Optimal Relays for Cooperative ARQ Protocol Based on Threshold of Distance

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ABSTRACT

Retransmission signals from relays to destination when the destination fails to decode received signal from the source in Automatic Repeat Request (ARQ) protocol make the destination receive signals more reliably. With using omni -direction antenna in the practical system, in communication range of both the source antenna and the destination antenna, there are some relays that can be used to transmit signal to the destination. However, using all relays to transmit signal consume power and bandwidth. In this paper, we propose a new protocol in which the best relays are chosen based on threshold of distance from the source to the relay and the relay to the destination when the relays use decode- and forward (DF) protocol. Simulation results prove the efficiency of the protocol when we compare using only the best relays with using all relays to transmit signal to the destination.

Key Words : Optimal relay, cooperative communication, ARQ, DF

I. Introduction

Automatic repeat request (ARQ) is a protocol in which the destination requests retransmission signal when it fails to decode signal. Retransmissions are always activated from the source or the relays when the received signal is incorrect, so ARQ technique is very efficient to combat the effect of fading. In the ARQ protocol, the destination uses cyclic redundancy check code (CRC) to check the received signal. The CRC is a part of the source message, it helps the destination know whether the received signal is correct or not. If the destination recognizes that the signal is wrong, it sends a Negative ACKnowledgement (NACK) message to the transmitter to inform that the signal is incorrect and it needs to be retransmitted. Otherwise, the destination sends the ACKnowledgement (ACK) message to inform correct signal and the source continues transmitting next signal. We assume that, the feedback channel is errorless so transmission NACK, ACK message is guaranteed successfully. In the communication ranges of both the destination and the source, there are several relays. All relays receiving both signals from the source and the NACK message from the destination can use to assist transmission signal to the destination. In [1], [2] the authors proved that in the slow fading channel, the performance of a traditional ARQ protocol (in traditional protocol whenever the destination sends NACK message, the source retransmits signal to the destination) is not as good as a protocol when retransmission is performed by the relays with an assumption the independent fading channel between the relays.

The processing signal before transmission to the destination at the relay consists of some different forms. The relay may decode the received signal and then forward the decoded signal (DF protocol) or simply amplify and forward it (AF protocol). In [3], a coded two user cooperation scheme was proposed by taking advantage of the existing

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channel codes, in which the coded information of each user is divided as two parts : one part is transmitted by the user itself (the source) and the other by its cooperator (the relay). We consider using the decode-and- forward cooperation protocol at the relay. From [4] decoding at the relay can take some variety of forms. Fixed decode and forward (Fixed DF), in which the relay receives signal, it always decodes and forwards decoded signal to the destination, it do not care about the accurate of signal. Or selective decode and forward protocol (Selective DF) in which the relay decodes and measures the characteristics of the channel or uses log likelihood ratio (LLR) [5] to decide forwarding to the destination or not. With an assumption that the destination can check correctly received signal by CRC, we consider in two cases. The first case, we use Fix DF and the other is perfect DF.

In fact, the antennas of the source and the destination are omni- directional antennas so some relays are far from the destination but in the communication range of source and destination antennas also receive this NACK message. Therefore, if we use all relays to forward signal to the destination, the efficiency of system is not good and it also consumes much power, bandwidth. In [6], the authors proposed a protocol to choose the best relay based on local measurement of the instantaneous channel conditions. In that paper, they consider the cooperation protocol, in which each relay overhears a single transmission of ready to send (RTS) message, and clear to send (CTS) message. Transmission of RTS message from the source allows for the estimation of the instantaneous wireless channel between the source and the relay and transmission of CTS message from the destination allows for the estimation of the instantaneous wireless channel between the relay and the destination. However, using that protocol, we consume bandwidth to send RTS, CTS message and when the channel varies faster, it is difficult to estimate the instantaneous channel condition. In this paper, we propose a new protocol to choose the best relays for retransmission to the destination. The best relays chosen are based on the threshold of distances from the source to the relays and the relays to the destination when the relays use DF protocol. We also propose the priority position of relay for transmission. The relay with first priority will be transmitted as soon as the relay receives NACK. Other relays will wait a time interval, if they don't receive ACK message from the destination to indicate receiving correct signal and the channel condition allows sending, they transmit signal. And the process continues until both source and the relays receive ACK message from the destination.

