Journal of Theoretical and Applied Information Technology
10th October 2015. Vol.80. No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

EFFECT OF AVERAGE-THROUGHPUT WINDOW SIZE ON PROPORTIONAL FAIR SCHEDULING FOR RADIO RESOURCES IN LTE-A NETWORKS

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ABSTRACT

The Proportional Fair (PF) scheduling technique is well known technique that is used to schedule radio resources at the mobile base station to the end-users. An efficient scheduling for radio resources in the physical layer of LTE-A base stations is challenging due to the high demand for various types of 4G wireless services such as VOIP calls, online gaming, HDTV, etc. In this paper, we derive the average-throughput window size (T_{PF}) formulas for LTE-A PF Scheduler, and then we investigate the effect of T_{PF} size on the performance and fairness of PF Scheduler for LTE-A network. Both of downlink system-level (SL) simulator and link-level (LL) simulator are used to evaluate the scheduler performance for different T_{PF} configurations. The simulation results showed that the long T_{PF} improves both of UE (User Equipment) throughput and cell (eNodeB) throughput, however the achieved scheduler fairness in this case is low. On the other hand, the short T_{PF} showed degradation in both of UE and cell throughput, but offers higher fairness values for the PF scheduler.

Keywords: *4G cellular networks, wireless communications, LTE-A, scheduling algorithms*

1. INTRODUCTION

The development of information and communication technology is growing rapidly; similarly, the demand on technology is increasing every year. In recent years, many mobile data services such as mobile HDTV, video and file sharing, location-based services and worldwide social networking have grown very fast. End user requirement and demand for higher download and upload speeds are increasing. The investment by the top 25 worldwide operators in LTE and LTE-A infrastructure is estimated to be $14 billion USD in 2015 [1]. LTE-A is the 4G technology that is proposed by 3GPP to fulfil the demand and requirements of end users [1].

The peak user throughput requirement for LTE (Release 8), as the 3GPP standard, is a minimum of 100 Mbps for downlink and 50 Mbps for uplink using channel bandwidth of 20 MHz [2]. The new standard of LTE technology is the LTE-Advance (LTE-A). It is initiated in 3GPP Release 10, and provides peak user throughput of 1 Gbps for downlink and 500 Mbps for uplink. The LTE-A downlink utilizes the OFDMA access technique for organizing the radio resource blocks (RBs) in order to be transmitted to the UEs [3]. In frequency domain, every 15 kHz of the downlink bandwidth is called sub-carrier (SC), and every 12 SCs are grouped together to build one resource block (RB) that occupies 180 kHz bandwidth. One major task for LTE-A mobile base station (eNodeB) is to schedule the radio resources to the end-users (UEs) based on preconfigured scheduling algorithm at the eNodeB. Therefore, the eNodeB scheduler is responsible for making decisions to allocate the RBs to the end-users in fair manner, as well it is responsible to prevent any of end-users to starve for long period of time with lower throughput than other users who are connected at the same eNodeB. In Proportional Fair algorithm, there are three criteria, namely, the best relative CQI, fairness and average user throughput, that the scheduler uses to allocate RB to any UE [4]. The Transmission Time Interval (TTI) for LTE-A eNodeB equals to 1 ms, as well every 1 ms of transmission is called sub-frame (SF). The scheduling of RBs is executed every 1 ms, i.e. the total number of allocated resource blocks (RBs) to each UE is changed after the eNodeB receives the measurement reports from each UE every 1 ms of the transmission.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The average-throughput window size (T_{PF}) is used by the eNodeB scheduler to average the end-user throughput. The eNodeB scheduler updates the new end-user throughput reading every 1 ms, and use it to decide whether to allocate more RBs to the end-user or not to allocate. T_{PF} is explained in previous publications [5-7]; however, none clearly analyzed or investigated the configuration of T_{PF} for LTE-A specifically. In this paper, the formulas of T_{PF} (measured in TTIs or milliseconds) for PF scheduling algorithm will be derived in section IV. As well, the performance of PF scheduling algorithm for LTE-A with focus on T_{PF} size will be analyzed in section V and section VI.

