Dynamic Load Balancing in 3GPP LTE Multi-Cell Fractional Frequency Reuse Networks

Zhihang Li, Hao Wang, Zhiwen Pan, Nan Liu and Xiaohu You

National Mobile Communications Research Laboratory, Southeast University, Nanjing, China
{zhihang.li, hao_wang, pzw, nanliu, xhyu}@seu.edu.cn

***Abstract*—3GPP LTE networks can provide a higher capacity by adopting advanced physical layer techniques and serve users with different Quality of Service (QoS) requirements. However, unbalanced user distributions and strong inter-cell interference (ICI) still deteriorate network performances severely. Since fractional frequency reuse (FFR) technique is recommended to mitigate ICI, we investigate the load balancing problem in a 3GPP LTE multi-cell FFR network with heterogenous services in this paper. Firstly we formulate a multi-objective optimization problem, whose objectives are intra- and inter-cell load balancing index for users with QoS requirements and total utility function for users without QoS requirements. Then we analyze the complexity of the problem and propose a practical algorithm which includes QoS aware intra- and inter-cell handover and call admission control. Extensive simulations are conducted, the results show that our algorithm can lead to significantly better performances, i.e., a lower new call blocking rate for users with QoS requirements, a larger utility for users without QoS requirements at the cost of a bit degradation of total throughput.**

***Index Terms*—LTE, load balancing, fractional frequency reuse (FFR), multi-objective optimization, Quality-of-Service (QoS).**

I. INTRODUCTION

3GPP LTE networks can achieve high spectrum efficiency due to the usage of multi-input and multi-output (MIMO) [1] antenna and orthogonal frequency division multiple (OFDM) [2] technology. However, the network performance is still influenced by several factors, among which inter-cell interference (ICI) and load imbalance are two major ones. There have been lots of researches investigating ICI [3]–[6] and load balancing [7]–[11] independently. And fewer paper consider them jointly [12]. However, to the best of our knowledge, there is still a lack of research which jointly considers both of them with heterogenous services.

In this paper, we investigate the load balancing problem in a practical 3GPP LTE multi-cell fractional frequency reuse (FFR) network with heterogenous services. We extend Son's work [12] by admitting users with different QoS requirements and reformulate the objective function under QoS and FFR consideration. First, we formulate the problem to be a multi-objective optimization problem, whose objectives are intra- and inter-cell load balancing index for users with QoS requirements and total utility function for users without QoS requirements with the constraints of physical resource limits and users' QoS demands. Then the complexity of the problem is analyzed, and a practical algorithm is proposed, which includes QoS aware intra- and inter-cell handover and call admission control. Extensive simulations are conducted, the results show that our algorithm can lead to significantly better performances, i.e., a lower new call blocking rate for users with QoS requirements, a larger utility for users without QoS requirements at the cost of a bit degradation of total throughput.

The remainder of this paper is organized as follows. In Section II, we introduce the system model. In Section III, we formulate the problem to be a multi-objective optimization problem and analyze its complexity. Then we propose a practical solution in Section IV. Simulation results are given in Section V and the whole paper is concluded in Section VI.

II. SYSTEM MODEL

A. Network Model

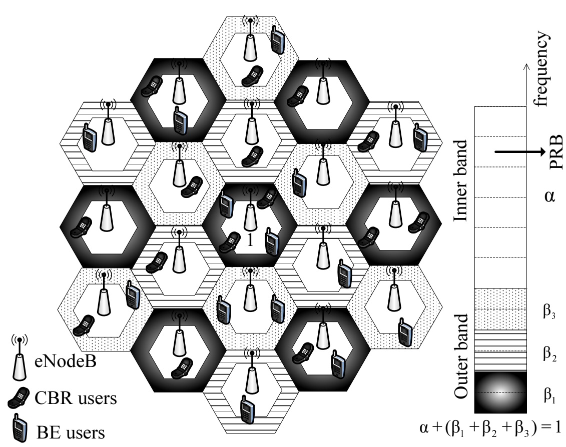

Fig. 1. Network Model

A 3GPP LTE multi-cell FFR network serving users with heterogeneous QoS requirements is considered here. As shown in Figure 1, there are two kinds of users with different QoS requirements, i.e., constant bit rate (CBR) users with rate requirements and best effort (BE) users with no QoS requirements. The network contains nineteen cells, each of

