Fair Boundary Scheduler for LTE system

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***Abstract*— Scheduling technique plays a significant role in distributions of Resource Blocks (RBs) in LTE system. In order to ensure the LTE system operates efficiently, the scheduler needs a good trade-off between the overall cell throughput and the fairness to all the users' equipment (UEs) in its respective cell. Improving the overall cell throughput while maintaining its fairness level is very crucial in order to ensure all UEs have been served fairly and efficiently. The proposed scheduler technique, which is referred to as Fair Boundary (FB) Scheduler is shown to improve the overall cell throughput while maintaining a high level of fairness among UEs. Our simulation showed that the Fair Boundary Scheduler achieved up to 13 percent improvement in term of the overall cell throughput. Furthermore, our simulation results also showed that the proposed scheduler exhibited better fairness compared to the widely used Proportional Fair (PF) and Round Robin (RR) schedulers.**

Keywords—LTE; Scheduling; fairness; throughput;

I. Introduction

In the downlink, LTE technology is based on Orthogonal Frequency Division Multiple Access (OFDMA). High spectral efficiency and efficient scheduling in both time and frequency domain can be achieved by exploiting multi-user diversity in the downlink transmission. When several user equipment (UE) with independent fading channels share a wireless medium, it is likely that at least one UE is experiencing a good channel, and the total throughput can be maximized by always serving the UE with the strongest channel [1][13].

The LTE downlink physical resource is organized into a time and frequency grid called resource element (RE). A resource block (RB) is made up of 84 REs covering 12 sub-carriers and 7 OFDM symbols for normal cyclic prefix (CP) [2]. The smallest scheduling unit that an LTE scheduler can allocate is one RB. In every time transmission interval (TTI) or a radio sub-frame of 1ms a total of 2 contiguous RBs with the same modulation and coding scheme (MCS) can be allocated to UEs.

The main objective of an LTE scheduler is to provide a certain level of fairness between UE throughputs. Well known Round Robin (RR) scheduler blindly allocates RE to each UE without considering channel information can only achieve fairness with low throughput. On the other extreme, with knowledge of channel information, the Best-CQI scheduler provides higher throughput only to UE closer to the eNodeB and starves others at far distance. A compromise between RR and Best-CQI metrics is Proportional Fair (PF) scheduler which provides the fairness and throughput joint-maximization.

Figure 1 shows the role of a scheduler where all incoming UE packets are first buffered and prioritized by time-domain packet scheduler (TDPS) and RBs are allocated according to channel quality information (CQI) feedback by frequency-domain packet scheduler (FDPS) [3] [4] [5].

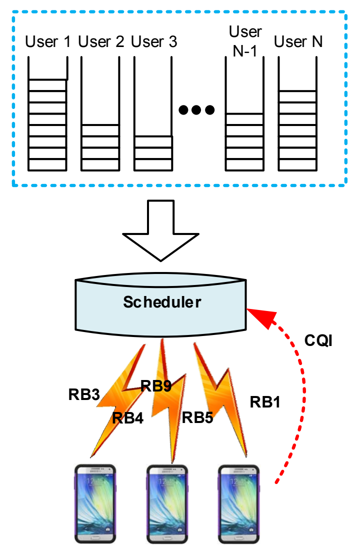

Fig. 1. Downlink LTE Scheduler.

Round Robin (RR) scheduler is a traditional scheduler that allocates equal time to each UE without considering the channel condition. Therefore, the RR scheduler achieves high fairness at the cost of lower overall cell throughput [7][8][9]. In this scheduling strategy it allocates RB to each UE based on first come first served principle in a periodic and cyclic manner with the same amount of available resources.

A channel-aware scheduler such as Best-CQI (BCQI) [6] allocates RBs in favor of UEs with the best radio link based on CQI feedback, hence achieving high overall cell throughput with poor fairness. The UEs located far from eNodeB are unlikely to be scheduled.

