Resource Allocation in LTE – Based Wireless Networks

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Abstract— **In this paper, resource allocation for heterogeneous downlink is studied in orthogonal frequency division multiple access (OFDMA) systems unicasting by multiple base stations (BSs). First, this paper formulates the resource allocation problem which is designed to maximize the sum rate of non-real time transmission while satisfying the quality-of-service (QoS) requirement of both the real time and non-real time transmission. In the considered scenario, each user is restricted to being covered by one BS, while each subcarrier is assigned to at most one user. Furthermore, due to frequency reuse in long term evolution (LTE) lead to unacceptable interference levels experienced by user equipment that is very far from its serving BS in a multi-cellular system. The herein proposed dynamic fractional frequency reuse scheme is a step forward towards effective inter-cell interference coordination in wireless networks. Simulations demonstrate that the proposed method provides a comparable performance with fixed fractional frequency reuse.**

I. INTRODUCTION

In orthogonal frequency division multiple access (OFDMA) systems, the transmission band is divided into orthogonal subcarriers to efficiently combat the effects of frequency selective fading for high-speed wireless data transmission [1]. The subcarriers are subject to flat fading with different channel gains if the bandwidth of subcarriers is sufficiently narrow. OFDMA allows for allocating power and rate optimally to subcarriers according to channel condition to enhance the system performance. Resource allocation problems are generally classified into two groups according to different quality-of-service (QoS). One is the rate-adaptive (RA) service, where sum rate is maximized while transmission power is limited [2], [3]. The other is the margin-adaptive (MA) service, where transmission power is minimized subject to fixed required rates [4], [5]. However, both groups of services may be required simultaneously in future wireless networks, so called heterogeneous transmission. Dual optimal resource allocation was provided for heterogeneous unicasting by a single base station (BS) in [6].

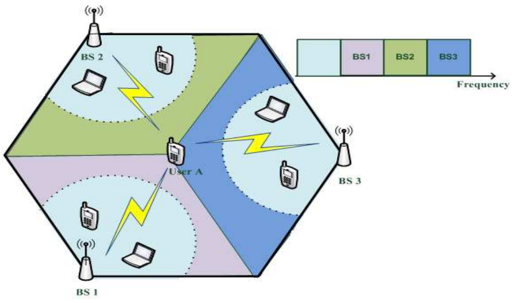

Figure 1. System model with heterogeneous traffic unicasting by multi-BSs.

In a multi-cellular network employing frequency reuse across different cells, inter-cell interference occurs when neighboring cells assign the same frequency bandwidth to different user equipment (UEs). Well designed coordination can reduce interference and improve user capacity and coverage at the cell edges. Fractional frequency reuse (FFR) is representative approach due to its effectiveness of inter-cell interference coordination (ICIC) [7]. FFR allocates different parts of available spectrum for users based on their distance to the BS. Frequency reuse one is applied to cell center area and a higher frequency reuse factor at the cell edge area.

In this paper, resource allocation is considered for heterogeneous unicasting by multiple BSs, shown in Fig. 1. There are three BSs located at the edge of the cell. Each BS segments into 120^o sectoring and serves three cells at the same time. To avoid strong interference among BSs in a cell, FFR is considered as an effective frequency reuse scheme for ICIC. Each subcarrier can be used by only one user served by that BS and each user can be covered by only one BS at any specific time. We aim at maximizing the sum rate for non-real time transmission subject to minimum rate demand by users. The remainder of this paper is organized as follows. Section II formulates the resource allocation problem for heterogeneous uniscasting by multiples BSs. Section III gives an efficient approach to find an appropriate ratio for frequency partitioning to mitigate inter-cell interference (ICI). With this approach, a heuristic method is proposed for resource allocation. Simulation results are presented in Section IV. Finally, the content of this paper is concluded.

II. PROBLEM FORMULATION

We consider the downlink transmission of an OFDMA system with C BSs and K+Q users over N subcarriers at each BS. It is assumed that transmissions of different users are subject to independent frequency selective fading and that perfect channel state information (CSI) is available at the BSs. The rates required for K users are lower bounded, e.g., web users. Fixed data rates demands by Q users, e.g., VoIP user and data users. To differentiate these two kinds of users, we denote the K users as RA users and Q users as MA users.

