PRIORITY BASED EXP/PF SCHEME FOR LTE DOWNLINK TRANSMISSION

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ABSTRACT: The variation of user demand in Long Term Evolution (LTE) without corresponding variation in radio resources places enormous burden on the fairness index of scheduling schemes. An attempt to improve on the fairness index would require a scheduling scheme that incorporates user demand variations in its operation. In this paper, a scheduling strategy for dynamic resource allocation schemes in LTE downlink transmission that incorporates the demand variations is proposed. Exponential proportional fairness (EXP/PF) scheduling scheme was modified by introducing type of packet prioritization parameter at each scheduling time to characterize for user demand variation. The modified scheduling scheme was tested using varying quality of service (QoS) class identifiers (QCI) standardized by 3GPP for LTE network to characterize different services. It was also tested on the basis of packet prioritization. The scheduler was simulated with LTE-Sim and compared with EXP/PF and PF schedulers. It performed better than EXP/PF and PF schedulers in terms of packet loss rate and throughput while accommodating user demand.

Keywords - EXP/PF, LTE, QCI, Scheduler, Priority.

1. INTRODUCTION

LTE was introduced by third generation partnership project (3GPP) as a fourth generation (4G) network [1], [2]. The main requirements for LTE are high spectral efficiency, high peak data rates, reduced latency as well as flexibility in frequency and bandwidth, support for varying classes of services such as voice, video streaming (live and buffered), video telephony, VoIP, real time gaming etc [3], [4]. In order to satisfy these requirements, LTE runs an all-IP network structure in its core layer with five bandwidth specification and implements an enhancement of 3G radio access network (node B) referred to as evolved Node B (eNB) [5].

Furthermore, LTE eNB implements Orthogonal Frequency Division Multiple Access (OFDMA) scheme in its downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in its uplink [6], [7]. The reason for the difference in downlink and uplink access schemes is to minimize the Peak to Average Power Ratio (PAPR) of the system [8]. In order to achieve the goals of low latency, improved spectral efficiency and fairness among users, a Radio Resource Management (RRM) in MAC layer of eNB implements some specified functions. These functions include a mix of advanced MAC and Physical layer functions such as radio resource allocation, Channel Quality Indication (CQI) reporting, link adaption through Adaptive Modulation and Coding (AMC) schemes, power allocation schemes and Hybrid Automatic Retransmission reQuest (HARQ) [9].

However, growing number of users of the LTE network infers that the classes of service demand from users will transmute rapidly [19]. These classes of service may be voice, video conferencing, gaming, file transfer etc. Besides, the implementation of HARQ scheme by LTE poses a complex challenge to the attempt to reserve the scarce resources for this scheme and also to the application of a separate allocation scheme to it. This poses a challenge to RRM layer.

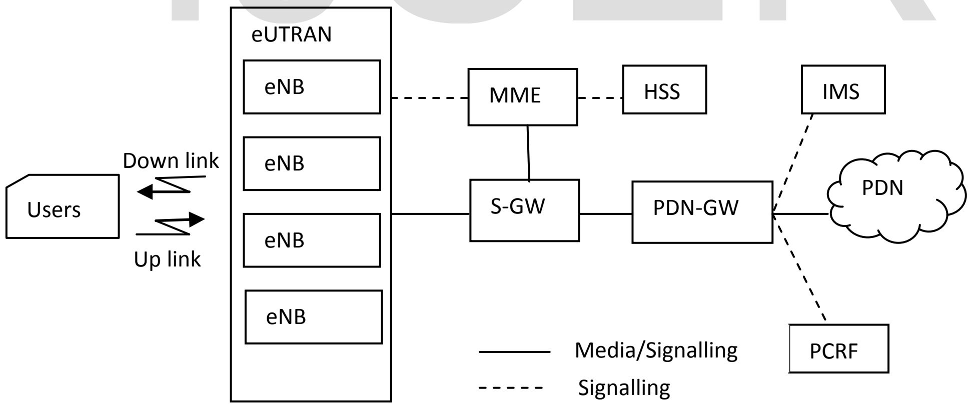
It has been observed that researches reported till date, agree that users should be scheduled before the allocation of resources [10], [11], [12], [13]. However, these researches did not consider the effect of rapid user demands variations on the scheduling strategies. Also they did not consider the prioritization of HARQ traffic over new (fresh) traffic. Emphases have always been laid on minimizing power and maximizing throughput of the system. These allocation schemes use scheduling strategies that do not perform optimally when HARQ is implemented and user demand varied. The practical LTE schedulers are both channel aware and QoS aware. Some of the schemes implemented by these schedulers are MLWDF, PF, VT-MLWDF, log/PF, EXP/PF, etc [9]. Among these schemes, the EXP/PF scheme performed better at high load and accommodated more scheduling parameters while making its decision [15]. Hence, EXP/PF scheme was adopted for this work.

