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Channel Aware Scheduling Algorithms for 3GPP LTE Downlink

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Abstract-Long Term Evolution (LTE), the standard specified by 3GPP on the way towards the fourth generation mobile networks, is intended to deliver high speed data and multimedia services to next generation mobile users. LTE is an all IP packet system in which guaranteeing QoS is a real challenge. The MAC scheduler is an important and crucial entity of the Long Term Evolution (LTE) and is responsible for efficiently allocating the radio resources among mobile users who have different QoS demands. The scheduler takes different considerations into account such as throughput and fairness when deciding the allocation of the scarce radio resources. This paper makes an attempt to study and compare the performance of PF, MLWDF, EXP/PF and FLS scheduling algorithms. The evaluation is considered for a single cell with interference scenario for different flows such as Best effort, Video and VoIP in a pedestrian and vehicular environment using the LTE-Sim network simulator [1]. The comparative study is conducted in terms of system throughput, fairness index, delay, packet loss ratio (PLR) and total cell spectral efficiency.

Keywords- Scheduling algorithms, LTE algorithms.

INTRODUCTION

The Long-Term Evolution (LTE) of the UMTS (3GPP-TS 36.300) is the de facto Standard for next generation cellular access networks. In an LTE cell, a base station or eNodeB(eNB) allocates radio resources to a number of User Equipments (UEs), i.e., handheld devices, laptops or home gateways, using Orthogonal Frequency Division Multiplexing Access (OFDMA) in the down link, and Single-Carrier Frequency Division Multiplexing (SC-FDMA) in the uplink. On each Transmission Time Interval (TTI, 1ms), a time/frequency frame of resource blocks (RBs) is allocated to the UEs, in both directions. Each RB carries a variable amount of bytes to/from an UE, depending on the selected modulation and coding scheme. The latter, in turn, is chosen by the eNodeB based on the Channel Quality Indicator (CQI) reported by the UE, which measures how the UEs perceive the channel.

In order to be able to meet the QoS demands for different services, many packet scheduling algorithms have been developed to allocate limited frequency and time resources efficiently and fairly to real-time and non-real-time traffic for all data transfer devices including mobile and wireless networks. Examples of such scheduling algorithms include Proportional Fairness (PF), Exponential Proportional Fairness (EXP-PF), and Modified Largest Weight

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Delay First (MLWDF) [6] and FLS. In this paper, we aim to evaluate the performance of several scheduling algorithms for VoIP and Video applications in terms of Throughput, Delay, PLR and Cell spectral efficiency in different scenarios. The simulation results were generated using the open source LTE system simulator called long term evolution-SIM (LTE-SIM) [1].

SCHEDULING ALGORITHMS IN LTE

LTE packet scheduling algorithm aims to maximize system performance. In order to make scheduling decisions, certain information such as the number of sessions, their reserved rates, link states, and the statuses of session queues are needed by the scheduler. The UEs periodically measure the channel quality and, on the basis of these measurements, compute the Channel Quality Indicator (CQI) which is then sent, with uplink control messages, to the scheduler located at an eNodeB. The CQI is exploited by the scheduler link adaptation module, which on this basis selects a UE with the most suitable modulation scheme and coding rate at the physical level with the objective of the spectral efficiency maximization, Fig 1 shows simple packet scheduler.

We assume that the metric assigned to stream i on jth subchannel is defined by $W_{i,j}$ to obtain metric, schedulers we usually need to know the average transmission rate $\bar{R}_i$ of flow i, and the flow rate available to the UE on the jth subchannel.

This approach is important when the metric takes into account the anterior performance of sequenced flow to balance the distribution of resources between UEs. In particular, at each TTI, the estimate $\bar{R}_i$ is given by:

$$\bar{R}_i\,(k) = 0.8\,\bar{R}_i\,(k\text{-}1)+0.2\,R_i(k)$$

Where $R_i(k)$ is the rate allocated to ith flow during the kth TTI and $\bar{R}_i$(k-1) is the average transmission data rate estimating at the (k-1)th TTI. In the following, the description of four different scheduling algorithms were used in all simulation scenarios, these are: PF as well as EXP-PF, MLWDF and FLS.

