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# 예측 정보를 이용한 적응적 협력 선택기법

# ( Prediction-Based Adaptive Selection Cooperation Schemes )

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## 요 약

협력다이버시티는 무선채널페이딩에 강건하고 다중안테나기술에 비해 낮은 단말기 구현 복잡도를 제공하는 장점으로 인해 최근 각광받고 있는 기술이다. 본 논문에서는 새로운 중계단말기 선택 기법과 결합된 예측 기반 의사결정을 이용하는 적응적 협력 선택기법을 제안한다. 제안된 기법에서 수신단말기는 중계단말기와 수신단말기간의 순간 채널 상태 정보를 이용하여 선택된 중계단말기로부터의 전송이 성공할지 실패할지 여부를 예측한다. 수신단말기는 예측 정보를 이용하여 결정된 협력 선택 명령을 전체 네트워크에 전달한다. 실험결과를 통해 새로운 중계단말기 선택 기법과 결합된 적응적 협력 선택기법이 기존 기법들에 비해 불능확률(outage probability)을 줄이고, 시스템 성능(throughput)을 개선하며, 전송 전력을 절약하여 네트워크의 수명(lifetime)을 연장시키는 것을 보인다.

## Abstract

This paper proposes two novel prediction-based adaptive selection cooperation schemes combined with a new relay selection strategy. In the proposed schemes, the destination predicts whether the transmission will be successful or not before a single relay is selected to transmit source's decoded data. Depending on the prediction, the destination feeds back a command to the whole network. Numerical results show that the proposed schemes combined with the relay selection strategy successfully reduce its outage probability, improve its throughput, save transmitted power, and prolong the lifetime of the network.

**Keywords:** 협력다이버시티, 선택적 협력, 예측 정보, 중계단말기 선택

## I. Introduction

Cooperative diversity has become an attractive field because of the improvement in robustness against to wireless fading with simplicity in terminals. However most of the works were proposed only to achieve smaller outage probability without considering throughput, transmitted power or lifetime problem for the network[1~6]. Even the works considering lifetime [7~8], they always show that the lifetime and the outage probability are in tradeoff, that is, to prolong the lifetime, the outage probability needs to be increased.

In this paper, we propose two novel prediction-based adaptive selection cooperation schemes. In the proposed schemes, before any relay is selected to transmits the decoded data, the destination predicts whether the transmission will be successful or not and gives back a command to the whole network depending on the predication results. Also according to the prediction, a relay selection strategy is proposed. We compare the outage

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probability, throughput, transmitted power, and lifetime of the proposed schemes with those of schemes in previous works[2, 6].

## Ⅱ. System model

Consider a decode-and-forward scheme for a wireless system consisting of one source, one destination, and $K$ relays, a total of $K+2$ nodes. Assume that each terminal has one antenna. Transmission is made through orthogonal time division or frequency division channels. Also assume that the channel has quasi-static flat Rayleigh fading with additive white Gaussian noise. Let $h_{ij}$ denotes the fading coefficient of the channel from the node $i$ to the node $j$ and $n_{ij}$ denotes the additive noise from the node $i$ to the node $j$. The channel coefficient $h_{ij}$ and the noise $n_{ij}$ are modeled as independent zero-mean circularly symmetric complex Gaussian random variables with variance $\sigma_{ij}^2$ and $N_0$, respectively. Suppose that the variance of the channel coefficient is given by[2]

$$\sigma_{ij}^2 = \eta d_{ij}^{-\alpha} \tag{1}$$

where $d_{ij}$ is the distance between the node $i$ to the node $j$, $\alpha$ is the propagation loss factor, and $\eta$ is a constant which depends on propagation environment. Assume perfect channel state information (CSI) is available at each receiver.

## Ⅲ. Prediction-based adaptive selection cooperation schemes

In this section, we propose two prediction-based adaptive selection cooperation schemes. Relays in the proposed schemes try to decode the source's signal and only one relay is selected to transmit its decoded data. Different from the other existing schemes, the destination in the proposed schemes predicts whether the transmission will be successful or not before a single relay is selected to transmit the decoded data to the destination.

