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Performance Evaluation of Cross Layer QoS scheduling for Long Term Evolution Network

D. Vinayagam[1], R. Kurinjimalar[2], D. Srinivasan[3]
Department of Electronics and Communication Engineering[1,2,3]
IFET College of Engineering Tamilnadu, India[1]
Sri Manakula Vinayagar Engineering College Puducherry, India[2,3]

Abstract

The Cross layer based Two-way scheduling Algorithm (CTSA) is proposed for scheduling both Real Time (RT) and Non-Real Time (NRT) services. The advantage of the complimentary characteristics of both RT and NRT services is utilized in CTSA to achieve a significant cell user throughput, a low delay, normalized fairness and a low packet loss ratio. The CTSA is the adaptation of the two scheduling algorithm supporting RT and NRT for effective utilization of channel. The LTE-Sim simulation tool is used to simulate the CTSA under multi-cell scenario environment for scheduling in the LTE (Long Term Evolution) network. The performances of the CTSA using Proportional Fair (PF), Modified Long Weighted Delay First (M-LWDF) and Exponential Proportional Fair (EXP/PF) schedulers are studied in terms of throughput, packet loss ratio, delay and cell spectral efficiency and fairness index. The simulation based comparison indicates that M-LWDF and EXP/PF scheduler outperforms PF scheduler especially during RT service. The PF scheduler has high throughput for NRT service. In all the simulations, the performance level of EXP/PF scheduling algorithm for multi-service scheduling seems to be an optimal solution for guaranteeing required QoS (Quality of Service).

Keywords

Cross layer based Two-way Scheduling Algorithm (CTSA), multi-service scheduling, LTE-Sim, cross layer, Priority based Two-way Scheduling Algorithm, QoS, LTE, 3.9G

1. Introduction

Long Term Evolution (LTE) is the evolution of mobile technology that will deliver users the benefits of faster data speeds and a new service by creating a new radio access technology that's optimized for IP based traffic and offers operators a simple upgrade path from 3G networks. Internet protocol (IP) is the traditional network-layer protocol for wired packet networks and is also considered the natural candidate in wireless systems. IP provides a globally successful open infrastructure for creating and providing services and applications. All IP could make wireless networks more robust, scalable and cost effective. The next generation networks are invariably all IP. IP is a connectionless datagram service. Its scheduling behavior to support various QoS requirement will not provide the optimized performance, without which sustaining the 4G requirements of high data rate, low latency will not be possible.

Future wireless network design requires cross layer optimization in order to achieve the pre-requisite service guarantees like high data rate, low latency, and tolerable user fairness index. In a packet network, one important component to achieve the aforementioned efficiency goals is a properly designed scheduling and resource allocation algorithm. Scheduling plays an important role in providing QoS support to multimedia communications in various kinds of wireless networks, including cellular networks, mobile ad hoc networks and wireless sensor networks. Cross Scheduling is basically a kind of cross layer optimization method mainly involving PHY and MAC to manage the system resources adaptively to achieve the system goal. If PHY and MAC layers are chosen to optimize the network resources, the best way to meet the objective is by exploiting the frequency and temporal dimension of the resource space. Scheduling optimization approaches attempt to dynamically match the requirements of data-link connections to the available physical layer resources to maximize some systematic.

2. Existing Scheduling Algorithm

The packet scheduling algorithms is normally classified into two categories: physical layer-channel quality information (PHY layer - CQI) based packet scheduling algorithm (Max C/I and RR (Round Robin)) and cross-layer packet scheduling algorithm (PF (Proportional Fairness), M-LWDF (Modified

Largest Weighted Delay First) and EXP-rule) which takes into consideration both PHY-layer CQI as well as data link layer buffer queue information. So far, among all the scheduling algorithms, Max C/I, PF (Proportional Fairness) and RR (Round Robin) have been most widely researched. However, these three scheduling schemes have two drawbacks in common taking into practical situation into consideration. First, all of the presented algorithm are designed for single-service situation, hence cannot satisfy the principle of multi-service directly. Second, none of these schemes take the user buffer queue information into consideration. Thus in practical situation, these schedulers would serve users without any buffer data, resulting in waste of resources. In order to make up for shortcomings of the three classical algorithms, several literatures considering cross-layer information based on the OFDMA system is considered. M-LWDF (Modified Largest Weighted Delay First) and EXP-rule, considering time delay, thus better delay and throughput performance can be achieved, but its packet loss rate performance is still insufficient. The adaptive EXP/PF scheduling scheme is to schedule the stream service and best-effort service with EXP-rule and PF-rule respectively.