The trade-off between throughput and fairness among users has been achieved by Proportional Fair (PF) [2] [10] [11] [12] scheduler that allocates RBs opportunistically to users with good channel condition without neglecting and sacrificing those who have poor conditions. This scheduling method allocates RB to UE with the best relative channel quality in a manner that considers a combination of desired CQI and fairness. Hence this scheduler provides a tradeoff between the fairness and throughput maximization.

In this paper we proposed a Fair Boundary (FB) algorithm, which adapts the PF scheduling strategy with new criteria that sets a limit to the total number of RB allocated to each UE in every TTI. The FB scheduler outperforms PF in throughput performance and achieves a better fairness among UEs in the LTE downlink.

The rest of this paper is organized as follows. In Section II, the simulation model is described in detailed. In section III, the functionality of the Fair Boundary Scheduler is explained thoroughly. Section IV presents and discusses the simulation results. Finally section V concludes this paper.

II. SIMULATION MODEL

The Vienna LTE simulator, which is developed by Vienna University of Technology [14] [15] [16] was used throughout this simulation work. Performance evaluation for the scheduling scheme is performed using the LTE System Level simulator [14]. The downlink simulator comprised of transmitter (eNodeB), user equipment (UEs) and a channel model. In order to perform scheduling, the UEs will give feedback to the eNodeB by generating CQI. The CQI is used for choosing the appropriate Modulation and Coding Scheme (MCS) with modulation type ranging between QPSK, 16 or 64-QAM modulation schemes.

Table I shows the simulation parameters used in the LTE system level simulator. The bandwidth is set to 10 MHz with 3 cell intra BBU system.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
System Bandwidth, MHz	10
Number of RBs per slot	50
Number of simulation time (TTI)	20
Number of UEs	10
Number of cell	3
Channel Model [17]	Winner II+ (TU)
Scheduler	RR, BCQI, PF, Fair Boundary
Antenna setting	2x2

Figure 2 shows the position of UEs in each cell. The UEs are set randomly in the cells. All the three cells will have 10 UEs for each cell.

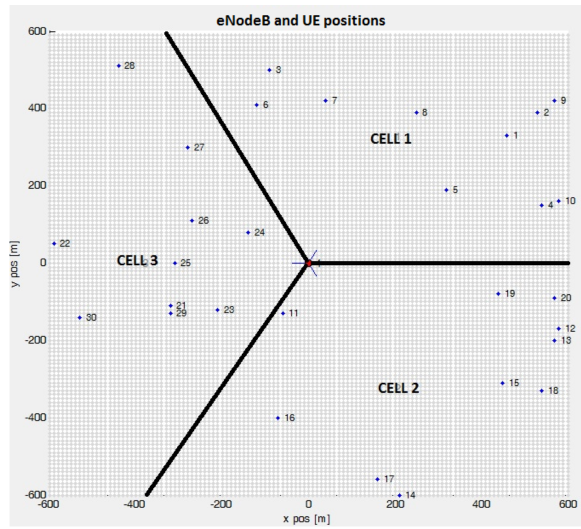

Fig. 2. eNodeB and UE position.

III. FAIR BOUNDARY SCHEDULER

A model of new Fair Boundary (FB) is developed to improve the scheduling performance of the LTE system. This scheduler system will limit the allocation of the RBs in one UE which will provide more chance to other UEs to receive the RBs.

A. *Fair boundary flow*

Figure 3 shows the flow chart of the FB scheduler. Initially, the level of Boundary Limit (BL) for the FB scheduler is defined, which determines the allowable RB allocation for one UE. The maximum number of RBs that can be assigned to each is represented by the Fair Boundary limit, *FB_lim*. Then the total RBs allocated to each UE is calculate and compared with the FB_lim value. If the amount of RBs allocated to one UE has reached its limit, the respective UE will be removed from the UE active list. This step will allow the remaining RB to be allocated to other UEs. Details of these settings will be discussed in the next section.

The RB allocation is based on the maximum efficiency of the UEs. All the UEs efficiency is compared and the UE with highest efficiency will receive the RB. For the case of multiple UEs that have the same highest efficiency, the RB will be given to the first UE found with the highest efficiency. However, with the boundary limitation setting, the other UE will receive the RB whenever that first UE have reached its limit.

