A QoS-Aware Downlink Packet Scheduler Using Token Bucket Algorithm for LTE Systems

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Abstract—**LTE is one of the leading technologies to meet the requirements of 4G telecommunication systems. Important design parameters intended to achieve this goal include high data rate, low latency and efficient network bandwidth requirements. Scheduling in LTE is one of the most important functions of the eNodeB due to the existence of different subcarriers in OFDMA modulation and the frequency diversity of the channel. However, the scheduling algorithms are not defined by the Third Generation Partnership Project (3GPP) and are left open for designers and manufacturers. In this paper, we propose a novel QoS-Aware scheduling algorithm in which a Token Bucket algorithm is used in order to limit the access to the resources used by the real time traffic. Simulation results show that the Token Bucket algorithm, by limiting the amount of resources allocated to real time and high priority traffic streams, causes other type of traffic not to be starved. This feature of the scheduling algorithm not only increases the efficiency of the frequency utilization, but also causes the QoS requirements of various traffic classes to be satisfied.**

Keywords-QoS; OFDMA; LTE; Token Bucket

I. INTRODUCTION

Increasing need for high-speed multimedia services in the communication systems and the expectation to access to these services from any location were two major motivations to introduce and develop the next generation cellular systems, Long Term Evolution (LTE), provided by the 3GPP. In LTE technology, Single Carrier Frequency Division Multiple Access (SC-FDMA) and Orthogonal Frequency Division Multiple Access (OFDMA) are major parts of the standard. The OFDMA is used for downlink while the SC-FDMA is used for uplink in this system. Unlike earlier generation of wireless cellular systems, LTE technology is based on the TCP/IP which is the core protocol of the Internet. LTE network supports different types of services that share radio access and core network resources. These services include best effort, delay sensitive and real time (RT) services. Each of the mentioned services has different QoS requirements in terms of bit rate, delay and packet loss which must be satisfied [1].

User Equipment (UE) and eNodeB are the major parts of the LTE systems. The first goal for all of the eNodeB is providing a high spectral efficiency for the cell. By this, more number of active users can receive the services in the network. The second critical issue is the users' satisfaction from the quality of the service (QoS) received by each individual user. In order to achieve these goals, the resource allocation in the eNodeB must be aware of the channel condition, type of services requested by UE and other parameters. eNodeB distributes the available radio resources in one cell among the active users. Therefore, designing an appropriate scheduling algorithm to support the traffics with different QoS requirements, especially for RT services, is essential. Several works have been conducted in this field and we address some of the previous works in the following.

In [2], the authors studied the performance of two scheduling algorithms in the downlink of LTE, namely Exponential/Proportional Fair (EXP/PF) and Modified-Largest Weighted Delay First (M-LDWF). Both of these algorithms perform the scheduling process in one domain. In [2] the authors used the simulation results in a system with bandwidth of 5MHz to indicate that the M-LDWF provides more throughputs than the EXP/PF. However, considering the required bandwidth for RT users, the M-LDWF satisfies the QoS requirements of almost 80 users while this number can be increased up to 125 in EXP/PF. Therefore, the authors in [2] suggested that the M-LDWF to be used in low-load networks and the EXP/PF as more complex algorithm to be used when the network load increases. As another sample of one-domain scheduling, the proposed work in [3] utilizes the CQI feedback, which sent the report of the free buffer value from the user and QoS requirements of the real time and non-real time services. The authors concluded that their proposed algorithm has more throughput than the PF and it lowers the packet loss probability.

References [4, 5] investigate some algorithms for scheduling of the VOIP traffic. The proposed method for scheduling of VOIP in [4] satisfies the QoS requirements of this service and prevents the undesired effects caused by the

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given priority to the VOIP service in the network. In the proposed scheduling algorithm the duration of the priority given to the VOIP is adjusted by packet drop. In [6] the QoS structure in LTE and WiMAX technologies are studied. In LTE, it is performed by using the bearers constructed between the users and the gateway. Any flow mapped to the bearers experiences one kind of the QoS behavior. These flows are classified based on the IP five-tuple and the bearers are assigned a scalar number QCI. In [7], the authors have utilized different policies in schedulers and showed that the different classes of QoS can be provided by their method.