Furthermore, EXP/PF considered user demand characteristics in its operation with the acceptable loss rate and delay threshold parameters representing the packet delay budget as recommended by 3GPP. However, some classes of services especially non-real time services have the same acceptable loss rate and delay threshold as shown in the QCI table [17]. These services, mostly non-guaranteed bit rate (NGBR) services, fail to show relevant impact to the EXP/PF scheduler especially when challenged with equal head on the line delay and channel condition. This limitation sectionalized this scheduler into implementing PF for non-real time services and EXP/PF for real time services. This limitation is the foundation upon which this work is based. The 3GPP standard however, allowed for scheduling to be further based on service priority level when the packet delay budget fails [17].

Therefore, in this paper, a new scheduler is proposed as a modification of the EXP/PF scheme by incorporating user demand variations parameter in its decision making. 3GPP standardized the classes of services offered by LTE in its QCI table [14], [17]. QCI priority parameter identifies these classes of service and integrates them in the proposed scheduling strategy.

2. NETWORK ARCHITECTURE

A typical LTE High level network architecture is presented in figure 1. The network basically comprised of the signalling and user traffic planes. A network user is connected to the network via the eNB using radio interface on both planes [4]. The PDN is accessed through the gateways (serving and PDN). Transmission across the radio interface is either downlink or uplink as illustrated in figure 1. The eNB resources are allocated dynamically for both downlink and uplink transmissions. The implication is that the scheduler is resident in the eNB.



KEY

MME: Mobility Management Entity; eUTRAN: evolved Universal Terrestrial Radio Access
S-GW: Serving Gateway; PDN-GW: Packet Data Network Gateway
HSS: Home Subscription Server IMS: IP Multimedia Subsystem
eNB: evolved Node B PCRF: Policy and Charging Resource Function

Figure 1: LTE High Level Network Architecture

3. TYPICAL LTE DOWNLINK SCHEDULER

A typical LTE eNB scenario can be modelled and simulated to generate the data required for computation at the analytical section of the model using an integrated approach. Figure 2 presents the integrated model of a typical LTE eNB scheduler. The eNB was positioned at the centre of a cell with all users connected to it wirelessly. The users of the network are randomly distributed in space and travelling at random speed.

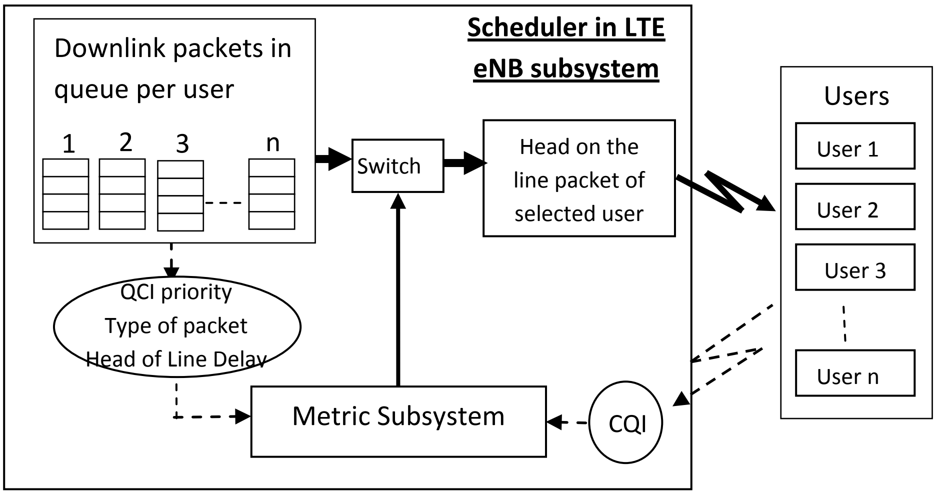


Figure 2: Integrated Simulation Model of LTE Scheduler

The parameters for the scheduling decision from the users and the eNB buffer are sent to the metric subsystem. This subsystem calculates a scheduling metric analytically for each user using a specified scheduler. It compares these metrics and selects the user with the largest metric for downlink transmission. The selected user is then given RBs for its transmission at a particular TTI. 3GPP recommends that primarily scheduling decisions should be based on packet delay budget while incorporating other scheduling parameters [17].