Our goal is to maximize the sum rate for the K RA users, $k=1,\dots, K$, while satisfying the QoS requirements of each user. The data rate for each user $k=1,\dots, K+Q$ is lower bounded by R_k. The optimization problem can be stated as

$$\text{maximize} \quad \sum_{c=1}^{C}\sum_{k=1}^{K}\sum_{n\in s_{k,c}} r_{k,n,c} \tag{1}$$

$$\begin{aligned}\text{subject to} \quad & r_{k,n,c} = \log_2(1+p_{k,n,c}g_{k,n,c}), && \forall k,n,c \\ & \sum_{c=1}^{C}\sum_{n\in s_{k,c}} r_{k,n,c} \geq R_k, && k=1,\dots,K+Q \\ & \sum_{n=1}^{N} r_{k,n}\cdot r_{l,n} = 0, && \forall k \neq l \\ & \sum_{n\in s_{k,c}} r_{k,n,c} \sum_{n\in s_{k,v}} r_{k,n,v} = 0, && \forall k, \forall c \neq v\end{aligned}$$

where $p_{k,n,c}$ and $r_{k,n,c}$ are the non-negative transmission power and rate allocated to subcarrier n for user k by BS c, respectively. The transmission power is equally distributed among subcarriers and fixed [2]. They are related by the first equality constraint, where $g_{k,n,c}$ denotes the channel gain-to-noise ratio (CNR). The subcarriers assigned to user k at BS c are with the cardinality $s_{k,c}$. One subcarrier is assigned to only one user at each BS, explained by second last constraint. One user is covered by only one BS, expressed by the last constraint.

III. FREQUENCY PARTITIONING AND RESOURCE ALLOCATION FOR HETEROGENEOUS TRANSMISSION

In a multi-cellular network employing frequency reuse across different cells, ICI occurs when neighboring cells assign the same frequency bandwidth to different users. For addressing this problem, many solutions have been proposed [8] and the FFR is considered the most common implementation of ICIC. The FFR scheme divides the available spectrum into two parts: a cell center bandwidth and a cell edge bandwidth. Cell center users (CCUs) who is close to their BS are scheduled in frequency band with frequency reuse one, while cell edge users (CEUs) who is far from their BS are scheduled in three different parts with frequency reuse factor three in the available spectrum. After frequency partitioning has performed, the RCG algorithm is applied to solve problem (1). It has been used on other problems of resource allocation for OFDMA systems, for example, [4]. However, to the best of our knowledge, it has not been applied to problem (1), where resource allocation for heterogeneous service considered.

A. *Dynamic Fractional Frequency Reuse Scheme*

Denote by C the number of BSs in the system, i.e., C=3 as per our working assumption in this paper and by N the number of available subcarrier that can be used for transmission. We formulated an optimization problem which seeks an optimal solution such that the sum of rate is maximized by deciding the number of subcarriers for CCUs and CEUs at each BS subject to power limits of BSs and minimum data rate requirement of CEUs R_k°. This optimal problem can be stated as

$$\text{maximize} \quad \sum_{c=1}^{C} N^\bullet \log_2\Big(1+\frac{P_c^\bullet}{N^\bullet}g^\bullet\Big) + \sum_{c=1}^{C} N^\circ \log_2\Big(1+\frac{P_c^\circ}{N^\circ}g^\circ\Big) \tag{2}$$

$$\begin{aligned}\text{subject to} \quad & N^\bullet + CN^\circ = N, \\ & P_c^\bullet + P_c^\circ = P_c, \\ & \sum_{c=1}^{C} N^\circ \log_2\Big(1+\frac{P_c^\circ}{N^\circ}g^\circ\Big) \geq R_c^\circ.\end{aligned}$$

where P_c is total transmission power of each BS c, $P_c^\bullet$ and P_c° are transmission power of center cell and edge cell of BS c, respectively. $N^\bullet$ and N° are number of subcarriers allocated for CCUs and CEUs, respectively. $g^\bullet$ denoted as average CNR of center cell and g° as average CNR of edge cell at BSs.

Now, we interpret the way to compute the $N^\bullet$ subcarriers for CCUs and N° subcarriers for CEUs in order to maximize the sum rate of the BSs. In this framework $N^\bullet$ and N° are calculated basing on transmission power and rate demand by CEUs. By taking the derivative of this objective regarding P_c°, the optimality condition is obtained as

$$\frac{P_c^\bullet}{N^\bullet} + \frac{1}{g_c^\bullet} = \frac{P_c^\circ}{N^\circ} + \frac{1}{g_c^\circ}, \tag{3}$$

$$P_c^\bullet + P_c^\circ = P_c. \tag{4}$$

Water level for CCUs must be equal to water level for CEUs as (3). Data rate of CCUs and CEUs at BS c is given by

$$r_c^\bullet = N^\bullet \log_2(1+SNR^\bullet), \tag{5}$$

$$r_c^\circ = N^\circ \log_2(1+SNR^\circ), \tag{6}$$

where SNR of CCUs and CEUs are computed as

$$SNR^\bullet = \frac{P_c^\bullet}{N^\bullet}g^\bullet, \tag{7}$$

$$SNR^\circ = \frac{P_c^\circ}{N^\circ}g^\circ. \tag{8}$$

Sequentially, we propose scheme of frequency partitioning. Our aim is to find set of N° subcarriers that can fulfill the rate