The data is transmitted in two half time slots. In the first half slot, the source broadcasts data to all other nodes and they attempt to decode the signal. Thus, the destination obtains instantaneous source-to-destination CSI and calculates the mutual information between the source and the destination after the first half slot, which is given by

$$I_{1D} = \frac{1}{2} log\left(1 + \frac{P_s}{N_0}|h_{sd}|^2\right) \tag{2}$$

where $h_{sd}$ is the fading coefficient of the channel from the source to the destination.

In the second half slot, each relay in the decoding set $D(s)$[6] transmits a symbol to the destination identifying itself as an element of $D(s)$, so that the destination obtains the instantaneous CSI about relay-to-destination channel, $h_{r_k d}$, for the relays in the decoding set $D(s)$. Then, the destination predicts the future mutual information $I_{2D}^{r_k}$ after the relay $r_k$ transmits the data in the second half slot, which is given by

$$I_{2D}^{r_k} = \frac{1}{2} log\left(1 + \frac{P_s}{N_0}|h_{sd}|^2 + \frac{P_r}{N_0}|h_{r_k d}|^2\right), \tag{3}$$

$r_k \in D(s)$, where $h_{r_k d}$ are the fading coefficients of the channels from the relays in the decoding set to the destination. Depending on the prediction, the destination gives back a command to the whole network and the source and relays follow the command.

### 1. Prediction-Based Adaptive Selection Cooperation Scheme I (PBASC-I)

Transmission is successful when the instantaneous mutual information between source and destination is larger than the target rate $R$. There are three cases depending on whether $I_{1D}$ and $I_{2D}^{r_k}$, $r_k \in D(s)$, are larger than the target rate $R$ or not. For each case, the prediction-based adaptive selection cooperation Scheme I works as follows:

*Case 1:* $I_{1D} \geq R$, which implies successful transmission in the first half slot.

The destination gives back a command for next-transmission. Then the source transmits next data, and all the relays delete their signals received in the first half slot.

*Case 2*: $I_{1D} < R$ and at least one relay $r_k$ in the decoding set has the future mutual information $I_{2D}^{r_k}$ larger than the target rate $R$. It implies successful transmission after the relay $r_k$ transmits the decoded data in the second half slot.

We define a success set $S_I(s)$ for the source as the collection of the relays which have successful transmission after transmitting the decoded data in the second half slot, that is,

$$S_I(s) \triangleq \left\{ r_k \in D(s) : \frac{1}{2} log\left(1 + \frac{P_s}{N_0}|h_{sd}|^2 + \frac{P_r}{N_0}|h_{r_k d}|^2\right) \geq R \right\} \tag{4}$$

Clearly, in Case 2 the cardinality of the success set $|S_I(s)|$ is larger than or equal to 1, i.e., $|S_I(s)| \geq 1$.

Depending on the prediction, the destination gives back a command to the whole network to select a single node in the success set $|S_I(s)|$. Then the selected node transmits its decoded data to the destination.

*Case 3*: $I_{1D} < R$ and all $r_k$ in the decoding set have future mutual information $I_{2D}^{r_k}$ smaller than the target rate $R$, which causes the transmission failure no matter which relay transmits the decoded data in the second half slot.

The destination gives back a command for re-transmission. Then the source re-transmits this data in the next first half slot and all the relays delete their signals received in the first half slot.

## 2. Prediction-Based Adaptive Selection Cooperation Scheme II (PBASC-II)

In order to reduce the outage probability, Scheme II let the selected relay transmit the decoded data using two times of relay power, $2P_r$, when needed. When $I_{1D} < R$ and all $r_k$, $r_k \in D(s)$, have future mutual information $I_{2D}^{r_k}$ smaller than the target rate $R$, the destination predicts the future mutual information $I_{2D}^{r_k}$ after a relay $r_k$ transmits the data in the second half slot using $2P_r$, which is given by

$$I_{2D}^{2r_k} = \frac{1}{2} log\left(1 + \frac{P_s}{N_0}|h_{sd}|^2 + \frac{2P_r}{N_0}|h_{r_k d}|^2\right), \tag{5}$$

$r_k \in D(s)$.

