A Modified Relay Selection Scheme in Opportunistic Relay Communications

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***Abstract*—In this paper, we develop a modified relay selection technique in opportunistic relay communications. In this approaches, we use a threshold level between source and intermediate (M) relay nodes. Then our proposed scheme can decreases the contending relay's collision probability. We compare the performance depending on different threshold level by using *Monte Carlo* computer simulation. Through this process, we verify the collision probability performance's analysis.**

I. Introduction

When the wireless links are unstable, data decoding failed in destination. So communication link's throughput and reliability destroyed by outages. As a solution of this problem, we can think of data retransmission via relay nodes. There have been several researches about relay communication techniques. Among them, [1] analyzes throughput enhancement by using multi-relay communication. However, multi-relay communication's synchronization at each packet is required among several different nodes. This requirement demands significant additional considerations. Then, in this paper, we will focus on single relay communication techniques.

In the single relay communication, finding retransmission relay node for reliable communications is very important. There are remarkably two different relay node selecting techniques. First is centralized relay selection technique in [2]. This technique uses each relay's GPS (Global Positioning System) information between relays and destination. So this scheme should have a centralized controller (super node) that gathers all relay's channel state information. They called that protocol's name as a HARVINGER (Hybrid ARq-Based INtracluster Geographic Relaying). Through the centralized controller, we can select the nearest relay node to the destination. Due to the central controller's almighty, this technique act optimally. But centralized technique has some of practical issues. When the numbers of contention relay nodes are increased, the centralized controller is hard to feedback whole channel state information because of its feedback load. Furthermore, the centralized controller's materialization is unrealistic in practical communication systems. As a reason of that, distributed relay selection technique can be considered as more reasonable approaches in practical wireless communication systems. Distributed technique requires no additional geographical channel information; they rely on only channel link's noise level. One of the well researched distributed relay selection algorithms is in [3]. This scheme selects single relay node by using timer protocol. In [4], they also select single relay node by using feedback probability. Both [3]and [4] use a channel gain in their own relay selection method. Each method designed to select the relay node with strong channel gain. But due to the feedback probability's uncertainty, the timer protocol in [3] has more chance to select the best relay node. As an expansion of in [3], [5] proposes less complex relay selection algorithm. Through this research, we can understand the operation of opportunistic relay communication as an aspect of low complexity and low power consumption.

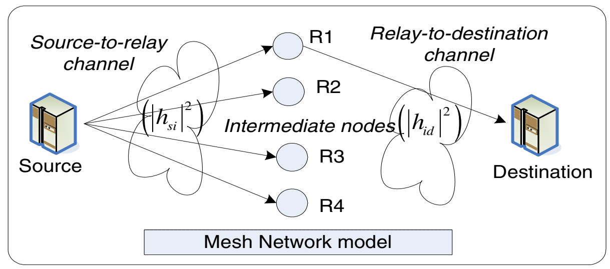

Fig. 1. The mesh network's system model ($M = 4$)

In this paper, we develop a modified relay selection technique in opportunistic relay communications. In section 2, we review an opportunistic relay selection protocol in [3] as our research's previous work. In section 3, we describe in details our proposed scheme's system model and key idea. In section 4, we verify our proposed relay selection scheme's performance by using *Monte Carlo* computer simulation. In this section, we can discuss the performance analysis depending on each threshold level. In conclusion, we summarize the entire proposed scheme.

II. Review of an Opportunistic Relay Selection Algorithm in [3]

One of the well researched relay selection techniques is introduced in [3]. This paper described how they can select the best relay node in distributed relay communication environments. The following is [3]'s overall scenario.

In the first stage, source transmits a data to the destination. At this time, whole relay nodes can overhear a transmitted data. If erroneous data detected at the destination, the destination broadcasts NACK message. Basically NACK message

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informs a data retransmission. Therefore, each relays can transform to the retransmission mode. During the retransmission period, source transmits RTS packet and destination transmits CTS packets. Through this RTS/CTS handshaking, we can estimate the source-to-relay channel gain ($|h_{si}|^2$) from the RTS packet and the relay-to-destination channel gain ($|h_{id}|^2$) from the CTS packet. After that process, opportunistic relay selection scheme starts in earnest. In order to selects the best relay node, this paper propose a special timer function.

$$T_i = \frac{\lambda}{a_i} \tag{1}$$

Each relays have their own timer which related with each channel links' gain (source-to-relays ($|h_{si}|^2$) and relays-to-destination ($|h_{id}|^2$). Basically, in relay communications, we have to consider both source-to-relay and relay-to-destination links. If the source-to-relay channel was in outage, each relay's data for the retransmission would be ruined. In the same manner, if the relay-to-destination channel was in outage, received data would be failed in destination; so both links are equally important. To reflect this property, there are two types of channel gain criterion. In [3], they consider both channel links at once in (2) and (3).

