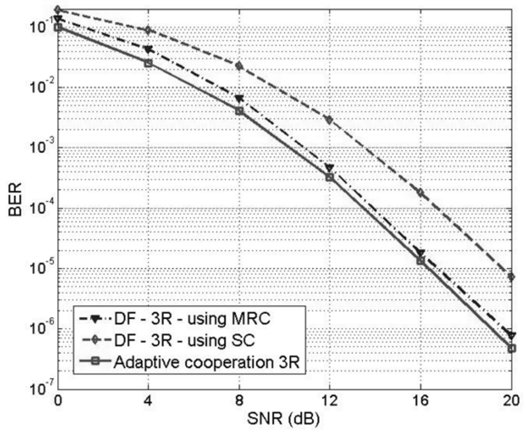

Fig 5. BER performances of Adaptive cooperation scheme and conventional DF schemes with K=3
그림 5. K=3에서 기존의 DF 기법과 적응형 협력 기법의 BER 성능 비교

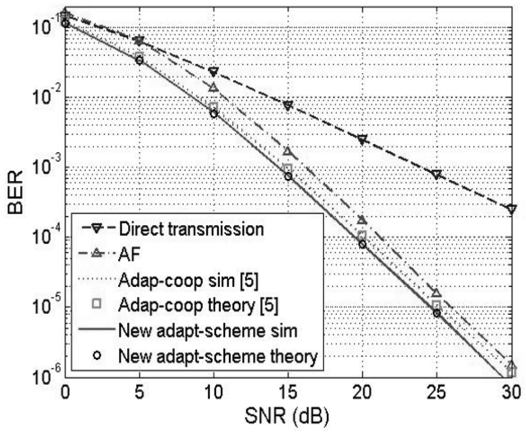

Fig 6. BER performances of Direct ransmission, AF and Adaptive schemes with one relay
그림 6. 하나의 릴레이에서 직접 통신과 AF기법, 그리고 적응형 기법의 BER 성능 비교

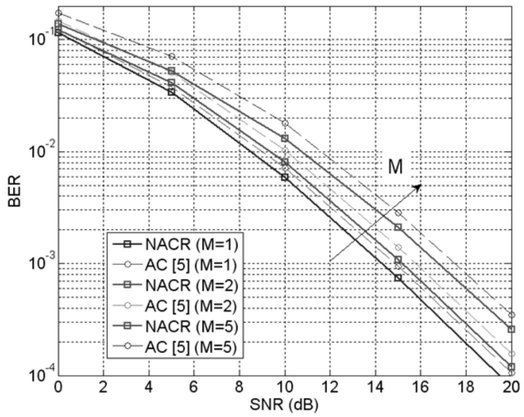

Fig 7. BER performances with i.n.d channel-variances $\Omega_0 = M\Omega_{SR} = \Omega_{RD}/M = 1$
그림 7. i.n.d 채널 환경에서 $\Omega_0 = M\Omega_{SR} = \Omega_{RD}/M = 1$ 분산값에서 BER 성능 분석

consider two paths of the relay link so although the source-relay channel is good, we choose the direct link if the relay-destination one is bad. It is contrary with the old scheme in [5], the system still chooses the relay link.

Ⅵ. Conclusion

We considered about the adaptive cooperation with relay-selection for the scheme multi-relay nodes in which the DF protocols can be applied whenever the direct link is of low quality. By apply the relay-selection technique; we reduce the number of transmissions to save the time slots and the bandwidth. Additionally, because of using the adaptive protocol to choose the best one between the direct transmission and Decoded and Forward cooperation, our scheme can outperform than some conventional works. Moreover, the simulation results show that with our proposed scheme we can get the better performance than another adaptive scheme [5] when consider both channels source-relay and relay-destination with the direct channel and the re-transmission when the relay link is fail. For the future work, we can improve this job with investigate the power allocation of the rate cooperation as in [11].