This work is supported in part by the National Special Key Program (2011ZX03003-002-02); the National Basic Research Program of China (973 Program 2012CB316004); the Research Fund of National Mobile Communications Research Laboratory, Southeast University (No. 2012A02); the Graduate Education Innovation Project of Jiangsu Province (CXLX_0116); the Liuda Rencai Gaofeng of Jiangsu Province; and Huawei Corp. Ltd.

978-1-4673-1881-5/12/$31.00 ©2012 IEEE

which is controlled by a central eNodeB. Throughout this paper, cell and eNodeB are used interchangeably. According to FFR, there are three types of cells in the network, the whole bandwidth of each cell is divided into two individual parts, the inner band α and the outer band (β_1 or β_2 or β_3), where $\alpha+(\beta_1+\beta_2+\beta_3)=1$. Type i cells are those which serve their outer users using β_i subbands. Adjacent twelve subcarriers are grouped into a Physical Resource Block (PRB) [13], which is the smallest unit that can be allocated to each user in a subframe (1 ms).

We use $\mathbf{N}, \mathbf{W}, \mathbf{K}, \mathbf{C}, \mathbf{B}$ to represent the set of all cells, whole bandwidth of a cell, total users, CBR and BE users, respectively. It is obvious that $\mathbf{K} = \mathbf{C} \cup \mathbf{B}$. We define an assignment indicator variable $I^w_{i,k}(t)$, which equals to 1 when user $k \in \mathbf{K}$ is served by cell $i \in \mathbf{N}$ in band $w \in \mathbf{W}$ at time t, and 0 otherwise. All time t mentioned in this paper represents the time for load balancing. The time span between any t and $t+1$ is an intra-cell load balancing cycle, which is much larger than a subframe.

B. Link Model

We assume that each user knows the instantaneous signal strength on its serving PRB from its serving and neighboring cells through pilot detection. And the channel state information is sent back to its serving cell within uplink transmission or by periodical report.

Then the instantaneous received signal to interference plus noise ratio (SINR) for user k on PRB l in band w from cell i at a subframe τ $SINR^w_{i,l,k}(\tau)$ is

$$SINR^w_{i,l,k}(\tau) = \frac{g^w_{i,l,k}(\tau) \cdot p^w_{i,l}(\tau)}{N_0 + \sum\limits_{j \in Q^w_i,\ j \neq i} g^w_{j,l,k}(\tau) \cdot p^w_{j,l}(\tau)} \tag{1}$$

where $g^w_{i,l,k}(\tau)$ and $p^w_{i,l}(\tau)$ represent the instantaneous channel gain between eNodeB i and user k and the transmit power of eNodeB i on PRB l in band w at subframe τ, respectively. Thus $g^w_{i,l,k}(\tau) \cdot p^w_{i,l}(\tau)$ is the corresponding received signal strength. N_0 is the uniform power of additive white Gaussian noise on each PRB. Q^w_i is the set of cells which use the same band w as cell i.

Given $SINR^w_{i,l,k}(\tau)$, the average bandwidth efficiency $e^w_{i,k}(t)$ of user k in band w of cell i during the time period $[t-1, t)$ is

$$e^w_{i,k}(t) = \frac{1}{|\mathbf{L^w_i}| \cdot n_{tot}} \sum_{\tau \in [t-1,t)} \sum_{l \in \mathbf{L^w_i}} log_2[1+SINR^w_{i,l,k}(\tau)][bps/Hz] \tag{2}$$

where $\mathbf{L^w_i}$ is the set of PRB in band w of cell i. $|\cdot|$ represent the cardinal number of a set. n_{tot} is the number of subframes in one intra-cell load balancing cycle. Each user reports the average bandwidth efficiency to its serving eNodeB.

