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레일리 페이딩 채널을 통해 결합된 등가 이득 협력 라우팅의 에너지 효율

Energy Efficiency of Cooperative Routing with EGC Over Rayleigh Fading Channel

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요 약 본 논문에선, 정적 무선 네크워크에서 에너지 절약을 얻기 위한 멀티 홉 협력 전송 프로토콜을 제안한다. 네트워크의 각 터미널에서는 수신된 신호를 각 수신단에서 등 이득 결합 기법을 사용하고 단일 안테나를 설치한다. 또한, 각 구간에서 최적의 전체 전송 전력의 할당 방법을 제안한다. 몬테-카를로 시뮬레이션으로 평균 전체 전송 전력과 구간의 평균 수의 부분에서 멀티 홉 직접 전송(MDT)와 Khadani에 의해 제안된 협력 라우팅 프로토콜을 제안된 프로토콜로 성능을 비교 분석한다.

Abstract In this paper, we propose a multi-hop cooperative transmission protocol to obtain energy savings in static wireless networks. Each terminal in the network is equipped with a single antenna and each receiver uses equal gain combining technique (EGC) to combine received signals. We also propose a power allocation strategy which optimizes the total transmit power at each stage. Monte-Carlo simulations are presented to evaluate and compare performance of the proposed protocol with the multi-hop direct transmission (MDT) and the cooperative routing protocol proposed by Khadani [8], in terms of the average total transmit power and the average number of required stages.

Key Words : Cooperative routing, equal gain combining, Rayleigh fading channel, multi-hop transmission.

Ⅰ. Introduction

Nowadays, the problem of energy efficiency communication in multi-hop wireless networks has received a lot of attention. To obtain energy savings for multi-hop approaches, cooperative communication [1-3] can be used efficiently. Cooperative diversity exploits the broadcast nature of the wireless channel and allows single-antenna radios to share their antennas to form a virtual antenna array. Cooperative protocols can obtain higher performance as compared to direct transmission in terms of diversity order and error rate. Hence, for the same performance such as throughput, transmission rate, outage probability, bit error rate, symbol error rate and packet error rate, the use of cooperative relaying techniques can reduce the average

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total transmit power which is an important issue in wireless systems such as wireless sensor networks (WSNs).

In multi-hop cooperative transmission strategies [4-8], each relay node exploits cooperative diversity transmission to enhance the reliability of the data transmission. In [8], Khandani et al proposed an efficient protocol in which a terminal cooperates previous ones to reduce the power consumption. However, the authors in [8] assumed that all channels between two nodes are same and capture slow Rayleigh fading channels. In practice, the channels between two arbitrary nodes can be different with each other and vary with time. Furthermore, because the protocol in [8] cannot reduce the number of stages for each data transmission, the transmission times used in this protocol cannot be reduced.

To enhance the system performance, one of the combining techniques [9], i.e., Selection Combining (SC), Equal Gain Combining (EGC) or Maximal Ratio Combining (MRC) can be employed at the receivers to combine the received signals. In SC technique, the signal from the diversity path with the largest instantaneous signal-to-noise ratio (SNR) is selected for the decoding. In EGC technique, the combiner coherently combines all available paths weighting each with equal gain while MRC technique coherently combines all available paths but weighs each with the respective ones. Among these techniques, MRC gives the best and the optimum performance, SC gives the most inferior performance, and EGC has a performance quality in between the others [10].

In this paper, we propose a cooperative routing protocol in order to reduce the power consumption and the number of transmission times in multi-hop networks. In the proposed scheme, each relay on the route uses EGC technique to combine received signals from the source and relays. We provide Monte-Carlo simulation results to evaluate and compare the performance of the proposed protocol (named CR2) with that of the multi-hop direct transmission protocol (MDT) and the protocol presented in [8] (named CR1). Results present that the proposed protocol reduces the average total transmit power and the average number of stages used for the transmissions.

The rest of the paper is organized as follows. The system model is described in Section II. The simulation results are presented in Section III. Finally, the paper is concluded in Section IV.