Appendix A

Calculate the integral in (9).
Let

$$
\begin{aligned}
I_1 &= \int_{\gamma_0}^{\infty}\int_{\gamma_{1i}}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{1i}}\right)f_{\gamma_{2i}}(\gamma_{2i})f_{\gamma_{1i}}(\gamma_{1i})d\gamma_{2i}d\gamma_{1i} \\
&= \int_{\gamma_0}^{\infty}\int_{\gamma_{1i}}^{\infty}\left[1+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\dots,n_k=1,\neq i\\ n_1<\dots<n_k}}^{K}e^{-\alpha_k\gamma_{1i}}\right] \\
&\qquad\times\Omega_{2i}e_{2i}^{-\Omega_{2i}\gamma_{2i}}\Omega_{1i}e^{-\Omega_{1i}\gamma_{1i}}d\gamma_{2i}d\gamma_{1i} \\
&= \int_{\gamma_0}^{\infty}\left[1+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\dots,n_k=1,\neq i\\ n_1<\dots<n_k}}^{K}e^{-\beta_{ik}\gamma_{1i}}\right] \qquad \text{(A.1)} \\
&\qquad\times\Omega_{1i}e^{-(\Omega_{1i}+\Omega_{1i})\gamma_{1i}}d\gamma_{1i} \\
&= \frac{\Omega_{1i}e^{-\alpha_i\gamma_0}}{\alpha_i}+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\dots,n_k=1,\neq i\\ n_1<\dots<n_k}}^{K}\frac{\Omega_{1i}e^{-(\alpha_i+\beta_{ik})\gamma_0}}{\alpha_i+\beta_{ik}}
\end{aligned}
$$

Similarly (A.1), we also get

$$
\begin{aligned}
I_2 &= \int_{\gamma_0}^{\infty}\int_{\gamma_{2i}}^{\infty}\prod_{k=1,\neq i}^{K}\left(1-e^{-\alpha_k\gamma_{1i}}\right)f_{\gamma_{1i}}(\gamma_{1i})f_{\gamma_{2i}}(\gamma_{2i})d\gamma_{1i}d\gamma_{2i} \\
&= \frac{\Omega_{2i}e^{-\alpha_i\gamma_0}}{\alpha_i}+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\dots,n_k=1,\neq i\\ n_1<\dots<n_k}}^{K}\frac{\Omega_{2i}e^{-(\alpha_i+\beta_{ik})\gamma_0}}{\alpha_i+\beta_{ik}} \qquad \text{(A.2)}
\end{aligned}
$$

Then, combine I_1 and I_2 we have the result as (10) with the notation that $\Omega_{1i}+\Omega_{2i}=\alpha_i$.

Appendix B

Calculate $P_e^{\Phi^D}$.

$$
\begin{aligned}
P_e^{\Phi^D} &= \int_0^{\infty}P_e\left(\gamma_{\Phi^D}|\Phi^D,\gamma_0\right)\Pr\left(\Phi^D,\gamma_0\right)f_{\gamma_0}(\gamma_0)d\gamma_0 \\
&= \int_0^{\infty}\frac{1}{\pi}\int_0^{\frac{\pi}{2}}e^{-\frac{P\gamma_0}{N_0\sin^2\theta}}\left[1+\sum_{i=1}^{K}(-1)^i\sum_{\substack{n_1,\dots,n_i=1\\ n_1<\dots<n_i}}^{K}e^{-\beta_i\gamma_0}\right] \\
&\qquad\times\Omega_0e^{-\Omega_0\gamma_0}d\gamma_0 \\
&= \frac{1}{\pi}\int_0^{\frac{\pi}{2}}\left[\begin{array}{c}\dfrac{\Omega_0}{\Omega_0+\dfrac{P}{N_0\sin^2\theta}}+ \\ \displaystyle\sum_{i=1}^{K}(-1)^i\sum_{\substack{n_1,\dots,n_i=1\\ n_1<\dots<n_i}}^{K}\dfrac{\Omega_0}{\Omega_0+\beta_i+\dfrac{P}{N_0\sin^2\theta}}\end{array}\right]d\theta \qquad \text{(B.1)} \\
&= B_0\left(1,\frac{P}{\Omega_0N_0}\right)+\sum_{i=1}^{K}(-1)^i\sum_{\substack{n_1,\dots,n_i=1\\ n_1<\dots<n_i}}^{K}B_0\left(1+\frac{\beta_i}{\Omega_0},\frac{P}{\Omega_0N_0}\right)
\end{aligned}
$$