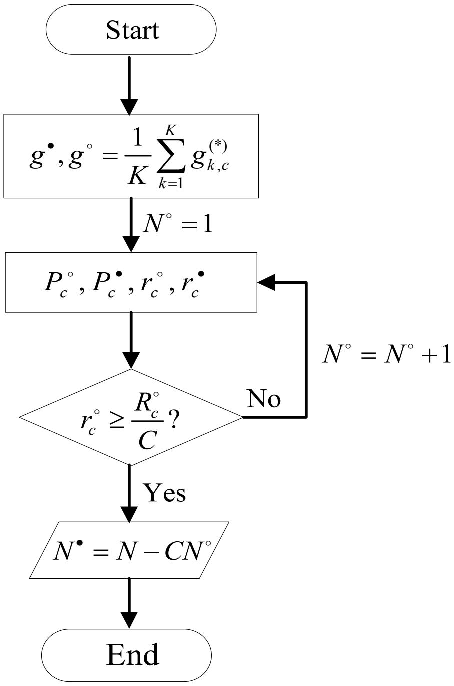

Figure 2: Flow chart for dynamic fractional frequency reuse scheme.

demand of CEUs R_c° and allocate the remaining subcarriers $N^{\bullet}$ to CCUs in order to maximize the sum rate of BSs. Noticeably, the adaption of number of N° subcarriers to CEUs is executed repeatedly with respect to resource demand by CEUs. The proposed dynamic fractional frequency reuse (DFFR) scheme is illustrated in flow chart, see Fig. 2.

B. Sensible Greedy Resource Allocation

From the above subsection, the DFFR is the key to find an appropriate ratio of subcarriers for CCUs and CEUs to mitigate ICI. Once DFFR is performed, next is resource allocation for heterogeneous transmission. We define that the resource allocation to users is characterized by how many subcarriers and which subcarriers can be assigned to each user to satisfy their rate demand. To solve the problem of resource allocation, we are separating this problem into two phases.

1) Resource Allocation to Users: The number of subcarriers or resource amount that each user *k* can get is computed based on the rate requirements and channel condition. To solve this problem, each user will be initially assigned the number of subcarriers, denoted n_k. It means that n_k would be calculated based on $SNR_{k,c}$ of user *k* served by BS *c* and its required rate. So, $SNR_{k,c}$ is computed as

$$SNR_{k,c} = \frac{p_{k,c} \cdot g_{k,c}}{N_{th}}, \tag{9}$$

where $p_{k,c}$ is the transmission power of user *k* over one subcarrier from BS *c*. We assuming that there is no power control, i.e., the transmission power are evenly distributed over all subcarriers. $g_{k,c}$ is channel gain between user *k* and its serving BS *c*. N_{th} is thermal noise power over one subcarrier. We assume that noise level is same on all subcarriers for all users. We define the reference data rate of user *k* in its serving BS *c* can be achieved using Shannon's formula,

$$r_{k,c} = BW_{sc} \cdot \log_2(1 + SNR_{k,c}) \tag{10}$$

where BW_{sc} is bandwidth of one subcarrier. The amount of resource that can get by users is estimated as

$$n_k = \left\lceil \frac{R_k}{r_{k,c}} \right\rceil, \qquad \forall k \tag{11}$$

$\lceil x \rceil$ is the nearest integer greater than or equal to x, R_k is denoted as the minimum required data rate of user *k*. To find the optimal distribution of subcarriers among users given the channel information, a greedy descent scheme is proposed. First, we sort the users according to their priority. VoIP users have the highest priority and they will be assigned at first, then data users and finally web users. We estimate the number of subcarriers that will be initially assigned to users based on equation (11). By doing so, the amount of resource occupied by users is determined. Finally, the remaining subcarriers are distributed among RA users fairly. This scheme is shown to converge to the distribution of subcarriers among users as shown in Fig. 3.