In [8], a two-stage scheduler, time domain and frequency domain, is used. The authors showed that this scheduler is suitable for HARQ management and provides fairness among the users. The time domain (TD) scheduler tries to provide the users' desired QoS parameters while the frequency domain (FD) scheduler goal is to achieve the most spectral efficiency using the input of the TD scheduler. The other conclusion of [8] is that the TD-BET/FD-TA scheduler gives better results than the TD-PF/FD-PF scheduler in terms of the average cell throughput and cell coverage. In [9] also a two-stage TD/FD scheduler is introduced in which the PF algorithm is utilized in time domain to make fairness among the users. But in the FD, different algorithms are exploited and compared. According to [9], the TD-PF/FD-PF two stage scheduler gives better throughput and fairness in comparison to the TD-PF scheduler.

Reference [10] divides the packet scheduler into frequency domain and time domain and investigates the performance of the packet scheduler when the MT, PF, BET and TTA algorithms are applied. The authors of [11] proposed a two stage scheduling method with a Frame Level (FL) scheduler used in the first step. The function of this scheduler is to determine the traffic amount that must be carried trough each instant flow for being prevented from the delay. The proposed scheduler does not use the channel state feedback provided by users. Then, the down layer allocates the resources to the users by exploiting the MT algorithm. As these resources are released, the service to the best effort traffics begins through the PF algorithm. In [12], a two stage scheduler is proposed. Before the time domain scheduling, the traffic is classified into two GBR and Non-GBR classes. In time domain, the users that should be scheduled are listed using the PF algorithm and provided for the frequency domain scheduler. Then, the resources are allocated to candidate users by the PF algorithm. The authors of [12] simulated four different traffic scenarios and showed that the proposed method can provide the required QoS of each traffic scenario.

In previous works, usually traffic related to GBR has handled with the most priority in the eNodeB. In this manner, by increasing the GBR traffic, the overall performance of the cell decreases. In this work we propose a QoS-Aware scheduling method which has two domains, time and frequency. In the proposed algorithm, at first, the different flows are mapped to different carriers using the Classical five tuple. Two different classes, GBR and Non-GBR are presented for LTE in which nine different values can be defined for the QCI [6]. We categorized the VOIP and Video traffic in GBR class and FTP and HTTP in Non-GBR class. In our proposed method, we utilize the Token Bucket algorithm in GBR class to prevent this class from using all resources. This technique not only makes an acceptable fairness between two classes, but also increases the total system throughput.

The rest of the paper is organized as follows. In Section II we study the downlink scheduling model in LTE. Section III investigates our proposed algorithm. The traffic model and simulation results are described in Section IV and finally the paper concludes in section V.

II. THE SCHEDULER STRUCTURE MODEL IN LTE DOWNLINK

The LTE technology utilizes the Orthogonal Frequency Division Multiple Access (OFDMA) in downlink, which can dedicate a set of sub carriers distributed in the whole spectrum to the users. The bandwidth is divided into 180 KHz sub-channels which include 12 consecutive sub-carriers. A time/frequency radio resource extend over two time slots in the time domain and over one sub-channel in the frequency domain is called Resource Block (RB) and it is the smallest element used for resource allocation in LTE. The number of RBs is depends to the system bandwidth, e.g. for 5 MHz system, the RBs number is 25 and in 10 MHz system the RBs number is 50 [1].

The eNodeB obtains the information on each user link using the Channel State Information. The users report their downlink flow status to the eNodeB in each TTI. The existent packets priority is determined by the scheduler of eNodeB according to parameters like packets delay, downlink status, buffer status, traffic type, etc. The number of dedicated RBs to a specific flow of packets depends on the resource allocation algorithm utilized in the scheduler [13].The packet schedulers in the most previous works have two phases. As shown in Fig. 1, firstly, the Time Domain, scheduler selects the set of users that request a service based on input parameters of the scheduling algorithm. Then, the Frequency Domain, scheduler allocates the resources to the users selected by its algorithm. The packet scheduler acquires the quality information of each channel in all RBs using the implemented CQI. In the mentioned configuration of the packet scheduler each domain has its own algorithms to select the users. Therefore, more design flexibility and less scheduling complexity is expected.

III. PROPOSED PACKET SCHEDULER FOR LTE

In LTE network, in order to achieve the desired QoS, every packet flow between users and eNodeB is placed in one bearer. Any service included in a specific bearer is treated identically in terms of the QoS behavior like scheduling, policy, rate shaping, queue management, etc. A scalar value indicating the QCI of a QoS is assigned to any of the bearers. Utilization of the mentioned classification results in more scalability in QoS-based schedulers design.

A. QCI classification

In the proposed scheduler structure, four different classes are defined: VOIP, Conversational Video (CV), FTP and HTTP. The first and second classes input the scheduler as the

GBR bearers while the last two classes are treated as the Non-GBR bearers.

