Downlink Scheduler Based on Deadlines for LTE Networks

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***Abstract*— The LTE (Long Term Evolution) networks, based on OFDMA (Orthogonal Frequency Division Multiple Access), provide support to a wide range of voice, data and video services. The LTE networks are designed to deliver high broadcast rates, low latency, and higher spectral efficiency than the 3G networks. However, due to the limited radio resources, the use of these resources in an efficient way is crucial. Therefore, a suitable strategy for resource allocation gains extreme importance so that the requirements of QoS (Quality of Service) are met. In this paper, we propose a scheduling algorithm based on deadlines to improve performance and fairness in the distribution of radio resources. The results of a performance study based on modelling and simulation were satisfactory.**

***Index Terms*— LTE, QoS, scheduling, deadline**

I. Introduction

With the growth of the Internet, the demand for multimedia services as well real-time services, brought demands for service quality requirements such as maximum throughput and minimum delay. Due to the challenges faced by wireless networks, the Long Term Evolution [1] was proposed as an alternative to meet the new demands. The LTE networks, fundamented in OFDMA (Orthogonal Frequency Division Multiple Access), support a wide range of services of multimedia Internet in a scenario of high mobility [2]. Thus, the LTE is designed to deliver high bit rates, low latency, and a spectral efficiency greater than the 3G networks. Techniques such as CQI (Channel Quality Indicator), AMC (Adaptive Modulation and Coding), HARQ (Hybrid Automatic Request Retransmition), scheduling, resource sharing and otimization are progressively employed by researchers in the pursuit of the realization of the objectives proposed for the LTE. Due to radio frequency channel limitations, the efficient use of these resources is of paramount importance. The strategy for resource allocation gains extreme importance so that the needs of QoS (Quality of Service) are met.

In this paper we propose a scheduling algorithm with guarantees of limited maximum delay and spectral efficiency based on the EDF (Earliest Deadline First) scheduling algorithm [3]. The organization of the remainder of this paper is as follows. Section II provides an overview on LTE networks. Section III presents the proposed architecture of the adaptive scheduler and, finally, Section IV presents the conclusion of this article.

II. Overview on LTE Networks

In 2004, the 3GPP (3rd Generation Partnership Project) LTE work was started with the definition of objectives. With the evolution of technology, the demands for wireless networks evolve, creating the need for improvements. The main goals defined by 3GPP were [2]:

- Spectral efficiency;
- Rate of 100 Mbps downlink and 50 Mbps uplink;
- RTT(Round Trip Time $< 10\ ms$);
- High level of mobility and safety;
- Energy efficiency;
- Flexibility in carrier frequency;
- Improved packet commutation.

The architecture consists of the core network called the Evolved Packet Core network and the radio access called Evolved Universal Terrestrial Radio Access Network, shown in Figure 1.

The EPC (Evolved Packet Core) consists of the MME (Mobility Management Entity), SGW (Serving Gateway) and PGW (Packet Data Network Gateway). The MME is responsible for the mobility of UEs (User Equipment) operating only in the control plan and not acting in the user's plan. The SGW function is to send and route IP packets and manage mobility when UEs move between eNodeBs (Evolved Node B). The SGW also stores information temporarily when the UEs operation is idle. The PGW is responsible for the IP addressing for the UEs and for the compliance with the requirements of QoS [4].

The access network of LTE, E-UTRAN (Evolved Universal Terrestrial Radio Access Network), has only two elements: The eNodeBs and UEs, which represent the end users. The eNodeBs are interconnected with each other and connected to the MME. The interconnection between eNodeBs improves response time to signaling procedures [2]. The RRM (Radio Resource Management), one of the functions of the E-UTRAN, is responsible for all activities related to radio bearers. The E-UTRAN is also responsible for the connectivity to EPC, by signaling to the MME / SGW [2].

The multiple access scheme of downlink uses OFDMA that offers high scalability and high robustness against interference between users and the uplink uses SC-FDMA (Single Carrier

Frequency Division Multiple Access) which is used to improve energy efficiency of UEs (User Equipament) since, in many cases, they can be powered by batteries [5]. The multiple access scheme is shown in Figure 2.

