Cooperative communication using mobile relays with α-proportional fair scheduling

Young Jin Sang, Hae Gwang Hwang, Ilmu Byun, Hyoung Yeol Lee and Kwang Soon Kim[†]
School of Electrical and Electronic Engineering, Yonsei University
134, Shinchong-dong, Seodaemun-gu, Seoul 120-749, Korea
E-mail: {yjmich, hwang819, dlfan, neolee, ks.kim}@yonsei.ac.kr
[†] Corresponding Author

***Abstract*— In this paper, a cooperative relaying system with α-proportional fair scheduling is proposed for multi-carrier systems. The cooperative relaying provides 'virtual' MIMO through combining the signals from the source and the relay at the destination in addition to the advantage of the simple relaying which reduces path-loss attenuation in the air interface. We have adopted the α-proportional fair algorithm as a scheduling algorithm to compromise between the capacity and the fairness of users using multi-user diversity and user's average rate. From the simulation results, it is shown that the proposed system improves the capacity compared to the conventional system without the cooperative relaying which maintaining the fairness of users. In addition, the proposed system can reduce the outage probability by 15% compared to the conventional system.**

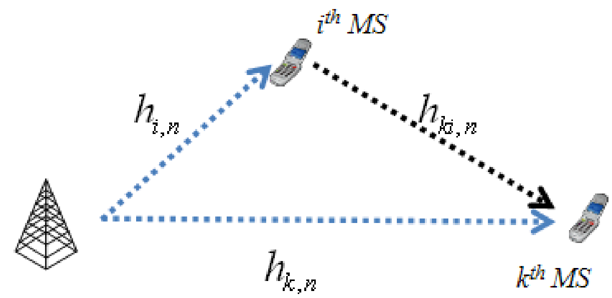

Fig. 1. The system for cooperative communication

I. Introduction

In wireless cellular systems, the data rates of users in a cell are highly asymmetric due to the propagation attenuation of radio and intercell interference. To deal with the above problem, adopting relaying in cellular systems has been widely investigated and cooperative relaying has been recently considered as a promising technique for capacity and coverage enhancement of cellular systems [1][2]. The key advantage of the cooperative relaying over the simple relaying is that the cooperation creates 'virtual' MIMO (Multiple Input Multiple Output) in addition to the advantage of the simple relaying which reduces path-loss attenuation in the air interface. In the cooperative relaying, the signal received at the destination from the source and the signal received at the destination from the relay is combined at the destination.

In cellular systems, the proportional fair (PF) scheduling algorithm was proposed to achieve a good compromise between the capacity and the fairness of users using multi-user diversity and user's average rate [4]. The PF scheduler with low complexity was adopted in a practical system such as Qualcomms' HDR system to increase the fairness between users with different average channel gain [5]. The various PF scheduling algorithms were proposed in different situations. In [6], the optimal PF scheduling with the multi-carrier system was proposed. Recently, the PF scheduling algorithm in relay enhanced system has been widely investigated [7][8]. Moreover, α-proportional fair scheduling algorithm was proposed in [9]. With the variable α, we can adjust the tradeoff between the capacity and the fairness. When α equals to 0, the scheduler represents the max-throughput scheduler and when it goes to infinite, it represents the max-min scheduler. As α increase, the scheduler focuses more on the fairness than the capacity.

In this paper, we adopt the α-PF scheduling scheme to the cooperative relaying for multi-carrier system and show the impact of cooperation on various aspects of the performance of the α-PF scheduling. The rest of the paper is organizes as follows. In section II, the system model of this paper is briefly described. In section III, the scheduling algorithm which is considered in this paper is described. In section IV, the simulation results are shown. Section V contains the summary and the conclusion.

