ISSN 22773061

On the Performance of PF, MLWDF and EXP/PF algorithms in LTE

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ABSTRACT

This paper explores the performance of three packet scheduling algorithms, namely, Proportional Fair (PF) algorithm, Exponential/Proportional Fair (EXP/PF) algorithm and Maximum Largest Weighted Delay First (MLWDF), from the real time traffic perspectives. Simulation results showed that in the downlink of the 3GPP LTE system, the MLWDF outperforms the PF and the EXP/PF algorithms in terms of packet throughput, packet-loss ratio, packet latency, fairness index and total cell spectral efficiency.

Council for Innovative Research
Peer Review Research Publishing System
Journal: **INTERNATIONAL JOURNAL OF COMPUTERS & TECHNOLOGY**

Vol 8, No. 1
editor@cirworld.com
www.cirworld.com, member.cirworld.com

I. Introduction

Long Term Evolution (LTE) is proposed by the Third Generation Partnership Project (3GPP) in order to provide support for a high-speed data networks. The access technology in the downlink of the 3GPP LTE system is the Orthogonal Frequency Division Multiple Access (OFDMA). In OFDMA, the available bandwidth is divided into groups of orthogonal and narrow-band subcarriers, and subcarriers are allocated to users based on their requirements, system configuration and current system load [1].

The radio access network of the LTE is composed of only single logical node called evolved Node Base station (eNB). The eNB handles all Radio Resource Management, including packet scheduling. Packet scheduler is responsible for transmitting user's data packets and efficient utilization of the available radio resources, so that users' Quality of Service (QoS) can be maintained [2]. In order to satisfy users' QoS, different packet scheduling algorithms have been developed for different traffic types. In this paper the performance of PF, MLWDF and EXP/PF algorithms [3][4][5] has been studied. In the aforementioned algorithms each connection between the user and eNB is assigned a priority, and then, the connection with the highest priority is scheduled firstly at each scheduling interval.

This paper is organized as follows. Section II describes the LTE downlink system model. Packet scheduling algorithms are described in more detail in Section III; simulation environment is presented in Section IV. Simulation results are shown in Section V, and finally Section VI concludes the paper.

II. Downlink 3GPP LTE system model

In downlink of the 3GPP LTE system, the minimum unit of resource that is allocated to the user called Resource Block (RB). The RB is defined in both time and frequency domains. In the frequency domain it comprises 12 consecutive subcarriers, with the bandwidth of each subcarrier is 15 kHz (i.e. total bandwidth of the RB is 180 KHz), while in the frequency domain it is made up of one time slot which lasts for 0.5 ms duration. A time slot is 7 OFDM symbols [6].

Packet scheduling and all RRM functionalities are conducted at the eNB. In this study an eNB processing 10 MHz bandwidth with inter-cell interference is modeled. The process of packet scheduling is conducted every 1 ms interval, or called Transmission Time Interval (TTI), and each user is allocated two consecutive RBs. In the uplink direction, users report their instantaneous downlink channel conditions on each RB (i.e. Signal-to-Noise-Ratio, SNR) to the serving eNB at each TTI. And the reported SNR values are used to determine the downlink data rate of each user in each scheduling interval (i.e. number of bits per two consecutive RBs) [7].

The proposed method in [8] can be used to calculate the number of bits per symbol for user *i* at time *t* at sub-carrier on RB *j* $(nbits_{i,j}(t)/symbol)$. The user's data rate $dr_i(t)$ during scheduling interval can be calculated using Equation (1).

$$dr_i(t) = \frac{nbits_{i,j}(t)}{symbol} * \frac{nsymbols}{slot} * \frac{nslots}{TTI} * \frac{nsc}{RB} \tag{1}$$

Where $nsymbols/slot$ is number of symbols per slot, $nslots/TTI$ is the number of slots per TTI and nsc/RB is the number of sub-carriers per RB. The SNR values and the associated data rate with these values are given in table 1.

Each active user has a buffer at the eNB as a packet container. The arriving packets toward the buffer are time stamped, and are transmitted to users based on First-in-First-out (FIFO) approach. At each TTI, the packet scheduler (located at the eNB) determines users priority based on the configured scheduling algorithm. Different algorithms use different scheduling criteria (e.g. Head-of-Line (HOL) packet delay, service type, channel condition, buffer status, etc.) when making scheduling decision. Once the user with the highest priority has been selected for transmission one or more resources are allocated to that user as shown in Fig 1.

