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Quadratic Proportional Fair Scheduling Algorithm for LTE-A Networks

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Abstract

In recent years, LTE-Advanced (LTE-A) networks can be classified as the most viable wireless broadband technology. LTE-A supports Quality of Service (QoS) by using Admission Control (AC) and Packet Scheduling (PS). Quality of Service (QoS) has many requirements, such as average throughput, fairness, used energy per bit and spectral efficiency. To efficiently improve the network performance, we should pick a powerful and faired scheduling algorithm. One of the most used scheduling algorithms in LTE-A is Proportional Fair (PF). In this paper, a quadratic proportional fairness algorithm is proposed, by using the root mean square value to compute the average throughput. The proposed algorithm is implemented and evaluated using the Vienna system level simulator with various numbers of users and users speed. It is also compared with the original PF and some of its modifications. The results reveal that, the proposed algorithm exceeds the other algorithms in terms of Average UE throughput, Average cell throughput, spectral efficiency, and average used energy per bit. However, PF-Geometric Mean Method has the best average edge throughput value and the PF has the best fairness value.

Keywords: Long Term Evolution-Advanced (LTE-A), Proportional Fair (PF), Quality of Service (QoS), Root Mean Square value, Uplink Packet Scheduler (PS).

I. INTRODUCTION

Opportunities and challenges for the wireless broadband mobile communication are gained by the rapid growth of mobile communication and the merging of the mobile network. Therefore, 4G Long Term Evolution (LTE) has been developed by the 3rd Generation Partnership Project (3GPP) has introduced as an emerging wireless technology that is considered as an important milestone in the path of mobile broadband evolution in terms of its enhanced features and enabling technologies. These features make LTE survive longer than the other wireless technologies such as WiMAX and the wired broadband networks such as ADSL [1].

The advanced release of LTE, named LTE-Advanced (LTE-A), is developed as the fourth generation Long Term Evolution. LTE-A has many features: Supporting high data rate, improving system capacity and providing strongly support the use of different types of applications simultaneously such as voice, streamed multimedia and gaming services with low-latency.

LTE-A also provides a highly support in Quality of Service (QoS) for multiple types of traffic. It organizes the different types of traffic flows in logical traffic pipes called bearer services based on their QoS requirements e.g. throughput, delay, and jitter. It has four traffic bearers, which are classified based on the QoS constraints on the bearer's traffic: Conversational class, Streaming class, Interactive class and Background class [2].

LTE-A Packet Scheduling is the main process of QoS. It is used to allocate sub-carriers resources for a fixed time (TTI) to each User Equipment (UEs) to maximize the desired performance target [2]. LTE-A has two traffic directions: uplink and downlink. Each direction has its own packet scheduling. There are many research works in the literature in uplink packet scheduling [3].

Proportional Fairness (PF) algorithm is the most used and powerful LTE-A uplink scheduling algorithm, because it maximizes fairness between users and with an acceptable performance in terms of average throughput, spectral efficiency and average system [4]. In the literature, PF modifications are proposed by changing the used method to compute the average throughput value of its cost function.

In [4], three modified versions of PF are introduced. These three different methods to compute the average throughput: Arithmetic Mean, Midrange Mean and Midrange Fair Mean. These methods had increased the performance compared to the original method of computing the average throughput. But, these methods had clearly trade off between fairness and average throughput. Other PF modifications are proposed in [5], where the PF scheduler performance is enhanced by using averaging methods, namely; median, range and geometric mean for computing the average throughput which is used to determine the priority function. The results showed that the performance of the proposed schedulers was enhanced, but these methods also had a trade off between fairness and average throughput.

An Adaptive and Potential Aware Scheduling Scheme (APASS) is introduced in [6], which is covering some scheduling objectives such as average system throughput, fairness and spectral efficiency. However, it has large average system energy per bit that is mainly a critical issue for UE, because it has a limited resource in power. A channel-aware traffic resource allocation algorithm is proposed by Ruey-Rong Su and *et al.* [7] which is aimed at enabling uplink traffic delivery in ideal and non-ideal channels. It used best CQI with Gray Relational Analysis, however, the main disadvantages of the algorithm is that it has not the ability to guarantee fairness between users. Salman and *et al.* [8] introduced a Packet Prediction Mechanism (PPM) for downlink scheduler by optimizing the energy and bandwidth. This algorithm gains the best performance, but it gives a low performance in terms of spectral efficiency.

In this paper, a quadratic proportional fairness algorithm is proposed, by using the root mean square value to compute the average throughput. It considers a trade off balance between throughput and fairness among users. A generalized performance study of the proposed algorithm is introduced by changing the number of UEs from 9 to 105 UEs per eNodeB and various UE speeds. It is also compared with the original PF and some of its modifications. The used performance metrics are average throughput for UE and cell, fairness, average used energy per bit, edge throughput per UE and spectral efficiency.

