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협력 통신의 거리에 따른 성능 영향 분석

Distance Influence on Performance of Cooperative Communication Schemes in Wireless Networks

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요 약 본 논문에서는 중계기의 위치에 따른 협력 통신의 성능을 분석한다. 이를 통해 최적의 중계기는 송신단과 수신단의 신호 전송의 성능을 높이거나 송신단의 신호를 수신단이 복호하지 못하였을 경우 재전송을 하는 일종의 송신단 역할을 한다. 본 논문에서는 최적의 중계기를 선택함으로써의 성능 향상을 보이며 관련 수식을 유도한다.

Abstract In this paper, we analyze effects of positions of relays on the performance of cooperative communication networks. From this, the best relays are chosen to assist transmitting the signal to the destination or to replace the source to retransmit the signal to the destination whenever the destination incorrectly receives the signal from the source. As the results, we show the significant improvement on performance of schemes choosing best relays, which is compared to the performance of other cooperative schemes. Moreover, the simulation results that match exactly with the theoretical results prove the correctness of the analysis.

Key Words : Distance influence, AF, DF, ARQ protocol, Cooperative communication.

Ⅰ. Introduction

Signal fading due to multi path propagation is a serious problem in wireless communication which can be mitigated by deploying multiple antennas at transmitters. However, it is impossible to apply this technique in some scenarios where wireless mobiles may not be able to support multiple antennas due to size or other constraints. Spatial diversity has received a great deal of attention as the best solution to combat the detrimental effects of fading or noise. Spatial diversity can be created by enabling a single antenna mobile in multi user environment to share their antennas and to generate a virtual multiple antenna transmitters[1]. At the moment, three cooperative methods dealt with the attention of a lot of people are amplify and forward (AF), decode and forward (DF) and coded cooperation (CC)[2]. All of them help transmitting the signal from a source to a destination more reliability. AF strategy is the simplest way in which the partners amplify their received signal before they transmit it to the destination. DF strategy consists of fix DF and selective DF protocols. Both have the common features, in which relays decode its received signals before it performs transmitting the decoded signal to the destination. However, in the Fix DF protocol, the relay always forwards the decoded signal to the destination, it does not care about correctness of signal. On the contrary, in the Selective DF protocol, the relays only send the decoded signal to the

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destination when it is fully decoded. CC is the most efficient way but it is very complex to perform.

Cooperative communication is the efficient solution, however in deep fading environment, to ensure the accurate signal at the destination, the destination requires for resending signal whenever it receives an erroneous signal[3]. This technique is called as automatic repeat request (ARQ) protocol.

In wireless networks, relay nodes are placed arbitrarily so the problem to choose the best relay nodes is a necessary requirement. Many recently proposed papers have attended to solve the problem. In [4], Bin Zhao and Mathew proposed the way to choose the best relay based on position of relays. By this way, the authors proved that the system obtains a better performance on the throughput, energy delay tradeoff, total energy consumption. A solution for the relay scheduling problem based on the most geographical advantage is proposed by Zorzi and Ran in[5],[6]. However, in all papers, the authors did not show the best position of the relays. So in this paper, we analyze influence of distance to operation of cooperative communication schemes over the slow fading environment in two cases including cooperative cooperation and cooperative ARQ protocol.

Ⅱ. System Model

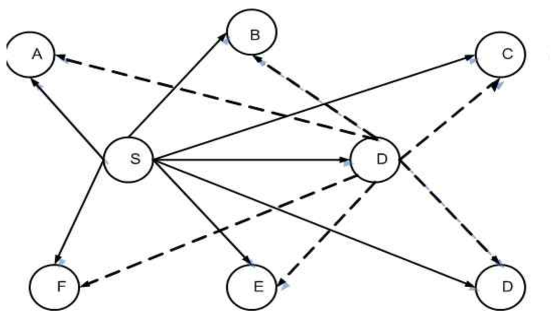

그림 1. 협력 ARQ 시스템 모델
Fig. 1. Cooperative ARQ system model.