The QoS aspects of the LTE downlink are influenced by a large number of factors such as channel conditions, resource allocation policies, available resources, and delay sensitive/insensitive traffic. In LTE the resource that is allocated to a user in the downlink system contains frequency and time domains, and it is called resource block. The architecture of 3GPP LTE system consists of some base stations called "eNodeB" where the packet scheduling is performed along with other RMM mechanisms. The whole bandwidth is divided into 180 kHz, physical resource blocks (RB's), each one lasting 0.5 ms and consisting of 6 or 7 symbols in the time domain, and 12 consecutive subcarriers in the frequency domain. The resource allocation is realized in every Transmit Time Interval (TTI), that is exactly every two consecutive resource blocks, like this, a resource allocation is done on a resource block pair basis.

It can be seen that, each user is assigned a buffer at the serving eNodeB. Packets arriving into the buffer are time stamped and queued for transmission based on a First-In-First-Out basis. In each TTI, the packet scheduler determines which users are to be scheduled based on a packet scheduling algorithm. In this system, there is a possibility that a user may be allocated zero, one, or more RBs (Resource Blocks) at each TTI (Transmission Time Interval). Users report their instantaneous downlink channel conditions (e.g., Signal-to-Noise-Ratio, SNR) to serving the eNodeB at each TTI. At the eNodeB the packet scheduler performs a user selection priority, based on criteria as channel conditions, HOL packet delays, buffers status, service types, etc. Each user is assigned a buffer at eNodeB. For each packet in the queue at the eNodeB buffer, the head of line (HOL) is computed; a packet delay is computed as well. If the HOL packet delay exceeds a specified threshold, then packets are discarded.

In particular, for every TTI, the estimation of $D_i(k)$ as given in the equation

$$\tilde{D}_i(k) = 0.8D_i(k-1) + 0.2D_i(k) \qquad (1)$$

Where $\tilde{D}_i(k)$ denotes the data rate which is achieved by the ith flow during the kth TTI and $D_i(k-1)$ is the data rate estimation in the previous TTI. To obtain the metric, scheduler algorithms usually need to know the average transmission data rate $\tilde{D}_i(k)$ of the i^{th} flow and the instantaneous available data rate of the receiver UE for the j^{th} sub-channel. This knowledge is useful when the metric has to take into account information about the performance guaranteed in the past to each flow in order to perform fairness balancing.

3. Proposed Cross layer based Two-way Scheduling Algorithm

The existing packet scheduling algorithm suits either for RT or NRT based on class of service. Users with bad channels are awfully penalized regarding users with good channels. The fairness condition among the user is not satisfied. The user with good channel conditions will be allocated with resource block. User with bad channel has to wait till the channel is good.

The PF scheduler assigns radio resources taking into account both the experienced channel quality and the past user throughput. The goal is to maximize the total network throughput and to guarantee fairness among flows. For this scheduler, the metric ($\omega_{i:j}$)is defined as the ratio between the instantaneous available data rate ($r_{i:j}$) and the average past data rate ($\omega_{i:j}$). That is, with reference to the i^{th} flow in the j^{th} sub-channel: The PF scheduler assigns radio resources taking into account both the experienced channel quality and the past user throughput. The goal is to maximize the total network throughput and to guarantee fairness among flows. For this PF scheduler, the metric ($\omega_{i:j}$) is defined as the ratio between the instantaneous available data rate ($r_{i:j}$) and the average past data rate ($\omega_{i:j}$). That is, with reference to the i^{th} flow in the j^{th} sub-channel.

$$\omega_{i:j} = \left(\frac{r_{i:j}}{R_i}\right) \qquad (2)$$

where ($r_{i:j}$) is computed by the AMC module considering the CQI feedback that the UE hosting the i^{th} flow have sent for the j^{th} sub-channel; and R_i is the estimated average data rate.