The rest of this paper is organized as follows. Section II describes the system model for ARQ protocol. The threshold of distance when the relays use DF protocol and the way to select the relay for signal transmission are analyzed in section III. Section IV gives some simulation results that compare using only the best relays and using all of relays prove the efficiency of the protocol and Section V concludes the paper.

II. System model

We consider the ARQ technique with two phases in a wireless network. In phase 1, the source broadcasts signal to the destination (the lines to transmit signal in phase 1 are indicated by solid lines). The relays in communication range of source antenna also receive the signal. The destination receives signal and checks signal by using CRC. If the signal is correct, the destination send ACK message to inform that signal is correct (the lines to transmit message are indicated by dashed lines) and the source continues transmitting next signal. Otherwise, if the signal is incorrect, the destination send NACK message to request retransmission from the source or the relays.

Considering the network in Fig. 1a, in which terminal S is the source, D is the destination. Because the antennas of the source and the destination are omni-directional so Ri are relays in the

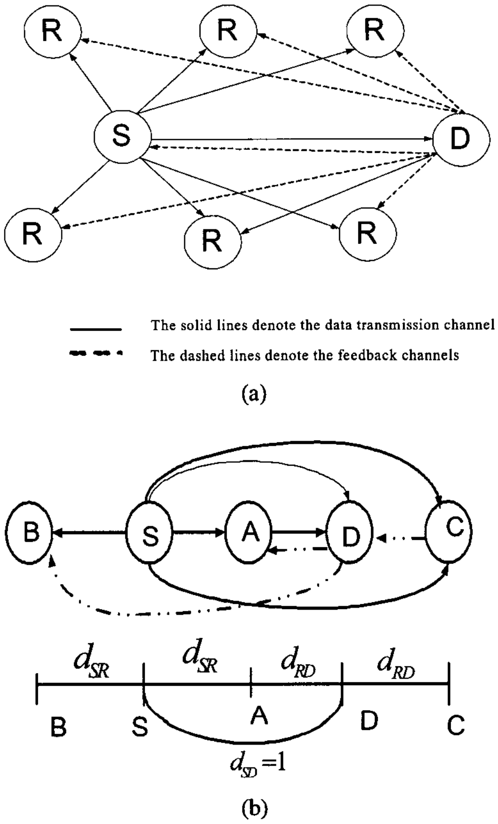

그림 1. 협력 ARQ 시스템 모델, (a) 실제적인 시스템, (b) 제안하는 시스템
Fig. 1. Cooperative ARQ system model.
(a) The practical system, (b) The proposed system

communication range of both the source antenna and the destination antenna. However, in this paper, we only consider the straight line model (the source, the relays and the destination are always placed on one line with three relays A, B, C (Fig. 1b) in which the distance from the source to relay is indicated by d_{SR} the distance from the relay to the destination is d_{RD}, and the distance from the source to the destination is $d_{SD}=1$). The time division multiplexing (TDM) system is assumed to be perfect in which two relays do not transmit at the same time and all terminals also can not receive and transmit at once. After receiving NACK, the relays measure the average channel conditions between the source - relay and the destination - relay to decide whether or not forwarding signal to the destination. If the measurement of channel conditions satisfies a predetermined threshold, the relay decodes signal and retransmits signal to the destination, otherwise it keeps silent.

