Wireless Ad-hoc Networks Using Cooperative Diversity-based Routing in Fading Channel

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ABSTRACT

We propose new routing scheme, Cooperative Diversity-based Routing (CDR)which utilize the cooperative space diversity for power saving and for performance enhancement of wireless ad-hoc networks. The end-to-end performance of the proposed routing, CDR, is analyzed based on the Haenggi's link model. 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 21.5 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.

In the past several years there has been increasing interest in cooperative diversity in ad-hoc networks. It is recently investigated, through Monte Carlo simulation, that the cooperative diversity technique can be applied to provide the network with substantially improved network performance[3],[4]. M. Haenggi studied on the performance of cooperative diversity in ad-hoc networks in analytical method[5]. More recently, it is shown that cooperative communication can provide increase capacity and power savings in ad-hoc networks[6].

In wireless communication network, two main factors to affect the performance of the network are the fading in physical layer and the distance between two transmit and receive nodes in network layer. Therefore M. Haenggi proposed a novel link model that is based on uncertainty on both fading state of the channel and the distance between transmitter and receiver[7].

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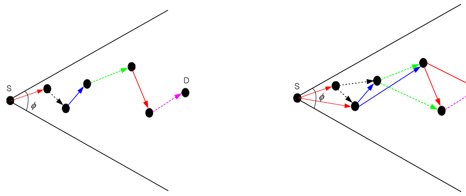
In this paper, we propose a cross layer optimization technique for cooperative diversity, named as Cooperative Diversity-based Routing (CDR), which supports the power saving routing in ad-hoc networks.The end-to-end performance of the proposed routing, CDR, is derived analytically based on the Haenggi's link model. The performance improvement is compared with Multi-hop Relay Routing (MRR)[8],[9] by analytical methods.

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

Ⅱ. Routing strategies

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 is



(a) MRR (b) Proposed CDR

Fig. 1 Routing strategies

relayed 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.

Fig. 1(b) describes CDR we propose. CDR utilizes cooperative diversity 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 such as 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 first 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. We assume there is a network controller to coordinate the retransmissions from the relay nodes.

Ⅲ. Performance analysis

3.1 Outage probability between two nodes

The received signal-to-noise ratio (SNR) γ at a receiver can be represented by

$$\gamma = \frac{P_t}{N} d^{-\alpha} = (SNR)_{Tx} d^{-\alpha} \tag{1}$$

where P_t is the transmit power of a transmitter, d is the distance between transmitter and receiver, α is the path loss exponent and $(SNR)_{Tx}$ is defined P_t / N.

In rich scattering, the Rayleigh fading model is commonly used. Under this assumption, the received SNR is exponentially distributed. The outage probability is defined the received SNR is less than the defined threshold Γ in a given condition of D, and written by

$$\begin{aligned} P_o &= E[\Pr(\gamma < \Gamma) | D] \\ &= E[1 - \exp(-\frac{\Gamma}{(SNR)_{Tx}} d^{\alpha}) | D] \end{aligned} \tag{2}$$

where $E[\bullet]$ denote expected values and D is the random variable of distance d.

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[10],

$$P\ [u\ nodes\ in\ A] = e^{-\lambda A} \frac{(\lambda A)^u}{u!} \tag{3}$$

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[11]

$$P_{d_n}(d) = d^{2n-1} (\frac{\phi}{2})^n \frac{2}{(n-1)!} e^{-(d^2 \phi / 2)} \quad . \tag{4}$$

Assume the path loss exponent α equals 2, then the probability density function (pdf) of $a = d_n^2$ is given by[7]

$$f_{d_n^2}(a) = \frac{\pi^n a^{n-1}}{\Gamma(n)} e^{-\pi a} \tag{5}$$

where $\Gamma(\bullet)$ is the Gamma function.