2) Subcarrier Assignment to Users: Once the number of subcarriers is determined, the next step is to assign specific subcarriers to users. This scheme begins with an estimate of the users transmission rate on each subcarrier and allocate

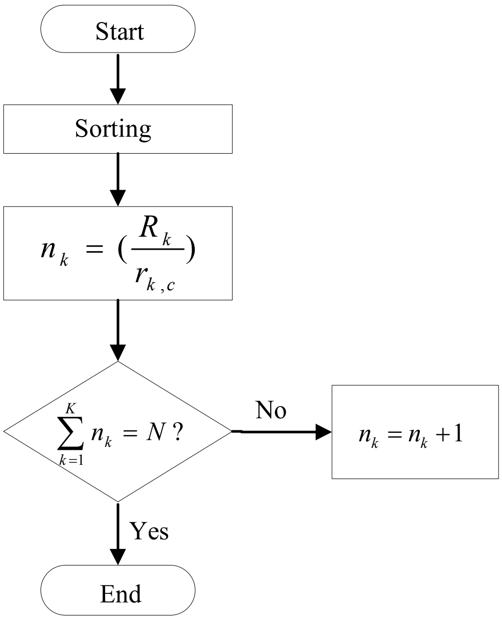

Figure 3: Flow chart for resource allocation to users.

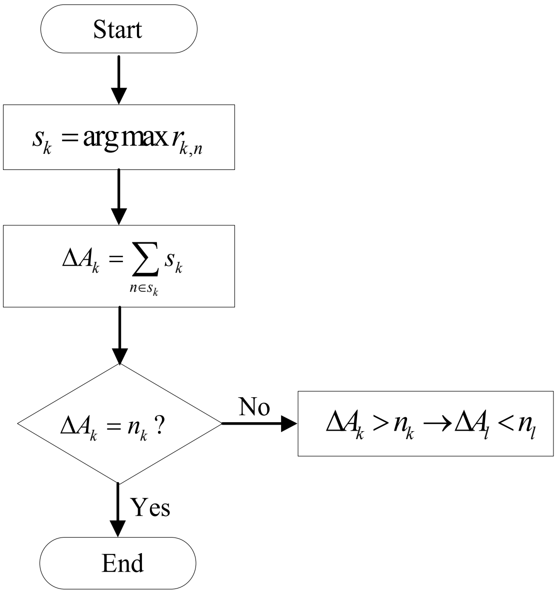

Figure 4: Flow chart for subcarrier assignment to users.

each subcarrier n to the user with maximum transmission rate $r_{k,n}$. Let ΔA_k denotes the set of subcarriers assigned to user k.While exist some user k such that ΔA_k greater than n_k, remove a subcarrier from user k and add a subcarrier to a user l such that ΔA_l less than n_l using a sequence of real-location. This scheme involves finding the shortest distance through a K-node graph and recalculating graph weights in each iteration until stopping criterion is met. The simplified version of this algorithm is outlined in Fig. 4.

IV. SIMULATION RESULTS

In this section, we first describe the configuration in our simulation work. Then numerical results and their analysis are presented.

A. *Simulation Configurations*

By using our simulation model we aim at a better understanding of DFFR and proposed resource allocation (PRA) scheme, including a comprehensive study of its advantages and an examination of its performance with other approaches. In our model, a cell with three BSs located at the edge of the cell is simulated. Each user's location is denoted by (θ, R) while θ and R are uniformly distributed within $[0^\circ, 120^\circ]$ and within $[0, 0.9]$ km, respectively. The multipath channel fading with an exponentially decaying profile is considered in our case. Path loss model from [9] are utilized to generate the path loss for testing our algorithm of resource allocation. The main simulation parameters are summarized in Table I.

In our simulation, 70% are margin-adaptive users, where 55% are VoIP and 15% are data users. The rest 30% are rate-adaptive users, where all are surfing in the web. A VoIP and web user requires 64kbps and a data user requires from 512 to 2000kbps. The concrete parameters are summarized in Table II.

TABLE I.
MAIN SIMULATION PARAMETERS

Parameter	**Value**
System bandwidth	16 MHz
Cell radius	750m
Subcarrier bandwidth	15 kHz
Number of resource block (RB)	85
Number of subcarriers per RB	12
Transmission power	46 dBm
Thermal noise	-174 dBm/Hz
Interference	15dB
Distance-dependent path loss	128.1+ 37.6 $\log_{10}$(R), R in km

TABLE II.
DIFFERENT TYPES USERS

Types	**Priority**	**Data rate (kbps)**	**Rate**	**Percentage**
VoIP	High	64	Fixed	55%
Data	Mid	[512,2000]	Fixed	15%
Web	Low	64	Min	30%