B. The Time Domain Scheduler

The most important function of the time domain packet scheduler is to select the active users requesting resources. The selection is performed based on the QoS parameters and the present status of the channel. In the first phase in which no resource is allocated to users, the TD scheduler determines the active bearers of different classes and sorts them according to the different requirements. As the TD scheduler has no information about the RBs allocated to each user, exploits the average of the users CQIs on all RBs in order to compare the users' channel conditions. The user acquired the most metric value has the most priority. The TD scheduler creates a sorted list of users and active bearers for transmission through the TTI and delivers it to the FD scheduler. The FD scheduler selects the users that have the most priorities in the list and distributes the resources among them. TD scheduler splits the bearers into the GBR and Non-GBR groups and deliver two separated lists to the FD scheduler.

The GBR bearers have a guaranteed data rate which must be provided. Usually the GBR bearers are related to the applications which are sensitive to delay. It means that these kinds of bearers must be serviced without any additional delays. Otherwise, they lose being RT characteristics. For example the VOIP is one of the most common GBR services and its delay must not exceed 100_{ms}. The maximum delay of CV is 150_{ms}. In the proposed scheduler of this paper, the QoS parameter for GBR bearers is calculated as follows. The important point is that the packets which spend more time in the eNodeB buffer have more priority for service delivery [14].

$$m_k^{GBR}(t) = \arg\max_k [W_{QoS\_j} * HOL_{delay\_k}] \quad (1)$$

In (1), the parameter $m_k^{GBR}(t)$ is the time domain metric for GBR, k indicates the bearer number, W_{QoS_j} is the QoS weight for j^{th} class, HOL_{delay_k} is delay of the packet existed in the start of the k^{th} bearer in the eNodeB buffer, parameter WQoS_j, is used in our simulations for VOIP and Video traffic in order to distinguish the different bearers of GBR based on the QoS requirement and delay. In some cases, if the bearers' delay exceeds the predefined delay value, it is possible to have such a procedure to eliminate this bearer from the scheduling candidates list and not to be put in TTI.

Non-GBR bearers often include the best effort services that unlink the GBR bearers are not delay-sensitive. The different active bearers of the Non-GBR classes are prioritized based on different conditions. Prioritization is done using the priority factor of Non-GBR which behaves similar to the WPF algorithm. However, some slight modifications are conducted. [15]:

$$M_{CQI}^k = \frac{1}{N}\sum_{n=1}^{N} \frac{v_{n,t}^k r_{n,t}^k}{\sum_{j=1}^{k} v_{n,t}^j r_{n,t}^j} \quad (2)$$

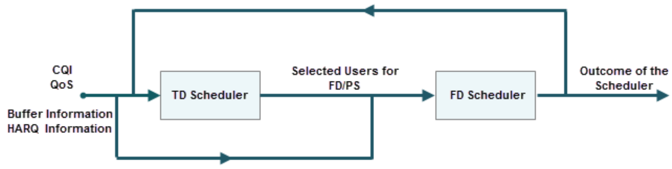

Fig. 1. Downlink Scheduling Framework

where index k in metric M_{CQI}^k determines the k^{th} user. The bit rate corresponding to CQI in the t^{th} second for the k^{th} user in the n^{th} RB is equal to $r_{n,t}^k$. Parameter $v_{n,t}^k$ is the weight of the channel state for the k^{th} user in the n^{th} RB and in the t^{th} moment. It is defined as follow:

$$v_{n,t}^k = 1 + \frac{r_{n,t}^k}{\bar{r}_n^k} \quad (3)$$

The parameter $\bar{r}_n^k$ is the bit rate average for the k^{th} user in the n^{th} RB. Non-GBR users which have higher value of this parameter are prior to others in resource allocation.

a) Token Bucket Algorithm

Token Bucket is a credit-based algorithm which is utilized to control the traffic volume entered from a source to the network. The Tokens are produced with a constant rate. The packets entered the queue are entered to the network only when there are enough Token in the buffer. The Fig. 3 depicts the Token Bucket functionality. The Token Bucket algorithm used in this paper only applies limitations on the service received by the GBR traffic. Using this algorithm, there is an acceptable fairness between the GBR and Non-GBR classes to avoid all resources to be used for GBR class, which has higher priority.