$$\text{Policy I } : a_i = \min\{ |h_{si}|^2, \ |h_{id}|^2\} \tag{2}$$

$$\text{Policy II } : a_i = \frac{2}{\frac{1}{|h_{si}|^2} + \frac{1}{|h_{id}|^2}} \tag{3}$$

where λ is a hardware parameter in $\mu sec\ \mu Watts$. In this formula, each relays' channel gain (a_i) are putted in timer function's denominator part. So the timer with the best channel conditions will expire first. And expired relay notify the source or destination with a short duration flag packet to prevent hidden node problems. All relays, while waiting for their timer to reduce to zero are in listening mode. If there was no collision event, source or destination transmits ACK message. Through this process, data retransmission via selected relay node is successfully finished.

III. Our Proposed Relay Selection Scheme

In this paper, we propose a modified relay selection scheme in opportunistic relay communication. Our proposed scheme's system model is in below.

<System Model>

$$\mathbf{y}_i = \mathbf{h}_{si}\mathbf{x} + \mathbf{w}_i, \ i = 1...M, \tag{4}$$

$$\mathbf{y'}_i = \mathbf{h}_{id}\mathbf{x} + \mathbf{w'}_i \ , i = 1...M' \quad \text{for } M \geq M', \tag{5}$$

Where $\mathbf{y}_i$ represent the received data from the source. And $\mathbf{y}'_i$ represent the retransmitting data between relay and destination channel link. And M represents the numbers of whole relays which can overhear the transmitted data from the source. And M' represents the numbers of total contending relays. Our proposed scheme uses a threshold level between source and relay node. Therefore, M' is equal or less than M.

In here, we assume that intermediate nodes located in same geographical region; so we consider only rayleigh flat fading. And each channel links are independent and static and symmetric. Also, we use DF (decoding and forwarding) method; it is necessary to decode successfully before retransmitting. Moreover, we consider the reciprocity system [6]; according to this assumption, we can think both forward and backward channel are same. In this work, we consider an automatic repeat request (ARQ) scheme; we didn't use hybrid code. Our proposed scheme described in fig 2.

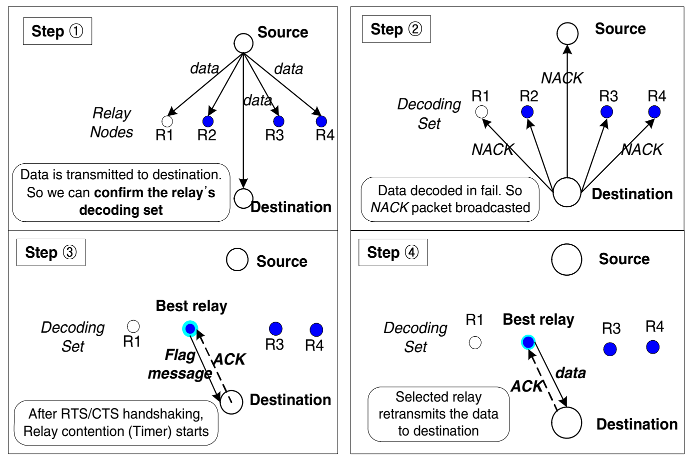

Fig. 2. The block diagram of our modified relay selection algorithm

In first stage, source transmits a data to the destination. At this time, whole intermediate relay nodes can overhear the transmitted data. Therefore, we can estimate the source-to-relay channel gains ($|h_{si}|^2$). Based on the source-to-relay channel gains, our proposed scheme restricts the relays' decoding set which is limited by the threshold level. Through this process, we can decrease the number of participating relays (M). As an information theory's point of view, it means that the relays with more than target data rate can participate in relay contention stage. In other words, we can suppose that all relays within the decoding set can satisfy the required transmission capacity. In fig 2, we represent the contending relays' decoding set with a blue color; this figure's M is 4 and M' (the number of contending relays) is 3. In second stage, if erroneous data detected at the destination, the destination broadcasts NACK message. So contending relays can transform the retransmission mode. According to the NACK signal, we can estimate the relay-to-destination channel gain ($|h_{id}|^2$) Other process is same with section 2's opportunistic relay selection protocol. Then, we sill skip the residual process.

