# Capacity Enhancement Based on Dynamically Adapted PF Scheduling Algorithm for LTE Downlink System

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**Abstract:** *Orthogonal Frequency Division Multiplexing (OFDM) with dynamic scheduling and resource allocation is a key component of most emerging broadband wireless access networks such as Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE). Resource allocation mechanisms in LTE are very critical issues, because scheduling algorithms have the main responsibility for determining how to allocate radio resources for different users. In this paper a dynamically adapted Proportional Fair (PF) scheduling algorithm for capacity enhancement of LTE system is proposed. Performance comparison with the conventional PF downlink scheduler, which is characterized by high fairness but with low throughput, and the Best-Channel Quality Indicator( Best-CQI) scheduling algorithm which is characterized by high throughput but with poor fairness performance is presented. Simulation results show that the proposed algorithm enhances the overall system capacity and also provides fairness in the distribution of the resources. The proposed algorithm improves the average cell throughput by more than 31 %, with a slight degradation in the fairness level as compared with the conventional Proportional Fair PF scheduling algorithm.*

**Keywords:** *LTE, packet scheduling, PF, Fairness, OFDM.*

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## 1. Introduction

The recent increase of mobile data usage and emergence of new applications such as Multimedia Online Gaming (MMOG), mobile TV, Web 2.0, streaming contents have motivated the 3rd Generation Partnership Project (3GPP) to work on the Long Term Evolution (LTE) [19].

The introduction of the LTE will bring significant enhancements compared to the High Speed Packet Access (HSPA) in terms of spectrum efficiency, peak data rate and latency. Since the initial release in 2008, a slightly modified version (Release-9) and a complete fourth generation standard named LTE-Advanced (Release-10) have been developed [5].

Orthogonal Frequency Division Multiple Access (OFDMA) scheme has been adapted for the 3GPP-LTE as a Down Link (DL) radio access technology.

OFDMA has several advantages such as, its robustness against multipath fading, higher spectral efficiency and bandwidth flexibility (support various bandwidth configurations from 1.4MHz up to 20MHz).

However the major disadvantages of OFDMA is that the high Peak-to-Average Power Ratio (PAPR).

So, OFDMA cannot be used for the Up Link (UL), because the power consumption is a critical issue for the User Equipment (UE). As a result, Single Carrier-Frequency Division Multiple Access (SC-FDMA) has been adapted for the 3GPP-LTE as the UL radio access technology. With almost the same advantages of OFDMA, SC-FDMA has lower PAPR. The downlink supports Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (QAM), and 64-QAM data modulation formats, and the uplink supports Binary-PSK (B-PSK), Q-PSK, 8-PSK, and 16-QAM [1, 13, 23, 26, 32]. In order to improve the transmission reliability and also, to increase the system data rate, Multiple Input Multiple Output (MIMO) antenna techniques have been adapted for both the DL and the UL. The maximum numbers of antennas that can be possibly used are four transmit antennas and four receive antennas [17].

LTE physical resource can be represented as a time-frequency radio resource grid, this means that resources are distributed in the time domain and in the frequency domain. In the time domain, radio resources are allocated every Transmission Time Interval (TTI), each TTI has a duration of 1ms. Each TTI is composed by two time slots and each time slot has a duration of 0.5ms. The number of the OFDM symbols within the time slot depends on the type of the cyclic prefix. For short cyclic prefix, which is the default configuration, there are 7 OFDM symbols per time slot. However, for extended cyclic prefix there are 6 OFDM symbols per time slot. The LTE frame consists of 20 time slot, so it has duration of 10ms. The Resource Block (RB) is the minimum resource that can be allocated to the UE and used for information transmission over the air. The RB is a two-dimensional resource (time and frequency), in the frequency domain it consists of 12 sub-carriers each of 15 kHz with total size of 180 kHz and this named as a sub-channel [22, 37].

This paper introduces a dynamically adapted Proportional Fair (PF) scheduling algorithm for capacity enhancement of LTE system. Section 2 deals with the framework for LTE Downlink scheduling. Section 3 reviews some related work in this area. We review and discuss the traditional PF algorithm, and then our modified PF scheduling algorithm is presented in section 4.

Performance evaluation and simulation results are given in section 5 followed by the conclusion in section 6.

## 2. Scheduling in LTE System

Basic LTE network elements consist of a powerful evolved Node B (eNB) station and several User Equipment (UEs) in addition to a gateway [13]. Basic packet scheduling is implemented by the network operator in UE and eNB station for both uplink as well as downlink. However, there are no rigid specifications set by 3GPP for scheduling mechanism leaving the details at the discretion of service provider. Packet scheduling comes under RRM and its main functionality is to decide users that would transmit their data on the air interface.

