Performance Analysis of M-LWDF and EXP-PF Schedulers for Real Time Traffic in Satellite LTE Networks

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Abstract- This paper investigates the performance of the Modified Largest Weighted Delay First (M-LWDF) and Exponential Proportional Fairness (EXP-PF) scheduling schemes for satellite LTE with the adoption of MIMO technology. The Satellite Long Term Evolution (LTE) air interface will provide global coverage and hence complement its terrestrial counterpart in the provision of LTE services to mobile users. A land mobile dual-polarized GEO satellite system has been considered for this work. The packet scheduling scheme is a vital element that is needed in order to effectively utilize the resources of the satellite LTE network. The aim of this paper is to conduct a performance evaluation of the two scheduling algorithms through simulations, using throughput, average delay, packet loss ratio, and fairness indices as metrics. Video streaming and VoIP flows have been considered to model real-time traffic.

Index Terms— GEO satellite, LTE, Packet scheduling, M-LWDF, EXP/PF

I. INTRODUCTION

The rapid growth in mobile users and continuous increment in the demands for different types of telecommunication services, like video streaming, video conferencing, Voice over IP (VoIP), Web browsing, multimedia messaging, video gaming and FTP downloads have necessitated the need for new technologies able to provide high data rates and also meet up with the demands of their respective Quality of Service (QoS) requirements. It is also worth to note that the available bandwidth is limited and this has made high spectrum efficiency an important target that must be addressed by future technologies.

The need to address these important challenges in future mobile networks formed the basis for International Telecommunication Union Radiocommunication sector Working Party 8F (ITU-R WP 8F) to define the future Fourth Generation Mobile (4G). The set of transmission capacity and QoS requirements are specified which allow any technology that meets up with these requirements to be included in the IMT-Advanced family [1]. This has led to the emergence of LTE and WiMAX 802.16x. Though, these two technologies do not fulfill the requirements, they are first steps towards the 4G [2].

The LTE technology, which is of interest to this paper, is made up of the radio access and packet core networks. The radio access network of LTE is referred to as Evolved UMTS Terrestrial Radio Access (E-UTRA) and the core network is denoted as Evolved Packet Core (EPC). LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) as its multiple access technology and it also employs MIMO technology [3].

In order to provide seamless mobile services to users irrespective of their locations, the satellite component of 4G systems will play a vital role, since the terrestrial component will not be able to provide a global coverage due to economic and technical limitations [4]. Therefore, future satellite air interfaces need to have a high-level of commonality with the 4G terrestrial air interface. Hence, both 3GPP LTE and WiMAX air interfaces have been proposed for the satellite scenario. An S-band GEO satellite system has been recommended for this purpose [5].

The ambitious 4G targets in terms of QoS, data rates and fairness can only be achieved with an effective scheduling scheme that will provide an optimal balance of all these requirements. The need for the scheduling scheme to be sensitive to the QoS requirements of real-time services is very important in order to meet up with the QoS demands of the mobile users.

Channel-aware schedulers like Proportional Fair (PF) and QoS aware schedulers like Earliest Deadline First (EDF), Proportional Fair Exponential Rule (PF-ER), [6], and Queue Aware Channel Based (QACB) [7] are some of the satellite HSDPA schedulers that have been proposed in the literature. Also, presented in the literature is the performance analysis of M-LWDF and EXP-PF schedulers in terrestrial LTE network [8], however, the analysis of these QoS aware schedulers are yet to be conducted for satellite LTE network. The aim of this work is to conduct a performance evaluation of M-LWDF and EXP-PF schedulers in a GEO satellite LTE network scenario in terms of throughput, delay, packet loss rate, spectral efficiency and fairness index. Though, these schedulers' performances have been evaluated on the terrestrial LTE network but to the best of our knowledge, the same cannot be said for satellite LTE network. Since the satellite scenario has some peculiarities like propagation delay, channel model, and channel reporting interval, the need to investigate the performance of these scheduling schemes in a satellite LTE scenario is very crucial.

The rest of this paper is organized as follows: System description is presented in section 2. In Section 3, the scheduling schemes are presented. Section 4 and 5 presents the simulation model and results respectively. Finally, Section 6 concludes the paper.