The M-LWDF scheduler supports multiple data users with different QoS requirements. For each RT flow, considering a packet delay threshold (τ_i), the probability δ_i is defined as the maximum probability that the Delay of the Head of Line Packet ($D_{HOL,i}$) exceeds the delay threshold. To prioritize RT flows with the highest delay for their head of line packets and the best channel condition, the metric $\omega_{i:j}$ is defined.

$$\omega_{i:j} = \alpha_i D_{HOL,i}\left(\frac{r_{i:j}}{R_i}\right) \qquad (3)$$

$$\alpha_i = -\left(\frac{\log \delta_i}{\tau_i}\right) \qquad (4)$$

The $D_{HOL,i}$ is the delay of the first packet to be transmitted in the queue. The $r_{i:j}$ is computed by the AMC module considering the CQI feedback that the UE hosting (α_i). Instead, for NRT flows, the considered metric is the one of the simple PF. In the current implementation of the M-LWDF allocation scheme, packets belonging to a RT flow are erased from the MAC queue if they are not transmitted before the expiration of their deadline. This operation is required to avoid bandwidth wasting. This implementation is not available for the PF, because it is not designed for RT services.

The EXP/PF is designed to increase the priority of RT flows with respect to NRT ones, where their head of line packet delay is very close to the delay threshold. For RT flows, the considered metric is computed by using the following equations:

$$\omega_{i:j} = \exp\left(\frac{\alpha_i D_{HOL,i}}{1+\sqrt{x}}\right)\left(\frac{r_{i:j}}{R_i}\right) \qquad (5)$$

$$x = \frac{1}{N_{rt}}\sum_{i=1}^{N_{rt}} \alpha_i D_{HOL,i} \qquad (6)$$

Where N_{rt} being the number of active downlink RT flows, $r_{i:j}$ and R_i have the same meaning of symbols in equation of proportional fair. Instead, for NRT flows, the considered metric is the simple PF. Also with EXP algorithm, packets belonging to a RT flow are erased from the MAC queue if they are not transmitted before the expiration of their deadline.

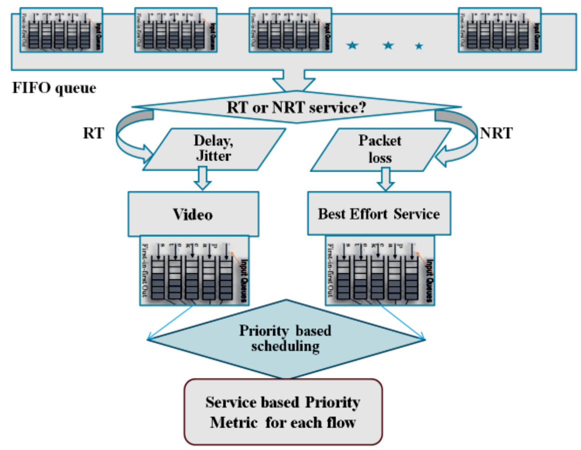

Fig.1: Priority based Two-way Scheduling Algorithm

The Cross layer based Two-way scheduling Algorithm (CTSA) is proposed for scheduling both RT and NRT services. The advantage of the complimentary characteristics of both RT and NRT services is utilized in CTSA to achieve a significant cell user throughput, a low delay, normalized fairness and a low packet loss ratio. The CTSA is the adaptation of the two scheduling algorithm supporting RT and NRT for effective utilization of channel. The CTSA algorithm is developed by using the PF, MLWDF and EXP rule schedulers work together in combined RT and NRT services.

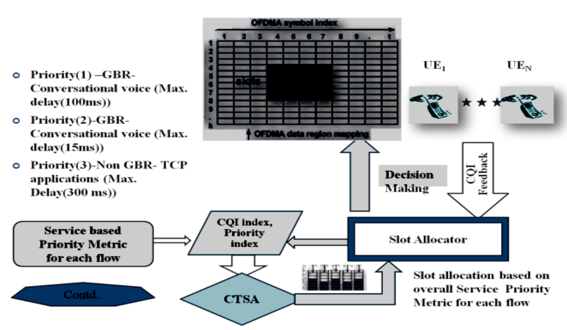

Fig.2: Cross layer based Two-way Scheduling Algorithm (CTSA)

The Cross layer based Two-way Scheduling Algorithm (CTSA) is proposed for scheduling both RT and NRT services. The CTSA is the adaptation of the two scheduling algorithm supporting RT and NRT for effective utilization of channel. Using the Cross layer based approach to provide fairness among the users based on the channel conditions. Instead of penalizing the user with bad channels, Based on channel condition low – high data transmission rate is possible.

Here in this work, three ways of scheduler combination are made for supporting NRT and RT service by CTSA scheduling algorithm. The firstly the PF schedulers itself is utilized for the NRT and RT services even though it suits only NRT service only for testing its performance with other schedulers. Then, secondly MLWDF and PF are combined to schedule based on type of service either NRT or RT service. Finally the Exponential scheduling algorithm and PF is combined to schedule based on type of service either NRT (Best service) or RT (Video).

