Study of Advanced-Opportunistic Proportionate Fairness Scheduler for LTE Medium Access Control

Saptarshi Chaudhuri[1], Debabrata Das[2], Ranjish Bhaskaran[1]
[1]CoE Wireless, Wipro Technologies, Bangalore, India, 560100
[2] I I I T- Bangalore, Electronic City, Bangalore – 560 100, India
[1]{saptarshi.chaudhuri, ranjish.bhaskaran}@wipro.com; [2]ddas@iiitb.ac.in

***Abstract*—Medium Access Control (MAC) scheduler entity forms one of the most important parts of any high speed packet access system like HSDPA or LTE. To the best of our knowledge the LTE MAC schedulers that had been proposed so far constitute of sub-carrier resource scheduling mostly based on single criteria like user throughput, link conditions, buffer constraints or power requirement. The above LTE MAC scheduler algorithms do not take care of user's queue weight calculation taking all the above mentioned parameters into consideration. In this paper, we proposed a novel algorithm to support dynamic queue weight calculation and referred it as Advanced-Opportunistic Proportionate Fairness Scheduler for LTE (A-OPFS-LTE). The A-OPFS-LTE, calculates the queue weight based on multiple parameters like flow control feedback, hybrid automatic repeat request (HARQ) retransmission status, service class type, guaranteed bit rate, access terminal (AT's) channel condition, queue's buffer utilization and later assigns the physical resource block. A-OPFS-LTE was able to schedule 14 uncompressed VoIP calls or 5 streaming type video calls every 1milli-second scheduling cycle with packet loss less than 2%. Compared with MAC scheduler [10, 11], A-OPFS-LTE scheduler supports 10% cell throughput improvement and 30% more users**

Keywords-component; A-OPFS-LTE, LTE, MAC, Scheduler

I. INTRODUCTION

Packet based wireless transmission requires MAC scheduler algorithm for effective radio resource allocation and transport block (TB) selection. The MAC scheduler algorithms that had been widely proposed and used so far are maximum carrier-to-interference power ratio (MCIR), round robin (RR) and the proportional fairness (PF) and its variants as presented in the references [1, 2, 3]. New MAC scheduler algorithm like OPFS [11] solves some of limitations of the earlier high speed scheduler algorithms for 3GPP's Release-5 networks by effectively selecting the transport block and coding/modulation schemes based on legacy block calculation or pure channel quality based selection method. Apart from multiple advantages of OPFS, one of the limitations is that, it statically allocated queue priority once during initialization which constrains its use for dynamic allocation resources in a multi user scenario.

As per new standard like LTE, the above scheduler algorithms were not able to maintain the guaranteed bit rate of the users due to high delay and packet loss. To the best of our knowledge, existing LTE MAC schedulers [4, 5, 6, 9, 10] proposes of packet scheduling and radio resource allocation based on single parameters like user throughput, link conditions, buffer constraints or power requirement. These algorithms do not take the overall system impacts like HARQ status, buffer utilization, and delays s in more cohesive manner.

In this paper, a novel LTE MAC scheduler algorithm referred as Advanced-OPFS for LTE (A-OPFS-LTE) is being proposed for eNodeB system and can also be extended to intelligent devices. This algorithm's main goal is to provide low packet loss in the downlink, with good fairness in terms of user throughput. To achieve this goal, the scheduling algorithm aims in calculating the queue weight by taking into consideration of actual buffer utilization, service class priority, the channel conditions reporting from the access terminal (AT), and the hybrid automatic repeat request (HARQ) retransmission status maintained for the terminal. Along with above parameters, we have introduced two time varying dynamic parameters called *Q_priority-LTE* and *Tput-deficit-LTE* which are derived from the instantaneous delay of a packet experienced by the user inside the queue and the throughput deficit (guaranteed throughput – average user throughput of a session; explained in Section II-B), respectively. After calculating the queue weight, A-OPFS-LTE scheduler calculates the physical resources and transport block size before sending to actual transmission.

In this paper, we have studied in detailed the effect of the two dynamic time varying parameters i.e., *Tput-deficit-LTE* and *Q_priority-LTE* on the overall cell throughput and packet loss. From the analytical results it has been observed that, for a 5MHz system bandwidth and 50 user scenario, A-OPFS-LTE was able to schedule 14 uncompressed VoIP calls or 5 streaming type video calls every 1 milli-second scheduling cycle and overall able to handle all the 50 users with packet loss less than 2%. The total cell users that A-OPFS-LTE was able to support are 100 for a packet loss still less than 5%. Thus A-OPFS-LTE scheduler was able to achieve a minimum 10% improvement on the cell throughput compared with respect to LTE MAC scheduler algorithm [10]. Compared with OPFS [11], A-OPFS-LTE scheduler supports 30% more users for the same system bandwidth of 5MHz.

