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적응형 복호 후 전달 협력 통신의 성능 분석

(Performance Analysis of Adaptive Cooperation Scheme with Decode-and-Forward)

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요 약

적응형 협력 시스템은 송신단과 수신단, 릴레이와 수신단사이의 순시 신호 대 잡음비의 차이를 기반으로 동작한다. 특별히, 만약 송신단과 수신단사이의 채널 환경이 릴레이와 수신단사이의 채널 환경보다 좋다면 송신단은 송신단의 가용한 전력으로 수신단까지 신호를 전송한다. 그렇지않다면, 송신단은 첫번째 시간 슬롯에서는 보다 적은 전력으로 신호를 브로드캐스팅하며 두번째 시간 슬롯에서는 릴레이가 수신된 신호를 올바르게 복호할 경우에는 해당 신호를 다시 인코딩하여 목적지로 전송하며 올바르게 복호가 되지 않는다면 송신단은 나머지 전력으로 수신단까지 신호를 전송한다.본 논문에서는 첫째로, 직접 전송과 협력 전송의 확률적 계산을 통하여 주파수 효율성을 수식적으로 이끌어내며 각 전송방식의 비트오류확률(BER) 수식을 고려하여 적응형 협력 기법의 비트오류확률(BER)을 계산한다. 마지막으로 Monte-Carlo 시뮬레이션을 통하여 제안하는 기법의 성능을 확인한다.

Abstract

An adaptive cooperation system is considered with the cooperation decision strategy based on the differences between instantaneous signal-to-noise ratio (SNR) S-D and R-D channels. Specifically, if the quality of the direct link (S-D) is better than that of the link from the relay to the destination (R-D), the source will transmit to destination directly with all scheme's transmitted power. Otherwise, the source broadcasts the signal with a lower power in the first time slot. Then, in the second time slot, if the relay decodes its received signal correctly, it re-transmits the re-encoded signal to the destination else the source will transmit again with the remaining power. Firstly, the spectral efficiency is derived by calculating the probabilities of direct transmission and cooperation mode. Subsequently, the BER performance for the adaptive cooperation schemes is analyzed by considering the BER routine of each mode. Finally, the Monte-Carlo simulation results are presented to confirm the performance enhancement offered by the proposed schemes.

Keywords : Bit Error Rate, Decode and Forward, Spectral efficiency

Ⅰ. Introduction

Diversity techniques have been developed in order to combat fading on wireless channels and to improve the reliability of the received message. Recently, cooperation has been proposed as a new mean to obtain "spatial" or "cooperative" diversity[1~2]. Some 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 two main families: decode-and-forward (DF), amplify-and-forward (AF).

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In this paper, we are interested in the first family which is studied most due to their simplicity. It just requires a symbol-by-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 (R) if the direct channel, between the source (S) and the destination (D), is of high quality and the relay link is not need. In addition, employing the direct transmission in some cases directly improves the spectral efficiency of the cooperative scheme[5]. 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. Nevertheless, in DF schemes, the quality of the received signal at the destination is based on the channels S-D and R-D (if relay just forwards the correct data). Thus, the relative quality differences between the two channels: S-D and R-D should be considered in selection of cooperation strategies.

Therefore, we propose a new strategy named adaptive cooperation in which the DF protocol can be applied or not based on the qualities of S-D and R-D channels. By using the instantaneous SNR as the performance measure, the source checks whether the S-D link or the R-D link is better in oder to decide the transmission protocol of the scheme. If the direct link is superior, the direct transmission mode will be employed in which the source communicate with destination directly with all power consumption. Otherwise, the cooperation mode is occurred where the source broadcasts the signal with a lower power and the relay re-transmits the re-encoded signal to the destination if it decodes correctly. 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 find 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 get the average efficiency of the scheme. Subsequently, to obtain the BER performance, initially, we calculate the BER routine of each mode by get the integrals with some specific conditionals. Then the end-to-end performance is achieved by getting the summation of all results. To conclude, we will use the Monte-Carlo simulations to confirm the mathematical results.

