레일레이 페이딩하에서 무선 ad-hoc 네트워크를 위한 전력제한된 선택결합 협동다이버시티

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Power-limited Cooperative Diversity with Selection Combining in Rayleigh Fading for Wireless Ad-hoc Networks

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요 약

선택결합을 갖는 협동 다이버시티 시스템의 성능을 만족시키는 연결노드의 전력제어 범위를 검토하였다. 그리고 전력제한이 있는 연결노드가 시스템의 성능에 미치는 영향을 분석하였다. 레일레이 페이딩 하에서 각 경로의 평균 신호 대 잡음비가 동일할 경우, 연결노드가 하나이며 선택결합을 갖는 협동 다이버시티의 이득은 수신오율 1×10^{-3} 에서 13.5 dB 이다. 그리고 전력제한이 있는 연결노드는 시스템의 성능에 많은 영향이 있음을 알 수 있었다. 그러므로 ad-hoc 네트워크에서 전력제한이 있는 노드는 협동 다이버시티의 연결노드로 바람직하지 않다.

Key Words : Cooperative diversity, Relay Network, Selection combining.

ABSTRACT

Based on the performance of a cooperative diversity with selection combining in Rayleigh fading, the power control range of a relay node is investigated. Also the effect of the power-limited relay node to the system performance is investigated. If the average signal-to-noise ratio(SNR) of each signal path is equal, the single relay cooperative diversity is obtained 13.5 dB gain at the outage probability of 1×10^{-3} in Rayleigh fading. We noticed that the limited power of a relay node severely degrades the system performance. Therefore the node with limited power in ad-hoc network is not recommended as a relay node in cooperative diversity system.

Ⅰ. Introduction

Recently, relay transmission and cooperative diversity have been focused to mitigate the effects of shadow fading and to reduce power consumption of a wireless ad-hoc network[1-4]. The outage probability with a two-hop relayed transmission is derived for decode and forward(regenerative) and amplify and forward(non-regenerative) systems in Rayleigh fading channel[1]. More recently, a cooperative diversity with maximal ratio combining(MRC) which is coherently combines the signals from a source node and from a relay node is investigated to improve the performance of a relayed network in fading channel[4].

It is well known that MRC receiver has the

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best performance improvements in wireless fading channel compared to the other special diversity technique, however, it requires the perfect knowledge of the channel state information(CSI)[5, 6]. Moreover the performance of the MRC receiver is very sensitive to imperfect CSI. The tracking of rapidly changing CSI in Rayleigh fading increases a receiver complexity, consequently this causes more power consumption. Since a wireless ad-hoc sensor network is power limited, the increase of power consumption of each node is fatal to the network lifetime and network reliability[1, 7]. The optimum power allocation to prevent the power consumption and to increase the performance of MRC cooperative system has been is analyzed[8-10].

To avoid the complexity and the powerconsumption of MRC receiver, the selection combining is introduced. The selection diversity does not need to track the fading channel to obtain CSI which is necessary for MRC, consequently the receiver has simple structure and less power consumption[6, 11, 12].

Therefore, the main contribution of this paper is to address follows: Firstly, Based on the performance of a cooperative diversity with selectioncombining, the power control range of the relay node is investigated to satisfy the given outage probability. Secondly, the performance degradation caused by the power-limited relay node to the cooperative diversity system with selection combining is analyzed.

This paper is organized as follows. Section II provides backgroundregarding the system model under consideration. And the outage probability of cooperative selection diversity is described as a performance measure in Section II. The effect of the power limit of a relay node to the system performance is discussed in Section III. Section IV considers some numerical examples and reviews the results. Finally, Section V summarizes the results of this paper.

Ⅱ. System model of a cooperative diversity

2.1 System model

A system model of a cooperative diversity is shown in Fig.1. S, R and D denote source node, relay node, and destination node, respectively. In this work we consider single relay node for simplicity. Generally, there are two types of cooperative networks - decode and forward(DF) and amplify and forward(AF) cooperative networks. The relay node of DF networks decodes the received signalfrom the source node and forwards the decoded signal to the destination node. While that of the AF cooperative networks amplify and forwards the received signal to the destination node. Since a wireless ad-hoc network is power-limited, the AF cooperative diversity is preferred for the less power consumption than DF diversity[13]. In this paper, we consider the AF cooperativediversity and assume each wireless channel between nodes has independent Rayleigh fading.

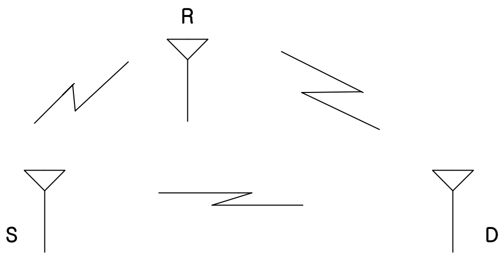

Figure 1. System model of a cooperative diversity.

