레일레이 페이딩 채널에서 무선 애드 혹 네트워크의 협동라우팅

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Cooperative Routing of Wireless Ad-hoc Networks in Rayleigh Fading Channel

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요 약

본 논문에서는 무선 애드혹 네트워크에서 전력 절약과 성능 개선을 위하여 협동 공간 다이버시티를 이용한 새로운 협동다이버시티 라우팅 방식을 제안한다. 제안한 방식은 기존에 사용되어온 방식인 다중 릴레이 라우팅 방법과 해석적인 방법으로 성능의 우수성을 비교하였다. 7개의 노드를 갖는 애드혹 네트워크에서 최종 노드에서 요구되는 오수신율이 1×10^{-3}일 때, 제안한 협동다이버시티 라우팅 방식은 다중 릴레이 라우팅방식과 비교하여 노드당 평균 15.5 dB 전력을 절약할 수 있었다.

Key Words : Ad-hoc network, Fading channel, Cooperative diversity, Routing, Power saving

ABSTRACT

We propose new routing scheme, Cooperative Diversity-based Routing (CDR) which utilizes the cooperative space diversity for power saving and performance enhancement of wireless ad-hoc networks. The improved performance is compared with Multi-hop Relay Routing (MRR) by analytical methods. When the required outage probability is 1×10^{-3} at the destination node in ad-hoc networks with 7 nodes, we noticed that each node can save power consumption by 15.5 dB in average, by using our proposed CDR compared to MRR.

Ⅰ. Introduction

In modern wireless ad hoc networks, multi-hop routing is used to deliver messages from a source to a destination. At each hop, the probability of successful transmission is dependent on the signal-to- noise ratio at the intended receiver of the transmission. Most nodes of wireless ad-hoc networks are power-limited, the power consumption becomes a critical issue in an ad hoc network design[1,2]. Especially, routing strategy that provides the maximum possible reliability and less power consumption is preferred. Nowadays, the node equipped with the Global Positioning

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System (GPS) makes it possible to provide location information. Since with the aids of GPS a source node knows the direction toward a destination node, multi-hop routing from a source node to a destination node via relay nodes is possible.

On the other hand, cooperative diversity technology, which mitigates the fading impairment in wireless channel, at the physical layer is introduced[3,4]. Multiple nodes in a network transmit the same signal and share their antenna to generate a virtual array. This technology utilizes the space diversity that receives the multiple faded copies of information from different transmitters and combines them to improve system performance without sacrifice spectrum resources.

Previous work[5] develops the end-to-end performance of multi-hop routingwith cooperative diversity on two-hops systems by analytical method derived in both non-regenerative and generative systems with Rayleigh fading channel. In[6], average symbol error probability is investigated when sufficiently high signal-to-noise ratio (SNR) is guaranteed for the Amplify and Forward Link with multiple cooperating branches

It is recently investigated[7,8], through Monte Carlo simulation, that the cooperative diversity technique can be applied to provide the network with substantially improved network performance. Later, M. Haenggi[9] studied on the performance of cooperative diversity in ad-hoc networks in analytical method. However, he assumed that the distance between any pair of nodes is deterministic and SNR is always sufficiently high.

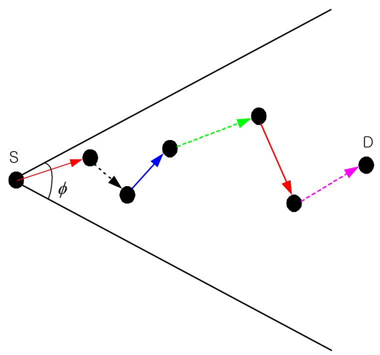
In this paper, we propose cross layer optimization technique for cooperative diversity, named as Cooperative Diversity-based Routing (CDR), which supports the power saving routing in ad-hoc networks. We assumed the communication nodes are distributed uniformly in ad-hoc networks. With this assumption, we can obtain the statistical mean distance between neighbor nodes. Also the generally accepted Rayleigh fading model is considered for the performance analysis of CDR. The improved performance is compared with Multi-hop Relay Routing (MRR) by analytical methods[10].

The rest of this paper is organized as follows. Section 2describes two different routing strategies of MRR and CDR. In Section 3, outage probability is derived analytically and the performance of two routing strategies is compared in Rayleigh fading channel. In Section 4, the numerical results are given, and finally we conclude our work in Section 5.