4. PROPOSED SCHEDULER (ANALYTICAL MODEL)

Channel Quality Indicator (CQI) is a feedback by the user to the eNB containing information as to the state of the channel. It is in the form of Signal to Interference Noise Ratio (SINR) for every corresponding channel bandwidth. The rate at which a user, i, would utilize a channel, k, at an instantaneous time, t, is calculated using Shannon Capacity expression stated in equation (1) [9].

$$d_{i,k}(t) = \log\left(1 + SINR_{i,k}(t)\right) (1)$$

If the base of the log is 2, we have our rate unit as bits per second (bps) and this rate becomes the CQI parameter. The primary goal of the scheduler in an LTE network is to choose a user among other users for a particular scheduling block. This is modelled mathematically as shown in equation (2).

$$\mathrm{Q[k]} = \mathrm{arg}max_i \; m_{i,k} \; (2)$$

Where Q[k] is the selected user priority on scheduling block, k while $m_{i,k}$ is the scheduling metric parameter of user, i, on scheduling block, k.

However, scheduling schemes are developed using general and specific constraints. Thus, equation (2) is bound generally with throughput maximization and equity in fairness among users. While specific constraints are dependent on the scheduler algorithm being developed such as maintaining packet delay budget for MLWDF and EXP/PF schemes, etc.

Furthermore, LTE schedulers are designated to act as an interface to select users for subsequent resource allocation in a particular TTI. So many schedulers have been proposed in literature ranging from channel unaware to channel aware schedulers; then to QoS dependent schedulers. A typical example of a channel aware scheduler is the proportional fairness (PF) scheduler. This scheduler implements a trade-off between fairness and spectral efficiency as shown in equation (3) [9, 12].

$$m_{i,k}^{pf} = \frac{d_{i,k}(t)}{R_i(t)} \quad (3)$$

Where, $d_{i,k}(t)$ - the throughput achievable by the user at time, t, for a particular channel, k, and $R_i(t)$ –-the average throughput of the user, i, in previous transmissions.

In PF, users with good channel quality are assigned more resources while users with poor channel quality are assigned less resources. PF is a combination of channel aware Maximum Throughput (MT) scheduler and the channel unaware Blind Equal Throughput (BET) scheduler [9]. A generalized PF approach by the addition of two novel parameters is given in equation (4) [9].

$$m_{i,k}^{GPF} = \frac{[d_{i,k}(t)]^a}{[R_i(t)]^b} \quad (4)$$

where a and b were used to modify the impact on the allocation policy of the instantaneous data rate and the past achieved throughput respectively.
However, in order to accommodate QoS requirements in channel aware scheduling, more complex and advanced schedulers were proposed in literature. A robust and widely used channel aware, QoS aware scheduler is the exponential proportional fairness (EXP/PF) scheduler. This scheduler takes into account the characteristics of PF and an exponential function of the end-to-end delay of the packet to be transmitted. EXP/PF distinguishes between real time and best effort flows. For best effort flows, EXP/PF becomes PF while for real time flows. EXP/PF is given in equation (5) [12, 16].

$$m_{i,k}^{EXP/PF} = \alpha_i exp\left(\frac{\alpha_i D_{HoL,i} - X}{1 + \sqrt{X}}\right) . \frac{d_{i,k}(t)}{R_i(t)} \quad (5)$$

where

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

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

D_{HoL} is the head of the line delay, δ_i is the acceptable loss rate and τ_i is the delay threshold, N_{rt} is the number of active downlink real-time flows, D_{HoL} is the Head on the Line Delay.