C. Intra-cell Load Balancing Index For CBR Users

We use $\rho^w_i(t)$ to represent the load of band w in cell i at time t, which is

$$\rho^w_i(t) = \frac{\sum_{c \in \mathbf{C}} I^w_{i,c}(t) \cdot s^w_{i,c}(t)}{s^w_{i,C}} \tag{3}$$

where $s^w_{i,C}$ is the total available resources for CBR users in band w of cell i, $s^w_{i,c}(t)$ is the quantity of resource allocated to CBR user c at time t. Assuming that adaptive coding and modulation is used to achieve the Shannon limit, $s^w_{i,c}(t)$ is

$$s^w_{i,c}(t) = \frac{\theta_c}{Bw \cdot e^w_{i,c}(t)} \tag{4}$$

where θ_c is the rate requirement of CBR user c, Bw is the unit bandwidth.

We define the intra-cell load balancing index $\xi_{intra}(t)$ at time t as follows

$$\xi_{intra}(t) = \frac{\sum_{i \in \mathbf{N}} [\rho^w_i(t) - \rho^{\bar{w}}_i(t)]^2}{|\mathbf{N}|} \tag{5}$$

where $\bar{w}$ is the opposite band to band w, and $|\mathbf{N}|$ is the number of cells in the network. The value of $\xi_{intra}(t)$ is in $[0, 1]$. A smaller $\xi_{intra}(t)$ denotes a more balanced load distribution between inner and outer bands. Thus we try to minimize $\xi_{intra}(t)$ at each intra-cell load balancing time t.

D. Inter-cell Load Balancing Index For CBR Users

Similarly, we use $\rho_i(t)$ to represent the total load of cell i at time t, which is

$$\rho_i(t) = \frac{\sum_{c \in \mathbf{C}} \sum_{w \in \mathbf{W}} I^w_{i,c}(t) \cdot s^w_{i,c}(t)}{s_{i,C}} \tag{6}$$

where $s_{i,C}$ is the total available resources for CBR users in cell i. And we use Jain's fairness index [14] to evaluate the status of inter-cell load balancing index as follows

$$\xi_{inter}(t) = \frac{[\sum_{i \in \mathbf{N}} \rho_i(t)]^2}{|\mathbf{N}|[\sum_{i \in \mathbf{N}} \rho^2_i(t)]} \tag{7}$$

The value of $\xi_{inter}(t)$ is in $[1/|\mathbf{N}|, 1]$. A larger $\xi_{inter}(t)$ denotes a more balanced load distribution among cells. Thus for inter-cell load balancing, we try to maximize $\xi_{inter}(t)$ at each inter-cell load balancing time t.

E. Total Utility For BE Users

Following the procedure analysis in [15], the achievable throughput of BE user b in band w of cell i at time t is

$$R^w_{i,b}(t) = s^w_{i,b}(t) \cdot Bw \cdot e^w_{i,b}(t) \cdot G[Y^w_i(t)] \tag{8}$$

where $s^w_{i,b}(t) = [s^w_i - \sum_{c \in \mathbf{C}} I^w_{i,c}(t) s^w_{i,c}(t)]/Y^w_i(t)$ is the quantity of resource allocated to user b at time t. s^w_i is the total resources of cell i in band w. $Y^w_i(t)$ is the number of active BE users in band w of cell i at time t. $G(\cdot)$ represent the multi-user diversity gain corresponding to the number of competing users.

For BE users, we utilize the well-known log utility function $U(\cdot) = log(\cdot)$. Then the total utility of BE users at time t is

$$\phi(t) = \sum_{i \in \mathbf{N}} \sum_{w \in \mathbf{W}} \sum_{b \in \mathbf{B}} log[I^w_{i,b}(t) R^w_{i,b}(t)] \tag{9}$$

The objective of load balancing for BE users is to maximize $\phi(t)$ at each time t.