II. System Model

1. Power Allocation Problems

At first, we consider the direct transmission between two nodes, e.g., node i and node j. The signal received at node j due to the transmission of node i is given by

$$y_{i,j} = \sqrt{P_i}\,h_{i,j}s + \eta_j \qquad (1)$$

where η_j is AWGN noise with variance P_η at terminal j, $h_{i,j}$ is fading coefficient between nodes i and j, s is the signal transmitted by node i and P_i is transmit power of node i. It is noted that although $h_{i,j}$ is assumed to follow Rayleigh distribution, our algorithm can be applied for all of the fading environments.

To take path loss in account, we can model the variance of channel coefficient $h_{i,j}$ as [5]:

$$\sigma_{i,j}^2 = d_{i,j}^{-\beta} \qquad (2)$$

where β is called path loss exponent and $d_{i,j}$ is the distance between nodes i and j.

From (1), the received SNR at node j is given by

$$\gamma_{i.,j} = P_i |h_{i,j}|^2 / P_\eta \qquad (3)$$

If $\gamma_{i.,j} \geq \gamma_{th}$, where γ_{th} is predetermined threshold, node j is assumed to decode successfully the received signal. Therefore, the minimum transmit power of node i is given as

$$P_i^* = \gamma_{th} P_\eta / |h_{i,j}|^2 \qquad (4)$$

Next, we consider the cooperative transmission scheme in which a set of N sources, i.e.,

$S=\{i_1,i_2,...,i_N\}$, which attempt to transmit the same signal s to the destination j. Node j uses EGC technique to combine all the received signals. In this case, the instantaneous SNR at the output of the combiner is given as [11]:

$$\gamma_{EGC}=\frac{\left(\sum_{a=1}^{N}\sqrt{P_a}|h_{i_a,j}|\right)^2}{NP_\eta} \tag{5}$$

where P_{i_a} is transmit power of the transmitter i_a, and $h_{i_a,j}$ is channel coefficient between nodes i_a and j.

Also, the received SNR at the destination j must satisfy the condition $\gamma_{EGC}\geq\gamma_{th}$ so that it can successfully decode the signal s. Therefore, our objective here is to find the minimum value of total transmit power $P_{S-j}=\sum_{a=1}^{N}P_i$. Now, utilizing Cauchy - Schwarz inequality for (5), we obtain (6) as

$$\gamma_{EGC}\leq\frac{(\sum_{a=1}^{N}P_a)(\sum_{a=1}^{N}|h_{i_a,j}|^2)}{NP_\eta} \tag{6}$$

For (6), the condition of equality can be given as

$$\frac{P_{i_1}}{|h_{i_1,j}|}=\frac{P_{i_2}}{|h_{i_2,j}|}=...=\frac{P_{i_N}}{|h_{i_N,j}|} \tag{7}$$

Hence, an optimal transmit power solution is given as

$$P_{S-j}^*=\sum_{a=1}^{N}P_{i_a}^*=\frac{NP_\eta\gamma_{th}}{\sum_{a=1}^{N}|h_{i_a,j}|^2} \tag{8}$$

where $P_{i_a}^*=\frac{NP_\eta\gamma_{th}|h_{i_a,j}|^2}{\left(\sum_{a=1}^{N}|h_{i_a,j}|^2\right)^2}$.

2. Minimum-Energy Evaluation

We consider an M-hop route between the source N_0 and the destination N_M. On the route, there are (M-1) relays, i.e., N_1, N_2, ..., N_{M-1}, which are ready to forward the source signal to the destination. The relays are numbered follows their distance to the destination, i.e., the N_1 is furthest and the relay N_{M-1} is nearest.