EXP/PF as shown in equation (5) considered user demand characteristics in its operation with the acceptable loss rate and delay threshold parameters representing the packet delay budget as recommended by 3GPP. However, some classes of services especially non-real time services have the same acceptable loss rate and delay threshold as shown in the QCI table [17]. These services, mostly non-guaranteed bit rate (NGBR) services, fail to show relevant impact to the EXP/PF scheduler especially when challenged with equal head on the line delay and channel condition. This limitation sectionalized this scheduler into implementing PF for non-real time services and EXP/PF for real time services.In order to ameliorate this limitation, a constraint that allows the type of packet waiting in the queue to be served is annexed to the EXP/PF scheme. This is achieved by the use of packet prioritization as elucidated in [17].

The 3GPP standard however, allowed for scheduling to be further based on service priority level when the packet delay budget fails [17]. In prioritizing packets, 3GPP maintained in its document that services with Priority 1 retained the highest priority level [17]. In view of this, this work modified the EXP/PF scheduler by dividing the DHoL with the priority level attached to each service requested by the user. The consequence of dividing with the priority ensures that the requirement of the 3GPP guideline is maintained. With this method, emphasizes is laid on the effect of prioritization of user demand in the proposed scheduler especially for NGBR services leading to an improvement of the EXP/PF. It ensures that the type of service being given to a user is a factor to the time a user would be selected. This priority is fixed depending on the QoS requirement status of the user as prescribed on the standardized QCI table. Different users with different QoS requirement would be represented with the priority of such a request. If two users have the same DHoL and similar channel condition, the type of service demanded by each user would influence the scheduling (selection) of a particular user. Hence, with higher priority, the greater the chances of the user

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to be selected for on-ward downlink transmission assuming all other parameters of the scheduler are constant. Hence, demand variation of each user is used while making the scheduling decision. In view of this, the proposed scheduler aims at prioritizing all types of traffic and the requirement of the service, together with the maximization of channel throughput and head on the line delay in order to ensure fairness among users. The priority of service represented in this work as PQCI is from the standard QCI table. With the implementation of the PQCI, the proposed scheduler can be used for both real and non-real time service scheduling. Equation (6) shows the analytical representation of the proposed scheduler.

$$m_{i,k}^{M-EXP/PF} = exp\left(\frac{\alpha_i \frac{D_{HoL,i}}{P_{QCI}} - X}{1+\sqrt{X}}\right) \cdot \frac{d_{i,k}(t)}{[R_i(t)]} \quad (6)$$

where

$$X = \frac{1}{N}\sum_{i=1}^{N} \alpha_i \frac{D_{HoL,i}}{P_{QCI}}$$

N is the number of active downlink flows, P_{QCI} is the QCI priority.

5. SIMULATION MODEL

The LTE-SIM simulator proposed by G. Piro et al [18] was used in simulating the schedulers (proposed EXP/PF, and PF schedulers). Simulation results for the scheduling metric of the proposed EXP/PF and the PF schedulers were averaged over five different simulations. The simulation parameters are shown in the table 1. The scheduler was tested with three classes of services prescribed in the 3GPP QCI table. These services are voice (QCI 1), Non-conversational video (QCI 4) and IMS Signalling (QCI 5). Simulation results for the scheduling metric of the proposed scheduler and the EXP/PF scheduler were averaged over five different simulations ran with randomly generated parameters to obtain more reliable data. The simulation parameters are shown in the table 1.

Table 1: Simulation parameters

Parameter	**Value**
Maximum number of users per cell (eNB)	100
Simulation scenario	Single cell with interference
Number of Simulations	5
Number of cells (eNB)	2
Bandwidth	5MHz
Service tasted	Voice, video and IMS signalling
Video bitrate	242Kbps

6. DISCUSSION AND RESULT ANALYSIS

The proposed scheduler (modified EXP/PF) was modelled and simulated with LTE-SIM simulator. The scheduler was allowed to run together with the PF and EXP/PF schedulers concurrently. This is to aid the comparison of the performance of the proposed scheduler. Furthermore, the schedulers were simulated to obtain the relationships of figures 3 – 9. The proposed scheduler is identified in the figures as Mod_EXP/PF. The simulation was carried out for three priority levels – Priority level 1, 2, and 5. These priority levels define specific services such as IMS signalling, VoIP and video services respectively. In order to aid statistical comparison, the data collected from each scheduler for the 100 users of the eNB were aggregated and presented in percentage.

