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협력통신에서 SEP 기반의 선택적 릴레이의 BER 성능

(BER Performance of SEP-based Selection Relaying in Cooperative Communications)

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요 약

선택적 릴레이는 일반적으로 신호대잡음비 (SNR)를 평가하여 재전송을 결정한다. 하지만, 이 방식은 릴레이에서 instantaneous 노이즈를 고려하지 않게 되므로 릴레이에서 오류가 있는 신호를 재전송할 위험이 있으며, 이는 결과적으로 목적지에서의 심볼 검출에 악영향을 끼친다. 이러한 문제를 극복하기 위하여 본 논문에서는 수신된 심볼의 신뢰성을 위해 SNR 대신 새로운 심볼에러확률(SEP)를 제안한다. 모의실험 결과는 제안한 SEP-based SR이 릴레이의 위치와 문턱 값에 상관없이 기존의 SNR-based SR에 비해 좋은 성능을 가짐을 알 수 있다.

Abstract

Selection relaying (SR) is usually based on signal-to-noise ratio (SNR) to decide whether or not to forward recovered symbols. However, instantaneous noise at relay is ignored, leading to the risk of erroneous retransmission induced by the relay that can be detrimental to the eventual detection of symbols at destination. To overcome this problem, we propose using new symbol error probability (SEP) related directly to reliability of received symbols instead of SNR. Simulation results show that the proposed SEP-based SR is considerably better than the conventional SNR-based SR under any relay position and threshold.

Keywords : Selection relaying, Rayleigh fading, AWGN. SNR, SEP.

Ⅰ. Introduction

The spatial diversity owing to the feasibility of deploying multiple antennas at both transmitter and receiver is an efficient solution to mitigate the fading in wireless communications[1]. However, when wireless mobiles may not be able to support multiple antennas due to size and power limitations or other constraints, this diversity technique is not exploited. To overcome such a restriction, a new technique, called cooperative communications, was born which allows single-antenna users to gain some benefits of transmit diversity[2]. The philosophy is that all users in wireless networks assist each other to transmit the information cooperatively. Each user sends out not only its own information but also the information of other users. Therefore, destination will receive the transmitted information more reliably since from statistical viewpoint, the probability that all channels to the destination are deeply faded is significantly reduced.

Selection relaying is one of the simple protocols to perform cooperative communications[3]. In this protocol, relay must make an independent decision on

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whether or not to decode and forward source information to destination. Different performance criteria for making decision at the relay were mentioned. In [4] cyclic redundancy check (CRC) is used but causes the waste of transmission bandwidth due to redundant information insertion. A more commonly alternative criterion without any loss of spectral efficiency is SNR or square amplitude of path gain in [3]. We refer SNR-based SR to as C-SR where only received signals with quality exceeding a predetermined threshold are decoded and retransmitted to the destination.

Since C-SR only relies on instantaneous fading level to decide retransmission without accounting for instantaneous noisy level at the relay, it reflects partially characteristics of received signals. Based on a new symbol error probability expression related directly to reliability of received symbols derived recently in [5], we propose SR based on SEP instead of SNR. We denote this new protocol as P-SR. Because the new SEP includes both instantaneous fading level and instantaneous noisy level, P-SR mitigates the risk of erroneous retransmission induced by the relay. Thus its BER performance is significantly better than that of C-SR for any relay position and threshold. This is confirmed by a variety of Monte-Carlo simulations.

Ⅱ. System model

Consider cooperative communications in a dual-hop wireless network where information is transmitted from a source (S) to a destination (D) with the assistance of a relay (R). All terminals equipped with single-antenna transceivers and sharing the same frequency band are under investigation. In addition, each terminal can not transmit and receive signal at the same time to mitigate implementation complexity since considerable attenuation over wireless channels and insufficient electrical isolation between transmit and receive circuitry make a terminal's transmitted signal dominate the signals of other terminals at its receiver input. Towards this end, we adopt time division multiplexing (TDM) for channel access in this paper.

Assuming that channels between terminals experience independent slow and frequency-flat Rayleigh fading, i.e., they are constant during a N-symbol block but change independently to the next. Without loss of generality, we only illustrate the analysis for the first symbol of each block. Because of slow fading, accurate channel estimation is possible at receivers[6]. Thus, we will assume perfect channel-state information at all the respective receivers but not at the transmitters.