The rest of this paper is organized as follows. Section II presents the system model of the adaptive cooperative relay scheme with decoded and forward. The BER performance will be investigated in Section III. Next, section IV illustrates Monte-Carlo simulation results. Finally, the paper is concluded in Section V.

II. Proposed scheme

Consider selection relaying in a wireless network where the information is transmitted from a source (S) to a destination (D) with the help of a relay (R) as shown in Figure 1. We assume all nodes are equipped with single-antenna transceivers and operate in a half-duplex mode using the same frequency slot over frequency-flat block Rayleigh fading channels denoted by their instantaneous channel coefficients, a_{SD}, a_{RD}, and a_{SR}. Let $\gamma_{ij} = |a_{ij}|^2$ (i=S,R and j=R,D) represents the S-R, S-D and R-D SNRs. As a result, γ_{SD}, γ_{RD} and γ_{SR} are modeled as exponential random variables with means δ^2_{SD}, δ^2_{RD} and δ^2_{SR}, respectively.

The rationale behind this scheme is that relaying

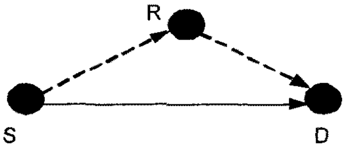

그림 1. 한 개의 릴레이를 가지는 적응형 협력 기법
Fig. 1. Adaptive cooperative scheme with one relay.

is not necessary if the S-D link is better than the R-D link. Due to the qualities of the channels, the source directly transmits to the destination when $\Phi^D = \{\gamma_{SD} \geq \gamma_{RD}\}$ happens and cooperates with the relay when $\Phi^R = \{\gamma_{SD} < \gamma_{RD}\}$ happens. Note that, the source does not require the destination to feedback the value of the R-D channel gain γ_{RD} at the beginning of each time slot. Instead, the destination only sends one bit that indicates whether the event $\{\gamma_{SD} \geq \gamma_{RD}\}$ 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. If $\gamma_{SD} \geq \gamma_{RD}$ happens, named direct transmission (DT) mode, the source will transmit data to destination with the total transmitted power of scheme. The received symbol at the destination can be modeled as

$$y_D^{\Phi^D} = \sqrt{P}\, a_{SD} s + n_{SD} \tag{1}$$

where P is the total transmitted power, s is the transmitted symbol of the source.

If $\gamma_{SD} < \gamma_{RD}$, 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. In the first time slot, the source broadcasts its symbol to both the destination and the relay. The received symbols at the destination and the relay can be modeled as

$$y_{D,1}^{\Phi^R} = \sqrt{P_1}\, a_{SD} s + n_{D,1};\ y_R^{\Phi^R} = \sqrt{P_1}\, a_{SR} s + n_{SR} \tag{2}$$

where P_1 is the source's transmitted power in the first time slot.

In the second time slot, if the relay decodes its received symbol correctly, it will retransmit the decoded symbol to the destination. Otherwise, it will inform the source to transmit to the destination once more. In this paper, we assume that the relay can decide whether the symbol is decoded correctly or not. That can be achieved by using Cyclic Redundancy Check code, or comparing the SNR with a given threshold. Hence, the received symbol at the destination in this time slot is given as

$$y_{D,2}^{\Phi^R} = \sqrt{P_2}\, \widetilde{a_D} s + n_{D,2} \tag{3}$$

where $\widetilde{a_D} = a_{RD}$ for case the relay decodes the symbol correctly and forwards this symbol, otherwise, $\widetilde{a_D} = a_{SD}$, the source transmits again; P_2 is the transmitted power of the relay or source in the time slot two with $P_1 + P_2 = P$. We assume that the channels are unchanged in two time slots. Let n_{SD}, n_{SR}, $n_{D,1}$ and $n_{D,2}$ are the additive noises and modeled as zero-mean, complex Gaussian random variables with variance N_0. Then, the destination combines two received signals within two time slots by using Maximum Ratio Combining technique to get the information.

Ⅲ. Performance Analysis

In this section, we obtain the probability of the DT and RC modes, then calculate the spectral efficiency. Afterward, we will analyze the Bit Error Rate (BER) of the scheme by investigating each mode separately.

