Journal of Network and Information Security
7 (2), December 2019, 23-27
http://www.publishingindia.com/jnis

Performance Analysis of a QAPF Scheduling Scheme in LTE Network

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Abstract: Long Term Evolution (LTE) is a cellular network that operates completely in packet domain. It can also support multimedia services. Due to this nature, provisioning the Quality of Service (QoS) requirements has become a challenge to the design of scheduler. Especially, the scheduler must guarantee for transmitting the real-time traffics such as VoIP (voice over IP). In this paper, a scheduler that satisfies the different QoS requirements is presented. This scheduler considers the additional QoS consideration to the Proportional Fair (PF), which is a well-known scheduling algorithm. As the core work of this paper, its performance is evaluated by comparing with the existing well-known schedulers. For non-real-time traffics such as file download, the performance of the scheduling scheme is evaluated by comparing with PF scheduler. For real-time traffics such as video live streaming, its performance is compared with Frame Level Scheduler (FLS).

Keywords: LTE, Multimedia services, OFDMA, QoS, TDMA.

I. INTRODUCTION

Long Term Evolution (LTE) is a 4G cellular network that is aiming to support a wide variety of applications. It can also guaranteethe different QoS (Quality of Services) requirements [1]. For transmitting signal, LTE is based on bearer channel. Bearer services are telecommunication services that are used to transfer user data and control signals between user equipment and core network. In LTE system, there are two main bearer types [2]: Guranteed Bit Rate (GBR) which is real-time traffic such as VoIP and non-Guaranteed Bit Rate (nonGBR) which is streaming such as data flow. For the downlink of LTE, OFDMA (orthogonal frequency division multiple access) is selected inachievingthe required performance of Universal Mobile Telecommunication System (UMTS). Thus, the spectrum is divided into multiple subcarriers in the frequency domain and several OFDMA symbols in the time domain. The smallest unit of scheduler in LTE network is PRB. Each subcarrier is 15 kHz bandwidth. Thus, one PRB has 180 KHz. For uplink, SC-FDMA (Single Carrier-OFDMA) is chosen since it uses low-to-average power ratio techniques of single carrier subsystem. In SC-FDMA, all subcarriers (12 subcarriers) are transmitted over one period of time so that it can reduce the inter symbol interference.

Radio resource scheduling is the core function for considering the network performance. Thus, the extensive research works are carried on the scheduling algorithms. Different algorithms have been deployed and their performances are evaluated with different measurements.

In this paper, a scheduler algorithm named as QoS-Aware Proportional Fair (QAPF) [3] is presented and evaluated by comparing with the existing well-known algorithms for both real-time and non-real-time traffics.

The section II describes the previous scheduling schemes of LTE network. The detail of the scheduling framework will be described in section III. Section IV will give the evaluation result of the scheduler. Finally, sectionV will wrap this paper.

II. RELATED WORKS

Some of the previous resources scheduling algorithms for the LTE network are presented in this section.

Proportional Fair (PF) algorithm [8] can maintain the balance between the fairness in consuming the radio resources and the overall system throughput. It gives the radio resources by considering the occurring channel quality and the previous user experienced throughput. It can consider not only the system throughput but also fairness among users. Being $r_j(t)$ is the maximum expected throughput for user j at time t and $\overline{r}_j(t)$ is the average past throughput for user j until time t, the priority matrix for PF is given by:

$$p_j(t) = \frac{r_j(t)}{\overline{r}_j(t)} \tag{1}$$

Piro *et al.* [10] proposed Frame Level Scheduler (FLS), which is designed for real-time communications in LTE downlink networks. It has two separate levels (upper level and lower level). At the upper layer, data allocation is evaluated by using complex algorithm based on Discrete-Time (DT) linear control loop method. At this layer, FLScan state the amount of data packet that will be transmitted in each TTI. At the lower level, radio resources are assigned to the users on every TTI using PF and Maximum Throughput (MT) strategy. MT allocates the resource blocks prior to the flows that have higher priority. PF is used to schedule the resource blocks for achieving the fairness. The lowest level packet scheduler thus ensures every TTI to get a trade-off between system throughput and fairness.

In [3], a new scheduler which can maintain the QoS requirements of different service classes, was proposed and evaluated the performance by comparing with the well-known schedulers: M-LWDF and Ex/PF. The work was extended in [4]. The performance of this scheduler was analyzed by comparing with PF for non-real-time traffics, and with Earliest Dead Line First scheduler for real-time traffics. According to both works [3] [4], the scheduler outperformed other schedulers for both real-time traffics and non-real-time traffics.

[6] and [7] made the comparative analysis of well-known schedulers in LTE network. In these analyses, it was found that FLS scheduler has higher performance than PF, M-LWDF, and Ex/PF.