In the MDT protocol, the source signal is relayed hop-by-hop from the source to the destination. Therefore, the MDT protocol must use M stages to relay the source signal. At each stage, by using (4), we obtain the minimum transmit power $P_{N_a}^*$ of node N_a. So, the minimum total transmit power of the MDT protocol is calculated by

$$P_{DT}^*=\sum_{a=0}^{M-1}P_{N_a}^*=\sum_{a=0}^{M-1}\frac{\gamma_{th}P_\eta}{|h_{N_a,N_{a+1}}|^2} \tag{9}$$

Now, we remind the operation of the cooperative routing protocol (CR1) proposed by Khadani in [8]. It is noted that for a fair comparison with our scheme, we assume that all of the receivers in the CR1 protocol use EGC technique to combine the received signals. At the first phase, the source N_0 transmits its signal to relay N_1. By using (4), the minimum transmit power of the source in the first stage is given as

$$P_{N_0}^*=\gamma_{th}P_\eta/|h_{N_0,N_1}|^2 \tag{10}$$

At the second phase, the nodes N_0 and N_1 cooperate to transmit the source signal to the node N_2. Then, the node N_2 uses EGC to combine the received signals and do decoding. Generally, at the m^{th} stage, nodes N_0, N_1, ..., N_{m-1} cooperate to transmit the signal to the node N_m. By using the results in (8), the optimal transmit power in this stage can be given as

$$P_{\{N_0,...,N_{m-1}\}-N_m}^*=\frac{NP_\eta\gamma_{th}}{\sum_{a=0}^{m-1}|h_{N_a,N_m}|^2} \tag{11}$$

Therefore, the optimal transmit power of the CR1 protocol can be obtained as

$$P_{CR1}^*=\sum_{m=1}^{M}P_{\{N_0,...,N_{m-1}\}-N_m}^* \tag{12}$$

Next, we present the operation of the proposed scheme. In our scheme, at each stage, we find a optimal receiver so that this receiver can decode the signal successfully and the total transmit power of the transmitting nodes is minimum. At the first phase, the source transmits its signal to the destination and relays. By using (4), we can obtain the minimum transmit power $P^*_{N_0,N_n}$ of the source so that node N_n can decode the source signal successfully, where $n \in \{1,2,\ldots,M\}$. Then, the receiver in this stage is chosen follows the strategy as

$$N_{i_1} = \arg\min\left(P^*_{N_0,N_n}\right) \tag{13}$$

If $N_{i_1} \equiv N_M$, we stop the search algorithm at this stage and in this case the total transmit power of the CR2 protocol is $P^*_{N_0-N_M} = \gamma_{th}P_\eta/|h_{N_0,N_M}|^2$. If $N_{i_1} \neq N_M$, the search algorithm goes to step 2 in which the source and the relay N_{i_1} cooperate to forward the source signal to remaining nodes. Generally, at the m^{th} stage, we assume the set of the transmitting nodes is $S_m = \left\{N_0, N_{i_1}, \ldots, N_{i_{m-1}}\right\}$. Also, at this stage, we also calculate the optimal transmit power $P^*_{S_m-N_n}$ by using (8), where $N_m \in \left\{\{1,2,\ldots,M\}/S_m\right\}$. Then, the node at this stage is chosen by using the following strategy as

$$N_{i_m} = \arg\min\left(P^*_{S_m-N_n}\right) \tag{14}$$

Next, if $N_{i_m} \equiv N_M$, the proposed algorithm ends at this stage and the total transmit power is given as

$$P^*_{CR2} = \sum_{a=1}^{m} P^*_{S_a-N_n} \tag{15}$$

Otherwise, the algorithm goes to step m+1 with the transmitting set $S_{m+1} = \left\{N_0, N_{i_1}, \ldots, N_{i_m}\right\}$. We can observe that the CR2 uses one stage at least and M stages at most. Hence, the proposed scheme can reduce the number of the required stages in average, as compared with the MDT protocol and the CR1 protocol.

III. Simulation Results

Now, we provide some Monte-Carlo simulations to evaluate and compare the performance of the considered protocols. We consider line network, in which all nodes are placed on straight line and the distance between two adjacent nodes is normalized to 1. In all simulations, we make 10000 trials and the total transmit power is averagely calculated.