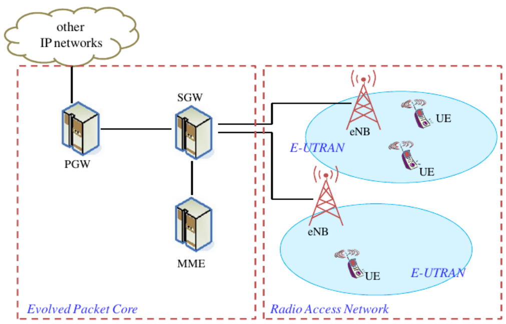

Fig. 1. Ilustration of the LTE service architecture in [6]

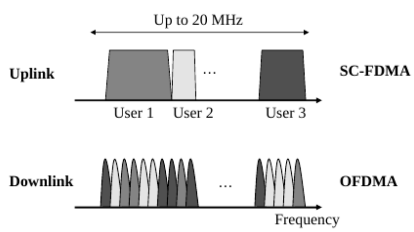

Fig. 2. Ilustration of the LTE Multiple Access Scheme in [2].

Resource allocation can be in time and in frequency domain. In the frequency domain the transmission units called RBs (Resource Blocks) have a resolution of 180 Khz, with each RBs having 12 equally spaced OFDM subcarriers. In the field of time the resources are allocated to each TTI (Transmission Time Interval), each lasting 1 ms. Each frame consists of 10 consecutive TTIs. Each TTI is divided into two 0.5 ms parts. This means that for every TTI, each subcarrier transmits two RBs.

In general, the scaling at OFDMA aims to allocate pairs of blocks of radio resources (1 ms and 12 subcarriers) between different users, so as to achieve the highest throughput possible in the cell. However, fairness in transmission is also desired. Aiming at providing the QoS requirements, various scheduling algorithms have been proposed in literature as PF (Proportional Fair) and M-LWDF (Modified Largest Weight Delay First).

A. *Proportional Fair Scheduler*

The PF (Proportional Fair) scheduler is in the class of schedulers that consider the state of the channel in their decisions. Initially proposed by Jalali at al. [7], the scheduler looks for a balance between offering maximum throughput and fairness in resource allocation. Through periodic feedbacks offered by CQI, it is possible to estimate the maximum throughput using the AMC.

Being $d_{i,k}(t)$ the estimated maximum throughput for user k for the i-th RB in k and $\overline{L_k(t)}$ the average of past data traffic at time t for user k, the metric for the PF scheduler is given by:

$$\text{metric}_{i,k} = \frac{d_{i,k}(t)}{\overline{L_k(t)}} \qquad (1)$$

B. *Modified Largest Weighted Delay First Scheduler*

The scheduler M-LWDF (Modified Largest Weighted Delay First Scheduler) [8] is an extension of LWDF (Largest Weighted Delay First). The M-LWDF takes into account the state of the channel. In this scheduler, the real-time flows and the streams in real time are treated in different ways. For streams in real-time, M-LWDF uses the same metric as the PF scheduler [6] and for real-time flows it uses the metric:

$$\text{metric}_{i,k} = \alpha_k.HOL_k.\frac{d_{i,k}(t)}{\overline{L_k(t)}} \qquad (2)$$

and

$$\alpha_k = -\frac{\log \delta_k}{\tau_k} \qquad (3)$$

where:

- HOL_k is the delay of the first packet to be transmitted by the user k (Head of Line Delay).
- δ_k is the acceptable probability for the k-th user whose packet is dropped due to non-compliance with the deadline.
- τ_k represents the maximum delay for the user k.

III. A Deadline-Based Scheduler for LTE Networks

The maximum limited delay for real-time services is guaranteed by an algorithm based on deadlines. The scheduler assigns a deadline for each flow that has a packet queued at the eNodeB. The deadlines are calculated taking into account the following parameters: the maximum delay for the class of flow τ_k), and the waiting time of the flow in the queue ($HOL_{i,k}$). If RB_i represents the i-th Resource Block of a stream of real-time, by means of equation 4 we can calculate the deadline of the i-th RB:

$$\text{DL}_{i,k} = \tau_k - HOL_{i,k} \qquad (4)$$

where:

- $DL_{i,k}$ is the *deadline* for the i-th RB user k.
- τ_k represents the maximum delay for the user k.
- $HOL_{i,k}$ is the delay of the first packet to be transmitted by the user k (Head of Line Delay).