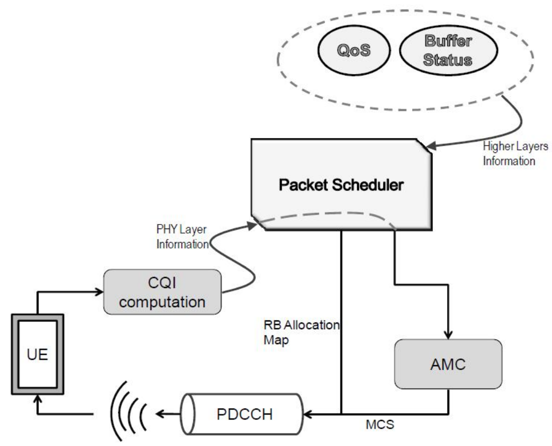

Fig 1 Simplified model of a packet scheduler

Proportional Fair (PF)

The PF scheduling algorithm provides a good tradeoff between system throughput and fairness by selecting the user with highest instantaneous data rate relative to its average data rate. For this algorithm, the metric east defines as the ratio between the instantaneous flow available for ith flow and the medium flow calculated at the moment (k-1) [2].

$$W_{i,j} = \frac{r_{i,j}}{\bar{R}_i}$$

where $r_{i,j}$ is calculated by the AMC module considering the value of the CQI on the j-th sub-channel is sent by the UE who is intended for i-th flow.

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Modified Largest Weighted Delay First (M-LWDF

M-LWDF is a type of algorithm designed for the purpose of supporting multiple real-time data users in CDMA-HDR systems [3]. This scheduler supports user being able to ask for multiple services with different requirements in QoS. For each flow real time, by considering the maximum time τ_i, the probability east is defined as the maximum probability δ_i that the time of the first package of the queue exceeds the fixed maximum time $D_{HOL,i}$ [4].
In order to give priority to real time flows having the highest time (time of the first package of the queue) and having the best conditions of propagation on the radio operator channel, the metric was defines in this scheduler by:

$$W_{i,j} = \alpha_i D_{HOL,i} \frac{r_{i,j}}{\bar{R}_l}$$

Where $r_{i,j}$ and $\bar{R}_l$ have the same signification in the previous equation, and α_i is given by:

$$\alpha_i = -\frac{\log \delta_i}{\tau_i}$$

Exponential *Proportional Fairness (EXP/PF)*

Exponential Proportional Fairness (EXP/PF) is a sort of algorithm, which configures the multimedia applications in a system of Adaptive Coding & Modulation/Time Division Multiplexing (ACM/TDM) system. This type of algorithm can have both the real-time service user as well as non-real-time service [5] and it can enhance the priority of real-time flow with respect to no-real-time flow [6]. For flows real time, the metric is calculated by using the following equations:

$$W_{i,j} = \exp\left(\frac{\alpha_i D_{HOL,i} - X}{1+\sqrt{X}}\right)\frac{r_{i,j}}{\bar{R}_l}$$

Where X is given by:

$$X = \frac{1}{N_{rt}} \sum_{i=1}^{N_{rt}} \alpha_i D_{HOL,i}$$

With N_{rt} is the number of active real time flows in downlink direction.

Frame Level Scheduler (FLS)

This QoS (Quality of Service) aware packet scheduling algorithm was proposed in [7] for RT downlink communications. FLS is a two-level scheduling strategy where the two distinct levels (upper level and lower level) interact with each other to dynamically allocate RBs to the users. At upper level, a resource allocation scheme (namely FLS), which utilizes a D-T (Discrete-Time) linear control loop, is implemented. FLS specifies the amount of data packets that a RT source should transmit frame by frame to satisfy its delay constraint. At lower level, in every TTI, RBs are allocated to the UEs using Proportional Fair (proposed in [8]) scheme with taking into consideration the bandwidth requirements of FLS. Particularly, the scheduler at the lower layer defines the number of TTIs/RBs through which each RT source will send its data packets. The amount of data to be transmitted is given by the following equation:

$$V_i(k) = h_i(k) * q_i(k)$$

Where, $V_i(k)$ is the amount of data to be transmitted by the i^{th} flow in k^{th} LTE frame, "*" is the D-T convolution operator, $q_i(k)$ is the queue level. The above equation says that $V_i(k)$ is obtained by filtering the signal

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$q_i(k)$ through a time-invariant linear filter with pulse response $h_i(k)$.