Table 1 Instantaneous downlink SNR to data rate mapping

Minimum SNR Level (dB)	Modulation and coding	Data Rate (Kbps)
1.7	QPSK (1/2)	168
3.7	QPSK (2/3)	224
4.5	QPSK (3/4)	252
7.2	16 QAM (1/2)	336
9.5	16 QAM (2/3)	448
10.7	16 QAM (3/4)	504
14.8	64 QAM (2/3)	672
16.1	64 QAM (3/4)	756

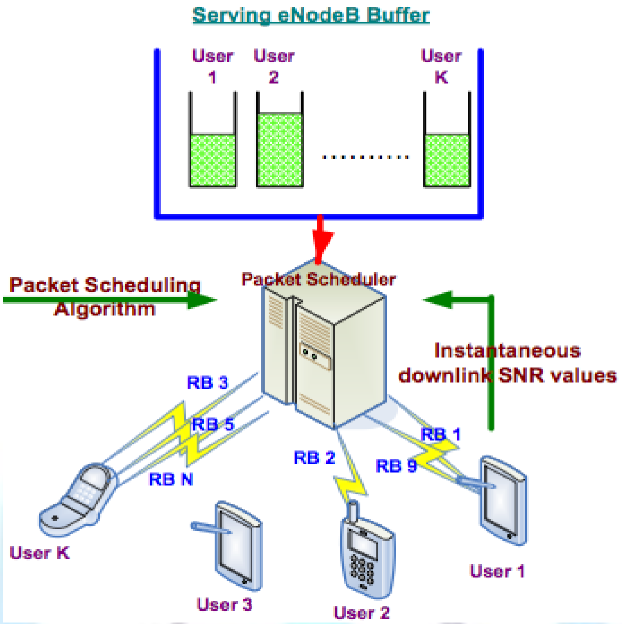

Fig.1 Packet Scheduling Model in the Downlink of the 3GPP LTE System [9]

III. Packet Scheduling Algorithms

The purpose of the packet scheduling algorithms is to maintain the QoS and fairness demands of each user along with an effective utilization of the available radio resources [9]. The packet scheduling algorithms to be considered in this paper were developed for single carrier wireless system, and these algorithms are: Proportional Fair (PF) algorithm, Maximum-Largest Weighted Delay First (MLWDF) and the Exponential/Proportional Fair (EXP/PF) algorithm.

A. Proportional Fair (PF) Algorithm

The PF algorithm was developed to support the Non Real Time (NRT) service in a Code Division Multiple Access- High Data Rate (CDMA-HDR) system [2]. It provides trade-off between the total system throughput and fairness among users. It takes into account both the past data rate and the experienced channel conditions when assigning radio resources. The PF algorithm allocates resources to the user who maximizes the metric *k,* defined as the ratio of:

$$k = \arg\max \frac{r_i(t)}{R_i(t)} \qquad (2)$$

Where;

$$R_i(t) = \left(1 - \frac{1}{t_c}\right) * R_i(t-1) + \frac{1}{t_c} * r_i(t-1) \qquad (3)$$

Where $r_i(t)$ is the achievable data rate of user *i* at time *t,* $R_i(t)$is the average data rate of user *i* at time *t,* $t_c$is the size of the update window; which enables the PF algorithm to maximize the throughput and fairness of each user, and $r_i(t-1)$*=0* if user *i* is not selected for transmission at time *t-1.*

B. Maximum Largest Weighted Delay First (M-LWDF) Algorithm

The M-LWDF was developed to support multiple real-time data users in CDMA-HDR system [10]. The M-LWDF considers channel variations when allocating radio resources and additionally in case of video traffic it considers time delay, thus, it is used in case of different QoS user's requirements. In M-LWDF a user who maximizes the following metric is granted radio resources:

$$k = \arg\max a_i W_i(t) \frac{r_i(t)}{R_i(t)} \qquad (4)$$

Where;

$$a_i = -\frac{(\log\delta_i)}{\tau_i} \qquad (5)$$

Where $W_i(t)$ is the HOL packet delay of user *i* at time *t* (i.e. time difference between current time and arrival time of the packet), $r_i(t)$ is the achievable data rate of user *i* at time *t*, $R_i(t)$ is the average data rate of user *i* at time *t*, τ_i is the delay threshold of user *i's* packet and δ_i is the maximum probability for HOL packet delay of user *i* to exceed the delay threshold of user *i.*