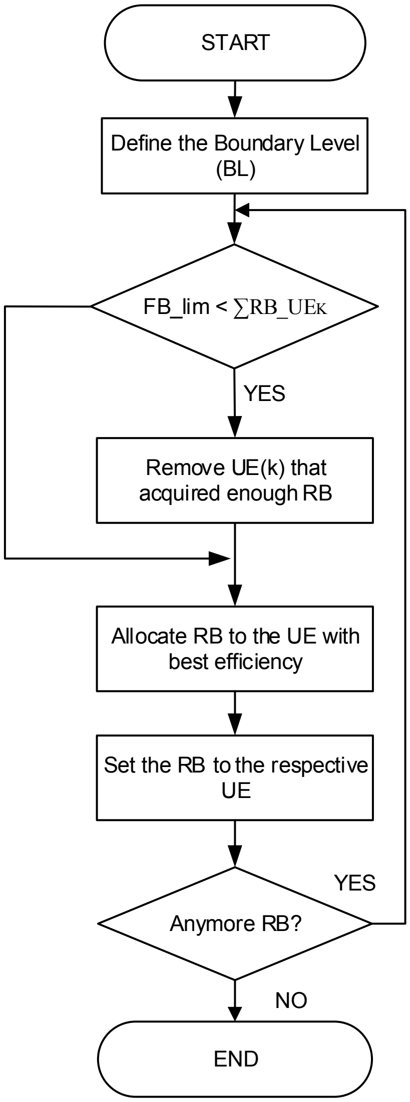

Fig. 3. Structure of Downlink LTE Link Level Simulator.

B. Fair Boundary Limit

The constant FB_lim is calculated based on the value of Boundary Limit (BL) as shown in Eq. (1). Let nRB be the number of available RBs and nUE the number of users. The range of the is BL ∈ {1, …, nUE}.

$$FB\_\lim = \frac{nRB}{nUE} \times BL \qquad (1)$$

If BL is equal to 1, the probability of having the total Rb per UE (RB_UE) greater than FB_lim to be met is very high as shown in (2). RB_UE_K is refer to the RB allocated for UE(k), k={1,.., nUE). This BL setting will give the highest fairness to all the UEs.

$$BL = 1 \Leftrightarrow P(\mathrm{FB\_lim} < \mathrm{RB\_UE_K}) \approx 1 \qquad (2)$$

On the other hand, if the BL is approaching nUE, the possibility of the FB_lim to be met is low as shown in (3).

$$BL \to nUE \Leftrightarrow P(\mathrm{FB\_lim} < \mathrm{RB\_UE_K}) \to 0 \qquad (3)$$

Figure 4 shows the aggregated UE throughput for different BL values. The throughput is the highest at BL equals to 1 and become saturated when BL is greater than 8. The saturation happens due to the very low probability to meet the FB_lim. The optimum value of BL is 1, which allows the RB to be limited and shared with other UEs.

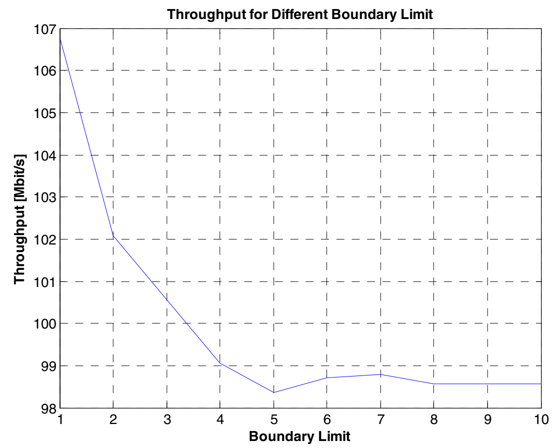

Fig. 4. Throughput for different Boundary Limit.

