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DESIGN AND DEVELOPMENT OF MODIFIED-PROPORTIONAL FAIR SCHEDULER FOR LTE/LTE-ADVANCED

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ABSTRACT

Long Term Evolution (LTE) 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 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 by utilizing LTE Downlink System Level Simulator. The proposed new scheduling algorithm, namely the Modified-PF scheduler divides a single subframe into multiple time slots and allocates the resource block (RB) to the targeted User Equipment (UE) in all time slots for each subframe 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 with comparale fairness as compared to RR and PF schedulers. Although PF scheduler has the best fairness index, the Modified-PF scheduler provides a better compromise between the throughput/spectral efficiency and fairness. This shows that the newly proposed scheme improves the LTE output performances while at the same time maintains minimal required fairness among the UEs.

Keywords: long term evolution, packet scheduling, radio resource management, spectral efficiency, throughput.

INTRODUCTION

Long Term Evolution (LTE) Release 10 which is also known as LTE-Advanced has been finalized at the end of 2011 by Third Generation Partnership Project (3GPP) to be proposed as one of the International Mobile Telecommunication-Advanced (IMT-Advanced) potential candidate. Currently, the LTE Release 12 and 13 that are the enhancements of the previous completed LTE Release 10 and 11 specifications are being researched to provide more enhanced features and performance as compared to their former releases. 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].

International Telecommunication Union (ITU) has already recognised Orthogonal Frequency-Division Multiple Access (OFDMA) which is a new method of modulation/access technique, as the core Physical Layer (PHY) for IMT-Advanced systems. What makes OFDMA really stands out is its flexibility in radio frequency allocation and inherent resistance to frequency selective multi-path fading.

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].

In wireless communication, scheduling plays an important role in determining system performance such as throughput, delay, jitter, fairness and loss rate [5]. Different from wired cases, scheduling in LTE networks need 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]. 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 [6].

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 existing scheduling schemes for performance comparative studies. For the simulation tool, we used Matlab-based LTE System Level Simulator [7] 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 network performance.

PACKET SCHEDULING MECHANISM ISSUES

Generally, there are various factors that contribute to the throughput performance of a UE such as scheduling algorithms, UE speed, multipath environment, distance from eNodeB and diversity. In this paper, we consider the effects of scheduling algorithms on the throughput performance. 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 [8,9].

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 [10]. 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 [11, 12]:

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

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

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

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 [13].

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.

METHODOLOGY

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:

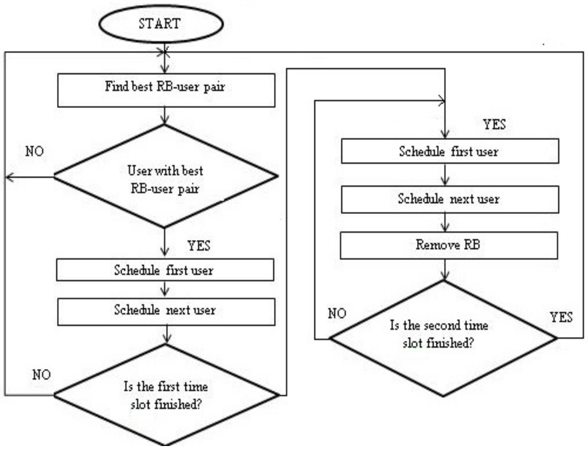

Figure-1. Modified-PF algorithm scheduling algorithm flowchart.

Table-1. Bandwidth and Resource blocks specifications [14].

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:

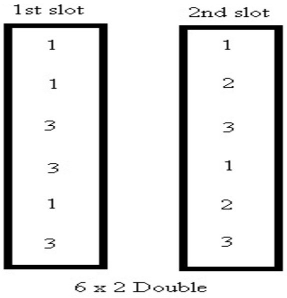

Figure-2. The modified-PF scheduling RBs mapping.

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 Figure-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.

