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Selection Relaying Scheme Based Geographic Information with Imperfectly Decoding Relays in ARQ protocols

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ABSTRACT

In the paper, a selection relaying scheme is proposed and analyzed in which relays retransmit the erroneous packet without checking the correctness of their received packets. The proposal not only achieves the full diversity gain in a limited number of retransmissions but it also gets better performance than other schemes. Additionally, a threshold in the number of retransmissions and the closed form expression for packet error rate (PER) are derived. Simulation results are given to confirm the accuracy of analysis and to significantly prove advantages of the proposal.

Key Words : Cooperative communications, ARQ protocol, Selection relaying schemes, Packet error rate.

Ⅰ. Introduction

In recent years, cooperative communication is considered as the best solution to mitigate effects of fading. Therefore, it is not only applied for repetition cooperative based diversity gain algorithms and space time code protocols[1-3], but it also takes advantage of throughput, energy efficiency in ARQ protocol [4-7]. In multi-hop networks, the use of cooperative ARQ protocols instead of the traditional ARQ also achieves advantages on packet error rate, throughput efficiency, and diversity gain[5-7]. On the performance of cooperative ARQ protocols, like that of other cooperative communications, one of the important problems is that how to select the best relays among available relays to retransmit a packet to the destination while the source unsuccessfully transmits this packet[5, 7-9]. In [9], the selection relaying scheme based on geographic information called Harbinger is analyzed as the best scheme for cooperative ARQ protocol by achieving higher throughput, bandwidth efficiency than other selection relaying schemes. Similarly, there are many authors utilizing advantages on selection relaying scheme based geographic information to propose selection relaying schemes[10,11]. However, in all schemes, when a relay is chosen, it has to fully decode its received packet. In general, to perfectly decode packets at all relays requires difficult and complex softwares. Moreover, in [2], various efficient cooperative diversity protocols including fixed decode-and-forward (FDF), selective decode-and-forward, amplify-and-forward, and incremental protocols, all of which, expect FDF protocol, were shown to achieve full diversity gain, were proposed and compared in terms of outage behavior which measures the robustness of the transmission to fading. A system can reach full diversity gain when the diversity gain equals $(N+1)$ where N is the number of relays between a source and a destination[7,12,13].

Additionally, there are some issues in operation of selection relaying schemes based on geographic information in cooperative ARQ protocols[9-11]. First, as above mentioned, the authors always assume that the relay nodes can perfectly decode the signal.

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Second, the fading is only considered in the case of flat fading. So, what will happen if the effect of fading to the system is slow fading or the relay node is unable to decode the packet? Third, closed form expression for packet error rate still is an open requirement. Consequently, in this paper, we propose a selection relaying schemes in which a chosen relay will retransmit a packet without caring about the correctness of its received packet. Additionally, the best relay is chosen based on the geographic information and the fading environment is slow fading. For simplicity, the proposal is referred as geographic relaying scheme (GeRaFARQ). Especially, the proposed scheme not only achieves the advantage of packet error rate but it also gets the full diversity gain.

Ⅱ. System Model

2.1 Protocol Description

Consider a network including a source R_0, a destination R_{N+1}, and N relays in communication range of the source R_0 and the destination R_{N+1}. The relays are numbered according to their distance to the destination in which the R_1 is the furthest and R_N is shortest.

In this paper, we first assume that a time division duplex (TDD) is covered and all nodes can not simultaneously receive and transmit in the same channel. When a node is assigned to transmit a packet to the destination, it uses a time slot. In addition, in order to save memory, whenever the destination receives an incorrect packet, it flushes its old memory. The relays, unlike the destination, only keep their old packet received from the source. In here, we consider probabilistic retransmission with the finite retransmissions[14]. It means that after the source transmits a packet to the destination, retransmissions from any node such as relays or the source is limited in a maximum number of retransmissions m $(0 < m < \infty)$. When a node retransmits the packet, the number of retransmissions increases by one. The transmission terminates when the destination receives the packet correctly or the system performs all maximum number of retransmissions allowed per packet m. We assume that the destination will count this value. After m retransmissions fail, the destination sends a message to the source to drop the packet and transmit a new packet.