During the relay contention process, if the first expired relay's flag packet collapsed with the second expired relay's flag packet, collision event is occurred. Collision probability formula presented in [3]; we rewrite this formula in (6).

$$\Pr(\text{collision}) : \Pr(Y_2 < Y_1 + c)$$
$$= \Pr(\tfrac{\lambda}{h_2} < \tfrac{\lambda}{h_1} + c),\ 0 < Y_1 < Y_2$$
$$= 1 - \Pr(Y_2 \geq Y_1 + c) \tag{6}$$

1. No hidden node case:

$$c = r_{\max} + |n_b - n_j|_{\max} + d_s$$

2. Hidden node case:

$$c = r_{\max} + |n_b - n_j|_{\max} + 2d_s + dur + 2n_{\max}$$

since,

- $|n_b - n_j|_{\max}$: maximum propagation delay difference between relay j and destination with between relay b and destination
- d_s: receive-to-transmit switch time of each radio.
- T_b: Timer performing period
- $r_{\max}$: maximum propadation delay between two relays.
- dur: duration of flag packet, transmitted by "best" relay

Where Y_1 is the first expired relay node (relay node with the best channel gain) and Y_2 is the second expired relay node. When the Y_1 transmits a flag packet, if the Y_2 transmits a flag packet within interval c, then collision event is occurred. In here, c is a parameter for decision collision event. And c is divided into two cases with each relays hidden node case (all relays are hidden from each other) and no hidden node case (all relays can listen to each other).

If collision event is occurred, crashed flag packets is erased. Therefore, we should wait until next expired relay transmits a flag packet. It produces an additional delay. Then, flag packet's collision event makes worse overall system performance. In particular, if timer's length becomes shorter, collision probability is increased. It is tie with a λ. If the λ becomes longer, collision probability is decreased. But timer length become longer. (This is mentioned in [3].) Therefore, we can design the λ parameter depending on the system objectives whether focusing on the collision probability or focusing on the timer length.

To find the collision probability's numerical formula, we have to derive the channel gain criteria's probability density function.

Analysis of the probability density function (Minimum method case in [3]) : $T_i = \frac{\lambda}{h_i}$

$$\begin{cases} \text{cdf}: F(t) = e^{-\frac{2\lambda}{t}} \\ \text{pdf}: f(t) = \frac{\lambda}{t^2} e^{-\frac{2\lambda}{t}} \end{cases} \tag{7}$$

Proof :

Basic probability density function presented in (8), (9). We bring this formula from [3].

$$\text{cdf}_{T_i}(t) = \Pr\{T_i < t\} = \Pr\left\{\tfrac{\lambda}{h_i} < t\right\}$$
$$= \Pr\left\{\frac{\lambda}{t} < h_i\right\} = 1 - \text{cdf}_{h_i}(\frac{\lambda}{t}) \tag{8}$$

$$\text{pdf}_{T_i}(t) = \frac{\lambda}{t^2}\text{pdf}_{h_i}(\frac{\lambda}{t}) \tag{9}$$

Minimum method in [3] has two variables; but, in here, we unified one variable as a x. Let, $\min(x_1, x_2) = x\ where\ |a_{si}|^2 = x_1,\ |a_{id}|^2 = x_2$. To derive the x's density function, we have to find the x's cdf, pdf formula.

$$x'\text{s cdf} = 1 - (1 - F_x)^2 \tag{10}$$

If we differentiate the cdf, we can get the pdf formula.

$$x'\text{s pdf} = 2(1 - F_x) f_a(x) \tag{11}$$

This paper assumes the rayleigh flat fading. Then each channel link's power leads the exponential distribution.

$$\begin{cases} \text{pdf}_{h_i} = e^{-x} \\ \text{cdf}_{h_i} = \int_0^x e^{-x} dx = 1 - e^{-x} \end{cases} \tag{12}$$

Putting (12) into the (10), (11), then we can get in (13)

$$\begin{cases} x'\text{s cdf} = 1 - e^{-2x} \\ x'\text{s pdf} = 2e^{-2x} \end{cases} \tag{13}$$

So we can have this timer cdf numerical formula.

$$F(t) = 1 - \left(1 - e^{-2\frac{\lambda}{t}}\right) = e^{-\frac{2\lambda}{t}} \tag{14}$$

If we differentiate the cdf, we can get the pdf formula.

Finally, we can have it

$$f(t) = \frac{\lambda}{t^2} e^{-\frac{2\lambda}{t}} \tag{15}$$

Following is the opportunistic relay selection scheme's collision probability formula.