In phase 1, the source broadcasts signal to the destination and the relays, the received signals at the destination and the relays are given by:

$$y_{SD}=h_{SD}\sqrt{P_S}x+n_{SD} \quad (1)$$

$$y_{SR_i}=h_{SR_i}\sqrt{P_S}x+n_{SR_i} \quad (2)$$

where

- y_{SD} is signal received at the destination.
- y_{SR} is signal received at relay i.
- x is the transmitted signal.
- h_{SD}, h_{SR} are fading realizations from the source to the destination and from the source to the relay i which are assumed to be independent zero-mean complex Gaussian random variables. We denote $\lambda_{SD}^2, \lambda_{SR}^2$ as variances of path loss of the channel with $\lambda_{SR}^2=(d_{SD}/d_{SR})^{\beta}$, here d_{SR} is the distance from source S to relay i, d_{SD} is the distance from the source to the destination (in this paper, we assume that $d_{SD}=1$) and β is the path loss exponent. For free space, we have $\beta=2$ [7].
- n_{SD}, n_{SR} is AWGN with variance $\sigma_{SD}^2, \sigma_{SR}^2$ at the destination and relay i.
- P_S is the transmitted power at the source.

In the phase 2, the destination checks signal (by using CRC). If received signal is wrong, the destination sends NACK message to request signal retransmission to relays. After receiving NACK from the destination, the relay measures the average condition channel from the source to the relay based on the signal that is broadcasted from source in phase 1 and average conditional channel between the relay and the destination based on NACK message. If all measurements satisfy the threshold, it considers the priority, listens to the channel condition. In the case, the relay decides transmitting signal to the destination, it decodes signal. If the relay uses Fix DF, after decoding, the relay forwards the signal to the destination. Otherwise, if the relay uses perfect DF, it only forward signal when decoded signal is correct.

The signals are received at the destination when the relay forwards decoded signal to the destination:

$$y_{RD} = h_{RD}\sqrt{P_R}\,\widehat{y_{SR}} + n_{RD} \qquad (3)$$

where

- h_{RD}, y_{SR}, n_{RD} are explained previously.
- $\widehat{y_{SR}} = h_{SR}^{*} y_{SR}$ is decoded signal at the relay.
- P_R is power of the relay I.

At the destination, signal is recovered by decoding only signal from the relay (it is called as NARQ protocol). The final signal at the destination is:

$$\widehat{y_D} = h_{SD}^{*} y_{RD} \qquad (4)$$

Ⅲ. Performance Analysis

3.1 The influence of relay position to the performance of the system.

In [4], the simulation proves that only with the fix decode and forward, we can't achieve the diversity gain for cooperation between the source and the destination. Otherwise, with perfect DF, we can obtain full diversity. In this paper, we consider the difference between using Fix DF and perfect DF for ARQ protocol. Firstly, we consider dependence of BER on the distance between the source and the relay when the relay is placed between from source and the destination in the Fix DF (the position of relay A in the Fig. 1).

The Fig. 2 presents the influence of the relay position to the performance of fix DF protocol for the different values of SNR. The symbol d indicates distance from the source to the relay A with $d = d_{SR}, d_{SR} + d_{RD} = 1$. From Fig. 2 when SNR is large enough (SNR>10), the closer to the source the relay is, the better performance is. The mathematic for the minimum of BER is showed clearly in the Appendix A.

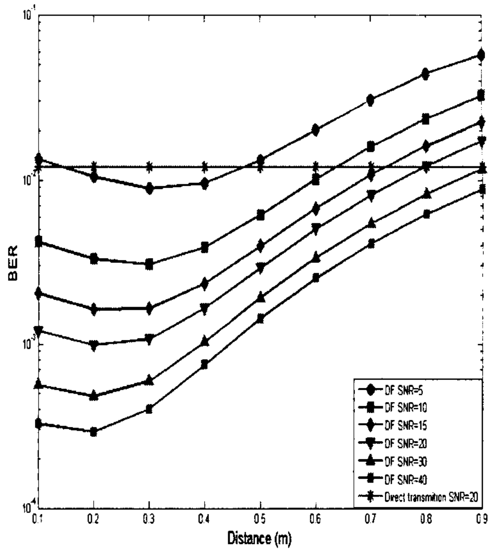

그림 2. Fix DF의 d에 따른 BER 성능 곡선
Fig. 2. BER performance versus d in Fix DF of relay A

