A Proposed Modified Proportional Fairness Scheduling (MPF-BCQI) Algorithm with Best CQI Consideration for LTE-A Networks

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***Abstract*—*Quality of Service (QoS) requirements, such as fairness, average throughput and spectral efficiency, are a set of the important parameters that assess the performance of scheduling algorithms. LTE-Advanced (LTE-A) is the most viable wireless broadband network that strongly supports QoS by using Admission Control (AC) and Packet Scheduling (PS). In LTE-A, Proportional Fair (PF) scheduling algorithm and its modified versions have proved to be the commonly used scheduling algorithms for their ability to provide fairness while Best Channel Quality Indicator (CQI) scheduling algorithm guarantees high throughput. In this paper, we propose a new scheduling algorithm by considering a tradeoff balance between throughput and fairness among users by combining Best CQI and PF schedulers' metrics. Moreover, we enhance the PF scheduler performance using new averaging methods namely; median, range and geometric mean for computing the average throughput which is further used to determine the scheduling priority. The performance evaluation is presented using Vienna system level simulator. The results reveal that the performance of the proposed scheduler, with the new averaging methods in PF, gives better performance than the compared to schedulers in terms of throughput, fairness and spectral efficiency.*

Keywords*—*Long Term Evolution (LTE); Uplink Packet Scheduler (PS); Proportional Fair (PF); Quality of Service (QoS); Best Channel Quality Indicator (CQI).

I. INTRODUCTION

The rapid growth of mobile communication and the merging of mobile network and Internet are creating the opportunities and challenges for the wide-band mobile communication. Therefore, the 3rd Generation Partnership Project (3GPP) has introduced 4G Long Term Evolution (LTE) as a wireless technology that is viewed as an important milestone in the path of mobile broadband evolution in terms of its enhanced features and enabling technologies. These features make LTE a strong competitor to wired broadband networks such as ADSL [1].

The fourth generation Long Term Evolution Advanced (LTE-A) network is able to serve the demands of the smartphone data traffic which has completely different characteristics compared to 2G and 3G mobile networks and broadband data users. It targets higher user data rate, improved system capacity and coverage and providing various services such as, e.g., voice, streamed multimedia and gaming services with low-latency. The 3rd Generation Partnership Project (3GPP) has defined Orthogonal Frequency Division Multiple Access (OFDMA) as the access technique for the downlink and Single Carrier FDMA (SC-FDMA) as the access technique for the uplink. Moreover, the Peak to Average Power Ratio (PAPR) of SC-FDMA is lower than OFDMA. This property is useful for mobile stations, since power is a precious resource for handheld mobile devices. While providing some benefits, SC-FDMA imposes major constraints on the resource allocation. It requires the subcarriers, and therefore the Physical Resource Blocks (PRBs) allocated to a single terminal to be adjacent in frequency domain. Moreover, the maximum number of users that can be scheduled at a time is upper-bounded.

LTE also aims at providing Quality of Service (QoS) for multiple types of traffic. According to 3GPP, LTE organizes the different types of traffic flows into logical traffic pipes called bearer services. Each bearer service associated with certain QoS attributes, depending on the type of traffic flows on it. These traffic bearers are categorized into four QoS classes, based on the QoS constraints of the bearer's traffic: Conversational class, Streaming class, and Interactive class and Background class [2].

LTE Packet Scheduling is defined as allocating pre-determined number of sub-carriers for a fixed time (TTI) to each requesting UEs to maximize the desired performance target [2, 3]. Designing a packet scheduler for LTE uplink can be broken into two stages: 1) Defining a Utility Function, and 2) Designing Search-based Allocation Scheme. A utility based uplink scheduling operation can be decoupled into per-domain scheduling: a Time Domain Packet Scheduling (TDPS), and Frequency Domain Packet Scheduling (FDPS) [2].

There are two types of packet scheduling in LTE-A, one for uplink and the other for downlink. There has been many work regarding the topic of Uplink (UL) Packet Scheduling (PS) where scheduling and resource block schemes have been proposed in the literature [3] which so far adopt the well-known time-domain Proportional Fair (PF) algorithm as a basic scheduling principle and apply the PF algorithm directly over each RB one-by-one independently. However, only few of them incorporate the QoS constraints for multiclass services in LTE Uplink [3].

Proportional Fairness (PF) algorithm is one of the standard uplink scheduling algorithm that aims to maximize fairness between users and also giving an acceptable performance in terms of average throughput, spectral efficiency and average system energy by calculating a priority value for each user on each RB and choose the highest value based on a priority function [4]. Best Channel Quality Indicator (CQI) is also known as channel aware scheduling algorithm. It assigns RB to the user that has the best channel quality. This scheduler aims to maximize the average throughput and spectral efficiency and also giving an acceptable value of fairness.