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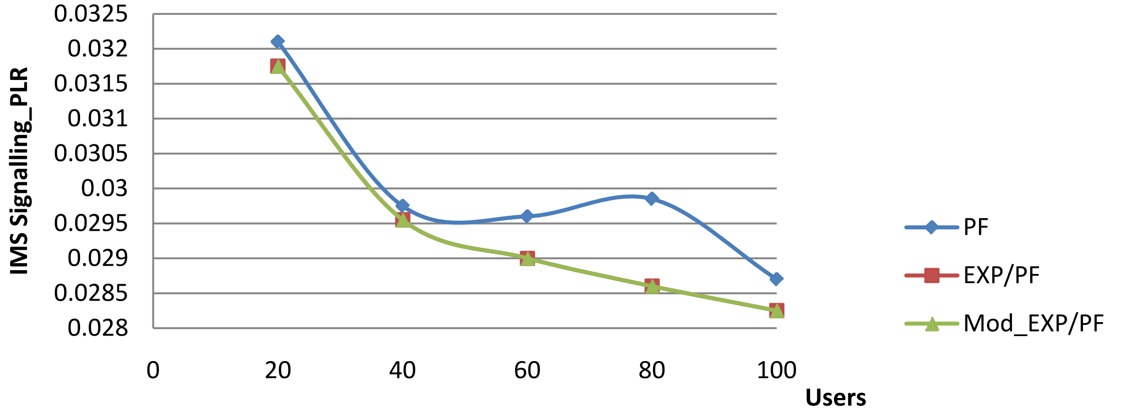

