Design and Analysis of Modified-Proportional Fair Scheduler for LTE/LTE-Advanced in Single Cell Networks

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***Abstract*—Nowadays, Long Term Evolution-Advanced (LTE-A) is well known as a cellular network that can support very high data rates in diverse traffic conditions. One way of achieving it is through packet scheduling which is the key scheme of Radio Resource Management (RRM) for LTE-A traffic processing that is functioning to allocate resources for both frequency and time dimensions. The main contribution of this paper is the design of a new scheduling scheme and its performance is compared with the Proportional Fair (PF) and Round Robin (RR) downlink schedulers for LTE-A by utilizing LTE-A Downlink System Level Simulator in femto cell for indoor coverage extension. The proposed new scheduling algorithm, namely the Modified-PF scheduler divides a single sub-frame into multiple time slots and allocates the resource block (RB) to the targeted User Equipment (UE) in all time slots of each sub-frame based on the instantaneous Channel Quality Indicator (CQI) feedback received from UEs. Simulation results show that the Modified-PF scheduler provides the best performance in terms of throughput and spectral efficiency. The Modified-PF scheduler provides a better compromise between the throughput and spectral efficiency. This shows that the newly proposed scheme improves the LTE output performances while at the same time maintains minimal required fairness among the UEs.**

***Index Terms*—Long Term Evolution; Packet Scheduling, Femto Cell, Radio Resource Management; Spectral Efficiency; Throughput.**

I. Introduction

Long Term Evolution-Advanced (LTE-A) network system is also known as evolution release of LTE. The Generation Partnership Project (3GPP) proposed this network system as one of the International Mobile Telecommunication-Advanced (IMT-Advanced) potential candidate. 3GPP strongly recommends LTE-Advanced due to its capability to support transmission bandwidths up to 100 MHz while increasing the capacity of the User-Equipment (UE) during transmission and reception processes [1][2]. LTE-A approached Orthogonal Frequency-Division Multiple Access (OFDMA) to achieve higher throughput and enhanced spectral efficiency

Radio Resource Management (RRM) is known as one of the key components of OFDMA which is critical in order to get the performance needed for managing a major component of both PHY and Medium Access Control (MAC) layers [3]. This system level control of important radio transmission characteristics in wireless communication systems has been well developed in the latest release of IEEE 802.16m and 3GPP Release 10 and a number of its techniques are already in place and applied in those releases [4].

Packet scheduling plays an important role in determining system performance, such as throughput, delay, jitter, fairness and loss rate [6]. Different from wired cases, scheduling in LTE networks needs to consider the unique characteristics such as location-dependent channel status. It is well understood that packet scheduling (PS) which is one of the core functionalities for radio resource management is also an important element to upgrade the performance of LTE system. In utilizing the scarce radio resources effectively, different PS algorithms have been proposed and deployed. In one such example, a PS can be designed to allocate each UE with better channel conditions accordingly. This requirement must also contain both realtime and non-realtime traffic conditions while supporting multiple users and at the same time making data requests from the networks [4][5]. Furthermore, the aspects of Guaranteed Bit Rate (GBR), delay and target Bit Error Rate (BER) should also be the main focus of LTE downlink scheduler. For consistency, 3GPP Release 10 specifies that scheduling of the uplink channel will take place at the base station, or eNodeB in order to enhance the system's response [7].

In this paper, the main contributions are to develop a new scheduler scheme which is also called Modified-PF (PF) scheduler and later on to compare it with the other two types of LTE-A existing scheduling schemes for LTE femtocells network performance comparative studies. For the simulation tool, we used Matlab-based LTE System Level Simulator [8] to compare different scheduling algorithms in the LTE downlink system. Based on the results obtained, we can identify which one is the most suitable scheduling scheme for a new deployment of LTE system and also for existing LTE femtocell network performance.

II. Packet Scheduling Mechanism Issues in Single Cell Network

In this paper, we consider the effects of scheduling algorithms on the throughput performance in LTE Single network. We apply Proportional Fair (PF), Round Robin (RR) and Modified-PF scheduling algorithm for LTE in order to find the best scheduler which provides high-quality cell throughput with fairness consideration. Each scheduler is required to serve multiple users and also expected to achieve individual Quality of Service (QoS) requirements in terms of bit rates and delays. Apart from that, UE will measure the received channel quality, e.g. Signal-to-Interference-Noise Ratio (SINR), and later on, the channel dependent Channel Quality Indicator (CQI) report is fed back to the base station in the uplink. It gives information to the RRM module about the time and frequency variants of the channel quality. In response to that, Link Adaption (LA) will select the suitable modulation and coding schemes (MCS) based on the CQI reports to maximize the spectral efficiency [9,10].