C. Exponential/Proportional Fair (EXP/PF) Algorithm

The EXP/PF algorithm was proposed for multimedia applications in the Adaptive Modulation and Coding and Time Division Multiplexing (AMC/TDM) systems. The EXP/PF algorithm is used if there are different types of services (NRT service or RT service). The resources are allocated to users based on the following metric:

$$k = \arg\max \begin{cases} \exp\left(\frac{a_i W_i(t) - a\overline{W(t)}}{1+\sqrt{a\overline{W(t)}}}\right)\frac{r_i(t)}{R_i(t)} & i\epsilon RT \\ \frac{w(t)}{M(t)}\frac{r_i(t)}{R_i(t)} & i\epsilon NRT \end{cases} \tag{6}$$

Where;

$$a\overline{w(t)} = \frac{1}{N_{RT}} \sum_{i\epsilon RT} a_i W_i(t) \tag{7}$$

$$w(t) = \begin{cases} w(t-1) - \varepsilon & W_{max} > \tau_{max} \\ w(t-1) + \frac{\varepsilon}{k} W_{max} < \tau_{max} \end{cases} \tag{8}$$

Where$M(t)$ is the average number of packets at the eNB's buffer at time *t*, *k* and ε are constants, W_{max} is the HOL packets delay of RT service and τ_{max} is the maximum delay of RT service users. Finally the EXP/PF algorithm prioritizes RT traffic users over the NRT traffic users when their HOL delays are approaching the delay deadline.

IV. Simulation Environment

In this paper a simulator called LTE-Sim is used to perform the entire simulation [11]. A single cell of 1 km with inter-cell interference is modeled. There are 50% of users having VoIP flows and the rest of them having video traffic. Users are uniformly distributed within the cell and moving constantly with a speed of 3km/h. The propagation loss model has been implemented and it includes: path-loss, penetration loss, multi-path loss and shadow fading which are summarized below [12]:

- Path-loss: $128.1 + 37.6\log_{10}(d)$, where *d* is the distance between the user and the eNB in km
- Penetration loss: 10 *dB*
- Multi-path loss: *Jakes model*
- Shadow fading: *log-normal distribution with a mean value and standard deviation of 0 dB and 10 dB, respectively*

The performance of the aforementioned algorithms is judged based on packets throughput, Packet Loss Ratio (PLR), packet latency (delay), fairness index and cell spectral efficiency. Fairness among users is implemented using Jain's method [13]. The entire system simulation parameters are shown in Table 2.

Table 2 LTE system simulation parameters

Parameters	
Simulation time	100 s
Cell radius	1 km
User speed	3 km/h
VoIP bit rate	8.4 kbps
Video bit rate	242 kbps
Frame structure	FDD
Bandwidth	10 MHz
Number of RBs	50
Number of subcarriers	600
Number of subcarriers/RB	12
Subcarrier spacing	15 KHz
Slot duration	0.5 ms
TTI	1 ms
Number of OFDM symbols/slot	7