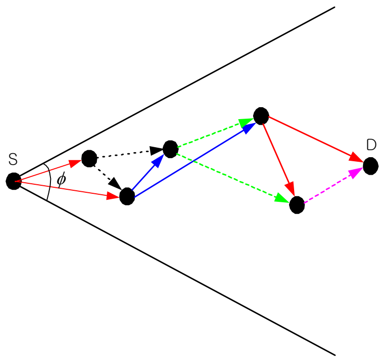
Ⅱ. Routing strategies

2.1 Routing Scheme

Fig. 1 describes two different routing strategies. S and D represent source node and destination node, respectively. For practical application, it is assumed that every node knows the location of itself and destination, so that a source node knows the direction towards destination. Fig.1 (a) shows MRR which is used conventionally as a routing scheme in ad hoc network. MRR regulates that a source node transmits a message to the nearest neighbor of it in a sector ϕ in the direction towards a destination node. Then, the message isrelayed to the next nearest neighbor of each relay nodes along the route from the source node to the final destination node. This multi-hop process is repeated until the transmitted message is reached to the final destination node.



(a) MRR



(b) Proposed CDR

Fig. 1. Routing strategies.

On the other hand, Fig. 1(b) shows the proposed CDR which is the nearest neighbor cooperative routing. CDR utilizes the cooperating node in addition to relaynode to mitigate the fading effect in Rayleigh fading channel. In this routing strategy, a transmit node transmits an information to the nearest neighbor node and to the 2nd nearest neighbor node simultaneously. Next time, the receiving node transmits the regenerated information to the nearest neighbor node and to the 2ndnearest neighbor node toward the destination node simultaneously. This multi-hop process is repeated to the destination node.

Fig. 1(b) describes CDR we propose. CDR utilizes cooperativediversity to mitigate fading effect through relay node which decodes and forward the received message from a previous transmitter. The proposed algorithm of CDR is as follow: a source node transmits a message to the first and the second nearest neighbors simultaneously by using broadcasting nature of transmission in wireless network at first. Here, we assume that every node knows the information about the locations of all the neighbors linked to it by GPS.

Next time slot, the first nearest neighbor which received the information message from the source node in the previous time slot will transmit to the fist and the second nearest neighbors toward the destination node simultaneously as the previous transmission to utilize cooperative diversity. This multi-hop process is repeated until the transmitted message is reached to the final destination node.

2.2 Node distribution

We assume that nodes are distributed uniformly with a density λ in the network area. Then, the probability that there are u nodes in an area A is given by Poisson distribution[11],

$$P\ [u\ nodes\ in\ A]\ =\ e^{-\lambda A}\frac{(\lambda A)^u}{u!}\ . \tag{1}$$

In a random network with uniform distribution and unit density ($\lambda = 1$), the probability density function of the distance d to the nth nearest neighbor in a sector ϕ is given by[12]

$$P_{d_n}(d) = d^{2n-1}\left(\frac{\phi}{2}\right)^n \frac{2}{(n-1)!} e^{-(d^2\phi/2)} \ . \tag{2}$$

$P_{d_1}(d)$ is Rayleigh distribution function for $n=1$, which means that the random variable of distance d between a node and its nearest neighbor in a sector ϕ has Rayleigh distribution. The expected value of the random variable d_n which is the distance between a source node and the nth nearest neighbor in a sector ϕ is given by

$$\begin{aligned} E[d_n] &= \int d_n\, p_{d_n}(d)\, dp \\ &\approx \sqrt{\frac{4(n-1)+\pi}{2\phi}} \end{aligned} \tag{3}$$

where the last approximation can be found in[13].

Ⅲ. Performance analysis

3.1 MRR

Generally, there are two types of relay node; Decode and Forward (DF) and Amplify and Forward(AF) relay node. The DF relay node decodes the received signal from a source node and forwards the decoded signal to the next relay node. The AF relay node amplifies and forwards the received signal to the next relay node. In this paper, we consider the DF relay node only for simplicity and assume that all the wireless communication channels are under independent Rayleigh fading.