THE SIMULATION SCENARIO

For our experiment, we used LTE-Sim simulator, which encompasses several aspects of the LTE and Evolved Packet Core networks. It supports single and multi-cell environments, QoS management, multi user's environment, user mobility, handover procedures, and frequency reuse techniques. Three kinds of network nodes are modeled: UEs, eNodeBs and Mobility Management Entities. At the application layer, the simulator implements four different traffic generators and supports the management of data radio bearer. Finally, it implements several well-known scheduling strategies, among them there are the PF, M-LWDF, EXP/PF and FLS strategies with the CQI feedback compared in our work.In all our scenarios, we simulated Single cell with interference to cover the whole service area with a radius equal to 1 km, 25 downlink and uplink channels, and a variable number of UEs from 20 to 100 users is considered. Video, VoIP bit rates are 242kbps and 8.4kbps of respectively.

RESULTS AND DISCUSSION

As the results of the simulation, we obtained comparisons of the metrics described in the scheduling algorithms; packets delay, packet loss ratio, throughput, and spectral efficiency. The comparisons were performed in a function of a UEs number: starting from 20 UEs and gradually increasing them to 100 with the step of 20.

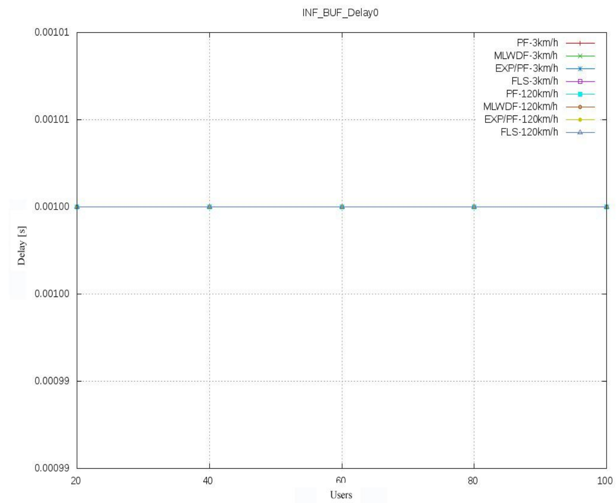

Fig 2 Delay of Best effort flow

Delay

Delay analysis is provided in this section and we can state that the selection of the scheduling algorithm has a considerable impact on packets delay experienced by the UEs. Fig 2 shows delay analysis for the best effort flow all the users' experiences constant delay with all proposed four algorithms. In the case of VIDEO flow PF scheduler experiences higher delays as the user's and the speed increases shown in fig 3.

