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PERFORMANCE ANALYSIS OF EXP-BET ALGORITHM FOR TRIPLE PLAY SERVICES IN LTE SYSTEM

Ku Siti Syahidah Ku Mohd Noh[a*], Darmawaty Mohd Ali[a], Zin Mar Myo[b], Ahmad Kamsani Samingan[c], Abdul Aziz Abdul Rahman[c], Norsuzila Ya'acob[a]

[a]Wireless Communication Technology Group (WiCoT), Advanced Computing and Communication Communities of Research, Faculty of Electrical Engineering, Universiti Teknologi Mara (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia
[b]University of Computer Studies, Yangon Myanmar
[c]TM Research & Development Sdn. Bhd, TM Innovation Centre, Lingkaran Teknokrat Timur, 63000 Cyberjaya, Selangor Malaysia

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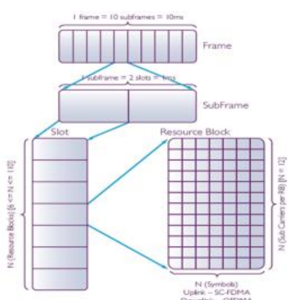
*Corresponding author
kusitisyahidah@salam.uitm.edu.my

Graphical abstract



Abstract

Quality of Service (QoS) is defined as user's satisfaction towards service performance that has been offered to them. Due to different traffic characteristics and QoS requirements of real-time and non-real-time services, thus provisioning the QoS requirements has become a challenge. In this study, we have compared our proposed algorithm namely the Exponential Blind Equal Throughput (EXP-BET) towards the Exponential Proportional Fairness (EXP-PF) and Frame Level Scheduler (FLS). The comparisons have been made in terms of fairness index, throughput,packet loss rate (PLR) and delay. From the simulation results, it is observed that EXP-BET delivers higher fairness and throughput and lower PLR and delay for real-time application. Instead, EXP-BET shows 17.72% improvement than FLS and 7.52% from EXP-PF in term of fairness index for the non-real-time application.

Keywords: LTE; packet scheduling algorithm; exponential blind equal throughput; LTE-Sim

1.0 INTRODUCTION

In order to give better Quality of Service (QoS) to mobile subscribers, Third Generation Partnership Project (3GPP) has introduced Long Term Evolution (LTE) system as an emerging and promising fourth generation mobile technology which is expected to offer ubiquitous broadband access to the mobile subscribers. The objectives of the LTE are to minimize latency, high user data rates, improved system capacity and coverage, better battery lifetime and reduced cost for the operator.

LTE system is an Internet Protocol (IP) technology which has used Orthogonal Frequency Division Multiple Access (OFDMA) as the multiple access technique for the downlink transmission while Single Carrier Frequency Division Multiple Access (SC-FDMA) is employed in the uplink transmission.

LTE has been designed as a highly flexible radio access technology in order to support several system bandwidth configurations. Bandwidth in LTE ranges from 1.25 to 20 MHz and supported the data rates of 100 Mbps for downlink and 50 Mbps for uplink. Two types of frame structure available in LTE system; Frequency Division Duplex (FDD) and Time Division Duplex (TDD) but in this study, we focused on the FDD.

The FDD frame structure consists of a frame which is equivalent to 10 sub-frames with 10 ms long as shown in Figure 1. Each sub-frame is divided into two slots (0.5 ms) and in 1 slot of the sub-frame contains several resource blocks (RBs). The number of RBs depends on the transmission bandwidth. A resource block contains 12 subcarriers with 6 or 7 OFDM symbols where the number of the OFDM symbols depends on the cyclic prefix (CP) either it is a normal CP or an extended CP.

There are several published studies that compare the performance of the scheduling algorithms. Research in [1] compared the performance of Modified Largest Weighted Delay First (M-LWDF), Exponential Proportional Fairness (EXP-PF), Exponential Rule (EXP Rule), Logarithmic Rule (LOG Rule) and Frame Level Scheduler (FLS) for video flow. The results show that FLS algorithm outperforms other algorithms in all performance metric.

Packet Prediction Mechanism (PPM) has been proposed by Wei Kuang Lai et. al. [2] which is suitable for the real-time applications. They claimed that their algorithm is accurate in predicting the behavior of future arrival packets. As a result, PPM shows an improvement in invalid packet rates and throughput and delivers low delay.

Author in [3] has included multiple services in their Queue-HoL-MLWDF algorithm. The proposed algorithm shows remarkable and balanced improvement for all flows in terms of packet loss, average throughput, fairness and spectral efficiency.