The source node transmits during the firsttime slot and the relay node transmits during the second time slot. The signals from the source node and from the relay node are selection combined at the destination. Define the signal path from the source node to the destination node is direct(source-destination) path, and the signal path from the relay node to the destination node is relay(relay-destination) path.

The received signal at the destination node during the first time slot is given by

$$y_S = \sqrt{P_s} h_{SD} x + n_D \tag{1}$$

where h_{SD} denotes the channel gain between the source node and the destination node. P_s is the transmitted power at the source node and x is a binary information symbol. n_D, which has zero mean and complex Gaussian distributed with variance N_0, denotes additive white noise.

And the received signal at the destination node during the second time slot can be written by

$$y_R = \sqrt{P_R}\, h_{RD} u + n_D \qquad (2)$$

where P_R is the transmitted power at the relay node. h_{RD} denotes the channel gain between the relay node and the destination node. u equals $\sqrt{P_s}\, h_{SR} x + n_R$ where h_{SR} denotes the channel gain between the source node and the relay node . And n_R, which has zero mean and complex Gaussian distributed with variance N_0, denotes additive white noise.

2.2 Selection combining diversity

As mentioned earlier, MRC receiver requiresco-phasing and weighting blocks in a receiver. This leads receiver complexity and power consumption. To avoid these blocks, we consider selection combining cooperative diversity.

Selection combing selects the strongest signal among the received signals. When all of the received SNR of the n branches are simultaneously less than or equal to a given threshold SNR Γ, then the outage is occurred. The outage probability $P_{out}(\Gamma)$ is given by [11]

$$P_{out}(\Gamma) = \Pr(\gamma_1, \gamma_2, ..., \gamma_n \le \Gamma) \qquad (3)$$

where $\gamma_i\,(1 \le i \le n)$ is the instantaneous SNR of each antenna branch. If we assume the received SNR of each branch is independent, the outage probability is written by

$$P_{out}(\Gamma) = \Pr(\gamma_1 \le \Gamma)\Pr(\gamma_2 \le \Gamma)...\Pr(\gamma_n \le \Gamma) \qquad (4)$$

In our system model in Fig.1, there are two receiving signals at the destination node; signals from the direct path during the first time slot and from the relay path during the second time slot. The outage probability $P_{D,out}(\Gamma)$ of the direct path in Rayleigh fading is given by [11]

$$\begin{aligned} P_{D,out}(\Gamma) &= \Pr(\gamma_D \le \Gamma) \\ &= 1 - \exp(-\Gamma/\bar{\gamma}_{SD}) \end{aligned} \qquad (5)$$

where γ_D and $\bar{\gamma}_{SD}$ is the instantaneous received SNR and the average received SNR of the direct path, respectively. The outage probability $P_{R,out}(\Gamma)$ of the relay path in Rayleigh fading is given by [1], [4]

$$\begin{aligned} & P_{R,out}(\Gamma) \\ &= \Pr(\gamma_R \le \Gamma) \\ &= 1 - \frac{2\Gamma}{\sqrt{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}} K_1\left(\frac{2\Gamma}{\sqrt{\bar{\gamma}_{SR}\bar{\gamma}_{RD}}}\right)\exp\{-\Gamma(\bar{\gamma}_{SR}+\bar{\gamma}_{RD})/\bar{\gamma}_{SR}\bar{\gamma}_{RD}\} \end{aligned} \qquad (6)$$

where γ_R is the instantaneous received SNR of the relay path. $\bar{\gamma}_{SR}$ and $\bar{\gamma}_{RD}$ denotes average received SNR from the source node to the relay node, and from the relay node to the destination node, respectively. K_1 is the 1st order modified Bessel function of the 2nd kind.

Assume the received signals are independent each other, the outage probability of selection combining can be written by

$$P_{out}(\Gamma) = P_{D,out} P_{R,out} \qquad (7)$$

III. Power limit of a relay node

The performance of cooperative diversity system can be improved under the assumption of the enough power of each node. In ad-hoc networks, however, there are many nodes between source and destination node. Each node can be different power. In this case there are many possibility to take different routes. An excess transmit power node is not desirable as a relay node. The excess power interferes to the other information path. Generally, a sensor network has insufficient power. Therefore power limited relay node cannot satisfy the required performance at destination because of the insufficient transmit power. In this section, the effect of the limited power node to the system performance is analyzed.