The positions $d_{SR} = 0.1, d_{RD} = 0.9$ and $d_{SR} = 0.4$, $d_{RD} = 0.6$ are considered as threshold of using Fix DF protocol because when the position of relay are farther than the relay at the position $d_{SR} = 0.4, d_{RD} = 0.6$, the saving power and the performance are not as good as the relay is placed in the threshold area. Fig. 3 show clearly the influence of the distance when the relay A moves between the source and the destination. In Fig. 4, we com-

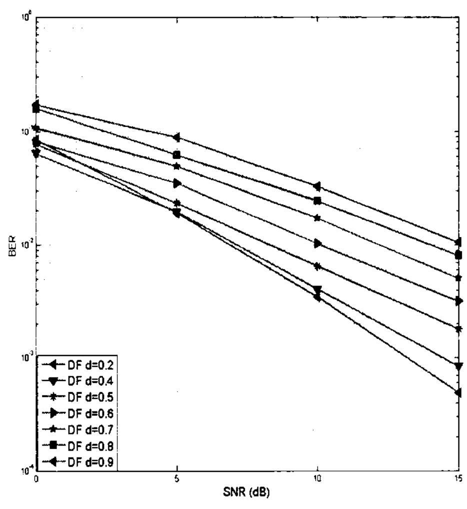

그림 3. Fix DF의 BER 성능 곡석
Fig. 3. BER performance in Fix DF

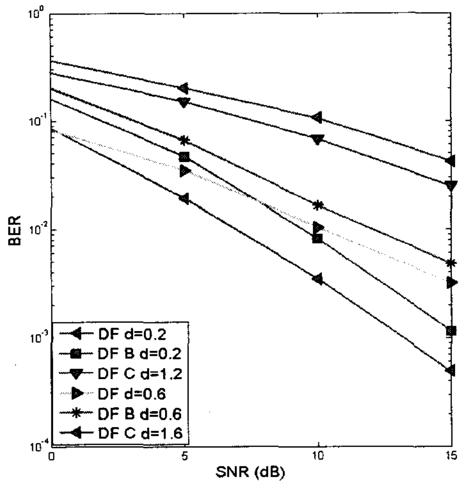

그림 4. Fix DF인 릴레이 A, B, C의 BER 성능 곡선
Fig. 4. BER performance of relay A, B, C in Fix DF

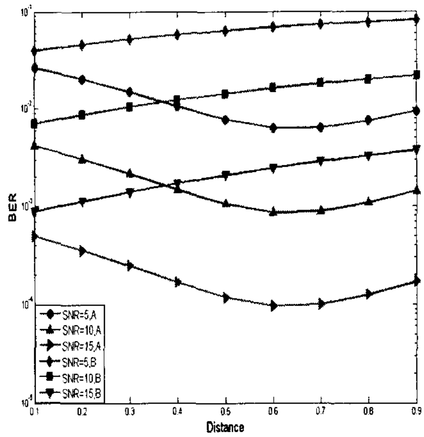

그림 5. 릴레이 A의 d에 따른 BER 성능 곡선
Fig. 5. BER performance versus variation d of relay A

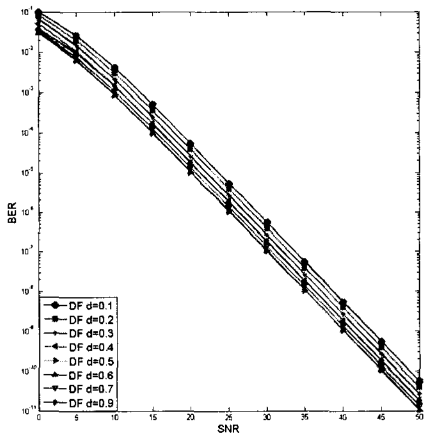

그림 6. Perfect DF인 릴레이 A, B, C의 BER 성능 곡선
Fig. 6. BER performance of relays A, B, C in perfect DF