The rest of the paper has been arranged as follows. Section II, presents the A-OPFS-LTE algorithm formulation. Section III presents the key performance indicators for A-OPFS-LTE scheduler. Section IV presents in brief the evaluation parameters. Section V, presents a brief description on our simulation setup. Section VI reveals the results and corresponding discussion. Section VII concludes the present work with futuristic possible studies.

978-1-4577-1328-6/11/$26.00 2011 IEEE

II. A-OPFS-LTE ALGORITHM FORMULATION

A-OPFS-LTE scheduler is mainly targeted for the LTE mode of transmission. Significant novel ideas have been introduced with respect to existing HSPA based OPFS [11] algorithm to make it compatible for LTE mode of transmission. The changes that got incorporated into the A-OPFS-LTE scheduler are summarized as given below:

- For achieving user queue selection to be identified for physical layer transmission, we have defined a new equation for queue weight calculations based on the two time varying factors namely the *Q_priority-LTE* and *Tput-deficit-LTE*, user buffer status and SNR feedback
- The physical resource block (**PRB**) defined according to the 3GPP [7]. The PRBs are finite values from the set $\triangleq \{1, 2, \ldots, \chi\}$ and allocated proportionately.
- As per the 3GPP [7] specification, each physical resource block constitute of twelve numbers of sub-carriers. A simple sub-carrier allocation methodology has been used for this paper as per the reference [9]
- A look up table (LUT) based modulation/coding scheme (MCS) and spectral efficiency (SE) determination based on received SNR value from the AT
- Finally the A-OPFS-LTE scheduler determines the MAC frame format based on the current MCS value. We have considered the transport block (**TB**) size selection for all possible cases of MCS from the finite set $\triangleq \{TB1, TB2, \ldots, TB_n\}$

Rest of the Section-II is arranged as follows. Section-II-A, describes the A-OPFS-LTE queue weight calculations. In Section-II-B, we describe in detail the two time varying parameters i.e. *Tput-deficit-LTE* and *Q_priority-LTE* estimation analysis. Next in Section-II-C, we describe the look up table based approach for SE/MCS determination respectively

A. A-OPFS-LTE Scheduler Queue Weigth calculations

As per A-OPFS-LTE the queue weight of i^{th} user (or AT) at t^{th} scheduling time i.e. $QWt_i(t)$ is considered as a time varying entity. This queue weight is dependent on user queue buffer utilization (χ_i), channel quality indicator(CQI_i), signal-noise-ratio(SNR_i), HARQ retransmission status ($HARQ_i^{retransmission}$), *Q_priority-LTE* ($\alpha\text{-}LTE_i(t)$) and *Tput-deficit-LTE* ($\beta\text{-}LTE_i(t)$). Logically the dependencies of the queue weight calculation are presented in Eqn. (1).

$$QWt_i(t) = f_n(\chi_i, CQI_i, SNR_i, \alpha\text{-}LTE_i(t), \beta\text{-}LTE_i(t), HARQ_i^{retransmission}) \quad (1)$$

For every scheduling cycle, each of the parameters of the Eqn. (1) gets modified either due to packets entering the user queue from the service application layer causing change in χ_i or due to the mobility of the access terminal generates new CQI_i/SNR_i or $HARQ_i^{retransmission}$ status. The other parameters i.e. $\alpha\text{-}LTE_i(t)$ and $\beta\text{-}LTE_i(t)$ also have dynamic values depending on the delay and throughput deficit. In this paper, we limit our scope of queue weight discussion only on the two parameters namely the *Q_priority-LTE* and *Tput-deficit-LTE*. From Eqn. (1), using the parameters χ_i, CQI_i/SNR_i, the instantaneous transmit capability of the i^{th} user at t^{th} instant (Ω_i) of time is given below Eqn. (1a).

$$\Omega_i(t) = \chi_i \,/\, min(\rho_{max\text{-}bits}, AT_{maxbits}) \quad (1a)$$

where the $\rho_{max\text{-}bits}$ is the maximum bits calculated for the i^{th} user (or AT) CQI_i/SNR_i feedback and $AT_{maxbits}$ is the maximum bits that the i^{th} AT can support as per its database. Finally the queue weight as shown in Eqn. (1) is rewritten by doing numeric addition of the $\Omega_i(t)$, $\alpha\text{-}LTE_i(t)$, $\beta\text{-}LTE_i(t)$ which is given in Eqn. (1b). Where *retx* is the packet transmission feedback from i^{th} user (or AT). If it is NACK, *retx* equals 0, else for ACK, *retx* equals 1.

$$QWt_i(t) = [\Omega_i(t) + \alpha\text{-}LTE_i(t) + \beta\text{-}LTE_i(t)]^{retx} \quad (1b)$$