Many versions of the original Proportional Fair (PF) and best CQI algorithms are found in the literature. Büyükoğlu et el. [4] introduced three methods for computing average throughput in PF: Arithmetic Mean, Midrange Mean and Midrange Fair Mean. These methods showed potentially good performance compared to the original method of computing the average throughput. Arithmetic mean increases scheduler fairness while midrange fair methods gives an acceptable value for Low Average (LA) throughput. However, the three methods increase the spectral efficiency in general but the main drawback of these methods is the clear trade off in Fairness and average throughput. A. Ragaleux et el. [5] introduced an Adaptive and Potential Aware Scheduling Scheme (APASS) which is standard-compliant and covers a wide range of scheduling objectives such as average system throughput, fairness and spectral efficiency but the main drawback is the average System Energy per bit that is considered a critical issue as UE is a limited resource in power and the compromise between fairness and average throughput is a must. Ruey-Rong Su and et el. [6] introduced ERAGRA algorithm which is a channel-aware traffic resource allocation algorithm aiming at enabling uplink traffic delivery on ideal and non-ideal channels which combine best CQI with Grey Relational Analysis, however, the drawback of this algorithm is it is not able to guarantee fairness between users. Salman et el. [7] introduced a modification on the downlink scheduler based on a Packet Prediction Mechanism (PPM) which is conducted at the eNodeB to optimize the energy and bandwidth resources while maintaining QoS at the downlink when a partial feedback is considered on the user equipment side. Thus, this two-sided algorithm gives the best tradeoff between uplink and downlink performances but it gives low performance in terms of spectral efficiency.

In this paper, we propose a new scheduler that considers a tradeoff balance between throughput and fairness among users. The benefits of both Best CQI and Proportional Fair schedulers have been combined in this proposed scheduler with new averaging methods for computing the average throughput for PF scheduler. Such combination ensures fairness and meanwhile better results of average throughput, spectral efficiency and system energy.

The paper is organized as follows. In section II, an overview of LTE-Advanced is introduced. Section III describes the Best CQI Scheduling algorithm. The Proportional Fairness Scheduling algorithm is presented in general terms in Section IV. In section V, the proposed scheduling algorithm to improve the efficiency and fairness of Proportional Fair algorithm are developed which includes the new averaging methods and the combination of PF and Best CQI. Section VI gives the simulation results and their analysis for the different parameter settings. Finally, conclusions and hints for further works are presented in section VII.

II. LTE-ADVANCED SYSTEM

Long Term Evolution LTE (Rel. 8) has many preferable features than the other wireless broadband technologies. One of these features is its high speed data rate that may approach the 100 Mb/s speed for downlink and 50Mb/s for the uplink which allows users to access the Internet through their mobile as well as through other electronic devices. 4G standard for LTE named LTE-A is developed in (Rel.10) and beyond that achieve higher level of system performance, compatibility, bandwidth flexibility, heterogeneous network support and many other features [3].

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

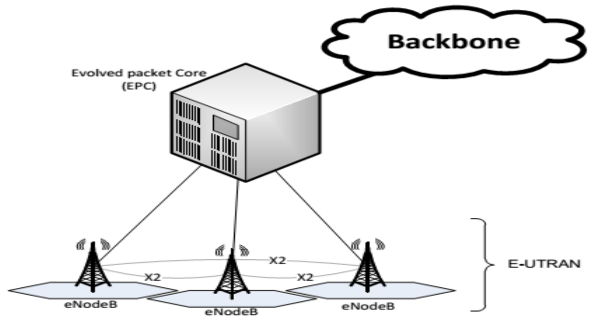

Fig. 1. LTE access network (E-UTRAN) architecture

LTE supports effectively the Quality of Service (QoS) for different traffic types such as voice over IP (VOIP), gaming, audio streaming and video streaming to achieve QoS in LTE-A. It has two wings: Packet Scheduling and Admission Control. Packet Scheduling is QoS-aware; it divides the shared data channel to the active radio bearers to fulfill their required QoS. 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].

Radio Resource Management (RRM) is a part of E-UTRAN in LTE-A. It manages all functions related to the radio bearers. It is responsible for accepting/rejecting connection requests and also responsible also for ensuring the efficient use of available radio resources. PS, is control manager of the MAC layer, and deals with associating RBs to UEs every Transmission time interval (TTI). There are various techniques for scheduling, such as channel dependent or channel aware scheduling and channel unaware scheduling [9].

III. Best CQI Scheduling Algorithm

As its name implies, CQI is an indicator carrying the information on how good/bad the communication channel quality is in order to get the RB allocation for each time, although the disadvantage that there is no good fairness for each user. As a result, the given RB are only allocations to users with the highest CQI. Best CQI is a proper algorithm to maximize the throughput by selecting the user with the highest CQI value as shown in Eq. (1).

$$M_{k,n} = \arg\max_{k}(CQI_{k,n}) \tag{1}$$

Where $M_{k,n}$ is define maximum value of channel quality indicator of K^{th} user on the n^{th} Resource Block (RB), $CQI_{k,n}$ is define as channel quality indicator value.