II. SYSTEM DESCRIPTION

The satellite LTE radio access technology is envisaged to use OFDMA for downlink transmission just like its terrestrial counterpart. OFDMA can be adopted for satellite as stated in [5], due to the fact that it easily exploits frequency selectivity and allows flexible bandwidth operation with low complexity receivers. It supports both Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) and allows for a wide range of different bandwidths (1.5, 3, 5, 10, 15 and 20 MHz) [9]. It also supports downlink multi-antenna schemes including both transmit diversity, spatial multiplexing and beamforming [10]. The spatial multiplexing, which includes single user and multi-user MIMO is of interest to this work. For the downlink of 3GPP LTE, the 2 x 2 MIMO is assumed to be the baseline configuration and 4 x 4 MIMO is also envisaged [11].

The transmission mode is selected depending on the MIMO technique of interest. Four of the seven transmission modes as specified for LTE are related to MIMO transmissions. The transmission mode 5, which is for MU-MIMO, has been considered for this work since the focus here is to evaluate the performance of scheduling algorithms of a satellite LTE in MU-MIMO transmission mode. The details of these modes are presented in [11]. For this work, the evolved Node B (eNodeB), which acts as the base station in satellite LTE scenario, is located on the earth station and it is considered to be equipped with two transmit antennas; the User Equipment (UE) has two antennas as well, according to the 2 x 2 MIMO configuration.

A. *Satellite Air Interface*

A transparent GEO Satellite has been adopted for this work. Dual-polarized antennas consisting of Right Hand Circular Polarized (RHCP) and Left Hand Circular Polarized (LHCP) antennas have been considered for both the GEO satellite and UEs.

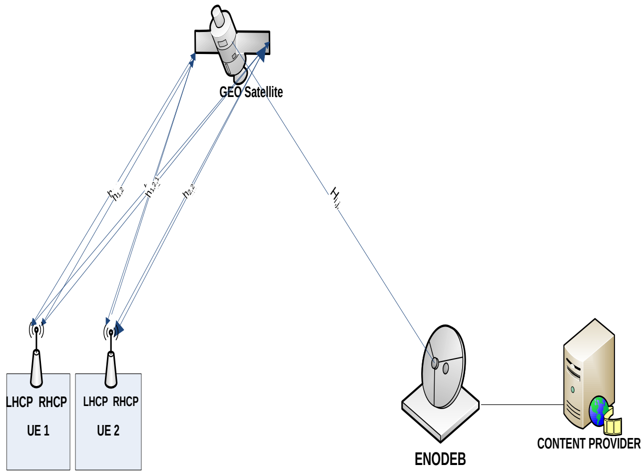

Figure 1 The system architecture of a satellite LTE network

As shown in Fig. 1, the satellite eNodeB uses two satellite dishes to transmit via the dual-polarized antennas of the GEO satellite to mobile users, as proposed in [12]. Hence, the downlink is formed between the eNodeB and the UE. This allows simultaneous transmissions from the two polarized antennas of the GEO satellite to different UEs. This transmission mode is closed-loop, hence, there is a UE feedback for link adaptation purposes, which is very vital in determining the transmission rate.

The UE will send the Channel Quality Indicator (CQI) message via the GEO satellite as recommended in [5] to the eNodeB on the earth station. The Round Trip Propagation Delay (RTPD) of approximately 540 ms is experienced in this scenario. This causes a misalignment between the reported UE's CQI at the eNodeB and the instantaneous CQI level experienced by the UE. The reported CQI is used for transmission and scheduling purposes at the eNodeB.

At the MAC layer of the eNodeB, the packet scheduler works with the Link Adaptation (LA) module and Hybrid Automatic Repeat Request (HARQ) to schedule users on resources at every Transmission Time Interval (TTI) which is 1 ms, as specified in LTE. The basic time-frequency resource that is allocated is the Physical Resource Block (PRB) and the smallest unit of the PRB is the Resource Element (RE). A RE can be 2, 4 or 6 bits, depending on the modulation used and the modulation type that will be used depends on the reported CQI value from UE to eNodeB.