In 3GPP LTE networks, RR and PF are the basic types of scheduling algorithms. The basic comparisons for these types of scheduler are based on overall throughput and fairness. In RR scheduler, it is capable of providing fairness and identical priorities among all UEs in a cell. The radio resources are assigned equally and fairly in both time and frequency slots without considering the channel state conditions experienced by UEs. However, it's less efficient in providing high data rate to certain UEs while some other resources are wasted. This is because some UEs will experience deep fades, thus, making the received signal less than the required threshold [11]. For PF scheduler, it provides a balance between overall system throughput and fairness. This scheduler supports fairness among UEs by allowing all UEs at least a minimal level of service and at the same time, it will maximize the system capacity. The scheduler starts by obtaining the feedback of the instantaneous CQI for each UE k in time slot t in terms of a requested data rate $R_{k,n}(t)$ by eNodeB (eNB). Then, it monitors the moving average throughput $T_{k,n}(t)$ of each UE k on every resource block (RB) n within a past window of length t_c. The scheduling mechanism gives a priority to the UE $k*$ in the t_{th} time slot and RB n that satisfy the maximum relative channel quality condition [12,13]:

$$k^* = \arg\max_{k=1,2,..,K} \frac{[R_{k,n}(t)]}{[T_{k,n}(t)]} \tag{1}$$

The eNodeB keep updating Tk,n(t) of the kth UE in the tth time slot using the exponential moving average filter below:

$$T_{k,n}(t+1) = \begin{cases} \left(1-\frac{1}{t_c}\right)T_{k,n}(t)+\frac{1}{t_c}R_{k,n}(t), k^*=k \\ \left(1-\frac{1}{t_c}\right)T_{k,n}(t)\ldots\ldots\ldots\ldots\ldots, k^*=k \end{cases} \tag{2}$$

III. The Proposed Modified-Proportional Fair Scheduling

The Modified-PF algorithm improves the ability to produce a better performance in terms of throughput and spectral efficiency, but it can still provide an acceptable fairness in the systems. This scheduling algorithm operates somewhere in between the PF and the RR scheduler. Conceptually, the Modified-PF scheduler divides a single subframe into multiple time slots and allocates the RBs to each slot for targeted users based on the CQI feedbacks from the UEs. By this way, it reaches a compromise between the spectral efficiency and the throughput and able to improve the UEs capacities and cells performance. This is because all the UEs would be scheduled although in different time slots.

The scheduling process begins when the eNB compares the instantaneous CQI feedbacks from the different terminals and the scheduler will pick one UE randomly when there are more than one terminal responds. The RBs will be allocated once the CQI feedbacks from the UEs are completed for the first time slot. After that, it will keep track the moving average throughput for each UE on the assign RBs. The process can be described in the flowchart of Figure 1 to show how the Modified-Proportional Fair scheduling algorithm functions.

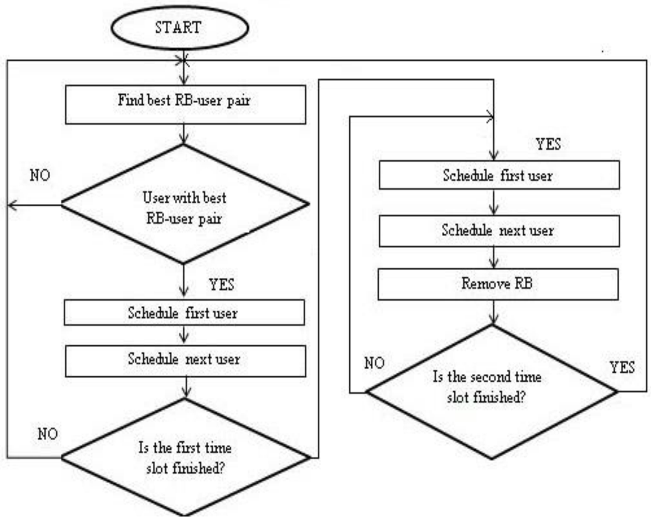

Figure 1: Modified-PF Algorithm scheduling algorithm flowchart.