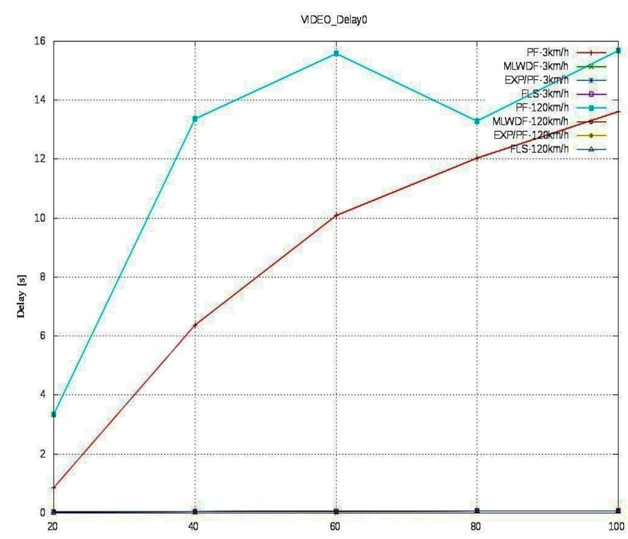

Fig 3 Delay of VIDEO flow

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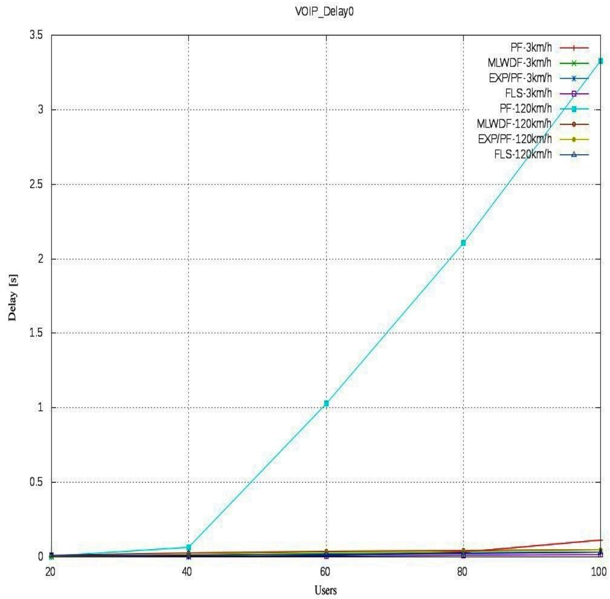

Fig 4 Delay of VOIP flow

Fig 4 shows delay analysis for VOIP flow, higher delays are with PF and it is significant at 40 users at a speed of 120km/h and exponential increases as the users are increasing. Target delay is possible with M-LDF, EXPF and FLS.

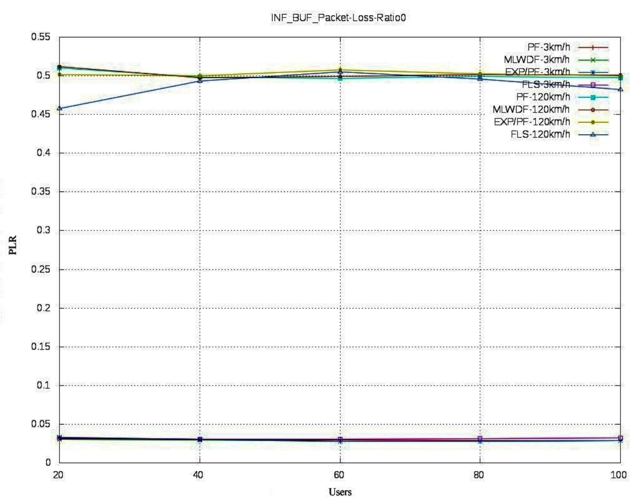

Fig 5 Packet loss ratio of best effort flow

Packet Loss Ratio

Fig. 5 shows Packet loss ratio analysis for best effort flow and user's experiences higher packet loss at 120km/h speed than 3km speed. PF, M-LDF, EXPF and FLS provide nearly same packet losses at both speeds as the number of user's increases. Fig 6 shows PLR analysis for the VIDEO flow; users are experiences almost exponential packet losses. FLS provides better performance at both proposed speeds than the other algorithms as the users are increasing while PF provides worst performance at both the speeds as the user's increases. Packet losses of M-LDF and EXPF are midway between FLS and PF.

Packet loss analysis for VOIP flow is shown in Fig 7 and it can be state that packet losses are significant at 120km/h than 3km/h and packet losses are exponentially increased as the speed and the number of users is increased because the feedback cannot follow the fast fading. On comparison FSL shows the better performance than PF, M-LDF, and EXPF at both 3km/h and 120km/h.