This paper proposes a packet scheduler namely the Exponential Blind Equal Throughput (EXP-BET) algorithm. To the best of author's knowledge, no other researchers have proposed the EXP-BET as the candidate of the downlink scheduler in LTE system.

Every user pays the same amount of money for the service that being offered by the provider. Thus, every user should receive an equal treatment, especially in terms of fairness and throughput. The main objective of the development of EXP-BET algorithm is to give equal treatment to users regardless of where they are located in a cell.

The performance of the EXP-BET algorithm will be evaluated for the performance metrics of fairness index, throughput, packet loss rate and delay for three different services; VoIP, video and best effort.

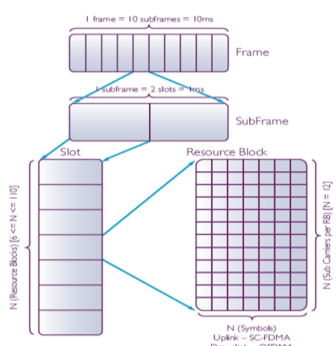


Figure 1 FDD LTE frame structure

2.0 PACKET SCHEDULING ALGORITHM

Scheduling process is performed in the Medium Access Control (MAC) layer and packet scheduler is one of the main components that may affect the system performance. The function of the scheduler is to allocate the radio resources to user in order to meet the various QoS requirements at the downlink and uplink transmissions.

The packet scheduler is located at the eNodeB and the scheduler may apply any packet scheduling algorithms in the system. Some examples of the packet scheduling algorithms are the EXP-PF and FLS.

2.1 Exponential Proportional Fairness (EXP-PF)

EXP-PF algorithm can support both real-time and non-real-time services. This algorithm has been designed to increase the priority of real-time services with respect to non-real-time services. The average Head of Line (HoL) packet delay is taken into account and the EXP-PF metric is calculated as follows:

$$j^{EXP-PF} = \max \alpha_i \frac{\mu_i(t)}{\overline{\mu_i}} \, exp\left(\frac{\alpha_i D_{HOL} - \beta}{1+\sqrt{\beta}}\right) \quad (1)$$

where α_i denotes the weight factor while D_{HoL} is the HoL packet delay. $\mu_i(t)$ is the data rate corresponding to the channel state of the user *i* at time slot *t*. $\overline{\mu_i}$ is the mean data rate of user *i*.

$\beta = \frac{1}{N_{rt}} \sum_{i=1}^{N_{rt}} \alpha_i \, D_{HOL}$ where N_{rt} is the number of active downlink real-time services. The EXP-PF behaves like Proportional Fairness (PF) algorithm when the HoL packet delay for all the users does not differ a lot and the exponential value is close to 1. If one of the user's HoL delay becomes higher, the exponential term overrides the channel state-related term, and the user gets the highest priority.

2.2 Frame Level Scheduler (FLS)

The FLS algorithm is a two level scheduling scheme [4]. Two different algorithms are implemented in these two levels. A low complexity resource allocation algorithm based on discrete time linear control theory is implemented in the upper level. It computes the amount of data that each real-time source should transmit within a single frame, to satisfy its delay constraint.

The PF algorithm is implemented in the lower level to assign radio resources to the users to ensure a good level of fairness. The FLS algorithm is represented as:

$$j^{FLS} = h_i(t) * q_i(t) \quad (2)$$

where j^{FLS} is the amount of data to be transmitted by the *i*-th flow in *t*-th LTE frame and "*" is the discrete time convolution. The j^{FLS} is calculated by filtering the signal $q_i(t)$ (i.e., the queue level) through a time-invariant linear filter with pulse response of $h_i(t)$.

2.3 Exponential Blind Equal Throughput (EXP-BET)

The EXP Rule algorithm is considered as an enhancement of the aforementioned EXP-PF algorithm. It is proposed to provide the QoS guarantees over a shared wireless link. A wireless channel is shared among multiple users and each user's packets arrive to the queue as a random stream where it awaits transmission or service. A scheduling rule in this context selects a single user or queue to receive service in every scheduling instant [5].

BET algorithm works on the principle of the past average throughput achieved by each user. It tries to reach fair throughput for all users regardless of their radio channel quality. BET algorithm is calculated as Eq. (3).

$$j^{BET} = \frac{1}{R_i(t-1)} \tag{3}$$

$R_i(t-1)$is the past average throughput achieved by user *i*-th during the t-1 window.