As the operation of ARQ schemes, the destination will send acknowledgment messages such as NACK and ACK messages to inform other nodes about its received packet. If the source receives an ACK message, it will send a new packet. Otherwise, if a NACK message is broadcasted from the destination, the system has to find the way to choose the best relay as well as how to access the channel and inform for other nodes to achieve the highest bandwidth efficiency. In other schemes [4-7], all nodes in the networks will send their information about the received packet by broadcasting the ACK or NACK messages. However, this way takes bandwidth inefficiency when the network has numerous nodes. In the proposal, relay nodes will perform retransmissions without checking about the correctness of the received packet, as the results, they do not send the ACK/NACK messages. Therefore, the proposal can get high bandwidth efficiency but we have to perform a new access channel scheme for the proposal as following. When a node receives the packet from the transmitter, we assume that the receiver can know the information about the position of the transmitter. From this information, whenever the relay node receives the NACK message from the destination, it decides a delay time T_S. The delay value T_S should be long enough so that the delay caused by propagation does not make a wrong competing resolution. The value of T_S is calculated by each relay based on the distance from the relay to the previous transmitter. If the transmitter is the source, the delay time at the relay R_i $(0 < i < N+1)$ follows the rule as $T_S^{R_i} = \lambda d_{R_i, R_{N+1}}$ where λ is a unit of time, $d_{R_i, R_{N+1}}$ is the distance from the node R_i to the destination. On the other way, in the case the relay R_i is a transmitter, the delay time of other nodes R_j

$(0 \leq j \leq N)$ is calculated as

$$T_S^{R_j} = \begin{cases} \lambda d_{R_i,R_j} & \text{if } d_{R_j,R_{N+1}} \leq d_{R_i,R_{N+1}} \\ \lambda\left(d_{R_i,R_j} + d_{R_j,R_{N+1}}\right) & \text{if } d_{R_j,R_{N+1}} > d_{R_i,R_{N+1}} \end{cases} \quad (1)$$

Based on calculating the delay time, we easily realize that in the first retransmission, the relay R_N is assigned to resend the packet. As previously mentioned, retransmissions terminate if the destination correctly receives the packet or the number of retransmissions exceeds the allowable retransmissions m. If the relay R_N incorrectly transmits the packet to the destination, the relay $R_{N-1}$is chosen to broadcast the packet to the destination again. If all relays from R_N to R_1 have already transmitted the packet but the destination still unsuccessfully receives the packet and the number of retransmissions does not exceed to the allowable retransmissions, the source repeats the packet again. After that, the above process is performed until the retransmissions finish.

2.2 Data Link Layer Model

We assume that the channels between two nodes are subject to block and slow Rayleigh fading, in which the channel remains unchanged during a number of transmissions. The packet received at a node R_j from a transmitter R_i is given as[6]:

$$\begin{aligned} y_{i,j} &= h_{i,j}\sqrt{P_x}\,x + n_{i,j} \\ i,j &= R_0, R_1, \ldots, R_{N+1}\ (i \neq j) \end{aligned} \quad (2)$$

where $y_{i,j}$ is the received packet at the node R_i. x is a sent packet which is an uncoded modulation with a predetermined packet size. $n_{i,j}$ is the noise at the node R_j and modelled as mutually independent complex Gausisan r.v's with zero mean and unit variance N_1. $h_{i,j}$ captures the effect of the fading from the node R_i to the node R_j . P_x is the transmitted power. $P_x = P_S$ if the transmitter is the source, otherwise, $P_x = P_R$.

As analyzed in [15], the received SNR per packet follows the probability density function as:

$$f_{\gamma_{i,j}} = \frac{1}{\overline{\gamma_{i,j}}} exp\left(-\frac{\gamma}{\overline{\gamma_{i,j}}}\right) \quad (3)$$

where $\overline{\gamma_{i,j}}$ is the average SNR. Where $\overline{\gamma_{i,j}}$ is the expected value of the instantaneous received SNR of $\gamma_{i,j}$. In order to take path loss into account, we model the variance of channel coefficient between the node R_i and the node R_j as the function of distance as

$$\overline{\gamma_{i,j}} = \frac{P_x}{N_1} d_{R_i,R_j}^{-\beta} = SNR \times d_{R_i,R_j}^{-\beta} \quad (4)$$

Where β is path loss exponent that varies from 2 to 6 on the basis of channel environment.