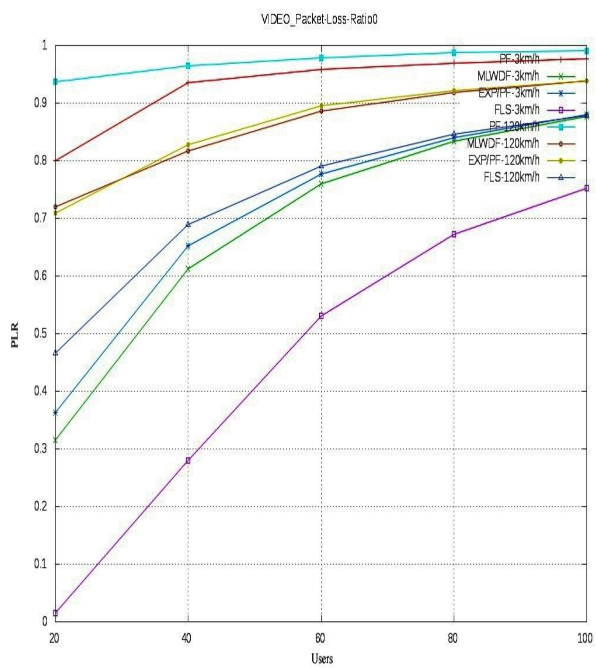

Fig 6 Packet loss ratio of VIDEO flow

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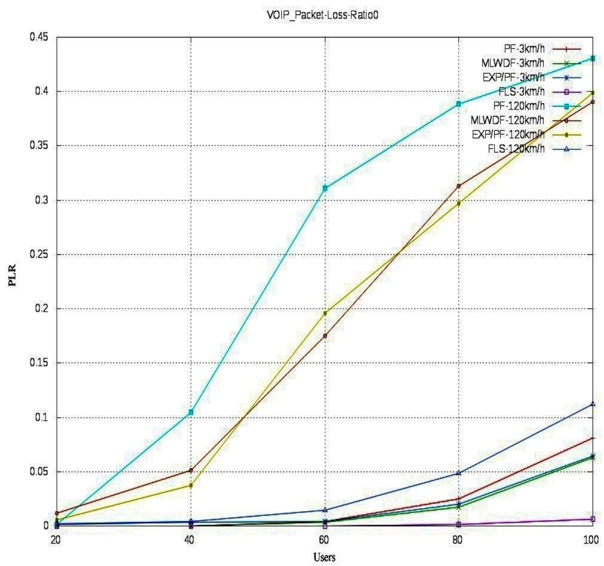

Fig 7 Packet loss ratio of VOIP flow

Throughput

Fig 8 shows Throughput analysis for best effort flow and throughput is decreasing as number of users is increasing. On comparison EXPF, M-LDF provides higher throughput at both proposed speeds. Performance of FLS is worst at both the speeds since in FLS real-time flows are prioritized over best effort flows. PF provides better throughput than FLS.