In every TTI, BET algorithm allocates resources to flow that have been served with low average throughput in the past. Under this allocation policy, user experiencing the lowest throughput will be served as long as the user does not reach the same throughput of other users in the cell. In this way, users with bad channel conditions are allocated more often than others.

In our proposed EXP-BET algorithm, we have combined the EXP Rule and the BET algorithms to support both the real-time and non-real-time services. The EXP Rule algorithm schedules the real-time services while the BET algorithm take cares of the non-real-time services.

3.0 SIMULATION MODEL

In this section, we will discuss on the simulation environment of the study. The LTE-Sim Simulator [6] is used to perform the simulations. A single cell consisted of one eNodeB and varying number of users (from 10 to 60) was simulated. The simulation parameters are summarized in Table 1.

Table 1 LTE downlink simulation parameters

Parameter	Value
Bandwidth	10MHz
Number of RB	50
Radius	1km
Max delay	0.1s
User speed	3km/h
Video bit rate	242 kbps
VoIP bit rate	8.4 kbps

In this simulation, the propagation loss model which is composed of path-loss, shadow fading, multipath fading and the penetration loss is considered too. The summarization of the propagation loss model is tabulated in Table 2.

Table 2 Propagation loss model

Parameters	*Value*
Path loss	128.1 + 37.6 $\log_{10}$ (*d*) where *d* is the distance between the user and eNodeB in km
Shadow fading	Log-normal distribution with 0 mean and 8 dB of standard deviation
Multipath fading	Jakes model
Penetration loss	10 dB

Each user is assumed to have one best effort, one video and one VoIP flow to be transmitted. The best effort flow model is based on the ideal greedy source that always have packets to send. For video, the application sends packets based on realistic video trace files, which are available from [7]. The selected video flow is encoded at the rate of 242 kbps using the H.264 encoder while G.729 is used to generate VoIP flow with a rate of 8.4 kbps. The ON/OFF Markov chain model has been applied in this application.

4.0 RESULT AND DISCUSSION

This paper evaluates the performance of EXP-BET, EXP-PF and FLS algorithms which are classified as a channel-aware packet scheduler. It considers the channel information when making a scheduling decision and can be included with or without QoS support. Four performance metrics are analyzed which are the fairness index, throughput, packet loss rate and delay.

Throughput is defined as the total amount of successful packet delivery by a system over a given interval of timewhile fairness index indicates that every user is receiving a fair share of the system resources. The throughput is calculated as in Eq. (4) while fairness index is implemented based on Jain's Fairness Index where the best value is 1.

$$Throughput = \frac{1}{T}\sum_{i=1}^{K}\sum_{t=1}^{T} Ptransmit_i(t) \tag{4}$$

$$Fairness\ index = \frac{(\sum_{i=1}^{n} x_i)^2}{n\ \sum_{i=1}^{n} {x_i}^2} \tag{5}$$

T represents the total time taken for simulation and $Ptransmit_i\,(t)$ describes the size of the transmitted packets. Meanwhile *K* is the total number of active users in the system. The parameter *x* in Eq. (5) is the normalized throughput (in kbps) of the *i*-th flow and *n* is the number of users in the network.

Delay or latency in communication is the amount of time a packet takes to traverse a system. If packets are not transmitted within the deadline, the packets will be discarded. The packet loss rate is the ratio of the total discarded packet size to total arrival packet size. Eq. (6) shows the equation of delay while packet loss rate is calculated as in Eq. (7).

$$Delay = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{K}\sum_{i=1}^{K} HoL_i(t) \tag{6}$$

$$Packet\ loss\ rate = \frac{\sum_{i=1}^{K}\sum_{t=1}^{T} Pdiscard_i(t)}{\sum_{i=1}^{K}\sum_{t=1}^{T} Psize_i(t)} \tag{7}$$

$HoL_i(t) = T_{current}(t) - T_{stamp}$is defined as the time difference between the current packet serving time and the time when the packet was stamped on its arrival to the service queue. $Pdiscard_i(t)$is the size of discarded packets and $Psize_i(t)$ is the size of all packets that have arrived into the eNodeB buffer of user *i*-th at time *t*.

4.1 Real-Time Services

A real-time service is an application that functions within a time frame and the user needs to response immediately. This application has a strict requirement on delay which needs to be provision. Some examples for real-time applications are video conference, VoIP, video streaming, online gaming, and some e-commerce transactions.