Every transmission time interval, the final scheduling queue weight set taking all the users into consideration is given by

$$QWt(t) \triangleq \{QWt_1\, QWt_2\, QWt_3 \ldots\ldots\ldots\, QWt_n\} \quad (1c)$$

A-OPFS-LTE starts the physical resource allocation based on maximum value of the Eqn. (1c) and continues till PRB $\triangleq \{1, 2, \ldots, \chi\}$ is not exhausted. Thus the j^{th} user is allocated n^{th} PRBs, based on the Eqn. (1d).

$$(j^*, n) = \arg\max QWt(t) \quad (1d)$$

B. Q_priority-LTE and Tput-deficit-LTE Analysis

The next novelty of A-OPFS-LTE scheduler algorithm is the proposition of two key parameters for each queue's weight calculation i.e. *Q_priority-LTE* and *Tput-deficit-LTE*. In this section, we define in detail these two time varying parameters.

The *Q_priority-LTE* ($\alpha\text{-}LTE_i(t)$) is defined as the weighted instantaneous priority of the user queue. During initialization, the user queue gets an initial priority κ_{init} randomly allocated between 0 and the maximum priority κ_{max}. The queue priority gets re-calculated every scheduling cycle. As time progresses, if the packets are not getting scheduled by the A-OPFS-LTE, the instantaneous delay experienced by the user queue increases resulting in increase of the queue priority by a constant factor. The final weighted priority $\alpha\text{-}LTE_i(t+1)$ value is the product of previous priority value $\alpha\text{-}LTE_i(t)$ and the constant factor. The empirical equation showing $\alpha\text{-}LTE_i(t)$ for the i^{th} user at t^{th} scheduling time is shown in Eqn. (2).

$$\begin{aligned} \alpha\text{-}LTE_i(t+1) &= (\kappa_{init} * 10/(\kappa_{max} + 0.1)) * \alpha\text{-}LTE_i(t) \\ &\quad \textit{for instantaneous delay} < \Phi_{max} \\ &= (\kappa_{init} * 15/(\kappa_{max} + 0.1)) * \alpha\text{-}LTE_i(t) \\ &\quad \textit{for instantaneous delay} >= \Phi_{max} \end{aligned} \quad (2)$$

where is Φ_{max} is the maximum queue jitter defined in the database for the particular traffic class.

Similarly *Tput-deficit-LTE* (β-$LTE_i(t)$) is defined as the weighted instantaneous throughput deficit experienced by the user queue. When the user's queue is not getting scheduled, A-OPFS-LTE scheduler calculates the throughput deficit $\Delta R_i\ (t)$ by calculating the difference between guaranteed bit rate (*GBR*) and average user throughput $R_i(t)$. Using the above two parameters, the throughput deficit is defined as in Eqn. (3).

$$\Delta R_i\ (t) = GBR - R_i(t) \qquad (3)$$

During initialization, the throughput deficit $\Delta R_i\ (t)$ is equated to 0. As time progresses, if the packets from the user queue are not getting scheduled by the A-OPFS-LTE, the average user throughput as per Eqn. (3) decreases resulting in increase of throughput deficit. The weighted instantaneous β-$LTE_i(t)$ is calculated by multiplying the throughput deficit and a constant factor. The empirical equation of weighted β-$LTE_i(t)$ for the i^{th} user at t^{th} scheduling time is defined in Eqn. (4)

$$\beta\text{-}LTE_i\ (t+1) = (\Delta R_i * 10/(\ GBR_i + 0.1)) * \beta\text{-}LTE_i\ (t) \quad for\ \ \Delta R_i < \Gamma_{max}$$
$$= (\Delta R_i * 15/(\ GBR_i + 0.1)) * \beta\text{-}LTE_i\ (t) \quad for\ \ \Delta R_i >= \Gamma_{max} \qquad (4)$$

where Γ_{max} is defined as the maximum threshold throughput deficit as defined in the database for that traffic class.

C. Look Up Table: - Spectral Efficiency and MCS

The allocation of the transport block size by A-OPFS-LTE scheduler is based on the instantaneous user spectral efficiency (*SE*) in terms of bits/Hz/cell. The spectral efficiency is dependent on the *SNR,* the modulation symbol *M*, the modulation gain G_{mcs}, the code rate *n/k* (where k is total useful information bits, n is total data bits), and the target bit error rate $P_{b,target}$. The equation showing the spectral efficiency is being referred from [8] and presented in Eqn. (5). The variation of the spectral efficiency *SE* with respect to *SNR* is being plotted in Figure 1

$$SE = min(\ 3log_2 M/\ 2*(M-1)*erfc^{-1}(P_{b,target} * log_2 M))^2 * n/kG_{mcs} * P_{b,target} * S/N,\ \ k/n * log_2 M) \qquad (5)$$