The paper is organized as follows. In section II, an overview of LTE-Advanced is introduced. Section III describes the Proportional Fairness Scheduling algorithm. In section V, the proposed scheduling algorithm is developed. The simulation results and their analysis for the different parameter settings are presented and discussed in section VI. Finally, conclusions and further works are listed in section VII.

II. LTE-ADVANCED SYSTEM

The main and strong feature of LTE-A is its high speed data rates , 100 Mb/s speed for downlink and 50Mb/s for uplink, which allows users to access many different types of applications. It also has: higher level of system performance, compatibility, bandwidth flexibility, heterogeneous network support and many other features [3].

The architecture of LTE-A consists of two main parts: Radio Access Network is known as E-UTRAN (Evolved Universal Terrestrial Radio Access Network) and an IP core network: Evolved Packet Core (EPC) as shown in Fig. 1 [3]. E-UTRAN part consists of cells. Each cell has an eNodeB (eNB) which has the responsibility of organizing the communication between UEs (User Equipment) in its cell. Also, It responsible for Admission Control (AC) and Packet Scheduling (PS) in uplink and downlink. EPC is responsible for connecting all eNBs with each other. Each eNodeB connects to EPC using X2 transmission media. Its other functions are authentication, security, mobility management and database of users' information [3].

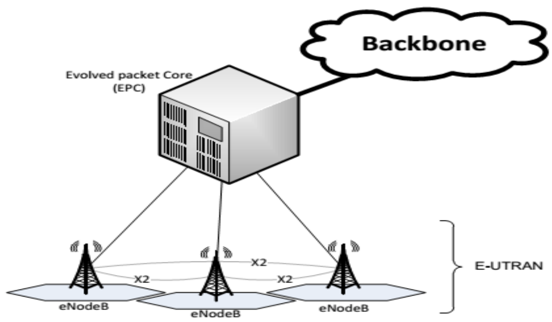

Figure 1. LTE access network (E-UTRAN) architecture

LTE-A supports effectively the Quality of Service (QoS) for different application types such as voice over IP (VOIP), gaming, audio streaming and video streaming. Strong QoS support needs two main parts: Packet Scheduling (PS) and Admission Control (AC). PS responses for dividing the shared data channel into radio bearers to fulfill their QoS requirements. Each bearer has some QoS attributes such as: Allocation Retention Priority (ARP), Maximum Bit Rate (MBR), Guaranteed Bit Rate (GBR) and QoS Class Identifier (QCI) that has Bearer Type, Packet Delay Budget (PDB) and Packet Loss Rate as parameters associated with each Service Data Flow (SDF) [8].

All functions of the radio bearers Radio can be found in Resource Management (RRM), which is a part of E-UTRAN. It achieves some functions as: accepting/rejecting connection requests and ensuring the efficient use of available radio resources. PS locates on the MAC layer, and deals with associating fairly Resource Blocks (RBs) to UEs every Transmission time interval (TTI). PS types can be classified into channel dependent or channel aware scheduling, for example, Best Channel Quality Indicator (CQI) scheduling algorithm and channel unaware scheduling ex. Proportional Fair (PF) scheduling algorithm [9].

III. PROPORTIONAL FAIR SCHEDULING ALGORITHM

Proportional fair is used mostly in wireless networks. Also, it is the most powerful algorithm used in LTE-A because, it can work based on maintaining a balance between throughput and fairness for all users [10, 11]. The PF priority function is shown in Eq. (1) [12, 13]. Its main argument is the value of average throughput which was used by users. K* variable is computed for each user then used to assign resource blocks for users.

The priority variable k* is determined as follows [12,13]:

$$K^* = \arg\max_k \left(\frac{r_{k,n}}{(t_c - 1)T_k + \sum_{n=1}^{N} P_{k,n} r_{k,n}} \right) \qquad (1)$$

Where,

- $r_{k,n}$ The instant service rate of k_{th} user on the n_{th} Resource Block (RB)
- $P_{k,n}$ The assignment indicator variable ($P_{k,n}$ =1, if n_{th} RB is assigned to k_{th} user and = 0 if it's not)
- t_c The average window size
- T_k The average throughput information of k_{th} user. It is given in equation (2)

$$T_k(t+1) = \begin{cases} (1-\frac{1}{t_c})T_{k,n}(t) + \frac{1}{t_c}R_k(t), & K=K^* \\ (1-\frac{1}{t_c})T_{k,n}(t), & K \neq K^* \end{cases} \qquad (2)$$

Where,

- T_k Information about the average throughput k_{th} , which assigned to UE in its all previous TTI
- R_k The throughput that UE gets in that TTI
- k The user index

In the above Equation, k=K* is hit if the k_{th} user gets resources in the previous TTI. So, Tk is updated every TTI.