For each RB, a $metric_{i,k}$ is calculated according to equation 5:

$$\text{metric}_{i,k} = \frac{d_{i,k}(t)}{(\overline{L_k(t)} * DL_{i,k})} \qquad (5)$$

where:

- $DL_{i,k}$ is the *deadline* for the i-th RB of user k.
- $d_{i,k}(t)$ factor represents the spectral efficiency for i-th RB of of user k.
- $\overline{L_k(t)}$ average of transmitted data for user k.

Then, the list is sorted from the largest metric. The RBs with the largest metrics are allocated. The $d_{i,k}(t)$ factor represents the spectral efficiency that is the estimate of the maximum throughput rate because of modulation adopted, depending on the frequency band. This parameter in the metric favors the stations with better transmission, increasing its efficiency. To provide fairness, the metric is divided by the average of transmitted data.

The presence of the deadline in the denominator makes the value of the metric increase as the queuing delay approaches the maximum delay. In case queuing delay exceeds the maximum delay, the metric becomes negative, and the packet will no longer be scaled and packet loss will occur.

The average of transmitted data present in the dominator equation 6, adds fairness to the metric once the packets of users, that have transmitted most data, will receive a smaller metric. A mobile average is used to form the average of transmitted data.

$$\overline{L_k(t)} = L_k(t) * \beta + L_k(t-1)(1-\beta) \qquad (6)$$

IV. Modelling and Simulation

In order to evaluate the performance of the proposed scheduler, a performance evaluation via the LTE-Sim [9] simulator was made. The scenario considered is composed of a cell and a number of users in the interval [10, 60] which move randomly at a speed of 3 km/h.The simulation took into consideration realistic channel models and other characteristics summarised in table 1.

TABLE I

Simulation Parameters.

Parameters	Value
Scenary	Single Cell with Interference
Flows duration	30 s
Simulation duration	40 s
Frame structure	FDD
Link Adaptation	QPSK, 16QAM e 64QAM
Radius	0.5 Km
Scheduling time	1 ms
Number of Cells	1
Number of RBs	50
Max delay	0.1 s
Traffic Models	Real time:H264(242 kbps), VoIP(8.4 kbps), BE: Infinite buffer
UE speed	3 Km/h
Mobility model	Random way-point
β	0.01

A. *MODEL DATA TRANSMISSION*

In the simulation, a video stream with a transmission rate of 242 Kbps is used. The video traffic is based on available real data captured in [10]. The VoIP application produces voice streams G.729. The voice stream is modeled with a Markov chain with ON periods exponentially distributed averaging 3 s, the OFF period with a PDF truncated exponential with superior limit of 6,9 s and an average value of 3 s [11]. During the ON period, the source sends packets of 20 bytes every 20 ms and during the OFF period the transmission rate is zero because silence detection is considered. Finally, the Infinite-Buffer application models an ideal source that always has packets to be sent.