The packet scheduler, at the eNB allocates the RBs for different active UEs. The optimum design of a packet scheduler algorithm should satisfy the Quality of Service (QoS) requirements for different UEs, maximize the system capacity, and provide high level of fairness while distributing the available RBs among active UEs. The Scheduling algorithms distribute the available RBs among the active UEs taking into account the channel quality between each UEs and the eNB. The channel quality between each UEs in the cell and the eNB is periodically measured by the UE and then, every UEs send this measurements as a Channel Quality Indicator (CQI) feedback message to the eNB [7]. The link adaptation module at the eNB benefits from the CQI feedback message for the selection of the appropriate Modulation and Coding Scheme (MSC), for each UE. The main objective of selecting suitable MSC is to maximize the overall system capacity. This technique has been used by many wireless technologies, such as Enhanced Data for GSM Evolution (EDGE) [12] and Worldwide Interoperability for Microwave Access (WiMAX) [3]. And this technique is simply known as Adaptive Modulation and Coding (AMC).

As shown from Figure 1 the assignments for downlink resources and uplink grants, including the used MCS are carried by the Physical Downlink Control Channel (PDCCH), which is the most important physical channel from a scheduling point of view [16]. The RBs are allocated for different UEs according to the metric up on which the packet scheduler has been designed. For example the *k-th* RBs will be allocated to the *i-th* UE, if this UE has the biggest instantaneous metric among all other UEs.

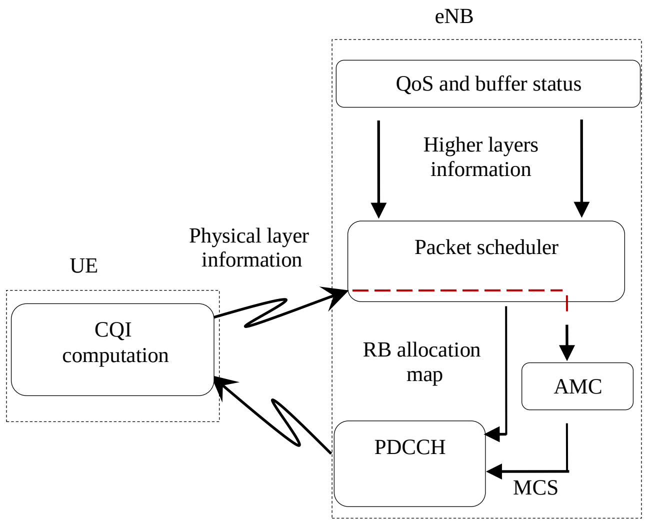


Figure 1. Simplified model of LTE packet scheduler.

Assuming that $m_{i,k}$ is the metric used by a certain packet scheduler in order to distribute the RBs among different UEs, so, the *k-th* RBs will be allocated to the *i-th* UE, if it satisfies the following Equation [4]:

$$m_{i,k} = \max_{j}\{m_{i,k}\} \tag{1}$$

For example the metric of the Best-CQI scheduling algorithm can be written as [15]:

$$m_{i,k}^{best-CQI} = r_k^i(t) \tag{2}$$

Where $r_k^i(t)$ is the instantaneous throughput for the *i-th* user at time instant (TTI) t on the *k-th* RB (calculated based on the CQI).

From Equation (2), it is obvious that each RB is only allocated to the UE that have the best CQI in the current TTI. So, this UE will be able to achieve the maximum throughput in the current TTI and as a consequence the overall will be maximized.

In terms of fairness this scheduling algorithm is not fair. In a practical situation, each mobile terminal will experience different channel conditions on each RB, due to differences in the distance and shadow fading between the base station and the mobile terminal. In this case, for a relatively long time, the channel conditions experienced by one mobile terminal could be worse than the channel conditions experienced by other mobile terminals, and the Best-CQI scheduling algorithm may ‘starve’ the mobile terminals with the bad channel condition in the way that the mobile terminal(s) with bad channel conditions will never be scheduled (i.e., example users at the cell edge). In a worst case scenario, (virtually all the time) only one user could be scheduled [32].

## 3. Related Work

A practical scheduler should be capable of maximizing the overall system capacity while still satisfying some degree of fairness between the users [9, 14, 28, 33].

Recently, there are several packet scheduling algorithms have been introduced in order to provide higher throughput with fairness ensured to all its users.