So we adopt the approximation physical packet error rate as[15,16]

$$PER(\gamma) = \begin{cases} 1 & \text{if } 0 < \gamma < \gamma_t \\ aexp(-g\gamma) & \text{if } \gamma \geq \gamma_t \end{cases} \quad (5)$$

where (a, g, γ_t) are found by least squares fitting method. The switching threshold γ_t is set such that

$$aexp(-g\gamma_t) = 1 \quad (6)$$

In slow fading, the channel gain between a transmitter R_i and a receiver R_j is unchanged. Thus, the average packet error rate (PER) of the channel between R_i, R_j with x erroneous packets and y correct packets is calculated as.

$$\begin{aligned} P_{i,j}^{x,y} &= \int_0^{\infty} PER^x(\gamma)\,[1 - PER(\gamma)]^y f_{\gamma_{i,j}}(\gamma)\,d\gamma \\ &= \sum_{l=0}^{y} (-1)^l C_y^l \int_0^{\infty} PER^{x+l}(\gamma) f_{\gamma_{i,j}}(\gamma)\,d\gamma \\ &= \sum_{l=0}^{y} (-1)^l C_y^l \left[1 - \frac{(x+l)\overline{\gamma_{i,j}}g}{1 + (x+l)\overline{\gamma_{i,j}}g} exp\left(-\frac{\gamma_t}{\overline{\gamma_{i,j}}}\right)\right] \end{aligned} \quad (7)$$

Ⅲ. PERFORMANCE ANALYSIS

3.1 Packet Error Rate

Based on the operation of the proposal, we can calculate the packet error rate of the proposal as

$$P_2 = PER\left(\gamma_{0,N+1}\right)PE_0^m \tag{8}$$

Where PE_0^m presents for the packet error rate by retransmitting the data with the maximum number of retransmissions m and the current transmitter R_0. Generally, packet error rate PE_k^K with the number of retransmissions K and the transmitter R_k is calculated as

$$PE_k^K = \begin{cases} PER\left(\gamma_{0,N,N+1}\right)PE_N^{K-1} & If\,(k=0)\cup(K\neq 0) \\ PER\left(\gamma_{0,k-1,N+1}\right)PE_{k-1}^{K-1} & If\,(k\neq 0)\cup(K\neq 0) \\ 1 & If\,(K=0) \end{cases} \tag{9}$$

In (9), $PER\left(\gamma_{0,k,N+1}\right)$ refers the packet error rate of indirect link from the source to the relay node R_k to the destination in which the node R_k transmits the packet without amplifying or checking the signal. It can be written as:

$$\begin{aligned} PER\left(\gamma_{0,k,N+1}\right) &= 1-\left[1-PER\left(\gamma_{0,N}\right)\right] \\ &\quad\times\left[1-PER\left(\gamma_{N,N+1}\right)\right] \\ &= PER\left(\gamma_{0,N}\right)+\left[1-PER\left(\gamma_{0,N}\right)\right]PER\left(\gamma_{N,N+1}\right) \end{aligned} \tag{10}$$

If the number of allowable retransmissions m is rewritten in the relationship with the number of relays N as $m = aN+b$ (a, b are integers with $0 \leq a,b \leq \infty$), we have a closed form expression for packet error rate of the proposal by applying the equation (10) into (9), and performing integral following different channels as equation (7) as :

$$P_2 = P_{0,N+1}^{a+1,0}\prod_{k=0}^{M-1}\left[P_{0,k}^{0,a+b_k}P_{k,N+1}^{a+b_k,0} + \sum_{l=0}^{a+b_k-1}\left(P_{0,k}^{1,l}P_{k,N+1}^{l,0}\right)\right] \tag{11}$$

where

$$\begin{aligned} b_k &= \begin{cases} 1\ \mathrm{if}\ k \leq b \\ 0\ otherwise \end{cases} \\ M &= \begin{cases} m\ \mathrm{if}\ a=0 \\ N\ otherwise \end{cases} \end{aligned} \tag{12}$$

3.2 Diversity Order

In this subsection, we analyze the diversity performance of the scheme, which corresponds to the performance at very high SNR region. The diversity gain is given by the magnitude of the slope of the packet error rate as the function of SNR[17]. As defined of average SNR, when SNR at the receiver of the channel from the node R_i to the node R_j goes to infinite, it can be presented as $\overline{\gamma}_{i,j}\rightarrow\infty$. In addition, the diversity gain of a system is limited by the weakest of all involved single links. Let ψ be defined as the diversity gain. The diversity gain ψ in the average packet error rate from the transmitter R_i and the receiver R_j over x erroneous packets and y correct packets is

$$\begin{aligned} &\min\left(\lim_{\overline{\gamma}_{i,j}\rightarrow\infty}P_{i,j}^{x,y}\right) \\ &= \lim_{\overline{\gamma}_{i,j}\rightarrow\infty}\left[1-\frac{x\overline{\gamma}_{i,j}g}{1+x\overline{\gamma}_{i,j}g}exp\left(-\frac{\gamma_t}{\overline{\gamma}_{i,j}}\right)\right] \end{aligned} \tag{13}$$