2. PROPORTIONAL FAIR SCHEDULER BASED APPROACH

The PF scheduler in Eq.1 pursues the maximum throughput for each user equipment (UE), while maintaining fair allocation of resource blocks (RBs) for all UEs[1].

$$\overline{R_k(m+1)} = \begin{cases} \left(1-\frac{1}{T_{PF}}\right)\overline{R_k(m)}+\frac{1}{T_{PF}}R_{k,n}(m), & \text{if user } k \text{ is selected} \\ \left(1-\frac{1}{T_{PF}}\right)\overline{R_k(m)}, & \text{if user } k \text{ is not selected} \end{cases} \quad (1)$$

where:
k: UE index
n: Resource Block (RB) index
$\overline{R_k(m)}$: Past average throughput of UE_k
$R_{k,n}(m)$: Estimated throughput of UE_k and RB_n

The UEs are assigned a portion of the available bandwidth by the scheduler according to the value of i in the priority function which is shown in Eq. 2. The assignment of RBs continues until the downlink bandwidth is completely used or all the required RBs have been assigned and the UEs become satisfied.

$$i = \arg max_{(k)} \frac{R_{k,n}(m)}{R_k(m)} \quad (2)$$

The processes of assigning resource blocks (RBs) to UEs by the PF scheduler are summarized as follows:

1: **For** UEs (1: Total number of active UEs) **and** RBs (1: Total number of RBs)
2: Calculate priority (i) based on Equation 2
3: **For** k= *1*: Total number of active UEs
4: Pick UE_k with maximum (i)
5: Assign RB_n to UE_k
6: Update the throughput $(\overline{R_k})$ for UE_k
7: **If** UE_k hasn't maximum (i)
8: Check (i) for UE_{k+1}
9: Assign RB_n to UE_{k+1}
10: Update the throughput $(\overline{R_{k+1}})$ for UE_{k+1}
11: **End If**
12: **End For**
13: **If** all active UEs are satisfied **or** all RBs are assigned
14: Stop scheduling RBs for current time slot (TTI)
15: **Else**
16: Repeat step 2
17: **End If**
18: **End For**

Fig. 1. Proportional Fair Scheduling Algorithm

The fairness of PF scheduler is calculated based on the end-user throughput, it aims to provide the same throughput to all end-users and can be adjusted by configuring appropriate T_{PF} size which should be in reasonable range. The scheduler fairness is defined by the Fairness Index (J) as follows [8]:

$$\text{Fairness Index } (J) = \frac{[\sum_{i=1}^{w} R_i]^2}{(w)\sum_{i=1}^{w}(R_i)^2} \quad (3)$$

where:
w: Total number of UEs.
R: Instant UE throughput.

3. DEFINITION OF AVERAGE-THROUGHPUT WINDOW SIZE (T_{PF}) FOR LTE-A PF SCHEDULER

The T_{PF} is PF scheduler feature which is used by the eNodeB in order to estimate the average throughput for each UE. A previous study [9] mentioned that the average-throughput window size (T_{PF}) should have large value in comparison with the scheduling period (1 ms). However, the large T_{PF} will not fulfil the real-time system purposes because the scheduling priority (i) for PF scheduler is defined as the ratio of the instant UE throughput and the achieved UE throughput to date.

In [7], both of finite and infinite T_{PF} have been discussed and simulated with different SINR values for limited-interference OFDMA network. The results showed different values of data rate that are achieved by changing the scheduler T_{PF} size.

The fairness of PF scheduler in both of frequency domain and time domain is important target to be considered for designing an efficient PF scheduler. It is shown that the fairness does not need to be fulfilled in very short time i.e., in few milliseconds, since the downloading of one web page will take longer than the time needed for transmitting one

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

LTE-A frame which is 10 ms. If the downlink scheduler takes few seconds to adjust the fairness among all users, then it should be sufficient[10]. This rule in scheduling will allow the scheduler to utilise the time variation in order to increase the end-user throughput and fairness.

4. DERIVATION OF AVERAGE-THROUGHPUT WINDOW SIZE (T_{PF})

There are two formulas for T_{PF} that we derived from Eq.1. The first formula is applied when the scheduler selects user k in order to be assigned specific resource block (RB). In this case, the derivation of T_{PF} will be as follows:

$$\overline{R_k(m+1)} = \left(1-\frac{1}{T_{PF}}\right)\overline{R_k\,(m)} + \frac{1}{T_{PF}}R_{k,n}(m)$$

$$\overline{R_k(m+1)} = [\overline{R_k\,(m)} - \frac{\overline{R_k\,(m)}}{T_{PF}}] + \frac{R_{k,n}(m)}{T_{PF}}$$

$$\overline{R_k(m+1)} - \overline{R_k\,(m)} = \frac{-\overline{R_k\,(m)} + R_{k,n}(m)}{T_{PF}}$$

$$T_{PF} = \frac{R_{k,n}(m) - \overline{R_k\,(m)}}{\overline{R_k(m+1)} - \overline{R_k\,(m)}} \quad (4)$$