II. System Model

A. Cooperative relaying with multi-carrier system

As shown in Fig. 1, we consider a downlink multi-carrier cellular system with cooperative relays. In cooperative relaying, the signal from the base station (BS) to a relay station (RS) which is another MS in the same cell can be received by the mobile station (MS) during the first phase of cooperative relaying due to radio propagation characteristics without any overhead at the BS. In the second phase, the RS transmits the relaying signal to the MS. At the MS, the signal from the BS and the RS during two different time slot can be combined. Therefore, we can achieve additional diversity gain with the propagation attenuation gain which is can be achieved from simple relaying.

Each subcarrier is shared by all users in the cell in time division multiple access (TDMA) mode. Each subcarrier is allocated to the user who satisfies the given criteria for a

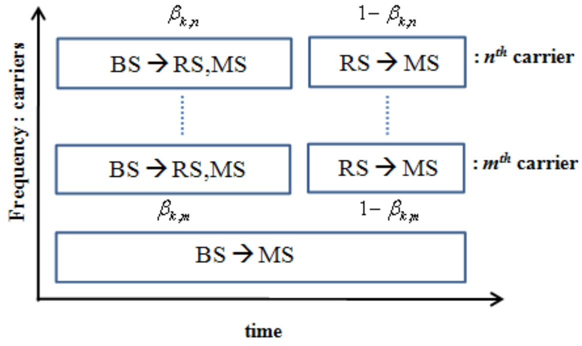

Fig. 2. The frame structure for multi-carrier system with cooperation

give time slot. We assume that the channel gains of all links, a link between the BS and a MS and a link between two MSs, are known at the BS. The channel between the BS and MS is independent among MSs and is fixed during a time slot. For the cooperative relaying transmission, the BS selects another MS as a RS which gives the higher rate than the direct transmission. The MS that is selected as a RS can not receive its own signal during the relaying processing.

B. System model

In the proposed system the BS transmits to K MSs in the cell either directly to a MS or using cooperative relaying. Fig. 2 shows the proposed frame structure. We assumed that there are N orthogonal subcarriers in the system. Each subcarrier can be used for direct transmission or cooperative relaying transmission. Among K MSs and N subcarriers, the channel gain between the BS and the k^{th} MS at the n^{th} subcarrier is given as $h_{k,n}$ and the channel gain between the k^{th} MS (destination) and the i^{th} MS (RS) at the n^{th} subcarrier is given as $h_{k,i,n}$.

Then, the capacity of the direct link of the k^{th} MS at the n^{th} subcarrier, $R^D_{k,n}$, is given as

$$R^D_{k,n} = \log_2(1 + \frac{h_{k,n}P_{BS}}{N_0}), \quad (1)$$

where P_{BS} denotes the power of the BS and N_o denotes the addictive white Gaussian noise.

As shown in Fig. 2, a time slot for cooperative relaying transmission, is divided into two sub-time slots. The first sub-time slot is allocated for the transmission of the BS to a RS and a MS and the second sub-time slot is allocated for the relaying transmission. Therefore, the capacity of cooperative transmission is determined by the minimum capacity of the first sub-time slot and the second sub-time slot due to the bottleneck problem.

The capacity of the relaying link of k^{th} MS using the i^{th} MS at the n^{th} subcarrier, $R^R_{ki,n}$, is given as

$$\begin{aligned} R^R_{ki,n} &= \max_{0\le\beta\le1}\{\min\{\beta_{k,i}\log_2(1+\frac{h_{k,i,n}P_{BS}}{N_0}), \\ &\quad \beta_{k,i}\log_2(1+\frac{h_{k,n}P_{BS}}{N_0}) \\ &\quad +(1-\beta_{k,i})\log_2(1+\frac{h_{i,n}P_{MS}}{N_0})\}\}, \quad (2) \end{aligned}$$

where P_{MS} denotes the power of a MS and $\beta_{k,i}$ denotes ratio of first sub-time slot to an entire time slot for the cooperative transmission of the k^{th} MS with the help of the i^{th} MS. In this paper, we assume that β of each subcarrier can be determined independently. Thus, the achievable data rate of the n^{th} subcarrier also can be obtained independently.

