韓國컴퓨터情報學會 論文誌
第15卷 第6號, 2010. 6.

2010-15-6-3-2

Cross-Layer Optimized Resource Allocation Scheme for OFDMA based Micro Base Stations

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OFDMA 기반 마이크로 기지국을 위한 계층간 최적화된 자원할당 기법

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Abstract

In this paper, a joint PHY-MAC layer optimized resource allocation scheme for OFDMA based micro base stations is investigated. We propose cross-layer optimized two-stage resource allocation scheme including cross-layer functional description and control information flow between PHY-MAC layers. The proposed two-stage resource allocation scheme consists of a user grouping stage and a resource allocation stage. In the user grouping stage, users are divided into a macro base station user group and a micro base station user group based on the PHY-MAC layer characteristics of each user. In the resource allocation stage, a scheduling scheme and an allotment of resources are determined. In the proposed scheme, diversity and adaptive modulation and coding (AMC) schemes are exploited as schedulers. Simulation results demonstrate that the proposed scheme increases the average cell throughput about 40~80 % compared to the conventional system without micro base stations.

요 약

본 논문은 직교주파수분할다중접속방식 기반의 마이크로 기지국을 위한 PHY-MAC 계층에서 최적화된 자원할당 기법에 대해 연구한다. 본 논문에서는 PHY-MAC 계층 간 제어 정보 흐름 및 기능 구현을 포함하여 계층 간 최적화된 2단계 자원할당 기법을 제안한다. 제안하는 2단계 자원할당 기법은 사용자 그룹핑 단계 및 자원할당 단계로 구성된다. 사용자 그룹핑 단계에서는 각 사용자별 PHY-MAC 계층 특성에 따라 사용자들을 매크로 기지국 자원을 할당받을 사용자 그룹과 마이크로 기지국 자원을 할당받을 사용자 그룹으로 분류한다. 자원할당 단계에서는 사용자 그룹 내의 각 사용자별로 실제 할당 받을 자원의 형태 및 양을 결정하는 스케줄러를 정의한다. 제안하는 기법에서는 다이버시티 및 AMC 기법을 스케줄러 정의에 활용한다. 시뮬레이션 결과는 제안하는 방법이 마이크로 기지국을 고려하지 않는 기존 방법에 비해 평균 셀 수율을 40~80% 증가시킬 수 있음을 보인다.

▸ Keyword : Micro base station, resource allocation, cross-layer optimization, diversity

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• 제1저자, 교신저자 : 조성현
• 투고일 : 2010. 03. 09, 심사일 : 2010. 03. 17, 게재확정일 : 2010. 05. 18.
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Ⅰ. Introduction