As shown in Fig. 2, CQI is the information that UE sends to the ENodeB to inform ENodeB with its Current Communication Channel Quality and which UE wants to get the data with this transport block size. This transport block size in turn can be directly converted into throughput. The CQI value can be expressed as a recommended transport-block size instead of expressing it as a received signal quality [10].

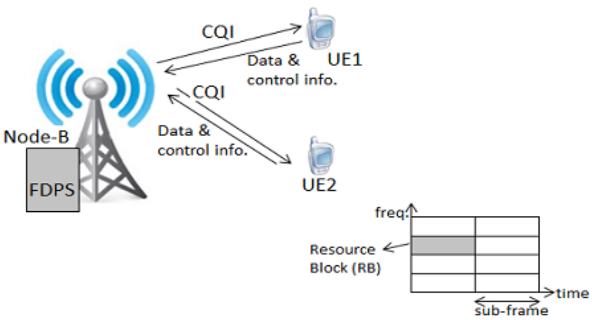

Fig. 2. The CQI feedback values sent from UE to eNodeB.

Quadrature phase shift keying (QPSK), 16 QAM, 64 QAM and 256 QAM are modulation schemas that have been specified for data transmission. In LTE, there are 15 different CQI values ranging from 1 to 15 (4bits). Mapping between CQI and modulation schemes is given in Table I.

Fig. 3 shows the flowchart of Best CQI scheduler which functions as follows [10]. It creates a 2D array where each row represents a UE and each column represents a single RB filled with elements that assign each RB to each UE. It then chooses the largest element to each UE on a specific RB. After that, it sets the element on the correspondent value of row i and column j of array element equals 0. These steps are repeated until the end of users.

TABLE I. 4-BIT CQI TABLE.

CQI Index	Modulation	Code Rate *1024	Efficiency	CQI Index	Modulation	Code Rate *1024	Efficiency
0	Out of range			0	Out of range		
1	QPSK	78	0.1523	1	QPSK	78	0.1523
2	QPSK	120	0.2344	2	QPSK	193	0.3770
3	QPSK	193	0.3770	3	QPSK	449	0.8770
4	QPSK	308	0.6016	4	16QAM	378	1.4766
5	QPSK	449	0.8770	5	16QAM	490	1.9141
6	QPSK	602	1.1758	6	16QAM	616	2.4063
7	16QAM	378	1.4766	7	64QAM	466	2.7305
8	16QAM	490	1.9141	8	64QAM	567	3.3223
9	16QAM	616	2.4063	9	64QAM	666	3.9023
10	64QAM	466	2.7305	10	64QAM	772	4.5234
11	64QAM	567	3.3223	11	64QAM	873	5.1152
12	64QAM	666	3.9023	12	256QAM	711	5.5547
13	64QAM	772	4.5234	13	256QAM	797	6.2266
14	64QAM	873	4.1152	14	256QAM	885	6.9141
15	64QAM	948	5.5547	15	256QAM	948	7.4063

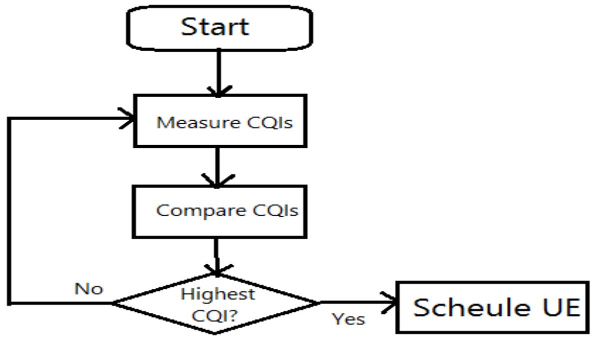

Fig. 3. Flowchart of Best CQI scheduler algorithm.

IV. Proportional Fair Scheduling Algorithm

Proportional fair is the most used scheduling algorithm in LTE-A. It mainly works based on maintaining a balance between maximization of throughput and fairness between users in each TTI [11]. The used priority function of PF is shown in Eq. (2) [12, 13] which is used to compute K* variable for each user then assigned resource blocks for users based on it.

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

$$K^{*} = \arg\max_{k}\left(\frac{r_{k,n}}{(t_c - 1)T_k + \sum_{n=1}^{N} P_{k,n} r_{k,n}}\right) \tag{2}$$

where rk,n is the instant service rate of kth user on the nth Resource Block (RB), is the assignment indicator variable (pk,n =1, if nth RB is assigned to kth user and = 0 if it's not), tc is the average window size, Tk is the average throughput information of kth, UE is used in the priority calculation algorithm to increase fairness of the system. It depends on the average throughput which is given in Eq. (3) [12, 13]:

$$T_k(t+1) = \begin{cases} (1-\frac{1}{t_c})T_{k,n}(t)+\frac{1}{t_c}R_k(t), & \text{K=K}^* \\ (1-\frac{1}{t_c})T_{k,n}(t), & \text{K}\neq\text{K} \end{cases} \quad (3)$$

where Tk is the array that stores information about average throughput kth which assigned to UE, Rk is the throughput that UE gets in that TTI. k=k* means if the kth user gets resources in the previous TTI. Tk is updated every TTI.