Each PRB consists of 12 consecutive subcarriers (180 kHz of the whole bandwidth) for duration of 0.5 ms for each slot [13]. Subcarrier spacing is 15 kHz and each slot contains 6 or 7 symbols depending on the type of cyclic prefix used. Assuming a normal cyclic prefix (7 symbols) is used, the PRB is made up of 84 symbols. It is worthy to note that the resource allocation is only finalized after every subframe of 1 ms. This means a pair of PRBs (i.e. scheduling block) is the resource allocation granularity and its on a TTI (= 1 ms) basis.

The users selected by the packet scheduler are mapped to the available pair of PRBs at every TTI (1 ms). The number of available PRBs in a scheduling interval depends on the size of bandwidth used and the number of antennas deployed (here 2 x 2 MIMO). The number of PRBs for a single antenna ranges from 6 to 100, depending on the bandwidth size, which ranges from 1.4 to 20 MHz [14].

B. Channel Model

The channel model that is considered here is an empirical-stochastic model for LMS-MIMO [15]. This is based on the fact that the model is validated and compared to other existing models, it considers interdependence between small scale fading. The stochastic properties of this model are derived from an S-band tree-lined road measurement campaign (suburban area) using dual circular polarizations at low elevations [16]. The channel matrix, H, is made up of co-polar and cross-polar circularly-polarized channels and is represented as follows:

$$H = \begin{pmatrix} h_{RR} & h_{LR} \\ h_{RL} & h_{LL} \end{pmatrix} \qquad (1)$$

The channel matrix, H, takes large scale fading (shadowing) and small scale fading (multipath) into account. A Markov chain is used to select between the possible regions of high and low shadowing values for both co-polar and cross-polar channels to model the mobile user movement across the buildings. There are four possible Markov states as presented in Fig. 2. The four possible states are due to the high or low state of both the co-polar (CP) and cross-polar (XP) channels. State transitions in the chain in Fig. 2 occur on a TTI basis.

The 4 x 4 transition matrix, P, below is used to predict the next possible state. The columns of the matrix represent the probability of one state moving to another listed in the right hand column while the rows represent the probability of moving to the state on the right hand column from the previous state on the bottom row. State 1 is CP Low XP Low, State 2 CP Low XP High, State 3 is CP High XP Low and State 4 is CP High XP High.

The probability matrix below is derived from the measurements obtained in [15]. The top right corner value of 0.1037 is the probability of “CP High, XP High” to “CP Low XP Low”.

$$P_{ij} = \begin{bmatrix} 0.6822 & 0.1579 & 0.0561 & 0.1037 \\ 0.2887 & 0.2474 & 0.0447 & 0.4192 \\ 0.1682 & 0.0966 & 0.1745 & 0.5607 \\ 0.0098 & 0.0199 & 0.0150 & 0.9554 \end{bmatrix} \qquad (2)$$

The large scale (shadowing) fading generation depends on the Markov chain. A high or low shadowing is generated on the basis of the state. The small scale fading is modelled using Ricean distribution.The Ricean fading for each of the MIMO branch is generated using Ricean factors. The details on how the large scale and small scale fading are obtained are shown in [15].

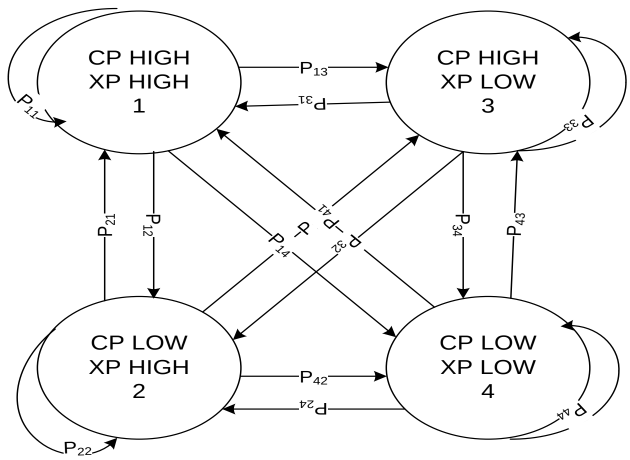

Figure 2 Four-state Markov model of an LMS-MIMO channel

Though the varying distance is of less significance to the total path loss, the path loss (in dB) at 2 GHz is computed as follows:

$$L_{Fs} = 190.35 + 20 \log \left(\frac{38500 + D}{35788} \right) \qquad (3)$$

The large scale fading and small scale fading obtained in (1) above are considered together with the path loss (L_{FS}) and polarization loss as part of the total loss experienced in the channel. The Signal-to-Noise-Interference Ratio (SNIR), which is obtained on a subchannel basis by dividing the received power by the noise power, can be expressed as follows;

$$SNIR(dB) = EIRP + G_R - L_{Total} - N - I\ (dB) \qquad (4)$$

The EIRP value of 63 dB, Polarization loss of 3.5 dB and a noise of -148.95 dBm for each subchannel is used to compute the SNIR. Also considered, it’s the inter-spotbeam interference, *I*, as a result of power received from eNodeBs sharing the same frequency. The SNR-CQI mapping derived from [16] for a BLER of 10^{-3} is used to determine the CQI from obtained SNR. This can be presented as follows;

$$\begin{gathered} if\ SNR < -4.8; \quad CQI = 1 \\ if -4.8 \le SNR \le 21.6; CQI = (0.55 * SNR) + 4 \\ if\ SNR > 21.6; \quad CQI = 15 \end{gathered} \qquad (5)$$

The CQI distribution of a mobile user with speed of 30 km/h is presented in Fig. 3. Based on the reported CQI, an appropriate Modulation and Coding Scheme (MCS) is used to transmit the packets of the selected mobile users. A much lower BLER target of 10^{-3} has been considered as compared to the BLER target of 10^{-1} that is used for the terrestrial scenario, since if the first transmission is unsuccessful in the terrestrial scenario, retransmission can quickly be employed to recover the lost packets. However, this is not the case for satellite scenario due to the long RTPD experienced. This practically prevents the use of retransmissions to recover lost packets (real-time traffic).

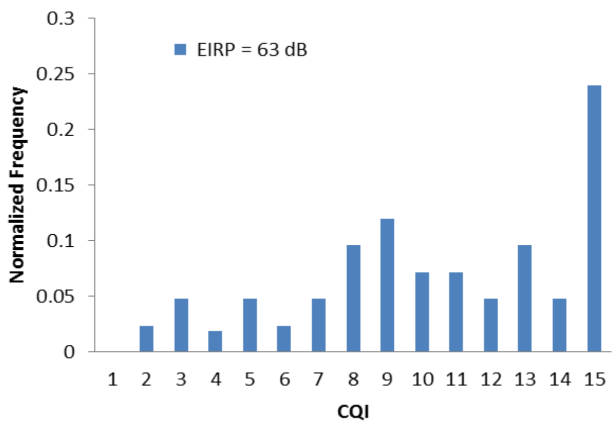

Figure 3. The CQI distribution of a UE at 30km/h

C. Traffic Model

The video streaming and VoIP traffic are the RT traffic that are considered for this work. The video streaming traffic is modeled using realistic video trace files that are provided in [17]. The mean bit rate of the video traffic source is 128 kbps.

The VoIP traffic is modeled using an ON/OFF Markov model. The ON period is exponentially-distributed with a mean vale of 3 s and the OFF period is also exponentially-distributed with a mean value of 3 s and truncated with a maximum limit of 6.9 s. The VoIP application generates G.729 voice flow. During ON periods, a constant packet size of 20 Bytes is generated every 20 ms, while during OFF periods, no packets is generated due to the presence of Voice Activity Detector [18].

III. Scheduling Algorithms

The packet scheduling schemes to be used for satellite LTE are meant to utilize the available resources, ensure fairness and satisfy the QoS requirements of varying users. The scheduling schemes that will actualize these targets must use both channel conditions and QoS factors in making scheduling decisions. Hence, this paper has considered M-LWDF and EXP-PF as possible candidates for satellite LTE network.