Appendix C

Calculate $P_{e,inc}^{\Phi^R}$

$$\begin{aligned}
P_{e,\in c}^{\Phi^R} &= P_e\left(\gamma_{\Phi^R}^{\in c}|\Phi^R\right)P_e\left(\gamma_{SR}|\Phi^R\right)\Pr\left(\Phi^R\right) \\
&= \sum_{i=1}^{K}\int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{\in c}|\Phi^R,\gamma_{\Phi^R}^{\in c}\right)\Pr{}_i\left(\gamma_{eq_i}\right)P_e\left(\gamma_{1i}|\Phi^R\right)f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right)d\hat{\gamma}_i \\
&= \sum_{i=1}^{K}\int_0^\infty\int_{\gamma_0}^\infty\frac{1}{\pi}\int_{\gamma_0}^\infty e^{-\frac{P\gamma_0}{N_0\sin^2\theta_1}}d\theta_1\frac{1}{\pi}\int_0^{\frac{\pi}{2}}e^{-\frac{P_1\gamma_{1i}}{N_0\sin^2\theta_2}}d\theta_2 \\
&\times\left[1+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_i}}^{K}e^{-\beta_{ik}\gamma_{eq_i}}\right]\Omega_{1i}e^{-\Omega_{1i}\gamma_{1i}}\Omega_{2i}e^{-\Omega_{2i}\gamma_{2i}} \\
&\times\Omega_0e^{-\Omega_0\gamma_0}d\gamma_{1i}d\gamma_{2i}d\gamma_0
\end{aligned}\tag{C.1}$$

Now we calculate the integrals inside the sum by consider an element which presents for all. We also divide this integral into two cases as (9).

$$P_{e,inc}^{\Phi^R}=\sum_{i=1}^{K}P_{e,inc}^{\Phi^R,i}=\sum_{i=1}^{K}\left(J_{1i}+J_{2i}\right)\tag{C.2}$$

1. For $\left\{\gamma_{1i}<\gamma_{2i},\gamma_{eq_i}=\gamma_{1i}\right\}$ we have

$$\begin{aligned}
J_{1i} &= \int_0^\infty\int_{\gamma_0}^\infty\int_{\gamma_{1i}}^\infty\frac{e^{-\frac{P\gamma_0}{N_0\sin^2\theta_1}}}{\pi}d\theta_1\int_0^{\frac{\pi}{2}}\frac{e^{-\frac{P_1\gamma_{1i}}{N_0\sin^2\theta_2}}}{\pi}d\theta_2 \\
&\times\left[1+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_i}}^{K}e^{-\beta_{ik}\gamma_{1i}}\right]\Omega_{1i}e^{-\Omega_{1i}\gamma_{1i}} \\
&\times\Omega_{2i}e^{-\Omega_{2i}\gamma_{2i}}\Omega_0e^{-\Omega_0\gamma_0}d\gamma_{2i}d\gamma_{1i}d\gamma_0 \\
&= \frac{1}{\pi^2}\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}}\left[\frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\alpha_i}\right. \\
&\times\frac{\Omega_0}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i} \\
&+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_k}}^{K}\frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\beta_{ik}+\alpha_i} \\
&\left.\times\frac{\Omega_0}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i+\beta_{ik}}\right]d\theta_1d\theta_2
\end{aligned}\tag{C.3}$$