V. Proposed Scheduling Algorithm: MPF-BCQI

The scheduler plays an important role in the allocation of time frequency resources of UEs at each time slot. It is used to produce a good value of throughput and fairness for each user. The most commonly used scheduling algorithms are Best CQI and Proportional Fair.

Best CQI will select the user with the highest CQI value that means better channel condition in order to get the RB allocation for each time, although the disadvantage that there is no good fairness for each user. As a result, the given RB are only allocations to users with the highest CQI. In contrast, PF main part of its priority function is the history throughput calculation of user because it is used to achieve the fairness between users.

In literature, there are many methods introduced to compute the average throughput in PF priority function [10, 11] such as Arithmetic Mean, Midrange Mean and Midrange Fair Mean. These methods achieve good performance compared to the original method of computing the average throughput.

In this paper, we propose a new scheduling algorithm called Modified Proportional Fair – Best CQI algorithm (MPF-BCQI) that tries to satisfy both the average throughput and the fairness enhanced with new averaging methods which are: Median, Range and Geometric Mean for calculating average throughput in PF priority function. The contribution of the proposed algorithm comes in two folds. The first is the modification of PF based on changing the method used to compute the average throughput for the user. These methods are: Median, Range and Geometric Mean methods. The second is calculating the metric for each UE as a combination of PF and best CQI metric in order to achieve better channel allocation for the user while satisfying the fairness between users. In what to follows we will explain each part in details.

A. Using Median to compute average throughput in PF algorithm

Median is a mathematical method for calculating average of a set of values [14]. We use it to calculate the average throughput value (Tk) at the current TTI which depends on the previous values of throughput. If the number of average throughput values is N and the throughput changes in each TTI as Rk1, Rk2 ….Rk,n which are arranged in an ascending order of their magnitude, the median is computed as shown in Eq. (4):

$$T_k(N+1) = \begin{cases} R_{k}(\frac{N+1}{2}), & \text{if N is odd} \\ \frac{R_{k}(\frac{N}{2})+R_{k}(\frac{N}{2}+1)}{2}, & \text{if N is even} \end{cases} \quad (4)$$

where Rk is the throughput that UE gets in that TTI is, N is the number of average throughput values.

B. Using Range to compute average throughput in PF algorithm

Range method is defined as in [14]. Assume Rk1, Rk2 ….Rk,n are the throughputs of UE after k of TTI. We first find the maximum and minimum assigned throughput values to the user, then the average throughput is computed by Eq. (5):

$$T_k(N+1) = \max(R_k(N)) - \min(R_k(N)) \quad (5)$$

where max(Rk(N)) is the maximum value of throughput that UE gets in that TTI, min(Rk(N)) is the minimum value of throughput that UE gets in that TTI, and N is the number of average throughput values.

C. Using Geometric Mean to compute average throughput in PF algorithm

Geometric mean [14] is a method for calculating the next state of the average throughput from the previous states. Assume that we have N throughput observations: $R_k(1)$, $R_k(2)$, ……….,$R_k(N)$, arranged in an ascending order of magnitude. The geometric median of these observations is computed as in Eq. (6):

$$T_k(N+1) = \sqrt[N]{R_k(1) * R_k(2) \ldots\ldots * R_k(N)} \quad (6)$$

Where R_k is the throughput that UE gets in that TTI, and N is the number of average throughput values.

VI. Combing Modified PF and Best CQI: MPF-BCQI Scheduling Algorithm

In the proposed MPF-BCQI scheduling algorithm, we calculate the scheduling metric for each UE as a combination of PF and CQI metric. In this manner, both fairness and throughput criteria are considered and satisfied. The RB is assigned to user which has the largest metric. According to the definition given above, the steps of the proposed algorithm are described as follows:

Step 1: Create 2D array of elements where each row represents UE and each column represents RB.

$$\begin{pmatrix} & RB_1 & RB_2 & ..... & RB_{N\,RB} \\ UE_1 & M_{1,1} & M_{1,2} & .... & M_{1,N\,RB} \\ UE2 & M_{2,1} & M_{2,2} & .... & M_{N,N\,RB} \\ ..... & & & & .... \\ UE_N & M_{N,1} & M_{N,2} & .... & M_{N,N\,RB} \end{pmatrix}$$

where Mx,y represents metric at the beginning the initial value is 0.

Step 2: For each subscriber (UE), calculate the average throughput using one of the proposed averaging methods from the above introduced three methods.