Assume the transmit power of the relay node is limited, and define the power limit coefficient β is

$$\beta = \frac{\bar{\gamma}_{RD,\max}}{\bar{\gamma}_{SR}} \qquad (8)$$

where $\bar{\gamma}_{RD,\max}$ is the maximum average received SNR of destination node when the relay node transmits maximum power. When the transmit power of the relay node is limited, the outage probability $P_{R,out}(\Gamma)$ of the relay path is obtained by replacing $\bar{\gamma}_{RD}$ in (6) to $\bar{\gamma}_{RD,\max}$ in (8),

$$P_{R,out}(\Gamma) = 1 - \frac{2\Gamma}{\bar{\gamma}_{SR}\sqrt{\beta}} K_1\left(\frac{2\Gamma}{\bar{\gamma}_{SR}\sqrt{\beta}}\right)\exp\{-\Gamma(1+\beta)/\beta\bar{\gamma}_{SR}\} \quad (9)$$

In (9), the outage probability is a function of the power limit coefficient β.

IV. Numerical results

For a numerical example of the no power limited case, we assume the received average SNR from the source-relay path $\bar{\gamma}_{SR}$ equals that of the relay(relay-destination) path $\bar{\gamma}_{RD}$ and define $\bar{\gamma}_R = \bar{\gamma}_{SR} = \bar{\gamma}_{RD}$. Fig.2 shows the performance of the cooperative diversity with selection combining where sc div. means cooperative diversity with selection combining and no. div means no diversity system. In this figure $\bar{\gamma}_{SD}$ denotes the received average SNR at destination node from the direct(source-destination) path. The system gain equals 13.5 dB for $\bar{\gamma}_{SD} = \bar{\gamma}_{RD}$, 15 dB for $\bar{\gamma}_{SD} = 0.5\bar{\gamma}_{RD}$, and 17 dB for $\bar{\gamma}_{SD} = 0.2\bar{\gamma}_{RD}$ at the outage probability of 1×10^{-3}. The gain increases with the direct path average SNR decreases. It is interpreted that the cooperative diversity is more effective when the received SNR from the direct path is poor.

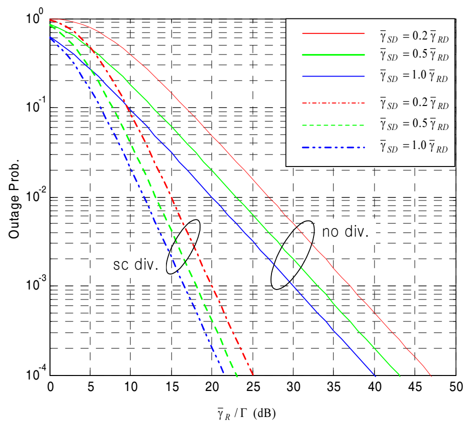

Figure 2. Outage probability of cooperative diversity with selection combining.

Fig. 3 shows the improvement in outage probability of pure selection combining with number of relay nodes at a given average SNR of the direct path to satisfy the outage probability of 1×10^{-3}. Though it is not linear, the performance, as we expected, the performance improves with the number of relay nodes. This figure shows that the best performance improvement is obtained when the number of relay node equals one. If the average SNR from the direct path and from the indirect path(relay node) are equal, the gain is 13.5 dB and 17.8 dB with single relay node and with two relay nodes, respectively.

Fig.4 shows the general trend of outage probability of selection combining as functions of $\bar{\gamma}_{SR}$ and $\bar{\gamma}_{RD}$. It is noticed that the outage probability is decreased with the average received SNR $\bar{\gamma}_{RD}$.

When the average SNR from the direct path and from the relay path are equal, the power control range of a relay node of selection combining at

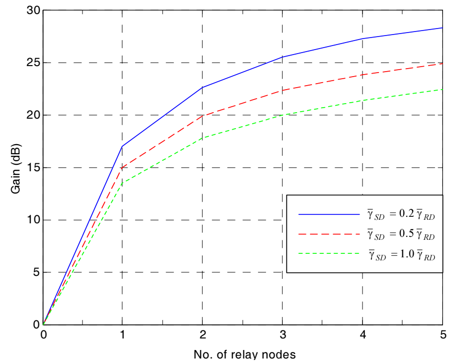

Figure 3. Gain of a cooperative selection diversity with selection combining($P_{out} = 1\times10^{-3}$)

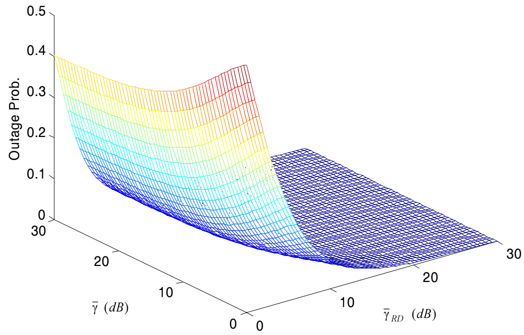

Figure 4. Outage probability vs. $\bar{\gamma}$ and $\bar{\gamma}_{RD}$ of selection combining ($\bar{\gamma} = \bar{\gamma}_{SD} = \bar{\gamma}_{SR}$).