Hence, the most important factor in the PF priority function is the UE average used throughput, which is calculated from the stored data about UE's used throughput history.

IV. PROPOSED SCHEDULING ALGORITHM

The main important role of the scheduler is the allocation of resources to UEs at each time slot to achieve maximization in throughput and fairness for each user. The most commonly used and powerful scheduling algorithm in LTE-A is Proportional Fair [12].

In literature, there are many modifications in the priority function of PF based on the used methods to compute the average UE throughput. It is used to gain the balance between throughput and fairness for all users.

The previous methods of PF modifications used Arithmetic Mean, Midrange Mean, Midrange Fair Mean, Median, Range and Geometric Mean for calculating the average throughput [4,5].

In this paper, we propose a scheduling algorithm named Quadratic Proportional Fair (QPF). QPF uses root mean square (RMS) method to compute the average throughput.

RMS is a mathematical method that is used to compute the average value of a set of numbers by getting the average of the squared values of the set of numbers then taking the square root of the average. The RMS is always the same as or a little bit larger than the average of the values. The use of RMS in PF priority function can increase the associated resource block for each UE. Then, it will increase the total cell throughput and cause best performance.

The proposed algorithm uses equation (3) to compute T_k , for PF function:

$$Tk(t+1) = \left(\frac{R_k^2(1)+R_k^2(2)+\cdots\ldots\ldots+R_k^2(N)}{N}\right)^{1/2} \qquad (3)$$

Where,

$R_k(1)$, $R_k(2)$, ………..,$R_k(N)$, are the history stored average throughput for Kth UE and N is the number of average throughput values.

V. SIMULATION NETWORKS AND RESULTS

A. Simulation setup

In our study of the performance of the proposed algorithm, we use Vienna LTE System Level Simulator [14]. The main objective of our performance evaluation is to proof that QPF is able to gain the QoS requirements of the different types of applications such as maximizing throughput with an acceptable level of fairness. Our study also takes into account the impact of user mobility on the performance of the network.

The performance of QPF is evaluated in terms of some performance indicators: Average UE throughput, Average cell throughput, UE edge throughput, spectral efficiency, energy per bit and Fairness. The simulation parameters are presented in Table 1 [4].

TABLE 1: SIMULATION PARAMETERS

PARAMETER	**Value**
Frequency	2.6 GHz
Bandwidth	20 MHz
eNodeB Antenna Gain	15 dB
Simulation time	100 TTI (100 ms)
Total Number of UEs	9,5,21,27,33,39,45,60,75,90, 105
Number of eNodeB	1
Number of Cells	1
UE Speed	3 km/h, 60 km/h, 120 km/h
Macroscopic Pathloss Model	TS36942
Simulation Environment	Urban
eNodeB Antenna Output Power	49 dBm
Inter eNodeB Distance	500 m
Channel model	winner+

QPF evaluation study is divided into two parts: the first part introduces a comparative study of QPF and the original PF based on changing the number of UEs from 9 to 105 UEs (small and large size networks) and the impact of user mobility. The second one presents a comparison between QPF, PF, and some modifications of PF, listed in the literature [4, 5]. Examples of the simulated networks are shown in Fig. 2.

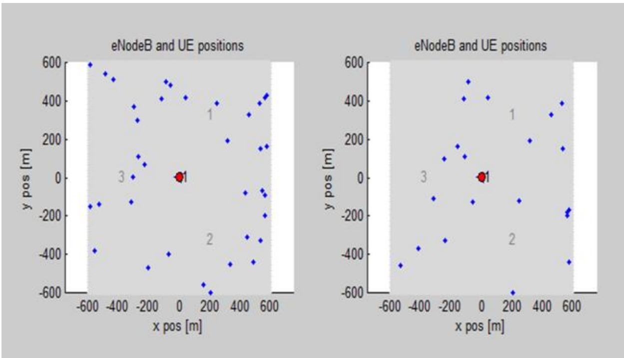

Figure 2. Simulated Networks

B. Results and discussion

In this paper, the performance evaluation of QPF is divided into two parts: QPF performance evaluation using different scenarios and Comparison of QPF performance with most used algorithms.

Part 1: QPF performance evaluation

In this section, the performance evaluation QPF scheduling algorithm based on changing the number of UEs from 9 to

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105 UEs (small and large size networks) and the impact of user mobility is presented. It is compared to the original PF.

