An Efficient Scheduling in Consideration of the Signaling Overhead for Relay Networks

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***Abstract*—An efficient scheduling for relay networks is proposed in consideration of the signaling overhead. A source node informs both relay and destination node about the resource assignments in every frame. The resource allocation process generates a substantial signaling overhead, which influences the system performance. However, the amount of the signaling overhead can be reduced by predetermining resource assignments of future frames. We develop a frame structure for scheduling and propose an efficient scheduling in consideration of the signaling overhead. The performance of the proposed scheduling is evaluated compared with that of the conventional scheduling in terms of the average capacity as both the number of relays increases and the average signal-to-noise ratio increases. Simulation results show that the average capacity of the proposed scheduling is greater than that of the conventional scheduling.**

Keywords-relay networks; persistent scheduling; signaling overhead.

I. Introduction

In the cellular networks, the relay node is one of the important techniques to improve the spectrum efficiency, link reliability, and coverage. Besides, an efficient scheduling algorithm is crucial for the efficient use of limited wireless resource. A scheduler in the relay networks determines a relay node which relays data from the source node to the destination node. Therefore, an optimal selection criterion of the relay node is dependent on the scheduling metric. A selection of the relay node is important to increase the system capacity. A signaling message usually broadcasts to users for every frame. The term signaling overhead is used to describe the information on the resource assignments and the path management. However, frequent route changes could cause high signaling overheads which influence the system performance [1]. For example, the amount of effective resources to transmit data traffic increases as the signaling overhead decreases. Hence, one of the important roles of the scheduler is to reduce the signaling overhead.

Many researchers have endeavored to develop an efficient scheduling algorithm to increase the system performance in the relay networks [2]-[5]. Lee and Hwang [2] proposed a scheduling algorithm to reduce the power, where a relay node is selected on the basis of channel conditions of relay nodes. Hence, the selected relay node meets the data rate requirement. In [3] and [4], authors propose a relay node selection algorithm in order to enhance the system performance. In [3], the optimal relay node selection strategies are proposed under fixed and variable transmit power. In [4], a centralized utility maximization frame work was introduced for relay networks. The physical layer transmission strategies are done efficiently by optimizing pricing variables as weighting factors. In [5], the relay selection strategies are proposed and evaluated in terms of spectral efficiency in the relay cellular network. To determine an optimal route for a data transmission, the scheduler takes into account the feature of multi-hop transmission.

However, the scheduling algorithms of [2]-[5] were not considered the signaling overhead that broadcasts information on resource assignments and path management. The resource allocation process generates a substantial signaling overhead, which influences on the amount of the available radio resources. Hence, the scheduler should consider the signaling overhead to increase the system capacity. Some studies have considered the signaling overhead in the scheduling metric for relay systems [6]-[7]. In [6] and [7], by taking the signaling overheads transmitted among relay nodes into consideration, the system capacity was evaluated. Bletas, Khisti, Reed, and Lippman [8] proposed a distributed relay selection algorithm for a two-hop amplified-and-forward system, where the selection criterion is to select the relay node which has the best instantaneous signal-to-noise ratio (SNR) across the two-hops. Although these studies consider the signaling overhead, the scheduling metric has no consideration to reduce the signaling overhead. The relay selection strategy was proposed in [9], which introduced a method to reduce the complexity and the signaling overhead of the relaying process. The feedback message for the channel state report is considered but the signaling message is not considered. In [10], the framework has been proposed for the relay selection in cellular networks while limiting the feedback overhead and complexity. However, the signaling message for data transmissions is not considered in the relay selection criterion.

This paper proposes an efficient scheduling in considera-

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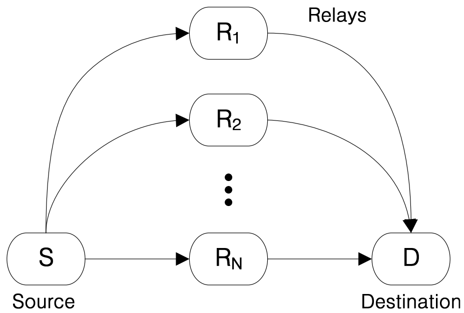

Figure 1. The multi-relay network

tion of signaling overhead for relay networks.