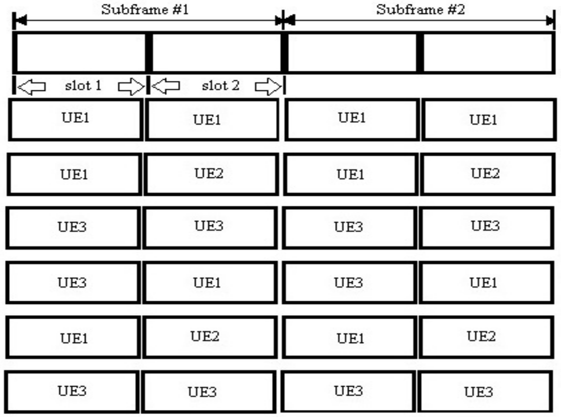

Figure-3. The modified-PF scheduling RBs mapping illustration.

RESULTS AND DISCUSSION

Simulation setup

In our simulation, 10 UEs are placed randomly in 3 sectors of a single eNB. The main simulation parameters are based on 3GPP specifications and are tested with RR, PF and Modified-PF algorithms. The implementation of 10 UEs in three different cells at various distances from the eNB and mapping of UEs and eNB can be observed in Table-2.

Figure-4 shows the mapping of UE and eNB position within the three different cells in which each cell contains 10 UEs. All the UEs are randomly located within 1200 metres range from the eNB.

Table-2. Simulation parameter for tri-sector antenna.

Parameter	Value
Bandwidth	20MHz
Operating Frequency	2.14GHz
Duplexing	FDD
Number of Tx	1
Number of Rx	1
Scheduler	Proportional Fair(PF), Round Robin(RR), Modified-PF
Transmission Time Interval (TTI)	1 ms
UE speed	5 km/h
eNodeB Distance	1000 m
Number of UEs	10
Transmission Power	46 dBm

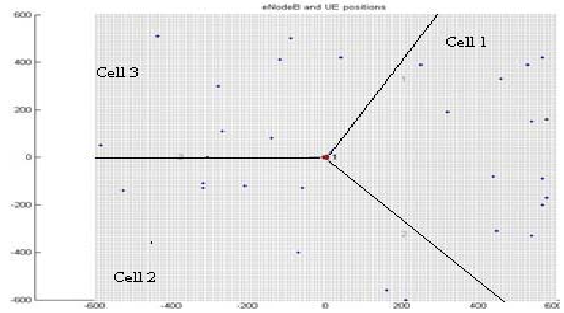

Figure-4. Mapping of UE and eNodeB within the three cells.

Average UE throughput

Our first analysis is to evaluate the throughput performance of three different types of scheduling algorithms. The performance graphs of the individual UE are displayed below:

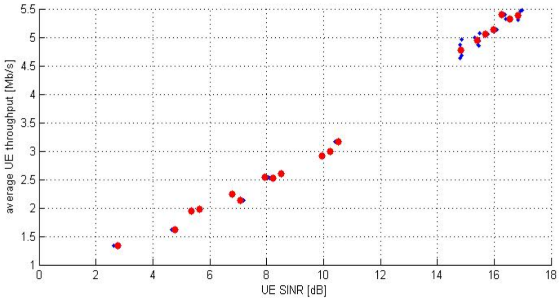

Figure-5. Round Robin UE SINR to throughput mapping.

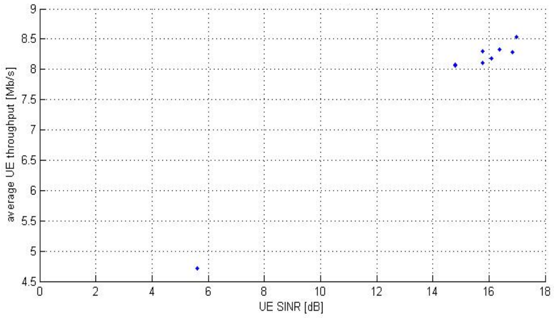

Figure-6. Proportional fair UE SINR to throughput mapping.

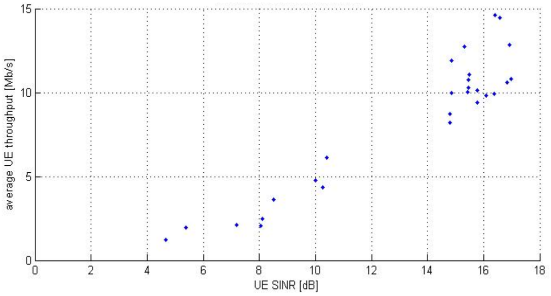

Figure 7. Modified-PF UE SINR to throughput mapping.