When there are Nnodes in a wireless network, the outage is declared when all of the received SNR of each node are simultaneously less than or equal to a given threshold SNR Γ. Assuming that the received SNR of each node is independent, the outage probability from a source node to a destination node is given by

$$P_{out}(\Gamma) = \Pr(\gamma_2 \le \Gamma)\Pr(\gamma_3 \le \Gamma)\ldots\Pr(\gamma_N \le \Gamma) \tag{4}$$

where Γ denotes threshold SNR and γ_i $(2 \le i \le N)$ is the instantaneous received SNR of the ith node. In Rayleigh fading channel, the outage probability of MRR which has N-1 hops from a source node to a final destination node is given by[14]

$$P_{out}(\Gamma) = 1-\exp(-\sum_{i=2}^{N}\frac{\Gamma}{\overline{\gamma}_i}) \tag{5}$$

where $\overline{\gamma}_i$ $(2 \le i \le N)$ is the average received SNR of the ith node.

The expected value of the received signal power is the function of distance and propagation loss exponent α, which is given by

$$S_R = P_0 d^{-\alpha} \tag{6}$$

where S_R is the received signal power, P_0 is the transmit power, d is the transmission distance. It is known that α is ranged from 2 to 5 in wireless fading channel[10].

3.2 Proposed CDR

The simple model of a cooperative diversity, which has single relay node, is shown in Fig. 2. S, R and D represent source node, relay node, and destination node, respectively. The transmission from the source node occurred at first. Then, once the message is received at both of the two intended receivers, the relay node regenerates and transmits the message at a later time slot. The destination will compare the signals from both the source and the relay node separately, and selects the signal with higher instantaneous SNR for decision to utilize the selection combining diversity.

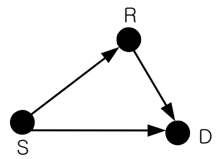


Fig. 2. Simple cooperative diversity model.

As shown in Fig. 2, in this cooperative diversity model, there are two independent signals received separately at the destination site. The one is the signal from the direct path (S-D) via the first transmission and the other one is from the relay path (S-R-D) via later transmission. The outage probability $P_{D,out}(\Gamma)$ of the direct path in Rayleigh fading is given by[15]

$$\begin{aligned} P_{D,out}(\Gamma) &= \Pr(\gamma_D \le \Gamma) \\ &= 1-\exp(-\Gamma/\overline{\gamma}_{SD}) \end{aligned} \tag{7}$$

where γ_D and $\overline{\gamma}_{SD}$ are the instantaneous and the average SNR at the destination node for the signal transmitted via the direct path from the source node, respectively. The outage probability $P_{R,out}(\Gamma)$ of the relay path is given by[14]

$$\begin{aligned} &P_{R,out}(\Gamma) \\ &= 1-\Pr(\gamma_{SR} \ge \Gamma)\Pr(\gamma_{RD} \ge \Gamma) \\ &= 1-\exp\{-\Gamma(\overline{\gamma}_{SR}+\overline{\gamma}_{RD})/\overline{\gamma}_{SR}\overline{\gamma}_{RD}\} \end{aligned} \tag{8}$$

where $\overline{\gamma}_{SR}$ represents the average SNR at the relay node for the signal transmitted from the source node, and $\overline{\gamma}_{RD}$ represents the average SNR at the destination node for the signal transmitted from the relay node.

Under the assumption that the received signals from each paths are independent for simplicity, the outage probability with the selection combining diversity can be given by

$$P_{out}(\Gamma) = P_{D,out} P_{R,out} \,. \qquad (9)$$

Now, we can expand the simple cooperative diversity model analysis to the N nodes ad-hoc network model in general, which is described in Fig. 3.

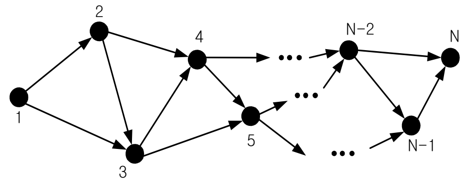


Fig. 3. Proposed CDR with N nodes.