B. *Results*

Fig. 5 gives the achieved sum rate for RA service with different number of users. The performance of DFFR is compared with that of a simple FFR. Since there is no previous FFR algorithm for heterogeneous services, we introduce a simple FFR algorithm referred to as the fixed fractional frequency reuse (FFFR). Assuming that CCUs is

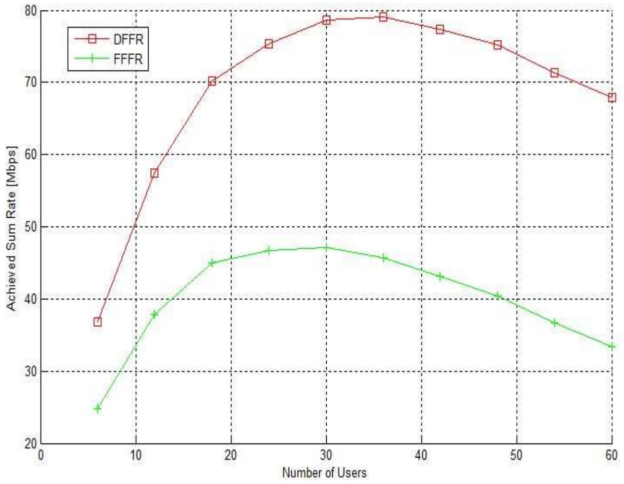

Figure 5: Achieved sum rate for RA users vs. number of total users with P_c=46dBm and N=1020.

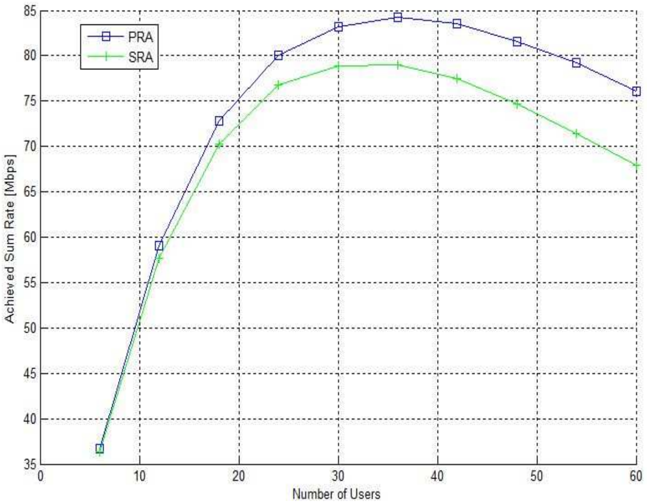

Figure 6: Achieved sum rate for RA users vs. number of total users with P_c =46dBm, $N^\bullet$ and N° computed by DFFR.

allocated with 516 subcarriers and CEUs with 168 subcarriers at each BS, then a simple resource allocation (SRA) is performed to compare the performance of the proposed method with FFFR. SRA allocate subcarriers to users consecutively proportional to their rate requirements. The subcarriers already allocated to some other users will be excluded from the selection for the following users. After selecting the subcarriers, the remaining subcarriers are assigned to RA users fairly. As can be seen, DFFR provide higher achieved sum rate than the FFFR. Obviously, this scheme computes number of subcarriers should allocate to CCUs and CEUs at each time instance while satisfying the rate required by CEUs. While allocating enough number of subcarriers for CEUs, the resource allocation for users are maximized compared to FFFR scheme. Clearly, higher number of subcarriers allocation for CCUs allows for significant higher achieved sum rate for RA users compared to higher number of subcarriers allocation for CEUs with FFFR scheme.

Fig. 6 shows the achieved sum rate for RA service of the PRA algorithm for different number of users, and compare it with SRA algorithm, when $N^\bullet$ and N° computed by DFFR. As mentioned before, the PRA method estimates number of subcarriers per user until all users satisfies their rate demand and supply services for RA users as good as possible. The simulation shows that the PRA algorithm significantly outperforms the SRA algorithm. The proposed method examines the information of user's channel and rate requirements to find a close approximation to the solution. From the above analysis and comparison, a good but not necessarily optimal solution if found which guarantees a certain level of service for each users.

V. CONCLUSION

In this paper, we have investigated resource allocation for heterogeneous unicasting by multiple BSs in a cell by proposing a dynamic fractional frequency reuse scheme in the 3GPP LTE systems. We have aimed at maximizing the achieved sum rate subject to the minimum required rates of users. To enhance the performance of resource allocation, a resource allocation algorithm for heterogeneous transmission has been proposed. For performance comparison, we introduced a simple resource allocation. The simulations have demonstrated that the proposed resource allocation algorithm significantly outperforms the simple resource allocation algorithm with dynamic fractional frequency reuse.

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