4.1.1 VoIP

VoIP flow is a method of delivering the voice communications and multimedia sessions over IP networks. Skype and Google Talk are the examples of VoIP flow.

Figure 2 presents the fairness index for VoIP flows. From the figure, it is observed that the performance of these three schedulers is comparable to each other. However, EXP-BET delivers the highest fairness index among the others.

The throughput of VoIP flows is illustrated in Figure 3. It shows that as the number of user increases, the throughput increases too. The VoIP flows are set with the highest priority to be scheduled as compared to the video and best effort flows. Thus, the throughput being delivered from these three algorithms are quite similar. However, the EXP-PF starts to deliver the lowest throughput when the number of users increases.

The QoS value for the VoIP delay and the packet loss rate are set to be less than 100 ms and $1x10^{-2}$ respectively as specified by the 3GPP standard [8]. Figure 4 and Figure 5 show the delay and packet loss rate for the VoIP flows. The three schedulers provision the requirements of the 3GPP where the delay and packet loss rate values are still within the defined range. The EXP-BET has the lowest delay as compared to EXP-PF and FLS.

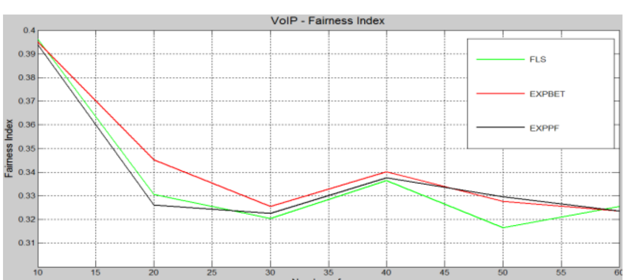


Figure 2 VoIP – fairness index

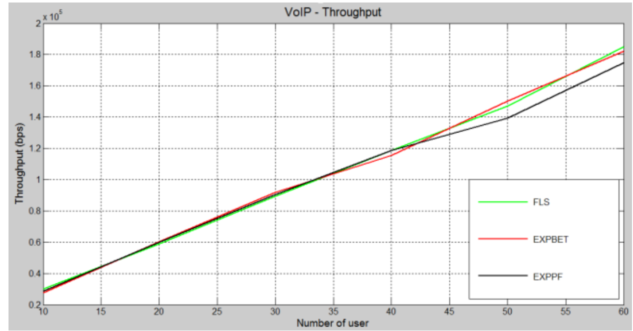


Figure 3 VoIP – throughput

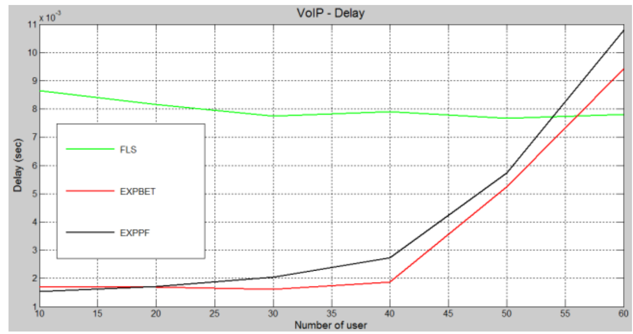


Figure 4 VoIP – delay

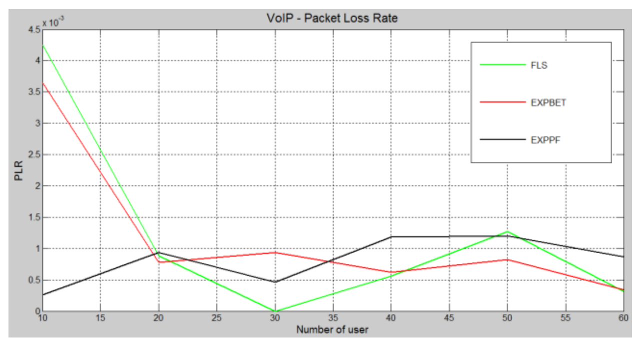


Figure 5 VoIP – packet loss rate

4.1.2 Video

Video streaming allows the user to begin viewing video clips stored on the server without downloading the entire file. After a brief period of initializing and buffering, the file will begin to stream or play in real time.

The simulation result in Figure 6 illustrates the fairness index for the video flows. The highest fairness value isachieved by the EXP-BET followed by FLS while EXP-PF shows the lowest. EXP-PF behaves like the PF algorithm when the HoL delays for all users are almost the same [2]. When this situation happened, the EXP-PF is not suitable anymore to schedule the real-time services.