Figures-5, 6, and 7 show the comparison of average UE throughput under SINR variations for 3 MAC schedulers, respectively. It can be observed that UE throughput for RR scheduler is the worst among these 3 schedulers. The highest throughput is mapped only at 5.5 Mbps for 17 dB SINR. Meanwhile, PF scheduler provides only 8.60 Mbps for the same SINR. On the other hand, the Modified-PF scheduler able to achieve between 11 and 15 Mbps UE throughput in all cells. Clearly, Modified-PF scheduler provides the best performance in terms of average UE throughput as compared to RR and PF schedulers.

Average UE spectral efficiency

Spectral efficiency can be defined as the optimisation of bandwidth or spectrum usage so that the maximum amount of data can be transmitted with the fewest transmission errors [15]. Again, in this part of results, the spectral efficiencies of the three schedulers are measured in bit/s/Hz to determine how the newly developed scheduling algorithm fair with the other two existing schedulers.

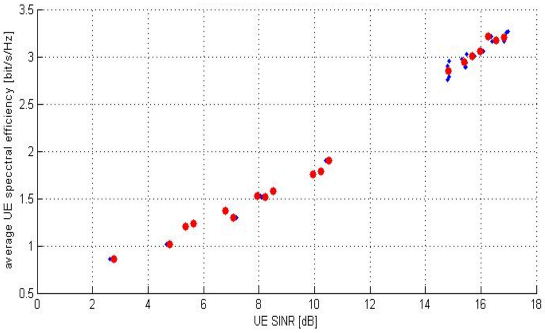

Figure-8. Round robin UE SINR to spectral efficiency mapping.

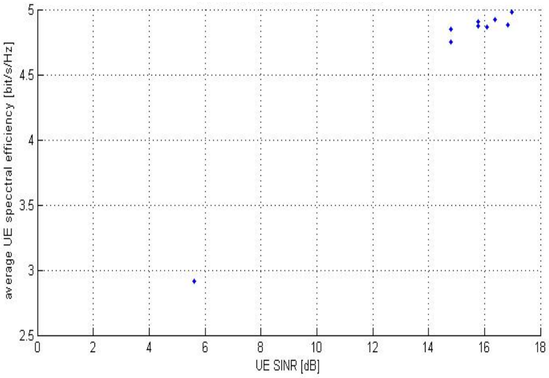

Figure-9. Proportional fair UE SINR to spectral efficiency mapping.

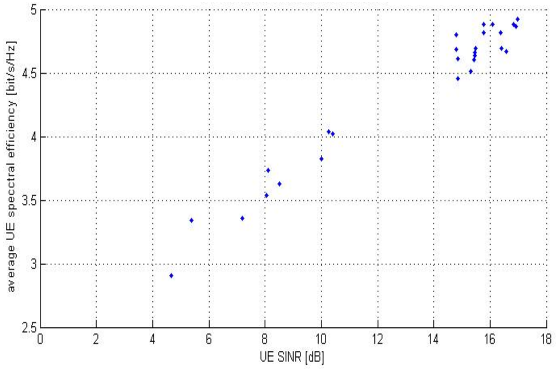

Figure-10. Modified-PF UE SINR to spectral efficiency mapping.

In the LTE network, spectrum efficiency reflects the maximum number of UEs per cell that can be provided while maintaining an acceptable QoS. In Figure-8, it shows that by utilizing RR scheduler the highest spectral efficiency can be achieved only at 3.35 bit/s/Hz for SINR ranging from 16 dB to 18 dB. By utilizing PF scheduler, an increment can be observed at 4.90 bit/s/Hz in the same range of SINR. Interestingly, the result of Modified-PF scheduler in Figure-10 indicates somewhat comparable spectral efficiency performance as PF scheduler.

Overall cell system

In this part, we present an analysis of the overall throughput system performance that contains all UEs in each cell. The comparison of the performance for the three scheduling algorithms is shown in the Figures-11 and 12.