To capture the effect of path-loss on BER performance, we use the model, which is commonly discussed in the literature (e.g. [7]), where variance of α_{ij} is given by $\lambda_{ij} = (d_{SD}/d_{ij})^{\beta}$ with α_{ij} and d_{ij} being path gain and distance between transmitter i and receiver j, respectively and β being path-loss exponent $i \in \{S, R\}$ and $j \in \{R, D\}$ hereafter.

For convenience of presentation, we utilize discrete-time complex equivalent base-band models to express all signals. Selection relaying takes place in two phases. In the first phase, S broadcasts a M-ary symbol x, thus the signals received at R and D are given by

$$y_{SR} = \alpha_{SR} x + n_{R1} \tag{1}$$

$$y_{SD} = \alpha_{SD} x + n_{D1} \tag{2}$$

where y_{ij} denotes a signal received at the terminal j from the terminal i, n_{jp} a zero-mean complex additive Gaussian noise sample with variance N_j at the terminal j in phase p.

In the second phase, R must evaluate the quality of the received signal y_{SR} and check whether it satisfies a predetermined requirement. If this is the case, R detects and forwards the restored data to D. Otherwise, it keeps silent in this phase.

Assuming that R assists S in data transmission, the signal arriving at D in the second phase is of the form

$$y_{RD} = \alpha_{RD}x' + n_{D2} \tag{3}$$

where x' is a M-ary signal decoded by R, using the maximum a posteriori probability (MAP) decision rule:

$$\begin{aligned} x' &= \arg \max_{x_m \in \{x_1,\dots,x_M\}} \Pr(x = x_m | y_{SR}, \alpha_{SR}) \\ &= \arg \max_{x_m \in \{x_1,\dots,x_M\}} \Pr(y_{SR} | x = x_m, \alpha_{SR}) \end{aligned} \tag{4}$$

with x_m being the mth M-ary signal, $m \in \{1,2,\dots,M\}$ and

$$\Pr(y_{SR}|x = x_m, \alpha_{SR}) = \frac{1}{\pi N_R} exp\left(-\frac{|y_{SR} - \alpha_{SR}x_m|^2}{N_R}\right) \tag{5}$$

The last equality in (4) is obtained using Bayes's rule and our assumption that each of M M-ary signals is transmitted with equal probability.

Now D combines the received signals from both phases based on maximum ratio combining (MRC) [8] to result in y as

$$y = \overset{*}{\alpha}_{SD} y_{SD} + \overset{*}{\alpha}_{RD} y_{RD} \tag{6}$$

Finally, the MAP decision rule is applied once again on y to restore the original symbol x.

Ⅲ. DECISION MAKING METHODS

Sending x' in (4) to D happens only if its SEP is below a predetermined threshold, T_{SEP}.

1. Based on SNR (C-SR)

Since SEP of any modulation scheme is a monotonically decreasing function $g(.)$ in SNR, the condition $\{SEP \le T_{SEP}\}$ is equivalent to the condition $\{SNR \ge T_{SNR}\}$ where $T_{SNR} = g^{-1}(T_{SEP})$. For example, SEP of quaternary phase shift-keying (QPSK) modulation is given by[9]

$$T_{SEP} = g(T_{SNR}) = 2Q(\sqrt{T_{SNR}}) - Q^2(\sqrt{T_{SNR}}) \tag{7}$$

where $Q(.)$ is Q-function.

Finding T_{SNR} in (7), given T_{SEP} is straightforward using numerical methods. Then T_{SNR} 's corresponding to T_{SEP}'s can be stored in look-up table for use later.

Now C-SR performs as follows. It first calculates received SNR γ according to (1): $\gamma = |\alpha_{SR}|^2 E_S/N_R$ with $E_S = E[|x|^2]$ being average symbol energy and $N_R = E[|n_{Rp}|^2]$ being noise variance at R; $E[.]$ denotes expectation. Then it sends x' if $\gamma \ge T_{SNR}$. Otherwise, it is idle. Consequently, data retransmission of R only depends on instantaneous fading level α_{SR} regardless of instantaneous noisy level n_{R1} in (1). Therefore, it reflects partially characteristics of the received signal, thus in several cases the condition based on SNR does not guarantee that R detects the signal reliably at a previously desired degree. As a result, if R resends the wrongly decoded symbols, the cooperation can be detrimental to the eventual detection of symbols at D.