1. Spectral efficiency analysis:

Due to Rayleigh fading, the pdf of γ_{ij} (i=S,R and j=R,D) performs as

$$f_{\gamma_{ij}}(\gamma_{ij}) = (1/\delta_{ij}^2)\exp(-\gamma_{ij}/\delta_{ij}^2) \tag{4}$$

With a certain value of γ_{SD}, the probability of the RC mode and the DT mode can be given by

$$\begin{aligned} \Pr(\Phi^R, \gamma_{SD}) &= \Pr(\gamma_{SD} < \gamma_{RD}) \\ &= \int_{\gamma_{SD}}^{\infty} f_{\gamma_{RD}}(\gamma_{RD})\, d\gamma_{RD} = e^{-\gamma_{SD}/\delta_{RD}^2} \end{aligned} \tag{5}$$

$$\Pr(\Phi^D, \gamma_{SD}) = 1 - \Pr(\Phi^R, \gamma_{SD}) \tag{6}$$

By averaging (5) and (6) over γ_{SD} we achieve the probability of two modes as follow

$$\Pr(\Phi^R) = \int_0^\infty \Pr(\Phi^R, \gamma_{SD}) f_{\gamma_{SD}}(\gamma_{SD}) d\gamma_{SD} = \int_0^\infty e^{-\frac{\gamma_{SD}}{\delta_{RD}^2}} \frac{1}{\delta_{SD}^2} e^{-\frac{\gamma_{SD}}{\delta_{SD}^2}} d\gamma_{SD} = \frac{\delta_{RD}^2}{\delta_{SD}^2 + \delta_{RD}^2} \tag{7}$$

$$\Pr(\Phi^D) = 1 - \Pr(\Phi^R) = \delta_{SD}^2 / (\delta_{RD}^2 + \delta_{SD}^2) \tag{8}$$

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

$$\tilde{r} = \Pr(\Phi^D) r + \Pr(\Phi^R) r/2 = \frac{2\delta_{SD}^2 + \delta_{RD}^2}{2(\delta_{SD}^2 + \delta_{RD}^2)} r \tag{9}$$

2. BER performance analysis

The end-to-end BER of this scheme is given as

$$BER(\gamma) = BER(\gamma_{\Phi^D} | \Phi^D) \Pr(\Phi^D) + BER(\gamma_{\Phi^R} | \Phi^R) \Pr(\Phi^R) = BER_{\Phi^D} + BER_{\Phi^R} \tag{10}$$

where $BER_{\Phi^D} = BER(\gamma_{\Phi^D} | \Phi^D) \Pr(\Phi^D)$ and $BER_{\Phi^R} = BER(\gamma_{\Phi^R} | \Phi^R) \Pr(\Phi^R)$ denote the BERs of the DT and RC modes, respectively. Thus, to calculate the end-to-end BER, we consider the BER of each mode separately.

가. Direct transmission mode

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

$$\gamma_{\Phi^D} = P\gamma_{SD} / N_0 \tag{11}$$

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

$$BER(\gamma_{\Phi^D} | \Phi^D) = \frac{1}{\pi} \int_0^{\pi/2} e^{-P\gamma_{SD}/N_0 \sin^2\theta} d\theta \tag{12}$$

By averaging (12) over γ_{SD} we can get the BER of the DT mode as (Appendix A.1, A.2)

$$BER_{\Phi^D} = \int_0^\infty BER(\gamma_{\Phi^D} | \Phi^D) \Pr(\Phi^D) f_{\gamma_{SD}} d\gamma_{SD} = B_1\left(1, \frac{P\delta_{SD}^2}{N_0}\right) - B_1\left(1 + \frac{\delta_{SD}^2}{\delta_{RD}^2}, \frac{P\delta_{SD}^2}{N_0}\right) \tag{13}$$

나. Relay-cooperation mode:

For the RC, we consider two cases depending the decoding status of the relay. If the relay cannot decode the received signal successfully, the source transmits twice in two time slots. From (3), the instantaneous SNR of the received signal at the destination can be written as

$$\gamma_{\Phi^R}^{inc} = (P_1\gamma_{SD} + P_2\gamma_{SD}) / N_0 = P\gamma_{SD} / N_0 \tag{14}$$