There are four cases depending on whether $I_{1D}$, $I_{2D}^{r_k}$ and $I_{2D}^{2r_k}$, $r_k \in D(s)$, are larger than the target rate $R$ or not. For each case, the prediction-based adaptive selection cooperation Scheme II works as follows:

*Case 1* and *Case 2* are the same as those in the Scheme I.

*Case 3*: $I_{1D} < R$, $I_{2D}^{2r_k} < R$, $r_k \in D(s)$, and at least one relay $r_k$ in the decoding set having the future mutual information $I_{2D}^{2r_k}$ larger than the target rate $R$. It implies successful transmission after the relay $r_k$ transmits the decoded data with $2P_r$ in the second half slot.

We define a success set $S_{II}(s)$ for the source as the collection of the nodes which have successful transmission after transmitting the decoded data with $2P_r$ in the second half slot, that is,

$$S_{II}(s) \triangleq \left\{ r_k \in D(s) : \frac{1}{2} log\left(1 + \frac{P_s}{N_0}|h_{sd}|^2 + \frac{2P_r}{N_0}|h_{r_k d}|^2\right) \geq R \right\} \tag{6}$$

Depending on the prediction, the destination gives back a command to select a single node in the success set $S_{II}(s)$. Then the selected node transmits its decoded data to the destination using $2P_r$.

*Case 4*: $I_{1D} < R$ and all $r_k$ in the decoding set have future mutual information $I_{2D}^{r_k}$ and $I_{2D}^{2r_k}$ smaller than the target rate $R$, which causes transmission failure no matter which relay transmits the decoded data in the second half slot with even $2P_r$.

The destination gives back a command of re-transmission. Then the source re-transmits this data in the next first half slot and all the relays delete their signals received in the first half slot.

To give back the command, the proposed schemes I and II require the overhead of $\log_2(K+2)$ and $\log_2(K+2)+1$ bits per coherent time interval, respectively. The latter requires one more bit than the former to indentify whether the relay power is $P_r$ or $2P_r$.

The proposed schemes have the following advantages. Firstly, the throughput is improved as the source transmits next data in Case 1. Secondly, the transmitted power is reduced because the relay power is saved when successful transmission happens after the first half slot and when transmission failure is predicted. Thirdly, fairness is improved without increasing the outage probability if considering relay selection in the success set.

### 3. Relay Selection

In the proposed schemes, the destination could select a single node in the success set. Since any node in the success set achieves successful transmission, we have more choices for relay selection without increasing the outage probability. Thus we can improve the fairness and prolong the lifetime.

Define the lifetime of the whole network as the number of data collections before a node in the network becomes out of energy, that is,

$$LT \triangleq \min\{m : E_k(m) < \mu\} \tag{7}$$

where $E_k(m)$, $k = 1,2,\ldots,K+2$, denotes the residual energy of node $k$ after the $m$-th message is transmitted and $\mu$ is the minimum energy needed for one data transmission.

Define the unit residual energy for each node as

$$E_k^{unit}(m) \triangleq E_k(m)\cdot d_{k,center}^{-\alpha} \tag{8}$$

where $d_{k,center}^{-\alpha}$ is the distance between the node $k$ and the center of the network.

The relay selection strategy works as follows. The destination gives back a command to select the node $k^*$ which has the maximum unit residual energy $E_k^{unit}$ among the nodes in the success set, that is,

$$k^* = \arg max E_k^{unit}(m) \tag{9}$$

where $k \in S_I(s)$ for Case 2 in Schemes I and II, and $k \in S_{II}(s)$ for Case 3 in Scheme II.

