An Opportunistic Relay Selection Algorithm for Hybrid-ARQ in Wireless Networks

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***Abstract*—This paper proposes a simple relay selection algorithm among N_r possible relays. The technique enhances reliability and performance of wireless communication system by retransmitting a data from the selected relay to the destination. The method finds a relay on distributed manner, i.e., no requirement of centralized node which has knowledge of whole network. The proposed algorithm is based on opportunistic feedback and channel information measured by each relay. The channel information controls the feedback parameter which affects the performance of system. Simulation result verifies performance of the proposed algorithm.**

***Index Terms*—Cooperative relay, distributed single relay selection, relays**

I. INTRODUCTION

In wireless communication environments, the outage is occurred by fading between a source and a destination. This makes some negative effects on throughputs and reliabilities of the communication system. Hybrid automatic-repeat-request (ARQ) has been proposed as an enabling method for satisfying quality-of-service (QoS) constraints in wireless system. Hybrid-ARQ can be applied in relay communication, where intermediate node(s) act as relays. The relay(s) can retransmit the data or forward additional parity bit instead of source. Because the relay(s) are closer than the source to the destination, this enhanced performance of the system by decreasing the number of retransmission.

Such relay(s) can be selected by the source. There has been research on single relay selection [1, 2, 3, 4, 5, 6] and multiple relay selection [7]. If the source selects multiple relays, cooperative diversity can be obtained. However, the multiple relay selection is required that feedback of channel state information (CSI) from the destination and control signal for multiple access between channels. Therefore, the research which the single relay selection is superior to multiple relay selection is introduced by [6].

There are two ways to select the relay(s); one for centralized and the other for distributed. Using the centralized method, relay is selected under the control of a super node which has knowledge of whole network. However, increasing a network size, the super node needs more storage and becomes hard to get the information as well. Therefore, the centralized method is difficult to implementation practically; a distributed method is more preferable.

A single relay selection algorithm on distributed manner introduced by [3] is mostly related to this paper. This algorithm relies on random access-based feedback to the source. In [3], the contention process is started when the destination fails to decoding a received message. The relays which have channel state above certain threshold can participate in a contention process. Each relay which joins the process is allocated to K contention slots. The relay sends a feedback message with own feedback probability to the source during a contention slots. After K contention slots has been completed, the source randomly selects a relay which succeed a feedback. If none of the relays succeed a feedback, source will retransmit a data.

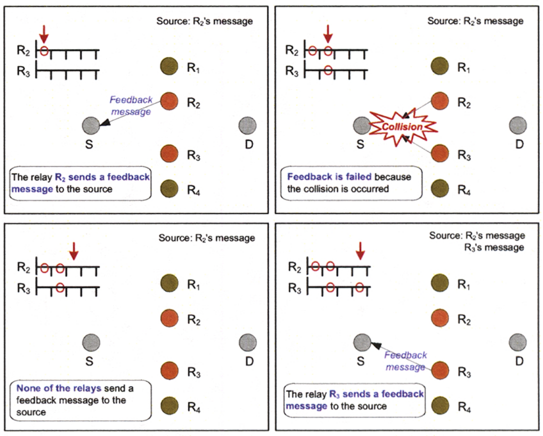

Fig. 1. Contention Process

Fig. 1 describes the example of contention process at $N_r = 4$, $K = 4$ and $p_i = 0.5$. It is assumed that the relay R_2 and the relay R_3 have the channel coefficients that are above the threshold. Hence, theses relays can join the contention process and are allocated the K minislot.

During first minislot, only the relay R_2 sends a feedback message to the source. Therefore, the source receives the feedback message of relay R_2 successfully. During second minislot, the relay R_2 and the relay R_3 send the feedback message to the source at a time. Feedback is failed because collision is occurred. In next minislot, none of the relays send a feedback message to the source. Finally, during forth minislot, the relay R_3 succeeds to feedback of message. Therefore, the source randomly selects the relay among relay R_2 and relay R_3.