We consider the operation of Cooperative ARQ protocol as shown in Fig. 1, in which a terminal S is a source, D is a destination. The antennas of the source and the destination are omni-directional antennas so A, B, C, D.. are relays in the communication range of both the source antenna and the destination antenna.

The distances from the source to the relay, the relay to the destination and from the relay to the destination are indicated by d_{SR}, d_{RD}, and $d_{SD}=1$,respectively.

Operation of ARQ protocol includes two phases. In the first phase, the source broadcasts signals to the destination and all relays, the received signals at the destination and 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}, y_{SR} are received signal at the destination and the relays, x is a sent symbol.h_{SD}, h_{SR_i} are channels responding from the source to the destination and from the source to the i^{th}relay which are assumed to be independent zero-mean complex Gaussian random variables. We denote λ_{SD}^2, λ_{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 i^{th} relay, d_{SD} is the distance from the source to the destination and β is the path loss exponent. For free space, we have $\beta=2$ [7].n_{SD}, n_{SR} is AWGN with variance σ_{SD}^2, σ_{SR}^2 at the destination and i^{th} relay. P_S is the transmitted power at the source.

In the second phase, if the destination receives an incorrect signal, it sends an informed message to request a retransmission. Signals at the relays are amplified with an amplification factor $\alpha_i=\sqrt{P_{R_i}/(P_S|h_{SR_i}|^2+\sigma_{SR_i}^2)}$. It then is forwarded to the destination by:

$$y_{R_iD}=h_{R_iD}\alpha_i y_{SR}+n_{RD} \quad (3)$$

where: P_{R_i} is power of the transmitted symbols at the i^{th} relay.

At the destination, detect performance is given by:

$$\widehat{x_{R_iD}} = \arg \underbrace{\min}_{x_i} (h^*_{SR_i} h^*_{R_iD} \sqrt{P_{R_i}} - y_{RD}) \quad (4)$$

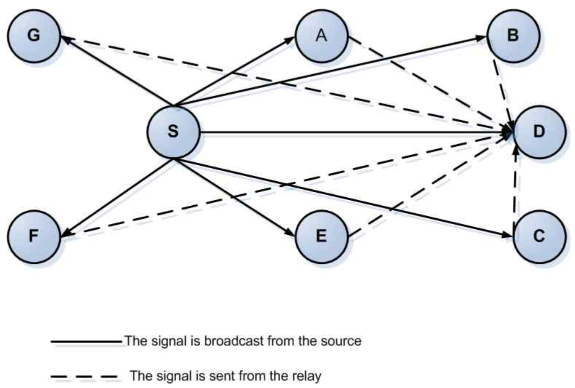

그림 2. 협력 통신 시스템 모델
Fig. 2. Cooperative communication system model.

In here, the destination only performs decoding the signal received from the relay as [10].

In cooperative communication system as shown in Fig.2, the operation of system also has two phases. Operation of the first phase is same with cooperative ARQ. In the second phase, the relay processes the signal and forwards it to the destination. At the destination, it combines both signals in two phases to decode. In the case, the relay uses Fix DF, it decodes and forwards decoded signal to the destination as:

$$y_{R_iD} = h_{R_iD} \sqrt{P_R}\, \widehat{y_{SR_i}} + n_{R_iD} \quad (5)$$

where

- $\widehat{y_{SR_i}}$ is decoded signal at the relay i. In the case of using BPSK, the decoded signal is performed as:

$$\widehat{y_{SR_i}} = sign(real(h^*_{SR_i} y_{SR_i})) \quad (6)$$

If the relay uses Perfect DF, it only sends the decoded signal to the destination when the received signal at the relay is correct.