In Eq.5 is the second derived formula for T_{PF} which is applied when user k is not requesting any more bandwidth (RBs). In this case, the PF scheduler will continue to update the user k throughput according to the past throughput reading $\overline{R_k\,(m)}$, and without considering any new throughput reading $R_{k,n}(m)$. As a result, the formula of T_{PF} in this case will be different from the first formula in Eq.4 and it is derived as follows:

$$\overline{R_k(m+1)} = \left(1-\frac{1}{T_{PF}}\right)\overline{R_k\,(m)}$$

$$\overline{R_k(m+1)} - \overline{R_k\,(m)} = -\frac{\overline{R_k\,(m)}}{T_{PF}}$$

$$T_{PF} = \frac{\overline{R_k\,(m)}}{\overline{R_k(m)} - \overline{R_k(m+1)}} \quad (5)$$

5. SIMULATION SCENARIOS OF THE DERIVED AVERAGE-THROUGHPUT WINDOW SIZE (T_{PF})

In order to show the PF scheduler's performance with different T_{PF} configurations for LTE-A, both of Vienna link-level (LL) and system-level (SL) simulators are used [11-13]. In the first simulation scenario, a link-level simulation is configured with single eNodeB station. The eNodeB has 500 meters radius, comprises three sectors with bandwidth of 5 MHz for each sector. The number of UEs at each sector is 10, all of them are stationary and distributed randomly within the sector. The purpose of this scenario is to simulate LTE-A downlink with Proportional Fair scheduler that uses two different sizes of T_{PF}. The rest of simulation parameters are explained in Table 1.

The second simulation scenario is a system-level (SL) simulation which consists of one cluster of seven eNodeBs. The effect of inter-cell interference and co-channel interference is considered and simulated for LTE-A cluster. Each sector at each eNodeB is configured with bandwidth of 20 MHz and Winner channel model. The other system parameters for the second scenario are explained in Table 1.

The T_{PF} is configured in both scenarios with two sizes; 20 ms and 70 ms, which is equivalent to 20 and 70 TTIs consecutively. This configuration were chosen based on [9] where it is shown that in multi-user multi carrier systems, the T_{PF} values which are lower than 40 ms is giving low outage probability, while the T_{PF} values in the range of 40 ms to 100 ms is showing higher outage probability.

TABLE 1. SIMULATION PARAMETERS FOR SCENARIO 1 AND 2

Parameter Name	Parameters of scenario 1	Parameters of scenario 2
Number of eNodeBs	1	7
Number of UEs	10	15
Bandwidth	5 MHz	20 MHz
Channel type	Flat Rayleigh	Winner
Simulation length	150 Sub-frames	1000 Sub-frames
Transmission mode	CLSM with 2x2 and 4x4 MIMO Channel	
Scheduler Type	Proportional Fair	
T_{PF} Size	20 and 70 TTIs	
Traffic Model	Full Buffer	

6. RESULTS AND DISCUSSION

Our simulation results showed improved throughput rate that is achieved from all simulation scenarios when T_{PF} is configured to have 70 ms length. The PF scheduler was able to maximise the cell throughput for both of 2x2 and 4x4 MIMO channels as shown in Fig. 2 and Fig. 3.

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Our derived equations, Eq.4 and Eq.5, are supporting the simulation results. Let us assume in Eq.4 that the throughput for one Resource Block $R_{k,n}(m)$ equals to 1.008 Mbps, the previous UE throughput reading $\overline{R_k(m)}$ equals to 10 Mbps, and the T_{PF} is 20 ms. Then, the calculated UE throughput $\overline{R_k(m+1)}$ for user k will be equal to 9.55 Mbps. On the other hand, if the T_{PF} is assumed to have 70 ms length, the calculated new UE throughput $\overline{R_k(m+1)}$ for user k will be equal to 9.87 Mbps, which is higher than the first case where 20 ms T_{PF} is used. By comparing both cases, we find that the eNodeB is reading higher UE throughput $\overline{R_k(m+1)}$ with T_{PF} length of 70 ms as calculated above, and the higher UE throughput will contribute to increase the cell throughput towards higher values as shown in Fig. 2 and Fig. 3. The resulted cell throughput from the simulation which is shown in Fig. 2 and Fig. 3, is matching our conclusion here, it is showing higher cell throughput when T_{PF} of 70 ms length is configured.

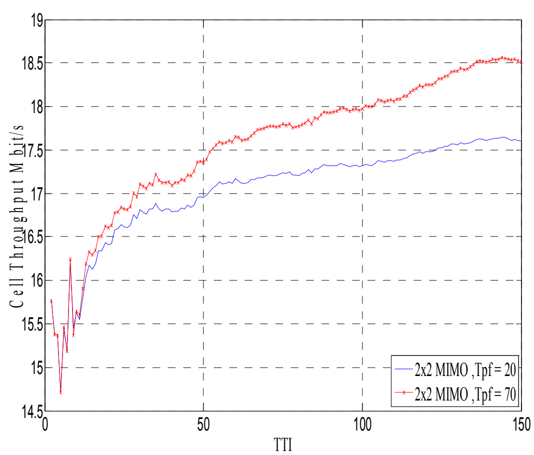

Fig. 2. Cell Throughput For Two T_{PF} Configurations, 20 And 70 Ttis With 2x2 MIMO Channel