2. For $\left\{\gamma_{1i}>\gamma_{2i},\gamma_{eq_i}=\gamma_{2i}\right\}$ we analyze similarly with (C.3) we have

$$\begin{aligned}
J_{1i} &= \int_0^\infty\int_{\gamma_0}^\infty\int_{\gamma_{2i}}^\infty\frac{e^{-\frac{P\gamma_0}{N_0\sin^2\theta_1}}}{\pi}d\theta_1\int_0^{\frac{\pi}{2}}\frac{e^{-\frac{P_1\gamma_{1i}}{N_0\sin^2\theta_2}}}{\pi}d\theta_2 \\
&\times\left[1+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_i}}^{K}e^{-\beta_{ik}\gamma_{2i}}\right]\Omega_{1i}e^{-\Omega_{1i}\gamma_{1i}} \\
&\times\Omega_{2i}e^{-\Omega_{2i}\gamma_{2i}}\Omega_0e^{-\Omega_0\gamma_0}d\gamma_{1i}d\gamma_{2i}d\gamma_0 \\
&= \frac{1}{\pi^2}\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}}\left[\frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\Omega_{1i}}\frac{\Omega_{2i}}{\frac{P_1}{N_0\sin^2\theta_2}+\alpha_i}\right. \\
&\times\frac{\Omega_0d\theta_1d\theta_2}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i} \\
&+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_k}}^{K}\frac{\Omega_{2i}}{\frac{P_1}{N_0\sin^2\theta_2}+\beta_{ik}+\alpha_i}\times \\
&\left.\frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\Omega_{1i}}\frac{\Omega_0d\theta_1d\theta_2}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i+\beta_{ik}}\right]
\end{aligned}\tag{C.4}$$

Combining the results from (C.3), (C.4) and note that $\Omega_{1i}+\Omega_{2i}=\alpha_i$, we have

$$\begin{aligned}
P_{e,\in c}^{\Phi^R,i} &= \frac{1}{\pi^2}\int_0^{\frac{\pi}{2}}\int_0^{\frac{\pi}{2}}\frac{\Omega_{1i}}{\frac{P_1}{N_0\sin^2\theta_2}+\Omega_{1i}} \\
&\times\left[\frac{\Omega_0}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i}\right. \\
&+\sum_{k=1}^{K-1}(-1)^k\sum_{\substack{n_1,\ldots,n_k=1,\neq i\\ n_1<\ldots<n_k}}^{K}\frac{\frac{P_1}{N_0\sin^2\theta_2}+\alpha_i}{\frac{P_1}{N_0\sin^2\theta_2}+\beta_{ik}+\alpha_i} \\
&\left.\times\frac{\Omega_0}{\frac{P_1}{N_0\sin^2\theta_2}+\frac{P}{N_0\sin^2\theta_1}+\Omega_0+\alpha_i+\beta_{ik}}\right]d\theta_1d\theta_2
\end{aligned}\tag{C.5}$$

Appendix D

Calculate $P_{e,co}^{\Phi^R}$

$$P_{e,co}^{\Phi^R} = \sum_{i=1}^{K} \int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{co} | \Phi^R, \gamma_{\Phi^R}^{co}\right) \Pr_i\left(\gamma_{eq_i}\right) \times \left[1 - P_e\left(\gamma_{1i} | \Phi^R\right)\right] f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right) d\hat{\gamma}_i = M_1 - M_2 = \sum_{i=1}^{K} \left(M_{1i} - M_{2i}\right) \quad \text{(D.1)}$$

with

$$M_{1i} = \int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{co} | \Phi^R, \gamma_{\Phi^R}^{co}\right) \Pr_i\left(\gamma_{eq_i}\right) f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right) d\hat{\gamma}_i = \int_0^\infty \int_{\gamma_0}^\infty \int_{\gamma_0}^\infty \frac{1}{\pi} e^{-\frac{P_1\gamma_0 + P_2\gamma_{2i}}{N_0 \sin^2\theta}} d\theta \times \left[1 + \sum_{k=1}^{K-1} (-1)^k \sum_{\substack{n_1,\ldots,n_k = 1, \neq i \\ n_1 < \ldots < n_k}}^{K} e^{-\beta_{ik}\gamma_{eq_i}}\right] \times \Omega_{1i} e^{-\Omega_1\gamma_{1i}} \Omega_{2i} e^{-\Omega_2\gamma_{2i}} \Omega_0 e^{-\Omega_0\gamma_0} d\gamma_{1i} d\gamma_{2i} d\gamma_0 \quad \text{(D.2)}$$

