

Adjustable Subcarrier Allocation for Spectral Efficiency and User Fairness in 3GPP LTE Downlink Systems

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Abstract— In this paper, adjustable subcarrier allocation algorithm is proposed for both system spectral efficiency and user-throughput fairness (or throughput requirement). There exists trade-off between two performance metrics. The proposed subcarrier allocation method can easily coordinate system performance between spectral efficiency and user-throughput fairness. To achieve adjustable goal, we define cost function combined by adjustable weightings to the terms of both spectral efficiency and user- throughput fairness. Based on 3GPP LTE downlink system model simulations, we can show that spectral efficiency mode in the proposed algorithm can achieve much lower outage probability than Wong's algorithm [7], which emphasizes spectral efficiency, with similar total spectral efficiency and throughput fairness. Also the user requirement-emphasized mode in the proposed one can achieve better performance than You's algorithm [5], which emphasizes user data rate requirements, in terms of spectral efficiency, outage probability, and fairness pattern.

Keywords— OFDMA, QoS, resource allocation, 3GPP LTE

I. INTRODUCTION

In order to achieve higher system spectral efficiency and accommodate a larger number of subscribers at Third Generation Partnership Project (3GPP) Long-Term Evolution (LTE), Orthogonal Frequency Division Multiple Access (OFDMA) has been selected for LTE down link (DL) radio access scheme. The strong points of OFDMA are higher spectral efficiency, robustness to multipath fading, and flexibility for adaptive frequency channel control [1]. In the OFDMA DL, subcarrier allocation module can assign different frequency portions to each user according to user's instantaneous channel gains. Based on subcarrier allocation algorithm, 3GPP LTE DL system divides whole bandwidth into multiple sub-bands (i.e. groups of subcarriers) referred to resource blocks (RBs) and assigns RBs to individual users. In order to improve spectral efficiency and reliable transmissions, Base Station (BS) or eNodeB needs Channel Quality Indicator (CQI) feedback from all users.

The most recent, channel -aware and adaptive subcarrier-

bit-and-power allocation algorithms for multi-user OFDMA systems have attracted plenty of interest from researchers. Different mobile users experience different channel attenuation through wireless communication multipath, then OFDMA systems need to optimize resource (e.g. subcarriers, power, rate, and bit) allocation schemes and to schedule packet data for both optimal system performance and different QoS requirements (e.g. delay and minimum data rate). Unlike conventional Frequency Division Multiple Access (FDMA), in OFDMA downlink, a number of users can share an OFDM symbol by dynamically assigned subcarriers in accordance with their instantaneous channel gains. Then frequency diversity as well as multiuser diversity gain is obtained. These characteristics are necessary to optimize resource allocation adaptively. Some papers [2,3] studied adaptive resource allocation methods to maximize the spectral efficiency and to minimize total transmit power for OFDMA systems. In [2], a joint carrier, power and bit allocation scheme is proposed using Lagrangian method. This scheme has good performance, but it is not practical due to high complexity to find optimal solutions. In [3], simplified method was proposed by predetermining both the modulation type and the number of subcarriers assigned to each user. Those papers show that optimal performance can be achieved when each subcarrier is allocated to a user having the best channel gain. The subcarrier and the transmitting power are assigned on the users and subcarriers through the water-filling method. In [4], proposed method is featured as a low complexity algorithm that uses adaptive modulation not using water-filling method.

Aforementioned papers tackle to optimize the overall system spectral efficiency, but those papers fail to satisfy different user Quality-of-service (QoS) requirements such as delay and minimum data rate. In most wireless communication systems, different QoS requirement of all users should be guaranteed for real time data services. In [5], the authors have proposed fair allocation algorithm for OFDMA system with different QoS requirements with balancing the fairness among users. In [6], the proposed algorithm shows a method to maximize the system capacity while assuring user's QoS requirements. To achieve high spectral efficiency, an allocation algorithm of

subcarriers and power to each user has proposed in [7] subject to constraints on total power. This algorithm is a non-iterative method that is possible by relaxation of strict user rate proportionality constraints, unlike root-finding iterative method. However, the mentioned algorithm can accomplish only one suboptimal system performance between system spectral efficiency and user throughput fairness (or QoS requirements). In other words, trade-off exists between them. Therefore, we need to propose adaptive algorithm, in accordance that which performance is more important, our algorithm can adaptively coordinates system performance between system spectral efficiency and QoS requirements.