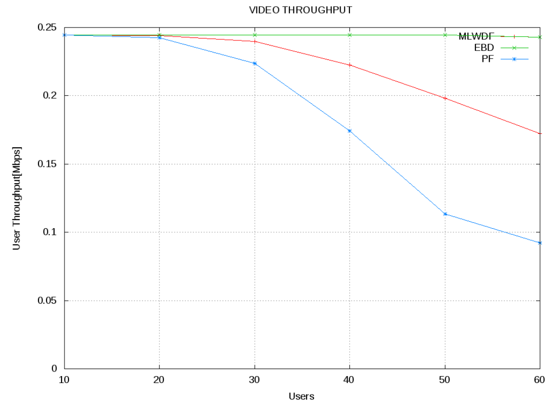

Fig. 3. Average Video throughput per UEs

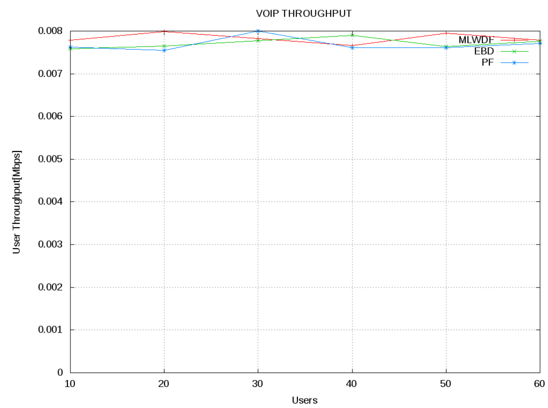

Fig. 4. Average VoIP throughput per UEs

B. *Results*

This work also evaluated the performance of PF and M-LWDF schedulers in the scenario considered to assist in analyzing the performance of the scheduler based on deadlines. In order to better undestand the results, the following notation is used: PF represents the Proportional Fair scheduler, M-LWDF represents the Modified Largest Weighted Delay First scheduler and EBD represents the proposed scheduler.

Figure 3 shows the average throughput per user for video streams for each scheduler considered. It is observed that the Scheduler Based on Deadlines has superior performance, especially for a number above 40 UEs.

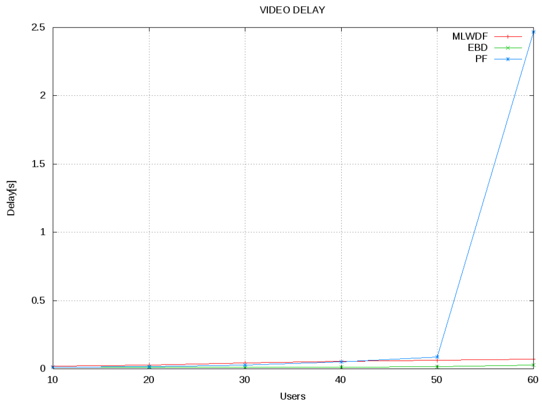

Fig. 5. Video Delay per UEs

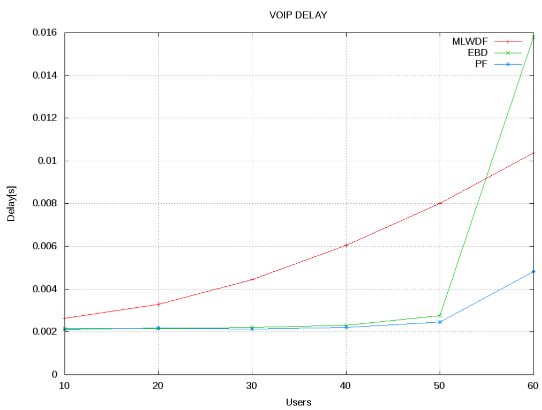

Fig. 6. VoIP Delay per UEs

For VoIP flows, as shown in Figure 4, all schedulers had similar performances. Figures 5 and 6 show the average delay for the video and VoIP streams respectively. It is observed that for the video streams, the EBD scheduler's performance was slightly higher during all the interval considered. As for the VoIP streams, the EBD scheduler outperformed the M-LWDF and was similar to PF, except in the simulation with 60UEs.

Figures 7 and 8 show the Jain fairness index [12] for VoIP and video streams, respectively. The scheduler proposed in this paper presents a performance superior to other schedulers considered for video streams, whereas for VoIP flows, it presents a performance similar to PF and M-LWDF. In Figures 9 and 10 it is observed that the EBD outperformed the other schedulers considered in the metric PLR (Packet Loss Rating), especially for video streams. In Figure 11 we can see that the EBD had higher spectral efficiency compared to the other schedulers.

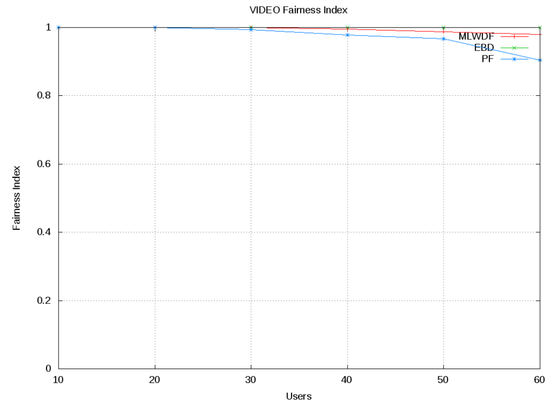

Fig. 7. Video Fairness Index

V. Conclusions

In this paper, we proposed a scheduling algorithm based on deadlines, with a focus on resource allocation for downlink system for real time services in LTE network. Four metrics were used to assess performance: Throughput, Delay, PLR (Packet Loss Ratio) and Fairness Index. We proposed scheduling algorithm where its performance was compared to PF and M-LWDF schedulers and the results analyzed by the metrics considered, seemed to be promising.