The EXP-BET delivers the highest throughput when the number of users increases as shown in Figure 7. The algorithm gives higher priority to user with the highest transmission delay or user that has more packets in its buffer which contribute to higher throughput delivery and lower delay and packet loss rate.

Figure 8 shows the delay for the video flows. The QoS value for delay and packet loss rate for the video flows must be less than 150 ms and $1x10^{-3}$ respectively [8]. The three schedulers are observed to have low delay which is still in the acceptable range to provision the Quality of user Experience (QoE).

Figure 9 shows the packet loss rate for all the three schedulers. When the number of user is less than 20, the packet loss rate is approaching zero. However as the load increased, all the schedulers start to violate the allowable value. The packet loss rate for the EXP-BET is the lowest and this is in accordance to its throughput performance. Higher throughput delivered will result in lower packet loss rate.

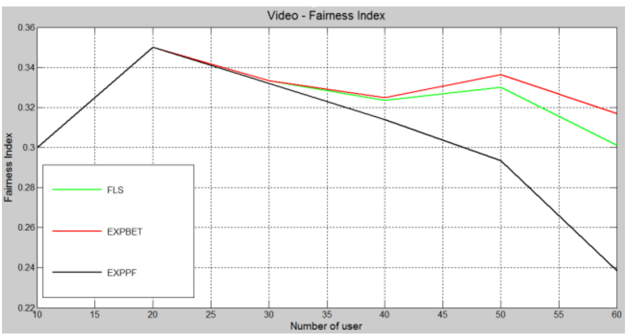


Figure 6 Video – fairness index

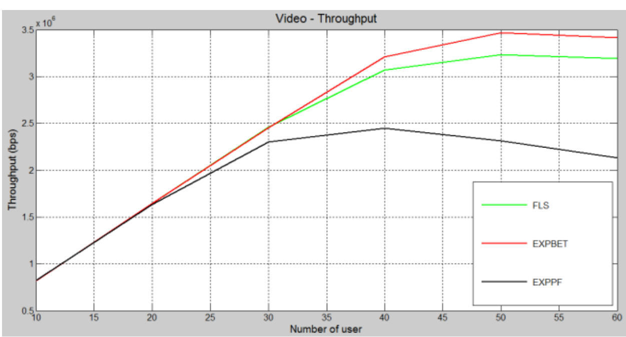


Figure 7 Video – throughput

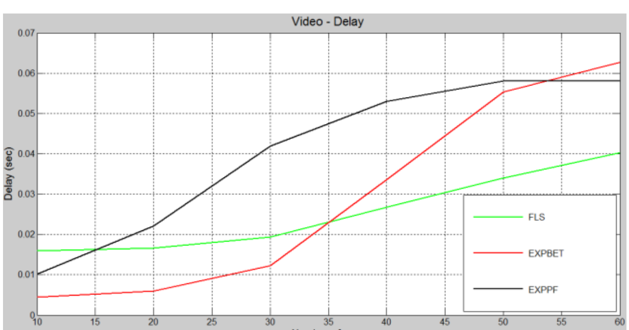


Figure 8 Video – delay

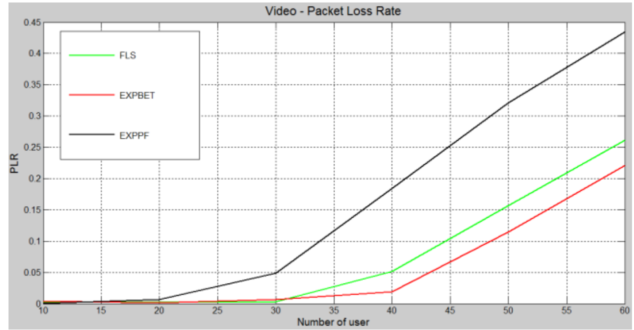


Figure 9 Video – packet loss rate

4.2 Non-Real-Time Services

A non-real-time application is describe as a process or event that does not occur immediately. Web browsing, file transfer, sending or receiving e-mails and forums are examples of the non-real-time applications.

4.2.1 Best Effort

Best effort refers to a network service that attempts to deliver messages to their intended destinations and does not provide any special features that can retransmit corrupted or lost packets. Thus, there is no QoS guarantee to this application.

Fairness index for the best effort flow is illustrated in Figure 10. The EXP-BET fairness index is better than the EXP-PF while FLS has the lowest value. The BET algorithm allocates resources to flow that have been served with low average throughput in the past. In this way, users with bad channel condition are allocated more often and lead to the fairness improvement.