The node 1 and the node N represent the source and the destination nodes, respectively. In this routing, the outage probability of node k, $P_{k,out}$ is given by

$$P_{1,out} = 0,$$
$$P_{2,out} = 1 - \exp(-\Gamma / \bar{\gamma}_{12}), \qquad (10)$$
$$P_{k,out} = \{1 - P_{(k-2),s} P_{(k-2)k,s}\}\{1 - P_{(k-1),s} P_{(k-1)k,s}\}, \quad 3 \le k \le N$$

where $\bar{\gamma}_{12}$ represents the average SNR at the node 2 site for the signal transmitted from the node1, and

$$P_{(k-j),s} = 1 - P_{(k-j),out},$$
$$P_{(k-j)k,s} = 1 - P_{(k-j)k,out}, \quad 3 \le k \le N, \; j = 1, \, 2 \qquad (11)$$

where $P_{nm,out}$ and $P_{nm,s}$ are the outage probability and the probability that the message is transmitted successfully from the node n to the node m, respectively. In Rayleigh fading channel $P_{nm,out}$ is given by

$$P_{nm,out} = 1 - \exp(-\Gamma / \bar{\gamma}_{nm}) \qquad (12)$$

where $\bar{\gamma}_{nm}$ represents the average SNR at the node m site for the signal transmitted from the node n, which is given by

$$\bar{\gamma}_{nm} = \frac{P_{0n} d_{nm}^{-\alpha}}{N_0} \qquad (13)$$

where P_{0n} is the transmission power from the node n, N_0 is the noise power of each node, and α is the propagation loss exponent given in (6). When the nodes are uniformly distributed in the network, the random variable d_{nm} which is the distance from the node n to the node m is given in (3). Suppose that the transmission power of all nodes are identical: $P_{0n} = P_0$, then (13) becomes

$$\bar{\gamma}_{nm} = \frac{P_0}{N_0} d_{nm}^{-\alpha} = (SNR)_{Tx} \, d_{nm}^{-\alpha} \qquad (14)$$

where $(SNR)_{Tx}$ is the SNR for the signal transmitted, which is given by $(SNR)_{Tx} = P_0 / N_0$.

V. Numerical examples

As we described previously, we assume that each node within a sector ϕ transmits with equal power and nodes are distributed uniformly in the network for simplicity. Fig. 4 shows the numerical results of outage probability at the destination node by MRR and by the proposed CDR with $\phi = \pi/2$ and α =3 in Rayleigh fading channel. It is noticed that the proposed CDR has better performance than MRR. When the required outage probability at the destination node in the network with 7 nodes is 1×10^{-3}, the satisfied SNRs for the transmitted signal from each node are 37.5 dB and 22 dB, which are normalized by the threshold SNR Γ, for the MRR and for the CDR, respectively. We obtain the power gain of15.5 dB with the proposed CDR scheme compared to the MRR, which means each node can save power consumption by 15.5 dB in average. When the numbers of node are 3 in the network, the power gain is 12.4 dB.

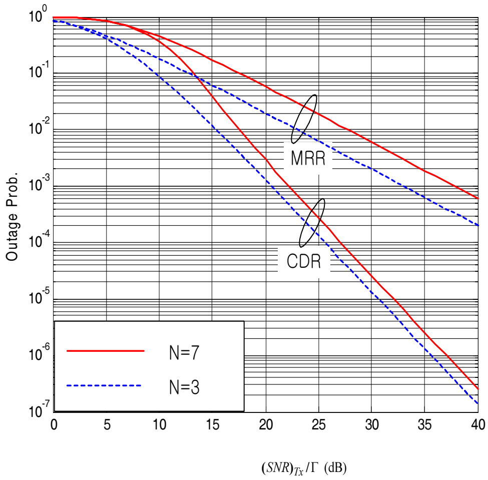


Fig. 4. Outage probability of MRR and CDR ($\phi=\pi/2$, $\alpha=3$).

Fig. 5 shows the numerical results of the power gain by the proposed CDR. It is noted that the power gain increases as the number of nodes increases for both the cases of $\phi=\pi/2$ and $\phi=\pi/4$. The results shows that the gain with $\phi=\pi/4$ is less than with $\phi=\pi/2$. It is because that the value of the average distance between nodes increases as the value of ϕ decreases as described in (3).