The scheduling algorithm in [6], for example, tries to make this balance using Assignment Model, which effectively maps UEs to RBs during each TTI. The proposed algorithm in [6] makes modification on the Best-Channel Quality Indicator (Best-CQI) algorithm, which is characterized by high data rates at cell level but poor fairness, trying to provide fairness in the distribution of the resources, while at the same time keeping the system capacity utilization as high as possible. In [29], the authors propose a method for multi-user scheduling that operates on the boundary of the achievable multi-user rate region while guaranteeing a desired long term average fairness. Another scheduling algorithm based on the utility function has been implemented in [21], in order to improve the performance of the LTE system, particularly, improving the throughput and fairness performance. The throughput fairness between users can be effectively controlled by dividing the packet scheduler into a time domain and a frequency domain and utilizing different algorithms in both domains, as implemented in [21].

A Generalized Proportional Fair (GPF) scheduling approach and its application to OFDMA with frequency scheduling has been presented in [34].

Compared to a system without frequency scheduling this increases the system throughput and yields an improved fairness with respect to the allocated resources and with respect to the achieved data-rate per user. An adaptive proportional fair scheduling algorithm for LTE system is proposed in [24], the author tried to design an algorithm that increases the fairness level among the UEs with a limited degradation of the whole system throughput, by adjusting the scheduling priority according to individual user's channel condition.

The PF scheduling algorithm is considered as the typical algorithm that can provide high level of fairness with acceptable throughput [10, 11, 20, 31, 36]. The design of a self-optimizing scheduler architecture which includes a controller element that dynamically adjusts the fairness parameters of the scheduler is proposed in [27]. The authors in [27] proposed the application of a controller that is able to automatically adjust the scheduler parameters and estimated the potential gain from such an adaptive parameterization. They presented a basic implementation of a controller which continuously adapts fairness parameters of an α-fair scheduler to the current load situation of a cell.

In this paper we try to improve the performance of the LTE system by improving the throughput performance of the well-known PF scheduling algorithm in a dynamic way. The proposed scheduling algorithm tends to distribute the resources fairly among different users, therefore enabling fairness while at the same time trying to maximize system capacity performances within the cell. We compare the performance of the proposed algorithm to other algorithms in the literature. Then we evaluate the performance of the proposed algorithm via simulations and reach to the conclusion that the proposed algorithm is very efficient in terms of both throughput and fairness.

## 4. Dynamically Adapted PF Scheduling Scheme

In PF scheme the past average throughput used as a weighting factor of the expected data rate to improve the fairness performance especially for UE in bad conditions [8, 25, 35]. The metric of PF scheme is as follows:

$$m_{i,k}^{PF} = \frac{r_k^i(t)}{\bar{R}^i(t)} \tag{3}$$

Where $\bar{R}^i(t)$ is the average delivered throughput to the *i-th* UE until time $t$ and can be updated using an exponentially weighted low-pass filter [2, 30]:

$$\bar{R}^i(t+1) = (1-\frac{1}{t_c})\bar{R}^i(t) + \frac{1}{t_c} r_i(t) \tag{4}$$

Here $t_c$ is the averaging window length over which the average delivered throughput is calculated and $r_i(t)$ denotes the actually realized throughput to the $i-th$ UE at the previous TTI.

According to Equation (3), for conventional PF scheduling algorithm the *k-th* RB should be allocated to the *i-th* UE such that:

$$j = \max_i(\frac{r_k^i(t)}{(\bar{R}^i(t)}) \tag{5}$$

The proposed scheduling algorithm aims to achieve a significant increase in the total throughput with a slight reduction in the fairness performance compared to the conventional PF scheduling algorithm. The new metric of the proposed Capacity Enhanced (Cap-Enh) scheduling algorithm can be written as:

$$m_{i,k}^{Cap-Enh} = \frac{r_k^i(t)}{(\bar{R}^i(t))^{\beta}} \tag{6}$$

Here $\beta$ is given by:

$$\beta = exp(\frac{-r_k^i(t)}{r_k^{max}(t)}) \tag{7}$$

where $r_k^{\max}(t)$ is the maximum instantaneous UE throughput of all UEs at time instant (TTI) t on the *k-th* RB.

