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Hop capacity balancing in OFDMA relay networks

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ABSTRACT

A novel scheduling scheme for the orthogonal frequency division multiple access (OFDMA) relay systems is proposed. In the relay systems, downlink frame is divided into two slots for two-hop transmission, corresponding to the base station (BS)–relay station (RS) and the RS–mobile station (MS) transmissions, respectively. If the capacities of two hops are not equal, cell throughput can be degraded by the bottleneck hop and radio resource can be underutilized on the non-bottleneck hop. The proposed scheme aims at increasing cell throughput while guaranteeing the minimum rate requirements of MSs, by balancing the capacities of two hops. We formulate a throughput maximization problem which satisfies the minimum rate requirements of MSs, by adjusting the lengths of both slots and allocating the subchannels appropriately. To alleviate the high computational complexity of the problem, we suggest a practical scheduling scheme that uses linear programming relaxation and postprocessing algorithm. The simulation results show that the proposed scheme guarantees the minimum rate requirements of real-time MSs more properly and provides higher cell throughput compared to the existing hop capacity balancing schemes for OFDMA relay systems.

1. Introduction

Orthogonal frequency division multiple access (OFDMA) system has been considered as one of the most promising technologies to support the increasing demands for wireless and mobile communication services since it can offer high transmission rate and high scheduling flexibility on time and frequency dimensions [1,2]. However, even with the advanced OFDMA technology, a cellular system often fails to guarantee the quality-of-service (QoS) of a mobile station (MS) when the MS is located at the cell edge and its channel from the base station (BS) is of inferior quality. Although this problem can be solved by installing additional BSs at the areas, the BS installation requires high cost and the site survey and location is not easy in practice. Among the other techniques that can compensate this poor channel quality, we focus on the relaying [3,4], since the relaying system is usually very small, inexpensive, and easy to implement.

On the downlink, a relay station (RS) receives data from BS and forwards it to the destination MS. By using relaying, since the long link between BS and MS is split into two short links, the channel quality can be heightened. Accordingly, the QoS of MS can be improved and the cell throughput is able to be increased with an appropriate resource management.

Various downlink scheduling algorithms for OFDMA relay networks have been proposed recently [5–11]. In these schemes, for guaranteeing RSs to finish the data reception before they forward data to MSs, the downlink OFDMA frame is divided into two slots, where the BS–RS and RS–MS transmissions are carried out at the first slot and at the second slot, respectively. When using this two-hop transmission, the amount of data that an MS is capable of

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receiving for a frame is restricted to the minimum of capacities of the first (BS–RS) hop and the second (RS–MS) hop. Thus, the bottleneck hop may cause cell throughput degradation and this, in turn, incurs underutilization of the scarce radio resource on the non-bottleneck hop. This type of throughput loss can be minimized when two hops have equal capacity, i.e., when the hop capacities are balanced. In this paper, we investigate the "hop capacity balancing".

The hop capacity balancing can be achieved in three approaches: (a) efficient subchannel assignment between two hops (frequency-domain approach); (b) suitable transmission power allocation among the transmitters of two hops (power-domain approach); and/or (c) appropriate slot length (i.e., transmission time) differentiation between the first and second slots in a frame (time-domain approach).

The scheduling schemes in [5,6] take the first approach. For example, the scheduling scheme proposed in [5] searches the best *subchannel pairs* for BS–RS and RS–MS transmission. However, since this scheme is unable to guarantee the equal capacity for both hops, some wireless resources may still be wasted. In fact, under the constraint that the amount of data transmitted at the second hop is restricted by that transmitted at the first hop, the hop capacity balancing is capable of being hardly accomplished by using just the subchannel assignment. This method, however, can be exploited adjunctively when other methods are used.

The scheduling schemes proposed in [7,8] allocate different *transmission power* for each of two hops in order to balance the capacities of two hops. If the condition of RS–MS channel is much poorer than that of the BS–RS channel, the RS uses considerably large transmission power to compensate the low channel quality of RS–MS hop. However, since RSs are usually located close to the cell edge, the increasing RS transmission power in this case will cause high interference to the neighbor cells. This interference may disturb the transmission in the neighbor cells and, in turn, cause the degradation of throughput in whole cellular system.