The outage probability in (2) can be written by

$$\begin{aligned} \mathrm{P}_o &= \int_0^{\infty} [1 - \exp(-\frac{\Gamma}{(SNR)_{Tx}} a)] f_{d_n^2}(a)\, da \\ &= 1 - \left(\frac{\phi / 2}{\phi / 2 + \Gamma / (SNR)_{Tx}} \right)^n \\ &= 1 - B^n \end{aligned} \tag{6}$$

where

$$B = (\phi / 2) / \{(\phi / 2) + \Gamma / (SNR)_{Tx}\} \tag{7}$$

3.2 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 for simplicity and assume that all the wireless communication channels are under independent Rayleigh fading.

In DF relay system, an outage occurs if either one of the links is in outage. The outage probability of MRR which has N-1 hops from a source node to a final destination node in Fig. 1 (a) is given by[12]

$$P_{N,out} = 1 - (1 - P_{N-1,out})(1 - P_{(N-1)N,out}) \tag{8}$$

where $P_{ij,out}$ is the outage probability that the message is transmitted unsuccessfully from the node i to the node j .Assume the transmit power of each node is same. Then we can have

$$P_{N,out} = 1 - B^{N-1} \quad . \tag{9}$$

3.3 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

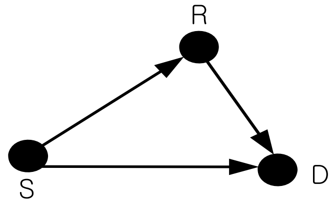


Fig. 2 Simple cooperative diversity model

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.

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. Assume the relay node is the nearest node from the source node and the destination node is the 2nd nearest node from the source node.

From (6), the outage probability $P_{D,out}(\Gamma)$ of the direct path is given by[7]

$$P_{D,out} = 1 - B^2 . \tag{10}$$

The outage probability $P_{R,out}(\Gamma)$ of the relay path is given by[12]

$$\begin{aligned} P_{R,out} &= 1-(1-P_{SR,out})(1-P_{RD,out}) \\ &= 1-B^2 \end{aligned} \tag{11}$$

where $P_{SR,out}$ and $P_{RD,out}$ are the outage probability between the source and the relay path, and the relay and the destination path, respectively.

Under the assumption that the received signals from each path are independent for simplicity, the outage probability with the selection combining diversity can be given by[13],[14]

$$P_{out}(\Gamma) = P_{D,out} P_{R,out} . \tag{12}$$

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.

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

$$\begin{aligned} &P_{1,\,out} = 0, \\ &P_{2,\,out} = 1 - B, \\ &P_{k,\,out} = \{1 - P_{(k-2),\,s} P_{(k-2)k,\,s}\}\{1 - P_{(k-1),\,s} P_{(k-1)k,\,s}\}, \quad 3 \le k \le N \end{aligned} \tag{13}$$

where

$$\begin{aligned} &P_{(k-j),\,s} = 1 - P_{(k-j),\,out} \\ &P_{(k-j)k,\,s} = 1 - P_{(k-j)k,\,out}, \quad 3 \le k \le N,\ j = 1,\,2 \end{aligned} \tag{14}$$

and where $P_{ij,\,out}$ and $P_{ij,\,s}$ are the outage probability and the probability that the message is transmitted successfully from the node i to the node j, respectively.

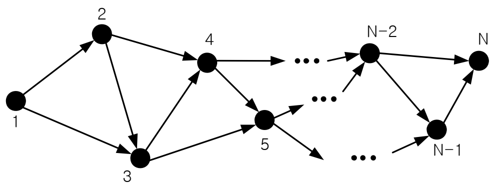


Fig. 3 Proposed CDR with N nodes

Ⅳ. Numerical examples

As we described previously, we assume that nodes are distributed uniformly in the network and each node within a sector ϕ transmits with equal power P_t for simplicity. Fig. 4 shows the numerical results of outage probability at the des-