To enhance the system performance of a next generation wireless access network, many supplementary technologies have been proposed and investigated. Recently, femto-cells or micro base stations have been actively studied to cover the shadowing area and cell boundary area. One of the challenging issues to introduce the micro base stations to the conventional cellular system is the resource allocation between a macro base station and a micro base station in a cooperative manner. In this paper, a macro base station means a base station in the conventional cellular systems. Each user should be assigned to a macro or micro base station by the resource allocation scheme in the way of achieving the maximum cell throughput. Another important issue to develop a resource allocation scheme is a PHY-MAC cross-layer optimized design. A resource allocation scheme should consider physical (PHY) layer issues such as channel quality, frame structure, and adaptive modulation and coding (AMC) as well as medium access control (MAC) layer issues such as fairness and quality of service (QoS). In orthogonal frequency division multiple access (OFDMA) systems, PHY layer information such as channel quality is used to criteria of subcarrier allocation to increase throughput and reduce outage probability. Especially, the PHY layer throughput can be increased using adaptive modulation and coding scheme since the channel quality of each user is frequency selective. *Max C/I* algorithm is the representative resource allocation scheme to maximize the PHY layer throughput [1]. It assigns the radio resources to a user which has the best channel quality in a user group. However, from the aspect of MAC layer, the performance of a resource allocation scheme is determined by the MAC layer metric such as the required QoS or fairness. Therefore, the PHY layer oriented algorithms [1],[2] like *max C/I* are not appropriate to maximize the MAC layer performance. *Round robin* (*RR*) and modified *max C/I* algorithms [3]-[5] are proposed to overcome this problem. These algorithms have better MAC layer performance but show worse PHY throughput compared to *max C/I*. Therefore, to achieve the high system performance of either layer, it is necessary to design PHY-MAC cross-layer optimized resource allocation scheme. Recently, many ideas have been proposed to resolve this problem [6]-[12]. However, previous works have several problems to apply to the interested systems of this paper. First, in the previous works, a micro base station has not been considered in resource allocation algorithms. Second, a user selection scheme, which selects users from a scheduling pool in the way of achieving the maximum performance, has not been clearly presented in the conventional algorithms. Finally, the practical aspect for the implementation has not been considered in the previous works. In [13], IEEE 802.16e OFDMA simulator, which considers PHY-MAC cross-layer protocol, was proposed. The simulation results in [13] shows that the MAC layer protocol design highly effects on the performance of PHY layer. Especially, it shows that the cross-layer resource allocation can improve the average cell throughput by 25% ~ 65%. Even this paper provided a good example of a cross-layer designed simulator, it didn't propose a novel cross-layer optimized resource allocation algorithm. In addition, it didn't consider the cellular systems with micro base stations. Therefore, this paper proposes a novel PHY-MAC cross-layer resource allocation scheme that adequately considers the deployment of the micro base stations and the cross layer optimization between PHY and MAC layers based on the results in [9]. The proposed resource allocation scheme provides an efficient user grouping method, PHY-MAC cross-layer function, and information flow design to optimize the proposed resource allocation scheme.

The paper is organized as follows. In Section II, we present the proposed cross layer resource

allocation scheme and cross layer functional design results. In Section III, simulation results will be explained in detail. Finally, we conclude with a summary in Section IV.

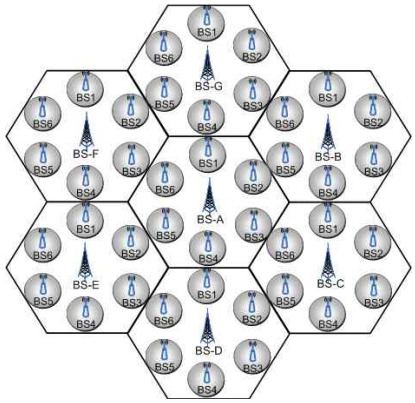
II. The Proposed Cross-Layer Optimized Resource Allocation Scheme

2.1 System model

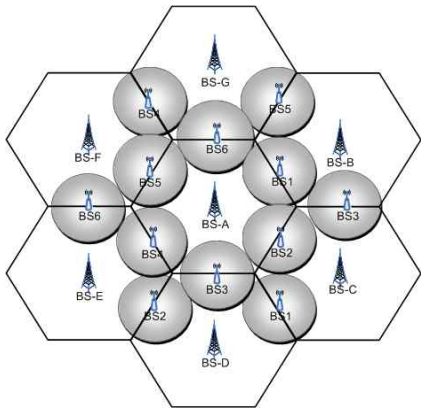
The interesting system of this paper is a cellular systems deployed macro and micro base stations which adopt OFDMA technologies. A micro base station is a small size base station deployed in an office or home. Fig. 1 depicts the typical deployment scenarios of micro base stations. It can be deployed inside a cell or overlapped on the boundary of adjacent cells. A micro base station can cooperatively communicate with the conventional cellular base stations. In addition, it will cover a micro (i.e. office or home) cell which consists of fixed devices or low speed mobile devices. The fixed or low speed mobile devices communicate under the low error channels. It means that the AMC can be aggressively used to improve the cell throughput in a micro base station. Therefore, we assume that the system has two types of data channel such as AMC channel and diversity channel. The AMC channel based on OFDMA is used for low speed and high SNR users near the desired base station. The AMC channel can be considered as a set of subbands that consist of variable number of symbols and subcarriers. However, diversity channel using fast or slow frequency hopping is used for users with high mobility or low SINR users in cell boundary. To classify the user groups in a base station, it is assumed that every users periodically feedback their signal to noise and interference ratio (SINR) to the base stations. Especially, the AMC users feedback their channel quality information of all subbands on channel quality index (CQI) channel. Feedback information is channel matrix or AMC level index.