III. Problem Formulation and Decomposition

In this section, we formulate an optimization problem for the above network. Our objective is to utilize enforced handover to achieve load balancing for CBR users to decrease the new call blocking rate and for BE users to increase the total utility.

We try to maximize $\phi(t)$, $\xi_{inter}(t)$ and minimize $\xi_{intra}(t)$ simultaneously at each time t. Since all of them are determined by the assignment between cells and users, the problem is equivalent to the following multi-objective optimization problem with QoS and resources constraints.

$$\max \quad [\xi_{inter}(t), -\xi_{intra}(t), \phi(t)]^T \tag{10}$$

$$s.t \qquad \sum_{k\in\mathbf{K}} I_{i,k}^{w}(t) s_{i,k}^{w}(t) \le s_i^w, \forall i \in \mathbf{N}, \forall w \in \mathbf{W} \tag{11}$$

$$\sum_{i\in\mathbf{N}}\sum_{w\in\mathbf{W}} I_{i,k}^{w}(t) = 1, \forall k \in \mathbf{K} \tag{12}$$

$$\sum_{i\in\mathbf{N}}\sum_{w\in\mathbf{W}} I_{i,c}^{w}(t) R_{i,c}^{w}(t) \ge \theta_c, \forall c \in \mathbf{C} \tag{13}$$

Constraint in (11) presents the resources occupied by all users in one band of a cell could not exceed the total available resources in that band. Constraint in (12) explains that a user can be served by only one band in only one cell at a specific time. Constraint in (13) tells the rate requirement of any CBR user must be satisfied.

Generally, we can construct a single Aggregate Objective Function (AOF) which converts the multiple objectives into a single objective function. A well-known combination is the weighted linear sum method. Since all the three objectives impact each other on the network performance and they also have different dimensions, it is hard to design the weight to different objectives. And for recent popular evolutionary algorithms, such as particle swarm optimization and simulated annealing [16], [17], both of them need a central controller to collect the QoS and SINR information of all users. Besides, a long processing time is need to achieve the Pareto optimum.

In LTE networks, there doesn't exist a central controller, meanwhile the handover decisions should be performed by each cell independently and promptly. Besides, the overhead should be low. Thus in the following, we propose a practical algorithm, which handover users with heterogenous QoS for load balancing (HQLB) within and among cells. It could be executed in a distributed manner with low overhead.

IV. Practical Algorithm

In this section, we give a practical framework to solve the above multi-objective optimization problem. It contains three parts: a QoS aware intra-cell handover scheme, a QoS aware inter-cell handover scheme, and a call admission control scheme. For simplicity, we omit the symbol t in the following analysis.

A. Intra-cell Handover

The intra-cell handover is just the procedure to change the band currently being used, rather than a real handover, so it brings low system overhead. The cycle of intra-cell handover should be short, we take 500 ms as an example.

1) For CBR users: Assuming handover a CBR user c in cell i from band w to band $\bar{w}$. The intra-cell load balancing index before and after the handover are

$$\xi_{intra}^{before} = \frac{\sum_{i\in\mathbf{N}}(\rho_i^w - \rho_i^{\bar{w}})^2}{|\mathbf{N}|} \tag{14}$$

$$\xi_{intra}^{after} = \frac{\sum_{n\in\mathbf{N},n\neq i}(\rho_n^w - \rho_n^{\bar{w}})^2 + [(\rho_i^w - x) - (\rho_i^{\bar{w}} + y)]^2}{|\mathbf{N}|} \tag{15}$$

where $x = s_{i,c}^w / s_{i,C}^w$ and $y = s_{i,c}^{\bar{w}} / s_{i,C}^{\bar{w}}$ denote the load of user c in its original and target band. Let $\xi_{intra}^{before} > \xi_{intra}^{after}$, we can get