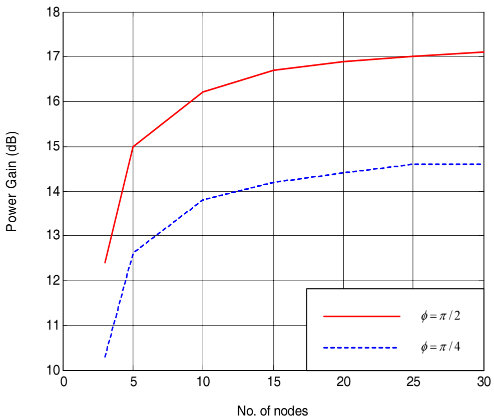


Fig. 5. Power gain ($\alpha=3$, $P_{out}=1\times10^{-3}$).

Ⅳ. Conclusions

We studied cross-layer approach to utilize cooperative diversity for supporting the power saving routing in wireless ad-hoc networks in analytical method. When the required outage probability is 1×10^{-3} at the destination site in ad-hoc networks with 7 nodes, the satisfied SNRs for the transmitted signal from each node are 37.5 dB and 22 dB, which are normalized by the threshold SNR, for the MRR and for the CDR, respectively. It means that we can achieve power gain of 15.5 dB, in other words each node in the network can save power consumption by 15.5 dB in average, by using our proposed CDR compared to MRR. Our numerical results also show that the power gain increases as the number of nodes increases. Based on our numerical results, it is considered that the cooperative diversity in conjunction with routing is effective not only for the system performance in terms of outage probability but also for the transmission power of the nodes in ad-hoc networks.

References

〔1〕 C.-K. Toh, "Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks," IEEE Communication Magazine, vol.39, no.6, pp.138-147, June 2002.

〔2〕 G. Franceschetti, S. Stornelli, *Wireless networks*, Ch. 6, Academic Press, 2006.

〔3〕 J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," IEEE Trans. on Information Theory, vol.50, no.12, pp.3062-3080, Dec. 2004.

〔4〕 A. Ribeiro, X. Cai, and G. B. Giannakis, "Symbol error probabilities for general cooperative links," IEEE Trans. on Wireless Communications, vol.4, no.3, pp.1264-1273, May 2006.

〔5〕 M. Hasna and M.-S Alouini, "End-to-end performance of transmission systems with relays over Rayleigh-fading channels," IEEE Trans. on Wireless Communications, vol.2, no.6, pp.1126-1131, Nov. 2003.

〔6〕 A. Ribeiro, X. Cai, and G. B. Giannakis, "Symbol error probabilities for general cooperative links," IEEE Trans. on Wireless Communications, vol.4, no.3, pp.1264-1273, May 2005.

〔7〕 M. Tope, J. McEachen, and A. C. Kinney, "Routing performance of cooperative diversity in ad-hoc networks,"Proceedings of IEEE Symposium on Computers and Communications (ISCC2006), pp. 505-510, June 2006.

〔8〕 M. Qin and R. S. Blum, "Capacity of wireless ad hoc networks with cooperative diversity: A warning on the interaction of Relaying and multi-hop routing," Proceedings of International Conference on Communications (ICC2005), vol.2, pp.1128-1131, May 2005.

〔9〕 M. Haenggi, "Analysis and design of diversity schemes for ad hoc wireless. IEEE Journal on Selected Areas in Communications,"vol.23, no.1, pp.19-27, Jan. 2005.

〔10〕 Andrea Goldsmith, *Wireless Communications*. Cambridge University Press, 2005.

〔11〕 E. Sousa and J. Silvester, "Optimum transmission ranges in a direct-sequence spread-spectrum multihop packet radio network," IEEE Journal on Selected Areas in Communications, vol.8, no.5, pp.762-771, June 1990.

〔12〕 M. Haenggi, "On distances in uniformly random networks. IEEE Trans. on Information Theory," vol.51, no.10, pp.3584-3586, Oct. 2005.

〔13〕 M. Haenggi, "On routing in random Rayleigh fading networks," IEEE Trans. on Wireless Communications, vol.4, no.4, pp.1553-1562, July 2005.

〔14〕 M. Hasna and M.-S. Alouini, "Optimal power allocation for relayed transmissions over Rayleigh fading channels," IEEE Trans. on Wireless Communications, vol.3, no.6, pp.1999-2004, Nov. 2004.

〔15〕 M. K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels,* John Wiley & Sons, Inc., 2005.

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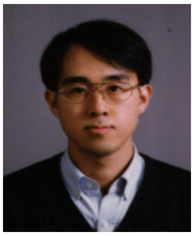

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