2.2 Cross-layer function design and interlayer control information flow

Fig. 2 shows the proposed PHY-MAC function block and corresponding information flow for efficient cross-layer resource allocation. The proposed *user grouping* and *resource allocation* stages are MAC layer function as shown in Fig. 2. For efficient resource allocation, these function blocks gather PHY and MAC layer control information from *Control Information Controller* and *MAC-c controller*, respectively.



(a) Deployment scenario 1



(b) Deployment scenario 2

Fig 1. Feature Detection Process and Result

Control Information Controller is a PHY layer function block. It generates and manages various

PHY layer control information such as channel quality, velocity, and location. On the other hand, *MAC-c controller* is a MAC layer function block and controls MAC layer control information such as fairness, QoS, etc. From the aspect of the implementation, primitives between PHY and MAC layers also should be defined to support efficient PHY-MAC integration.

2.3 Cross-layer protocol for CQI feedback

One of the most important functions to implement an efficient resource allocation scheme is a CQI feedback. To optimize the performance of the proposed resource allocation scheme, we design a cross-layer CQI feedback protocol. In OFDMA systems, the condition of uplink (UL) and downlink (DL) channels should be considered in scheduling for the purpose of increasing throughput. For this reason, IEEE 802.16 defines variable UL control channels. Based on these control channels, we propose a cross-layer protocol for CQI feedback as shown in Fig. 3. This figure shows PHY-MAC primitives, the cross-layer protocol sequence of the CQI feedback for DL channel measurement, and the UL sounding signal for UL channel measurement. All AMC subchannel users that have a transport connection identifier (CID) should periodically transmit a DL channel measurement report on CQICH. To construct a CQI feedback message, the MAC layer needs to receive channel measurement results from the physical layer. Primitives such as CQI-MSG.request and CQI-MSG.response in the DL CQI feedback of Fig. 3 are used for this purpose. Once a CQI feedback message is constructed in MAC layer of a mobile station , it is transmitted to MAC layer of a base station on CQICH. This information is exploited in scheduling and resource allocation. The UL sounding in Fig. 3 shows the transmission sequence of the UL sounding signal. UL sounding is a kind of UL pilot signal and is defined to support