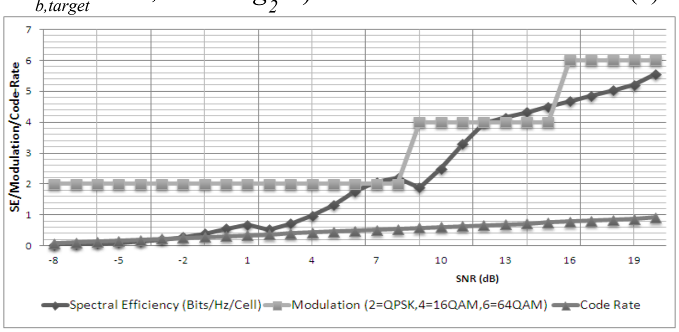

Figure 1: Spectral Efficiency<marker type-daimonds>, Modulation<marker type-square>, and Code Rate <marker type-triangle> variation versus SNR.

A-OPFS-LTE scheduling logic determines a transport block size close to this theoretical *SE* value calculated from Eqn. (5).

The modulation $Mod_i(SNR)$ allocated to the i^{th} user at t^{th} time instant is dependent on the *SNR* which is presented in Eqn. (6). This step function is calculated from the sample points of spectral efficiency (*SE)* and modulation/coding scheme (*MCS)* as per the 3GPP specifications [7]. The complete modulation distribution with respect to *SNR* is being plotted, with *SNR* in the X-axis and modulation in the Y-axis as shown in Fig. 1.

$$Mod_i(SNR) = \begin{cases} \text{QPSK} & \text{for } -\infty < \text{SNR} < 8 \text{ dB} \\ \text{16-QAM} & \text{for } 8 \text{ dB} \le \text{SNR} < 14 \text{ dB} \\ \text{64-QAM} & \text{for } 14 \text{ dB} \le \text{SNR} < \infty \end{cases} \qquad (6)$$

The code rate variation is a simple linear variation with respect of *SNR* and presently left out of scope of this paper.

III. Key Performance Indicators

To evaluate how best the A-OPFS-LTE scheduler is performing per transmission time interval, we define three key performance indicators. These three key indicators are the user throughput, the overall cell throughput and packet drop rate. The descriptions of these factors are presented is subsequent paragraphs.

Once the user queue is ready for transmission, the basic throughput equation as defined in reference [2] gets modified for LTE mode transmission. The modified average user throughput $R_i(t+1)$ for i^{th} user at scheduling time instant $t+1$ used by A-OPFS-LTE scheduler is dependent three parameters. The first parameter is the transport block size *TB* taken from a finite set ≜ {TB1,TB2,….,TB_n}which are chosen by taking into the consideration of the physical resource block (***PRB***) and the modulation/coding scheme (***MCS***). The second parameter is the time difference between present scheduling time and previous scheduled time (ΔTTI) in milli-seconds. The third parameter is the previous average user throughput $R_i(t)$. Once the user queue is ready for transmission, the instantaneous user throughput in bits/second is calculated using *TB*1000/ΔTTI* where the constant '1000' is due to ΔTTI's unit conversion from milli-second to seconds. The final average user throughput $R_i(t+1)$ for i^{th} user at the scheduling time instant *t+1* is the addition of previous average throughput and instantaneous throughput is presented in Eqn. (7) till the maximum average throughput is less or equal to guaranteed bit rate of the user as given in Eqn. (7a)

$$R_i(t+1) = R_i(t) + TB*1000)/\ \Delta TTI \qquad (7)$$

$$R_i(t+1) = max(\ GBR,\ R_i(t+1)\ ) \qquad (7a)$$

The Eqn. (7) and (7a) is used for calculating the user throughput for every new transmission or retransmission scenario from the scheduler. The user whose queues are getting scheduled for that scheduling slot is called as scheduled users.

When a particular user queue didn't get a scheduling slot, A-OPFS-LTE reduces the average throughput $R_i(t)$ for i^{th} user at the scheduling time instant $t+1$ using a constant factor as presented in Eqn. (8). The constant '0.99' is being taken from the reference [2]. The user whose queues didn't get scheduled is called as non-scheduled users.

$$R_i(t+1) = R_i(t)*0.99 \quad (8)$$

Once the scheduling cycle is complete, A-OPFS-LTE finally calculates the overall cell throughput. This is defined as the summation of the entire average user(s) throughput present in the cell. So the cell throughput Cell-Tput(t) at t^{th} scheduling time is presented in Eqn. (9)

$$Cell-Tput\ (t) = \sum_1^N Ri(t) \quad (9)$$

$$Cell\text{-}Tput\ (t)_{max} = GBR*N \quad (9a)$$

where N is defined as the total number of users in a cell and GBR is the guaranteed bit rate of the user. The overall cell throughput attains a maximum value $Cell\text{-}Tput(t)_{max}$ which is the product of GBR and N as shown in Eqn. (9a)

