Proportional fair buffer scheduling algorithm for 5G enhanced mobile broadband

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Article Info	ABSTRACT
	The impending next generation of mobile communications denoted 5G intends to interconnect user equipment, things, vehicles, and cities. It will provide an order of magnitude improvement in performance and network efficiency, and different combinations of use cases enhanced mobile broadband (eMBB), ultra reliable low latency communications (URLLC), massive internet of things (mIoT) with new capabilities and diverse requirements. Adoption of advanced radio resource management procedures such as packet scheduling algorithms is necessary to distribute radio resources among different users efficiently. The proportional fair (PF) scheduling algorithm and its modified versions have proved to be the commonly used scheduling algorithms for their ability to provide a tradeoff between throughput and fairness. In this article, the buffer status is combined with the PF metric to suggest a new scheduling algorithm for efficient support for eMBB. The effectiveness of the proposed scheduling strategy is proved through à comprehensive experimental analysis based on the evaluation of different quality of service key performance indicators (QoS KPIs) such as throughput, fairness, and buffer status. *This is an open access article under the [CC BY-SA](#) license.*

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1. INTRODUCTION

Based on analog technology, the first generation of mobile communications 1G was intended exclusively for voice communication. In the context of its evolution, 2G has improved voice and text messaging thanks to the digitization. The third-generation 3G was developed to support optimized voice as well as low-cost and low-data mobile Internet. By the time, the demand for high data application has increased, introducing the fourth generation 4G known as long term evolution (LTE) and offering high capacity and data for large telecommunications networks. Aiming to enable a fully connected world, 5G communication incorporates current and new infrastructures, innovative and heterogeneous technologies to satisfy the severe capability needs and guarantee maximum coverage for users in different circumstances [1]. This full connectivity is targeted not only to communicating people, but also enables the communication of machines and things that can bring evaluated value to improve the operational efficiency of the society and facilitate our everyday life [2].

Towards this achievement, three main use scenarios are supported by 5G. According to international telecommunications union-radio communication sector (ITU-R), 5G use cases are classified as enhanced mobile broadband (eMBB) requiring higher data rates, ultra-reliable and low latency communications (URLLC) where devices rely on very short latency to perform their task and massive machine-type communications that connect a large number of devices [3]-[5]. To support these use cases, new requirements have been defined such as 10Gbps throughput for eMBB, a latency of 1 millisecond for URLLC cases, and a high connection density for massive machine type communications (mMTC) [6]. In addition to these specifications, the upcoming 5G technology proposes common requirements for all use cases, it aims to increase bandwidth efficiency, improve energy consumption, and provide a scalable and customizable network [7]. Despite the benefits of the physical layer features that come in support of those requirements, improving the spectral efficiency and increasing the throughput to meet the quality of service (QoS) requirements of eMBB remains challenging [8].

In the literature, numerous articles considered radio resource allocation, and proposed divers scheduling algorithms and schemes. As presented in [9], C. F. Müller the Round Robin algorithm consists of sharing the resources equally to serve all user equipments (UEs) in the current cell. Known as one of the simplest scheduling algorithms, Round Robin is used by many systems because it is easy to implement. The sest CQI scheme takes the channel quality information into account, by assigning resource blocks to users with the best radio link conditions through the analysis of UE feedback that contains channel quality indicator (CQI) as detailed in [10]. The PF scheduler presented in [11] allocates resources to users according to their average achievable data rate, in this manner, it equally serves users even those having a very low CQI value. maximum largest weight delay first is a scheduling scheme for real-time and non-real-time services [12]; it considers the time of the first package of the queue $D_{HOL, i}$ to offer priority to real-time traffic. Exponential/PF (EXP/PF) considers both real time and non-RT traffic [13]. EXP-MLWDF, based on the modified largest weighted delay first (MLWDF) algorithm, this scheme promotes the users with bad channel conditions by applying the exponential term on the MLWDF metric as detailed in [14]. In [15], M. I. Saglam and M. Kartal the authors proposed a 5G NR eMBB downlink lean algorithm that aims to balance resource efficiency and flow fluency. In order to improve the overall QoS, the authors in [16] proposed a power-efficient QoS Scheduler. M. Kalil [17] proposes an efficient low-complexity scheduler that meets the scheduling to the virtualization techniques. The virtual token scheme (VT-MLWDF), Queue-HOL-MLWDF, Channel-QoS aware, and E-MQS schemes given in [18]-[21] respectively have associated virtual token queue to their metrics to avoid packet loss. The qos class identifier (QCI) scheduler presented in [22] consists on a scheduling algorithm based on the demands of QoS.