Ⅲ. Performance Analysis

1. Distance Influence in Cooperative ARQ scheme.

The probability error for the symbol is calculated as

$$\Pr = \Pr_{SD} \Pr_{R} \quad (7)$$

where P_{SD} is the probability of error of the source destination link and is given as[7]

$$\Pr_{SD} = \frac{1}{\Pi} \int_0^{(M-1)\Pi/M} \left(1 + \frac{\overline{\gamma_{SD}} g_{PSK}}{\sin^2\theta}\right)^{-1} d\theta \quad (8)$$

where:

$g_{PSK} = \sin^2(\Pi/M)$ and $\overline{\gamma_{SD}} = P_S |h_0|^2 / \sigma^2_{SD}$ is the SNR at the destination. The $\Pr_R$ is the probability of error of the relay link is written as[8]:

$$\Pr_R = \frac{1}{\pi} \times \int_0^{(M-1)\Pi/M} \frac{\dfrac{4\overline{\gamma_p}(l(\phi) - \overline{\gamma_\sigma})}{\sqrt{l^2(\phi) - 4\overline{\gamma_p}}} ln\left(\dfrac{l(\phi) + \sqrt{l^2(\phi) - 4\overline{\gamma_p}}}{2\sqrt{\overline{\gamma_p}}}\right) + \overline{\gamma_\sigma} l(\phi) - 4\overline{\gamma_p}}{l^2(\phi) - 4\overline{\gamma_p}} \quad (9)$$

where

$\overline{\gamma_{SR}} = P_S |h_{SR}|^2 / \sigma^2_{SR}$, $\overline{\gamma_{RD}} = P_R |h_{RD}|^2 / \sigma^2_{RD}$ are the SNR at the relay and the destination $\overline{\gamma_\sigma} = \overline{\gamma_{RD}} + \overline{\gamma_{SR}}$,

$\overline{\gamma_p} = \overline{\gamma_{RD}}\,\overline{\gamma_{SR}}$, $l(\phi) = \overline{\gamma_\sigma} + \overline{\gamma_p} g_{PSK} / \sin^2(\theta)$.

From[8], we have the upper bound of the probability error at the destination as.

$$\Pr_{up} = \frac{1}{\Pi} \int_0^{(M-1)\Pi/M} \left(1 + \frac{g_{PSK}}{\sin^2(\theta)} \frac{\overline{\gamma_p}}{\overline{\gamma_\sigma}}\right)^{-1} d\theta \quad (10)$$

For special case of BPSK modulation, we have

$$\Pr_{up} = \frac{1}{\Pi} \int_0^{\Pi/2} \left(1 + \frac{1}{2\sin^2(\theta)} \frac{\overline{\gamma_p}}{\overline{\gamma_\sigma}}\right)^{-1} d\theta \quad (11)$$

Let $\dfrac{\overline{\gamma_p}}{\overline{\gamma_\sigma}} = a$, from (11), we have

$$\Pr_{up}=\frac{1}{\Pi}\int_0^{\Pi/2}\left(1+\frac{a}{2\sin^2(\theta)}\right)^{-1}d\theta$$
$$=\frac{2}{\Pi}\int_0^{\Pi/2}\left(\frac{\sin^2(\theta)}{\sin^2(\theta)+a}\right)d\theta$$
$$=\frac{2}{\Pi}\int_0^{\Pi/2}\left(1-\frac{a}{\sin^2(\theta)+a}\right)d\theta$$
$$=\left(1-\sqrt{\frac{a}{a+1}}\right) \tag{12}$$

$$=\left(1-\sqrt{\frac{\frac{\overline{\gamma_p}}{\overline{\gamma_\sigma}}}{\frac{\overline{\gamma_p}}{\overline{\gamma_\sigma}}+1}}\right)=\frac{1}{2}\left(1-\sqrt{\frac{\overline{\gamma_p}}{\overline{\gamma_p}+\overline{\gamma_\sigma}}}\right)$$
$$=\left(1-\sqrt{\frac{\overline{\gamma_{SR}}\,\overline{\gamma_{RD}}}{\overline{\gamma_{SR}}\,\overline{\gamma_{RD}}+\overline{\gamma_{SR}}+\overline{\gamma_{RD}}}}\right)$$