$$\frac{2(\rho_i^w - \rho_i^{\bar{w}})}{x+y} > 1 \tag{16}$$

Define the left part of the above inequality as the intra-cell handover gain $\delta_{i,c}^{intra}$. To avoid handover oscillation, we only handover the user c^* satisfying the following condition

$$c^* = \text{argmax} \quad \delta_{i,c}^{intra} > 1 \tag{17}$$

2) For BE users: Assuming handover a BE user b in cell i from band w to band $\bar{w}$. Its utility function before and after the handover are

$$U_{i,b}^{w(\bar{w})} = log(R_{i,b}^{w(\bar{w})}) = log[s_{i,b}^{w(\bar{w})} \cdot BW \cdot e_{i,b}^{w(\bar{w})} \cdot G(Y_i^{w(\bar{w})})] \tag{18}$$

Assuming the number of users of cell i in band $w/\bar{w}$ are large enough, then the increase of total utility only depends on the increase of user $b's$ utility. Let $U_{i,b}^{\bar{w}} > U_{i,b}^{w}$, and define $\eta_{i,b}^{intra} = R_{i,b}^{\bar{w}} / R_{i,b}^{w}$ as the intra-cell handover gain. Similar to CBR users load balancing, we only handover the user b^* which satisfies

$$b^* = \text{argmax} \quad \eta_{i,b}^{intra} > 1 \tag{19}$$

B. Inter-cell Handover

Comparing to the intra-cell handover, inter-cell handover is a true handover and brings additional system overhead. Thus the cycle of inter-cell handover should be long, we take 1 second as an example.

1) For CBR users: Assuming handover a CBR user c from cell i to cell j. The inter-cell load balancing index before and after the handover are

$$\xi_{inter}^{before} = \frac{(\sum_{i\in\mathbf{N}}\rho_i)^2}{|\mathbf{N}|(\sum_{i\in\mathbf{N}}\rho_i^2)} \tag{20}$$

$$\xi_{inter}^{after} = \frac{(\sum_{i\in\mathbf{N}}\rho_i + y - x)^2}{|\mathbf{N}|[\sum_{n\in\mathbf{N},n\neq i}\rho_n^2 + (\rho_j + y)^2 + (\rho_i - x)^2]} \tag{21}$$

where $x = s_{i,c}/s_{i,C}$ and $y = s_{j,c}/s_{j,C}$ represent the load of user c in its original and target cell. Make $a = \sum_{i\in\mathbf{N}}\rho_i$, $b = \sum_{i\in\mathbf{N}}\rho_i^2$, and let $\xi_{inter}^{before} < \xi_{inter}^{after}$, we can get

$$\frac{(a+y-x)^2 b}{(b + x^2 + y^2 - 2\rho_i x + 2\rho_j y)a^2} > 1 \tag{22}$$

We also use the left part of the above inequality as the inter-cell handover gain $\delta_{i,j,c}^{inter}$. To avoid handover oscillation, we only handover the user c^* satisfying the following condition

$$c^* = \text{argmax} \quad \delta_{i,j,c}^{inter} > 1 \tag{23}$$

2) For BE user: Assuming handover a BE user b from cell i to cell j. Then its utility before and after the handover are

$$U_{i(j),b}^{w} = log(R_{i(j),b}^{w}) = log[s_{i(j),b}^{w} \cdot BW \cdot e_{i(j),b}^{w} \cdot G(Y_{i(j)}^{w})] \tag{24}$$

Similar to intra-cell BE users load balancing. Let $U_{j,b}^{w} > U_{i,b}^{w}$, and define $\eta_{i,j,b}^{inter} = R_{j,b}^{w}/R_{i,b}^{w}$ as the inter-cell handover gain, we only handover the user b^* which satisfies

$$b^* = \text{argmax} \quad \eta_{i,j,b}^{inter} > 1 \tag{25}$$

C. Call Admission Control

For a new CBR user h, we will access it if and only if its rate requirement can be strictly satisfied, which means

$$s_{i,h}^{w} \leq s_{i,C}^{w} - \sum_{c \in \mathbf{C}} I_{i,c}^{w} \cdot s_{i,c}^{w} \tag{26}$$