Average UE throughput is shown in fig. 3. Fig. 3(a), (b), and (c) show the UE average throughput with different UEs speed: 3, 60, and 120 Km/h, respectively. Through these results, QPF achieves better throughput than PF at all UEs speed. This is due to the use of RMS value to compute the average throughput, which gives an average value greater than the average value calculated by other methods (Arithmetic Mean Method and Geometric Mean Method).

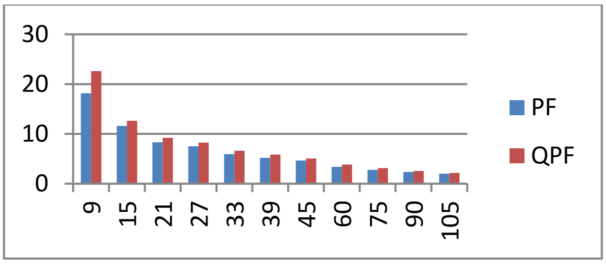

Figure 3(a). Average UE Throughput (Mbps) vs. No. of UEs at 3Km/h

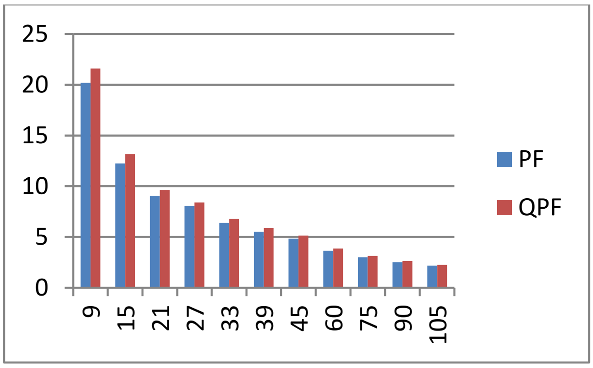

Figure 3(b). Average UE Throughput (Mbps) vs. No. of UEs at 60 Km/h

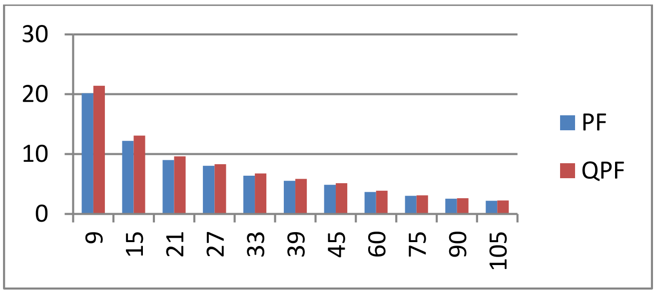

Figure 3(c). Average UE Throughput (Mbps) vs. No. of UEs at 120 Km/h

Fig. 4 shows the average UE Spectral efficiency, which also experiences a decline in performance as the velocity increases in both algorithms –QPF and PF- but, QPF exceeds PF in UE spectral efficiency. This has resulted from the use of RMS value to compute the average throughput, since spectral efficiency is a function of average throughput.