II. SYSTEM MODEL

In this paper, we consider a single cell OFDMA system with total K active wireless users. The system bandwidth B is divided into total N subcarriers. At each time instance multiple subcarriers can be assigned to a single user, but each subcarrier can be allocated to one user at most. In this paper we assume an infinitely backlogged model, i.e. at each time instance the base station has data available for transmission to all users in the cell. Thus, the base station can schedule all N subcarriers at every time instance.

For wireless channel, we adopt slowly time-varying channel and Rayleigh multipath fading channel as frequency selective channel. Due to frequency selective fading, each user may have one different channel gain on different subcarrier. Therefore, one CQI feedback is sent from each user to base station at the end of each time instance (subframe). Then, the base station can allocate each n -th ($1 \leq n \leq N$) subcarrier to user k ($1 \leq k \leq K$) having best channel gain based on the CQI feedback. And transmitting power on each subcarrier n allocated to user k is $p_{k,n}$ and channel gain is denoted as $g_{k,n}$. At this time, adaptive power allocation might be used for optimal performance, but the performance difference between equally distributed power method and adaptive power allocation is quite small. And the complexity for the adaptive one is considerably high [8], [9]. Thus, we adopt equally distributed power allocation method from now on. That is, transmit power is allocated to $p_{k,n} = P_{\text{tot}}/N$, if $q_{k,n} = 1$. Where $q_{k,n}$ is a subcarrier allocation variable to indicate whether or not subcarrier n is assigned to user k at the time instance. The SNR of each subchannel is $h_{k,n} = g_{k,n}^2/\sigma^2$, where $\sigma^2 = N_0 B/N$ is additive white Gaussian noise (AWGN) power spectral density on the each subchannel. Therefore received SNR for the k -th user on subcarrier n is $\gamma_{k,n} = p_{k,n} h_{k,n}$. The aforementioned slowly time-varying assumption is essential for perfect channel estimation. In order to meet the BER constraint, the effective SNR needs to be adjusted accordingly. The approximation BER of a square M-level QAM with gray coded as a function of received SNR $\gamma_{k,n}$ and number of bits $c_{k,n}$ can be defined to within 1dB for $c_{k,n} \geq 2$ and $\text{BER} \leq 10^{-3}$ as [8]

$$\text{BER}_{\text{MQAM}}(\gamma_{k,n}) \approx 0.2 \exp \left[\frac{-1.6\gamma_{k,n}}{2^{c_{k,n}} - 1} \right]. \quad (1)$$

Solve the Eq. (1) on $c_{k,n}$, then

$$c_{k,n} = \log_2 \left(1 + \frac{\gamma_{k,n}}{\Gamma} \right) = \log_2 (1 + p_{k,n} H_{k,n}) \quad (2)$$

where $\Gamma \triangleq -\ln(5\text{BER})/1.6$ is channel estimation gap, and $H_{k,n} \triangleq h_{k,n}/\Gamma$ is the effective subchannel SNR. Thus the objective of subcarrier allocation is defined as

$$\max_{q_{k,n}} \sum_{k=1}^K \sum_{n=1}^N q_{k,n} c_{k,n} \quad (3)$$

s.t. C1 : $\sum_{k=1}^K q_{k,n} \leq 1, q_{k,n} \in \{0, 1\}, \forall n = 1, 2, \dots, N$

C2 : $\sum_{k=1}^K \sum_{n=1}^N q_{k,n} \leq N$

C3 : $\sum_{k=1}^K \sum_{n=1}^N q_{k,n} p_{k,n} \leq P_{\text{tot}}$

C4 : $R_k \geq R_k^{\text{req}}$

where $R_k = \sum_m q_{k,m} c_{k,m}$, $m \in \{\text{subcarriers allocated to } k \text{ user}\}$ is total achieved data rate on subcarrier allocation, and R_k^{req} (bits/OFDM symbol) is QoS requirement (e.g., required user throughput) of user k .