For a new BE user h, we will access it if and only if it can improve the total utility, which means

$$\Delta U = log[s_{i,h}^{w} \cdot Bw \cdot e_{i,h}^{w} \cdot G(Y_i^{w})] > 0 \tag{27}$$

V. Simulation Results

A. Simulation Setup

The network considered here is shown in Figure 1. The distance between neighboring eNodeBs is 500 meters. The maximum transmission power of each eNodeB is 38 dBm and the bandwidth is 10 MHz, which are consistent with the simulation scenario recommended by 3GPP [18]. To avoid border effects, wrap-around technique is used [19].

In order to make simulation more practical, we perform it in a dynamic setting. Users uniformly arrive in any cell i according to a Poisson process with rate λ_i and depart from the system after a holding time that is exponential distribution with the mean of 100 seconds. The average number of users in each cell depends on the arrival rate and the holding time. The rate requirement of each CBR user is set to 128 kbps or 256 kbps randomly. We set cell 1 as the overloaded one with the same alterable arrival rates for both CBR and BE users while that in other cells are both 0.2 user/second. One simulation contains 500 seconds and we perform the simulation dozens of times for each arrival rate of cell 1.

B. Simulation Results

A cycle with 200 m radius is used as the boundary between inner and outer band. Firstly we evaluate the system performances with different α.

We set the arrival rate of cell 1 to be 1.8 user/second for both CBR and BE users, and perform the simulation only considering FFR. α is set to be 0, 0.1,..., 1.0 orderly.

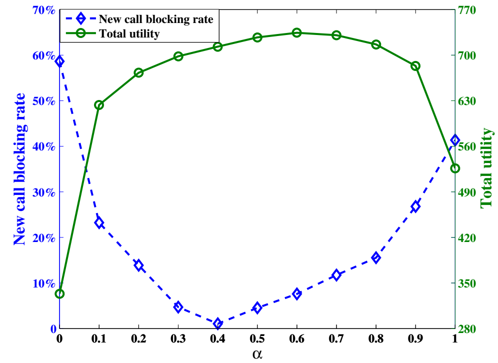

Fig. 2. Decision of the Optimal α

1) Decision of the Optimal α: Figure 2 shows the new call blocking rate and the total utility with different α. We can find that the new call blocking rate decrease monotonously as the increase of α until $\alpha = 0.4$. We can also find that the total utility achieves its maximum when $\alpha = 0.6$. Comparing to the maximum, $\alpha = 0.4$ has only 2.89% deterioration in total utility. Thus we select $\alpha = 0.4$ in the following simulations since CBR users have higher priority than BE users and the performance of CBR users should be guaranteed preferentially.

For convenience, we use *NA*, *FFR* and *HQLB* to represent no load balancing and no FFR, FFR alone, both load balancing and FFR, respectively.