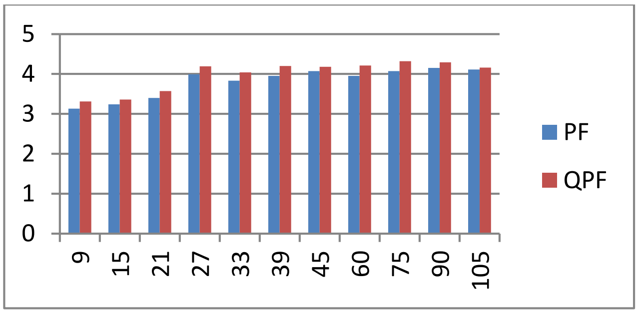

Figure 4(a). Average UE Spectral Efficiency (bits/Hz) vs. No. of UEs at 3Km/h

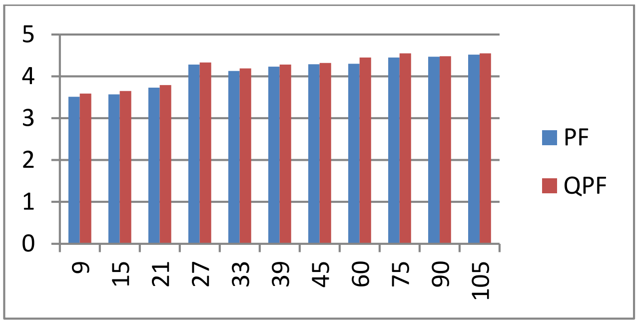

Figure 4(b). Average UE Spectral Efficiency (bits/Hz) vs. No. of UEs at 60 Km/h

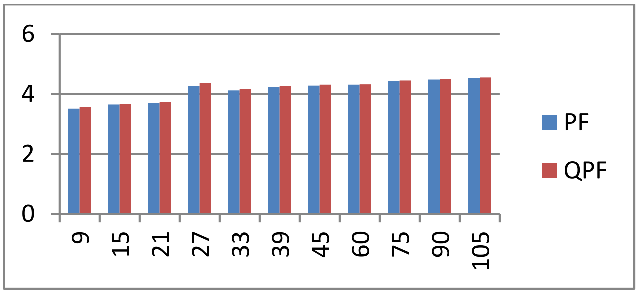

Figure 4(c). Average UE Spectral Efficiency (bits/Hz) vs. No. of UEs at 120 Km/h

The average Energy per bit vs. number of UEs at different UEs speed is shown in fig. 5 (a), (b), and (c). As the figure indicates, QPF has less average energy per bit than PF in small and large size networks. QPF also outperforms PF in low and high UEs speeds.

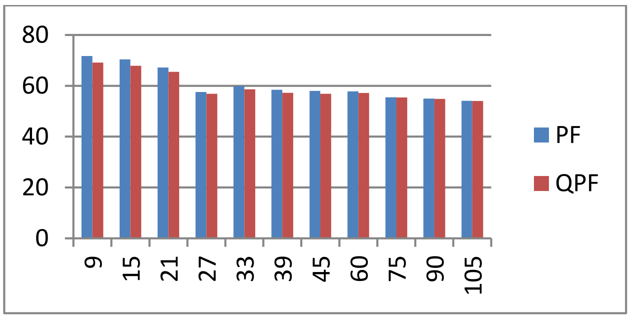

Figure 5(a). Average Energy per bit (J) vs. No. of UEs at 3Km/h

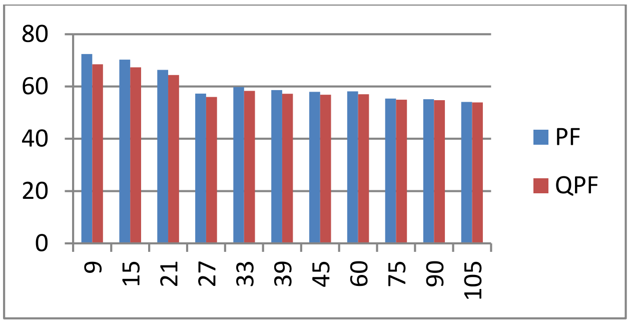

Figure 5(b). Average Energy per bit (J) vs. No. of UEs at 60 Km/h

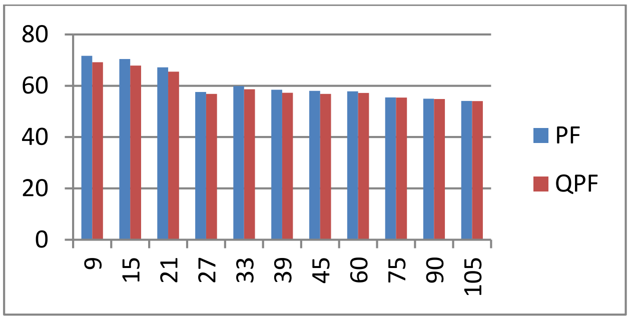

Figure 5(c). Average Energy per bit (J) vs. No. of UEs at 120 Km/h

An increase in the average UE throughput based on the use of the RMS method in QPF is causing an increase in the total cell average throughput with all network sizes and UEs speeds. This is clearly shown in fig. 6.