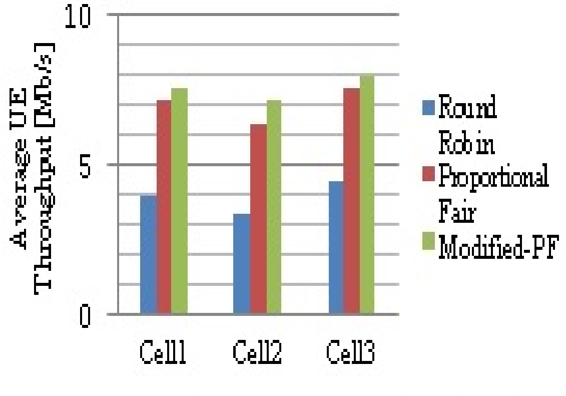

Figure-11. Comparison of average UE throughput in each cells.

Table-3. Average cell throughput for each cell.

	Average UE throughput [Mb/s]		
	Cell1	Cell2	Cell3
Round Robin	4.03	3.39	4.51
Proportional Fair	7.16	6.41	7.61
Modified-PF	7.59	7.23	8.03

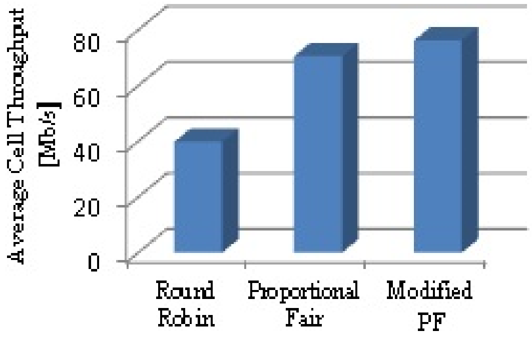

Figure-12. Performance of overall system for each scheduler.

Table-4. Overall average cell throughput.

Scheduler	RR	PF	Modified-PF
Throughput [Mbps]	39.79	70.59	76.18

Figure-11 shows the average UE throughput for each cell, namely cell 1, cell 2 and cell 3 which have been simulated for the 3 schedulers. The overall throughput of Modified-PF scheduler outperforms the overall UE throughput of RR scheduler and slightly higher than the overall UE throughput of PF scheduler as evidenced in Figure-11 and Table-3. Further, a performance analysis of the overall system (see Figure-12 and Table-4) reveals that Modified-PF scheduler outperforms RR and PF schedulers by almost doubling the RR throughput from 39.79 Mbps to 76.18 Mbps (92% increment) and significantly boost the PF throughput by 10% increment.

Overall system fairness index

For the last part of the results, we analysed the fairness index obtained for the scheduler algorithms. Figure-13 shows the performance of the fairness index and Table-5 shows the data in details for each scheduler.

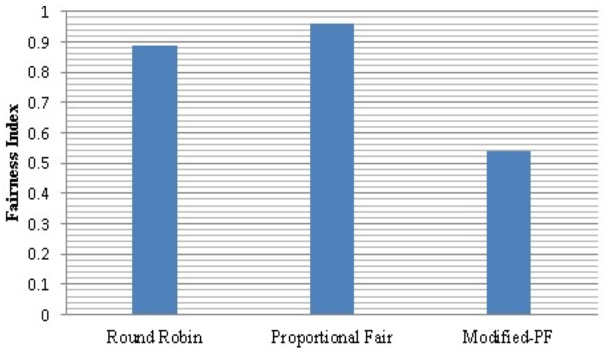

Figure-13. Fairness index for each scheduler.

Table-5. Fairness index for different schedulers.

Scheduler	RR	PF	Modified-PF
Fairness Index	0.8898	0.9596	0.7537

In term of fairness, the Modified-PF algorithm sees its performance dropped in which the UE(s) that is/are located at the cells' edge suffer(s) limited access when experiencing bad channel condition. The margins of fairness between RR, PF and Modified-PF are not so large and still acceptable. Although it seems the Modified-PF scheduler performs the worst in terms of fairness, it is deemed superior in terms of average UE/cell throughput and spectral efficiency while still maintaining significant amount of fairness to all users.

CONCLUSIONS

The main focus of this paper is to evaluate a comprehensive study on various LTE scheduling schemes. We have proposed and developed a Modified-PF scheduling scheme for the downlink transmission mode in LTE 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 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 subframes was implemented which gives opportunity for the next UE to be scheduled. Furthermore, the results also show that the Modified-PF scheduler achieved a good compromise between throughput and fairness. 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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