Design and Analysis of Modified-Proportional Fair Scheduler for LTE Femtocell 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 for 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 by 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 new deployment of LTE system and also for existing LTE femtocell network performance.

II. PACKET SCHEDULING MECHANISM ISSUES IN LTE FEMTOCELL NETWORK

In this paper, we consider the effects of scheduling algorithms on the throughput performance in LTE Femtocell 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 in 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 *tc*. The scheduling mechanism gives a priority to the UE $k*$ in the tth time slot and RB n that satisfy the maximum relative channel quality condition [12,13]:

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

The eNodeB keep updating $T_{k,n}(t)$ of the k^{th} UE in the tth time slot using the exponential moving average filter below:

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

The PF scheduler treats the RBs independently, and then keeping the updates of the system in every time slots. However, the performance of this scheduler is still limited because PF is not fully optimized for mobility. However, the performance of this scheduler is still limited because PF is not fully optimized for mobility. It can be seen when some UE in a mobility position, the throughput will drop significantly with the increasing speed of the UE although it can still retain the fairness for the UE [14].

Due to the issues mentioned above with regard to RR and PF schedulers, a new scheduling algorithm namely Modified-Proportional Fair scheduler will be developed which takes into account the channel conditions of all the users and redistribute the resources accordingly while maintaining significant fairness towards its users.

The implementation of LTE femtocell network is not only aiming to solve that the network for indoor, edge coverage poor using problem, but also to efficiently avoid the issues of the interference between cells and enhance handover quality [15].

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 slots 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 is 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 below to show how the Modified-Proportional Fair scheduling algorithm functions:

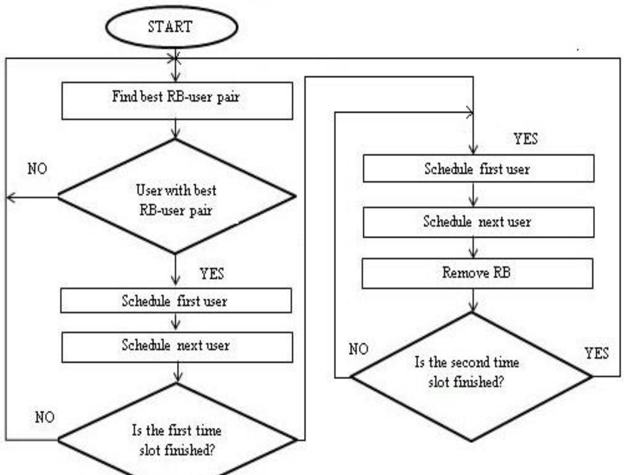

Figure 1: Modified-PF Algorithm scheduling algorithm flowchart.

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:

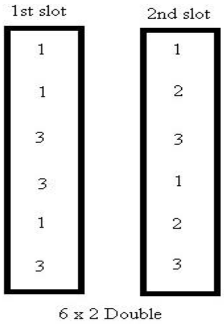

Figure 2: The Modified-PF scheduling RBs mapping.

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.

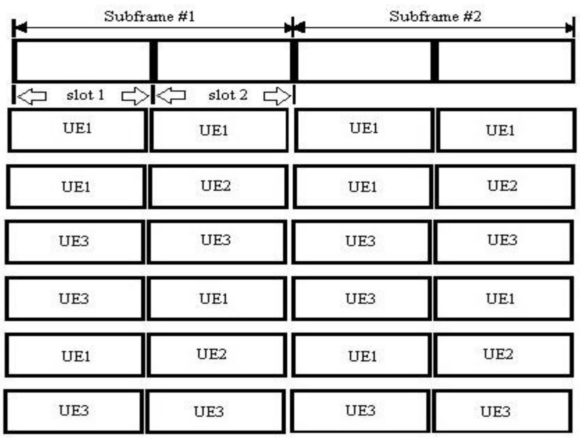

Figure 3: The Modified-PF scheduling RBs mapping illustration.

IV. Results and Discussion

This section, the implementation of femtocell is adapted to verify the performance of proposed scheduling algorithm. This is due to the increasing number of mobile user in order to satisfy QoS need and reducing a power consuming that can extend battery life. Here, the number of eNodeB used is about 172 eNodeB with ten UE's are attached to each eNodeB. The UEs for a single eNodeB are placed randomly in different sectors. The main simulation parameters are set up based on 3GPP specifications and the scheduling algorithms that are; Round Robin, Proportional Fair and Modified-Proportional Fair scheduling algorithms. The implementation of random UEs into different cells at various distances from the eNodeB and mapping of UEs and eNodeB can be observed in Table 2.