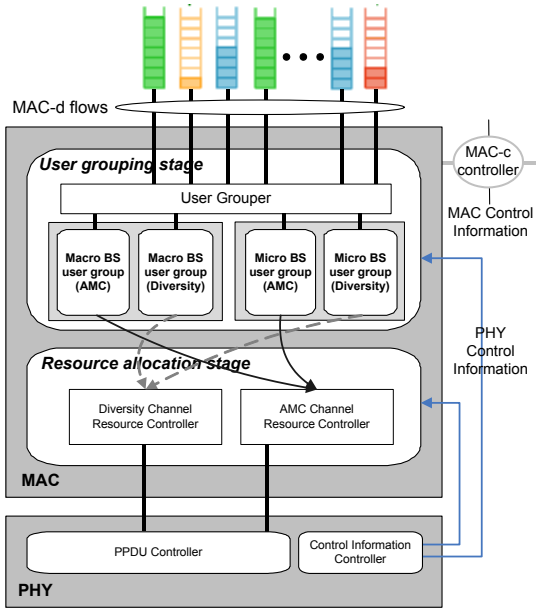


Fig 2. Cross-layer function design and information flow

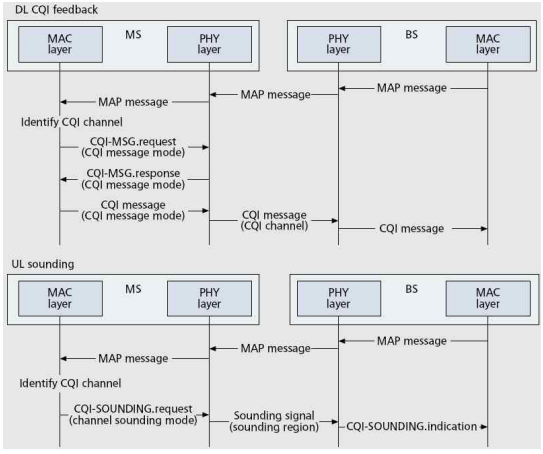


Fig 3. Cross-layer protocol for CQI feedback

smart antenna or MIMO in 802.16e. If an MS confirms its sounding channel allocation in a UL_MAP message, an MS MAC layer sends a SOUNDING.request primitive to an MS PHY. Then an MS PHY sends a sounding signal on the allocated UL sounding region. A BS can use the received sounding signal to measure the quality of the UL channel and translate the measured UL channel quality under the assumption of time division duplex (TDD) reciprocity.

2.4 PHY-MAC cross-layer resource allocation scheme

The proposed two-stage resource allocation scheme consists of *user grouping* stage and *resource allocation* stage as shown in Fig. 4. In *user grouping* stage, users are assigned to a macro BS or a micro BS according to the channel quality and QoS requirements. In *resource allocation* stage which is based on the result in [9], subchannels or subcarriers are allocated to each user. The details of each stage will be explained in the following section.

2.4.1 User grouping stage

In *user grouping* stage, users are classified into a macro BS user group and a micro BS user group in which users receive the radio resources from a macro BS and a micro BS, respectively. To help a BS classify the user groups, each user periodically estimates its channel quality and reports it to the adjacent base stations. Base stations, which receive the channel quality from users, determine an appropriate group for each user. SINR is mainly used as a criterion to classify the user groups. Once the users are assigned to a macro or micro base station, then users in each group are subdivided into AMC channel and diversity channel users based on PHY-MAC cross-layer characteristics such as QoS requirements, user velocity, and channel quality. Diversity channel is allocated to diversity channel users that are located on cell boundary or have high speed. For the diversity channel users, AMC level is fixed during one scheduling cycle. In the proposed resource allocation scheme, AMC channels are assigned by two steps. In the first step, to guarantee required QoS, resources are allocated to high priority users. In the second step, if there are available resources after the first step, the resources are allocated based on the channel quality to maximize system throughput. For the first step, user scheduling or ordering mechanism is needed. To determine the optimal subset of users for transmission, we propose a user ordering criteria. Every scheduling epoch t, the scheduler forms the following metric for all active users (i=1,2,⋯,k):

$$\varphi_i = \pi_1^{\left|\frac{\partial C}{\partial H_i}\right|} \cdot (1-\pi_2^{(t-T_i)}) \cdot \pi_3^{\left|\frac{f_i(t)}{f}\right|} \cdot \pi_4^{\left|\frac{C_i(t)}{C_i}\right|} \quad \cdots\cdots\cdots (1)$$

where $\pi_1(\geq 1)$, $\pi_2(\leq 1)$, $\pi_3(\leq 1)$, and $\pi_4(\geq 1)$ are positive empirical constants. T_i is the time when user i was last scheduled. $f_i(t)$ is the remaining queue size for user i at time t. f is the average queue size. $\partial C/\partial \mathbf{H}_i$ denotes the sensitivity of user i's channel to the sum capacity[14]. $C_i(t)$ is the current supported data rate for user i at time t. C_i is the average data rate for user i. Users with $\phi_i > \phi_{threshold}$ are pre-selected for resource allocation during time epoch t.