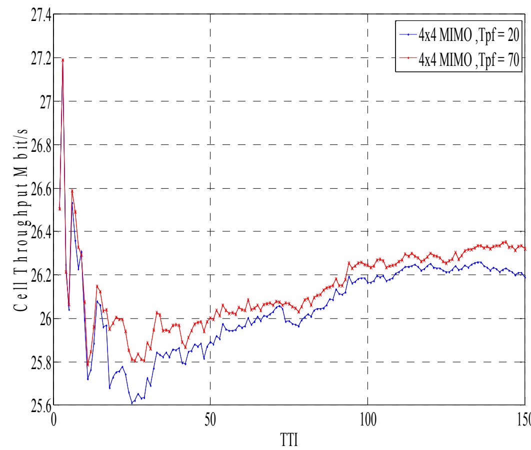

Fig. 3. Cell Throughput For Two T_{PF} Configurations, 20 And 70 Ttis With 4x4 MIMO Channel

The scheduler fairness (J) has been analysed in Fig. 4 and Fig. 5, it showed higher fairness index (J) for T_{PF} length of 20 ms, meanwhile it showed lower fairness index (J) for T_{PF} length of 70 ms.

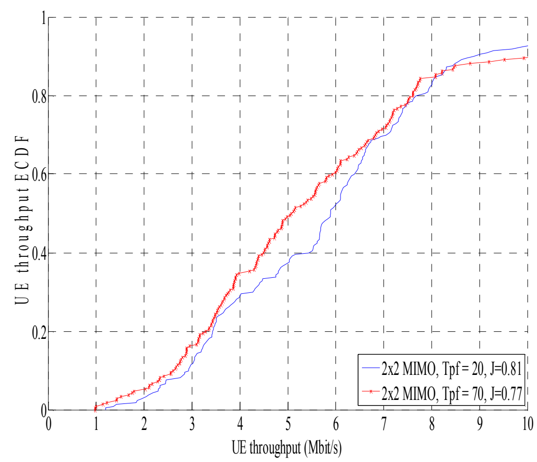

Fig. 4. Scheduler Fairness-Index (J) For Two T_{PF} Configurations; 20 And 70 Ttis With 2x2 MIMO Channel

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

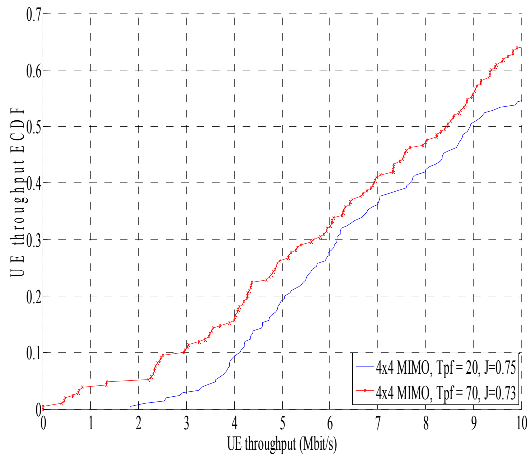

Fig. 5. Scheduler fairness-index (*J*) for two T_{PF} configurations; 20 and 70 TTIs with 4x4 MIMO channel

It is concluded from the fairness results that configuring the PF scheduler with short T_{PF} will make the scheduler aware about the current throughput for each UE in a shorter time. As a result, the PF scheduler will make faster decisions in increasing the throughput for the UEs who have poor throughput by allocating more RBs to them, so the scheduler will be able to provide better fairness in allocating the available bandwidth for the users (UEs) instantly once they need it. The fairness results are summarized in Table 2.

TABLE 2. TABULAR SIMULATION RESULTS FOR THE SCHEDULER FAIRNESS-INDEX (*J*)

T_{PF} Size	Fairness Index (*J*)	
	2x2 MIMO Channel	4x4 MIMO Channel
20	0.81	0.75
70	0.77	0.73

7. CONCLUSION

In this paper, we derived the average-throughput window size (T_{PF}) formulas for PF scheduler of LTE-A eNodeB. The effect of T_{PF} size on the fairness and the throughput of LTE-A PF scheduler has been analysed. There was trade-off between maximising the end-user or cell throughput and improving the fairness of PF scheduler.

The results showed that LTE-A PF scheduler with large T_{PF} size, is able to maximise the end-user and cell throughputs much better than PF scheduler with small T_{PF} size. On the other hand, the fairness of PF scheduler showed improvement when small T_{PF} size is utilized.

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