A. M-LWDF Scheduler

The M-LWDF scheduler provides good QoS performance with each user having its own probabilistic QoS requirement of the form;

$$\Pr(d_k > T_{k,deadline}) \le \delta_k \tag{6}$$

where d_k is the waiting time of the Head Of Line (HOL) packet.in user queue k, $T_{k,\ deadline}$ is the delay deadline for user k and δ_k is the probability of exceeding the delay deadline. According to [19], the scheduler selects user k for subchannel j based on:

$$U_{k,j} = max\left(\frac{\gamma_k d_k(n)}{T_k(n)}\right) \tag{7}$$

$$\gamma_k = a_k R_{k,j}(n) \tag{8}$$

$$a_k = \frac{-\log \delta_k}{T_{k,deadline}} \tag{9}$$

where $d_k(n)$ is the waiting time of the HOL packet in user queue k at TTI n, $R_{k,j}(n)$ is the instantaneous transmission rate of user k for subchannel j at TTI n, $T_k(n)$ is the average transmission rate of user k over previous TTI before TTI n and $T_{k,deadline}$ is the delay deadline for the packet, this varies depending on the traffic type. $T_{k,deadline}$ for RT packet is assumed to be 160 ms. The term a_k is used for QoS differentiation where δ_k varies based on the priority of the service being demanded by the user.

B. EXP-PF Scheduler

The EXP/PF was designed to support RT services in an Adaptive Modulation and Coding and Time Division Multiplexing (AMC/TDM) system. It uses both Proportional Fair (PF) and an exponential function in taking scheduling decisions. The EXP/PF algorithm can be stated as follows [20];

$$U_{k,j} = \max\left(exp\left(\frac{a_k W_k(n) - \overline{aW(n)}}{1+\sqrt{\overline{aW(n)}}}\right)\frac{R_{k,j}(n)}{T_k(n)}\right) \tag{10}$$

and $$\overline{aW(n)} = \frac{1}{N}\sum_{k\in N} a_k W_k(n) \tag{11}$$

$R_{k,j}(n)$, $T_k(n)$ and a_k represent the same terms as stated in M-LWDF scheduler. $W_k(n)$ is the waiting time of the HOL packet of user k at the TTI n.

IV. Simulation Model

An event-driven-based open source simulator called LTE-Sim [21] is used for simulations in this paper. It is a standalone version of the LTE module in NS-3 and is written in C++. The simulator has been adapted for the satellite scenario by making necessary changes to both its physical layer and propagation delay. A new channel model for satellite which includes shadowing, multipath fading and path loss was added and the propagation delay was modified.

Table 1 Simulation parameters

Parameters	Value
Simulation Time	150 seconds
RTPD	560 ms
Channel Model	4 state Markov model
CQI Reporting Interval	40 TTI
TTI	1 ms
Frequency Re-use	7
Spotbeam radius	3 km
Mobile user Speed	30 km/h
RLC Mode	UM
VoIP Traffic Model	On/off Exponential
Video Traffic Model	Trace based @ 128 kb/s
Schedulers	M-LWDF & EXP/PF
Bandwidth	15 MHz

A single spotbeam of radius 3 km has been considered with users capable of making both VoIP calls and doing video streaming uniformly-distributed within a serving eNodeB footprint. The channel and traffic model presented in the previous section are adopted for the simulations. Each user is assumed to be reporting its channel condition at certain intervals to the eNodeB. A reporting interval of 40 TTI has been considered for this work in order to reduce the frequency of reporting so as to save user equipment's power. The details of the simulator parameters are provided in Table 1 below.

V. SIMULATION RESULTS

The simulation results obtained are presented below. To ensure high level of reliability of the results, each simulation was run five times. The following performance indices were computed. It is generally observed that two schedulers produce a similar performance. As shown in Fig. 4, the Packet Loss Ratio (PLR) experienced for VoIP is lower than that of the video streaming traffic. The two schedulers have similar performance except for at fifty users, where EXP-PF has a higher PLR compared to M-LWDF for both traffic.