- Median method

$$T_k(N+1) = \begin{cases} R_k(\frac{N+1}{2}), & \text{if N is odd} \\ \frac{R_k(\frac{N}{2})+R_k(\frac{N}{2}+1)}{2}, & \text{if N is even} \end{cases}$$

- Range method

$$T_k(N+1) = \max(R_k(N)) - \min(R_k(N))$$

- Geometric Mean method

$$T_k(N+1) = \sqrt[N]{R_k(1) * R_k(2) .... * R_k(N)}$$

Step 3: Determine the priority for each UE by calculating the combination of PF and Best CQI metric for each RB as shown in Eq.(7).

$$a_{k,n} = \arg\max_k \left(\frac{r_{k,n}}{(t_c - 1)T_k + \sum_{n=1}^{N} P_{k,n} r_{k,n}} + CQI_{k,n} \right) \qquad (7)$$

where $\alpha_{k,n}$ is combination metric of PF and Best CQI Metric for each RB

Step 4: Assign RB to UE which has the highest value and set the elements on correspondent row and column of array element to 0.

Step 5: Form new array for the rest elements and repeat the above steps.

The pseudo code of the proposed scheduling algorithm is given in Fig. 4 that represents the four steps mentioned above.

Function Proposed _scheduler ()
For each subscriber
For I= 1 to the numbers of subscribers
Calculate Average throughput using one of the introduced methods

❖ *Median method*

$$T_k(N+1) = \begin{cases} R_k(\frac{N+1}{2}), & \text{if N is odd} \\ \frac{R_k(\frac{N}{2})+R_k(\frac{N}{2}+1)}{2}, & \text{if N is even} \end{cases}$$

❖ *Range method*

$$T_k(N+1) = \max(R_k(N)) - \min(R_k(N))$$

❖ *Geometric Mean method*

$$T_k(N+1) = \sqrt[N]{R_k(1) * R_k(2) .... * R_k(N)}$$

Calculate the combinational Metric of PF and Best CQI

$$a_{k,n} = \arg\max_k \left(\frac{r_{k,n}}{(t_c - 1)T_k + \sum_{n=1}^{N} p_{k,n} r_{k,n}} + CQI_{k,n} \right)$$

Search element in Matrix array of the largest value row I of Matrix array

Set the elements on correspondent row I and Column j of array element=0

Assign the rest element of Matrix to form a new Matrix
Next I

End For
End

Fig. 4. Pseudo code of the proposed MPF-BCQI scheduling algorithm

VII. Simulation Networks and Results

A. Simulation setup

In order to study the performance of the proposed MPF-BCQI scheduling algorithm, we use Vienna LTE System Level Simulator [15]. The main objective of this evaluation is to prove that the proposed scheduling algorithm is able to make a tradeoff between the fairness and throughput achieving the maximum possible fairness at the proper throughput preserving system energy and spectral efficiency. We conducted two set of experiments; the first experiment aims to test the effect of the averaging methods used in the PF scheduling algorithm, while the second experiment aims to evaluate the performance of the proposed MPF-BCQI scheduling algorithm against both the PF and Best CQI algorithms.

The performance of the scheduling algorithms is evaluated in terms of a group of the most important metrics in the field namely; Average throughput, Average cell throughput, Peak Average throughput, Low Average throughput spectral efficiency, energy per bit and Fairness performance metrics. The simulation parameters are presented in Table II. The bandwidth is taken to be 2.6 GHZ to fit urban environment.

The movement speed of User Equipment (UEs) are assumed to be 5 Km/hr. [4].

TABLE II. 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	21, 36
Number of eNodeB	1
Number of Cells	3
Scheduling Algorithm	Proportional Fair and Best CQI
UE Speed	5 km/hr
Macroscopic Pathloss Model	TS36942
Simulation Environment	Urban
eNodeB Antenna Output Power	49 dBm
Inter eNodeB Distance	500 m
Channel model	winner+

Simulations are carried out in two parts: the first part represents the scenario of small size network where the number of UEs is 21 UEs arranged in three cells with seven UEs per cell. The second part represents the scenario of large size (congested) network where the number of UEs is 36 UEs arranged in three cells with twelve UEs per cell. The simulated networks are shown in Fig. 5.

Vienna Simulator was chosen to perform the simulation as it has the ability to calculate different performance parameters such as Average throughput, Average cell throughput, Peak Average throughput, Low Average throughput spectral efficiency, energy per bit and Fairness which is calculated using the relation in Eq. (8) [16, 17]:

$$f_a(x) = \frac{(\sum x_i)^2}{\sum x_i^2} \tag{8}$$

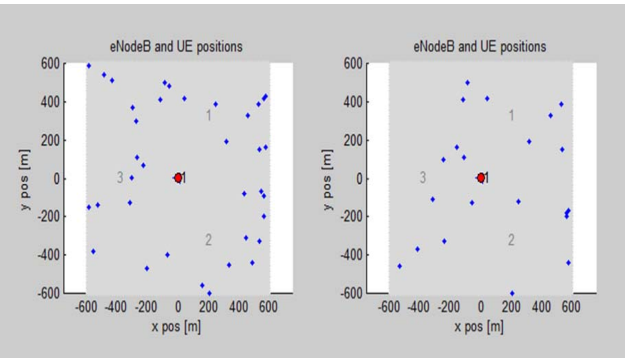

Fig. 5. Positions of eNodeB and UEs of 21 and 36 UEs

B. Results and discussion

Part 1: Comparison of PF scheduling algorithm with new averaging methods

In this section, the performance evaluation of the PF scheduling algorithm using the proposed averaging methods is investigated compared with those in [4] and with the original Proportional Fair. The size of network is assumed to be small size with 21 UEs and large sized with 36 UEs.