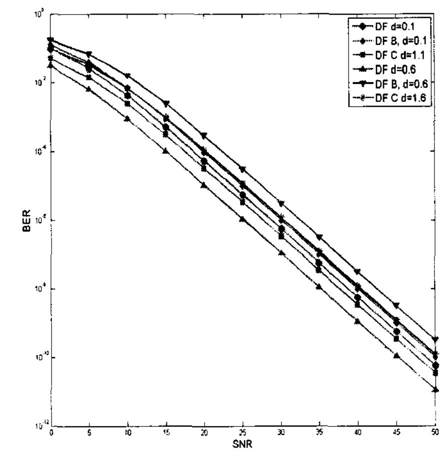

그림 7. Perfect DF의 d에 따른 BER 성능 곡선
Fig. 7. BER performance versus d in perfect DF

pare BER performance with variance of distance for the relay A, B, C. The indicated symbol d in relay A satisfies $d=d_{SR}, d_{SR}+d_{RD}=1$, in the relay B is $d=d_{SR}$, $d_{RD}=d_{SR}+d_{SD}$ or $d_{RD}=1+d_{SR}$ and in the relay C is $d=d_{SR}$, $d_{RD}=d_{SR}+d_{SD}=d_{SR}-1$ The performance of the system at position of the relay A is the best.

We consider influence of distance when the relay uses perfect DF. The mathematic for choosing the best relay position is showed in the Appendix B. In Fig 5, 6, 7, we consider performance of system by using the simulation. The symbol d1 indicates the distance from the source to the relay and d2 indicates the distance from the relay to the destination.

From the Fig 2, 3, 5, 7, we can see the different performance between the fix DF and perfect DF protocol when the relay A moves between the source and the destination. With the Fix DF, the closer to the source the relay is, the better performance is. Otherwise, with the perfect DF protocol the better performance is, the farther of the position of relay is. At the position $d_{SR}=0.2, d_{RD}=0.8$, the Fix DF obtains the best performance, and the position $d_{SR}=0.7, d_{RD}=0.3$ the perfect DF obtains the best performance.

In the Fig. 6, we compare performance of two relays A, B in which the distance from the source to the relay A is $d_{SR}=0.7$, the distance from the relay to the destination is $d_{RD}=0.3$ and that of the relay B is $d_{SR}=0.2, d_{RD}=1.2$, the power can save 2dB at $BER=10^{-3}$. Similarly, comparing the relay A with position of the relay C $d_{SR}=1.2, d_{RD}=0.2$, the relay A can save power from 4dB at the $BER=10^{-3}$. The reason for this is that the relay C is too far from the source so it can not receive signal correctly as the relay is close to the source and the relay B is placed near the source but too far the destination so when it transmits to the destination, it is affected by noise so deeply. From Fig. 4, 6, the best performance of system for both Fix DF and perfect DF is the relay placed at position A. Fig. 7 shows the influence of the distance for relay A, B when the relay uses perfect DF. When the relay is placed at the position B, the best performance of system obtains at position $d_{SR}=0.1, d_{RD}=1.1$ because at the position the effect of noise for signal from the relay to the destination is the smallest. And at the position of relay A, the best performance is $d_{SR}=0.7, d_{RD}=0.3$.

3.2 Threshold of the distance

In all cases of using DF, the performance of system when relay is placed at position A is always better than the relay at the position B, C. We have threshold for the average conditional channel from the relay to the destination as $\lambda_{RD}^2=(d_{SD}/d_{RD})^\beta=1/d^\beta_{RD}$ with $\beta=2$,we have $\lambda_{RD}^2=1/d^2_{RD}\rightarrow\lambda_{RD}^2>1$. The condition $\lambda_{RD}^2>1$ ensures that the relay is not placed at the position B as Fig. 1 (because the distance of the relay B is $d_{RD}=d_{SR}+d_{SD}>1$). If condition of channel from the relay to the destination satisfies, the relay continues measuring the conditional channel from the source to the relay based on signal from the source. For the threshold of distance from the source to the relay, it depends on the protocol using at the relay (Fix DF protocol or perfect DF protocol). If the relay uses Fix DF protocol, the channel condition from the source to the relay satisfies the threshold $1/0.4^2\le\lambda_{SR}^2\le1/0.1^2$, otherwise, if the relay uses perfect DF protocol, the threshold of distance from the source to the relay is $1/0.9^2\le\lambda_{SR}^2\le1/0.5^2$. In those areas, the performance of the system obtains the best performance in saving power and diversity gain. The first priority relay for transmission to the destination using Fix DF is the position $d_{SR}=0.2, d_{RD}=0.8$ and that of perfect DF protocol is $d_{SR}=0.8, d_{RD}=0.2$.