L. F. Bittencourt *et al.* [12] proposed a technique to be classified the scheduling in distributed system. They mainly targeted for the cloud computing schedulers. They considered the scheduling problem which is based on a problem by Pinedo [13]. Their consideration was based on two execution environments: identical machines in parallel and different machines in parallel.

Malhotra *et al.*[15] explored the exiting the resource scheduling algorithms employed in cloud computing and drew a contrast among them. Then, they could make a conclusion about best available strategy for clouding providers.

In this paper, the performance of the scheduler which has been proposed in [3] is thus evaluated by comparing with FLS scheduler for real-time traffic or delay-sensitive traffics.

III. RESOURCE SCHEDULING FRAMEWORK

In this section, the scheduling scheme named as QoS-Aware Scheduling Framework (QAPF) [3] is presented.

Fig. 1 shows the general framework of the QAPF scheduler. The scheduler is divided into three parts: (1) traffic differentiation (GBR or nonGBR), (2) Time Domain (TD) scheduling, and (3) Frequency Domain (FD) scheduling.

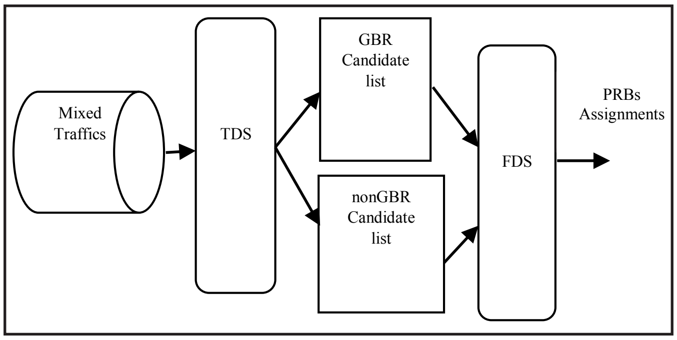

Fig. 1: General Framework of Scheduler

A. Traffic Classification

The scheduler firstly classifies the mixed traffics into GBR or nonGBR. It maps the IP packets of the traffics to the corresponding bearer type as shown in Table I of 3GPP TS 23.203(V11.3.0) [11].

TABLE I: STANDARDIZED QOS CLASS IDENTIFIERS (QCIS)

Bearer Type	Traffic Type	Priority	Packet Delay Budget
GBR	VoIP	2	100 ms
	Live Video Streaming	4	150 ms
	Real Time Gaming	3	50 ms
	Video (Buffer Streaming)	5	300 ms
nonGBR	IMS Signaling	1	100 ms
	Interactive Gaming	7	100 ms
	Application with TCP: browsing, email, file download, etc	6	300 ms
		8	300 ms
		9	300 ms

B. Time Domain Scheduling (TDS)

The bearer prioritization list is generated by TD scheduler. In generating the prioritization list, it must consider their QoS requirements of each bearer type. TD scheduler thinks in the matter of bearers astwo prioritization lists: GBR bearer's prioritization and nonGBR bearer's prioritization.

The main factor for prioritizing the bears in GBR list is the HoL delay. In generating the prioritization matrix, bearers which have HoL delay exceeding the maximum delay budget are excluded. This consideration looks like this

If maximum delay budget, Db, > HoL, then drop that bearer

This can lead to avoiding the bandwidth wasting. For the prioritization matrix, emergency bearers which have delay closing to the maximum delay are first extracted such that

If maximum delay budget, Db, - HoL delay > minimum delay threshold, insert that bearer to the emergency list

Then, these extracted emergency bearers are sorted in descending order according to their delay. After prioritizing all emergency bearers, bearers whose delay below the minimum threshold are prioritized by using their delay value. This means that the bearers closing to expiration are obtained the high priority. In this way, system spectrum efficiency can be saved. For the priority matrix for nonGBR list, delay is out of consideration because it is for the best effort services, such as file download. Thus, the generation of priority matrix for nonGBR service is based on channel condition. For the fairness consideration, it thus takes into account of average channel throughput. For distinguishing the priorities among the non-real-time traffics, it uses the weight factor of the priority list in Table I of CQI standardized, i.e., IP Multimedia sub system among the nonGBRservices should be given higher weight value because it has lower delay tolerant budget than other background service, such as web browsing, email, and file download. The priority calculation for bearer *i* at time *t*, $nonGBR\_\ P_i(t)$ is:

$$nonGBR_{P_i(t)} = \arg\max\left[w_i * \frac{r_i}{\overline{r}_i} \right] \tag{2}$$

where, w_i is weight factor of bearer *i*, r_i is the instantaneous throughput and $\overline{r}_i$ is average throughput for bearer *i*. The time average throughput of user *k* is updated by the moving average as below as:

$$\overline{r}_i(t) = (1-\alpha)\overline{r}_i(t-1) + \alpha r_i(t) \tag{3}$$

where, $\alpha = \frac{2}{1+N}$ is scaling factor of *N* time period.