Table 1
Bandwidth and Resource Blocks Specifications [16]

Bandwidth [MHz]	1.4	3	5	10	15	20
Number of RBs	6	15	25	50	75	100
Subcarrier Spacing [kHz]	15	15	15	15	15	15
Number of occupied subcarriers	72	180	300	600	900	1200

Basically, the idea is to divide a single subframe channel into different slots of RB that contain at least two columns and six rows of bandwidth 1.4 MHz in matrix form. For simplicity, let's say 3 UEs are considered for the selected bandwidth of 1.4MHz. It has been mentioned in Table 1 that the number of RBs is 6 for the bandwidth of 1.4 MHz. The RBs are allocated to the identified UEs for each provided column. The first column matrix represents the first time slot of subframe and the second column of the matrix represents the second time slot of the subframe. This is clearly shown as a representation matrix in Figure 2.

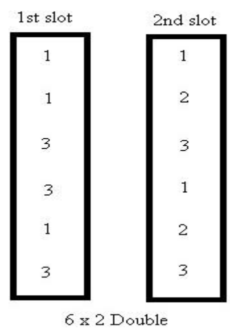

Figure 2: The Modified-PF scheduling RBs mapping

In a normal transmission process, eNB regularly performs channel estimation with its UEs. The way this method works is when eNB receives the CQI feedback from UE1, the algorithm will map UE1 to RB1; UE3 is mapped to RB3 and so on as depicted in Fig. 2. So, RB1 and RB2 are allocated to UE1, RB3 and RB4 to UE3 in the first time slot. Meanwhile, RB5 is allocated to UE1 and RB6 is allocated to UE3 in the first time slot. However, it can be seen that UE2 is not scheduled in the first time slot. This is possible due to bad channel condition on UE2. So, the second time slot is used to solve the unfairness issue for UE2 that was not assigned any RBs in the first slot. Working as a complementary to the first time slot, the second time slot will assign the first 3 RBs consecutively to all three UEs including UE2. As a result, UE1, UE2 and UE3 will be respectively mapped onto RB1, RB2, and RB3 cyclically in turn. We observe that the problem of unfairness for UE2 is resolved in the second slot period of Figure 3 since two RBs are allocated to UE2 independently of its channel condition. It is also shown that the RBs allocation in subframe 1 is replicated in subframe 2 as well.

Based on this new concept, the eNB is required to repeat the same process in determining the instantaneous CQI feedback from UE in order to assign RBs in the first and in the second time slots. This new process of scheduling mechanism is expected to improve LTE system's throughput and spectral efficiency by accommodating all the users QoS and fairness requirements.

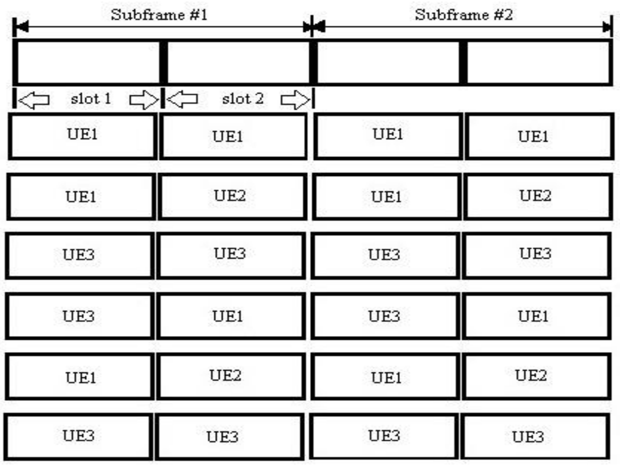

Figure 3: The Modified-PF scheduling RBs mapping illustration

IV. Results And Discussion

In this section of parameter setup, the numbers of 10 UEs were placed randomly in a single eNodeB. The main simulation parameters were based on 3GPP specifications and were tested with different scheduling algorithms; Round Robin (RR), Proportional Fair (PF) and Modified-Proportional Fair (Modified-PF) schedulers. In this first section, the implementation of Multiple Input Multiple Output (MIMO) was used to clarify the reliability of the link between the transmitter and the receiver. The throughput and spectral efficiency for different transmission schemes (MIMO (2x2), MIMO (4x2) and MIMO (4x4)) had been plotted. The performance for every UE was taken and plotted into a graph to be compared and evaluated for each scheduling algorithm involved. Table 2 summarizes the implementation of the essential simulation settings and parameters used for 10 UEs in a single cell with one eNodeB.