Ⅳ. Simulation Results

In this section, we use Monte- Carlo simulation to verify the theory result in section 3, We use BPSK modulation to transmit over fading channels. In all simulations, we assumed that the variance of Gaussian white noises equals 1 $(\sigma_{SD}^2=\sigma_{SR}^2=\sigma_{RD}^2)$ and we present average BER curves as a function of SNR. For fair comparison, the total power of the cooperative system should not exceed that of corresponding direct transmission system. If P_T is the average transmit energy of the source in the direct transmission, in the ARQ protocol the energy for transmission from the source to the destination in the first phase is $P_T/2$ and the relays are $P_T/2R$ with R is the number of relay uses in the system. It means that if the system has two relays, we only use the best relay R=1, otherwise R=2. To prove efficiency of using the best relay with using all of relays, we use three positions of relay as Fig. 1 A, B, C in which only relay A satisfies the threshold, the relay B and C do not satisfy the threshold.

Firstly, we consider using Fix DF protocol at the relay. In Fig. 8 symbol d indicates the distance from the source to the relay B or C. We consider two cases. The first case we only use one relay that satisfies the threshold and the second case we use two relays at the position A, B or A, C (The position of relay A is $d_{SR}=0.2, d_{RD}=0.8$, the position of relay B is $d_{SR}=0.2$, $d_{RD}=1.2$ or $d_{SR}=0.4$, $d_{RD}=1.4$ the position of relay C is$d_{SR}=1.2, d_{RD}=0.2$). From Fig. 8, using only the relay A is better than using all relays A, B or A, C when the SNR is small ($SNR < 10$). Specially, performance of using only relay A is always better than using two relays B, C (at target $BER = 10^{-3}$, the gains for using relay A can save 2dB in comparison with using two relays B, C). The reason is that when SNR is small, the signal can not surpass the effect of noise. In the case using Fix DF, the effect of noise at the relay B, C is so significant but the relay B, C don't check correctly of signal, they always forward signal to the destination. We combine those signals with signal from relay A at the destination, final signals also affect by the noise.

Continue considering effect of distance with perfect DF protocol at the relay, we compare using only relay A with using A, B or A, B, C as Fig. 9. Fig. 9 shows influence of distance when the position of the relay A is fix ($d_{SR} = 0.7, d_{RD} = 0.3$), position of relay B moves, using two relays A (or the system has two relays satisfied the threshold) or using all three relays. The performance of system with perfect checking at the relay is nearly same with Fix DF. The performance of choosing best relay is better than using all of relay when the SNR is small ($SNR < 10$). With the small SNR, at the relay B if signal is decoded correctly, but when it transmit to the destination, it can not surpass effect of the noise because the distance of relay B to the destination is too far (the distance from

the relay to the destination of relay B is $d_{RD} = d_{SR} + d_{SD}$). With the large SNR, the performance of using two relay A, B is better than using only one relay A. The performance of using relay A, B with position of relay B $d_{SR} = 0.4, d_{RD} = 1.4$ can save power 2dB in comparison with using only relay A at the target $BER = 0.7 \times 10^{-4}$. And when we compare using two relay A with relay A, B, C (position of relay B is $d_{SR} = 0.2, d_{RD} = 1.2$ and the position of relay C is $d_{SR} = 1.2, d_{RD} = 0.2$), the performance of using two relay A is better than using relay A, B, C when SNR is small ($SNR < 10$) and is worse when the SNR is large. The difference between choosing one relay and using all relays is that we can use only one time slot instead of using two slots. So using the best relay can save power, bandwidth.