Figure 3: IMS Signalling (Priority 1) Packet Loss Rate

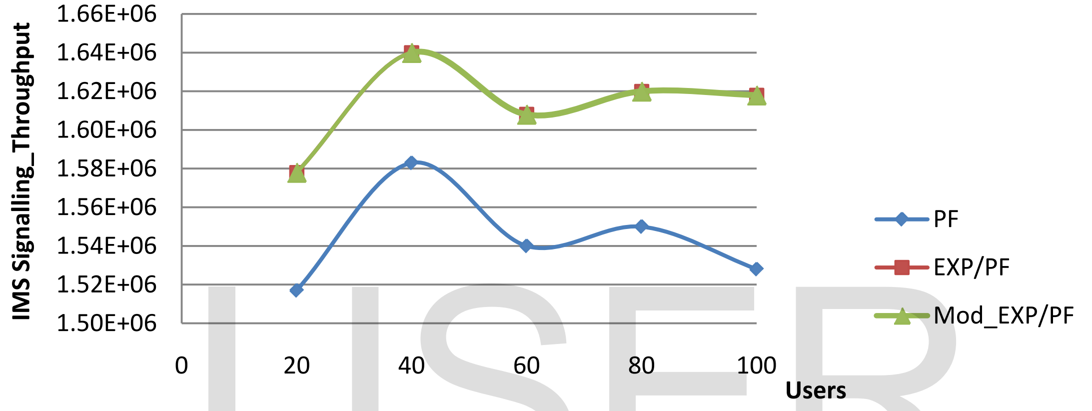

Figure 4: IMS Signalling (Priority 1) Throughput

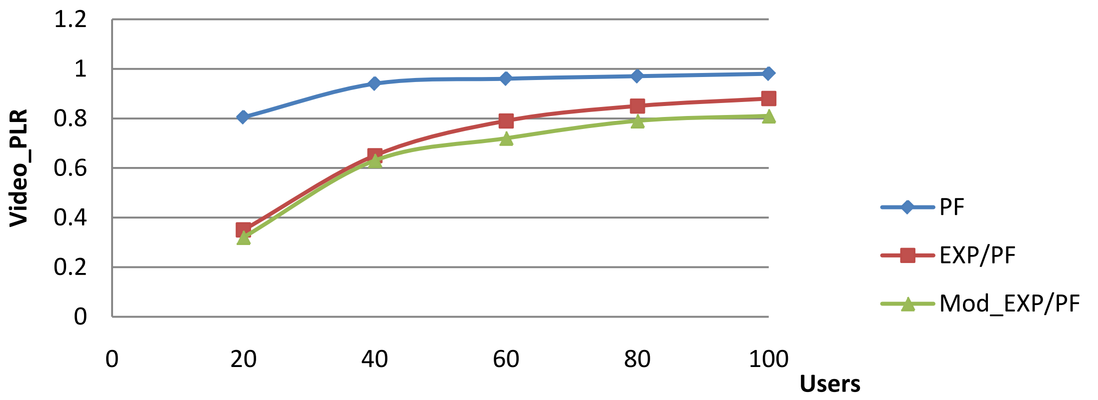

Figure 5: Video (Priority 5) Packet Loss Rate

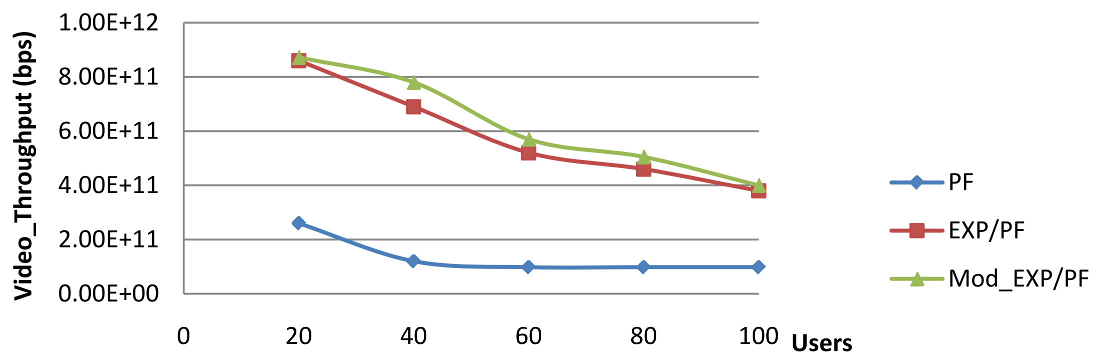

Figure 6: Video (Priority 5) Throughput

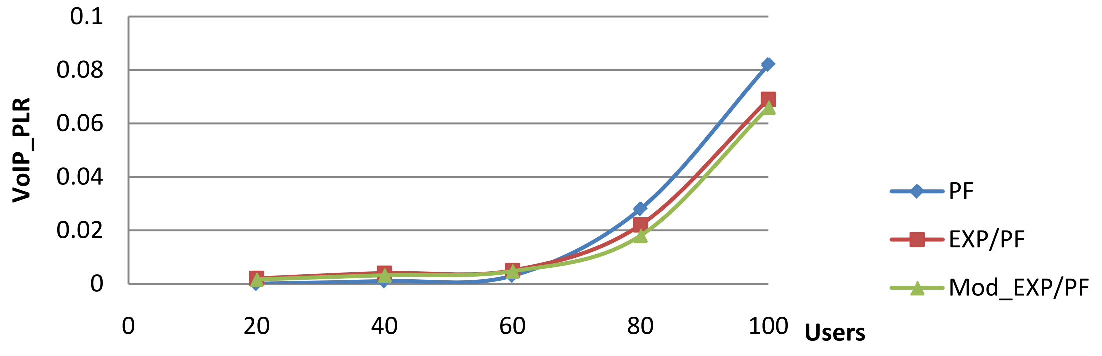

Figure 7: VoIP (Priority 2) Packet Loss Rate

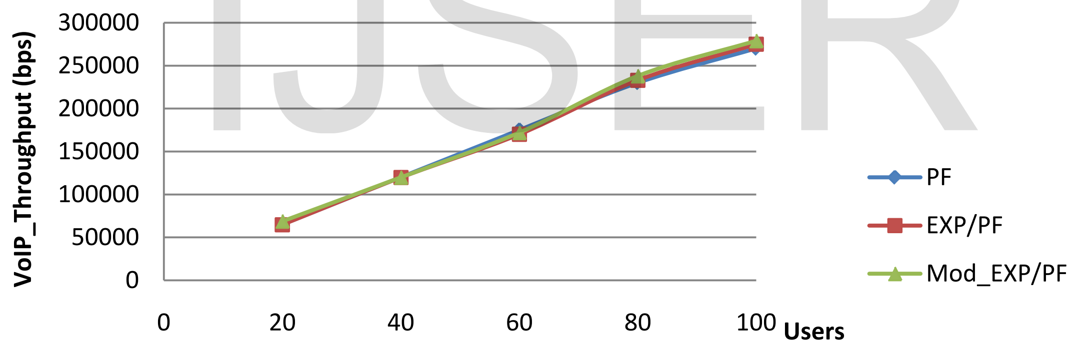

Figure 8: VoIP (Priority 2) Throughput

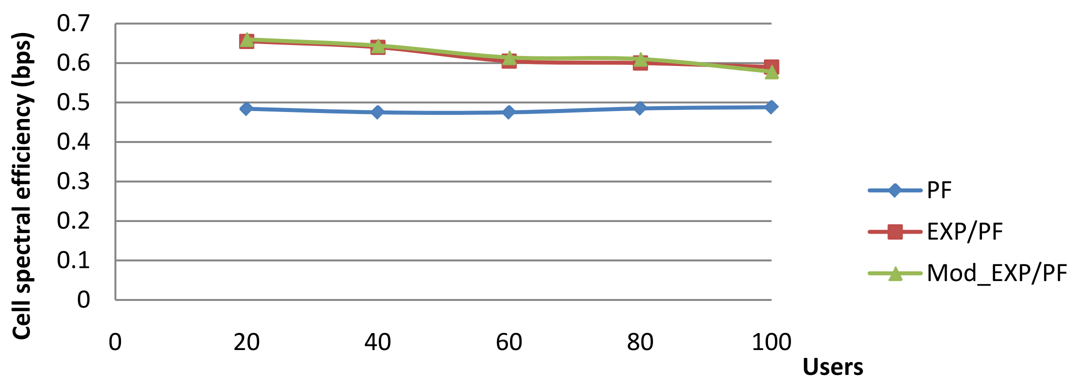

Figure 9: Cell Spectral Efficiency

The packet loss rate (PLR) for all 100 users are shown in figures 3, 5 and 7 for services with priority level 1 (eg. IMS Signalling), priority level 5 (eg. Video), and priority level 2 (eg. VoIP). The lower the PLR value for each scheduler, the better the performance of the scheduler in terms of PLR. In figure 3, the proposed scheduler's performance is the same with the EXP/PF scheduler. This is because at a priority of 1, the proposed scheduler would become a normal EXP/PF scheduler. This deduction can be made from the analytical expression shown in equation (5). However, average data collected showed that the proposed scheduler and the EXP/PF schedulers performed better than the PF scheduler with 1.9%. Furthermore, figure 7 shows that the proposed scheduler performed better than the EXP/PF and PF schedulers in terms of packet loss ratefor services with priority 2. The average data obtained from this graph show that the proposed scheduler has 8.33% and 17.98% better performance percentage over the EXP/PF and PF schedulers respectively. Figure 5 shows the relationship between the PLR and the number of user for services with priority 5. The proposed scheduler performed better than EXP/PF and PF schedulers with an average data of 7.1% and 29.75% respectively. It can also be observed that for this service, as the number of users grows the PLR increases for services.