C. RB allocation and UE removal

The RBs will be allocated to a respective UE based on the efficiency matrix **M**. The matrix **M** consists of the efficiency rate (C) from all the UEs for all the RBs. The row represents the RB, while the column represents the UE.

$$\mathbf{M} = \begin{bmatrix} C_{1,1} & C_{1,2} & \cdots & C_{1,9} & C_{1,nUE} \\ C_{2,1} & C_{2,2} & \cdots & C_{2,9} & C_{2,nUE} \\ . & . & \cdots & . & . \\ . & . & .. & . & . \\ . & . & \cdots & . & . \\ C_{48,1} & C_{48,2} & \cdots & C_{48,9} & C_{48,nUE} \\ C_{49,1} & C_{49,2} & \cdots & C_{49,9} & C_{49,nUE} \\ C_{nRB1} & C_{nRB,2} & \cdots & C_{nRB,9} & C_{nRB,nUE} \end{bmatrix} \qquad (4)$$

The algorithm will determined the maximum efficiency value, C_{max}, among all elements in matrix **M**, which is represented mathematically as follows:

$$C_{\max} = \max_{\forall i, \forall j}[C_{i,j}], \begin{array}{l} i = 0,...,nRB \\ j = 0,...,nUE \end{array} \quad (5)$$

where $C_{i,j}$ denotes efficiency value for the i-th RB associated with the j-th UE. Having located the maximum efficiency value, the RB associated with that maximum efficiency value (indicated by the row of **M**) will be granted to the UE denoted by the column of matrix **M**. Then, the row associated with the selected RB will be set to all zero elements. This step can be realize using the following equation

$$\mathbf{M}_1 = \mathbf{M} \times \mathrm{R}_k \quad (6)$$

where $\mathbf{R}_k$ is a diagonal matrix, where values of the diagonal elements are '1' except for the one associated with maximum efficiency value, which will be set to '0'. This step effectively removed that particular RB from the remaining RB allocation iterations. $\mathbf{M}_1$ represent the new matrix of **M** which nullified the row for assigned RB.

The allocated RBs per UE, RB(k) is accumulated and compare with FB_lim as shown in (8). In the case of RB(k) is more than FB_lim the UE is remove (REM_UE) by replacing the respective matrix column with zero value as shown in (9).

$$RB\_UE = \sum_{1}^{nRB} RB\_UE(k) \quad (7)$$

$$FB\_\lim > RB\_UE \Rightarrow REM\_UE = 1 \quad (8)$$

$$REM\_UE = 1 \Rightarrow \mathbf{M}_2 = \mathbf{U}_k \times \mathbf{M}_1 \quad (9)$$

where $\mathbf{U}_k$ is a diagonal matrix with values of all diagonal elements equal to '1' except for the one associated with the UE that is granted the RB and that particular diagonal element is set to zero.

The $\mathbf{M}_2$ will replace the current **M** for the next iteration until all RBs are assigned. The UE removal step definitely provides greater chance to the other UEs to have the RBs.

IV. Simulation Result

The simulation configuration is listed in Table 1. Figures 5, 6 and 7 portray the total throughput of Cell 1, 2, and 3, respectively when four different scheduling algorithms, namely the Round Robin, the Proportional fair and the Fair Boundary Schedulers, were used. The BL value is set to 1, which is the optimum value for BL. It is shown that the cell throughput performance of the FB scheduler outperformed the other schedulers by up to 13%. The throughput performance results for each individual cell are summarized in Table II.

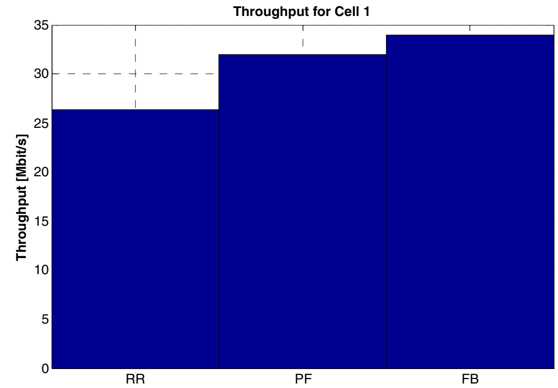

Fig. 5. Throughput for cell 1.