Collision probability numerical formula

$$\Pr(\text{collision}) = 1 - I_c$$
$$I_c = a \int_c^\infty \frac{2\lambda}{t^2} e^{-\frac{2\lambda}{t}} \left(1 - e^{-\frac{2\lambda}{t}}\right)^{M'-2} e^{-\frac{2\lambda}{t-c}} dt \tag{16}$$
$$a = M'(M'-1)$$

Proof :

The basic collision probability formula derived in (17). We bring this formula from [3].

$$\Pr(Y_2 < Y_1 + c) = 1 - I_c$$
$$I_c = M'(M'-1) \int_c^\infty f(y)[1 - F(y)]^{M'-2} F(y - c) dy \tag{17}$$

From the (8),(9), we can get the collision probability numerical formula by putting into the (17).

$$I_c = M'(M'-1)\int_c^{\infty} \frac{2\lambda}{t^2} e^{-\frac{2\lambda}{t}} [1-e^{-\frac{2\lambda}{t}}]^{M'-2} e^{-\frac{2\lambda}{t-c}} dt \quad (18)$$

IV. Simulation Results and Performance Analysis

To analyze our proposed scheme's performance results, we execute the *Monte Carlo* computer simulation based on the $\lambda = 400\mu s$, $c = 1\mu s$. We use a BPSK modulation and Rayleigh flat fading channel. And we restrict the number of initial contending relays to 10.

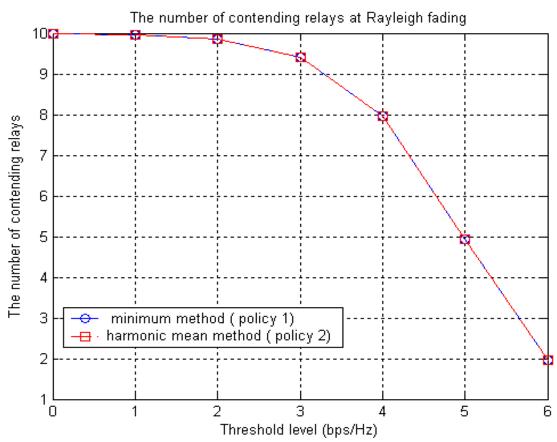

Fig. 3. The number of contention relays depending on the source-to-relay's threshold level

Fig 3 represents the numbers of contending relays depending on the source-to-relay threshold level. As increase of threshold level, the numbers of contending relays (M') are decreased. In opportunistic relaying system, all contending candidates (M') should wake up to listen for the data transmission. If relays with poor channel links participate in the contending process, that will lead the huge power waste. Therefore, through our threshold setting process, we can have benefits of low complexity and low power consumption. Also, in this figure, we can find out the actual numbers of contending relays depending on the threshold. Hence, we can apply this numerical value (M') to (16). Through this process, we can confirm the exact collision probability result.

As previously mentioned, the collision event produces an additional delay time that makes worse overall system performance. Therefore, we should analyze the collision probability's exact trend depending on the threshold. To verify the proposed collision probability's simulation result, we put the collision probability numerical formula in (16) to the mathematica program. The exact numbers of contending relays (M') are represented in fig 3. Therefore, through the combination of (16) and fig 3, we can analyze the collision probability's numerical formula calculation result. (Numerical formula calculation result is called as Theory curve in fig 4.)

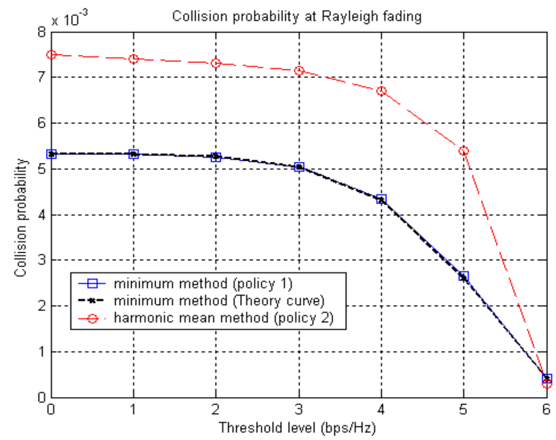

Fig. 4. The collision probability trend depending on the source-to-relay's threshold level

The numerical formula calculation result (Theory curve) exactly matched with the simulation curve in minimum method. Therefore, we can find out, as increase of threshold value, collision probability decreased more and more. In particular, after 4bps/Hz threshold level, decreasing trend is changed sharply. Hence, if we want to decrease the collision probability more effectively, we'd better to use a higher threshold value (more than 4bps/Hz). Also, in this figure, we can compare the collision probability performance between minimum method (policy 1) and harmonic mean method (policy 2). Through this comparison, we can derive the minimum method (policy 1)'s benefit on the collision probability.

V. Conclusion

We develop a modified relay selection technique in opportunistic relay communications. In this approaches, we derived the probability density function's numerical formula related to the collision probability. And we make the performance analysis depending on each threshold level. Through this process, we verify the collision probability's simulation results with the numerical formula calculation results. Then our proposed scheme decreases the contending relay's collision probability. Especially, more than 4bps/Hz threshold level makes a sharp decrease.

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