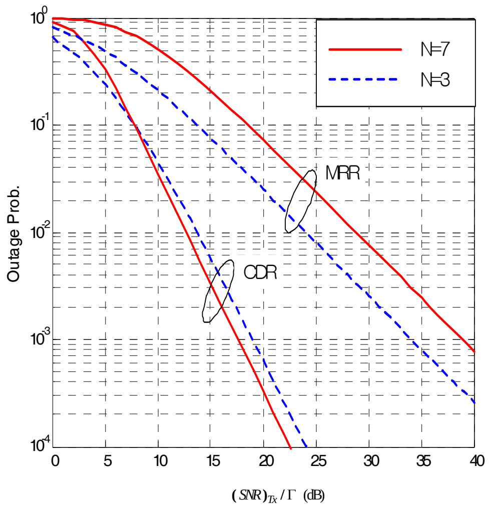


Fig. 4 Outage probability of MRR and CDR ($\phi = \pi/2, \ \alpha = 2$).

tination node by MRR and by the proposed CDR with $\phi = \pi/2$ and α =2in Rayleigh fading channel. It is noticed that the proposed CDR has better performance than MRR. When the required outage probability is 1×10^{-3} at the destination node in the network with 7 nodes, the satisfied SNRs for the transmitted signal from each node are 39 dB and 17.5 dB, which are normalized by the threshold SNR, Γ, for the MRR and for the CDR, respectively. We obtain the power gain of 21.5 dB with the proposed CDR scheme compared to the MRR: to satisfy the required outage probability of 1×10^{-3}at the destination node, each node can reduce the transmit power of 21.5 dB in average with CDR compared with that of MRR. When the numbersof node are 3 in the network, the power gain is 15.1 dB.In Fig. 4, it is denoted that the required average SNRs, which satisfy the given outage probability, are increasing with the number of nodes in MRR. However, the required average SNRs decrease with the increase of the number of nodes in proposed CDR. Thus, with the CDR scheme that we proposed in this paper, we have improved performance in terms of power consumption.

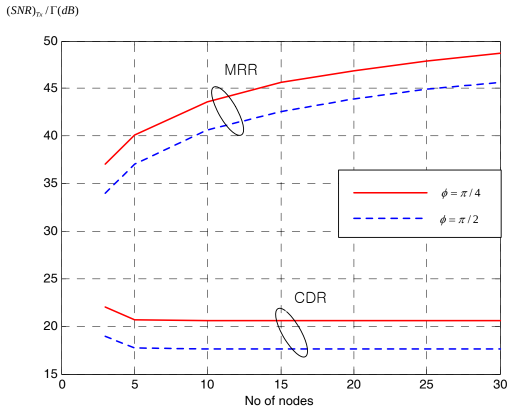


Fig. 5 Required SNR ($\alpha = 2, \ P_{out} = 1\times10^{-3}$).

Fig. 5 shows the numerical results of the required SNRs for outage probability of 1×10^{-3}. The results shows that the required SNRs with $\phi = \pi/4$ is greater than with $\phi = \pi/2$. It is because that the value of the average distance between nodes increases as the value of ϕ decreases.

On the other hand, it is noted that the required SNRs increase as the number of nodes increases for MRR both the cases of $\phi = \pi/2$ and $\phi = \pi/4$.However, for CDR the required SNR is decreasing with the number of nodes as mentioned in Fig.4.

Ⅴ. Conclusions

We studied cross-layer approach to utilize cooperative diversity for supporting the power saving routing in wireless ad-hoc in analytical method. We apply the newly proposed joint link model by M. Haenggi for the end-to-end outage analysis of the proposed CDR. When the required outage probability is 1×10^{-3} at the destination node in ad-hoc networks with 7 nodes, the satisfied SNRs for the transmitted signal from each node are 39 dB and 17.5dB, which are normalized by the threshold SNR, for the MRR and for the CDR, respectively. It means that we can achieve power gain of 21.5 dB, in other words each node in the network can save power consumption by 21.5 dB in average, by the proposed CDR compared with MRR.

The required average SNR for the target outage probability increases with the number of nodes in MMR. However, the required average SNR decreases with the increase of the number of nodes in CDR. This means that the transmit power of each node to satisfy the target outage probability is reduced by increasing number of nodes in CDR. This is the advantage for introducing the cooperative diversityin ad-hoc network by sacrificing the throughput of the network.

Based on our numerical results, we concludethat 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.

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