and

$$M_{2i} = \int_{\hat{\gamma}_i} P_e\left(\gamma_{\Phi^R}^{co} | \Phi^R, \gamma_{\Phi^R}^{co}\right) \Pr_i\left(\gamma_{eq_i}\right) P_e\left(\gamma_{1i} | \Phi^R, \gamma_{1i}\right) f_{\hat{\gamma}_i}\left(\hat{\gamma}_i\right) d\hat{\gamma}_i = \int_0^\infty \int_{\gamma_0}^\infty \int_{\gamma_0}^\infty e^{-\frac{P_1\gamma_0 + P_2\gamma_{2i}}{N_0 \sin^2\theta}} d\theta \frac{1}{\pi} \int_0^{\frac{\pi}{2}} e^{-\frac{P_1\gamma_{1i}}{N_0 \sin^2\theta_2}} d\theta_2 \times \left[1 + \sum_{k=1}^{K-1} (-1)^k \sum_{\substack{n_1,\ldots,n_k = 1, \neq i \\ n_1 < \ldots < n_k}}^{K} e^{-\beta_{ik}\gamma_{eq_i}}\right] \times \Omega_{1i} e^{-\Omega_1\gamma_{1i}} \Omega_{2i} e^{-\Omega_2\gamma_{2i}} \Omega_0 e^{-\Omega_0\gamma_0} d\gamma_{1i} d\gamma_{2i} d\gamma_0 \quad \text{(D.3)}$$

Dividing two equation above into two cases as (9) and calculating each sub-integral step-by-step, we can get the result as

$$M_{1i} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \frac{\Omega_{2i}}{\frac{P_2}{N_0 \sin^2\theta} + \Omega_{2i}} \left[\frac{\Omega_0}{\frac{P}{N_0 \sin^2\theta} + \Omega_0 + \alpha_i} + \sum_{k=1}^{K-1} (-1)^k \sum_{\substack{n_1,\ldots,n_k = 1, \neq i \\ n_1 < \ldots < n_k}}^{K} \frac{\frac{P_2}{N_0 \sin^2\theta} + \alpha_i}{\frac{P_2}{N_0 \sin^2\theta} + \beta_{ik} + \alpha_i} \times \frac{\Omega_0}{\frac{P}{N_0 \sin^2\theta} + \Omega_0 + \alpha_i + \beta_{ik}}\right] d\theta \quad \text{(D.4)}$$

and

$$M_{2i} = \frac{1}{\pi^2} \int_0^{\frac{\pi}{2}} \int_0^{\frac{\pi}{2}} \frac{\Omega_{1i}}{\frac{P_1}{N_0 \sin^2\theta_2} + \Omega_{1i}} \frac{\Omega_{2i}}{\frac{P_2}{N_0 \sin^2\theta_1} + \Omega_{2i}} \times \left[\frac{\Omega_0}{\frac{P_1}{N_0 \sin^2\theta_2} + \frac{P}{N_0 \sin^2\theta_1} + \Omega_0 + \alpha_i} + \sum_{k=1}^{K-1} (-1)^k \sum_{\substack{n_1,\ldots,n_k = 1, \neq i \\ n_1 < \ldots < n_k}}^{K} \frac{\frac{P_1}{N_0 \sin^2\theta_2} + \frac{P_2}{N_0 \sin^2\theta_1} + \alpha_i}{\frac{P_1}{N_0 \sin^2\theta_2} + \frac{P_2}{N_0 \sin^2\theta_1} + \beta_{ik} + \alpha_i} \times \frac{\Omega_0}{\frac{P_1}{N_0 \sin^2\theta_2} + \frac{P}{N_0 \sin^2\theta_1} + \Omega_0 + \alpha_i + \beta_{ik}}\right] d\theta_1 d\theta_2 \quad \text{(D.5)}$$

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