Table 2
Simulation parameters for Femto-cell

Parameter	Value
Bandwitdh	20MHz
Operating Frequency	2.14GHz
Number of Tx	1
Number of Rx	1
Scheduling Algorithms	Proportional Fair(PF), Round Robin(RR), Modified-Proportional Fair (Modified-PF)
Transmission Time Interval (TTI)	100
UE speed	5km/h
eNodeB Radius	2000m
Transmission Power	46dBm

Figure 4 shows the mapping of UE and eNodeB position within the different cells in which each cell contains ten UEs. All the UEs are randomly located within 2000 meters radius range from the eNodeB

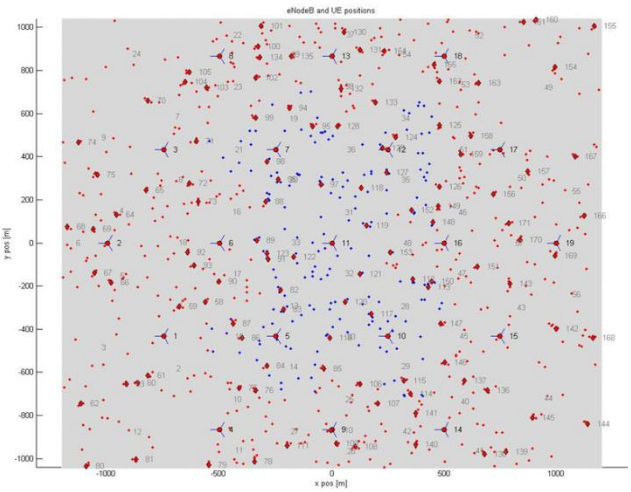

Figure 4: Mapping of UE and eNodeB within femto cells.

A. Average UE Throughput

The first simulation analysis is to evaluate and clarify the throughput performance of three different types of scheduling algorithms involved. In this section, an implementation of Femto-cell with a large number of cells and UE is involved. The performance graphs of the individual UE are displayed in Figure 5.

Figure5 represent the comparison of average UE throughput under SINR variations for three MAC scheduling algorithms accordingly. The UE throughput for RR scheduling algorithm can be observed as the worst among these three scheduling algorithms. The highest throughput for the RR scheduling algorithm is mapped only at 27.0 Mbps for the highest dB SINR. For PF scheduling algorithm, it provides only 35.0 Mbps for the same SINR. On the other hand, the Modified-PF scheduler able to achieve a comparable UE throughput in all cells same as the PF scheduling algorithm. However, from the beginning of SINR, the Modified-PF shows a comparable result of throughput until 6 dB of SINR. Later, the Modified-PF seems like plotting more than PF scheduling algorithm and provide an exact throughput for an allocate SINR. Clearly, Modified-PF scheduler provides the best performance in terms of average UE throughput as compared to RR and PF scheduling algorithms.

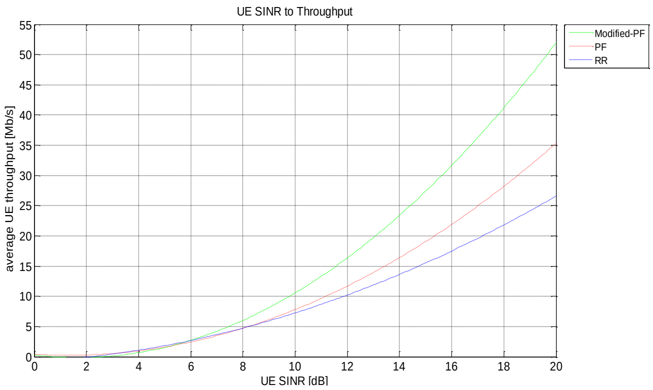

Figure 5: Scheduling Algorithms of UE SINR to throughput.

B. Average UE Spectral Efficiency

Same as previous section above, spectral efficiency performance is evaluated and analysed for different scheduling algorithms for Femto-cell scenario. In this part of the result, the spectral efficiencies [17] of the three schedulers are measured again in bit/s/Hz to validate how the newly developed scheduling algorithm fair with the other two existing schedulers.

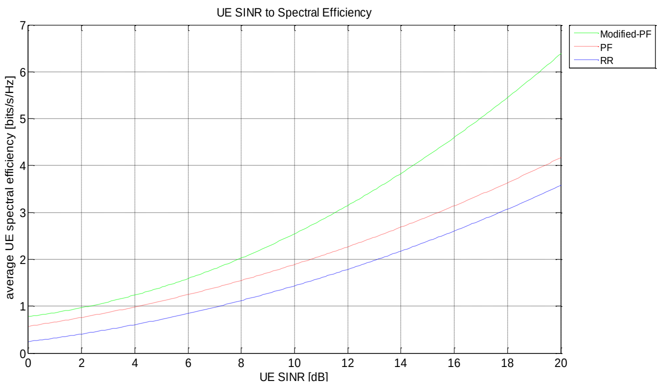

Figure 6 Scheduling Algorithms of UE SINR to spectral efficiency

Although in a different scenario, the function of spectrum efficiency still remains the same to reflect the maximum number of UEs per cell in order to maintain an acceptable QoS in the LTE system. In Figure 6, it can be analysed that by utilizing a RR scheduling algorithm the highest spectral efficiency can be achieved only at 3.80 bit/s/Hz for SINR ranging from 18 dB to 20 dB. By utilizing a PF scheduling algorithm in the figure, it can be seen and observed an increment about 4.05 bit/s/Hz in the same range of SINR from 18 dB until 20 dB. Interestingly, the result of Modified-PF scheduling algorithm in figure above performs a better spectral efficiency performance at 4.40 bit/s/Hz compared to the PF scheduling algorithm for the same range of SINR.