C. Frequency Domain Scheduling (FDS)

FD scheduler will distribute the resources blocks (PRBs) among the bearers. In its PRBs distribution, it chooses the bearer to be served within next TTI, from the priority bearer list generated by TDS, its previous stage.

It starts assigning the PRBs with the GBR bearer list which is real-time traffic. Assigning the PRBs starts from the highest priority bearer to lowest priority one in the GBR list. After all GBR bearers have been set down, FD scheduler will continue to schedule nonGBR bearers. However, the whole nonGBR list may not be assigned the PRBs and the subset of all nonGBR bearers may be chosen by picking the highest nonGBR bearers from the nonGBR candidate list generated by TDS. This is because the remaining PRBs after serving the all GBR bearers may not be enough for all nonGBRs services. Therefore, highest priority nonGBR bearers may be served within each TTI.

IV. EVALUATION RESULT

In this section, the performance of the presented scheduler (QAPF) is evaluated for both real-time and non-real-time traffic. For this evaluation, LTE-sim, open source simulator [19], is used. The simulation parameters are as shown in Table II. In the experiment, buffer data is tested as non-real-time traffic or nonGBR service, and video flow is used as the representative of GBR service. The measurements which are used in the evaluation are:

- Average Delay: Time from the arrival to queue until departure from queue.
- Average Throughput: Total data received by all users over the simulation time.
- Fairness: Determination of whether users are receiving a fair share system resources, or not. Jain's fairness index [12] is used.
- Packet Loss Ratio: The ratio of amount of packet losses probability at the receiving end.

TABLE II: SIMULATION PARAMETERS

Parameters	Values
Simulation Duration	60 sec
Cell radius	1 km
Minimum number of users	5
Maximum number of users	60
Interval between users	5
User speed	3 km/h
Bandwidth	10 MHz
Number of PRBs	50
Transmission time interval	1 ms

D. Evaluation for nonGBR Service

For nonGBR services which are non-real-time traffics, the performance of scheduler is evaluated by comparing with PF scheduler, in terms of fairness and average throughput.

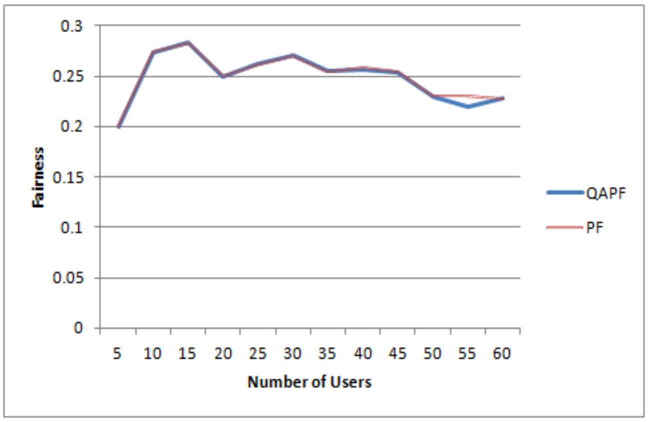

Fig. 2: Fairness Index for nonGBR Services

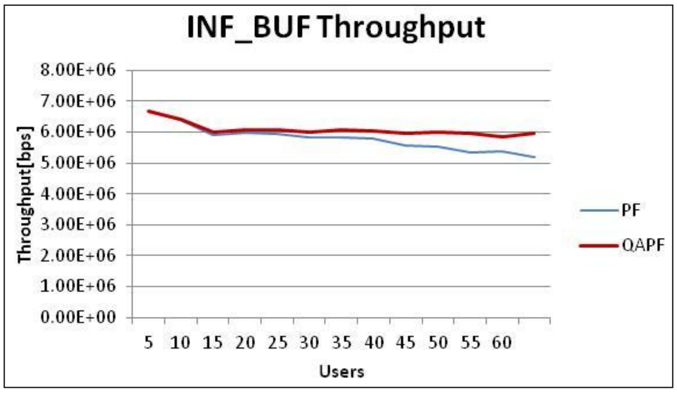

Fig. 3: Average Throughput for nonGBR Services

As shown in Fig. 2, QAPF has similar fairness index as PF. As the throughput measurement, it has higher performance than PF when the number of users is increased as shown in Fig. 3.