The remaining part of this paper is organized as follows: Section II contains the description of the system model. In Section III, we propose an efficient scheduling algorithm in consideration of the signaling overhead and analyze the system capacity of the proposed scheduling. We provide simulation results in Section IV and finally, Section V presents conclusions and future works.

II. System Model

We consider the downlink relay networks, consisting of a single source, N relays, and a single destination denoted by S, R, and D, respectivley. The system investigated in this paper is shown in Fig. 1. We assume that Rayleigh fading channels [11] between the source and relays, denoted by $S-R$ links, and the Rayleigh fading channels between the relays and the destination, denoted by $R-D$ links. Moreover, independent and identically distributed Rayleigh fading is assumed across all links. It is assumed that the entire links have the same average SNR. The source has no direct link with the destination and the data transmission is performed by one of N relays. The source broadcasts the signaling message in order to inform on resource assignments to both relays and the destination. We assume that the signaling message is only transmitted in S-R link and is not transmitted in R-D link. Therefore, the signaling message includes information on both S-R link and R-D link.

Let $\gamma_{i,j}$ denote the instantaneous SNR of i-j link, where $i = \{S, 1, \cdots, N\}$ and $j = \{1, \cdots, N, D\}$. For Rayleigh fading channels, $\gamma_{i,j}$ is an exponential random variable, and its cumulative density function (CDF), $F(\gamma_{i,j})$, and probability density function (PDF), $f(\gamma_{i,j})$, are given as

$$F(\gamma_{i,j}) = 1 - e^{-\frac{\gamma_{i,j}}{\bar{\gamma}}}, \tag{1}$$

$$f(\gamma_{i,j}) = \frac{1}{\bar{\gamma}} e^{-\frac{\gamma_{i,j}}{\bar{\gamma}}}, \tag{2}$$

where $\bar{\gamma}$ is an average SNR of i-j link.

The relay selection is performed as follows:

Step 1) For each relay link, determine a minimum SNR between $\gamma_{S,n}$ and $\gamma_{n,D}$:

$$\Omega_n = \min_{n=1,2,\cdots,N} \{\gamma_{S,n}, \gamma_{n,D}\}, \tag{3}$$

where Ω_n is the instantaneous SNR when data is transmitted by the relay n. The CDF, $F_{\Omega_n}(\Omega_n)$ and PDF, $f_{\Omega_n}(\Omega_n)$ can be formulated as

$$\begin{aligned} F_{\Omega_n}(\Omega_n) &= 1 - \Pr(\gamma_{S,n} > \Omega_n) \Pr(\gamma_{n,D} > \Omega_n) \\ &= 1 - e^{-\frac{\Omega_n}{\bar{\gamma}}} e^{-\frac{\Omega_n}{\bar{\gamma}}} \\ &= 1 - e^{-\frac{2\Omega_n}{\bar{\gamma}}}, \end{aligned} \tag{4}$$

$$f_{\Omega_n}(\Omega_n) = \frac{dF_{\Omega_n}(\Omega_n)}{d\Omega_n} = \frac{2}{\bar{\gamma}} e^{-\frac{2\Omega_n}{\bar{\gamma}}}. \tag{5}$$

Step 2) The source node selects a relay for data transmissions by following as:

$$\gamma_{n^*} = \max_{n=1,2,\cdots,N} \{\Omega_n\}. \tag{6}$$

We define a minimum SNR of the selected relay as γ, i.e., $\gamma = \gamma_{n^*}$. The parameter, n^*, means a selected relay. The PDF, $f_\gamma(\gamma)$, can be derived by using a knowledge of order statistics [12], [13]. Using both (4) and (5), the PDF of γ can be formulated as

$$\begin{aligned} F_\gamma(\gamma) &= \prod_{n=1}^{N} \Pr(\Omega_n \le \gamma) \\ &= \left(1 - e^{-\frac{2\gamma}{\bar{\gamma}}}\right)^N, \end{aligned} \tag{7}$$

$$f_\gamma(\gamma) = \frac{dF_\gamma(\gamma)}{d\gamma} = N \frac{2}{\bar{\gamma}} e^{-\frac{2\gamma}{\bar{\gamma}}} \left(1 - e^{-\frac{2\gamma}{\bar{\gamma}}}\right)^{N-1}. \tag{8}$$