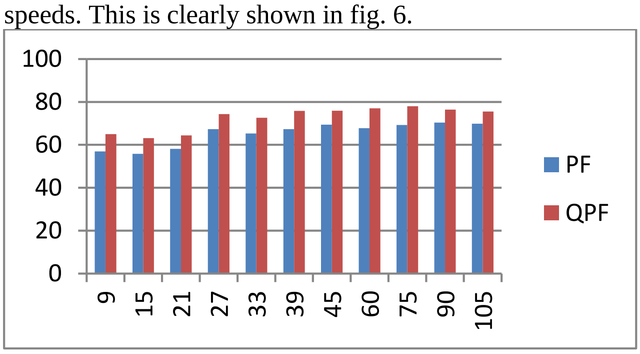

Figure 6(a). Average Cell Throughput (Mbps) vs. No. of UEs at 3Km/h

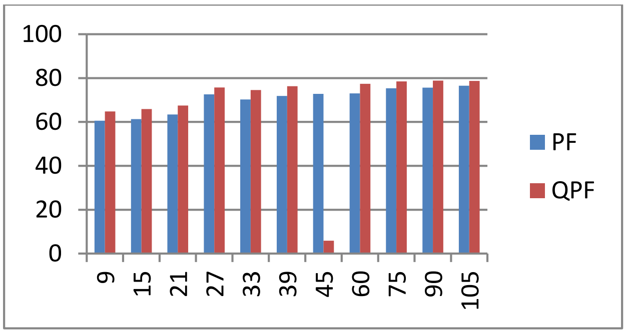

Figure 6(b). Average Cell Throughput (Mbps) vs. No. of UEs at 60 Km/h

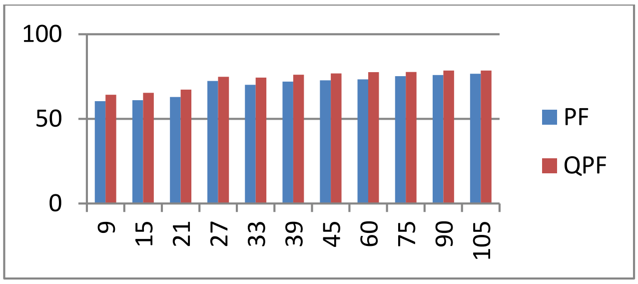

Figure 6(c). Average Cell Throughput (Mbps) vs. No. of UEs at 120 Km/h

The average UE edge throughput and fairness are shown in fig. 7 and fig. 8, respectively. As we can see, that PF exceeds QPF in these both performance indicators.