C. Overall System Performance

Same as the previous section, this part discussed an overall system performance of scheduling algorithms. Here in this part, an analysis of the overall throughput system performance that contains all UEs in each cell is presented in a different scenario. The comparison of the performance of the three scheduling algorithms can be seen in the Figure 7 and Figure 8.

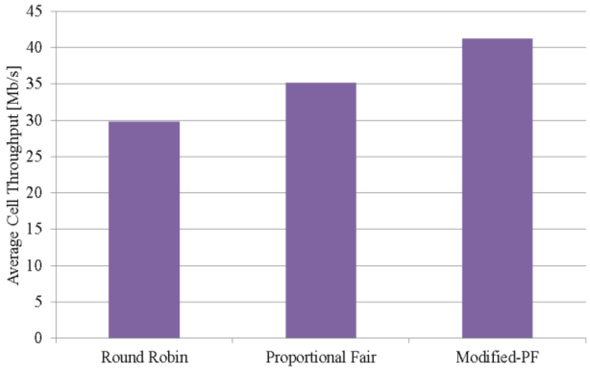

Figure 7: Throughput performance of overall system for each scheduling algorithm

Table 3
Overall average cell throughput performance.

Scheduler	Round Robin	Proportional Fair	Modified-PF
Throughput [Mb/s]	29.84	35.18	41.25

Figure 7 shows the average UE throughput for each cell same as previous part which have been simulated and analyzed for the three different scheduling algorithms. The performance of overall throughput of Modified-PF scheduling algorithm performs better than the overall UE throughput of RR and PF scheduler scheduling algorithm as proved in Figure 7 and Table 3. The throughput of Modified-PF scheduling algorithm increase about 38% increment from the RR scheduling algorithm and 17% increment from the throughput of PF scheduling algorithm. This result shows that the Modified-PF scheduling algorithm has produced a better result than other scheduling algorithms in terms of average cell throughput in Femto-cell case.

Figure 8 represents the average UE spectral efficiency for each cell, namely cell 1, cell 2 and cell 3 which have been simulated in this scenario for the three scheduling algorithms. The overall spectral efficiency of Modified-PF scheduler outperforms the overall UE spectral efficiency of the RR scheduling algorithm and slightly higher than the overall UE spectral efficiency of Proportional Fair scheduler as shown in Figure 8 and Table 4. The increment of spectral efficiency for the RR scheduling algorithm is about 42% from 1.11 bits/s/Hz to 1.58 bit/s/Hz of Modified-PF scheduling algorithm. Meanwhile, for the Modified-PF scheduling algorithm increment of spectral efficiency performance is about 10.5% from the Proportional Fair scheduling algorithm. It can be summarized that the Modified-PF scheduling algorithm outperforms RR and PF scheduling algorithms in all cells.

Table 4
Overall average cell spectral efficiency performance.

Scheduler	Round Robin	Proportional Fair	Modified-PF
Spectral Efficiency [bit/s/Hz]	1.11	1.43	1.58

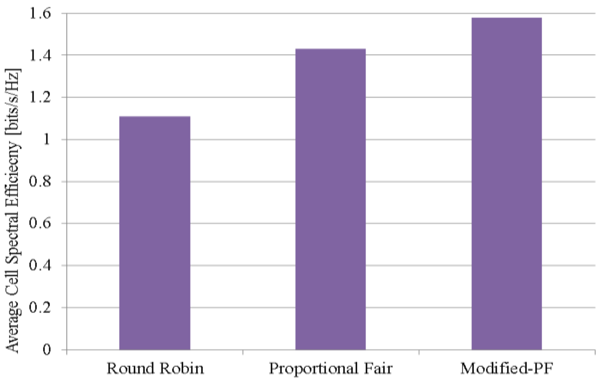

Figure 8: Spectral efficiency performance of overall system for each scheduler

V. CONCLUSION

The main focus of this paper is to evaluate a comprehensive study on various LTE-A scheduling schemes in Femto cell area. We have proposed and developed a Modified-PF scheduling scheme for the downlink transmission mode in LTE-A and it was later compared with the other two existing scheduling schemes, namely PF and RR schedulers. The performances of these 3 scheduling algorithms were evaluated and compared in terms of throughput and spectral efficiencies for both UEs and cells in a femto cell networks. In addition, the number of users and SINR values were also included to observe their performance. The results from simulations show that the proposed Modified-PF proves that it performs the best as compared to the other two schedulers especially in terms of UE throughput, UE spectral efficiency and cell throughput. The reason mainly due to the modification done where an adaptive RB allocation in two sub-frames was implemented which gives opportunity for the next UE to be scheduled. Besides that, it is also interesting to study the effects of UE mobility on the system throughput and spectral efficiency performance for all the schedulers in our next research.

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