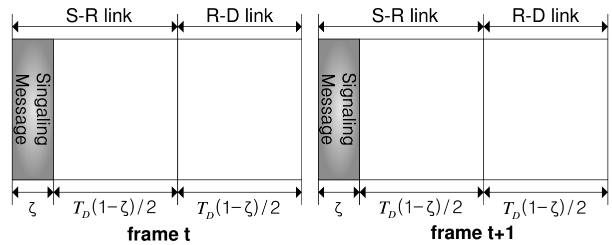

Figure 2. The frame structure of the conventional scheduling

III. Performance Analysis

A. Conventional Scheduling

In the conventional scheduling, the source broadcasts the signaling message for every frame to inform the allocations of radio resources in the downlink relay networks. The signaling message contains the information that indicates the path management and resource assignments. For conventional scheduling, we propose a modified frame structure, as shown in Fig. 2.

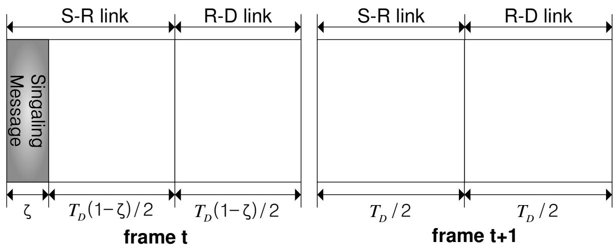

Figure 3. The frame structure of the proposed scheduling

Let ζ denote the ratio of the signaling message used to transmit information to both relays and the destination. The ratio, ζ, is defined as follows:

$$\zeta = \frac{\text{Resource used to transmit a signaling message}}{\text{Resource used to transmit data}}. \quad (9)$$

Let T_D be the frame duration. Then, $T_D(1-\zeta)/2$ denotes the duration for data transmission at S-R and R-D link, respectively. The duration of a subframe for S-R link, $\zeta + T_D(1-\zeta)/2$, is different from the duration of a subframe for R-D link, $T_D(1-\zeta)/2$. The frame structure is not symmetric between the S-R link and the R-D link. However, because the duration for data transmissions at the S-R link and at the R-D link is identical, the frame structure provides the equal opportunity for each link in view of the data transmission. The performance of conventional scheduling is evaluated in terms of the average capacity, where the capacity, C, is calculated by Shannon's capacity as follows:

$$C = \log_2(1+\gamma) \text{ [bps/Hz]}, \quad (10)$$

where γ is the SNR [14]. The average capacity of the conventional scheduling can then be rewritten by using the PDF of γ obtained from (8). The average capacity can be obtained as follows:

$$\begin{aligned}\bar{C} &= \frac{T_D(1-\zeta)/2}{T_D}\int_0^\infty \log_2(1+\gamma) f_\gamma(\gamma) d\gamma \\ &= \frac{1-\zeta}{2}\int_0^\infty \log_2(1+\gamma) f_\gamma(\gamma) d\gamma \ \text{ [bps/Hz]}, \quad (11)\end{aligned}$$

where the factor of $1/2$ is used because the frame is divided into two subframes, and the factor of $(1-\zeta)$ is used because the signaling overhead is reduced.

B. Proposed Scheduling

To increase the system performance, the source performs an efficient scheduling taking the signaling message into consideration. In the conventional scheduling, the signaling message is transmitted in every frame. However, the resource allocation process generates a substantial signaling overhead, which influences the system performance.