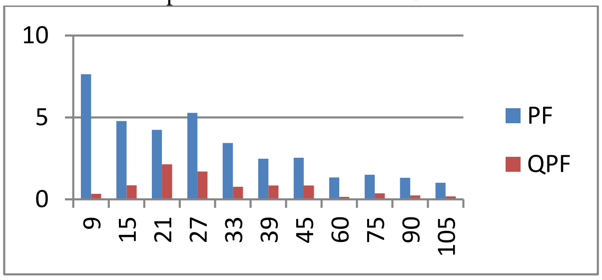

Figure 7(a). Average UE EdgeThroughput (Mbps) vs. No. of UEs at 3Km/h

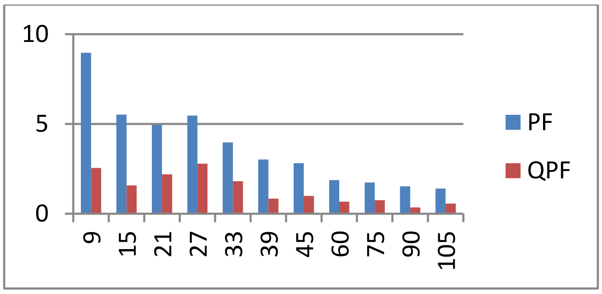

Figure 7(b). Average UE Edge Throughput (Mbps) vs. No. of UEs at 60 Km/h

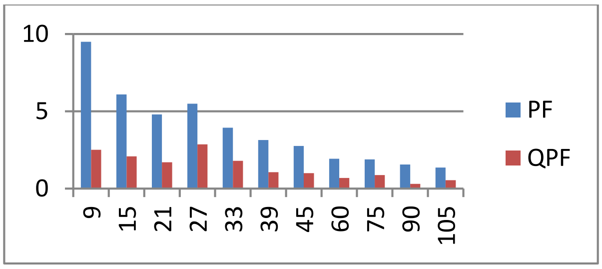

Figure 7(c). Average UE Edge Throughput (Mbps) vs. No. of UEs at 120 Km/h

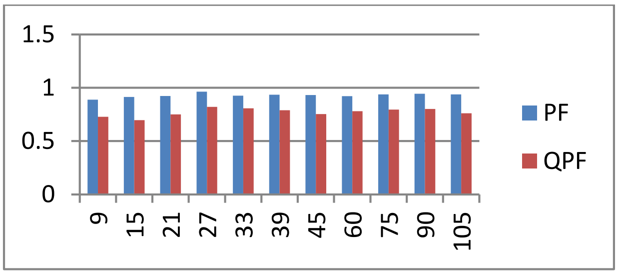

Figure 8(a). Fairness vs. No. of UEs at 3Km/h

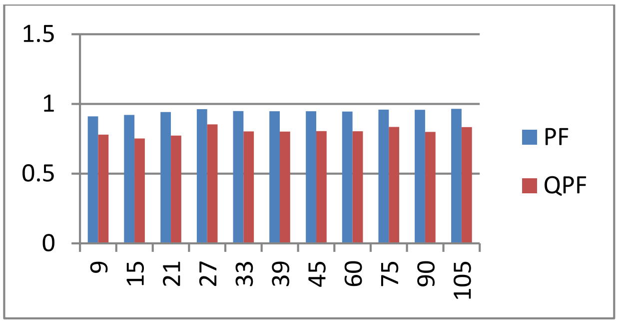

Figure 8(b). Fairness vs. No. of UEs at 60 Km/h

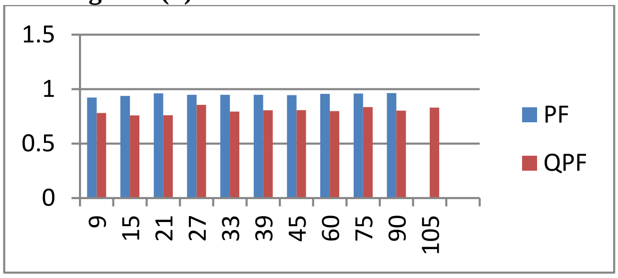

Figure 8(c). Fairness vs. No. of UEs at 120 Km/h

From the previous performance study of the proposed algorithm, we found that, QPF gives a good improvement for average UE and cell throughput, spectral efficiency and finally, energy per bit compared to the original PF scheduler by 8.31%, 8.34%, 3.34%,and 2.42%, respectively. However, PF still has better performance than QPF in edge throughput and fairness in all network sizes and all various UEs speeds.

Part 2: Comparison of QPF performance with previous algorithms

In this part, a comparison of QPF, PF and some PF modifications is introduced. PF-Arithmetic Mean Method [4] and PF-Geometric Mean Method [5] are considered in this comparison. The same performance indicators in part 1 are used, but at a number of UEs: 21 and 36 only and the UE speed is 5Km/h as has been taken in [4,5]. The results are shown in fig. 9 to fig. 14.