In the next section, through computer simulation, we compare the performance of the proposed schemes with those of the conventional selection cooperation scheme with the best relay selection (SC)[6], the conventional selection cooperation scheme with automatic repeat request (SC-ARQ), the distributed space-time cooperation scheme (DSTC), and the direct transmission (DT). The SC needs overhead of $\log_2 K$ bits per coherent time interval[6], and SC-ARQ needs one more overhead bit per half coherent time interval than that to identify if the transmission is successful or not[9].

## IV. Numerical results

Suppose that the target rate $R = 1\,bit/s/Hz$, the propagation loss factor $\alpha = 3$, $\eta = 1$, and the noise variance $N_0 = 1$. Assume that the source power $P_s$ and relay power $P_r$ are same and the sum of them is equal to the transmitted power of the direct transmission $P_{tot}^{DT}$ which satisfies

$$10\log\left(\frac{P_{tot}^{DT}}{N_0}E\left[|h_{sd}|^2\right]\right) = SNR\,(dB) \tag{10}$$

Suppose that the number of relays $K = 2$, the source and the destination are located at $0+0j$ and $10+0j$, $3-5j$, respectively, and that the relays are located at $4+1j$ and $3-5j$.

Fig. 1 shows the outage probability of the proposed schemes. It is shown that the proposed schemes achieve lower outage probability than DSTC. Also it is shown that PBASC-I has the same outage probability as SC and SC-ARQ, while PBASC-II has lower outage probability than the other schemes.

Fig. 2 shows the throughput of the proposed schemes. It is shown that the two proposed schemes have much larger throughput than SC, DSTC, and

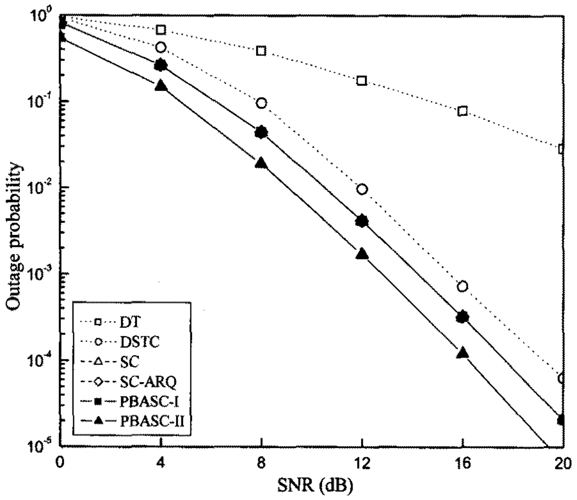

그림 1. 제안된 기법의 불능확률 $(K=2)$
Fig. 1. Outage probability of the proposed schemes $(K=2)$.

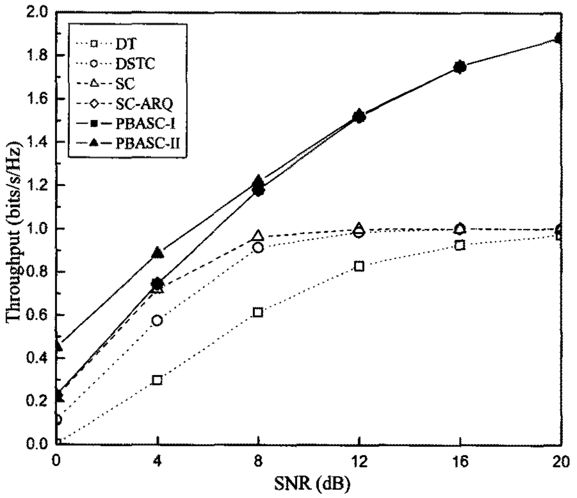

그림 2. 제안된 기법의 시스템 성능(throughput) $(K=2)$
Fig. 2. Throughput of the proposed schemes $(K=2)$.