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

$$BER_{\Phi^R}^{inc} = \int_0^\infty BER(\gamma_{SR}) f_{\gamma_{SR}}(\gamma_{SR}) d\gamma_{SR} \times \int_0^\infty \int_{\gamma_{SD}}^\infty BER(\gamma_{\Phi^R}^{\in c} | \Phi^R) f_{\gamma_{RD}}(\gamma_{RD}) f_{\gamma_{SD}}(\gamma_{SD}) d\gamma_{RD} d\gamma_{SD} \tag{15}$$

By averaging (15) over γ_{SR}, γ_{RD} and γ_{SD} step by step, we can get the result as (Appendix A.3)

$$BER_{\Phi^R}^{inc} = B_1\left(1, \frac{P_1\delta_{SR}^2}{N_0}\right) B_1\left(1 + \frac{\delta_{SD}^2}{\delta_{RD}^2}, \frac{P\delta_{SD}^2}{N_0}\right) \tag{16}$$

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

$$\gamma_{\Phi^R}^{co} = (P_1\gamma_{SD} + P_2\gamma_{RD}) / N_0 \tag{17}$$

The probability of this case is the probability of successful transmission from S to R, so we have

$$BER_{\Phi^R}^{co} = \left[1 - \int_0^\infty BER(\gamma_{SR}) f_{\gamma_{SR}}(\gamma_{SR}) d\gamma_{SR}\right] \times \int_0^\infty \int_{\gamma_{SD}}^\infty BER(\gamma_{\Phi^R}^{co} | \Phi^R) f_{\gamma_{RD}}(\gamma_{RD}) f_{\gamma_{SD}}(\gamma_{SD}) d\gamma_{RD} d\gamma_{SD} \tag{18}$$

Based on appendix A.4, A.5 and A.6, we get

$$BER^{co}_{\Phi^R} = \left[1 - B_1\left(1, \frac{P_1\delta^2_{SR}}{N_0}\right)\right] \frac{1}{P_2\delta^2_{RD} - P_1\delta^2_{SD}} \qquad (19)$$

$$\times \left[P_2\delta^2_{RD}B_1\left(1, \frac{P_2\delta^2_{RD}}{N_0}\right) - P\delta^2_{SD}B_1\left(1 + \frac{\delta^2_{SD}}{\delta^2_{SR}}, \frac{P\delta^2_{SD}}{N_0}\right)\right]$$

Finally, the end-to-end BER of the scheme can be achieved by summation of (13), (16) and (19) as

$$BER(\gamma) = BER_{\Phi^D} + BER^{inc}_{\Phi^R} + BER^{co}_{\Phi^R} \qquad (20)$$

Ⅳ. Simulation results and discussions

In this section, we use the Monte-Carlo simulation to evaluate the performances of some different cooperation schemes in terms of their BER and spectral efficiency. We will compare the BER performance of our proposed scheme with that of DT, the Amplify and Forward (AF) scheme[4] and the scheme in [5]. For a fair of comparison to DT, equal power allocation is used, that is $P_1 = P_2 = P/2$.

Fig. 2 illustrates the bit error rates versus (P/N_0) of various cooperative schemes: DT, AF scheme[4], adaptive schemes in [5] and our proposed scheme. Here, we consider the channel-variances as $\delta^2_{SD} = \delta^2_{SR} = \delta^2_{RD} = 1$. In comparing with AF scheme in [4] and the scheme in [5], the simulation result shows that the proposed adaptive scheme can achieve full diversity and outperform to them. Fig. 2 also demonstrates that our scheme provides a performance gain of about 1dB over the scheme in [5] and 2dB over the AF scheme for any value of P/N_0.