We consider the case, we use only one relay, so $P_S=P_R$, from (12), we have

$$\Pr_{up}=\left(1-\sqrt{\frac{\frac{d_{SD}^2}{d_{SR}^2}\frac{d_{SD}^2}{d_{RD}^2}}{\frac{d_{SD}^2}{d_{SR}^2}\frac{d_{SD}^2}{d_{RD}^2}+\frac{d_{SD}^2}{d_{SR}^2}+\frac{d_{SD}^2}{d_{RD}^2}}}\right)$$
$$=\left(1-\sqrt{\frac{1}{d_{SR}^2+d_{RD}^2+1}}\right) \tag{13}$$

In the simplest case, when $d_{SR}+d_{RD}=1$, from (13)

$$\Pr_{up}=\left(1-\sqrt{\frac{1}{d_{SR}^2+d_{RD}^2+1}}\right)$$
$$=\left(1-\sqrt{\frac{1}{d_{SR}^2+(1-d_{SR})^2+1}}\right) \tag{14}$$

$$\rightarrow \Pr_{\min}\rightarrow d_{SR}=d_{RD}=0.5 \tag{15}$$

From (14), we have influence of distance to BER as:

$$d_{SR}^2+d_{RD}^2=\frac{1}{(1-\Pr_{up})^2}-1 \tag{16}$$

2. Distance Influence in Cooperation scheme.

In the case, the relay uses Fix DF. In[7], we have the average BER as:

$$\overline{P_e}=\Pr[\overline{y}=1|x=-1]$$
$$=\Pr[-\sqrt{P_S}(|h_{SD}|^2+|h_{RD}|^2)+n>0]\Pr[\epsilon=1]+$$
$$\Pr[-\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)+n>0]\Pr[\epsilon=-1]$$
$$=\overline{P_{e1}}(1-\Pr[\epsilon=-1])+\overline{P_{e2}}Pr[\epsilon=-1]$$
$$=\overline{P_{e1}}-\Pr[\epsilon=-1](\overline{P_{e1}}-\overline{P_{e2}}) \tag{17}$$

where:

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

- $\epsilon=-1$ means the relay makes a wrong decision on the symbol.

We have

$$\Pr[\epsilon=-1]=\frac{1}{2}\left[1-\sqrt{\frac{P_S\lambda_{SR}^2/\sigma_{SR}^2}{1+P_S\lambda_{SR}^2/\sigma_{SR}^2}}\right] \tag{18}$$

$$P_{e1}=\Pr[-\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)+n>0]$$
$$=\Pr[n>\sqrt{P_S}(|h_{SD}|^2+|h_{RD}|^2)] \tag{19}$$

In[7], the authors divides into two cases. In the first case, both paths S-D, R-D have the similar quality. Or the positions of source, relay are placed in the circle with radius $r=d_{SD}=d_{RD}$.

The average BER is written as:

$$\overline{P_e}=\frac{1}{2}\overline{P_{e1}}\left(1+\sqrt{\frac{P_S\lambda_{SR}^2}{1+P_S\lambda_{SR}^2}}\right)+\frac{1}{2}\sqrt{\frac{P_S\lambda_{SR}^2}{1+P_S\lambda_{SR}^2}}$$
$$=\frac{1}{2}\overline{P_{e1}}\left(1+\sqrt{\frac{P_S}{d_{SR}^2+P_S}}\right)+\frac{1}{2}\sqrt{\frac{P_S}{d_{SR}^2+P_S}} \tag{20}$$

From (20), with $\overline{P_{e1}}=const$ and $\overline{P_{e1}}>0$, the minimum average BER of (20) obtains when d_{SR}^2 is minimum.