2. Based on SEP (P-SR)

[5] derived the conditional SEP, given α_{SR} and y_{SR}, as

$$\Pr(x \ne x' | y_{SR}, \alpha_{SR}) = 1 - \frac{1}{\sum_{m=1}^{M} \exp(-\Lambda_m)} \tag{8}$$

where the reliability of symbol x_m is given by

$$\Lambda_m = \frac{|y_{SR} - \alpha_{SR}x_m|^2 - |y_{SR} - \alpha_{SR}x'|^2}{N_R} \tag{9}$$

Given (8), we propose SR based on SEP as follows. First, R computes SEP in (8) and then decides to forward x' if

$$\Pr(x \ne x' | y_{SR}, \alpha_{SR}) \le T_{SEP} \tag{10}$$

From (8)-(10), we realize that the proposed SR is different from C-SR in that the condition of retransmitting x' in (4) accounts for both fading and noise terms embedded in y_{SR} since

$\Pr(x \neq x' | y_{SR}, \alpha_{SR})$ is a function of y_{SR} and α_{SR}. Therefore if (10) holds, the probability that x is successfully decoded by R at a previously desired degree is rather high. As a result, it is expected that the erroneous retransmission caused by R is reduced significantly; thus, P-SR will result in a better performance than C-SR. However, P-SR requires more computation than C-SR; especially for large constellation sizes.

Ⅲ. SIMULATION RESULTS

A network geometry is examined where R is located on a straight line between S and D[7]. The direct path length S-D is normalized to be 1. We also denote d as the distance between S and R. In all presented results, the path-loss exponent β=3 is under investigation.

Although SR can be applied to any modulation scheme, we only take QPSK as an example. Additionally, we assume both S and R transmit with the same power and noise variances at R and D are equal $N_R = N_D = N_0$.

Monte-Carlo simulations are performed to verify the superiority of P-SR to C-SR. Fig. 1 compares BER performances of P-SR and C-SR with $T_{SEP} = 10^{-4}$ when relay position changes. When R is near S, the quantity $|\alpha_{SR}|^2$ is usually large due to small path-loss, leading to the first term in (1) to dominate the remaining term and high γ. That is the noise term may not have a significant impact on y_{SR}. Therefore in such a case, both C-SR and P-SR perform well and their performance gap is not large. It is seen that P-SR outperforms C-SR about 1dB for d=0.4 over the whole range of E_S/N_0. However as d increases, the above property is no longer correct due to large path-loss and now, the noise term n_{R1} may dramatically affect the received signal y_{SR}. In other words, actual value of received SNR may be different from the estimated SNR γ (i.e. we can not ignore the noise term in computing SNR). Consequently, $\gamma \geq T_{SNR}$ may not bring an expectation that instantaneous SEP $g(\gamma)$ at R is below T_{SEP}. As a result, C-SR performs worse for d=0.6 and 0.8. The performance degradation also occurs similarly for P-SR. However since P-SR evaluates the reliability of the received signal based on y_{SR}, not on α_{SR} and n_{R1} individually, its performance is superior to C-SR. Specifically, P-SR achieves a gain of 1.5dB over C-SR for d=0.6 and 0.8 for any value of E_S/N_0.

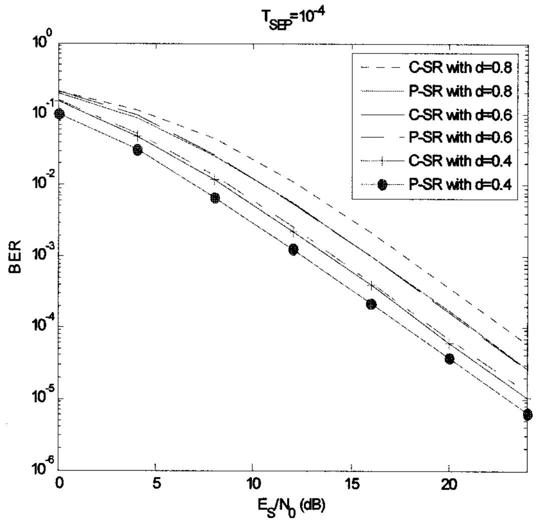

그림 1. d에 따른 C-SR과 P-SR의 BER 비교 그래프
Fig. 1. BER comparison between C-SR and P-SR via d.