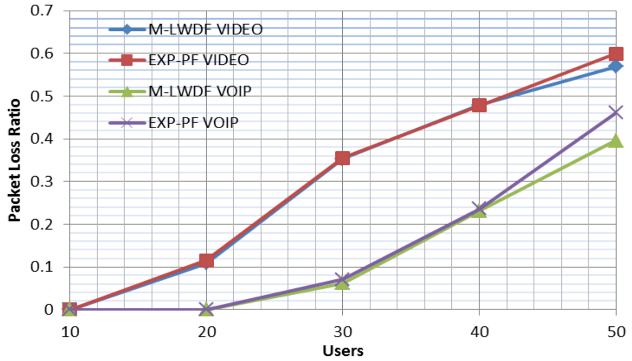

Figure 4 Packet Loss Ratio of Video and VoIP users

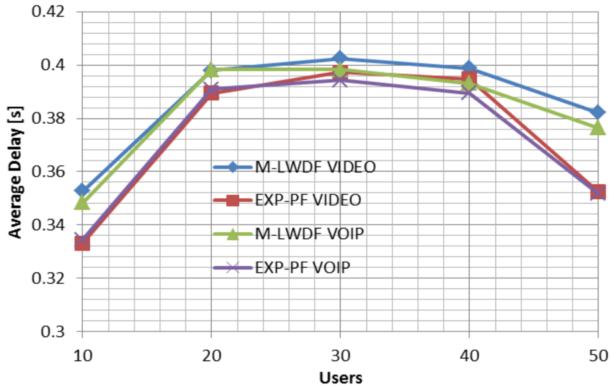

Figure 5 Average Delay of Video and VoIP users

The average delay performance as shown in Fig. 5 is pretty close across all the varying number of users, this is due to the stringent QoS policy adopted by both schedulers of dropping packets with waiting time higher than the set deadline. This delay reflects the sum of the time spent in queue and the one way propagation delay. However, It must be said that the EXP-PF scheduler gives a very slightly better delay performance as compared to M-LWDF scheduler for both traffic. This is due to the fact that the EXP-PF scheduler using its exponential function guarantees delay targets for RT traffic compared to M-LWDF scheduler. This also explains the reason for a little higher PLR compared to M-LWDF scheduler with high number of users. This is due the fact that EXP-PF is more stringent with delay constraints, hence, more packets may be dropped.

As shown in Fig. 6, the throughput performances of both schedulers are very close. However, at high number of users (50 users), the M-LWDF scheduler gives approximately 6% and 12 % better throughput as compared to EXP-PF scheduler for video and VOIP traffic respectively. Due to space limitation, the VOIP throughput cannot be put on a separate graph for better visibility. The throughput of video users is far more than that of the VOIP users, this is due to the fact that the video traffic is generated at a data rate far higher than that of VOIP.

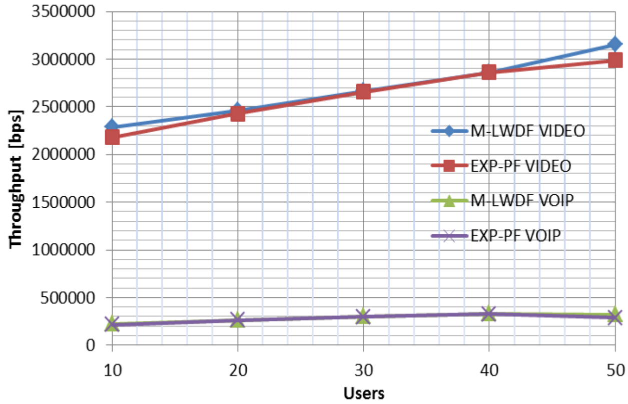

Figure 6 Average Throughput of Video and VoIP users

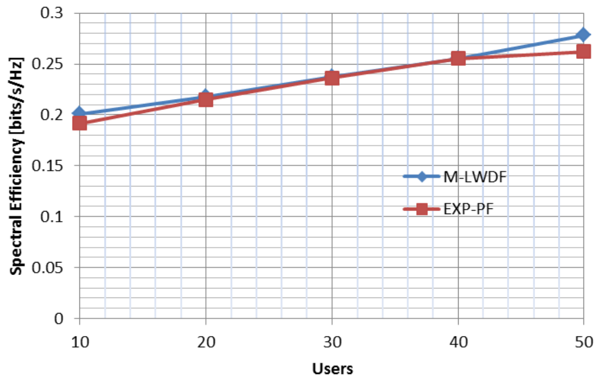

Figure 7 Spectral Efficiency for varying users

Fig. 7 shows that a similar performance is produced by both schedulers, except at 10 and 50 users where M-LWDF gives a better performance. The M-LWDF scheduler produces 6% better spectral efficiency as compared to EXP-PF scheduler.