In the second case, the fading level of the channel of the propagation paths to the receiver is different from the other, we have:

$$P_{e2}=\Pr[n>\sqrt{P_S}(|h_{SD}|^2-|h_{RD}|^2)]\leq\frac{1}{2} \tag{21}$$

From (17), (18) 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 (20), $P_e \le \overline{P_{e1}} - \Pr[\epsilon = -1](\overline{P_{e1}} - \frac{1}{2})$

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

$$\Pr[\epsilon = -1] = \frac{1}{2}[1 - \sqrt{\frac{P_S\lambda_{SR}^2/\sigma_{SR}^2}{1 + P_S\lambda_{SR}^2/\sigma_{SR}^2}}] = \frac{1}{2} - \frac{1}{2}\sqrt{\frac{P_S\frac{d_{SD}^2}{d_{SR}^2}/\sigma_{SR}^2}{1 + P_S\frac{d_{SD}^2}{d_{SR}^2}/\sigma_{SR}^2}} \quad (22)$$

We assume the $d_{SD} = 1, \sigma_{SR}^2 = 1$, from (22) we have

$$\Pr[\epsilon = -1]_{Min} \rightarrow d_{SR}\ is \min \quad (23)$$

$$P_{e1} = \frac{\lambda_{RD}^2}{2(\lambda_{RD}^2 - \lambda_{SD}^2)}[1 - \sqrt{\frac{1}{1 + \lambda_{SD}^2/P_S}}] - \frac{\lambda_{SD}^2}{2(\lambda_{RD}^2 - \lambda_{SD}^2)}[1 - \sqrt{\frac{1}{1 + \lambda_{RD}^2/P_S}}]$$

$$P_{e1} = \frac{d_{SD}^2/d_{RD}^2}{2(d_{SD}^2/d_{RD}^2 - 1)}[1 - \sqrt{\frac{1}{1 + 1/P_S}}] - \frac{1}{2(d_{SD}^2/d_{RD}^2 - 1)}[1 - \sqrt{\frac{1}{1 + d_{SD}^2/d_{RD}^2 P_S}}] \quad (24)$$

From (24),

$$\overline{P}_{e1\min} \rightarrow d_{RD\max} \quad (25)$$

From (23), (25) and $0.1 \le d_{SR}, d_{RD} \le 0.9$, we have the closer to the source, the better of performance of system.

In the case, the relay uses Perfect DF, we calculate the relay position for minimizing BER of Perfect DF as:

From[9], we have:

$$P_{PSK} \le \frac{\sigma^2}{b_{PSK}^2 P_S \lambda_{SD}^2}(\frac{A^2}{P_S\lambda_{SR}^2} + \frac{B^2}{P_R\lambda_{RD}^2}) \quad (26)$$

Where:

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

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

$$P_{PSK_{\min}} \rightarrow \frac{A^2}{P_S\lambda_{SR}^2} + \frac{B^2}{P_R\lambda_{RD}^2} = \frac{A^2}{P_S d_{SD}^2/d_{SR}^2} + \frac{B^2}{P_R d_{SD}^2/d_{RD}^2}$$

We have

$$\frac{d_{SR}^2}{P_S/A^2} + \frac{d_{RD}^2}{P_R/B^2} = P_{PSK_{\min}} \quad (27)$$

In the simplest case $d_{SR}, d_{RD} = 0.1:0.1:0.9$, and $d_{SR} + d_{RD} = 1$,

$P_{PSK_{Min}} \rightarrow d_{SR} = 0.7, d_{RD} = 0.3$

Ⅳ. Simulation Results

In this section, we use Monte-Carlo simulation to verify the theory results in Section III, We use BPSK modulation. In all simulation, we assume that variances of Gaussian whilte noise equal 1 and the average BER curves modulation. In all simulations, we assume that variances of Gaussian white noises equal 1 ($\sigma_{SD}^2 = \sigma_{SR}^2 = \sigma_{RD}^2 = 1$) and the average BER curves are presented as a function of SNR. For fair comparison, the total energy of the cooperative system should not exceed that of corresponding of the direct transmission. If P_T is the power of the source in the direct transmission, in the first phase the power for transmitting signal from the source to the destination is $P_T/2$ and in the second phase, the power for each relay is $P_T/2R$ in which R is the number of relays used in the system.