In the fading channel environments, the instantaneous SNR is somewhat predictable. Hence, the scheduler reduces the signaling overhead by transmitting an initial assignment message, which is valid in a following of future frames. In the proposed scheduling, as shown in Fig. 3, the source broadcasts information on resource assignments in the signaling message only for frame t and does not broadcast the signaling message for frame $t+1$. The source allocates a persistent resource to both relay and destination when it first schedules the both relay and destination; and the allocated resource is valid in frame $t+1$. Hence, the signaling overhead decreases and the effective downlink resource increases. In the proposed scheduling, if the instantaneous SNR in frame $t+1$ is equal or greater than the instantaneous SNR in frame t, the proposed scheduling may result in some efficiency because the source transmits data without notification of signaling messages. However, if the signaling message which is predetermined in frame t is not suitable for frame $t+1$, the performance degradation will occur in frame $t+1$.

The instantaneous SNR may vary in every frame in accordance with the time-varying channel conditions. The probability that the highest SNR is greater at frame $t+1$ than at frame t, is defined as

$$P = \Pr(\gamma_1 \le \gamma_2), \quad (12)$$

where γ_1 and γ_2 are the highest SNR at frame t and at frame $t+1$, respectively.

The average capacity of the proposed scheduling is twofold. First, when the source broadcasts the signaling message, the average capacity for frame t, which is denoted by C_1, can be written as the total capacity averaged over the PDF, $f_\gamma(\gamma)$, as follows:

$$\bar{C}_1 = (1-\zeta)\frac{1}{2}\int_0^\infty \log_2(1+\gamma) f_\gamma(\gamma) d\gamma \ \text{ [bps/Hz]}. \quad (13)$$

The average capacity, C_1, is equal to the average capacity of the conventional scheduling because the source broadcasts the signaling message to both relays and the destination.

Second, when the source transmits data without the notification of the signaling messages, the average capacity for frame $t+1$, which is denoted by C_2, can be written as the total capacity averaged over PDF, $f_\gamma(\gamma)$, as follows:

$$\begin{aligned}\bar{C}_P &= P\cdot\frac{1}{2}\int_0^\infty \log_2(1+\gamma) f_\gamma(\gamma) d\gamma, \quad (14)\\ \bar{C}_{1-P} &= (1-P)\cdot\frac{1}{2} \\ &\quad \times \int_0^\infty \log_2(1+(1-\alpha)\gamma) f_\gamma(\gamma) d\gamma, \quad (15)\\ \bar{C}_2 &= \bar{C}_P + \bar{C}_{1-P} \quad \text{[bps/Hz]}, \quad (16)\end{aligned}$$

where the $\bar{C}_P$ and $\bar{C}_{1-P}$ are the average capacity when $\gamma_1 \le \gamma_2$ and $\gamma_1 > \gamma_2$, respectively. The SNR variation parameter, α, is a ratio of amount of a falling SNR value when $\gamma_1 > \gamma_2$. The average capacity for frame $t+1$ is determined by the sum of $\bar{C}_P$ and $\bar{C}_{1-P}$.

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Table I
SIMULATION PARAMETERS

Parameter	Value	
	Default	Variation
The number of relays, N	5	1∼10
The average SNR of S-R link, γ^{S-R}	10 dB	0∼14 dB
The average SNR of R-D link, γ^{R-D}	10 dB	0∼14 dB
The signaling overhead ratio, ζ	20%	10%, 30%
The SNR decrease ratio, α	20%	-
The probability, P	80%	60%, 80%, 100%