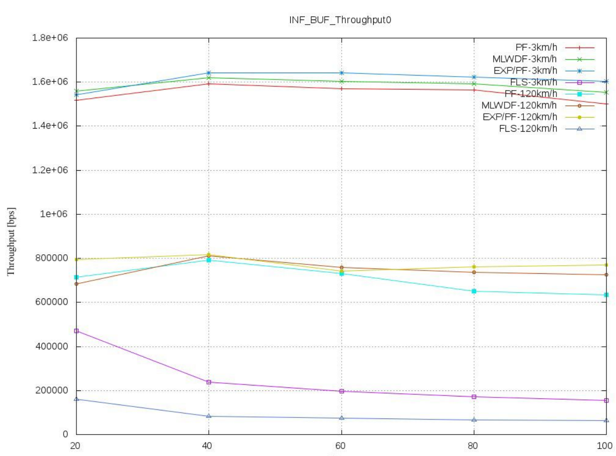

Fig 8 Throughput of best effort flow

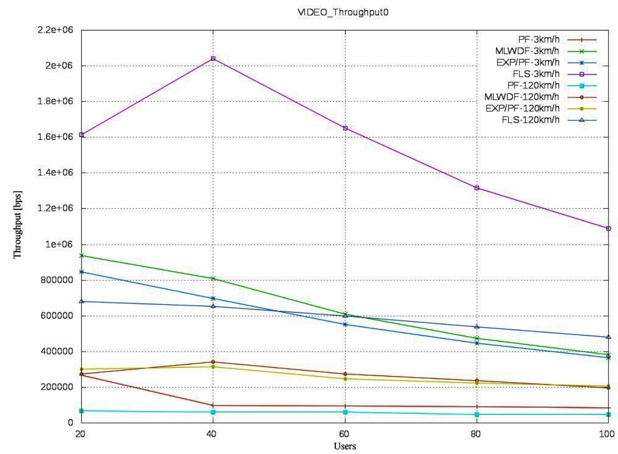

Fig 9 Throughput of VIDEO flow

Fig 9 shows Throughput analysis for the video flow, as the number of users is increasing throughput is decreasing because of interference among the users. FLS at 3km/h shows the higher throughput than other scheduling algorithms. PF at 120km/h Shows lower throughput and M-LDF, EXPF provides average guaranteeing throughput. The throughput of the VoIP flows is shown in Fig. 10. It can be noticed that the throughput is increasing with the rice of the number of VoIP users. There is a slightly change in throughput in all algorithms when increasing mobility of users.

Fairness

The fairness index for the best effort flows is shown in Fig11. It can be noticed that the fairness index for all scheduling algorithm except FLS at 120km/h increases between 20 and 40. Then it stars to in decrease up to 60 again increases from 60 users to 100 users. Fairness of FLS is decreased from 20 to 60 users than increased from 60 to 100users.

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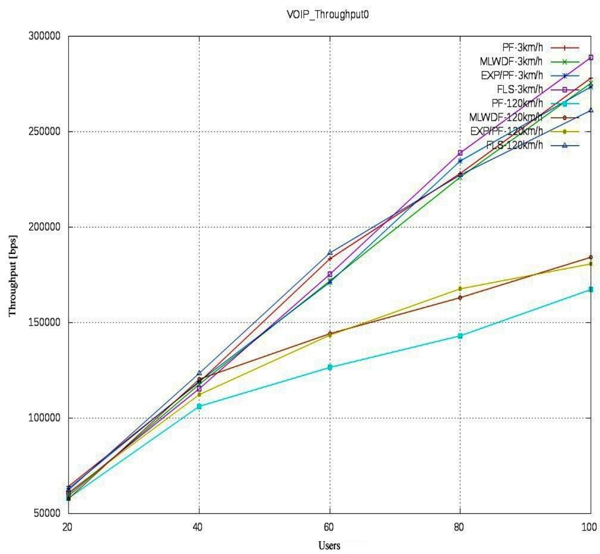

Fig 10 Throughput of VOIP flow

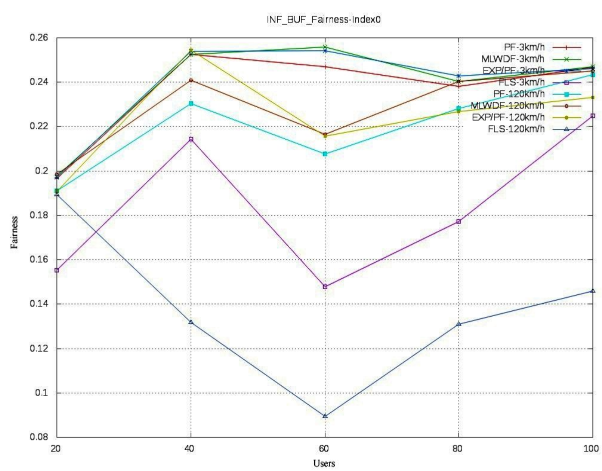

Fig 11 Fairness of best effort flow

Fig. 12 shows the fairness index for VIDEO flow, it can be seen that PF maintains almost equal fairness among the users as the users are increasing and also at both the proposed speeds. M-LDF, EXPF, and FLS shows fairness decreases as the number of users are increasing.

The fairness index for VOIP flows is shown in Fig. 13. It can be seen that PF maintains almost equal fairness among the users as the users are increasing and also at both the proposed speeds. M-LDF, EXPF, and FLS shows fairness decreases as the number of users are increasing.