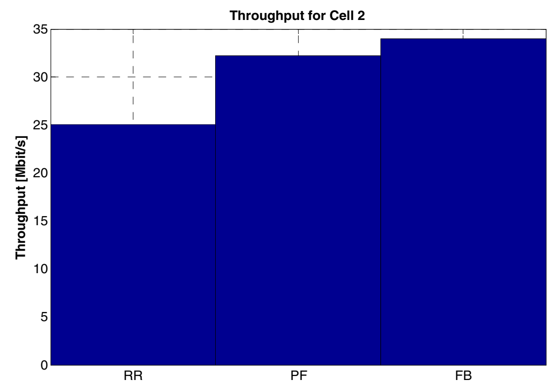

Fig. 6. Throughput for cell 2.

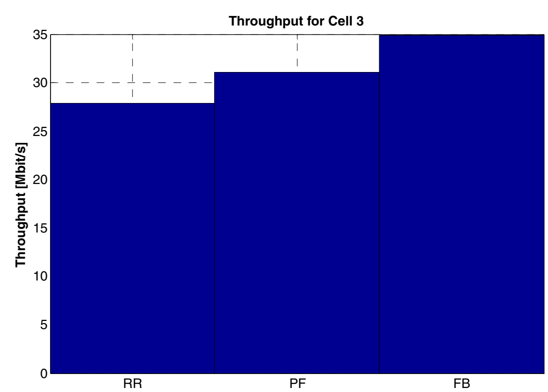

Fig. 7. Throughput for cell 3.

Table II summarized the results of the throughput for all the scheduler within one cell.

TABLE II. THROUGHPUT TABLE FOR ALL THE CELLS.

Cell Number	Schedulers		
	Round Robin	***Proportional fair***	***Fair Boundary***
Cell 1	26.3	32	34
Cell 2	25	32.2	34
Cell 3	27.9	31	35

Figure 8 shows the total fairness index for all three cells in the system. The result shows that the fairness index for FB Scheduler is at par with round robin and proportional fair. This is due to the RB limit for every UE that gives more chance for other UEs to get the RBs.

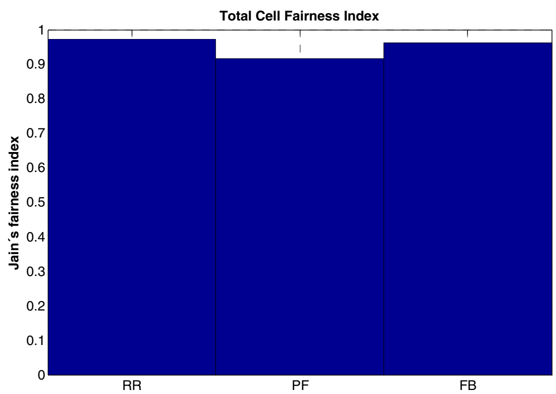

Fig. 8. Fairness for total cell.

Table III summarizes the comparison between the aggregated throughput and fairness index for all the scheduler techniques. The FB scheduler has the highest throughput and fairness index compared to other scheduler methods.

TABLE III. TOTAL THROUGHPUT AND FAIRNESS

Cell Number	Schedulers		
	Round Robin	***Proportional fair***	***Fair Boundary***
Throughput	79.2	95.2	103
Fairness	0.973	0.917	0.962

V. CONCLUSION

This paper has proposed a new scheduling technique that can improve the cell performance in term of throughput and fairness. The limitation of RB allocation has been imposed to the UE that already reach its limit. The results show that the Fair Boundary scheduler has better performance compare to Round Robin, and Proportional Fair. The throughput performance improvement is up to 13 percent. The fairness index also shows the performance improvement of Fair Boundary scheduler compare to others.

REFERENCES

[1] A. Aguiar, A. Wolisz and H. Lederer, “Utility-Based Packet Scheduler for Wireless Communication,” Proceedings 31st IEEE Conference on Local Computer Networks, pp. 863 – 870, 2006.