Finally the packet drop rate (*PDR*) is last key indicators used for A-OPFS-LTE scheduler performance evaluation. *PDR* conceptually is dependent on two factors. The first factor is $Packet_{Dropped}$ which is defined as total packet dropped by A-OPFS-LTE either due to delay of packet crossing the maximum delay for that service class or the packet retransmission crossing the maximum allowed value. The second parameter is $Packet_{ACKED}$ which is defined as the total number of packets that A-OPFS-LTE got an acknowledgement from the AT. Thus the *PDR* is the ratio of $Packet_{Dropped}$ in the numerator and summation of $Packet_{ACKED}$ plus $Packet_{Dropped}$ in the denominator which is presented the Eqn. (10).

$$\boldsymbol{PDR} = Packet_{\ Dropped} \,/\, Packet_{\ ACKED} + Packet_{\ Dropped} \quad (10)$$

IV. Evaluation Parameters

The normally considered LTE network level parameters used for the evaluation are presented in Table-I,

TABLE I. Considered parameters for Scheduling

Parameters Name	Value
Carrier frequency	2GHz
System bandwidth	5MHz, 10MHz, 20MHz
Transmission Time Interval(TTI)	1ms
Cellular Layout	Hexagonal Grid, Omni
Cell Radius	1Km
Path Loss Model	L=128.1 + 37.6log10(R)
Log Normal Shadowing	0 mean, 8dB
eNodeB Transmit Power	43dBm
White Noise Power	-174 dBm/Hz
Number of Interfering Cell	10
AT Mobility	30km/hr, User moves till Cell Edge and Return
Traffic Model	Basic G.711 uncompressed VoIP of 64kbps Streaming of 1Mbps
Max Delay (ms)	100 (VoIP Call) or 400 (Streaming)
Max Number of Re-Transmission	3

V. Simulation Setup Details

In this paper, we focused on the point-to-multipoint mode specified in the LTE standard, i.e., base station serves multiple access terminals (ATs). For both VoIP and streaming traffic generation scenario, we have used standard constant bit rate and Poisson's traffic distribution, with a rate varying from 64kbps and 1Mbps or 5Mbps with cutoff threshold of 640bits and 1000 or 5000bits respectively. The AT admission control is modeled using simple time based user admission. So every 50 milli second, each of the user get into the simulation execution. The execution time of this simulation is 500second and kept constant for each scenario. Lastly the channel model is kept as free space path loss and log-normal fading for every simulation scenario.

VI. Results and Discussions

To observe the dynamic performance of the A-OPFS-LTE, we analyzed thoroughly the cumulative probability distribution of the cell throughput and packet drop rate. The variation of the cell throughput will indicate A-OPFS-LTE performance with respect to the maximum achievable cell throughput. Also by observing the packet drop rate variation, we get the maximum users that the A-OPFS-LTE can support. Determining the maximum user helps the operator to plan the traffic and sector dimensioning. Along with the above performance indicators, we also have analyzed the cumulative probability distribution of the two important factors of Eqn. (1b) that is the *Q_priority-LTE* and *Tput-deficit-LTE*. The effect of the variation of *Q_priority-LTE* and *Tput-deficit-LTE* on the overall cell throughput is also being explained. The analyses for all the above parameters are being conducted by varying the total number of cell users from 50 to 125.

Rest of section is arranged as follows. In Section-VI-A, we study the results of cumulative probability distribution of *Q_priority-LTE* and *Tput-deficit-LTE* occurrences. In Section-VI-B, we study the cell throughput variation and the effect of *Q_priority-LTE* and *Tput-deficit-LTE* on it. In Section-VI-C, the packet drop rate variation its distribution with respect to number of cell users is being discussed. Lastly in Section-VI-D, the average user throughput is being studied with respect to the different channel conditions.

A. Q_priority-LTE and Tput-deficit-LTE distributions

Figure 2 presents, cumulative probability distribution of *Q_priority-LTE* (*α-LTEi(t)*) on Y-axis versus $\alpha\text{-}LTE_i(t)$ bin value sizes (*i.e., Q_priority*) on X-axis, from Eqn. (2). Similarly Figure 3 presents, cumulative probability distribution of *Tput-deficit-LTE* ($\beta\text{-}LTE_i(t)$) on Y-axis versus $\beta\text{-}LTE_i(t)$ bin value sizes (*i.e. Tput-deficit*) on X-axis, from Eqn. (4).