In this article, we focus on downlink traffic of eMBB, whose challenges reside in enhancing the user's achieved bit rate, reducing the amount of data in the buffer, and the limited available radio resources to satisfy these needs. Additionally, this paper is addressing the scheduling problem by dynamically assigning radio resource blocks (RBs) to each user according to its buffer status. As well as, a novel downlink resource allocation algorithm that uses the buffer status and channel conditions to address performance degradation is proposed. The new algorithm metric provides radio resource allocation to users based on the status of their buffer to satisfy the demands of QoS.

The rest of this paper is organized is being as, in section 2 we present the 5G technology architectures and its downlink scheduling process as defined by the 3GPP for release 15. Section 3 defines our novel scheduling algorithm. In section 4 we analyze and compare the performances of the newly developed algorithm with the literature scheduling schemes. Finally, a conclusion to summarize this work in section 5.

2. PROPOSED SCHEDULING ALGORITHM

In the previous works [19], [21], [23], the buffer size was used only to avoid buffer overflow in order to minimize packet loss. Meanwhile, in our proposed algorithm we are using the buffer size information to perform an effective downlink resource allocation. The buffer status report is a signal sent from the UE to the nbridge (Enb) (called gNodeB (gNB) for 5G systems), carrying the information on how much data is in the buffer to be sent out. Since the buffer state information is tightly connected to the QoS, in our new scheduling algorithm called "The Proportional Fair Buffer", we use the buffer size parameter to allow a flexible assignment of the resource according to the amount of data to be sent. In this way, the flow with a higher buffer size will have a higher metric, hence the highest priority to have more RB assigned than other flows, and this will automatically enhance the achievable throughput. However, higher data rates are not the only requirements of eMBB, guarantee fairness between all cell users remains important. Thus, to maintain the network equity in our scheduling scheme, the second part of the metric is the same as the PF metric known to be a fair scheduler. Our metric expressed in is denoted $w_{i,j}$ to refer to the i-th user at j-th RB.

$$w_{i,j} = \frac{r_{i,j}}{\overline{R_i}} \times b_i \tag{1}$$

This metric is calculated by adding the buffer size denoted b_i, to the ratio of the instantaneous rate assigned to i-th flow at the j-th RB $r_{i,j}$, and the average transmission data rate $\overline{R_i}$. In the metric, the average throughput information is updated as in [24]. α parameter takes a value between 0 and 1. Each resource block is assigned to the subscribers with the highest metric order in each TTI.

$$\overline{R_i} = ((1-\alpha)*PastDataRate) + (\alpha*InstantaneousDataRate) \tag{2}$$

The complete procedure of our new algorithm is summarized is being as:

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Algorithm: The proportional Fair Buffer
Inputs:
        •   The buffer status: bᵢ
        •   Average Data rate: Rᵢ
        •   Number of resource block:Nᵣᵦ
        •   Number of symbols per slot for UEi in the jth RB: sᵢ,ⱼ
        •   TTI Duration:Dₜ
        •   Number of eligible UEs: Nᵤ
Initialisation: selectedUE=0
for i = 1: Nᵤ do
        for j=1:   Nᵣᵦ do
            bᵢ = bufferStatus(i)
            Rᵢ = pastDataRate(i)
            if (bᵢ > 0) then
                rᵢ,ⱼ = ((Nᵣᵦ* sᵢ,ⱼ * 14 * 12)*1000)/ Dₜ
                wᵢ,ⱼ = (rᵢ,ⱼ/ Rᵢ)* bᵢ
                if (wᵢ,ⱼ > maxW) then
                    maxW = wᵢ,ⱼ
                     selectedUE = eligibleUEs(i);
                  end if
            end if
        end for
        Output: selectedUE
   end for
```

3.   RESEARCH METHOD

The technical report European telecommunications standards institute (ETSI) 3 generation partnership project (3GPP) technical report (TR) 38.912 version 15.0.0 release 15 [25], presents two ranges of carrier frequencies, frequency range 1 denoted FR1 where frequency bands are sub-6GHz and frequency range 2 denoted FR2 which uses mm-Wave (beyond 6 GHz). The 5G new radio (NR) is expected to take advantage of this spectrum, with up to 400 megahertz of bandwidth and possibly more later. Moving onto more detailed points on the physical layer, the subcarrier spacing fixed in long term evolution (LTE) at 15 kilohertz can now take values between 15 and 240 kilohertz according to different numerologies specified in [26].

The study of non-standalone (NSA) between frequencies sub-6 GHz band and the mm-wave band was intensively conducted and concluded that for NSA both bands (used for LTE and NR) are below 6 GHz. [25] In this paper, our scheduling strategy, based on the non-standalone architecture, assigns the physical downlink shared channel (PDSCH) [27] resources to a set of static user equipment (UEs) connected to a gNB. In this simulation, we use frequency division duplexing (FDD) mode because frequency domain scheduling provides a significant contribution to the performance advancements. The performance of the scheduling strategy is evaluated in terms of achieved medium access control (MAC) throughput and fairness in resource sharing.

According to Technical Report 38.913, possible deployment scenarios are indoor, rural, with urban cells, air-to-ground, and connected cars as potential applications. In this work, we mainly concentrate on the resource scheduling for a downlink wireless network, where a single gNB is deployed at the center of an urban cell coverage area. High traffic loads and high user densities in city centers are the main features of the dense urban microcellular scenario [28]. Conforming to the attributes listed in Table 6.1.2-1 of the 3 GPPP technical report, the carrier frequency used for evaluation purposes of frequency range 1 (FR1) is 4 GHz, a

density of 10 users per TRxP with full buffer traffic is the baseline for this scenario, also a max bandwidth of 100 MHz is defined with 30 KHz of subcarrier spacing, which results in 273 RB as per 3 GPP TS 38.104 [29]. The sum-up of the main scenario parameters is presented in Table 1.

Table 1. Scenario parameters

Parameter	Value
Carrier frequency	4 GHz macro layer
OFDMA Cyclic Prefix	Normal (7) [30]
Bandwidth	100MHz
Number of slots/frames	20
Number of frames/simulations	100
Durations of frame	10ms
Simulation time	1 s
Number of RB	273
Subcarrier spacing	30 kHz
Number of users	10
Number of cells	1
Modulation order	64QAM -256QAM (depending on CQI value)
Channel Model Speed of UE	Pedestrian
Antenna number	8
Number of UE receive antennas	2

The performance evaluation of the proposed proportional fair buffer (PF-Buffer) downlink scheduler and other commercial schedulers is analyzed according to their throughput, goodput, fairness, and accumulated buffer values. The user performance corresponds to the ratio of the successfully delivered data bits by the overall simulation time [31]. The throughput is defined as an important indicator of the performance and quality of a network connection.

$$Throughput = \frac{\sum RxPacketSize}{DeliveryTime} \tag{3}$$

Goodput is an important performance measure to evaluate the effective rate experienced by the user. Also known as the application-level throughput of communication, the goodput considers the number of useful data bits successfully delivered over a communication channel, which is divided by the time it takes to successfully transmit it [32]. According to [33] the goodput is expressed by (4):