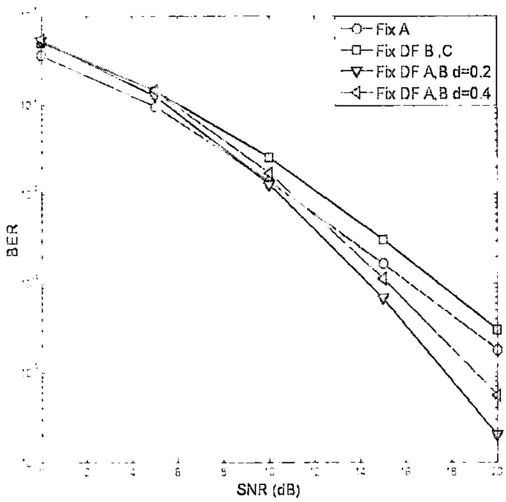

그림 8. Fix DF의 릴레이의 BER 성능 곡선
Fig. 8. BER performance of the relays using Fix DF

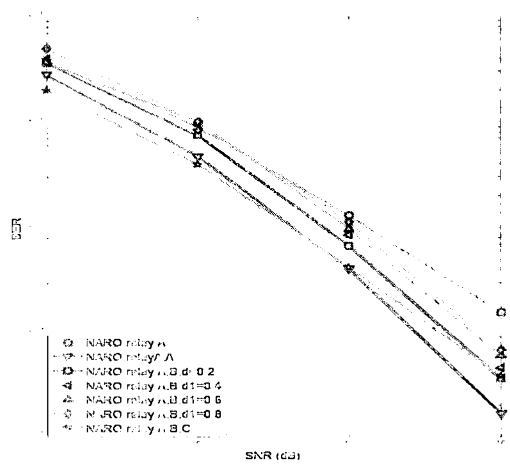

그림 9. Perfect DF의 릴레이 A, B, C
Fig. 9. BER performance of relay A, B, C using perfect DF

V. Conclusion

In this paper, we have shown a dependence of performance on the position of the relay when the relay uses DF protocol. Based on the threshold of distance, we choose the best relays in communication range of both source antenna and the destination antenna to retransmit signal when the destination fails to decode received signal from the source.

In the simulation, we compare the performance of using only the best relays that satisfy the threshold with the performance of using all relays. From the simulation results, we can see the efficiency of choosing the best relay in saving power and bandwidth.

However, in this paper, we only consider the straight line model so as the future work, we plan to develop our result in the practical system. For this purpose, the formula of distance $d_{SR} = d_{SR}\cos\theta$ with θ is angle between the S-D path and S-R path, and d_{SR} presents the distance from the source to the relay since they provide better tractability.

Appendix A

This appendix calculates the relay position for minimum BER of Fix DF in section III

Using fix DF from [7], we have

$$\begin{aligned} P_e &= \Pr[y=1|x=-1] \\ &= \Pr[-\sqrt{P_S}(|h_{SD}|^2+|h_{RD}|^2)+n>0]\Pr[\epsilon=1] + \\ &\quad \Pr[-\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)+n>0]\Pr[\epsilon=-1] \\ &= \overline{P_{e1}}(1-\Pr[\epsilon=-1])+\overline{P_{e2}}\Pr[\epsilon=-1] \\ &= \overline{P_{e1}}-\Pr[\epsilon=-1](\overline{P_{e1}}-\overline{P_{e2}}) \end{aligned} \tag{5}$$

where:

- $\Pr[\epsilon=-1]$ is the instantaneous error probability of BPSK signal transmission over Rayleigh Fading channel from the source to the relay.
- $\epsilon=-1$ mean the relay made wrong decision on the symbol.