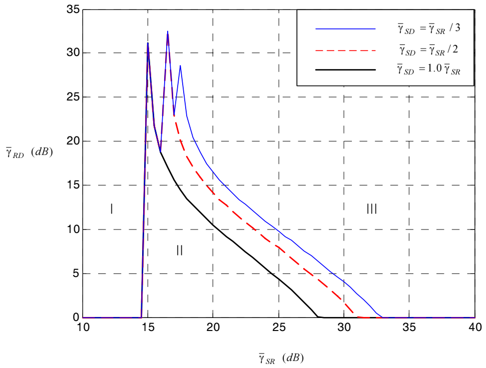

Figure 5. Power control of a relay node with selection combining($P_{out} = 1\times10^{-3}$)

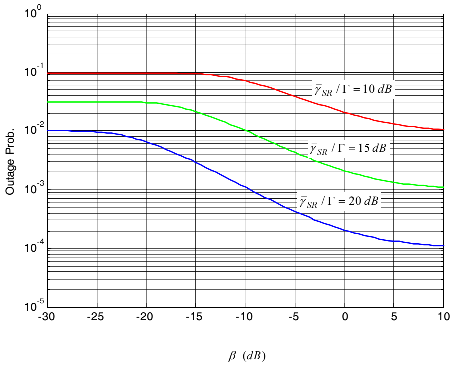

Figure 6. Outage probability versus β ($\bar{\gamma}_{SD} = \bar{\gamma}_{SR}$)

the outage probability of 1×10^{-3} is shown in Fig. 5. For example, for a given $\bar{\gamma}_{SR} = 20\,dB$, the required average SNR from the relay node is 10.5 dB when $\bar{\gamma}_{SD} = \bar{\gamma}_{SR}$, 14.2 dB when $\bar{\gamma}_{SD} = \bar{\gamma}_{SR}/2$, , and 16.5 dB when $\bar{\gamma}_{SD} = \bar{\gamma}_{SR}/3$. The power control of a relay node cannot satisfy the outage probability of 1×10^{-3} in area I(unable area).

And within area III(no-need area), the direct path is enoughto satisfy the outage probability. The area II(power control area) is the available power control area of the relay node and shows the required average SNR of the relay node to achieve the outage probability of 1×10^{-3}. The power control range is 14 dB(28.5 ~ 14.5 dB), 15.5 dB(31.5~16 dB), and 16 dB(33~17 dB) when $\bar{\gamma}_{SD} = \bar{\gamma}_{SR}, \bar{\gamma}_{SD} = \bar{\gamma}_{SR}/2$, and $\bar{\gamma}_{SD} = \bar{\gamma}_{SR}/3$, respectively.

Fig. 6 shows the outage probability versus power limit coefficient of selection combining diversity system($\bar{\gamma}_{SD} = \bar{\gamma}_{SR}$). For example, when $\bar{\gamma}_{SR}/\Gamma = 15\,dB$ and β is less than −18 dB, the outage probability approaches to that of the no diversity system. When β is greater than −18 dB, the outage probability, however, decreases with β. It means that the performance of the cooperative diversity is sensitive to the power limit factor. We can conclude that the performance improvements of a cooperative diversity is limited by the maximum transmit power of the relay node.

V. Conclusions

In this work we consider the performance of a selectioncombining cooperative diversity in Rayleigh fading. When the received average SNR of the source-relay path, the relay-destination path, and the source-destination path are equal, the system gain of selection combining cooperative diversity is 13.5 dB at the outage probability of 1×10^{-3} .

And the power control range of the relay node is investigated to satisfy the given outage probability. For a given outage probability, the power control range of the relay node can be divided three areas; unable area, power control area, and no-need area. The power control of the relay node cannot reach the given outage probability in unable area. Because the direct path is enough to satisfy the given outage probability, the relay path is not necessary in the no-need area. In the power control area, the transmit power of the relay node can be controlled to satisfy the given outage probability, consequently this power control prevents power consumption and interference to the other nodes.

The performance degradation caused by the power-limited relay node to the cooperative diversity system with selection combining is analyzed. We can conclude that the performance improvement of a cooperative diversity is limited by the maximum transmit power of the relay node. Therefore the node with limited power in ad-hoc network is not recommended as a relay node in cooperative diversity system.

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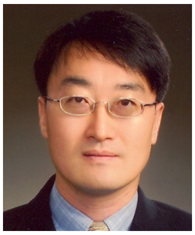

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