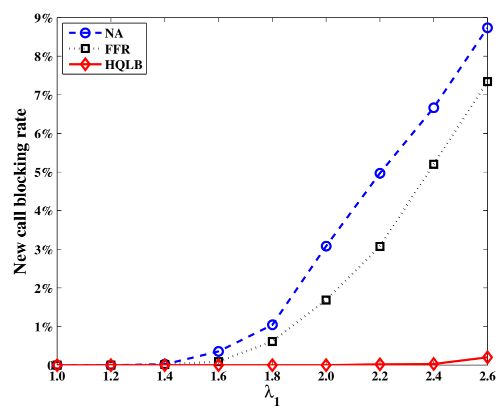

Fig. 3. New call blocking rate with alterable λ_1

2) New Call Blocking Rate with alterable λ_1: Figure 3 shows that the new call blocking rate of *NA*, *FFR* and *HQLB* all increase monotonously with λ_1. This is because that a bigger arrival rate brings more users, which results in a higher new call blocking rate with constant resource. The new call blocking rate of *NA* is the highest because it neither utilize FFR to reduce cell-edge interference nor perform handover for load balancing. Since *FFR* improves the SINR of boundary users, it can serve more users with less resource, thus performs better than *NA*. For *HQLB*, it can not only inherit the benefit of *FFR*, but also switch users from a congested area to an idle area for load balancing, the performance of it is the best.

3) Total Throughput with alterable λ_1: Figure 4 shows the total throughput of *NA*, *FFR* and *HQLB* with different λ_1.

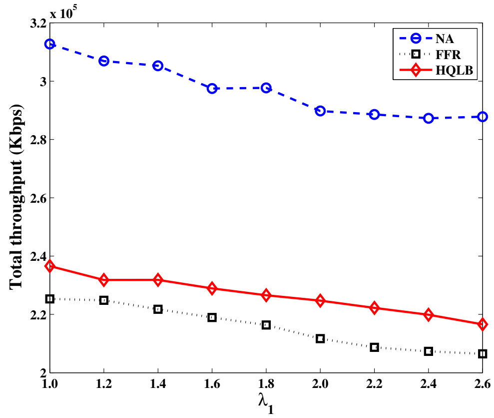

Fig. 4. Total throughput with alterable λ_1

Since *NA* has the most available resource, its performance is the best. Although *FFR* improves the SINR of boundary users, it leaves less resource to each cell compared to *NA*, so its performance is worse than *NA*. Since handover a user from the inner band to the outer band of a cell will improve its SINR, meanwhile the available resource in *HQLB* and *FFR* are the same, the total throughput of *HQLB* is larger than *FFR*.

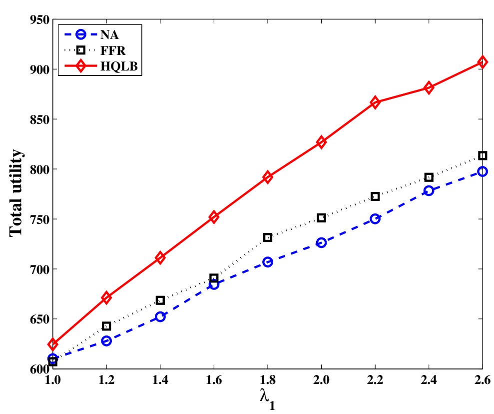

Fig. 5. Total utility with alterable λ_1

4) Total Utility with alterable λ_1: Figure 5 shows the total utility of *NA*, *FFR* and *HQLB* all increase monotonously with λ_1. The reasons for that *NA* has the worst performance and *FFR* performs better than *NA* are similar to the illustration in Fig 3. Handover a CBR user from the inner band to the outer band will release more resources for BE users in inner band, which could bring a large utility gain for all BE users in inner band than the loss of utility in outer band. Meanwhile, handover a CBR user from a congested cell to an idle cell will also bring a similar gain. Furthermore, switch BE users for load balancing can increase the total utility. Thus, *HQLB* has the best performance. Compared Figure 4 with Figure 5, we can find that although *HQLB* doesn't have the highest total throughput, it has the largest total utility, which means that *HQLB* can effectively distribute the load of cell 1 to neighboring cells so as to enhance the fairness of resource allocation among all BE users in the network.

VI. Conclusion

In this paper, we investigate the load balancing problem in a practical 3GPP LTE multi-cell FFR network with heterogenous services. We first formulate the problem to be a multi-objective optimization problem, whose objectives are intra- and inter-cell load balancing index for users with QoS requirements and total utility function for users without QoS requirements with the constraints of physical resource limits and users' QoS demands. Then the complexity of the problem is analyzed, and a practical algorithm is proposed, which includes QoS aware intra- and inter-cell handover and call admission control. Extensive simulations are conducted, the results show our algorithm can significantly decrease the new call blocking rate for users with QoS requirements and improve the total utility for users without QoS requirements at the cost of a bit degradation of total throughput.