III. PROPOSED ALGORITHM

In this section, we propose an adjustable algorithm for system spectral efficiency and user throughput (i.e., Minimum Data Rate, MDR) in 3GPP LTE downlink system. This algorithm takes two steps. In first step, the subcarriers are allocated to user who has maximum channel gain. Afterwards, in second step, subcarrier reallocation is fulfilled to satisfy each user's MDR. In the following, the algorithm is described in detail.

A. Step 1 – Maximize System Spectral Efficiency

In this step, without considering user's MDR constraint, the objective of subcarrier allocation problem becomes like in [4]

$$\max_{q_{k,n} c_{k,n}} \sum_{k=1}^K \sum_{n=1}^N q_{k,n} c_{k,n}$$

where $q_{k,n}$ is allocation indicator and $c_{k,n}$ is number of bits of user k on subcarrier n . The maximum capacity can be achieved by finding

$$k'_n = \arg \max_k (c_{k,n}) \quad (4)$$

and then let

$$q_{k,n} = \begin{cases} 1 & \text{for } \forall k = k' \\ 0 & \text{else} \end{cases} \quad (5)$$

for all n . This procedure is for the maximum throughput whose spectral efficiency is maximized. But this subcarrier allocation solution does not guarantee MDR of every user. Therefore we need to reallocate subcarrier to users whose MDR constraint has not been satisfied yet.

B. Step 2 – Enhance User Throughput Fairness

In this step, subcarrier reallocation is fulfilled to satisfy user throughput fairness. However, subcarriers allocated in step 1 were assigned to the user who has maximum channel rate. Accordingly, subcarrier reallocation fatally leads to a reduction in overall throughput. To minimize the bad effect of reallocation, we proposed cost function in Eq. (6) and several heuristics are used in following process.

- 1) Find excessive subcarrier allocated to user k' whose total data rates greatly exceed their desired data rate R_k^{req} , and denote them as excessive subcarrier n' .
- 2) Sort exceeded users in descending order according to $\sum_m R_{k',m} - R_k^{\text{req}}$, where $\{m \in \text{allocated subcarriers to exceed user } k'\}$
- 3) In sorted sequence of exceeded user, sort the excessive subcarriers with respect to channel rate $c_{k',n'}$ in ascending order.
- 4) In sorted sequence of subcarrier, reallocate the excessive subcarrier n' to scarce data rate user k with $R_k < R_k^{\text{req}}$, minimizing the cost function in given by

$$e_{k,n'} = \alpha \left(\frac{c_{k',n'} - c_{k,n'}}{c_{k,n'}} \right) + \beta \left(\frac{R_k}{R_k^{\text{req}}} \right), \text{ for } k \in \{R_k < R_k^{\text{req}}\} \quad (6)$$

In the cost function, the first fraction term is related to system spectral efficiency and second term is to user throughput fairness. Namely, in case that α is bigger than β , the spectral efficiency is emphasized. Otherwise, user throughput fairness is major consideration in subcarrier reallocation. Consequently, adjusting the relative magnitude between two parameters, we can control which system performance is more considerable in the given system.

IV. EVALUATION

A. Environment of Simulation

In order to evaluate the performance of proposed algorithm, we use system model in 3GPP LTE downlink. Basic system parameters are total transmission bandwidth as 5MHz, total subcarrier as 512, and subframe duration as 0.5ms. Therefore the channel state information is sampled and feedbacked every 0.5ms to update the subchannel allocation. For wireless channel, the frequency selective multipath fading channel is modeled as consisting of six independent Rayleigh multipath, with an exponentially decaying profile. A maximum Doppler spread of 30Hz and maximum delay spread of 5 μ s is assumed. The total transmit power was assumed to be 1W, the average subchannel SNR is 38dB, and required $\text{BER} \leq 10^{-3}$, and estimated SNR gap $\Gamma \triangleq -\ln(5\text{BER})/1.6 \approx 3.3$ was considered. This gap is used for calculation of the current data rate $c_{k,n}$ of user k on subcarrier n given (2).