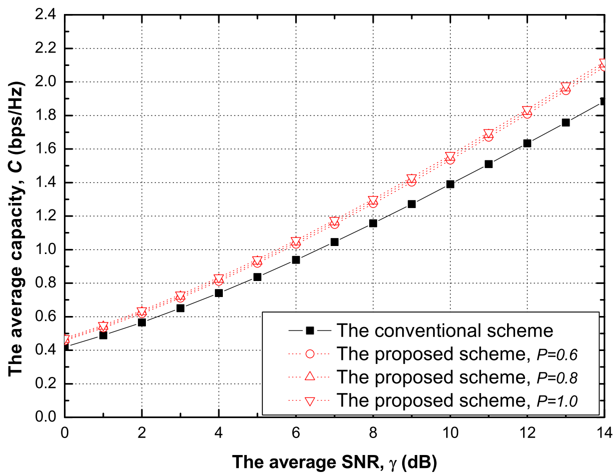

Figure 4. The average capacity versus the average SNR, γ (dB)

The average capacity of the proposed scheduling can be obtained by

$$\bar{C} = \frac{1}{2}\left(\bar{C}_1 + \bar{C}_2\right) \text{ [bps/Hz].} \tag{17}$$

IV. SIMULATION RESULTS

Simulation environments assume the downlink of a relay network with N active relays, in which all relay links have the same average SNR, $\bar{\gamma}$. Each link of channels has a Rayleigh channel environment of $f_{\gamma_{i,j}}(\gamma_{i,j}) = 1/\bar{\gamma}\exp(-\gamma_{i,j}/\bar{\gamma})$, where $\gamma_{i,j}$ is the instantaneous SNR from i node to j node where $i = \{S, 1, \cdots, J\}$ and $j = \{1, \cdots, J, D\}$. The ratio of the signaling overhead is assumed to be $\zeta = 0.2$. The probability of $\gamma_1 \leq \gamma_2$ is assumed to be $P = 0.8$. We perform the simulation according to the value of P because the channel environment can be experienced slow fading or fast fading. The other parameters used in our simulation are described in Table 1. The performance of the proposed scheduling is evaluated in terms of the average capacity.

Figure 4 shows the average capacity when $P = 0.6, 0.8$ and 1.0. The average capacity increases as the value of the average SNR increases. Because the conventional scheduling uses the signaling message to allocate resource in every frame, the system capacity decreases as the amount of the signaling overhead increases, regardless of the probability, P. However, the proposed scheduling predetermines the information on the resource assignments for frame $t+1$ in frame t. Therefore, the average capacity of the proposed scheduling is dependent on the probability, P. The proposed scheduling increases the average capacity by reducing the number of transmissions of the signaling messages. At $\gamma = 15$ dB, the average capacity of the proposed scheduling is about 12.5% greater than that of the conventional scheduling when $P = 1.0$ and about 10.96% greater than that of the conventional scheduling when $P = 0.6$.