Fig. 1 presents the average total transmit power as a function of the number of hops M when the path-loss exponent and the threshold value are 3 and 1, respectively. As we can see, the transmit power of the CR2 protocol is lower than that of the MDT protocol and the CR1 protocol for all values M. It is apparent from this figure that the total transmit power of the protocols increase with the increase of M.

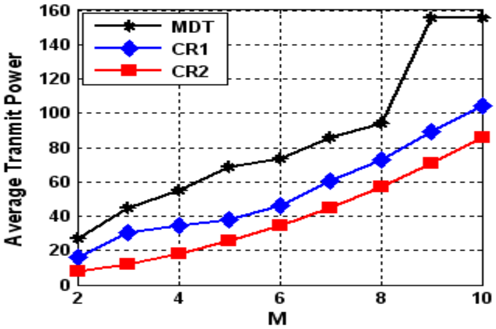

그림 1. $\beta=3$, $\gamma_{th}=1$일 때, M 개 홉의 함수에 대한 평균 전체 전송 전력

Fig. 1. Average total transmit power as a function of the number of hops M when $\beta=3$ and $\gamma_{th}=1$.

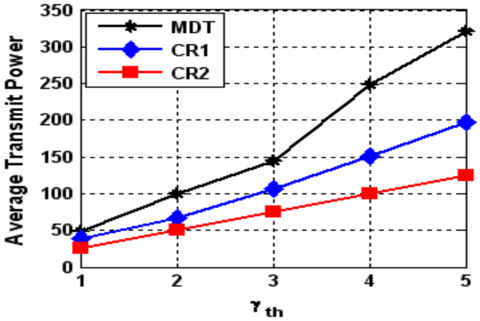

그림 2. M = 4, $\beta=4$ 일 때, γ_{th}의 함수에 대한 평균 전체 전송 전력

Fig. 2. Average total transmit power as a function of γ_{th} when M=4 and $\beta=4$.

In Fig. 2, we investigate impact of the threshold value γ_{th} on the average total transmit power when M=4 and $\beta=4$. The simulation results present that the CR2 protocol consumes least power, among three considered protocols. In addition, it can be seen that the average total power consumption increases with increasing γ_{th}.

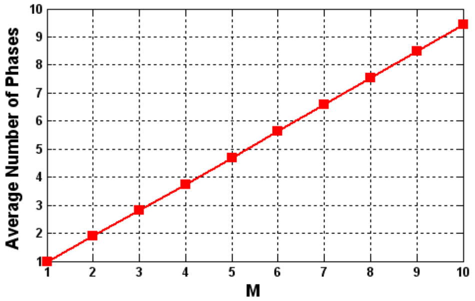

그림 3. $\beta=3$, $\gamma_{th}=1$일 때, M 개 홉의 함수에 따른 CR2 프로토콜을 사용한 구간의 평균 수

Fig. 3. Average number of stages used in the CR2 protocol as a function of M when $\beta=3$ and $\gamma_{th}=1$.

In Fig. 3, we draw the average number of stages used in the CR2 protocol as a function of the number of hops M with $\beta=3$ and $\gamma_{th}=1$. It can be seen that the average number of stages increases as we increase the number of hops. In addition, the number of stages of the MDT protocol and the CR1 protocol always equal to M. Therefore, the CR2 protocol can reduce the number of stage in of the data transmission. Furthermore, when the time division multiple access is used to relay the signal, the decreasing of the number of stages can reduce the delay time, which is an important criterion in multi-hop transmission schemes.

Ⅳ. Conclusion

In this paper, we proposed a multi-hop cooperative routing protocol in which each node on the route exploits cooperative communication to reduce the average total transmit power and the average number of stages. We proposed a power allocation strategy when the EGC technique is employed at the receivers. Monte-Carlo simulations were presented to compare the performance of the proposed protocol with the multi-hop direct transmission protocol (MDT) and the multi-hop cooperative transmission protocol (CR1) proposed in[8]. Results presented that the proposed scheme outperforms the MDT protocol and the CR1 protocol in terms of the average total transmit power and the average transmission stages.

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