a) Results of PF scheduling algorithm with new averaging methods for small size network with 21 UEs

As we have mentioned above, the contribution of the proposed algorithm comes in two folds. Table III. shows the results for the first one. We compare the performance of PF scheduling algorithm with new averaging methods (Median, Range and Geometric Mean) for small size network with 21 UEs with the performance of the original PF and with the averaging methods is investigated compared with those in [4] (Arithmetic Mean, Midrange Mean and Midrange Fair Mean).

The first key performance indicator to be investigated is Fairness. The original PF scheduler is the scheduler that achieved the highest value for fairness compared to the other schedulers. The modified PF with our proposed averaging methods (Median Method, Range Method and Geometric Mean Method), increases the fairness compared to those methods introduced in [4], and the modified PF with Geometric averaging method gives the best value for fairness compared to the other averaging methods.

The second key performance indicator to be investigated is Average throughput. The modified PF with averaging methods in [4] gives improvement in Average throughput value than the original PF scheduler while the modified PF with our proposed averaging methods gives acceptable values for Average throughput larger than the original PF but less than in [4], however, the modified PF with Geometric averaging method gives the best improvement for average throughput compared to the original PF scheduler by 10.19%.

TABLE III. COMPARISON OF ORIGINAL PF SCHEDULER, PF WITH PREVIOUS AVERAGING METHODS IN [4] AND PF WITH THE PROPOSED AVERAGING METHODS FOR 21 UES

Averaging Method	**Average UE Throughput**	**Peak UE Throughput**	**LA UE Throughput**
Original PF	7.95	11.52	4.54
PF-Arithmetic Mean Method [4]	9.33	17.46	2.73
PF-Midrange Method [4]	9.92	29.58	0.73
PF-Midrange Fair Method [4]	9.5	19.66	2.22
Proposed PF-Median	7.75	12.63	3.9
Proposed PF-Range	7.74	12.87	3.74
Proposed PF-Geometric Mean	8.76	12.82	4.88

Averaging Method	Fairness	Average Cell Through put	Average UE Spectral Efficiency	Average System Energy per bit
Original PF	0.911644	55.63	3.24	75.87
PF-Arithmetic Mean Method [4]	0.782017	65.34	3.66	66.79
PF-Midrange Method [4]	0.472513	69.42	3.82	63.01
PF-Midrange Fair Method [4]	0.724606	66.5	3.7	65.72
Proposed PF-Median	0.871936	54.18	3.12	80.73
Proposed PF-Range	0.853956	54.1	3.11	80.74
Proposed PF-Geometric Mean	0.904191	61.35	3.6	69.59

The third key performance indicator to be investigated is the Lowest Average (LA) throughput. The modified PF with our proposed averaging methods gives better value of LA throughput compared to the original PF scheduler and those in [4]. Modified PF with Geometric averaging method gives the best value for LA throughput compared to the other avenging methods and the original PF scheduler as LA is increased by 7.49%.

We conclude from the above discussion that the modified PF with Geometric Mean averaging method gives the best performance in terms of fairness, average throughput, LA throughput, spectral efficiency and energy per bit compared to the original PF scheduler and modified PF with averaging methods (Arithmetic Mean, Midrange Mean and Midrange Fair Mean).

b) Results of PF scheduling algorithm with new averaging methods for large size (congested) network with 36 UEs

Table IV shows the results for large size (congested) network that contains 36 UEs. The results indicate the modified PF with Geometric averaging method gives the best performance in terms of fairness, average throughput, LA throughput, spectral efficiency and energy per bit compared to the original PF scheduler, modified PF with averaging methods in [4] and modified PF with new proposed averaging methods (Median Method, Range Method).