Therefore, the achievable data rate of the k^{th} MS at the n^{th} subcarrier, $R_{k,n}$,is given as

$$R_{k,n} = \max_{i\in K, i\neq k}\{R_{k,n}, R^R_{ki,n}\}. \quad (3)$$

Here, $R_{k,n}$ denotes the highest achievable data rate of the k^{th} MS at the n^{th} subcarrier at given time slot through direct transmission or cooperative relaying transmission.

III. Scheduling algorithm

The conventional PF scheduling algorithm takes advantages of fading characteristics of wireless channel for multi-user diversity without sacrificing the fairness between the MSs in the cell. In [6], the PF scheduling for the multi-carrier system has been proposed. The PF scheduling algorithm for multi-carrier system, S, given as

$$S = \arg\max_s \prod_{k\in U_s}\left(1 + \frac{\sum_{n\in C_k} R_{k,n}}{(T-1)R'_k},\right) \quad (4)$$

where U_s denotes a set of selected user set, C_k denotes a set of subcarriers allocated to the k^{th} MS, R'_k is the average data rate of the k^{th} MS and T is the average window size. However, this algorithm has high complexity, K^N , for the implementation. For a simpler implementation, we can adopt PF scheduling algorithm for each subcarrier. Then the complexity can be reduced to KN. The selected MS at the n^{th} subcarrier, s_n , is given as

$$s_n = \arg\max_k \frac{R_{k,n}}{R'_k}. \quad (5)$$

The system throughput difference between the PF algorithm in [6] and PF scheduling algorithm for each carrier is ignorable when the average window size becomes long enough.

The α-proportional fair scheduling algorithm was proposed [9], so that we can design the scheduler for the different requirement by varying α. As α becomes larger, we can give more priority to the user with bad channel condition and as α goes close to zero, α-proportional scheduler become the max throughput scheduler. To extend PF scheduler ,the α-proportional fair scheduling algorithm for cooperative communication is proposed in [8]. At each time slot, s^{th}_n MS is selected to maximize $U(R'_k)$, where

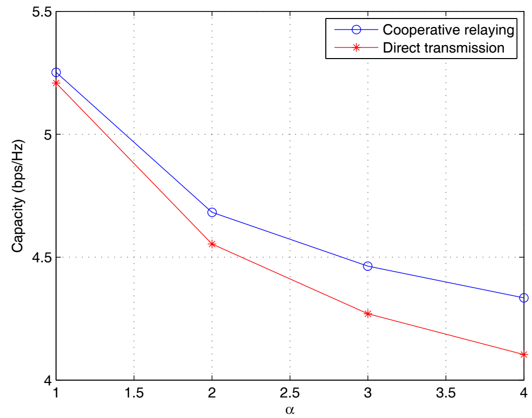

Fig. 3. Capacity of cooperative relaying and direct transmission via various α

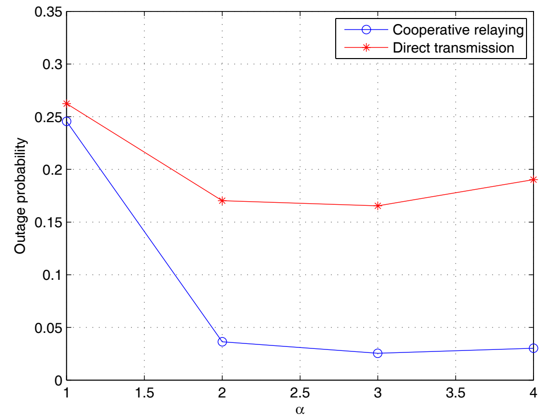

Fig. 5. Outage probability of cooperative relaying and direct transmission via various α