C. The Frequency Domain, FD, scheduler

The FD scheduler is responsible to distribute the RBs among different bearers. The Fig. 2 depicts the flowchart of FD scheduler utilized in this paper. The FD scheduler uses the candidates list to determine that in a specific TTI, what bearers must be serviced. As mentioned before, the candidate list includes the bearers prioritized based on the QoS requirements and is delivered by the TD to FD scheduler. The FD scheduler firstly services the GBR bearers and then services the Non-GBR ones. Using the Token Bucket algorithm, the FD scheduler determines the proper GBR bearers which can use the resources. Afterward, these bearers are scheduled using the Modified LWDF, M-LWDF [13].

When the GBR traffic or related Tokens finished, the FD scheduler starts to allocate the resources to the Non-GBR users. The PF algorithm is exploited which results a good balance between the fairness among the users and the overall cell performance. In this algorithm the present status of the user channel and the previous received services are calculated. The PF is not a suitable choice for RT traffics because it is a QoS-unaware algorithm but it is suitable for non-RT traffic cases because of using the channel characteristics [13].

$$m_{i,k}^{PF} = \frac{d_k^i(t)}{\overline{R}^i(t-1)} \tag{4}$$

$$\overline{R}^i(t) = \beta\overline{R}^i(t-1) + (1-\beta)r^i(t) \ , \ 0 \le \beta \le 1 \tag{5}$$

Where parameter $\overline{R}^i(t)$ is past average throughput achieved by the i^{th} user until time t and $r^i(t)$ determines the data rate achieved by the i^{th} user at time t.

In order to study the effects of the proposed scheduler of this paper on the resource allocation system in RT traffic cases, the TD-PF/FD-PF scenario and also the without-Token-Bucket case are simulated. The without-Token-Bucket scheduling is similar to the proposed scheduling method, without using the Token-Bucket algorithm in it. In this case, because of higher priority of the GBR bearers than the Non-GBR ones, the scheduling of the VOIP and Video traffics are performed in the first step. Then, the other kinds of traffics are scheduled. It is clear that the mentioned procedure decreases the Non-GBR users chance to be scheduled. Moreover, the cell throughput is decreased.

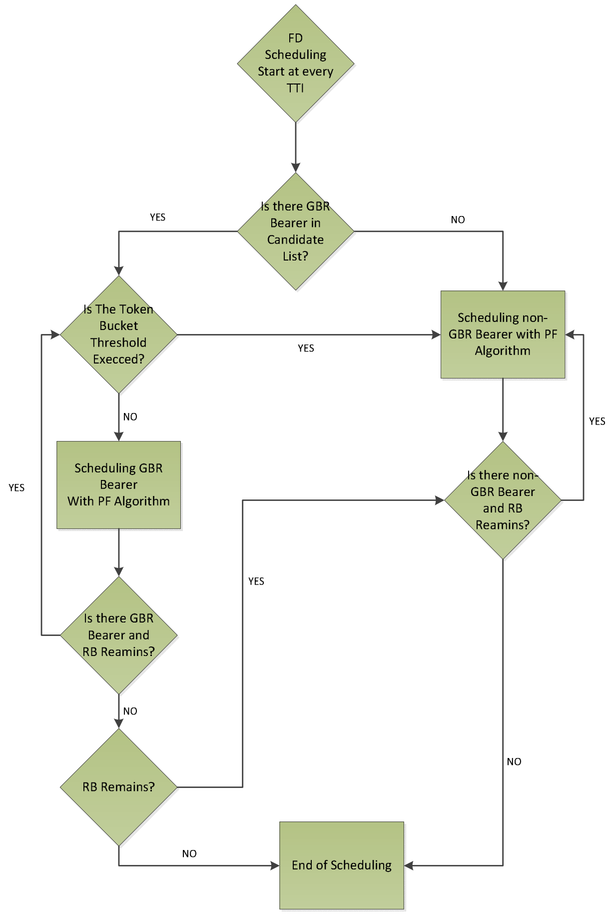

Fig. 2. FD Scheduling in the proposed Algorithm

IV. Simulation Results AND Discusson

In this paper, the utilized simulator is based on the system level LTE simulator developed by Institute of Communications and Radio-Frequency Engineering, Vienna University of Technology, Austria. This simulator is implemented using MATLAB software and the version of 1.6r885 id utilized in this paper. Some modifications are exerted on the simulator to be used in this paper. The modifications include the traffic definition capability and creation of the base station buffer for traffic transmission. The simulations consist of a cell with radius of 0.5 Km in which the users are distributed uniformly. The simulation parameters and the considered traffic model is summarized in TABLE I. In total, three scenarios are simulated. They are summarized in TABLE II.