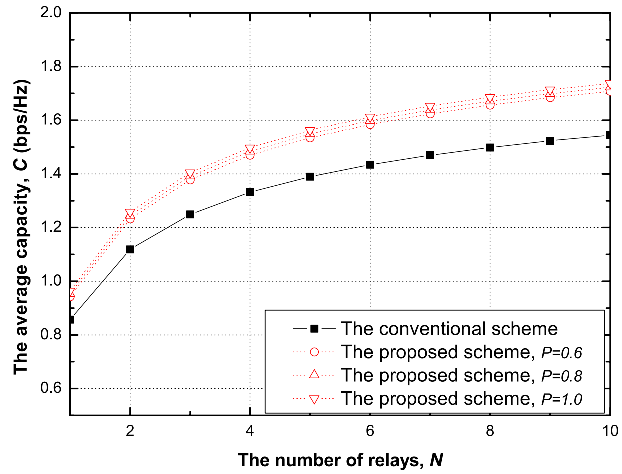

Figure 5. The average capacity versus the number of relays, N

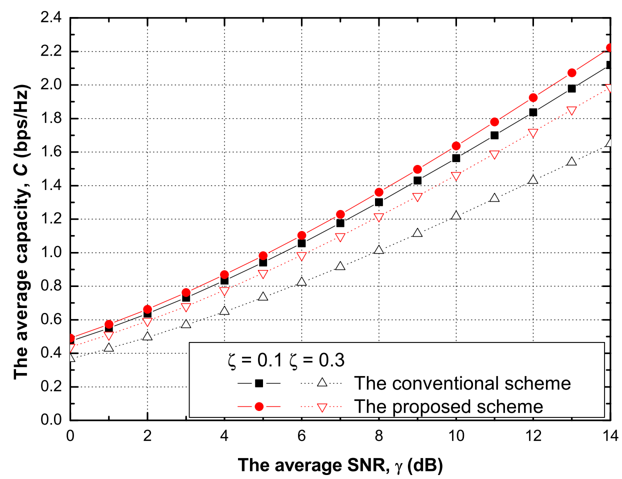

Figure 6. The average capacity versus the average SNR, γ (dB)

Figure 5 shows the average capacity as the number of relays increases when $P = 0.6, 0.8$ and 1.0. As expected, the average capacity increases as the number of relays increases. However, when the number of relays exceeds a certain value (about 10), the average capacity approaches an asymptotic limit. The average capacity of the conventional scheduling has a same performance regardless of the probability, P. At $\bar{\gamma} = 10$ dB, the average capacity of the proposed scheduling

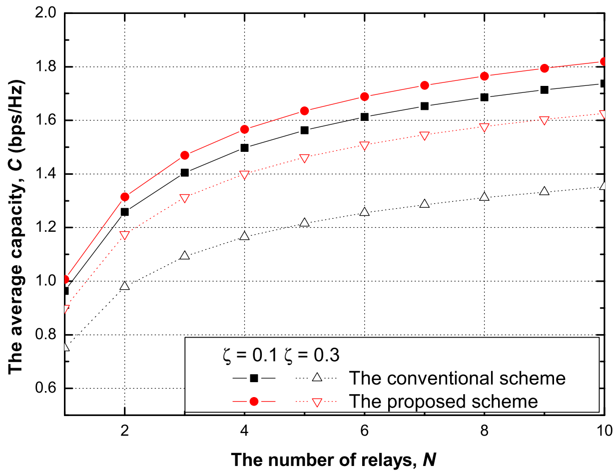

Figure 7. The average capacity versus the number of relays, N

increases by about 12.5% when $P = 1.0$ and by about 10.59% when $P = 0.6$.

Figure 6 shows the average capacity when $\zeta = 0.1$ and 0.3. The average capacity increases as the value of the average SNR increases. The proposed scheduling outperforms the conventional scheduling in an entire SNR region. The available resource for data transmissions in the proposed scheduling is greater than in the conventional scheduling because the number of transmissions of the signaling messages in the proposed scheduling is less than in the convention scheduling. At $\gamma = 15$ dB, the average capacity of the proposed scheduling is about 20.17% greater than that of the conventional scheduling when the ratio of signaling overhead, $\zeta = 0.3$.

Figure 7 shows the average capacity as the number of relays increases when the ratio of the signaling overhead is $\zeta = 0.1$ and 0.3. When the number of relays exceeds a certain value (about 10), the average capacity approaches an asymptotic limit. The asymptotic limit of the average capacity is proportional to the ratio of the signaling overhead. The proposed scheduling outperforms the conventional scheduling as the number of relays increases. The average capacity of the proposed scheduling increases by about 20.3% when $\zeta = 0.3$.

V. Conclusion and Future Work

The paper proposed an efficient scheduling in consideration of the signaling overhead for the downlink relay networks. Additionally, we developed a modified frame structure for scheduling. In the proposed scheduling, the source broadcasts a signaling message only for frame t and does not broadcast the signaling message for frame $t+1$. Hence, the signaling overhead decreases and the system capacity increases. The simulation results show that the proposed scheduling outperforms the conventional scheduling in terms of the average capacity. When the ratio of signaling overhead is 30%, the average capacity of the proposed scheduling is roughly 20% higher than that of the conventional scheduling.

To develop the proposed scheduling, we have several directions for future work that can be envisioned. One is to consider a specific channel state transition model. Second is to consider a concrete model for the signaling overhead. Another is to determine an optimal the number of frames without the notification of the signaling messages.

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