So, according to the new metric the *k-th* RB should be allocated to the *i-th* UE such that:

$$j = \max_i\left(\frac{r_k^i(t)}{(\bar{R}^i(t))^{\beta}}\right) \tag{8}$$

The new adaptive parameter $\beta$ introduced in the proposed metric Equation is responsible for significantly improving the average cell throughput with slightly lower fairness level than that of the conventional PF scheduling algorithm. The operating range of $\beta$ is between 0.3679 and 1 ($0.3679 < \beta < 1$). The effect of the adaptive parameter $\beta$ can be explained as follow:

- As the *i-th* UE instantaneous throughput $r_k^i(t)$ increases to the maximum ($r_k^{\max}(t)$), the parameter $\beta$ decreases to the minimum value $\beta_{\min}=0.3679$, and hence metric of the proposed scheduling algorithm $m_{i,k}^{Cap-Enh}$ increases which increase the opportunity of allocating the *k-th* RB to this UE. So, the proposed scheduling algorithm becomes able to give high priority to UE with significantly high instantaneous throughput and hence to significantly improve the throughput performance with slightly lower fairness level than that of the conventional PF scheduling algorithm.
- On the other hand, as the *i-th* UE instantaneous throughput $r_k^i(t)$ becomes significantly lower than $r_k^{\max}(t)$ ($r_k^i(t) << r_k^{\max}(t)$), the parameter $\beta$ increases to the maximum value $\beta_{max}=1$, and hence metric of the proposed scheduling algorithm $m_{i,k}^{Cap-Enh}$ becomes the same as metric of the PF algorithm $m_{i,k}^{PF}$ which means that the performance of the proposed scheduling algorithm becomes the same as that of the PF algorithm to improve the fairness performance.

We can say that the proposed scheduling algorithm dynamically adapts its performance according to the channel conditions between the UE and the eNB which directly affect the UE instantaneous throughput $r_k^i(t)$ to significantly improve the throughput performance. This can be explained by looking deeply at the values of $\beta$, for a very poor channel conditions (low CQI), $\beta$ increases toward the maximum value ($\beta \cong 1$). In this case, the performance of the proposed scheduling algorithm tends to approach the performance of the PF scheduling algorithm with fairness improvement. On the other hand, for a very good channel conditions (high CQI), $\beta$ decreases toward the minimum value ($\beta \cong 0.3679$). In this case, the performance of the proposed scheduling algorithm tends to approach the performance of the Best-CQI scheduling algorithm with throughput enhancement.

Thus, the proposed scheduling algorithm tends to give a compromised performance between that of the Best-CQI scheduling algorithm which is characterized by high throughput but with poor fairness performance, and that of the conventional PF scheduling algorithm which is characterized by high fairness but with low throughput.

## 5. Performance Evaluation and Simulation Results

The performance evaluation of the proposed scheduling algorithm is done by using the LTE Link Level Simulator (LLS) [15]. Table 1 summarises the main simulation parameters that are used in the performance evaluation of the considered scheduling algorithms.

Table 1. The system simulation parameters [30].

| Parameter | Value |
|---|---|
| Frequency Band | 2.14 GHz |
| System Bandwidth | 20 MHz |
| No. of User Equipment (UE) per eNB | 10, 20… 60 UEs |
| No. of eNB | 7 eNBs |
| Simulation Length | 100 TTIs |
| Antenna Configuration | 1 Transmit, 1 Receive (1X1) |
| UE Speed | 5 km/hr |
| Uplink Delay | 3 TTIs |
| The Distance between eNBs | 500 m |
| eNB's Transmit Power | 40 watts |
| The Thermal Noise Density | -174 dBm/Hz |
| Receiver Noise Figure | 9 dB |

Simulation results are presented to analyse and compare the performance of the proposed scheduling algorithm (referred to as Cap-Enh) with that of the Best-CQI and the conventional PF scheduling algorithms.

Figure 2 presents the average cell throughput of the proposed scheduling algorithm compared with that of the PF and the Best-CQI scheduling algorithms for different number users per cell. It is shown that the proposed scheduling algorithm significantly improves the average cell throughput by more than 31% as compared with the conventional PF scheduling algorithm.

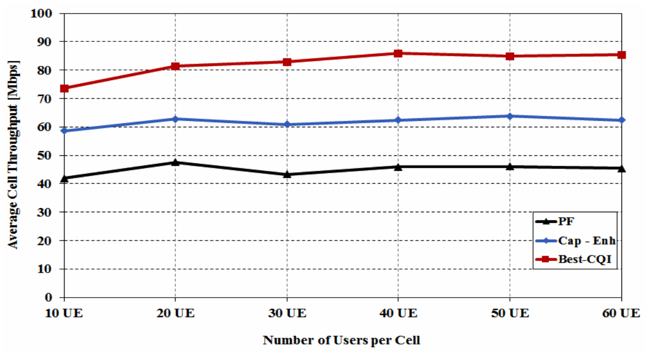


Figure 2. Average cell throughput for different scheduling algorithms.

Also, it is shown that as the number of users in the cell increases the cell capacity slightly increases, especially for the Best-CQI scheduling algorithm, while the proposed scheduling algorithm and the conventional PF scheduling algorithm still have to take into account the fairness performance. The Best-CQI scheduling algorithm benefits from multi-user diversity, which can be explained as, when the number of UEs in a cell increased, the probability of finding a UE with a good CQI at a given time and on a given frequency increased.