In order to study the different aspects of the proposed scheduling algorithm, in all simulations the results are compared with the “without-Token-Bucket” and TD-PF\FD-PF scenarios. The average of the performance for all users in depicted in Fig. 4 for all scenarios. The TD-PF\FD-PF algorithm gives better performance than other two algorithms because it does not use the QoS parameters related to GBR bearers. In fact, in this algorithm there is no priority for resource allocation to the different traffics. The Without-Token-Bucket algorithm gives the worst performance because it considers the most priority to the GBR bearers. The proposed algorithm of this paper, with Token Bucket, is an intermediate of two previous ones in terms of giving priority to the GBR bearers.

In scenario 2, a constant number of users are added to both GBR and Non-GBR bearers compared to scenario 1. However, in the third scenario the increment of GBR users in two times greater than Non-GBR users. In the without-Token-Bucket scheduler, there is an absolute priority for the users of Real Time (RT) traffic.

TABLE I. Simulation Parameters

Parameters	Assumption
Number of eNodeBs	1 eNodeB with one cell
Spectrum	5 MHz (~ 25RB)
Mobility Model	Random Way Point (RWP)
Channel model	ITU Veh-A
VOIP Traffic Model	Frame per Packet: 1 Frame Size: 20ms Coding Rate : 13 Kbps Packet Size : 260 bit
Video Traffic Model	Frame Inter-arrival time = 0.1 sec Frame size: 3200 bytes
HTTP Traffic Model	Number of pages per session = 1 pages Number of objects in a page = 1 Objects size = constant 100 Kbytes Reading time (default) = constant 12 sec
FTP Traffic Model	Inter-request time (sec): uniform (30,60) File size: constant 3 Mbytes
Simulation time	2000 sec

TABLE II. SIMUALTION SCENARIOS

Scenario	Scenario 1	Scenario 2	Scenario 3
VOIP users Number	40	50	60
Video users Number	20	20	30
HTTP users Number	20	30	30
FTP users Number	20	20	20

Therefore, it can be seen that by increasing the number of GBR bearers the decrement of the average performance is more than what it is two other schedulers. Our objective in the proposed algorithm is increasing the cell performance together with the satisfaction of QoS requirements.

The effect of increment in users' amount on the cell performance is depicted in Fig. 5 in which the decrement of the cell performance in scenarios 2, 3 compared to scenario 1 is shown. In scenario 2, the least performance decrement is related to TD-PF/FD-PF algorithm. However, by 66% increment of the number of GBR users in scenario 3 compared to scenario 1, the TD-PF/FD-PF results the most cell performance decrement in among all cases. The proposed algorithm in this paper, as expected, gives the least cell performance decrement in scenario 3.