TABLE IV. COMPARISON OF PF, PREVIOUS AVERAGING METHODS IN [4] AND THE PROPOSED AVERAGING METHODS FOR 36 UES

Averaging Method	Average UE Throughpu t	Peak UE Throughput	LA UE Throughput
Original PF	5.22	7.59	2.35
PF-Arithmetic Mean Method [4]	6.1	10.4	1.51
PF-Midrange Method [4]	6.54	21.07	0.08
PF-Midrange Fair Method [4]	6.26	11.82	1.01
Proposed PF-Median	5.31	9.38	1.87
Proposed PF-Range	5.36	9.52	1.89
Proposed PF-Geometric Mean	5.71	8.23	2.55

Averaging Method	Fairness	Average Cell Through put	Average UE Spectral Efficiency	Average System Energy per bit
Original PF	0.887694	62.64	3.6	69.75
PF-Arithmetic Mean Method [4]	0.79303	73.18	4.06	61.36
PF-Midrange Method [4]	0.471878	78.45	4.16	60.92
PF-Midrange Fair Method [4]	0.740645	75.12	4.13	59.83
Proposed PF-Median	0.854982	63.68	3.65	70.55
Proposed PF-Range	0.852868	64.32	3.66	70.44
Proposed PF-Geometric Mean	0.898605	68.56	3.97	64.35

Part 2: Comparison of MPF-BCQI scheduling algorithm with new averaging methods

In this section, the performance evaluation of the proposed MPF-BCQI scheduling algorithm using the proposed averaging methods is investigated compared to those in [4] and with both the original Proportional Fair and Best CQI algorithms. The size of network is assumed to be small size with 21 UEs and large sized with 36 UEs.

a) Results of the proposed MPF-BCQI scheduling algorithm with new averaging methods for small size network with 21 UEs

Table V shows the results for the second fold which compares the proposed MPF-BCQI scheduling algorithm using the proposed averaging methods compared to modified PF with averaging methods in [4] and with both the original Proportional Fair and Best CQI algorithms at small size with 21 UEs. Through these results, it is clear that there is a tradeoff between average throughput and fairness in the original PF scheduler and Best CQI scheduler. The original PF scheduler gives the best value for fairness while Best CQI scheduler gives the worst value for fairness. We found that the proposed MPF-BCQI scheduling algorithm with the original method of computing average gives an acceptable value for fairness but after applying our proposed averaging methods (Median, Range and Geometric Mean methods), we found out that the value of fairness is increased especially in MPF-BCQI with Geometric Mean Method that gives the best fairness value.

TABLE V. COMPARISON OF PF, BEST CQI AND MPF-BCQI WITH THE PROPOSED AVERAGING METHODS FOR 21 UES

Averaging Method	Average UE Throughput	Peak UE Throughput	LA UE Throughput
Original PF	7.95	11.52	4.54
Original Best CQI	9.91	28.98	1.03
Proposed MPF-BCQI	9.35	20.58	3.6
Proposed MPF-BCQI with Median	7.58	15.33	3.6
Proposed MPF-BCQI with Range	7.45	14.86	3.72
Proposed MPF-BCQI with Geometric mean	8.44	15.1	3.85

Averaging Method	Fairness	Average Cell Throughput	Average UE Spectral Efficiency	Average System Energy per bit
Original PF	0.911644	55.63	3.24	75.87
Original Best CQI	0.503756	69.38	3.91	61.28
Proposed MPF-BCQI	0.687117	65.43	3.6	68.48
Proposed MPF-BCQI with Median	0.802672	53.03	3.04	86.27
Proposed MPF-BCQI with Range	0.795574	52.16	3.01	88.86
Proposed MPF-BCQI with Geometric mean	0.821864	59.09	3.36	74.11

With respect to average throughput, Best CQI scheduler gives the best value. We found out that the proposed MPF-BCQI scheduling algorithm with the original method of computing average gives an acceptable value for Average throughput but after applying our proposed averaging methods, fairness is increased, especially in MPF-BCQI with Geometric Mean method that gives an increase of 6.16%.

For the LA throughput, the proposed MPF-BCQI scheduling algorithm with Geometric Mean Method gives an acceptable value which is larger than all the other algorithms except for original PF.

From the above explanation, we found out that the proposed MPF-BCQI scheduling algorithm with Geometric Mean Method gives the best balance tradeoff between Average throughput, LA throughput and fairness with better performance in terms of spectral efficiency and energy per bit.

b) Results of the proposed MPF-BCQI scheduling algorithm with new averaging methods for large size (congested) network with 36 UEs

Table VI shows the results for the second fold which compares the proposed MPF-BCQI scheduling algorithm using the proposed averaging methods compared to modified PF with averaging methods in [4] and with both the original Proportional Fair and Best CQI algorithms at large size (congested) network with 36 UEs. The results are the same pattern as in 21 UEs. Proposed MPF-BCQI with Geometric Mean Method gives the best balance tradeoff between Average throughput, LA throughput and fairness with better performance in terms of spectral efficiency and energy per bit compared to the original PF, original Best CQI, MPF-BCQI and MPF-BCQI with new proposed averaging method (Median and Range methods).