Finally, VoIP users have a better Jain fairness index as compared to video users as the number of users increases for both schedulers as depicted in Fig. 8. As the number of users increase, the M-LWDF scheduler produces a better fairness index as compared to EXP-PF. The reason for this is that the PF component, which ensures fairness, of the M-LWDF scheduler is more dominant as compared to its QoS component. This is not the case for EXP-PF, since, its QoS component (exponential function) ensures more adherence to delay bounds. It is worthy to note that as the number of users increase, the fairness index performance drops.

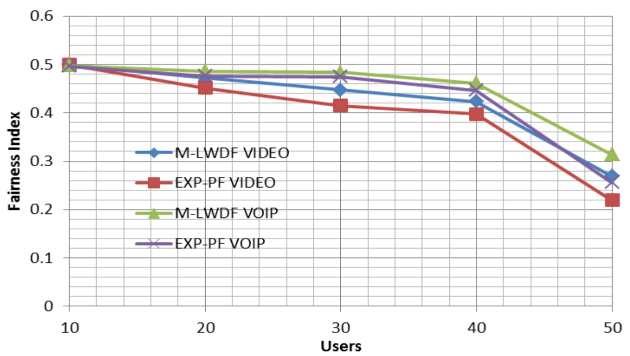

Figure 8 Fairness indexes of video and VoIP users

VI. CONCLUSION

This paper presents the performance analysis of two popular QoS-aware schedulers, considering different performance indices like average delay, PLR, throughput, spectral efficiency, and fairness index.

The results obtained shows that M-LWDF gives slightly-better performance in terms of throughput, PLR and spectral efficiency at high number of users (50 users) and a better fairness index, while EXP-PF scheduler produces a slightly better delay performance as compared to M-LWDF scheduler. The results obtained also show that both are candidates for satellite LTE network and that satellite LTE network can complement its terrestrial counterparts to ensure provision of seamless LTE services. The results obtained for satellite scenario are close to that of the terrestrial counterparts except for the delay which is as a result of the long propagation delay experienced in the satellite scenario.

However, it is worthy to note that for future work, there is room for the investigation of novel scheduling schemes suitable for the satellite scenario.

REFERENCES

[1] D. Martín-Sacristán, J. F. Monserrat, J. Cabrejas-Peñuelas, D. Calabuig, S. Garrigas, and N. Cardona, “On the Way towards Fourth-Generation Mobile: 3GPP LTE and LTE-Advanced,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, Article ID 354089, 10 pages, 2009. doi:10.1155/2009/354089.

[2] J. Duplicy, B. Badic, R. Balraj, et al.,“MU-MIMO in LTE Systems,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2011, Article ID 496763, 13 pages, 2011. doi:10.1155/2011/496763.

[3] Spencer, Q.H.; Peel, C.B.; Swindlehurst, A.L.; Haardt, M.; , "An introduction to the multi-user MIMO downlink," *IEEE Communications Magazine*, vol.42, no.10, pp. 60- 67, Oct. 2004 doi: 10.1109/MCOM.2004.1341262.

[4] F. Bastia, C. Bersani, E. A. Candreva, et al., “LTE Adaptation for Mobile Broadband Satellite Networks,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, Article ID 989062, 13 pages, 2009. doi:10.1155/2009/989062.

[5] ESA, “Study of Satellite Role in 4G Mobile Networks Final Report,” May 2009.

[6] Giambene, G., et al. "*Traffic management in HSDPA via GEO satellite.*,", Space Communications, Vol. 21, No. 1-2, pp. 51-68, 2007.