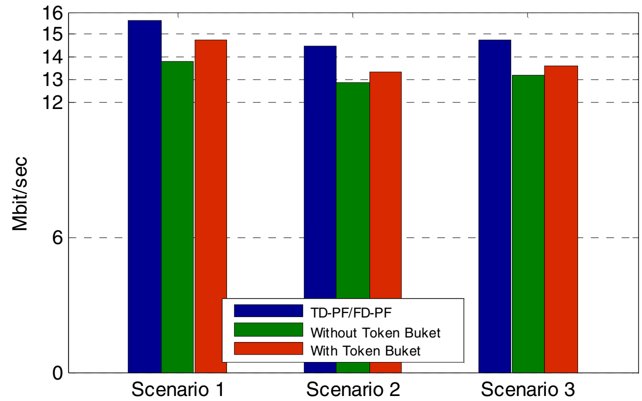

Fig. 3. Cell Throuput for three scenario

Fig. 4. Cell Throughput Decrement

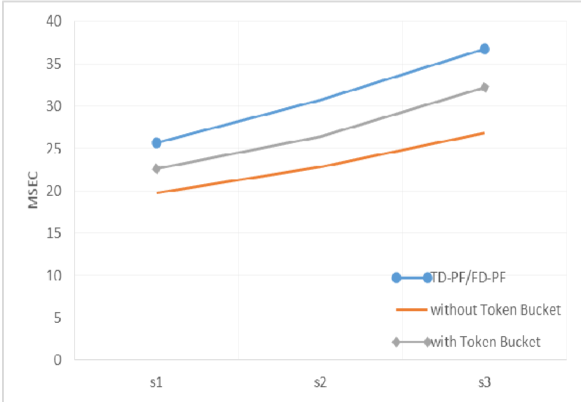

Fig. 5. VOIP average delay

Simulation results for the experienced delay in VOIP and Video traffic are presented in Fig. 4 and Fig. 5, respectively. The TD-PF\FD-PF scheduler has the most delay for VOIP and Video because it does not consider any priority for GBR traffic. The without-Token-Bucket scheduler results the least delay for VOIP and Video because of its absolute priority for these two classes. But, it reduces the users' average performance and decreases the reach of other classes to resources. As shown, by using the proposed scheduling, we can achieve the moderate status. The noticeable point is that in our simulations, only the network delay is considered. It means that the delays include the scheduling delay, the queue delay in eNodeB and transmission delay. As an example if we want to calculate the E2E delay for VOIP, we must add the encoder delay, dependent to its type, to previous delays.

The Response Time and Download Time of the HTTP and FTP traffics are depicted in Fig. 7 and Fig. 8, respectively. By increasing the number of the RT users, the efficiency of the proposed algorithm is more tangible because it gives an acceptable balance between the users' average performance and QoS requirements by management of the resource allocation between the GBR and non-GBR users.

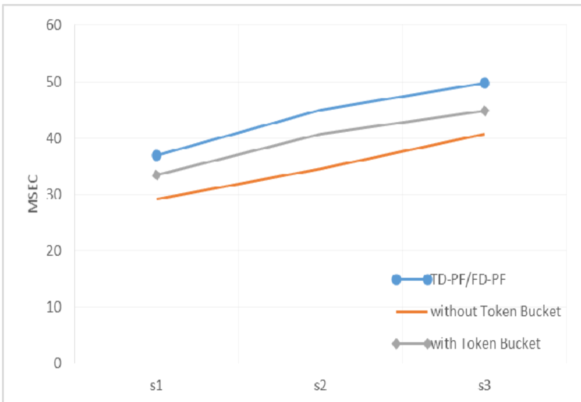

Fig. 6. Video average Delay

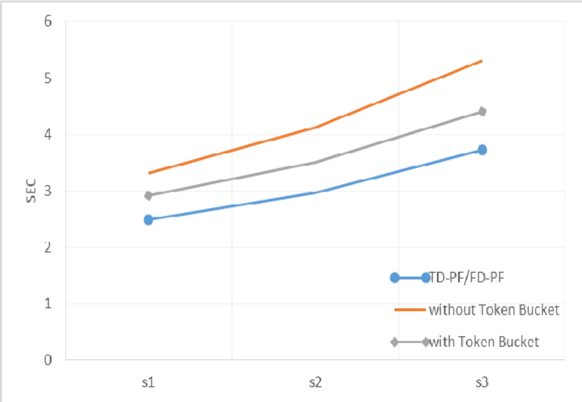

Fig. 7. HTTP average Response Time

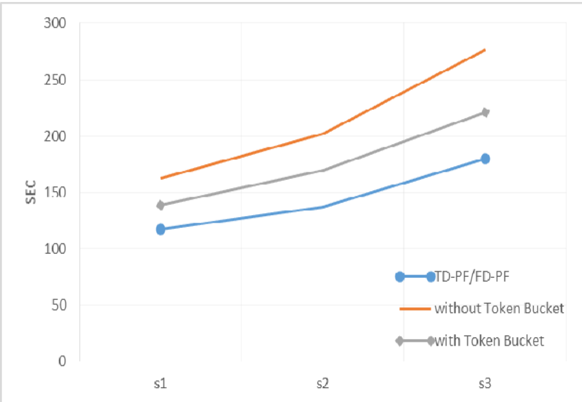

Fig. 8. FTP average Download Time

V. CONCLUSION

In this paper we proposed a downlink scheduler with Token Bucket algorithm in a LTE system. We divided the proposed scheduler into time and frequency domains. In the frequency domain, we utilized the Token Bucket algorithm in order to improve the spectral efficiency of the cell. In this work the bearers that were demanding different QoS requirements were separated into GBR and non-GBR. In our simulations the main goal was the study of the impact of the Token Bucket algorithm for increased GBR traffic. We showed that how to serve VOIP, Video, FTP and HTTP traffics while satisfying the different QoS requirements of each service. Therefore, in simulated scenarios we investigated the spectral efficiency of the cell and variation of the QoS parameters of each class for increasing VOIP and Video traffic. The results showed that Token Bucket algorithm increases the cell performance together with the satisfaction of QoS requirements.

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