The number of users in the system is varied from 10 to 40 incremented by 2. A total 100 different channels and 100 time samples per each channel realization were used for users. The users requiring different QoS are divided into three groups (i.e., group 1, group 2, and group 4) whose data

required rate proportion are 1:2:4 with probability 0.5, 0.3, and 0.2, respectively. In other words, three different user's QoS requirements exist in the given system.

B. Simulation Result

In this paper, we compare proposed adjustable subcarrier algorithm with two algorithms proposed in [5] and [7], respectively.

We briefly explain the algorithm proposed in [7]. First, the number of subcarriers is determined to be initially assigned to each user, according to the rate-proportion in total system capacity. Second, the subcarriers are assigned to each user in a way that ensures rough proportionality. Finally, the rest of the subcarriers not assigned to any user are allocated to user having best channel gain. Therefore, this algorithm emphasizes system spectral efficiency than user throughput fairness. Consequently, algorithm in [7] has good system spectral efficiency, but causes higher outage probability, which is denoted as the probability of the number of users that cannot reach required data rate R_k^{req} (bits/OFDM symbol), given by [5]

$$P_{\text{outage}} = \text{prob}(R_k < R_k^{\text{req}}(1 - \delta) | \text{user } k \text{ in cell}) \quad (7)$$

where δ is relaxation parameter of requirement. Because channel estimation gap exists, it is impossible for BS to allocate subcarrier to some users with insufficient data rate.

Figure 1 shows the comparison of Spectral Efficiency (SE) and Outage Probability (OP) between the proposed algorithm and Wong's algorithm [7] which emphasizes system spectral efficiency. Notice that the spectral efficiency increases as the number of users increases. This phenomenon is due to the effect of multiuser diversity gain. When the proposed algorithm uses SE mode with parameter $\alpha = 10, \beta = 1$, SE of the proposed algorithm is similar to Wong's method, but OP is lower than Wong's by almost half. Thus proposed algorithm can satisfy different user QoS requirement more than Wong's algorithm. In this simulation, QoS requirement relaxation parameter is set to 0.05.

Second, You *et al.* [5] establishes an optimization model supporting multi-service resources allocation scheme in the case of two services: voice and high-speed packet data. Because the voice is sensitive to delay, they firstly allocate subcarriers to the voice users, aiming to minimize the OP, and then packet data user can acquire remaining subcarriers. In brief, You's subcarrier allocation algorithm stresses the QoS requirements of voice user than spectral efficiency. In this paper, voice user is mapped to data proportion group 1 and data packet user is assigned to group 2, and group 4. In Fig. 2, You's algorithm reveals lower SE unlike Wong's, but the OP gradually decreases as the number of users increases. The reason is that the portion of voice user in the cell is increased as the number of users increases. On the other hand, the proposed algorithm is set as OP mode ($\alpha=1, \beta=10$) in order to satisfy QoS requirement first and ours has higher SE than You's method and has relatively low, stable OP. The reason is that the reallocation processes minimize the number of user with insufficient QoS requirement regardless data form.