References

[1] Gesbert, D. and Shafi, M. and Da-shan Shiu and Smith, P.J. and Naguib, A., "From theory to practice: an overview of mimo space-time coded wireless systems," *Selected Areas in Communications, IEEE Journal on*, vol. 21, no. 3, pp. 281 – 302, Apr. 2003.

[2] 3GPP TS 36.300 V9.2.0, "E-utra and e-utran overall description," December. 2009.

[3] V. H. MacDonald, "The cellular concept," *Bell System Technical J.*, vol. vol. 58, no. 1, pp. pp. 15–41, Jan. 1979.

[4] G. Li, H. Liu, "Downlink radio resource allocation for multi-cell ofdma system," *IEEE Trans. on Wireless Com.*, vol. 5, pp. 3451–3459, Dec. 2006.

[5] T. Bonald, S. Borst, and A. Proutiere, "Inter-cell scheduling in wireless data networks," *in Proc. European Wireless*, Apr. 2005.

[6] S. Liu, J. Virtamo, "Inter-cell coordination with inhomogeneous traffic distribution," *Proc. NGI 2006*, pp. 64–71, Apr. 2006.

[7] H. Wang, L. Ding, P. Wu, Z. Pan, N. Liu, X. You, "Qos-aware load balancing in ofdma-based multi-cell networks," *ICC' 2011*.

[8] S. Das, H. Viswanathan, and G. Rittenhouse, "Dynamic load balancing through coordinated scheduling in packet data systems," *IEEE Proc. INFOCOM*, 2003.

[9] H. Wang, L. Ding, P. Wu, Z. Pan, N. Liu, X. You, "Dynamic load balancing and throughput optimization in 3gpp lte networks," *IWCMC' 2010*.

[10] A. Sang, X. Wang, M. Madihian, and R. D. Gitlin, "Coordinated load balancing, handover/cell-site selection, and scheduling in multi-cell packet data systems," *Wirel. Netw*, vol. 14, no. 1, p. 103C120, 2008.

[11] Z. Li, H. Wang, Z. Pan, N. Liu, X. You, "Joint optimization on load balancing and network load in 3gpp lte multi-cell networks," *WCSP' 2011*, pp. 1–5, Nov.2011.

[12] K. Son, S. Chong, G. Veciana, "Dynamic association for load balancing and interference avoidance in multi-cell networks," *IEEE Trans. on Wireless Com.*, vol. 8, no. 7, pp. 3566–3576, 2009.

[13] 3GPP TS 36.201 V9.1.0, "Lte physical layer: General description," 2010.

[14] D. Chiu and R. Jain, "Analysis of the increase and decrease algorithms for congestion avoidance in computer networks," *Computer Networks and ISDN Systems*, vol. 17, no. 1, p. 1C14, 1989.

[15] H. J. Kushner and P. A. Whiting, "Convergence of proportional-fair sharing algorithms under general conditions," *IEEE Trans. Wireless Commun*, vol. vol. 3, pp. no. 4, pp. 1250C1259, Jul. 2004.

[16] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: Nsga-ii," *IEEE Trans. on Evolutionary Computation*, vol. vol. 6, no. 2, p. 182C197, Apr. 2002.

[17] Carlos A. Coello Coello, Gregorio Toscano Pulido, and Maximino Salazar Lechuga, "Handling multiple objectives with particle swarm optimization," *IEEE Trans. on Evolutionary Computation*, p. 256C279, Jun. 2004.

[18] 3GPP TR 25.814 V7.1.0, "Physical layer aspects for e-utra," 2006.

[19] 3GPP2 C.R1002-0, "cdma2000 evaluation methodology," December. 2004.