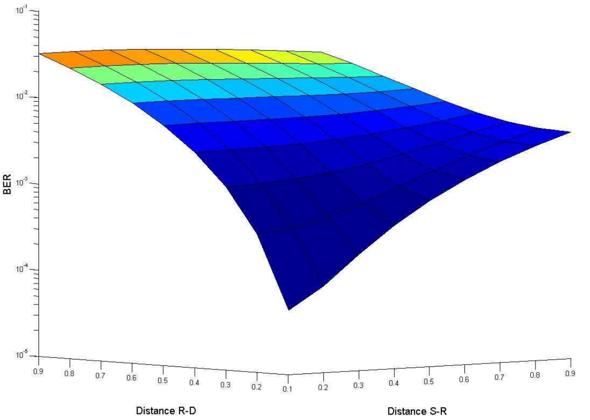

그림 3. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 3 BER performance vs. distance of fixed DF with $d_{SR}+d_{RD}=1$ over three dimensions

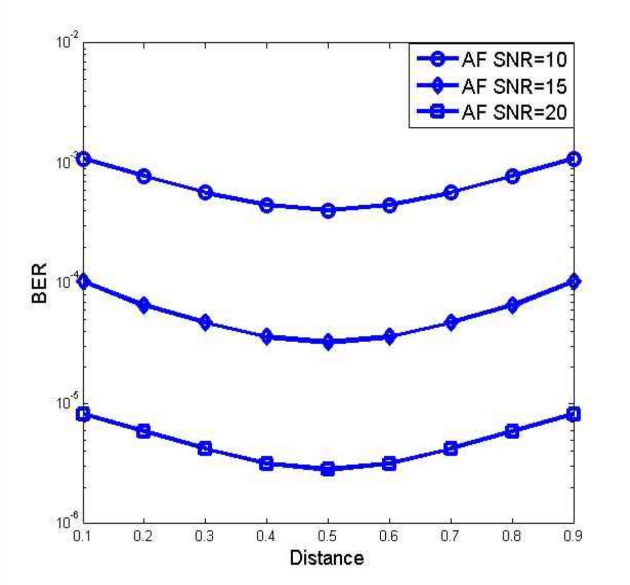

그림 4. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig 4. BER performance vs distance at different SNR using AF

In Fig 3, 4, we show the effect of distance on the performance of the system by two and three dimensions. The theoretical results match exactly with the simulation results, in which the best position of relays for cooperative ARQ protocol is $d_{SR}=d_{RD}=0.5$. Advantages of using the best relay in performance of ARQ protocol are shown in Fig 5 in which although the system uses only a relay A at the position $d_{SR}=0.5$, and $d_{RD}=0.5$, it obtains better performance than the system using two relays A, B (The position of relay B is $d_{SR}=0.5$, $d_{RD}=1.5$) or using relays A ,C (The position of relay C is $d_{SR}=1.5$, $d_{RD}=0.5$), when SNR is small. Especially, when we use two relays at position A, the system achieves better performance than the system using three relays at the position A, B, C in all values of SNR.