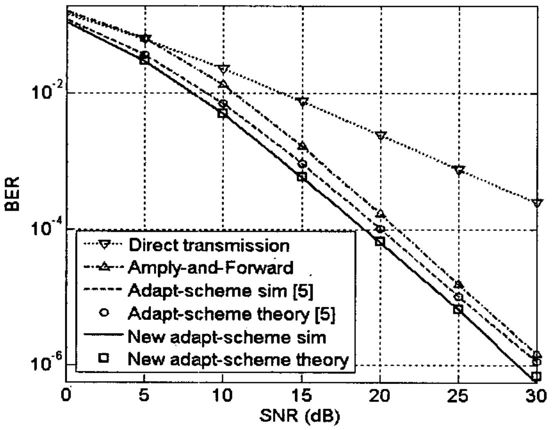

그림 2. 하나의 릴레이를 가진 DT, AF, 적응형 기법의 BER 성능 분석

Fig. 2. BER performances of DT, AF and Adaptive schemes with one relay.

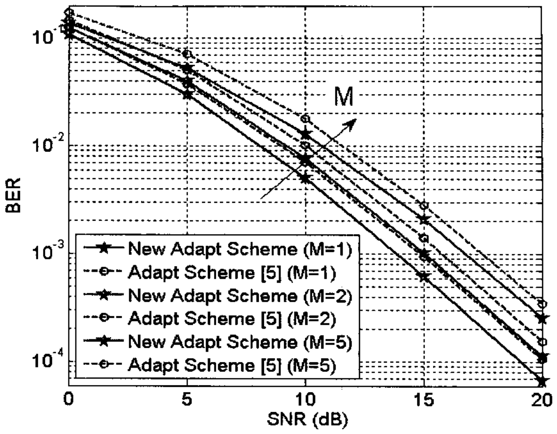

그림 3. $\delta^2_{SD} = \delta^2_{SR}/M = M\delta^2_{RD} = 1$ 일때의 BER 성능 분석

Fig. 3. BER performances with channel-variances $\delta^2_{SD} = \delta^2_{SR}/M = M\delta^2_{RD} = 1$.

Fig. 3 illustrates the BER of the proposed scheme and the scheme in [5] with the relations among the variances perform as $\delta^2_{SD} = \delta^2_{SR}/M = M\delta^2_{RD} = 1$. Here, we would like to consider the case that 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 1.5dB.

Fig. 4 depicts the spectral efficiency of the adaptive cooperation and the conventional cooperation schemes for the different value of $\delta^2_{RD}/\delta^2_{SD}$. We plot both of simulation results and theoretical analysis given by eqn. (9) with the S-D channel variance is 1 $(\delta^2_{SD} = 1)$ and the R-D channel variance (δ^2_{RD}) runs from 1/32 to 32. We consider that the spectral efficiencies of the DT and RC modes equal one symbol per channel use (SPCU) and ½ SPCU. Due to Fig. 4, the spectral efficiency of the proposed scheme decreases down to ½ as δ^2_{RD} rises. It can be explained

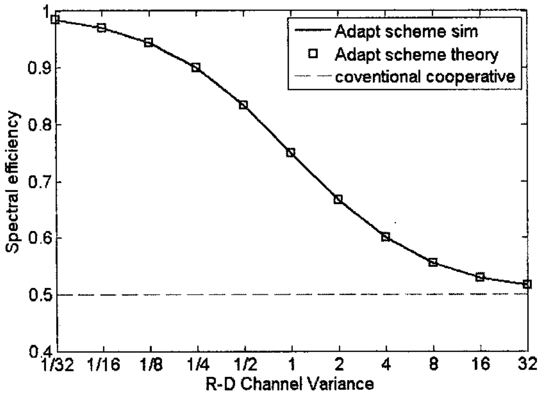

그림 4. $\delta^2_{RD}/\delta^2_{SD}$에 대한 주파수 효율 분석
Fig. 4. Spectral efficiency versus the value of $\delta^2_{RD}/\delta^2_{SD}$.

that increasing the value of δ^2_{RD} boosts the probability that R-D link is better than the S-D link. Additionally, the spectral efficiency of the conventional cooperative schemes, $R_{conv} = 1/2\,\mathrm{SPCU}$, is plotted to show the significant increase in spectral efficiency of the proposed adaptive cooperative scenario over the conventional cooperative scheme. The figures also show that the simulations and the mathematical results are exactly match together.