This paper proposes a distributed single relay selection algorithm that modifies above algorithm. In this approach, the relay selection is based on opportunistic feedback same as above selection algorithm. In proposed algorithm, however, a relay whose channel coefficient is higher than others will send more feedback message to the source. Therefore, the possibility that the relay which has best relay-to-destination channel gain among relays is selected is increased. Furthermore the processing time is shortened by selecting a relay which succeed a feedback first, and stopping a selection algorithm. Consequently, we obtain gain of normalized channel capacity, $C_{nomalized}$ = log $(1+|h_{i,r}|^2 SNR)$ / processing time.

The remainder of the paper is organized as follows: We describe our system model in section II and proposed algorithm in section III. In section IV, we verify and analyze performance of proposed scheme using *Monte Carlo* simulation. Finally, we conclude in section V.

II. System model

Consider a system model described in Fig. 2. There are N_r relays between the source and the destination. We apply the system constraints in [3], so each relay operates in a half-duplex mode and is equipped with a single antenna. The wireless channel is modeled as a block fading channel. When source transmits a data, the destination receives the transmitted data and all relays overhear the data.

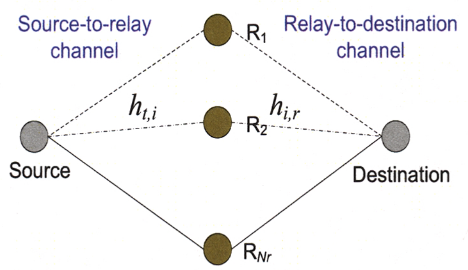

Fig. 2. Relay network.

Initially, the source and the destination perform RTS/CTS handshaking with the result that the synchronization is achieved. The source transmits a message x. The received signal at destination is

$$y_r = h_{t,r}x + n_r, \tag{1}$$

where $h_{t,r}$ is a Rayleigh fading coefficient for the channel between the source and the destination, and n_r is additive white Gaussian noise at destination.
The received signal at relay $i \in \{1,2,\ldots,K_r\}$ is

$$y_i = h_{t,i}x + n_i, \tag{2}$$

where $h_{t,i}$ are a Rayleigh fading coefficient for the channel between the source and the relay node i, and n_i is additive white Gaussian noise at the relay node i. We assume that all fading and additive Gaussian noise are independent each other. It is also assume that the system is reciprocity system in [8], i.e., forward channels and backward channels are same.

The destination performs decoding of x. If the destination decodes the received message x successfully, broadcasts an ACK message to the source and the entire relay nodes. If the destination fails to decoding, broadcasts a NACK message to the source and the entire relay nodes.

After all relay nodes which receive a NACK message start relay selection process. Now, we describe the relay selection algorithm.

III. Proposed opportunistic relay selection algorithm

We modify the opportunistic feedback approach in [3] to select a single relay. Using the algorithm introduced in [3], a fairly high instantaneous channel gain can be achieved. But, this method doesn't guarantee that selected relay is best. So, we modify the scheme that a relay which has higher channel coefficient than other relays has more possibility to be selected. The flow chart of proposed algorithm is shown in Fig. 3.

Let R_{sel} denote the set of relays which join to the relay selection process, which have a channel coefficient to the destination above a certain threshold η_{opp}. All relays observe their channel coefficient by performing RTS/CTS handshaking. The channel gain between the source and the relay i, $h_{t,i}$ is estimated by transmission of RTS. Similarly, the channel gain between the relay i and the destination, $h_{i,r}$ is estimated by transmission of CTS.