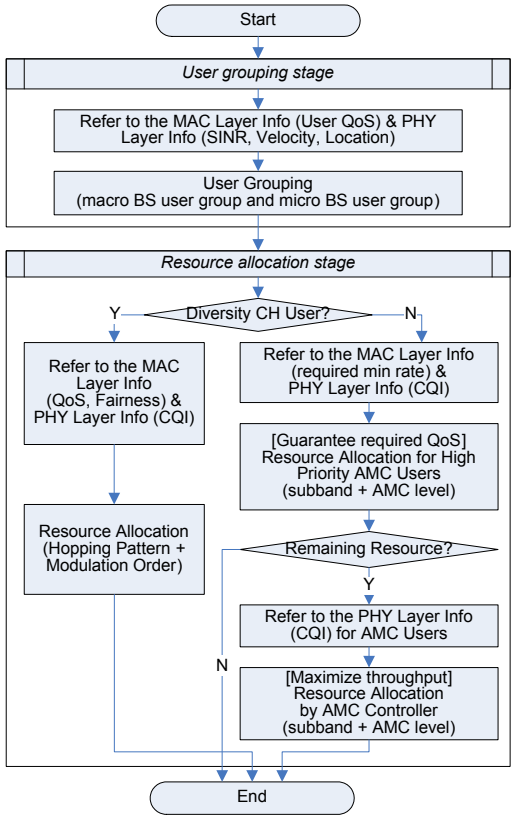


Fig 4. The proposed resource allocation scheme

2.4.2 Resource allocation stage

In *resource allocation* stage, subbands in the diversity channel and the AMC channel are allocated to selected user. For the diversity channel, one or more hopping patterns are assigned to diversity channel users according to their PHY-MAC layer information such as channel quality, QoS requirements, and fairness. For AMC channel, we select an AMC subbands for pre-selected user K based on the following criterion:

$$Subband_j = \arg\max_{j=1,\ldots,N} \max_{i=1,\ldots M} (\max(MCS_{j,K} - MCS_{j,i})) \quad \cdots\cdots (2)$$

where $MCS_{j,i}$ means modulation and coding level of user i's subband j. j is a subband index and i is an user index. N and M are the number of subbands and users in the system, respectively. If we still have unused AMC subbands after the previous step, the remaining resources are allocated to AMC users according to the AMC schemes such as *water-filling* [2] or *max C/I* [1] to maximize throughput.

III. Performance Evaluation

3.1 System model

To evaluate the performance of the proposed resource allocation scheme, computer simulators are modeled. We firstly compare the performance of the proposed scheme to the *max C/I* [1] and the round robin (RR) [3] in terms of cell throughput. For the fair comparison, a micro base station is not included in the this simulation. In the second simulation, we investigate the effect of the deployment of micro base stations on the cell throughput. In this simulation, we compare the cell throughput of the proposed scheme without and with micro base stations which are deployed by the typical scenarios as shown in Fig. 1. The simulation parameters are given in Table 1. In the simulation, OFDMA cellular systems are assumed where a basic resource allocation unit is a subband that is a set of subcarriers. In addition, we assume that AMC users send CQI for all subbands without error. We consider three traffic types which require high data rate, medium data rate, and no constraint on the data rate, respectively.

Table 1. Simulation parameters

Parameter	Value
Bandwidth	20 MHz
# of subcarrier/symbol	1024
# of symbol/frame	50
# of subcarrier/subband	132
Downlink/Uplink ratio	2:1
Min. MCS level	QPSK, 1/12 coding rate
Max. MCS level	64QAM, 1/2 coding rate
Traffic type	Class A, B, C
Required data rate	Class A: 3000 bits/frame Class B: 100 bits/frame Class C: n/a

3.2 Simulation results

Fig. 5 shows the average cell throughput of the *max C/I*, the RR, and the proposed algorithms. The x and y axes mean simulation time (hour) and throughput (kbps), respectively. The proposed algorithm shows better cell throughput compared to the *RR* by assigns more resources to the users with good channel condition. However, *max C/I* shows better throughput than the proposed algorithm because it always allocates radio resources to the user which has the best channel quality. Therefore, *max C/I* is an optimal algorithm to achieve the maximum cell throughput. However, *max C/I* does not guarantee the QoS or fairness requirements to the users with poor channel conditions. On the other hand, the proposed algorithm provides better QoS fulfillment with marginal throughput loss by considering the fairness to determines the scheduling priority of each user.