$$Goodput = \frac{UsefulData}{TransmissionTime} \tag{4}$$

Fairness in mobile systems has been widely studied as an important system performance metric enabling the equal sharing of radio resources between all the users [34]. A fairness calculation is necessarily correlated with a certain achievement, including reducing delays and maximizing the amount of resources allocated [35]. Fairness can be obtained in many ways considering different perspectives, the commonly used fairness metrics in the literature are detailed in [36]. According to the most used fairness metric, Jain's index [37], the level of equity received by each stream is the flow rate reached by each flow at the end of each simulation. In the (5), xi is the user's throughput, while n represents the active flows.

$$Fairness_{Index} = \frac{(\sum x_i)^2}{n \times \sum x_i^2} \tag{5}$$

4. RESULTS AND DISCUSSION

We present in this paragraph the analysis of the simulation results of the proposed proportional fair buffer (PFB) scheduler compared to conventional scheduling algorithms (Round Robin [9], best CQI [10], and proportional fair [11]) and the recent algorithms in the literature (CQI scheduler [22] and Lean Scheduler [15]). The obtained results are analyzed in terms of throughput, goodput, fairness, and accumulated buffer values.

4.1. Throughput

Figure 1 shows that the best continuous quality improvement (CQI) and the proposed PF-Buffer provide high throughput in the order of 239.4 Mbps and 238 Mbps respectively while the lean scheduler that provides 224.3 Mbps comes third and the QoS class identifier (QCI) scheduler takes the fourth position giving a 218 Mbps throughput compared to the PF with 213.4 Mbps data rate and revenue regulations (RR) which does not exceed 200 Mbps. Despite providing the higher data rate value, the best CQI assigns only 0.23 Mbps to users with bad channel conditions since its metric is based only on channel quality indicator. Whereas, the proposed algorithm guarantees to users having bad channel conditions and a higher amount of data to be sent in the buffer, a minimum of 9.2 Mbps throughput, surpassing significantly the minimum data rate of the other scheduling algorithms which does not exceed 4.6 Mbps. Furthermore, it can be seen from Figure 1 that the Best CQI max user data rate is higher than the proposed PF-Buffer algorithm, presenting respectively 59.9 Mbps and 56.4 Mbps. Meanwhile, the proposed algorithm is outperforming the Best CQI algorithm in terms of the gap between the maximum throughput and the minimum data rate that a user can have. Namely, the Best CQI and the proposed PFB algorithm present a gap of 59 Mbps and 47.2 Mbps respectively. Note that the gap information provides a clear idea about how efficiently the resources are allocated. Overall, the proposed algorithm seems to provide the best performance in terms of throughput.
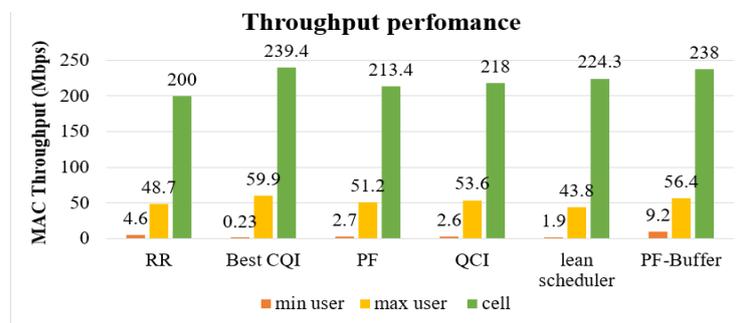

Figure 1. Throughput performance

4.2. Goodput

As depicted in Figure 2, the best CQI scheduler presents the higher cell goodput too, in a range of 214.4 Mbps, followed up by the proposed PF-Buffer with 212 Mbps. The lean scheduler comes third presenting a goodput of 200.7 Mbps. The QCI scheduler and PF provide almost the same goodput 197.8 Mbps and 195.5 Mbps respectively. The RR allocates the lowest goodput level in order of 173 Mbps per cell. The proposed scheduling scheme guarantees a minimum goodput of 6.6 Mbps for the distant users or those having poor channel conditions meanwhile the best CQI assigns only 0.1 Mbps goodput for those users. As the goodput refers to the throughput achieved by the end application, a user having a higher goodput value means that this user is experiencing a high quality of experience (QoE) since he uses his application as much efficient as it is possible. According to the simulation results in Figure 2, the proposed PF-Buffer scheduling scheme affords the second highest cell goodput value to the users, besides, it is the only one that guarantees a meaningful goodput to cell edge users.
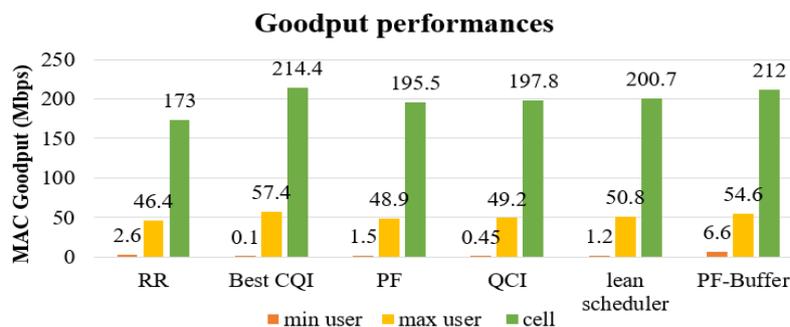

Figure 2. Goodput performance

4.3. Fairness

It can be noticed from Figure 3, that fairness performance differs from a scheduler to another. Where the RR is the most equal algorithm having a fairness index that exceeds 98%. The proposed PF-Buffer comes second with 91.28% fairness of resources sharing among the users. The QCI scheduler and the PF achieve respectively 86% and 84.11% besides the lean scheduler reach the 78.6% threshold while the best CQI achieved only 50% equity. As a result, our proposed scheme remains the fairest among these scheduling algorithms, following the Round Robin scheduler, known as the classical fair scheduling scheme in literature.