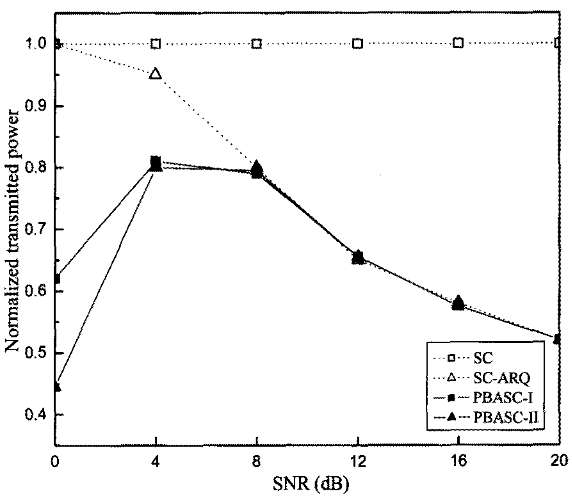

그림 3. 제안된 기법의 정규화된 송신전력 $(K=2)$
Fig. 3. Normalized transmitted power of the proposed schemes $(K=2)$.

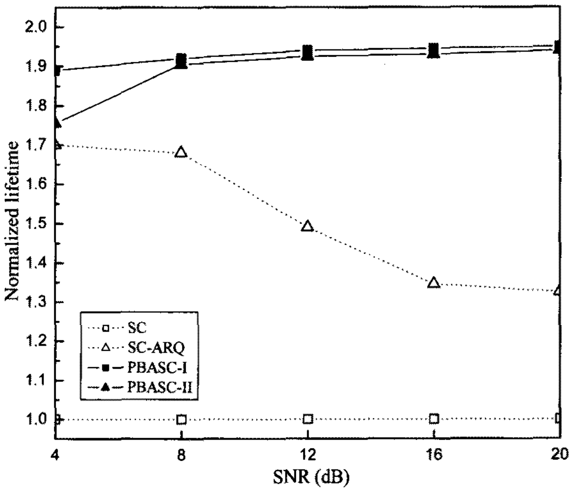

그림 4. 제안된 기법의 정규화된 수명(lifetime) $(K=2)$
Fig. 4. Normalized lifetime of the proposed schemes $(K=2)$.

DT. PBASC-I has the same throughput as that of SC-ARQ and PBASC-II has larger throughput than the other schemes.

Fig. 3 shows the normalized transmitted power of the proposed schemes. It is shown that the proposed schemes spend less power than both SC, which has normalized power of 1, and SC-ARQ.

Fig. 4 shows the normalized lifetime of the proposed schemes in an ad-hoc network, having 8 relays and a total of 10 nodes at $1+1j$, $1-1.5j$, $-1+2j$, $-1-1j$, $0+4j$, $0-5j$, $3+0j$, $-4-3j$, $2+4j$, and $1-1.8j$. Suppose that each node in this ad-hoc network has the same probability to access the channel and transmits to any other node in the network. Assume the initial energy of each node $E_k(0)=2\times10^9$, $k=1,2,...,K+2$. It is shown that PBASC-II has almost the same normalized lifetime as that of PBASC-I. Also it is shown that the lifetimes of the proposed schemes are always longer than SC and DT which has normalized lifetime of 1. It is shown that the increase in the lifetime of the proposed schemes becomes more significant in high SNR.

## Ⅴ. Conclusions

In this paper, we propose two novel prediction-based adaptive selection cooperation schemes. In the proposed schemes, the destination performs prediction before a relay is selected to transmit the source's decoded data. It is shown that by utilizing the prediction-based decision, the proposed schemes successfully reduce the outage probability, achieve larger throughput and prolong the network lifetime with lower transmitted power at the cost of slight increase in the amount of feedback command bits.

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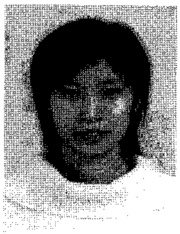
## 저자소개



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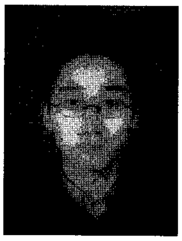

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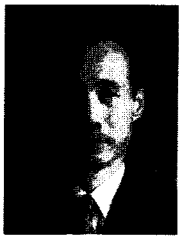

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