Table 2
Simulation Parameters for A Single eNodeB Network

Parameter	Value
Bandwidth	5MHz
Operating Frequency	2.10GHz
Transmission Scheme	MIMO (2x2), MIMO (4x2) and MIMO (4x4)
Scheduler	Proportional Fair(PF), Round Robin(RR), Modified-Proportional Fair (Modified-PF)
Transmission Time Interval (TTI)	100 ms
UE speed	5 km/h
eNodeB Distance	1000 m
Number of UEs	10
Transmission Power	1Watt

Figure 3 shows the mapping of UE and eNodeB position in a single cell with a single eNodeB and 10 User Equipment's. All the UEs were randomly located within 1000 meters radius from the eNodeB.

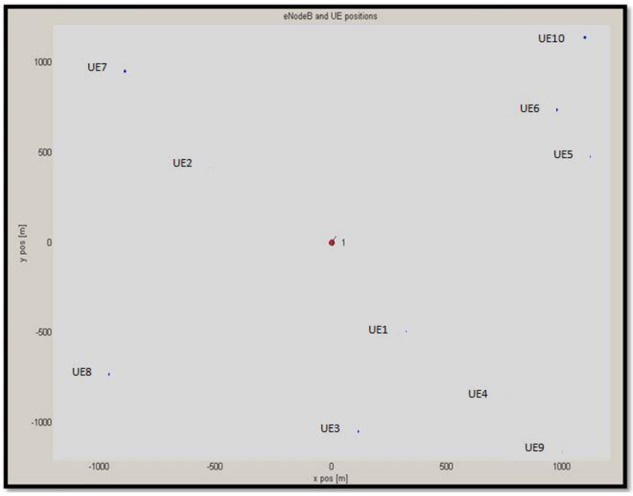

Figure 3: Mapping of UE and eNodeB in a single cell

A. *Average User Equipment Spectral Efficiency (Single Cell, 10 User Equipment's)*

In this part, a scenario was created by using a single cell. The scenario of simulation in this part contained a single eNodeB with 10 UEs. The capability of spectral efficiency can be described as the function to fully utilize the usage of bandwidth or spectrum frequency. So, a maximum number of data can be transmitted in order to improve the LTE's system performance. The results of the spectral efficiency performance for every user's equipment for all transmission schemes part-by-part were evaluated and analyzed and the unit that had been identified was bits per second per Hertz (bit/s/Hz) [17].

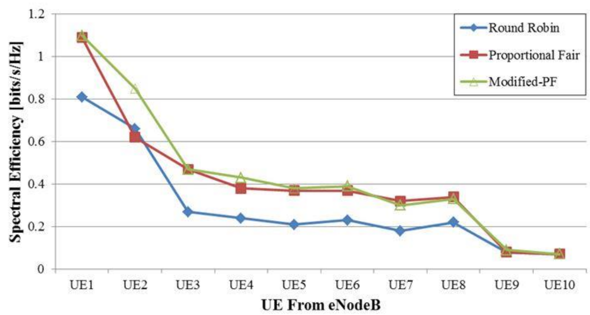

Figure 4: Spectral efficiency performances for each UE in the transmission scheme of MIMO (2x2).

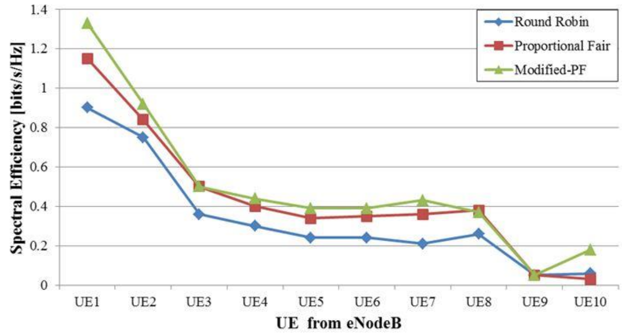

Figure 5: Spectral efficiency performances for each UE in the transmission scheme of MIMO (4x2)

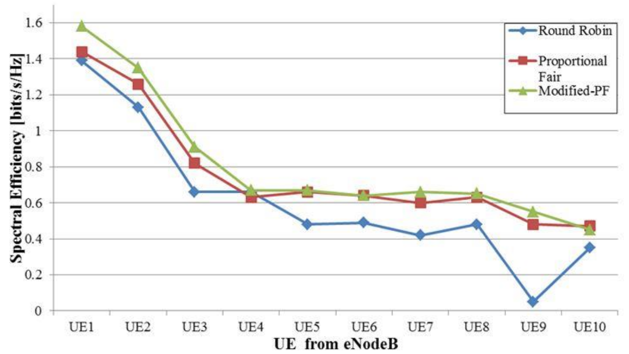

Figure 6: Spectral efficiency performances for each UE in the transmission scheme of MIMO (4x4).