If $x=0$

$$\lim_{\overline{\gamma}_{i,j}\rightarrow\infty}P_{i,j}^{x,y}=1 \tag{14}$$

From (14), we have $\psi=0$.

When $x \neq 0$

$$\begin{aligned} &\lim_{\overline{\gamma}_{i,j}\rightarrow\infty}\left[1-\frac{x\overline{\gamma}_{i,j}g}{1+x\overline{\gamma}_{i,j}g}exp\left(-\frac{\gamma_t}{\overline{\gamma}_{i,j}}\right)\right] \\ &= \left(-\frac{\gamma_t}{\overline{\gamma}_{i,j}}\right) \end{aligned} \tag{15}$$

From (15), $\psi=1$. The diversity gain of the proposal is calculated as

$$\begin{aligned} &\min\left(\lim_{\overline{\gamma}_{i,j}\rightarrow\infty}P_2\right) \\ &= \lim_{\overline{\gamma}_{i,j}\rightarrow\infty}\left\{P_{0,N+1}^{a+1,0}\prod_{k=0}^{M-1}\left[\begin{array}{l} P_{0,k}^{0,a+b_k}P_{k,N+1}^{a+b_k,0} + \\ \min\displaystyle\sum_{l=0}^{a+b_k-1}\left(P_{0,k}^{1,l}P_{k,N+1}^{l,0}\right) \end{array}\right]\right\} \\ &\equiv \lim_{\overline{\gamma}_{i,j}\rightarrow\infty}\left\{P_{0,N+1}^{a+1,0}\prod_{k=0}^{M-1}\left[P_{0,k}^{0,a+b_k}P_{k,N+1}^{a+b_k,0}+P_{0,k}^{1,l}\right]\right\} \\ &= \left(-\frac{\gamma_t}{\overline{\gamma}_{0,N+1}}\right)^1\prod_{k=0}^{M-1}\left[\begin{array}{l} \left(-\frac{\gamma_t}{\overline{\gamma}_{0,k}}\right)^0\left(-\frac{\gamma_t}{\overline{\gamma}_{k,N+1}}\right)^1 \\ +\left(-\frac{\gamma_t}{\overline{\gamma}_{0,k}}\right)^1 \end{array}\right] \end{aligned} \tag{16}$$

From (16), $\psi = M+1$. So, with any value of the number of retransmissions m, the diversity order of the system equals $M+1$. For example, we have N relays between the source and the destination, if the allowable retransmissions equal N and $N+2$, the diversity of the system still equals $N+1$ for both cases. Thus, the limited number of allowable retransmissions should not exceed the number of relays between the source and the destination.

Ⅳ. Simulation Results

In the simulation, we use BPSK modulation without FEC (Forward Error Code) to simulate performance of schemes. The length of a packet is set to be 1080 bits and the (α, g, γ_t) parameters in (5) are (67.7328, 0.9819, 6.3281dB)([15], Table. 1).

The definition of the SNR in the following figures is the ratio of the transmitted power over the noise variance at the receiving node which is assumed to be 1 ($N_1 = 1$). The source, the relays and the destination is corresponded to an equidistant line network in which the distance from a node to adjacent node equals 1. Additionally, the reference distance d_0 and the path lost equals 1, 3, respectively.

In order to prove benefits of the proposed scheme, we compare performances of the proposal with two different schemes. One is the traditional ARQ scheme. The other is a scheme having the same operations as [9, 11] but it is considered in the similar conditions as the proposed scheme. Conditions of the paper includes: Schemes are operated over slow fading channels and truncated ARQ does not use. Due to difference on the conditions of the scheme compared to [9, 18], we refer the scheme[9] as GeRaFARQ2.