TABLE VI. COMPARISON OF PF, BEST CQI AND MPF-BCQI WITH THE PROPOSED AVERAGING METHODS FOR 36 UES

Averaging Method	Average UE Throughput	Peak UE Throughput	LA UE Throughput
Original PF	5.22	7.59	2.35
Original Best CQI	6.63	18.29	0.04
Proposed MPF-BCQI	5.5	10.06	2.03
Proposed MPF-BCQI with Median	4.97	9.26	1.88
Proposed MPF-BCQI with Range	4.48	9.33	1.81
Proposed MPF-BCQI with Geometric mean	6.15	13.11	1.23

Averaging Method	Fairness	Average Cell Through put	Average UE Spectral Efficiency	Average System Energy per bit
Original PF	0.887694	62.64	3.6	69.75
Original Best CQI	0.50528	79.59	4.57	52.41
Proposed MPF-BCQI	0.81421	66	3.73	69.4
Proposed MPF-BCQI with Median	0.814988	59.62	3.48	79.56
Proposed MPF-BCQI with Range	0.805687	85.13	3.44	81.84
Proposed MPF-BCQI with Geometric mean	0.686961	73.8	3.98	64.23

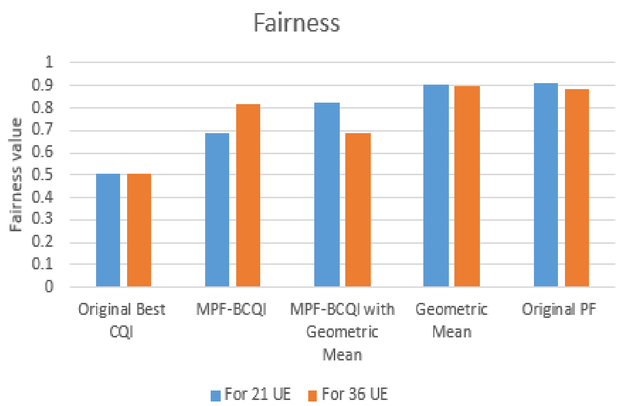

Fig. 6. Fairness for 21 and 36 UEs

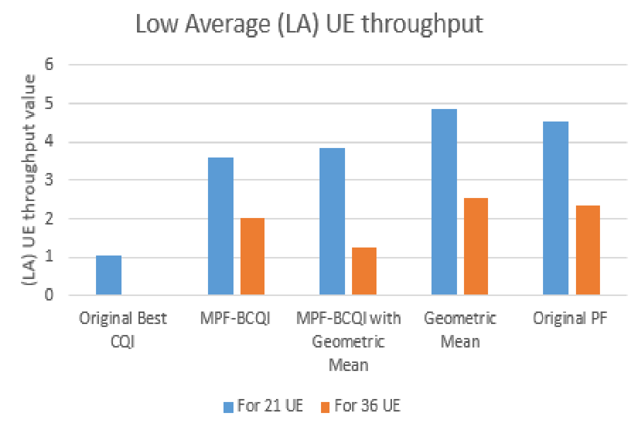

Fig. 7. LA UE Throughput for 21 and 36 UEs.

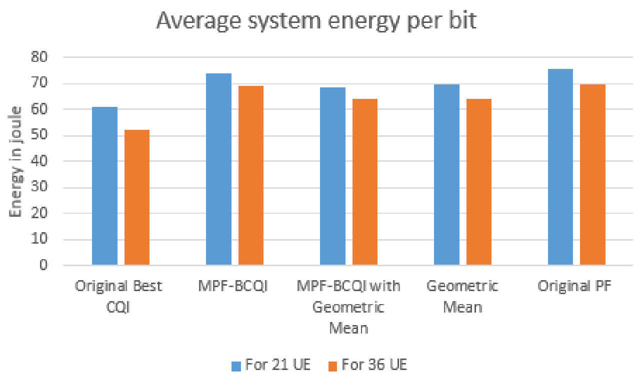

Fig. 8. Average Energy per bit for 21 and 36 UEs.

From the above figures (Fig. 6, 7 and 8), it is clear that the proposed MPF-BCQI scheduling algorithm with geometric mean averaging method gives a proper tradeoff between Fairness and average throughput compared to Best CQI and original PF scheduler in both 21 UEs and 36 UEs scenarios.

CONCLUSION

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. LTE-A is one of the emerging and viable wireless broadband technologies. The main feature of it is it QoS supporting with many application types. To achieve strong support for QoS, LTE-A needs high performance packet scheduling algorithm. In this paper, new scheduling algorithm is proposed based on changing the average throughput computational equation in PF algorithm and on the combination of PF and Best CQI metrics. Using the simulation evaluation of the proposed algorithms using Vienna simulator, the proposed modified PF algorithm, compared to other three averaging methods introduced in [4], shows better fairness. Moreover, the proposed MPF-BCQI scheduling algorithm compared to the original PF and the Best CQI Schedulers shows a good compromise between fairness and throughput. The proposed algorithm with geometric mean average method was the best among the three proposed averaging methods especially in congested networks environment.

In the future work, the performance of the proposed algorithm can be compared with other packet scheduling algorithms such as Round Robin.

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