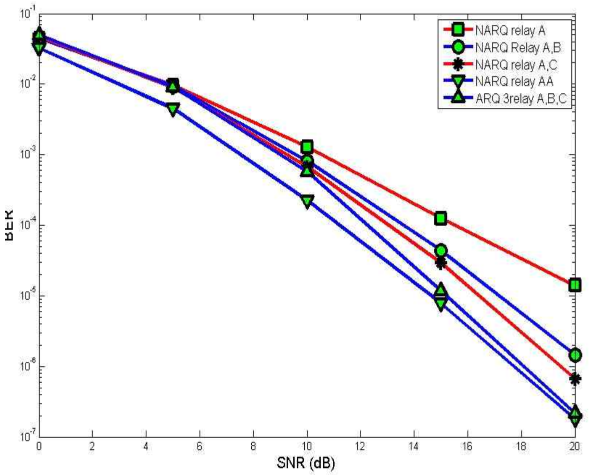

그림 5. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 5 BER performance with different positions of relays

In the Fig 6,7 we investigate the performance of the system when it uses the Fix DF protocol. As analyzed in Section Ⅲ, the best position of using Fix DF is the close to the source. Comparing performance of using 2 relays and 3 relays in cooperative communication with only one relay at the best position is show in the Fig 8. Performance of the system using only one relay A (at the position $d_{SR}=0.2$, $d_{RD}=0.8$) can save 4dB compared to performance of system using 2 relay A, B (The position of relay B is $d_{SR}=0.2$, $d_{RD}=0.8$) at $BER=10^{-3}$.

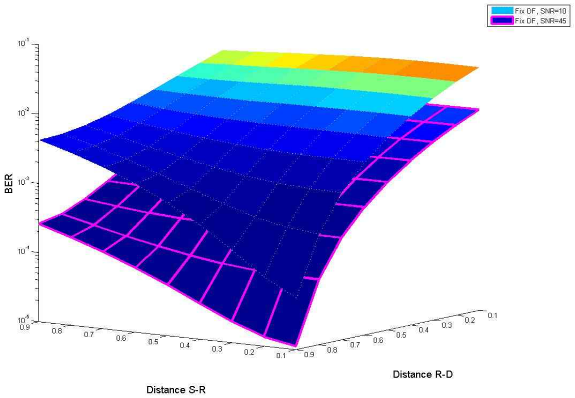

그림 6. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 6 BER performance vs distance when the SNR of the system changes

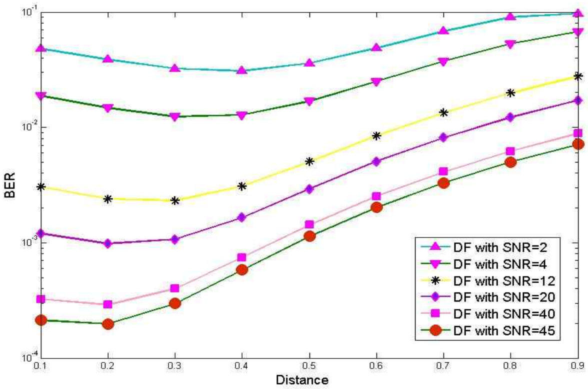

그림 7. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 7 BER performance vs distance S-R using fix DF with different values of SNR

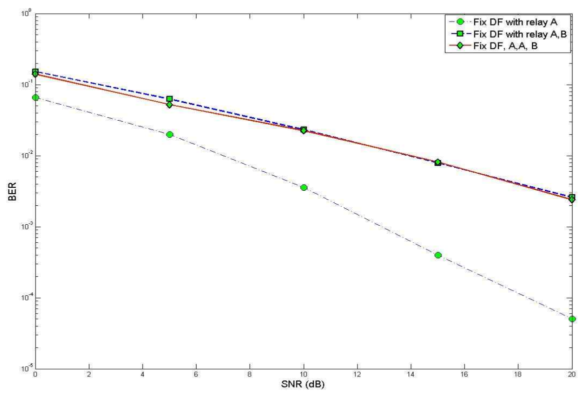

그림 8. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 8 The BER comparison of the system with different number of relays in Fix DF scheme