V. Simulation Results

Fig. 2 shows the average throughput per video flow. As the cell is charged with more users; the average throughput per video flow decreases for all scheduling algorithms. When the number of users exceeds 20, the PF algorithm suffers from a sharp decrease in the average throughput, while the MLWDF and EXP/PF algorithms show a small decline in the average throughput per flow. It is shown in Fig. 3 that the PLR of all algorithms is less than 1% when the number of users in the cell is 20. When the cell is charged with more users, the PLR shows rapid increase in case of the PF and EXP/PF algorithms with slightly lower growth for MLWDF algorithm. Fig. 4 shows video delay. It is clear that, while the number of users in the cell is less than 40, all algorithms have similar performance. When the number of users exceeds 40, packet delay of video flow in case of PF sharply increases and remains constant for the other algorithms. As shown in Fig. 5, the fairness index of all simulated algorithms is close to 0.5 when the number of users in the cell is less than 30 users. When the number of users in the cell exceeds 30 users, fairness index in case of PF goes down to 0.35 while in the other algorithms it is around 0.4. The average throughput per VoIP flow is shown in Fig. 6. It is clear that the average throughput per packet for VoIP flow is same for all scheduling algorithms, and it maintains between 3600 bps and 3450 bps. The PLR of the VoIP flow is shown in Fig. 7. It is clear that when the number of users in the cell is less than 40 users, there is no considerable difference in PLR performance between the three algorithms. When the number of users exceeds 40 users, the PF algorithm shows sharp increase in the PLR value compared to the other algorithms; it has a value of 3% when the number of users is 80, whereas it has values of 1.5 % and 0.5% for the EXP/PF algorithm and MLWDF algorithm, respectively, at the same number of users. The packet delay of VoIP flows is shown in Fig.8. As the number of users increases, users suffer from a longer latency. When there are more than 30 users, packet delay of VoIP flows shows faster growth when implementing the PF algorithm than that in the case of MLWDF or EXP/PF algorithms. When there are 80 users, packet delay of VoIP flow is 0.25 second, while it is less than 0.05 second when using MLWDF or EXP/PF algorithms. The fairness index for VoIP flows is almost the same for all simulated algorithms and its values are around 0.5, as shown in Fig. 9. Finally, Fig. 10 shows the total cell spectral efficiency. Generally the total cell spectral efficiency increases with increasing number of users up to certain point and tends to maintain after that point.