We may easily see that in Fig. 1 when number of relays equals to the maximum number of retransmissions allowed per packet ($m = N$), the proposal can achieve full diversity gain which can be seen the slopes of the performance curves which become more steeper with increasing the number of relays. As expected, the proposal really outperforms the traditional ARQ scheme. For example, at the transmitted powers $P_S = P_R = 30dB$, while the PERs of the proposal only equal 0.5×10^{-4}, 10^{-4}, and 10^{-3} with the number of relays $N = 2, 3, 4$, respectively, that of the traditional ARQ scheme comes to 0.1, 0.5, and 0.7.

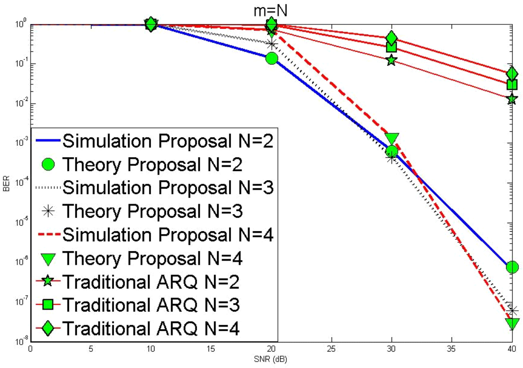

Fig. 1. PER performance of the proposal and the traditional ARQ scheme with different number of relays

From the simulations, we clearly realize that the theoretical and the simulation results match exactly. It means that the performance analyses are derived correctly.

Normally, when the number of retransmissions increases, the performance of the system is better[14]. However, in Fig. 2 we simulate the case when the number of retransmissions equals 4 while the number of relays equals 2, 3, and 4. It is not difficult to recognize that the performance of system compared to Fig. 1 is nearly similar. It is obvious that we can not get any benefits as diversity gain or higher PER performance if we increase the number

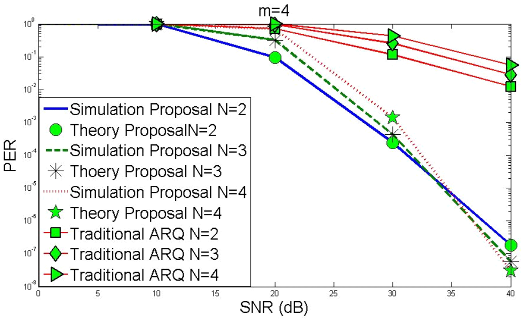

Fig. 2. PER performance of the proposal and the traditional ARQ scheme with fixed the number of retransmissions.

of retransmissions m. As the result, the threshold for number of retransmissions of a system over slow fading should be equal to the number of relays.

On Fig. 3, we compare the performance of the proposal with the GeRaFARQ2 scheme in the reference[9] in the same conditions. The performance of the proposal and GeRaFARQ2 scheme is similar when the SNR is small ($SNR \le 20dB$). When SNR is high enough, the proposal achieves higher performance than the GeRaFARQ2 scheme. Especially, the number of relays increases, the performance of both schemes decreases. The reason is explained as follows. Because the source, the relays, and the destination are placed in an equidistant line, when the number of nodes increases, the distances from the source to the destination or the source to the closest relay R_N also increase. It leads to the probability that the destination or the relay R_N correctly receives the signal decreases. As the results, other relays perform retransmissions. However, relays R_i $(i < N)$ is so far from the destination. Therefore, they may not utilize advantages on distance to the destination.

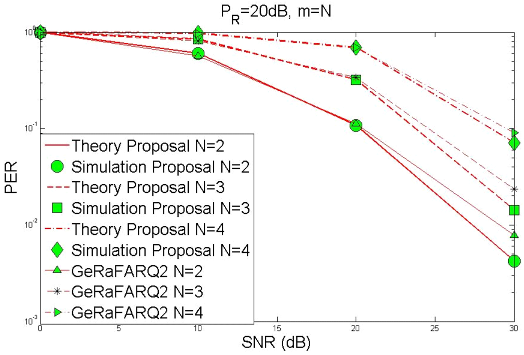

Fig 3. Packet error rate comparison between the proposal with the reference[9] when the transmitted power at the relays equals 20dB.

Ⅴ. Conclusion

In this paper, we propose and analyze a new selection relaying scheme used in the ARQ protocol in which perfectly decoding the packet at the relays does not require. Especially, although the relay performs retransmissions without amplifying the signal by an amplifier or checking the signal by a threshold, the proposal still achieves full diversity gain and better performance than other schemes. Moreover, a threshold of the number of retransmissions also is suggested to achieve the best performance for the system.

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