V. Conclusion

We above considered about the adaptive scheme in which the DF protocols can be applied whenever the direct link is of low quality. The simulation results show that with our proposed scheme we can get the better performance than some literature ones. Moreover, with the adaptive cooperation scheme we can improve the spectral efficiency in order to save the resource of the wireless network. For the future work, we will develop this work by investigating the scheme with multi-relay nodes.

Appendix

1. Calculate BER_{Φ^D}

$$BER_{\Phi^D} = \int_0^\infty BER\left(\gamma_{\Phi^D}|\Phi^D\right)\Pr\left(\Phi^D\right) f_{\gamma_{SD}} d\gamma_{SD}$$

$$= \int_0^\infty \frac{1}{\pi}\int_0^{\pi/2} e^{-\frac{P\gamma_{SD}}{N_0\sin^2\theta}} d\theta \left(1 - e^{-\frac{\gamma_{SD}}{\delta^2_{RD}}}\right)\frac{1}{\delta^2_{SD}} e^{-\frac{\gamma_{SD}}{\delta^2_{SD}}} d\gamma_{SD}$$

$$= \frac{1}{\pi}\int_0^{\pi/2}\int_0^\infty \frac{1}{\delta^2_{SD}}\begin{bmatrix} e^{-\left(\frac{P}{N_0\sin^2\theta}+\frac{1}{\delta^2_{RD}}\right)\gamma_{SD}} \\ -e^{-\left(\frac{P}{N_0\sin^2\theta}+\frac{1}{\delta^2_{RD}}+\frac{1}{\delta^2_{SD}}\right)\gamma_{SD}}\end{bmatrix} d\gamma_{SD} d\theta$$

$$= \frac{1}{\pi}\int_0^{\pi/2}\left(\frac{1}{1+\frac{P\delta^2_{SD}}{N_0\sin^2\theta}} - \frac{1}{1+\frac{\delta^2_{SD}}{\delta^2_{RD}}+\frac{P\delta^2_{SD}}{N_0\sin^2\theta}}\right) d\theta$$

$$= B_1\left(1, \frac{P\delta^2_{SD}}{N_0}\right) - B_1\left(1+\frac{\delta^2_{SD}}{\delta^2_{RD}}, \frac{P\delta^2_{SD}}{N_0}\right) \qquad (\mathrm{A.1})$$

with

$$B_1(i,j) = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} \frac{\sin^2\theta d\theta}{isin^2\theta + j} = \frac{1-\sqrt{j/(i+j)}}{2j} \qquad (\mathrm{A.2})$$

2. Calculate $BER^{inc}_{\Phi^R}$

$$BER^{\in c}_{\Phi^R} = \int_0^\infty BER(\gamma_{SR}) f_{\gamma_{SR}}(\gamma_{SR}) d\gamma_{SR}$$

$$\times \int_0^\infty \int_{\gamma_{SD}}^\infty BER\left(\gamma^{\in c}_{\Phi^R}|\Phi^R\right) f_{\gamma_{RD}}(\gamma_{RD}) f_{\gamma_{SD}}(\gamma_{SD}) d\gamma_{RD} d\gamma_{SD}$$

$$= \frac{1}{\pi\delta^2_{SR}}\int_0^{\pi/2}\int_0^\infty e^{-\left(\frac{P_1\gamma_{SR}}{N_0\sin^2\theta}+\frac{\gamma_{SR}}{\delta^2_{SR}}\right)} d\gamma_{SR} d\theta \frac{1}{\pi\delta^2_{RD}\delta^2_{SD}}$$

$$\times \int_0^{\pi/2}\int_0^\infty\int_{\gamma_{SD}}^\infty e^{-\left(\frac{P\gamma_{SD}}{N_0\sin^2\theta}+\frac{\gamma_{RD}}{\delta^2_{RD}}+\frac{\gamma_{SD}}{\delta^2_{SD}}\right)} d\gamma_{RD} d\gamma_{SD} d\theta$$

$$= \frac{1}{\pi}\int_0^{\pi/2}\frac{d\theta}{1+\frac{P_1\delta^2_{SR}}{N_0\sin^2\theta}} \frac{1}{\pi}\int_0^{\pi/2}\frac{d\theta}{1+\frac{\delta^2_{SD}}{\delta^2_{RD}}+\frac{P\delta^2_{SD}}{N_0\sin^2\theta}}$$

$$= B_1\left(1, \frac{P_1\delta^2_{SR}}{N_0}\right) B_1\left(1+\frac{\delta^2_{SD}}{\delta^2_{RD}}, \frac{P\delta^2_{SD}}{N_0}\right) \qquad (\mathrm{A.3})$$