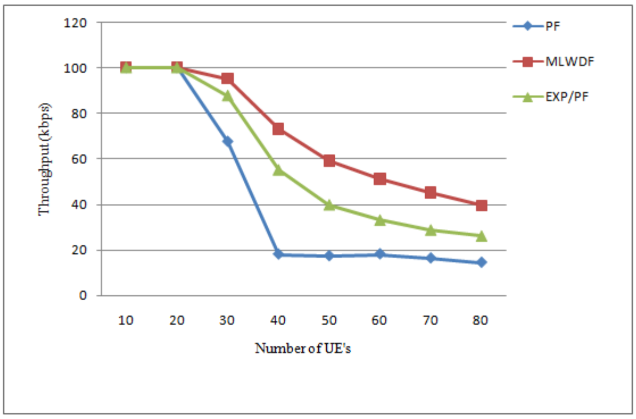

Fig.2 Average Throughput per Video Flow

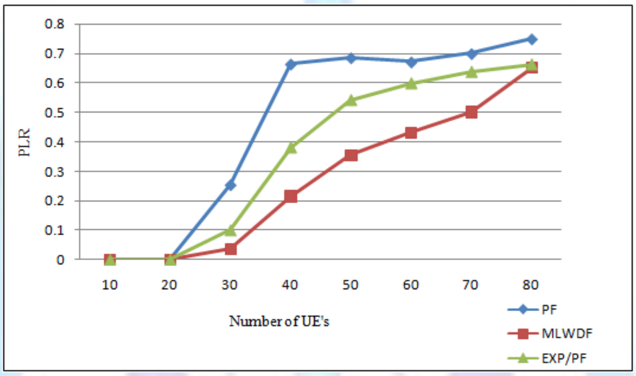

Fig.3 PLR of Video Flows

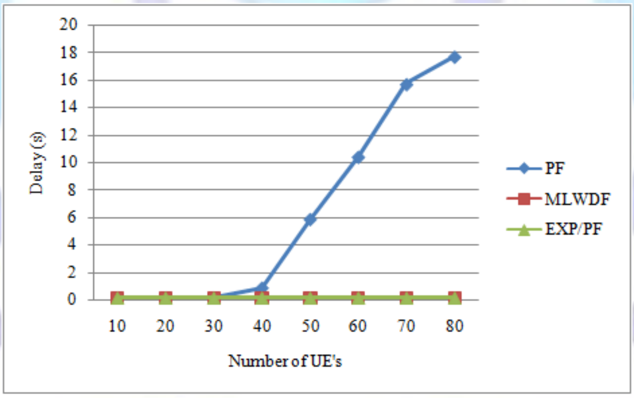

Fig. 4 Packet Delay of Video Flows

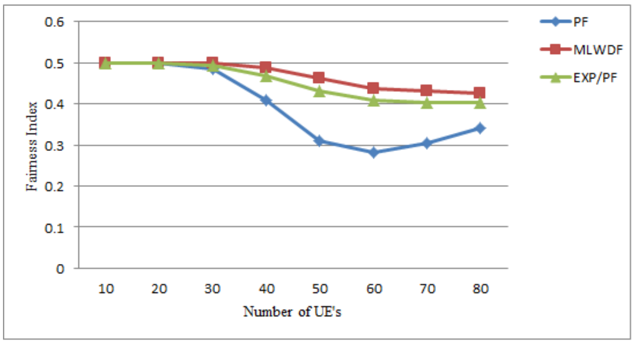

Fig.5 Fairness Index of Video Flows

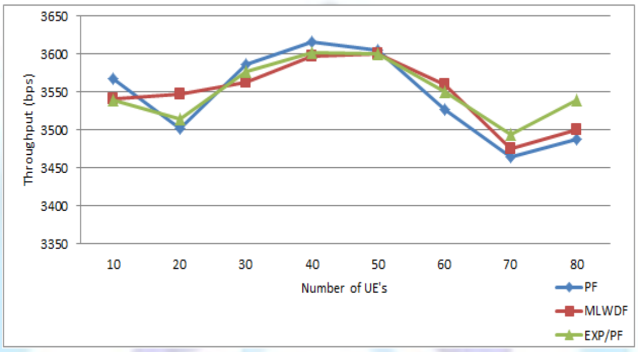

Fig. 6 Average throughput per VoIP Flow

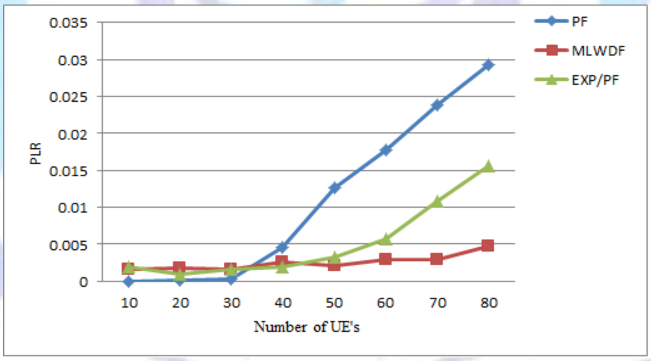

Fig. 7 PLR of VoIP Flow

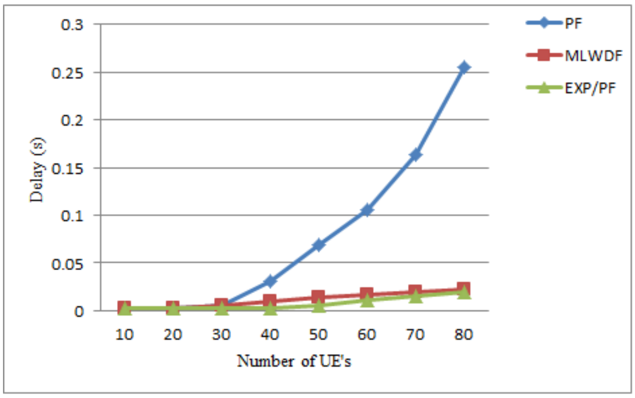

Fig.8 Packet delay of VoIP flows

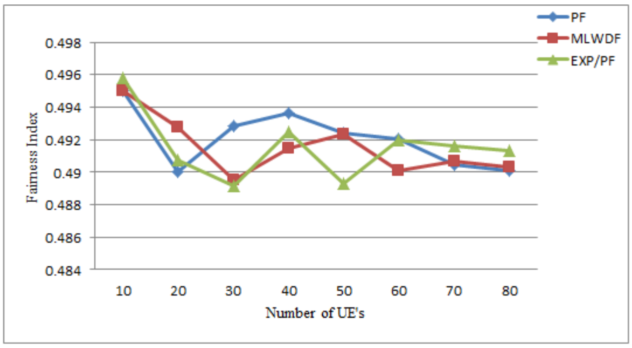

Fig. 9 Fairness Index of VoIP flows

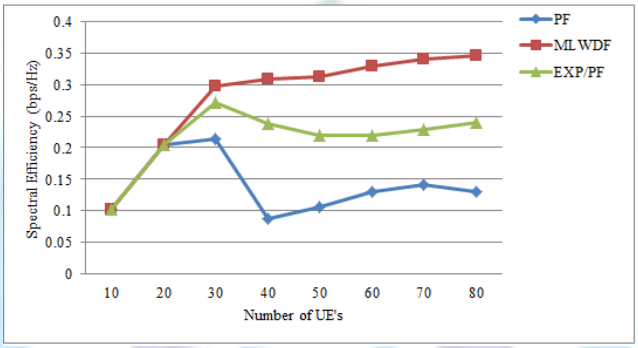

Fig. 10 Total Cell Spectral Efficiency

VI. Conclusion

This paper investigates the performance of three packet scheduling algorithms; PF algorithm, EXP/PF algorithm and MLWDF algorithm that were developed for single carrier wireless systems. The performance of these algorithms is tested from the RT perspectives. Five metrics, namely packet throughput, PLR, packet delay, fairness index and total cell spectral efficiency are used to evaluate the performance of these algorithms. Simulation results indicated that the MLWDF algorithm outperform other algorithms in terms of previous metrics when these algorithms are used for RT traffic.

REFERENCES

[1] H. A. M. Ramli, R. Basukala, K. Sandrasegaran, and R. Patachaianand, "Performance of well known packet scheduling algorithms in the downlink 3GPP LTE system," in *Communications (MICC), 2009 IEEE 9th Malaysia International Conference on*, 2009, pp. 815-820.

[2] B. Liu, H. Tian, and L. Xu, "An efficient downlink packet scheduling algorithm for real time traffics in LTE systems," in *Consumer Communications and Networking Conference (CCNC), 2013 IEEE*, 2013, pp. 364-369.

[3] A. Jalali, R. Padovani, and R. Pankaj, "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system," in *Vehicular Technology Conference Proceedings, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st*, 2000, pp. 1854-1858.