All relays in R_{sel} are allocated the same K contention slots for feedback of a “Hello” message to the source. During one contention slot, each relay i send a “Hello” message to the source with probability p_i. The feedback probability is proportional to relay-to-destination channel state, according to the following:

$$p_i = \begin{cases} a^{h_{i,r}-c}, h_{i,r} < c \\ 1 \quad , h_{i,r} \geq c \end{cases} . \tag{3}$$

Using equation (3), p_i is set that the relay with better channel state than others has higher probability than other relays. We adopt a convex function mapping the probability to minimize a collision. If there are two or more relays which have high channel coefficient and all the relays have high feedback probability, collision is occurred so that any relays don't succeed feedback. The convex function makes a huge difference of probability between them, which decrease a collision. Also, we have consideration of two parameters, a and c. The c value is large enough not to allocate too high probability. Finally, the a values is determined by

$$\int_{-\infty}^{\infty} f_{p_i}(p)dp = 1, \tag{4}$$

where $f_{p_i}(p)$ is probability density function (pdf) of the feedback probability p_i.

Now, we evaluate the pdf of the feedback probability p_i. The feedback probability p_i is function of random variable $h_{i,r}$. The way to evaluate the pdf of a function of a random variable is introduced in [9]. We should evaluate a probability distribution function (PDF) first to get a pdf. The PDF of the feedback probability p_i is Pr $\{p_i \leq p\}$ by definition. So we can get easily

$$F_{p_i}(p) = \begin{cases} F_{h_{i,r}}(\log_a p + c), & p < 1 \\ 1 & , p \geq 1 \end{cases}, \tag{5}$$

where $F_{h_{i,r}}$ is PDF of $h_{i,r}$. Taking derivation an equation (5), we can be obtained

$$\begin{aligned} f_{p_i}(p) &= \frac{d}{dp} F_{p_i}(p) \\ &= \frac{d}{dp} F_{h_{i,r}}(\log_a p + c) \qquad , p < 1 \\ &= f_{h_{i,r}}(p \log_a p + c) \cdot \frac{1}{p \ln a} \quad , p < 1 , \\ &= \begin{cases} \dfrac{\log_a p + c}{p \ln a} \cdot e^{-(\log_a p + c)^2/2} & , p < 1 \\ b\delta(p-1) & , p = 1 \end{cases} \end{aligned} \tag{6}$$

where $f_{h_{i,r}}$ is pdf of $h_{i,r}$ which is $f_{h_{i,r}}(h) = he^{-h^2/2}$, and b is a constant of discontinuity. So, we find the a value which satisfies following equation:

$$\int_{-\infty}^{\infty} \left[\left(\frac{\log_a p + c}{p \ln a} \cdot e^{-(\log_a p + c)^2/2} \right) \cdot (u(p) - u(p-1)) + b\delta(p-1) \right] dp = 1 , \tag{7}$$

where $u(\cdot)$ is unit step function.

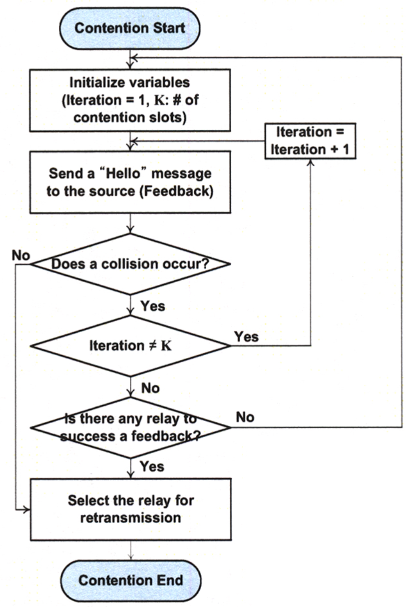

Fig. 3. Flow chart of proposed relay selection algorithm

During a first contention slot if two or more relays send "Hello" message to the source, the relays is a failure in feedback because of a collision. Successful feedback occurs that only one relay sends "Hello" message to the source during the contention slot. If feedback is successful, the source selects the relay for retransmission and transmits the ID of the relay to all the other nodes. Then, the selected relay will retransmit a data to destination. If feedback is fail, repeat above process before K contention slots are completed. After K contention slots there aren't any relays to success a feedback, repeat overall relay selection algorithm to select a relay for a retransmission.