As seen from the Fig. 2, for the same system bandwidth, as users in the cell increases, user queue priority or *Q_priority-LTE* increases. This is because as the user is delayed in the queue for getting physical resource block(s), A-OPFS-LTE gradually increases the user priority as predicted in Eqn. (2). This increase in user queue priority directly increases the queue weight as per Eqn. (1b). The minimum and maximum value of the user queue priority is 0 and 10 respectively, depending on the instantaneous delay experienced by the user. As the users under the base station increases, A-OPFS-LTE schedules the packet with longer scheduling gaps. As a result, the average user throughput decreases as per Eqn. (8). This decrease in average user throughput results in increase of throughput deficit as per Eqn. (3). This in turn causes throughput deficit factor *Tput-deficit-LTE* to increase as per Eqn. (4), resulting increase of the queue weight as predicted in Eqn. (1b). From the Fig. 3, we conclude that *Tput-deficit-LTE* increases from a minimum value of 20 till a maximum value of 80 depending on the instantaneous throughput deficit experienced by the user queue. Due to this increase of queue weight, the non scheduled users get physical resource(s) for transmission.

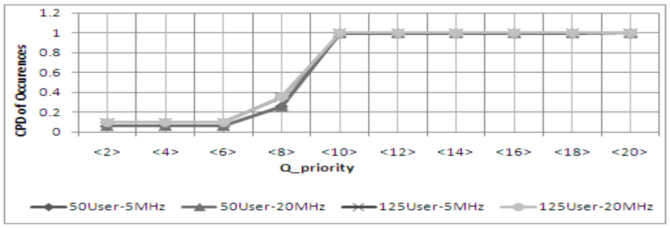

Figure 2: Cumulative probability distribution (CPD) of *α-LTEi(t)* occurrences

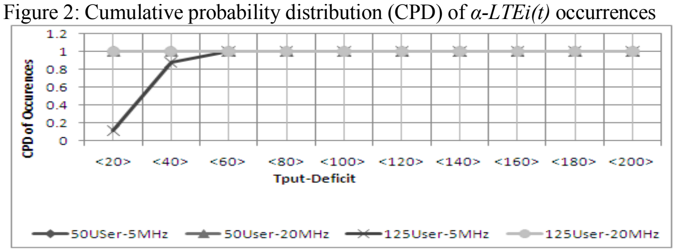

Figure 3: Cumulative probability distribution (CPD) of *β-$LTE_i(t)$* occurrences

Interestingly as the system bandwidth increases to 10MHz or beyond, we see a flat distribution of *Tput-deficit-LTE*. This is because users are getting scheduled very often by A-OPFS-LTE scheduler with the default value of *Tput-deficit-LTE* and the throughput deficit is almost zero.

B. Cell Throughput distribution

The cell throughput occurrences with respect to 50 and 125 cell users for different system bandwidth are being plotted in Figs. 4 and 5 for Voice and Video streaming, respectively.

As per the Eqn. (9), the cell throughput is dependent on the average user throughput as presented in Eqn. (7), (7a), (8) and total number of cell users i.e. *N*. Apparently, as more non scheduled users get scheduled by A-OPFS-LTE per TTI, cell throughput to increases, reaching a maximum value as predicted in Eqn. (7a). The goal of A-OPFS-LTE is to how increase the queue weight of the non scheduled users so that it gets resources to transmit in that scheduling slot. But the drawback of this increased cell users is that, the each user packets might wait longer in the queue before getting the physical resource block(s).

The way with which the non scheduled user can now gets scheduled is by increasing the queue weight value at every scheduling cycle. This can be achieved by increasing the *Q_priority-LTE*, *Tput-deficit-LTE* or both. As described in Section-II-B, *Q_priority-LTE* and *Tput-deficit-LTE* causes the queue weight of the non scheduled user to increase. These in turn make the non scheduled user getting scheduled more often resulting in increase the user throughput $R_i(t)$. Due to this increase in the user throughput, the cell throughput as per Eqn. (9) also increases. A-OPFS-LTE was able to schedule 14 uncompressed VoIP calls (minimum 10% improvement compared with [10]) or 5 streaming type video calls every 1milli-second scheduling cycle. As the system bandwidth increases, the physical resource blocks also increases [Table-I] resulting more and more users getting scheduled in every scheduling cycle resulting in increase cell throughput.