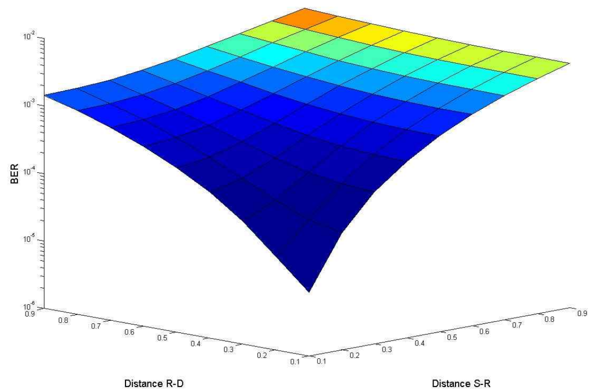

그림 9. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 9 BER performance of the system using perfect DF scheme in three dimensions.

Similarly, in the Fig 9, 10, 11, we show the average BER performance for the case of Perfect DF. The best position of relay in the figure is similar with analyzing in Section III. the best relay at the position $d_{SR}=0.7, d_{RD}=0.3$. Advantages of the system using only one relay at the best position in cooperative communication are show in the Fig. 11. From Fig.11, when we use two relays at the position $d_{SR}=0.6$, $d_{RD}=1.6$ and $d_{SR}=0.2, d_{RD}=1.2$, performance of the system using the best relay is better than that of the system using two relays.

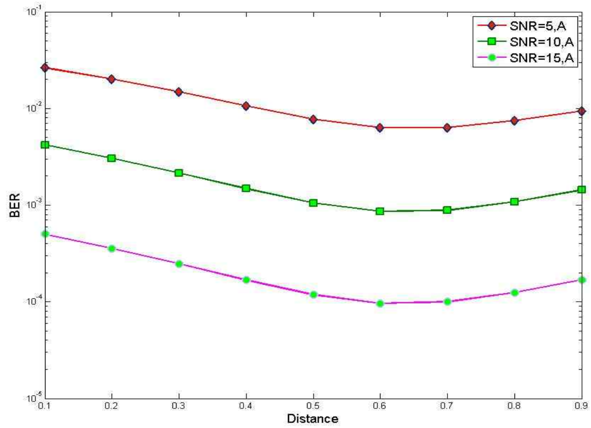

그림 10. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 10 BER performance of the system with different values of SNR

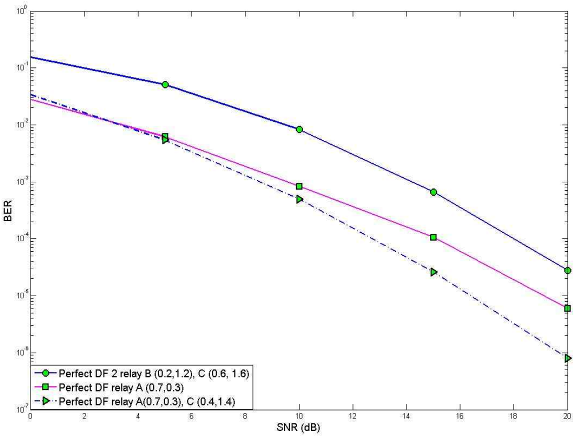

그림 11. $d_{SR}+d_{RD}=1$에서 증폭 후 재전송(AF)의 거리 대 BER 성능

Fig. 11 BER comparison of the system using perfect DF with different number of relays

V. Conclusion

In this paper, we have shown the influence of the relay position to perform of the system when the relay uses AF protocol, DF protocol. Based on distance from the source to the relay and the relay to the destination, we have chosen the best relays and proved advantages of the best relays compared the scheme without choosing the best relays. Simulation results prove the correctness of the theoretical results.

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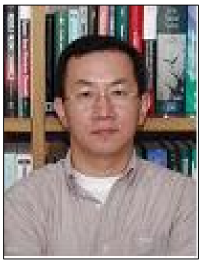

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