If the destination doesn't decode successfully in spite of retransmission, broadcasts another NACK message to the source and all of the relays. Then, the relay selection algorithm is repeated to select another relay. This process is repeated until decoding is successful at destination.

IV. SIMULATION RESULT AND ANALYSIS

To compare performance between the previous scheme in [3] and the proposed scheme, we evaluate following equation

$$C_{normalized} = \frac{\log(1+|h_{i,r}|^2 SNR)}{\text{processing time}}. \quad (8)$$

Here, to simplify the problem we assume that all of the relays' locations are same, and a distance from the source to the destination is two times of that from the relay to the destination.

BPSK modulation is used, and all of the relays and the destination use ML decoding. We adopt a same parameter in [3] to compare a normalized channel capacity of previous scheme. We employ a η_{opp} = 2, p_i = 0.3, and the number of contention slots, $K = \lfloor N_r/2 \rfloor$. The reason to adopt above values, η_{opp} and p_i, is that the normalized channel capacity is maximized using such value in previous scheme. The number of contention slots is assigned arbitrarily.

Fig. 4 represents an expected value of channel capacity normalized by processing time. The proposed scheme outperform previous scheme because the received SNR is increased, and moreover processing time is decreased. There are two reasons to explain such increments on the received SNR. One is found on the feedback probability proportional to the channel coefficient. Another is that the relay selection algorithm is repeated when relay selection is failed. This repeating mechanism is different from the previous scheme. In the previous way, if there is a failure in the relay selection, the retransmission has to be taken by the source. Although this repetition lengthens processing time, the overall processing time is decreased by using early termination.

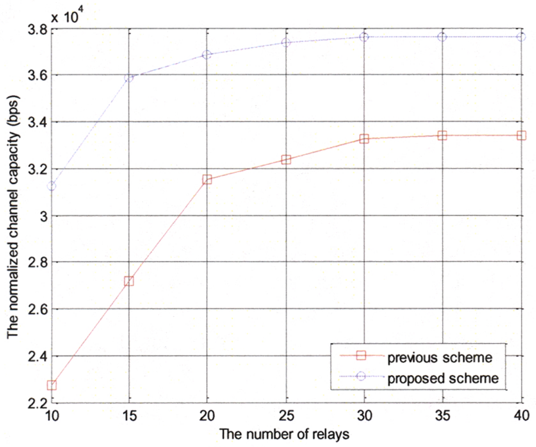

Fig. 4. Normalized channel capacity as a function of the number of relays

In both scheme, the normalized channel capacity is increased as increasing the number of relays. As the number of relays is increased, the relays which can participate in the contention process are also increased. Thus, there exist many relays which have high channel coefficient. The gain of proposed scheme over previous scheme is decreased as increasing the number of relays. It is the reason that in previous scheme all of the relays perform a feedback in same probability, 0.3, but in proposed scheme feedback probability is larger than 0.3 in general. This increases the likelihood of a collision; this collision delay selecting a relay, which lengthens processing time.

V. CONCLUSIONS

This paper proposes an algorithm to select the appropriate single relay which enhances a performance of wireless communication systems. The proposed method selects a relay on distributed manner. The key advantage of this method is that a communication among the relays isn't required, i.e., each relay needs only own channel information estimated by transmission of RTS/CTS. The proposed method achieves a fairly high instantaneous relay-to-destination channel gain. Furthermore, we control the feedback probability so that a relay with high relay-to-destination channel gain has more possibilities to be selected. The proposed method enhanced the performance by repeating the selection algorithm when the source fails to select a relay. The processing time is reduced by selecting a relay which sends feedback message first, and stopping a selection algorithm. Finally, we verify performance gain of this scheme over previous scheme to evaluate normalized channel capacity.

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