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

Gbolahan Aiyetoro¹, Giovanni Giambene² and Fambirai Takawira³

Department of Electrical, Electronic and Computer Engineering
University of KwaZulu-Natal¹, Durban 4041
Tel: +27 312602736, Fax: +27 312602500

Department of Information Engineering,
University of Siena², Via Roma, 56, 53100 Siena, Italy

School of Electrical and Information Engineering,
University of the Witwatersrand³, Johannesburg, South Africa
email: g.aiyetoro@ieee.org¹, giambene@unisi.it², fambirai.takawira@wits.ac.za³

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 HSDPAs 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.

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:

\[ H = \begin{pmatrix} h_{RR} & h_{RL} \\ h_{RL} & h_{LL} \end{pmatrix} \]  

(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.

\[ P = \begin{pmatrix} 0.6822 & 0.1579 & 0.0561 & 0.1037 \\ 0.2887 & 0.2474 & 0.0447 & 0.4192 \\ 0.1682 & 0.0966 & 0.1745 & 0.5607 \\ 0.0098 & 0.0199 & 0.0150 & 0.9554 \end{pmatrix} \]  

(2)

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”.

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].

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:

\[ L_{PF} = 190.35 + 20 \log \left( \frac{38500 + D}{35788} \right) \]  

(3)

The large scale fading and small scale fading obtained in (1) above are considered together with the path loss (L_{PF}) 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;

\[ SNIR(dB) = EIRP + G_R - L_{Total} - N - I \]  

(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;

\[ \begin{align*} 
& \text{if } SNR < -4.8; \quad CQI = 1 \\
& \text{if } -4.8 \leq SNR \leq 21.6; \quad CQI = (0.55 \times SNR) + 4 \\
& \text{if } SNR > 21.6; \quad CQI = 15 
\end{align*} \]  

(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).
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 $T_{k,\text{deadline}}$ is the delay deadline for the packet, this varies depending on the traffic type. $T_{k,\text{deadline}}$ for RT packet is assumed to be 160 ms. The term $a_k$ is used for QoS differentiation where $a_k$ 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];

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

and

$$\overline{aW}(n) = \frac{1}{N} \sum_{k=1}^{N} a_k W_k(n)$$

$R_{k,j}(n)$, $T_k(n)$ 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>
<thead>
<tr>
<th>Table 1 Simulation parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Simulation Time</td>
</tr>
<tr>
<td>RTPD</td>
</tr>
<tr>
<td>Channel Model</td>
</tr>
<tr>
<td>CQI Reporting Interval</td>
</tr>
<tr>
<td>TTI</td>
</tr>
<tr>
<td>Frequency Re-use</td>
</tr>
<tr>
<td>Spotbeam radius</td>
</tr>
<tr>
<td>Mobile user Speed</td>
</tr>
<tr>
<td>RLC Mode</td>
</tr>
<tr>
<td>VoIP Traffic Model</td>
</tr>
<tr>
<td>Video Traffic Model</td>
</tr>
<tr>
<td>Schedulers</td>
</tr>
<tr>
<td>Bandwidth</td>
</tr>
</tbody>
</table>

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.

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.
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 show 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


Aiyetoro Gbolahan received the B.Sc. degree in Electronic and Computer Engineering from Lagos State University, Nigeria and MSc.Eng in Electronic Engineering from University of KwaZulu-Natal, Durban, South Africa. He is currently undergoing his PhD at the same University. His research interests is radio resource management in wireless communications.

Giovanni Giambene received the Dr. Ing. Degree in Electronics in 1993 and PhD degree in Telecommunications and Informatics in 1997 both from University of Florence, Italy. He is currently a full-time researcher and an adjunct Professor of the Department of Information Engineering at the University of Siena, Italy and involved in the ESA SatNEX II project. His research interests include IP-based satellite networks, radio resource management for satellite systems and cross-layer design.

Takwira Fambirai received the B.Sc. degree in Electrical Engineering (first-class honours) from Manchester University, Manchester, UK in 1981, and Ph.D degree from Cambridge University, Cambridge, UK, in 1984. He is currently a Professor of School of Electrical and Information Engineering at the University of Witwatersrand, South Africa. His research interests includes digital communications, data networks and radio resource management in wireless communications.