B. Evaluation for GBR Services

FLS scheduler outperforms M-LWDF, Ex/PF for real-time traffics [6, 7]. For GBR services or real-time traffics, the performance of the scheduler is thus evaluated by comparing with FLS in terms of average delay, average throughput and packet loss ratio, as an extension work of [3] and [4].

QAPF has more guarantees in the low delay under more video traffics load, although FLS has low delay while video flows are less as shown in Fig. 4. When the throughput performance of QAPF is compared with those of FLS for video flows, the users increase more; the performance of QAPF drops more although it has same throughput under low traffic load, as shown in Fig. 5.

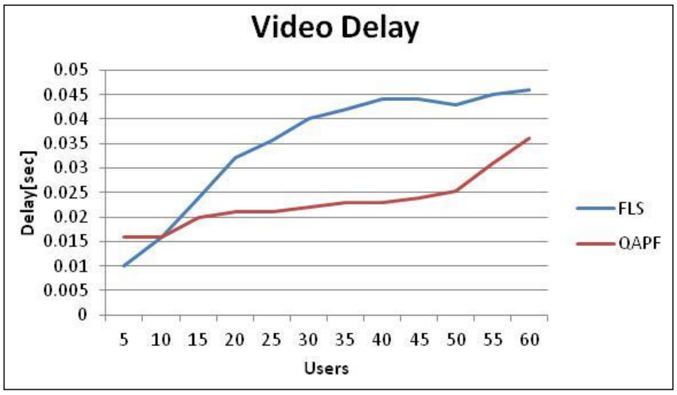

Fig. 4: Delay of QAPF and FLS for Video Flows

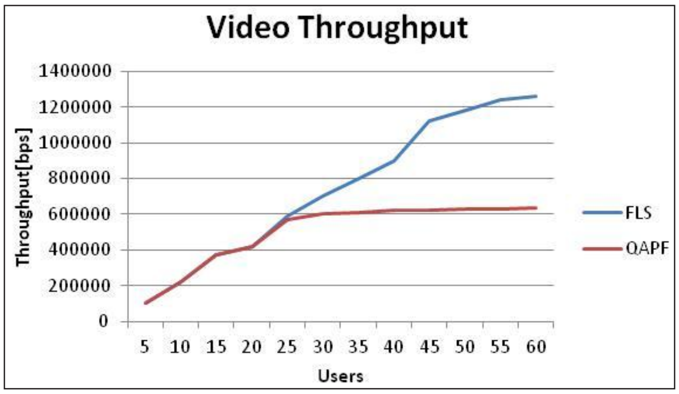

Fig. 5: Average Throughput Comparison Results of QAPF and FLS for Video Flows

In packet loss rate, QAPF also has lower performance than FLS which outperforms M-LWDF and Ex/PF especially when the number of users increases. This is because QAPF drops the packets which have the maximum delay budgets of QCIs Table I.

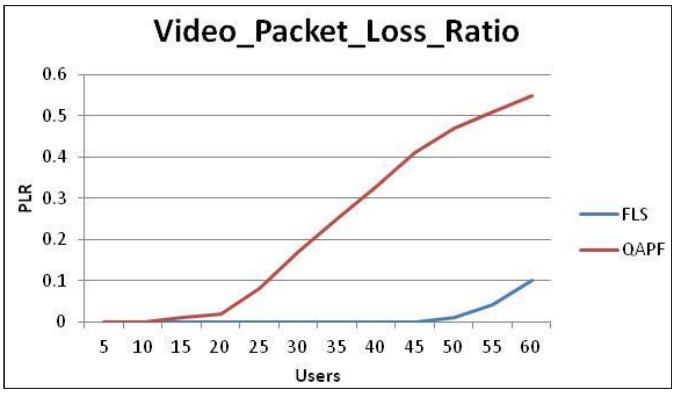

Fig. 6: Packet Loss Ratio of QAPF and FLS for Video Flows

V. CONCLUSION

In this paper, a scheduler named as QAPF which is proposed in [3] is presented and evaluated by comparing with PF, and FLS which has higher performance than M-LWDF and Ex/PF for real-time traffics. According to the experiment through simulation for LTE network, it was found that QAPF can maintain a certain degree of fairness and can get the higher throughput for the data flow or nonGBR service. It also has higher performance in delay for video flows when it is compared with FLS. Although QAPF improves the performance in terms of average throughput and packet loss rate while comparing with M-LWDF and Ex/PF [3] [4], it gets lower average throughput and higher packet loss rate for video flows, in comparison with FLS. The reason behind this is that QAPF drops the packets that violate the maximum delay budget.

In addition to this work, we also read and took a view of resource scheduling in parallel or distributed system [14, 15, 16]. Thus, we will extend the consideration on resource scheduling works, especially for cloud computing.

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