The throughput of the service priorities under study are shown in figures 4, 6 and 8. The higher values of throughput indicate better performance of the scheduler. Figure 4 show that for services with priority level 1.Also, the performance of the proposed scheduler is the same in terms of throughput when compared to EXP/PF scheduler as deduced from the analytical expression in equation (5). However, these schedulers perform better than the PF scheduler with an average of 4.29%. Figure 6 show the relationship between throughput of service with priority of 5. Average data obtained reveal that the proposed scheduler performed better than the EXP/PF and PF schedulers with 6.9% and 78.4% respectively. Figure 8 show the relationship in terms of throughput for the proposed, PF and EXP/PF schedulers for services with a priority of 2. The average data collected showed that the proposed scheduler performed better than the EXP/PF and PF schedulers with 1.72% and 2.02% respectively.

The cell spectral efficiency based on equation 5 is shown in figure 9. This figure shows that as the number of users increase for both the proposed scheduler and the EXP/PF scheduler, the spectral efficiency of the cell reduces. However, the proposed scheduler has a better cell spectral efficiency of 0.52% than the EXP/PF scheduler.

7. CONCLUSION

The provision of an adequate scheduling scheme that is fair to user location, the QoS requirement of the users and the retransmission of packets is the facet upon which this work was developed. In the work, we proposed a downlink resource scheduling scheme that performs optimally in achieving the afore-mentioned aim. The proposed scheduler is a modification of the EXP/PF metric scheduler. We considered the introduction of packet prioritization as recommended by 3GPP in generating the metric used to perform the scheduling of LTE downlink transmission. Comparing the overall performance of the proposed scheduler (equation (6)), the EXP/PF and PF schedulers, we concluded that the proposed scheduler performed favourably than the EXP/PF and PF schedulers.

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