Fig. 6 compares the normalized cell throughput of the proposed scheduling algorithm without and with micro base stations. In the simulation, the micro base stations are deployed by scenarios 1 and 2

depicted in Fig. 1. Two important simulation parameters, i.e. r_e and r_b, are defined which are a cell radius and a radius of inner region that is covered by a macro base station, respectively. As shown in Fig. 6, the cell throughput of the proposed algorithm can increase about 40~80% by exploit the micro base stations because the average SINR of the cell boundary users can be improved by the micro base stations. Note that the deployment scenario 1 is more favorable to increase the cell throughput than the deployment scenario 2. The cell throughput of the proposed scheduling algorithm in scenario 1 increases by 2~18% according to the cell load than it in scenario 2. Therefore, in terms of the throughput or capacity gain, deployment scenario 1 is more profitable even it may require more deployment and operational cost.

IV. Conclusions

In this paper, we propose the PHY-MAC cross-layer resource allocation scheme in the cellular systems with micro base stations. The PHY-MAC layer function and information flow are designed in way of cross-layer optimized for the efficient resource allocation. The proposed resource allocation scheme consists of *user grouping* stage and *resource allocation* stage. In *user grouping* stage, users are classified into a macro BS user group and a micro BS user group in which users receive the radio resources from a macro BS and a micro BS, respectively. In *resource allocation* stage, we propose a specific user selection criterion for the resource allocation. According to the criteria, the proposed scheme select appropriate users and allocate hopping pattern or AMC subband. Simulation results show that the proposed scheme can guarantee the required QoS of high priority users with 0.7% loss of throughput compared with the *max C/I*. In addition, the performance of the proposed algorithm can be increased about 40~80% by the introduction of the micro base station in a cellular system. The proposed algorithm can be applied to the femto-cell or the next generation wireless systems with micro base stations.

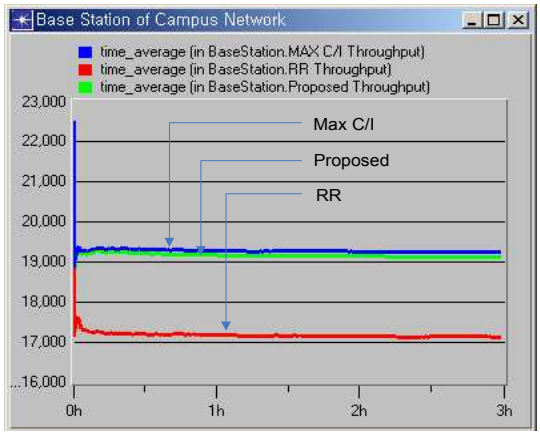


Fig 5. Average cell throughput in the proposed scheme, *max C/I*, and *RR*

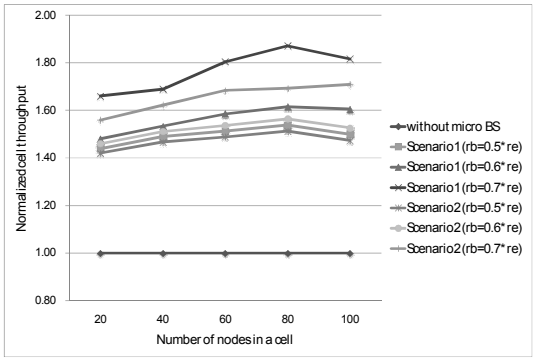


Fig 6. Normalized cell throughput of the proposed scheme without and with micro base stations

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