The influence of the threshold T_{SEP} on BER performance of C-SR and P-SR is depicted in Fig. 2 for d=0.7. It is well-known that if T_{SEP} is small, then diversity order is reduced since the probability that the relay retransmits the source information is small. Also, the large threshold increases the percentage of incorrect detection at the relay, thus decaying the performance of the receiver. This point is once again shown in Fig. 2 for both C-SR and P-SR. Moreover, we expect the optimal thresholds but unfortunately, so difficult to find out unless through exhaustive experiments.

Fig. 2 also demonstrates that P-SR provides a performance gain of about 2dB over C-SR for any value of E_S/N_o and investigated T_{SEP}. In particular,

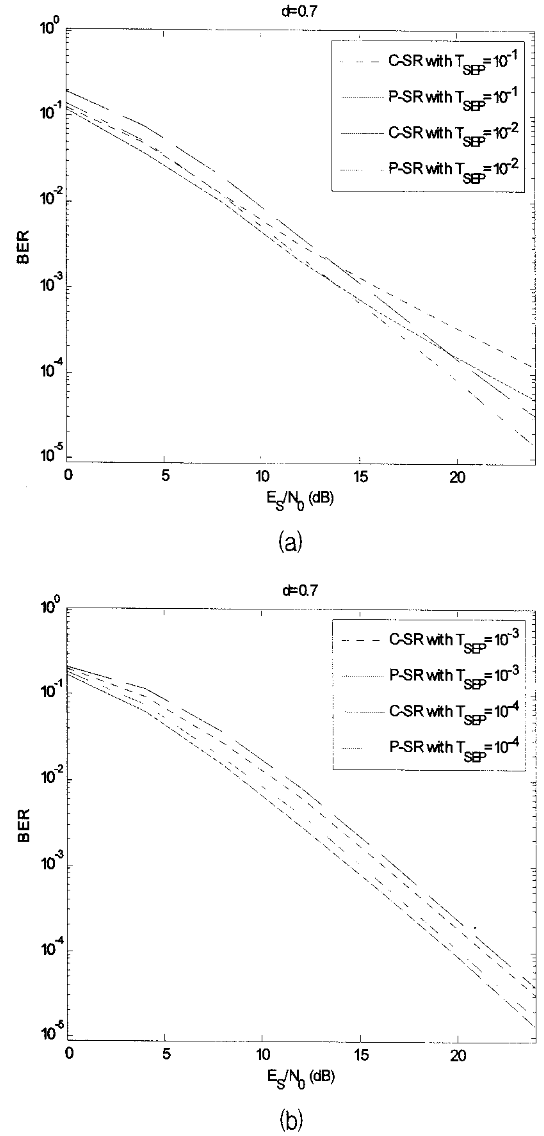

그림 2. 문턱값에 따른 BER 성능 그래프
Fig. 2. BER performance of via thresholds.

this improvement keeps increasing when T_{SEP} and E_S/N_o are large. For example, P-SR can achieve a gain of greater than 3dB with $T_{SEP}=10^{-1}$ and target BER of less than 10^{-4}.

Ⅳ. CONCLUSION

The new SEP expression is an efficient measure for evaluating the reliability of a signal. Its application in selection relaying illustrates that P-SR dramatically outperforms C-SR under any scenario of SEP threshold, relay position and E_S/N_o. Since P-SR is a very simple protocol but with high BER performance, it should be considered as a promising technical solution for cooperative communications in future wireless networks to improve the quality of information transmission and extend the coverage area as well.

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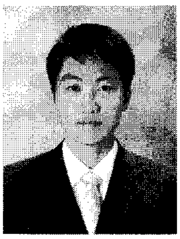

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