The scheduling schemes suggested in [8–11], adjust the *transmission times* of the first and second slots. Although [9] has suggested a good analytic model for time-domain approach, it considers the relay system with only one MS, while a number of MSs are served at the same time in practical OFDMA systems. In [8,10], the first and second slots are exclusively used by BS and RSs, respectively. However, since the BS transmits data not only to RSs but also to MSs in a direct manner, the efficiency of radio resource can be improved by heightening the flexibility of BS in utilizing slots. In [11], we have designed a transmission time adjustment scheme that permits BS to transmit data in the second slot as well as in the first slot, which increases the flexibility of BS in resource usage. Nevertheless, Ref. [11] uses only a heuristic design method and the resulting scheduling algorithm can be improved highly by using another elaborate design approach.

The hop capacity balancing in time-domain does not have the shortcomings of other approaches. Moreover, this approach can harmonize well with the time division duplex (TDD) mode of OFDMA operation since TDD is also a time-domain resource management method (we do not treat TDD issue here). In this paper, we investigate the hop capacity balancing with a time-domain approach, together with a frequency-domain approach adjunctively. We design a scheduling scheme such that the BS is a unique transmitter to RSs and MSs in the first slot, while the BS and RSs are the transmitters to the respective MSs in the second slot. Specifically, we propose a scheduling problem that decides the lengths of two slots for given frame length and allocates subchannels to MSs on a per OFDM symbol basis, for maximizing the cell throughput while guaranteeing QoS and taking multiple MSs into account. The remainder of the paper is organized as follows. The system model under consideration is described in Section 2. The proposed scheduling scheme is presented in Section 3. In Section 4, we discuss the performance of the proposed scheme with simulation results. The paper is concluded with Section 5.

2. System model

We consider the downlink of an OFDMA-TDD system which consists of a BS, K MSs, and N RSs, as shown in Fig. 1. The total bandwidth B is divided into M subchannels with equal bandwidth $B_s := B/M$ (see Fig. 2). The length of a downlink frame is denoted by T_f and each subchannel has L OFDM symbols in a downlink frame. The resource allocation unit in time can be one or more fixed number of OFDM symbol times. In this paper, for the convenience in description, we assume that an OFDM symbol time is the resource allocation unit in time. The downlink frame is again divided into two slots for supporting the two-hop transmission where l denotes the number of OFDM symbols in the first slot.

Both BS and RSs are transmitters. The RSs transmit data only at the second slot, whereas the BS can transmit data at the second slot as well as at the first slot. We denote the BS as the 0th transmitter and the RS n as the nth transmitter ($n = 1, \ldots, N$). Each MS in the cell is served by either BS or RS according to the channel condition. An MS served by BS is referred to as a "direct" MS, whereas an MS whose data is relayed by RS is regarded as an "indirect" MS. We assume that the serving transmitter for each MS is determined a priori, by using an appropriate transmitter selection scheme which we do not treat in this paper, as in [12]. For the relay selection problems, one can refer to other literatures (e.g., [13,14]). We consider the minimum

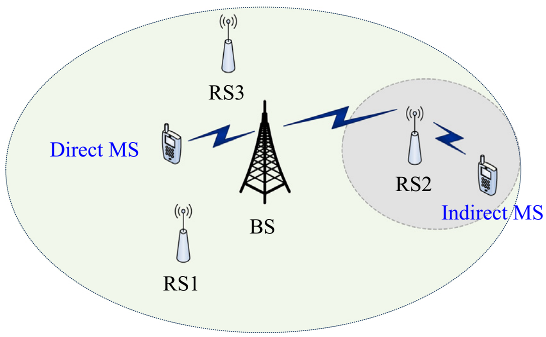

Fig. 1. Architecture of OFDMA relay system.