With respect to these measures, we conclude that our proposal presents a better performance with respect to packet loss rates and delay, which was expected due to the use of deadlines. Our proposal also provides better throughput for video flows. With respect to VoIP throughput, our algorithm achieved a similar performance to other schedulers, as the low rate of G.729 cannot be benefited by the metrics used. The gains made by the proposed scheduler, showed no negative impact on fairness in real time services.

The proposed scheme allows low complexity in its implementation, which is suitable for LTE networks. Future work will be directed to the use of other indicators of QoS in the metrics scheduler and a comparison with other schedulers such as Exponential Rule, Logaritmic Rule and Exponential Proportional Fair.

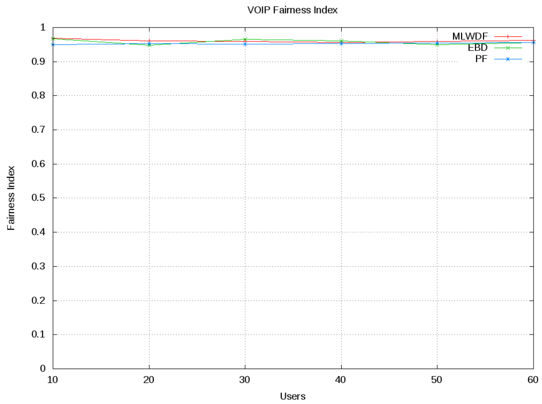

Fig. 8. VoIP Fairness Index

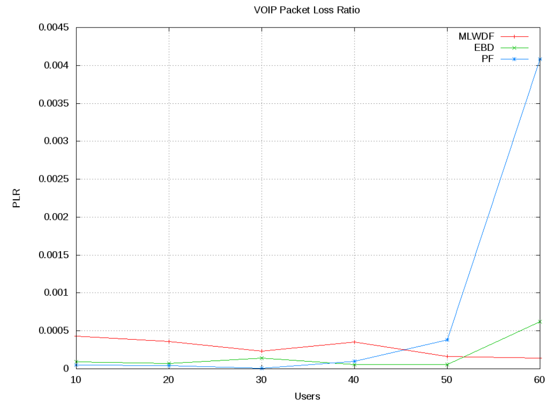

Fig. 10. VoIP Packet Loss Ratio per UEs

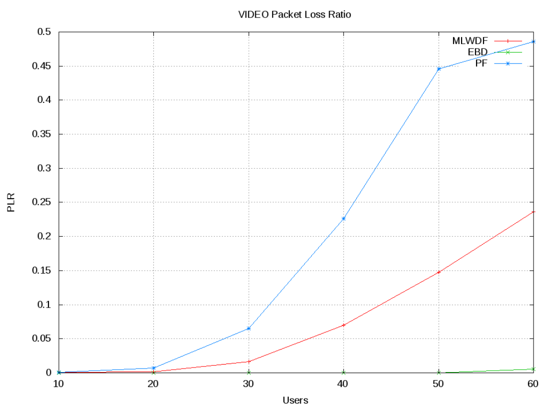

Fig. 9. Video Packet Loss Ratio per UEs

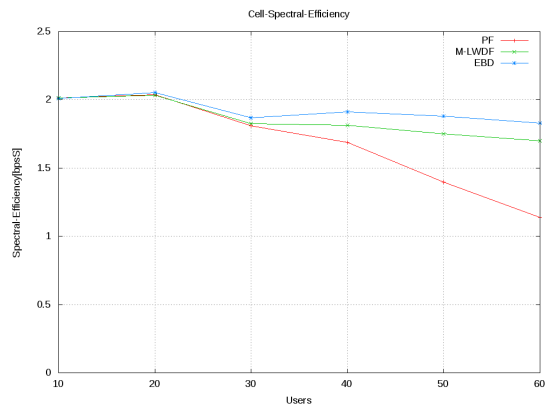

Fig. 11. Total Cell Spectral Efficiency

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