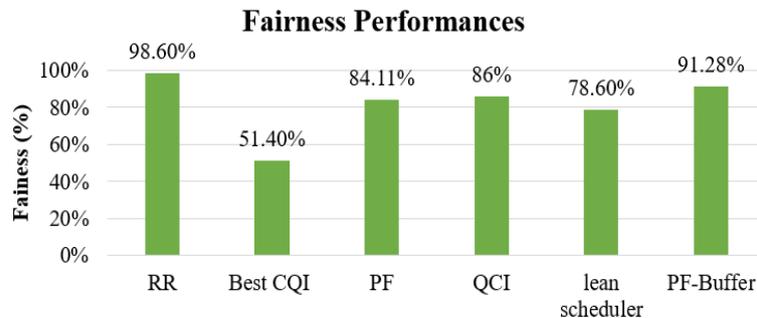

Figure 3. Fairness performance

4.4. Buffer status

The buffer status is an important measure of the performance of communication systems since it refers to the ability of networks to deliver all the data that one user transmits. In this simulation results, we analyze the accumulated buffer which is calculated by amassing the buffer status of all cell users at the end of the simulation. Remarkably, the proposed scheduling scheme enables to process the maximum data compared to the other algorithms. As illustrated in Figure 4, the proposed PF-Buffer algorithm permits the transmission of a big amount of data and empty the users' buffer, the accumulated buffer of users at the end of the evaluation simulation is 176.72 KBs, followed by the Best CQI scheme with 177 KBs buffer data, whereas the lean scheduler and the PF scheduler buffer remain full of almost 228.8 KBs and 244 KBs respectively. The QCI scheduler and RR come in the last place with 255.2 KBs and 300.72 KBs respectively. Besides using the buffer as a parameter in our metric to enhance the overall scheduling performance, the proposed PFB algorithm avoids the buffer's overflow, therefore, it reduces the packets' loss and strengthens the reliability of the system that is an important requirement for 5G eMBB.
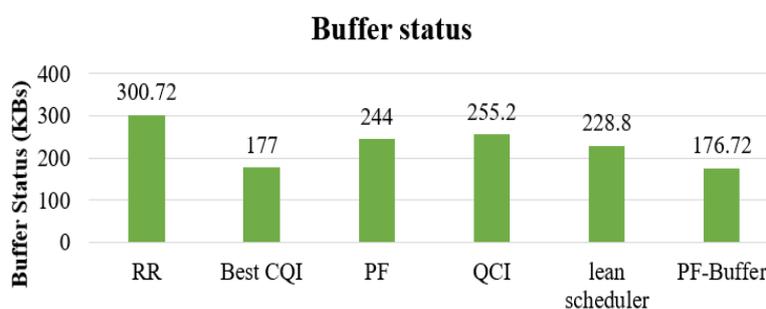

Figure 4. Accumulated buffer performance

As depicted in Table 2, the overall performance evaluation results show that the new scheduler (PF-Buffer) has a superior cell throughput and goodput performance over all the evaluated algorithms except the Best CQI. The fairness performance of our proportional fair buffer scheduler is located between RR and QCI scheduler. The novel scheduling scheme empties the users' buffer by transmitting the maximum data within the simulation duration. As stated previously, our proposed scheduling algorithm responds efficiently to 5G eMBB needs by providing the best tradeoff between the different requirements such as throughput, goodput, fair resource allocation, and reliability of the data transmitted.

Table 1. Ranking of the evaluated methods

Rank	Throughput	Goodput	Accumulated buffer	Fairness
1	Best CQI	Best CQI	PF-Buffer	RR
2	PF-Buffer	PF-Buffer	Best CQI	PF-Buffer
3	lean scheduler	lean scheduler	lean scheduler	QCI
4	QCI	QCI	PF	PF
5	PF	PF	QCI	lean scheduler
6	RR	RR	RR	Best CQI

4.5. Implementation and execution

The presented experiments have been performed on a Lenovo LEGION with Intel ® Core i5-9th Processor 2.4 GHz Boost, 8 GB of RAM, running with Windows 10x64 operating system and equipped with NVIDIA GeForce GPU GTX1660Ti. The proposed algorithm is coded using the 5G Toolbox of Matlab2020a environment. The authors are willing to share more details of this algorithm's steps and codes with the scientific community.

5. CONCLUSION

The enhanced Mobile BroadBand (eMBB) of the fifth-generation wireless systems aims to provide higher performances compared to its anterior 4G besides assigning radio resources efficiently. In this perspective, several works have studied radio resource allocation and scheduling. Throughout this paper, we optimized 5G mobile communication resources and flow efficiencies by exploiting the buffer status parameter. As a result, we propose a new downlink scheduling algorithm designed for eMBB. The proposed scheduler aims to provide an efficient downlink scheduling of UEs. The metric uses the channel condition information and the buffer status to allocate radio resources to the users. Compared to classic schedulers and newly developed algorithms in the literature, the new scheme is more accurate according to efficiency, fairness, and buffer status. Our proposed scheduling algorithm provides a good tradeoff between the fairness and the experienced data rate by guaranteeing a minimum acceptable goodput to all the users in the cell. Also, it enables a fluent transmission of the buffer's data. Despite the enhancement provided by our new scheduling algorithm, we intend in future works to propose a new scheduling algorithm that increases the experienced data rate to meet the requirements of eMBB 5G networks for dense urban scenarios.

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