[7] Gbolahan, A.; Fambirai, T., "A novel packet scheduling scheme in HSDPA via GEO Satellite," *AFRICON, 2009. AFRICON '09.*, pp.1-6, 23-25 Sept. 2009.

[8] Ramli, H.A.M.; Basukala, R.; Sandrasegaran, K.; Patachaianand, R.; , "Performance of well-known packet scheduling algorithms in the downlink 3GPP LTE system," 2009 IEEE 9th Malaysia International Conference on Communications (MICC), vol., no., pp.815-820, 15-17 Dec. 2009 doi: 10.1109/MICC.2009.5431383.

[9] Parkvall, S.; Furuskär, A.; Dahlman, E.; , "Evolution of LTE toward IMT-advanced," IEEE *Communications Magazine*, vol.49, no.2, pp.84-91, February 2011 doi: 10.1109/MCOM.2011.5706315.

[10] Qinghua Li; Guangjie Li; Wookbong Lee; Moon-il Lee; Mazzarese, D.; Clerckx, B.; Zexian Li; , "MIMO techniques in WiMAX and LTE: a feature overview," *IEEE Communications Magazine*, , vol.48, no.5, pp.86-92, May 2010 doi: 10.1109/MCOM.2010.5458368.

[11] Ghaffar, R.; Knopp, R.; , "Making multiuser MIMO work for LTE,", *2010 IEEE 21st International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC*, pp.625-628, 26-30 Sept. 2010 doi: 10.1109/PIMRC.2010.5671753.

[12] Schwarz, R.T.; Knopp, A.; Lankl, B.; Ogermann, D.; Hofmann, C.A.; , "Optimum-Capacity MIMO Satellite Broadcast System: Conceptual Design for LOS Channels," *Advanced Satellite Mobile Systems, 2008. ASMS 2008. 4th*, vol., no., pp.66-71, 26-28 Aug. 2008 doi: 10.1109/ASMS.2008.19.

[13] Tech. Specif. Group Radio Access Network; Physical Channel and Modulation (Release 8), 3GPP TS 36.211.

[14] Motorola, Inc (2007). Long Term Evolution (LTE): Overview of LTE Air-Interface Technical White Paper Retrieved from http://www.motorola.com.

[15] King, P.R.; Brown, T.W.C.; Kyrgiazos, A.; Evans, B.G.; , "Empirical-Stochastic LMS-MIMO Channel Model Implementation and Validation," *Antennas and Propagation, IEEE Transactions on* , vol.60, no.2, pp.606-614, Feb. 2012 doi: 10.1109/TAP.2011.2173448.

[16] C. Mehlf¨uhrer, M. Wrulich, J. C. Ikuno, D. Bosanska, and M. Rupp, “Simulating the long term evolution physical layer,” in Proc. of the 17th European Signal Processing Conf., EUSIPCO, Glasgow, Scotland, 2009.

[17] Video trace library. [Online]. Available: http://trace.eas.asu.edu/.

[18] C. Chuah and R. H. Katz, “Characterizing packet audio streams from Internet multimedia applications,” in Proc. ICC, New York, Apr. 2002, pp. 1199–1203.

[19] M. Andrews, K. Kumaran, K. Ramanan, A. Stolyar, P. Whiting, and R.Vijayakumar, "Providing Quality of Service over a Shared Wireless Link," IEEE Communications Magazine, vol. 39, pp. 150-154, Feb. 2001.

[20] J.-H. Rhee, J. M. Holtzman, and D. K. Kim, "Scheduling of Real/Nonreal Time Services: Adaptive EXP/PF Algorithm," in the 57th IEEE Semi-annual Vehicular Technology Conference. vol. 1, 2003, pp. 462-466.

[21] Piro, G.; Grieco, L.A.; Boggia, G.; Capozzi, F.; Camarda, P.; , "Simulating LTE Cellular Systems: An Open-Source Framework," IEEE Transactions on Vehicular Technology, vol.60, no.2, pp.498-513, Feb. 2011doi: 10.1109/TVT.2010.2091660.

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