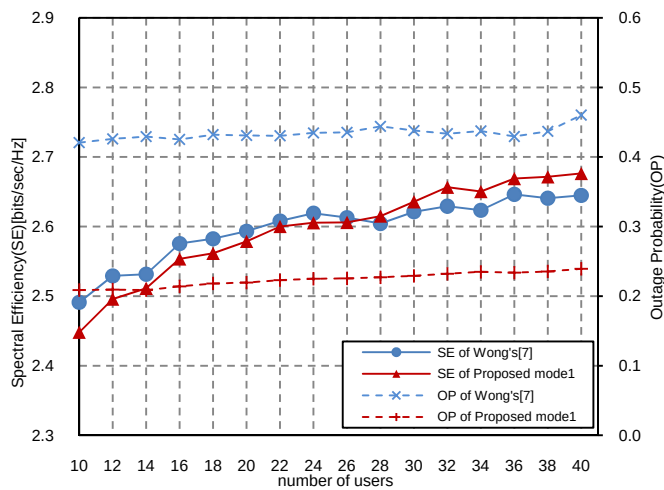


Figure 1. Wong's algorithm vs. proposed SE mode with emphasis on Spectral Efficiency ($\alpha=10, \beta=1$)

Therefore, proposed OP-mode algorithm can achieve higher SE and similar OP compared with You's algorithm.

Until now, we show that the proposed algorithm can coordinate system performance by changing the relative magnitude of two parameters α, β in cost function in Eq. (6). The simulation result shows that system performance varied in accordance with parameter setting; if $\alpha > \beta$, then system spectral efficiency is emphasized and similar to compared algorithm but achieves lower outage probability by almost half. If $\alpha < \beta$, then different QoS requirement is enhanced and system spectral efficiency is higher than You's method emphasizing QoS requirement acquisition. Next, in order to compare user throughput fairness, we defined Weighted Jain Fairness (WJF). To obtain WJF index, at first Jain Fairness index among group user is computed having same data rate proportion. Second, the portion of each different group user number occupied in total user number is multiplied and is summed up by the index of each group. The WJF's result was described in Table 1. Like above results, by adjusting the two parameters of proposed cost function, WJF index values have varied according to the parameter setting. In SE-emphasized mode, WJF index values relatively low, but OP-mode emphasizing QoS requirement shows highest value among comparing algorithms. For reference, the closer to one on WJF index value, the better user throughput fairness.

V. CONCLUSION

In wireless communication systems, both enhancing system spectral efficiency and satisfying different QoS requirement are important, but there exists a trade-off between them. Most of previous resource allocation

Table 1. At 40 user number, Weighted Jain Fairness on different mode

Parameter Variation	Proposed	Wong's[7]	You's[5]
$\alpha = 10, \beta = 1$ (mode 1) (Spectral Efficiency emphasized)	0.82	0.89	0.95
$\alpha = 1, \beta = 10$ (mode 2) (QoS requirement emphasized)	0.97		

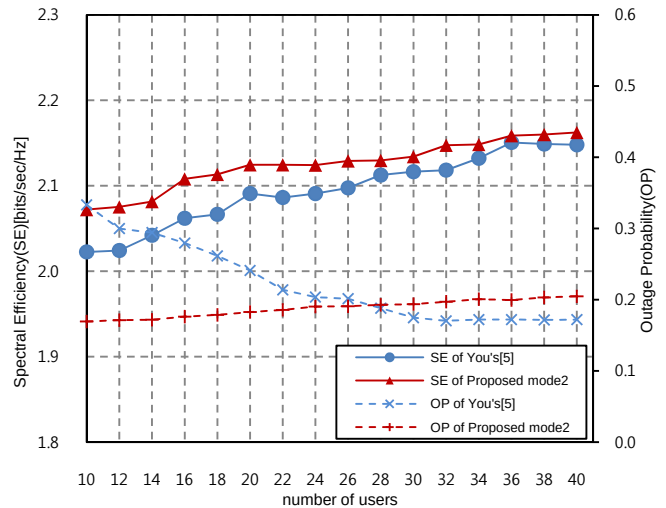


Figure 2. You's algorithm vs. proposed OP mode with emphasis on user throughput fairness ($\alpha=1, \beta=10$)

algorithms can achieve an optimal solution for only one of these two performances. In this paper, we proposed a multi-objective and adjustable subcarrier allocation algorithm by changing relative weightings between spectral efficiency and throughput requirement in proposed cost function. We shows that the SE mode of proposed algorithm can achieve much lower OP than Wong's with similar SE and fairness. And the OP mode achieves better performance than You's in terms of SE, OP, and fairness.

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