[4] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R. Vijayakumar, "Providing quality of service over a shared wireless link," *Communications Magazine, IEEE,* vol. 39, pp. 150-154, 2001.

[5] J.-H. Rhee, J. M. Holtzman, and D. K. Kim, "Performance analysis of the adaptive EXP/PF channel scheduler in an AMC/TDM system," *Communications Letters, IEEE,* vol. 8, pp. 497-499, 2004.

[6] J. Zyren and W. McCoy, "Overview of the 3GPP long term evolution physical layer," *Freescale Semiconductor, Inc., white paper,* 2007.

[7] B. Riyaj, M. R. H. Adibah, and S. Kumbesan, "Performance analysis of EXP/PF and M-LWDF in downlink 3GPP LTE system," 2009.

[8] X. Qiu and K. Chawla, "On the performance of adaptive modulation in cellular systems," *Communications, IEEE Transactions on,* vol. 47, pp. 884-895, 1999.

[9] S. C. Nguyen, K. Sandrasegaran, and F. M. J. Madani, "Modeling and simulation of packet scheduling in the downlink LTE-advanced," in *Communications (APCC), 2011 17th Asia-Pacific Conference on*, 2011, pp. 53-57.

[10] A. Alfayly, I.-H. Mkwawa, L. Sun, and E. Ifeachor, "QoE-based performance evaluation of scheduling algorithms over LTE," in *Globecom Workshops (GC Wkshps), 2012 IEEE*, 2012, pp. 1362-1366.

[11] G. Piro, L. A. Grieco, G. Boggia, F. Capozzi, and P. Camarda, "Simulating LTE cellular systems: an open-source framework," *Vehicular Technology, IEEE Transactions on,* vol. 60, pp. 498-513, 2011.

[12] M. Iturralde, T. Ali Yahiya, A. Wei, and A. Beylot, "Resource allocation using shapley value in LTE networks," in *Personal Indoor and Mobile Radio Communications (PIMRC), 2011 IEEE 22nd International Symposium on*, 2011, pp. 31-35.

[13] R. Jain, D.-M. Chiu, and W. R. Hawe, *A quantitative measure of fairness and discrimination for resource allocation in shared computer system*: Eastern Research Laboratory, Digital Equipment Corporation, 1984.