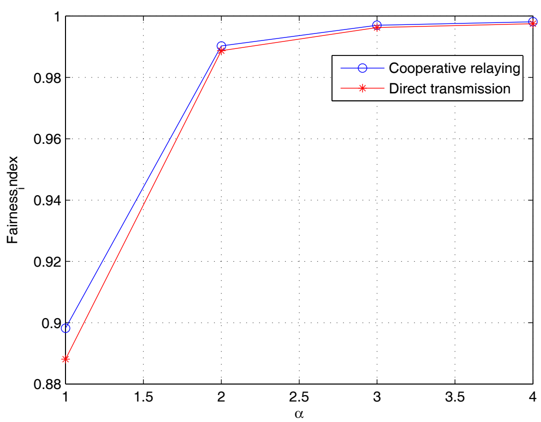

Fig. 4. Fairness index of cooperative relaying and direct transmission via various α

$$U(R'_k) = \begin{cases} \sum_k \frac{1}{1-\alpha}(R'_k)^{1-\alpha} & \alpha \neq 1 \\ \sum_k \log(R'_k), & \alpha = 1 \end{cases} \tag{6}$$

and

$$s_n = \arg\max_k \frac{R_{k,n}}{(R'_k)^{\alpha}}. \tag{7}$$

In this paper, we consider the α-PF scheduling algorithm for the cooperative communication with multi-carrier. As shown in [6], the optimal PF scheduling with multi-carrier system requires too high complexity to implement. It is known that carrier by carrier PF scheduling with enough window size shows almost same performance compared to the optimal solution. Therefore, we adopt the α-PF scheduling algorithm at each subcarrier independently to perform the α-PF scheduling in cooperative relaying with multi-carrier system.

IV. Simulation Results

In the simulation, the channel gain between the BS and MSs are consisted of path-loss and Rayleigh fading. The path-loss exponent is set to 4. For the simulation we consider $10MHz$ bandwidth and 4 subcarriers. 55 users are uniformly distributed in the cell. For the sake of simplicity, we assume that the power of the BS and that of a MS at a subcarrier are equal. The power of the BS of a subcarrier is set to make the received signal to noise ratio (SNR) of the cell-edge user is 0dB. The time-sharing value, β in II-B is obtained to maximize the rate of cooperative relaying using the computer simulation.

Figs. 3 and 4 show the capacity and fairness comparison between the proposed system and the system with direct transmission only with α-PF scheduling. Here, the fairness index is used as a measure of fairness, which is given as

$$I = \frac{(\sum_{k \in K} R_k)^2}{(\sum_{k \in K} R_k^2)}, \tag{8}$$

where R_k denotes the rate of k^{th} MS. Even though the system capacity of both systems decrease as α increases, the capacity gain of the proposed system over the system without cooperative relaying increases without loss in the fairness. The capacity enhancement due to cooperative relaying is about 10% when α becomes 4. The PF scheduling gives the selection priority to users who experience low rate, so the capacity gain of cooperative relaying is not outstanding. In Fig. 5, the outage probability of the proposed system is improved compared to the conventional system. Here, the outage probability is defined as users with average capacity less than 512Kbps. The cooperative relaying system gives more chances for the users in the bad channel condition to increase its rate. Thus, the outage probability of users with cooperative relaying is almost 15% less than that of the system with out cooperative relaying when α is 4. From the result, it is shown that the outage performance is much improved and becomes insensitive to the value of by using cooperation.

V. Conclusion

In this paper, we have adopted the cooperative relaying system for the α-PF scheduling with multiple subcarriers. By adopting the cooperative relaying and the α-PF scheduling algorithm for multi-carrier system, the average capacity improvement was about 10% without any loss in the fairness. Morerover, the outage probability of proposed system was reduced by 15% compared to that of the system without relaying. We can conclude that the cooperative relaying with the α-PF scheduling can improve the system capacity and the outage probability without sacrificing the fairness between the users. We have assumed that every channel gain is known at the BS. Even though that is an ideal assumption, the adopting the cooperative relaying is quite a promising technique to solve the coverage and outage problem of the users in the celledge. The feedback amount of message for the channel gain is a big burden to the system. The effect channel feedback should be considered to the system performance at future work.

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