We have

$$\Pr[\epsilon=-1] = \frac{1}{2}[1-\sqrt{\frac{P_S\lambda_{SR}^2/\sigma_{SR}^2}{1+P_S\lambda_{SR}^2/\sigma_{SR}^2}}] \tag{6}$$

$$\begin{aligned} P_{e1} &= \Pr[-\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)+n>0] \\ &= \Pr[n>\sqrt{P_S}(|h_{SD}|^2+|h_{RD}|^2)] \end{aligned} \tag{7}$$

$$P_{e2} = \Pr[n>\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)] \le \frac{1}{2} \tag{8}$$

From (7), (8) with $|h_{RD}|^2>0$, we have $\Pr[n>\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)] > \Pr[n>\sqrt{P_S}(|h_{SD}|^2+|h_{RD}|^2)]$

or $P_{e1}<P_{e2}$

from (5), $P_e \le \overline{P_{e1}}-\Pr[\epsilon=-1](\overline{P_{e1}}-\frac{1}{2})$

so to P_e is min, $\begin{cases} P_{e1} & is\min \\ \Pr[\epsilon=-1] & is\min \end{cases}$

$$\begin{aligned} \Pr[\epsilon=-1] &= \frac{1}{2}[1-\sqrt{\frac{P_S\lambda_{SR}^2/\sigma_{SR}^2}{1+P_S\lambda_{SR}^2/\sigma_{SR}^2}}] \\ &= \frac{1}{2}-\frac{1}{2}\sqrt{\frac{P_S\frac{d_{SD}^2}{d_{SR}^2}/\sigma_{SR}^2}{1+P_S\frac{d_{SD}^2}{d_{SR}^2}/\sigma_{SR}^2}} \end{aligned} \tag{9}$$

We assume the $d_{SD}=1, \sigma_{SR}^2=1$, from (9)

$$\Pr[\epsilon=-1]_{Min} \to d_{SR}\ is\min \tag{10}$$

$$\begin{aligned} P_{e1} &= \frac{\lambda_{RD}^2}{2(\lambda_{RD}^2-\lambda_{SD}^2)}[1-\sqrt{\frac{1}{1+\lambda_{SD}^2/P_S}}] \\ &\quad -\frac{\lambda_{SD}^2}{2(\lambda_{RD}^2-\lambda_{SD}^2)}[1-\sqrt{\frac{1}{1+\lambda_{RD}^2/P_S}}] \\ &= \frac{d_{SD}^2/d_{RD}^2}{2(d_{SD}^2/d_{RD}^2-1)}[1-\sqrt{\frac{1}{1+1/P_S}}] \\ &\quad -\frac{1}{2(d_{SD}^2/d_{RD}^2-1)}[1-\sqrt{\frac{1}{1+d_{SD}^2/d_{RD}^2P_S}}] \end{aligned} \tag{11}$$

From (10),

$$P_{e1_{min}} \to d_{RD_{min}} \tag{12}$$

From (10), (12) and $0.1 \le d_{SR}, d_{RD} \le 0.9$, we have the closer to the source, the better of performance of system.

Appendix B

This appendix calculates the relay position for minimum BER of Perfect DF in section III

From [8], we have:

$$P_{PSK} \le \frac{\sigma^2}{b_{PSK}^2 P_S \lambda_{SD}^2}\left(\frac{A^2}{P_S \lambda_{SR}^2}+\frac{B^2}{P_R \lambda_{RD}^2}\right) \quad (13)$$

Where:

$$A=\frac{1}{2}+\frac{\sin\Pi}{4\Pi},\ B=\frac{3}{16}+\frac{\sin\Pi}{4\Pi}-\frac{\sin 2\Pi}{32\Pi} \quad (14)$$

$$g_{PSK}=\sin^2(\Pi/2)$$

$$P_{PSK_{\min}} \to \frac{A^2}{P_S \lambda_{SR}^2}+\frac{B^2}{P_R \lambda_{RD}^2} \quad (15)$$

$$=\frac{A^2}{P_S d_{SD}^2/d_{SR}^2}+\frac{B^2}{P_R d_{SD}^2/d_{RD}^2}$$

We have $d_{SR}, d_{RD} = 0.1:0.1:0.9$, $d_{SR}+d_{RD}=1$ $P_{PSK_{\min}} \to d_{SR}=0.7, d_{RD}=0.3$

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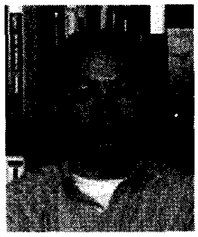

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