B. Average User Equipment (UE) Throughput (Single Cell, 10 User Equipment's)

For this part, the results of UE throughput performances will be discussed. The value for each UE was plotted in the graph to be evaluated compared the performance for all scheduling algorithms; RR, PF and Modified-PF scheduling algorithms.

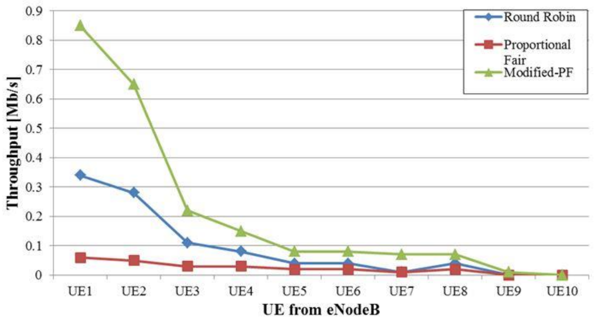

Figure 7: Average UE throughputs for each UE in the transmission scheme of 2x2 MIMO.

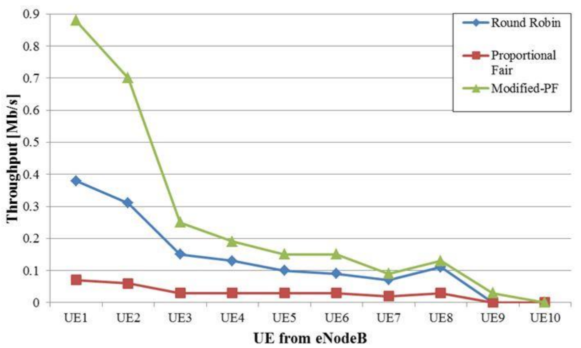

Figure 8: Average UE throughputs for each UE in the transmission scheme of 4x2 MIMO

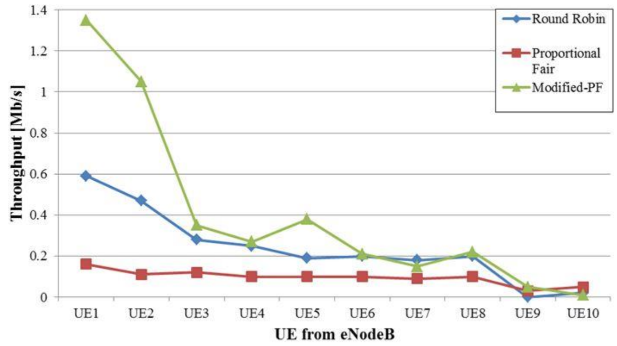

Figure 9: Average UE throughputs for each UE in the transmission scheme of 4x4 MIMO.

Based on the overall results from single eNodeB simulation, it had been seen that the Modified-PF had improved the LTE downlink FDD system throughput and spectral efficiency performance. The overall figures in this result section depicted the user throughput for different transmission schemes. The reason for using different transmission schemes was to validate that MIMO transmission scheme could improve the system performance. It can be observed that the user equipment throughput of a MIMO (2x2) system was lower than the throughput of a MIMO (4x2) system. On the other hand, the transmission schemes gave a big impact to produce a higher throughput and spectral efficiency. This section also showed and proved that the throughput of a MIMO (4x4) system was almost twice higher than the throughput of a MIMO (4x2) system and the throughput of a MIMO (2x2) system. In terms of spectral efficiency performance, the increasing number of transmission scheme also improved the LTE system performance. It can be seen clearly that the Modified-PF scheduling algorithm had the ability to improve the throughput and spectral efficiency of the user equipment, although there was a certain part when some UE performance dropped from the RR and PF scheduling algorithms. In conclusion, the Modified-PF can be considered to be accepted in terms of performance compared to the other scheduling algorithms. This was due to the performance of some UE that was able to produce an output for the Modified-PF when the other scheduling algorithms could not produce an output.

V. Conclusion

The design of the Modified-PF scheduling algorithm was able to support the single user and multi-user in different scenarios for the LTE/LTE-Advanced after the worst channel and cell loading conditions were considered. A comparative analysis and findings between the scheduling algorithms involved based on their throughputs and spectral efficiency for different simulation setups (different scheduling techniques, different antenna transmission system, a different number of cells and different number of users) had been carried out.

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