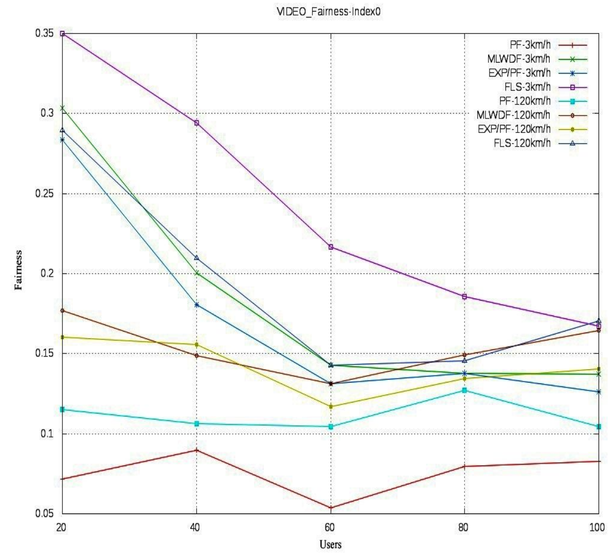

Fig 12 Fairness of VIDEO flow

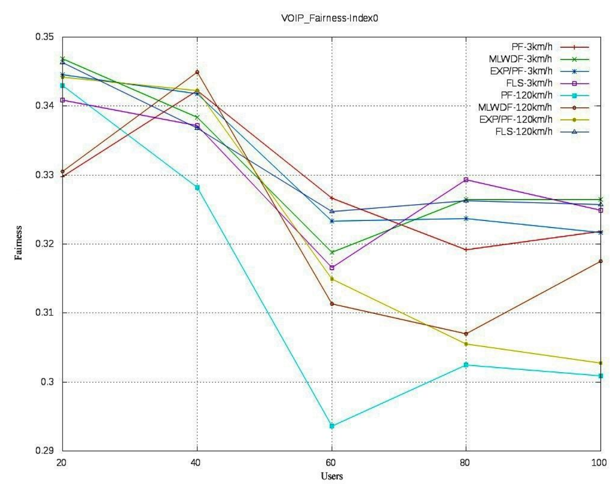

Fig 13 Fairness of VOIP flow

Spectral Efficiency

Fig. 12 shows Cell spectral efficiency analysis. M-LDF and EXPF are provides higher spectral efficiency in comparison with other algorithms. Constant spectral efficiency is possible with PF even though users are increasing.

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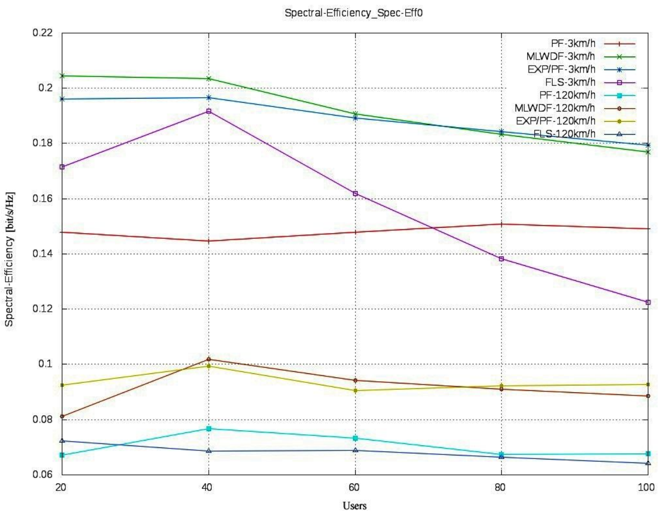

Fig 14 Spectral efficiency

CONCLUSION

In this article, we evaluated the packet scheduling performance of four LTE downlink schedulers: PF, M-LWDF, EXP/PF and FLS. We compared packets delay induced by the schedulers, system throughput, packet loss ratio, and spectral efficiency of the schedulers. For the sake of comparison, we used several simulation scenarios consisting of a real-time video streaming service, VoIP conversations and non-real time network applications. The UEs, supporting the above services and applications, were moving at pedestrian and vehicular environment.

The simulation results show that the PF scheduler is usually considerably outperformed by the three other schedulers in the case of fairness. For the real-time traffic FLS outperformed by the three other schedulers. The performances of the M-LWDF and EXP/PF algorithms are comparative, with a slight predominance of the M-LWDF algorithm in the case of packets loss and data throughput.

The research shows the importance of proper selection of scheduling strategy at a network base station. The lack of multimedia traffic awareness by the scheduling algorithms implemented at the base station will lead to major degradation of video and VoIP services, even for a relatively small number of UEs in a network.

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