[2] Xiao Xiao, Xiaoming Tao and Jianhua Lu,“Energy-Efficient Resource Allocation in LTE-Based MIMO-OFDM Systems with User Rate Constraints,” IEEE Transactions on Vehicular Technology, vol. 64, no. 1, pp. 185 – 197, 2015.

[3] Yinsheng Xu, Hongkun Yang, Fengyuan Ren, Chuang Lin and Xuemin Shen, “Frequency Domain Packet Scheduling with MIMO for 3GPP LTE Downlink, ” IEEE Transactions on Wireless Communications, vol. 12 , no. 4, pp. 1752 – 1761, 2013.

[4] Suk-Bok Lee, S. Choudhury, A. Khoshnevis,Shugong Xu and Songwu Lu, “Downlink MIMO Frequency-Domain Packet Scheduling for 3GPP LTE,” IEEE INFOCOM 2009, pp. 1269 – 1277, 2009.

[5] P. Kela, J. Puttonen, N. Kolehmainen, T. Ristaniemi, T.Henttonen and Martti Moisio, “Dynamic Packet Scheduling Performance in ULTRA LTE Downlink,”
3rd International Symposium on Wireless Pervasive Computing (ISWPC 2008), pp. 308 – 313, 2008.

[6] B. Rebekka and B. Malarkodi, “Performance Evaluation of Resource Allocation Schemes in LTE Downlink,” International Conference on Electronics and Communication Systems (ICECS), pp. 1 - 4, 2014

[7] S.A. AlQahtani and M. Alhassany, “Comparing Different LTE Scheduling Schemes,” 9th Wireless Communications and Mobile Computing Conference (IWCMC), International, pp. 264 – 269, 2013.

[8] B.Varadarajan, Runhua Chen, Onggosanusi, N. Eko, Il Han Kim and A.G. Dabak, “Efficient Channel Quality Feedback Schemes for OFDM Systems with Different Schedulers,” IEEE 69th Vehicular Technology Conference, 2009.

[9] S. Schwarz, C. Mehlfuhrer and M. Rupp, “Low Complexity Approximate Maximum Throughput Scheduling for LTE,” Conference Record of the Forty Fourth Asilomar Conference on Signals, Systems and Computers (ASILOMAR), pp. 1563 – 1569, 2010

[10] Hung-Chin Jang and Yun-Jun Lee,“QoS-Constrained Resources Allocation Scheduling for LTE Network,” International Symposium on Wireless and Pervasive Computing (ISWPC), pp. 1-6, 2013

[11] Xiao Xiao, Xiaoming Tao and Jianhua Lu,“Energy-Efficient Resource Allocation in LTE-Based MIMO-OFDMA Systems With User Rate Constraints,” IEEE Transactions on Vehicular Technology, vol. 64, issue 1, pp. 185 – 197, 2015

[12] T. Ghariani and B. Jouaber,“Energy Consumption Evaluation for LTE Scheduling Algorithms,” International Symposium on Networks, Computers and Communications (ISNCC), pp. 1 – 5, 2015.

[13] Jinping Niu, Daewon Lee, Xiaofeng Ren, G.Y. Li, and Tao Su, “Scheduling Exploiting Frequency and Multi-User Diversity in LTE Downlink Systems,” IEEE Transactions on Wireless Communications, vol. 12, issue 4, pp. 1843 – 1849, 2013

[14] Taranetz, M. and Blazek, T. and Kropfreiter, T. and Muller, M.K. and Schwarz, S. and Rupp, M, “Runtime Precoding: Enabling Multipoint Transmission in LTE-Advanced System-Level Simulations”, in IEEE Access, vol. 3, pg. 725-736, 2015

[15] Stojan Kitanov, “Simulator for the LTE Link Level Performance Evaluation,” in ICT Innovations 2011 Web Proceedings

[16] Christian Mehlfuhler, “The Vienna LTE simulators – Enabling the reproducibility in wireless communications research,”Eurasip Journal on Advances in Signal Processing, 2011

[17] L. Hentilä, P. Kyösti, M. Käske, M. Narandzic , and M. Alatossava. (2007, December.) MATLAB implementation of the WINNER Phase II Channel Model ver1.1 [Online].