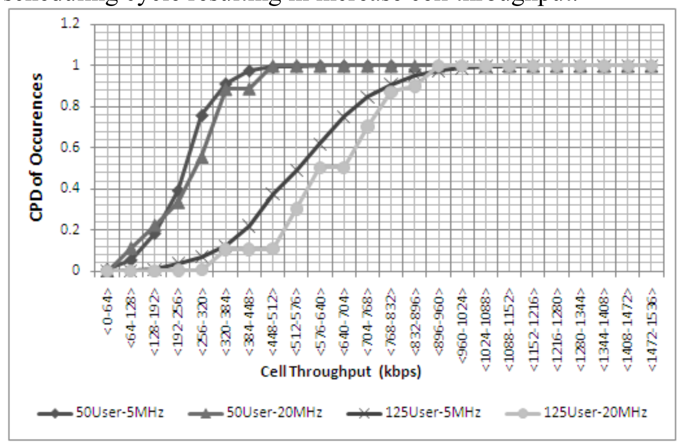

Figure 4: Cumulative probability distribution of VoIP cell throughput occurrences

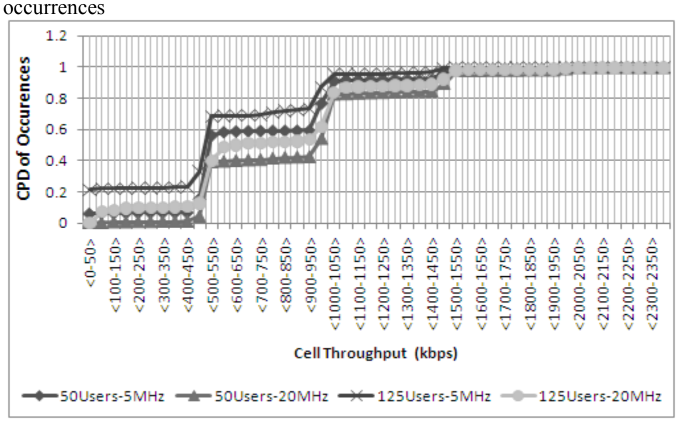

Figure 5: Cumulative Probability distribution of streaming type video cell Throughput occurrences

The lower values of cell throughput in Figs. 4 and 5 are contributed by the non scheduled users whose user throughput is calculated using Eqn. (8). Observing Fig. 5, the cell throughput for streaming type video call has generated a sharp step mode due to sudden jump of transport block size. This is more relevant in case of streaming type video call than VoIP call as A-OPFS-LTE allocates fixed block size for VoIP rather variable block size in case of streaming type video call. This step distribution of cell throughput closely replicates the Modulation-SNR variation as per Eqn. (6). As on when the user's SNR crosses those definite SNR values, both SE and Modulation value rises in step resulting in the sudden jump of transport block size *TB*. This increase in transport block size increases the instantaneous user throughput as presented in Eqn. (7). But as long as the modulation remains constant for a window of SNR variation, the cell throughout changes slowly. This is because the transport block size varies more or less in a smooth manner.

C. Packet Drop Rate (PDR)

The PDR variation for different cell users is presented in Figure 6. This variation is being measured for the whole execution cycle. A-OPFS-LTE tries to minimize the PDR as much as possible so that the average user and cell throughput does not deteriorate causing loss of operator revenues.

As per Eqn. (10), the PDR performance severely gets affected if the packets get dropped due the increase in cell users. For 5MHz system bandwidth, as the user in the cell increases, packet in user's queue wait for longer duration of time for getting the physical resource blocks from the scheduler.

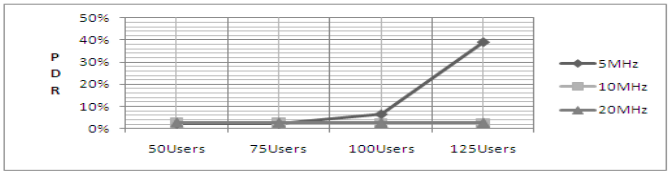

Figure 6: PDR verses VoIP cell users

Due to the long wait in the queue, A-OPFS-LTE discards those delayed packets if it crosses the maximum allowed delay time for that service class. Packet also gets discarded due if the total number of retransmission crosses the maximum allowed threshold value. From the Fig. 6, it can be concluded that for 5MHz system bandwidth and 50 user scenarios the PDR is less than 2%. As the user is increased to 100, PDR is less or equal to 5%. Beyond the 100 cell user scenario, PDR increases significantly due to packet getting dropped every scheduling cycle. Thus PDR gives an operating threshold of A-OPFS-LTE scheduler. Compared with OPFS, A-OPFS-LTE supports 30% more users for the same system bandwidth of 5MHz.

As the system bandwidth increases beyond 5MHz, number of physical resource block also increases proportionately. Refer Table-I for more detail. This results more number of users getting scheduled by A-OPFS-LTE per scheduling cycle. As shown in Fig. 6, the PDR is not zero due to the fact that packet still gets discarded due to the retransmission crosses the maximum allowed threshold value of delay.