3. Calculate $BER^{co}_{\Phi^R}$

$$BER^{c0}_{\Phi^R} = \left[1 - \int_0^\infty BER(\gamma_{SR}) f_{\gamma_{SR}}(\gamma_{SR}) d\gamma_{SR}\right]$$

$$\times\int_{0}^{\infty}\int_{\gamma_{SD}}^{\infty}BER\left(\gamma_{\Phi^R}^{\infty}|\Phi^R\right)f_{\gamma_{RD}}(\gamma_{RD})f_{\gamma_{SD}}(\gamma_{SD})d\gamma_{RD}d\gamma_{SD}$$

$$=\left[1-\frac{1}{\pi\delta_{SR}^2}\int_0^{\pi/2}\int_0^{\infty}e^{-\left(\frac{P_1\gamma_{SR}}{N_0\sin^2\theta}+\frac{\gamma_{SR}}{\delta_{SR}^2}\right)}d\gamma_{SR}d\theta\right]\frac{1}{\pi\delta_{RD}^2\delta_{SD}^2}$$

$$\times\int_0^{\pi/2}\int_0^{\infty}\int_{\gamma_{SD}}^{\infty}e^{-\left(\frac{P_1\gamma_{SD}+P_2\gamma_{RD}}{N_0\sin^2\theta}+\frac{\gamma_{RD}}{\delta_{RD}^2}+\frac{\gamma_{SD}}{\delta_{SD}^2}\right)}d\gamma_{RD}d\gamma_{SD}d\theta$$

$$=\left(1-\frac{1}{\pi}\int_0^{\pi/2}\frac{d\theta}{1+\frac{P_1\delta_{SR}^2}{N_0\sin^2\theta}}\right)$$

$$\times\frac{1}{\pi}\int_0^{\pi/2}\frac{1}{1+\frac{P_2\delta_{RD}^2}{N_0\sin^2\theta}}\frac{d\theta}{1+\frac{\delta_{SD}^2}{\delta_{RD}^2}+\frac{P\delta_{SD}^2}{N_0\sin^2\theta}} \tag{A.4}$$

We have

$$\int_0^{\pi/2}\frac{1}{1+\frac{P_2\delta_{RD}^2}{N_0\sin^2\theta}}\frac{d\theta}{1+\frac{\delta_{SD}^2}{\delta_{RD}^2}+\frac{P\delta_{SD}^2}{N_0\sin^2\theta}} \tag{A.5}$$

$$=\frac{P_2\delta_{RD}^2B_1\left(1,\frac{P_2\delta_{RD}^2}{N_0}\right)-P\delta_{SD}^2B_1\left(1+\frac{\delta_{SD}^2}{\delta_{RD}^2},\frac{P\delta_{SD}^2}{N_0}\right)}{P_2\delta_{SD}^2-P_1\delta_{RD}^2}$$

Thus,

$$BER_{\Phi^R}^{\infty}=\left[1-B_1\left(1,\frac{P_1\delta_{SR}^2}{N_0}\right)\right]\frac{1}{P_2\delta_{RD}^2-P_1\delta_{SD}^2} \tag{A.6}$$

$$\times\left[P_2\delta_{RD}^2B_1\left(1,\frac{P_2\delta_{RD}^2}{N_0}\right)-P\delta_{SD}^2B_1\left(1+\frac{\delta_{SD}^2}{\delta_{SR}^2},\frac{P\delta_{SD}^2}{N_0}\right)\right]$$

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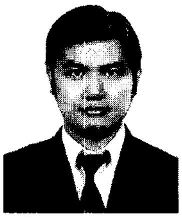
저자소개



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