The result obtained from the simulation shows that EXP-BET has the lowest throughput as depicted in Figure 11. The EXP-BET has delivered high throughput for the VoIP and video flows. Thus, the best effort flows need to wait for the next frame to be transmitted. Furthermore, the best effort flows has the least priority to be scheduled as compared to the VoIP and video.

The EXP-BET has the highest PLR as shown in Figure 12 and this is in accordance to the throughput performance. Moreover, there is no QoS requirement need to be provision by the best effort flow.

Figure 13 shows the delay for the best effort flows. LTE deploys the infinite buffer model for the generation of the best effort flow causing the delay to be constant at 1 ms[9].

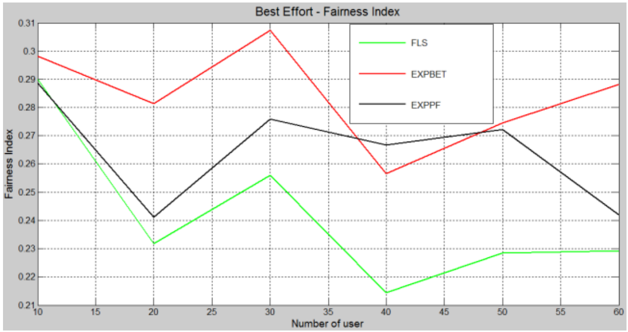


Figure 10 Best effort – fairness index

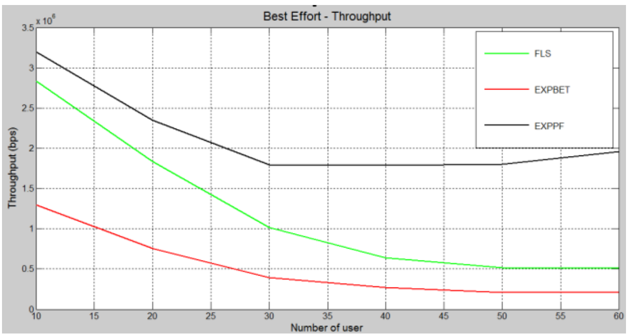


Figure 11 Best effort – throughput

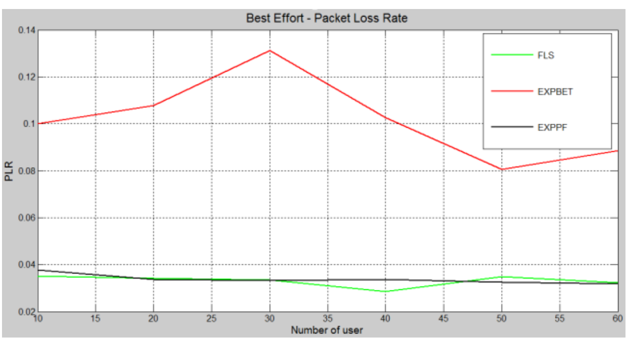


Figure 12 Best effort – packet loss rate

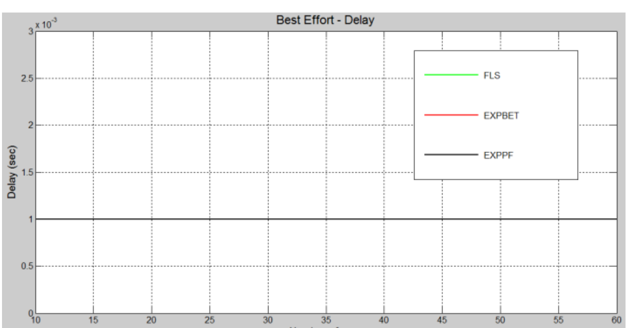


Figure 13 Best effort – delay

5.0 CONCLUSION

This research has studied the performance of EXP-BET, EXP-PF and FLS algorithms in terms of fairness index, throughput, packet loss rate and delay. VoIP, video and best effort flows have been used as the traffic applications in the simulation. The simulation results show that EXP-BET algorithm outperformed the EXP-PF and FLS algorithms for the real-time services. For the non-real-time services, EXP-BET has shown 17.72% improvement than FLS and 7.52% for EXP-PF in fairness index.

Scheduling could be recommended as one of the method to solve the problem of the cell-edge users who are not receiving fair share of the system resources. As for the future recommendation, we will focus on improving the throughput and packet loss rate for the EXP-BET algorithm for the non-real-time services.

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