D. Throughput variation for different channel conditions

The variation of the average user throughput for both VoIP and streaming users with respect to the signal to noise ratio is being presented in Figure 7. The y-axis represents the average user throughput in log-scale and x-axis represents the SNR. As seen from the Fig. 7, at low value of SNR, the average user throughput for both the VoIP and the streaming type video call is low compared with the throughput at the high value of the SNR. This is due to the fact that the number of packet retransmission at low SNR value is high compared with no-retransmission at high value of SNR. Currently we have kept the retransmission count to be "3" as shown in Table-I. The average throughput variation stabilizes towards the maximum guaranteed bit rate of the users.

I. Conclusions and Further Scope of Work

The A-OPFS-LTE scheduler model indicates that the for a 5MHz system bandwidth and 50 user scenario, A-OPFS-LTE was able to schedule 14 uncompressed VoIP calls or 5 streaming type video calls every 1milli-second scheduling cycle with packet loss less than 2%. Thus A-OPFS-LTE scheduler was able to achieve a minimum 10% improvement on the cell throughput compared with the existing LTE MAC scheduler algorithm in one of the recent literature [10]. Compared with HSPA based OPFS, A-OPFS-LTE supports 30% more users for the same system bandwidth of 5MHz.

In the future work, we will consider the 2x2 MIMO models to boost cell throughput for streaming traffic class users. Currently we have taken the 3GPP standard based VehA30 as our mobility model. Moreover, we need to change the mobility model and see the effect of cell throughput for VoIP and streaming calls.

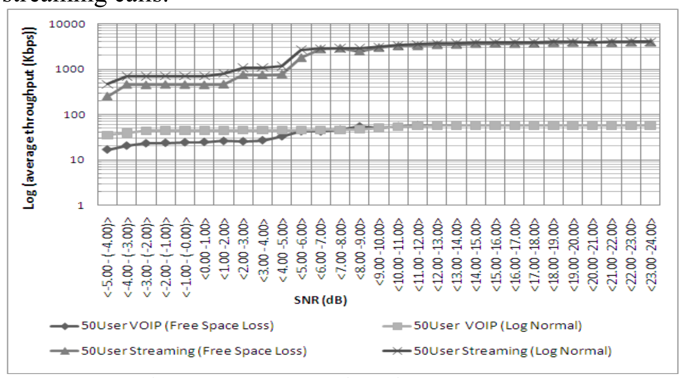

Figure 7: User average throughput verses SNR

References

[1] Y. Choi, Y. Han, "A channel-based scheduling algorithm for cdma2000 1xEV-DO system", Proc. Of IEEE Personal, Indoor and Mobile Radio Communications 2002 (PIMRC02), Lisboa, Portugal, Sept. 2002, Vol. 5, pp. 2259-2263

[2] A Jalali, R. Padovani and R. Pankaj, "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless systems", Proc. of IEEE Vehicular Technology Conference Spring 2000 (VTC2000-Spring), Tokyo, Japan, May 2000, Vol. 2, pp. 1854-1858

[3] Y. Ofuji, S. Abeta and M. Sawahashi, "Comparison of packet scheduling algorithms focusing on user throughput in high speed downlink packet access", IEICE Transaction on Communications, Vol. E86-B, No. 1, Jan. 2003, pp. 132-139

[4] Randall Berry Northwestern University Dept. of EECS Joint work with J. Huang, R. Agrawal and V. Subramanian- "Gradient-based scheduling and resource allocation in OFDMA systems" CTW 2006.

[5] Yingqun Yu and Georgios B. Giannakis – "Joint Congestion Control and OFDMA Scheduling for Hybrid Wireline-Wireless Networks".

[6] Guoqing Li and Hui Liu Department of Electrical Engineering University of Washington, Seattle, WA98195-2500 – "Dynamic Resource Allocation with Finite Buffer Constraint in Broadband OFDMA Networks"

[7] 3GPP TS 36.211, 36.212, 36.213, 36.321, 36.302, 36.306 Specification (FDD)" - (Release 8)

[8] Pedro Vieira, Paula Queluz and Ant´onio Rodrigues- "Improving MIMO Spectral Efficiency in 4G Macro-Cellular Networks" ANACOM 2009

[9] Chen Yue-yun, Deng Xiao-hui – "A Novel Sub-carrier Allocation Algorithm in 3G LTE System"

[10] Sunggu Choi, Kyungkoo Jun, Yeonseung Shin, Seokhoon Kang, Byoungjo Chois - "MAC Scheduling Scheme for VoIP Traffic Service in 3G LTE" , IEEE Xplore

[11] Avinash Ventakesh, Baiju Parameswaran, Saptarshi Chaudhuri– "Opportunistic Proportionate Fairness Adaptive Scheduler for High Speed Packet Access System" – IEEE COMSWARE_2007

[12] Klemens Freudenthaler, Andreas Springer et al – "Novel SINR-to-CQI Mapping Maximizing the Throughput in HSDPA" – WCNC 2007 proceedings