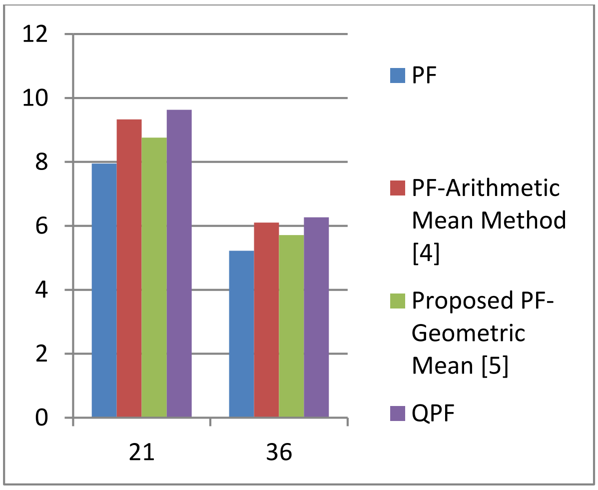

Figure 9. Average UE Throughput (Mbps) vs. No. of UEs

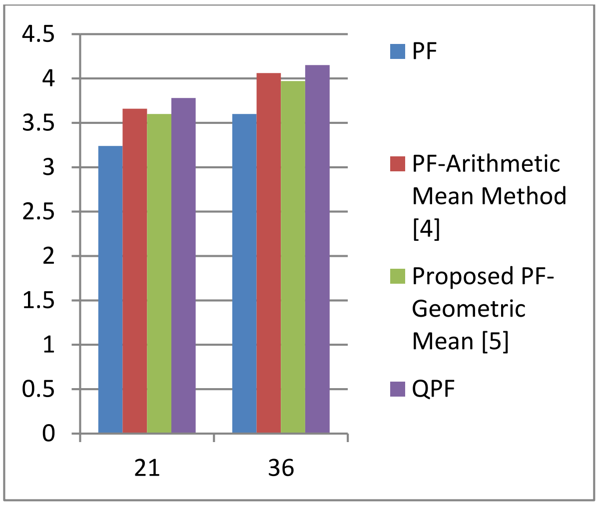

Figure 10. Average UE Spectral Efficiency (bits/Hz) vs. No. of UEs

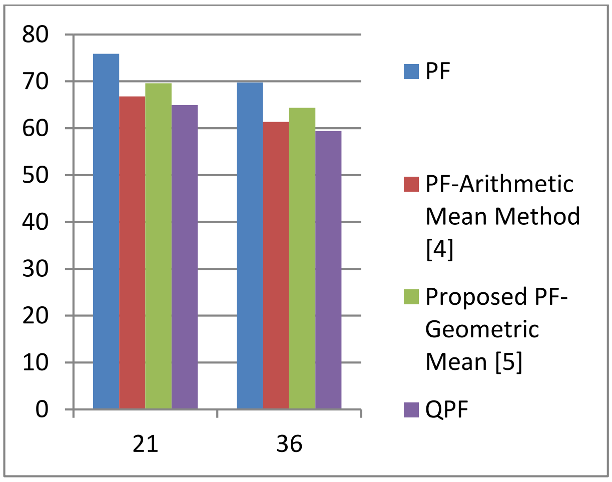

Figure 11. Average Energy per bit (J) vs. No. of UEs

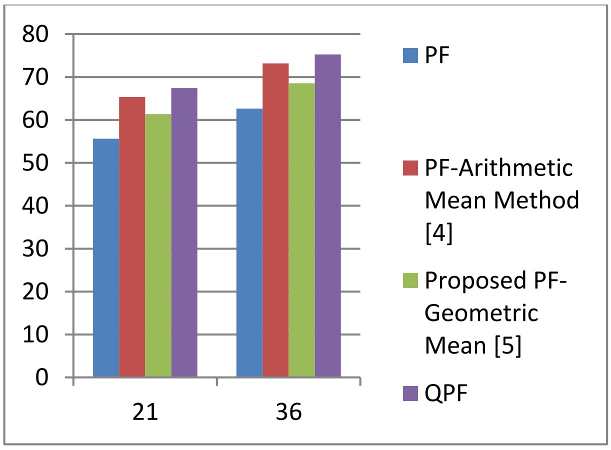

Figure 12. Average Cell Throughput (Mbps) vs. No. of UEs

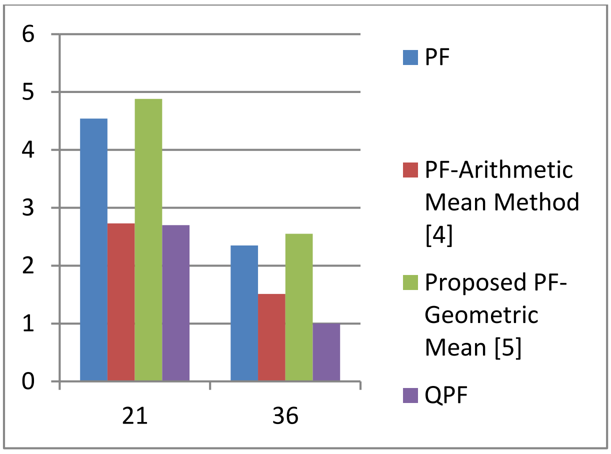

Figure 13. Average UE Edge Throughput (Mbps) vs. No. of UEs

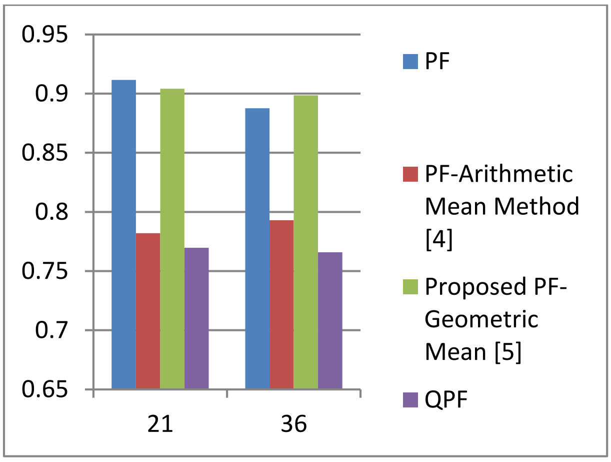

Figure 14. Fairness vs. No. of UEs

The average UE throughput shown in fig. 9. As clearly shown, QPF has the best value of average UE throughput. This has resulted from the use of the RMS method to compute the average throughput. The same improvement was obtained in the average UE Spectral efficiency, the average energy per bit and average cell throughput, QPF exceeds the others, as shown in Figures from 10 to 12, respectively.

In fig. 13, PF-Geometric Mean Method has the best average edge throughput. Finally, PF has the best fairness as clearly shown in fig. 14.

VI. CONCLUSION AND FUTURE WORKS

Growing of mobile communication technologies offers many opportunities and challenges in satisfying the QoS requirements for the new real-time applications such as voice over IP, streaming multimedia and online gaming. So, there is a critical need for an emerging and viable wireless broadband technologies such as LTE-A. It can achieve strongly support for QoS, by selecting a reliable and powerful packet scheduling algorithm.

In this paper, a quadratic proportional fair scheduling algorithm is proposed based on changing the average throughput computational equation in the original PF algorithm by using the RMS method. Simulation evaluation of the proposed algorithms using Vienna simulator is introduced. The proposed algorithm is compared with PF, PF-Arithmetic Mean Method [4] and PF-Geometric Mean Method [5]. The used performance indicators: Average UE throughput, Average cell throughput, UE edge throughput, spectral efficiency, energy per bit and Fairness.

After the performance evaluation of QPF, We can conclude that QPF outperforms the others algorithms in terms of Average UE throughput, Average cell throughput, spectral efficiency, and energy per; PF-Geometric Mean Method has the best average edge throughput; Finally as clearly shown, PF has the best fairness.

In the future work, the performance of the proposed algorithm can be compared with other packet scheduling algorithms such as Best CQI. Also, we can evaluate its performance using heterogeneous networks.

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