Similarly, Figure 3 shows the same behaviour of the considered schedulers by presenting the average cell spectral efficiency.

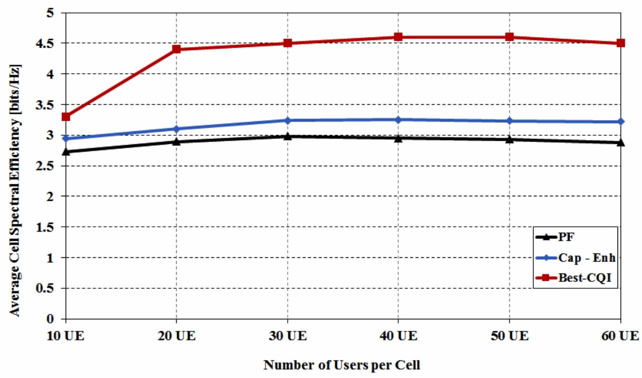


Figure 3. Average cell spectral efficiency for different scheduling algorithms.

The well-known Jain's fairness index [18] of the proposed scheduling algorithm compared with that of the PF and the Best-CQI scheduling algorithms for different number UEs per cell is presented in Figure 4. Jain fairness index has a maximum value of one, so, the more this value closes to one the more the scheduling algorithm behaves fair in allocating the RBs among the UEs. It is obviously that the Best-CQI scheduling algorithm provides the worst fairness performance and cannot guarantee an acceptable level of fairness among the active UEs. On the other hand, the proposed scheduling algorithm and the conventional PF scheduling algorithm are able to guarantee significantly high fairness level. Also, the fairness performance the conventional PF scheduling algorithm slightly outperform that of the proposed scheduling algorithm.

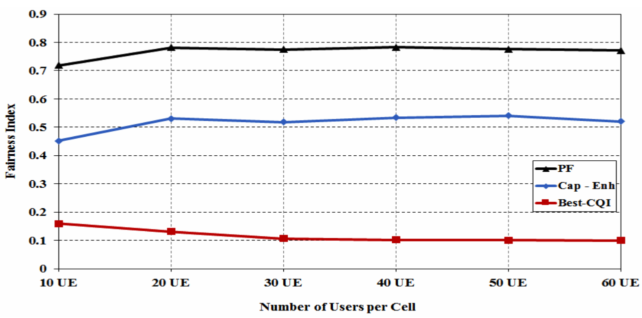


Figure 4. Jain's Fairness Index for Different Scheduling Algorithms.

It is important to mention that the average UE throughput is increased as the number of UEs per cell decreased as shown in Figure 5, and this is normal because the scheduling algorithms have to distribute the same amount of RBs among all the active UEs.

Also, the Best-CQI scheduling algorithm and the proposed scheduling algorithm provide more significant increase in the average UE throughput as the number of UEs per cell decreases.

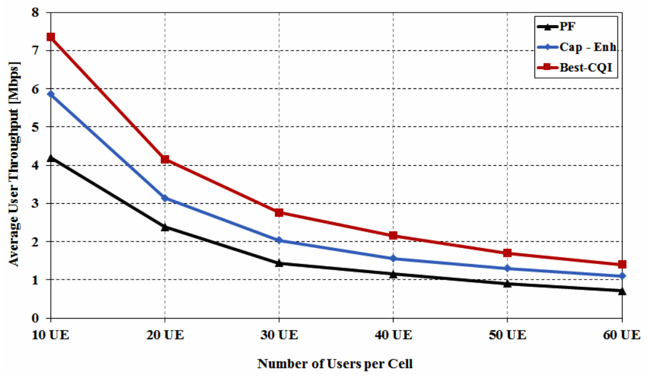


Figure 5. Average user throughput for different scheduling algorithms.

## 6. Conclusions

In this paper a dynamically adapted PF scheduling algorithm for capacity enhancement of LTE system is proposed. Its performance is compared with the Best-CQI and the conventional PF algorithms.

The proposed scheduling algorithm tends to give a compromised performance between that of the Best-CQI scheduling algorithm which is characterized by high throughput but with poor fairness performance, and that of the conventional PF scheduling algorithm which is characterized by high fairness but with low throughput.

So, the proposed scheduling algorithm becomes able to significantly improve the throughput performance with slightly lower fairness level than that of the conventional PF scheduling algorithm. Simulation results show that the implementation of the proposed scheduling algorithm enables improvement of the overall system capacity and also provide fairness in the distribution of the resources.

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