4. Simulation Results

The LTE-Sim simulation tool is used to simulate the CTSA under multi-cell scenario environment for scheduling in the LTE (Long Term Evolution) network. The performances of the CTSA using different combination of scheduling algorithms Proportional Fair (PF), Modified Long Weighted Delay First (M-LWDF) and Exponential Proportional Fair (EXP/PF) schedulers are studied in terms of throughput, packet loss ratio, delay and cell spectral efficiency and fairness index. For the Multi-Cell /Multi-User scenario, the number of cells assumed in the single cluster is 7 cells and number of cluster considered in this scenario is 3, and mobility model for UEs to roam inside and outside the home location is random direction.

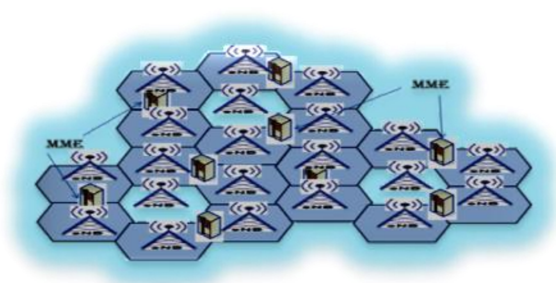

Fig.3: Multi-Cell/Multi-User Simulation Scenario

The LTE network is created with a Multi Cell-Multi User scenario having the cell radius equal to 1 km, total numbers of UEs (range [10 - 50]) are uniformly distributed in a cell. UEs travel inside the area following the Random Walk mobility model in an urban macro cell scenario. The whole bandwidth is distributed among cluster of cells, to guarantee 10 MHz of bandwidth in the downlink, for each cell.

Table I: Parameter Configuration for Multi-Cell Scenario

Parameter	Description
Simulation time	100 s
Type of frame structure	FDD
Number of resource blocks	50
Cell radius	1 km
Scheduling time (TTI)	1 ms
Video tracing	440 kbps
Flows duration	100 s
Bandwidth	10 MHz
Slot duration	0.5 ms
Type of scheduler	PF, MLWDF, EXP/PF
Max. delay	0.002 s
Flows duration	100 s
Bandwidth	10 MHZ
Slot duration	0.5 ms

The LTE propagation loss model calculations are manipulated as follows

a. The Path Loss Model for Urban Environment (L) = I + 37.6log10(R) where L is the propagation path loss in urban cell channel realization, R, in kilometers, is the distance between two nodes (the UE and the eNodeB), I = 128.1 at 2GHz.
b. Multipath: Jakes model, Penetration Loss: 10 dB.
c. Shadowing: log-normal distribution (mean = 0 dB, standard deviation = 8 dB).

The traffic model for application layer flow services

a. A video service with 242 kbps source video data rate traffic is a trace-based application that sends packets based on realistic video trace files.
b. Best effort flows are created by an infinite buffer application which models an ideal greedy source that always has packets to send.

[1] Throughput of end to end service vs. Number of User Equipment/ Cell

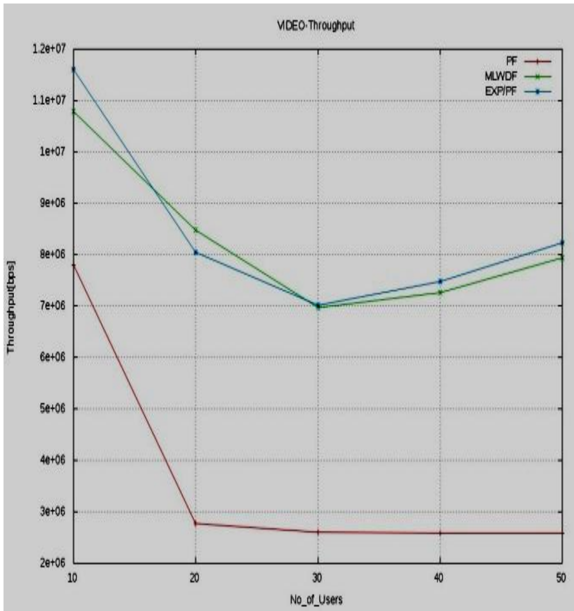

Fig.4: Throughput for video flow vs. No. of User Equipments/ Cell

The M-LWDF and EXP/PF scheduler algorithm schedules the RT service with tolerable delay and high priority whereas the PF scheduler is prone to delay intolerable scheduling. Hence the M-LWDF and EXP/PF provides low throughput because it can schedules the services.

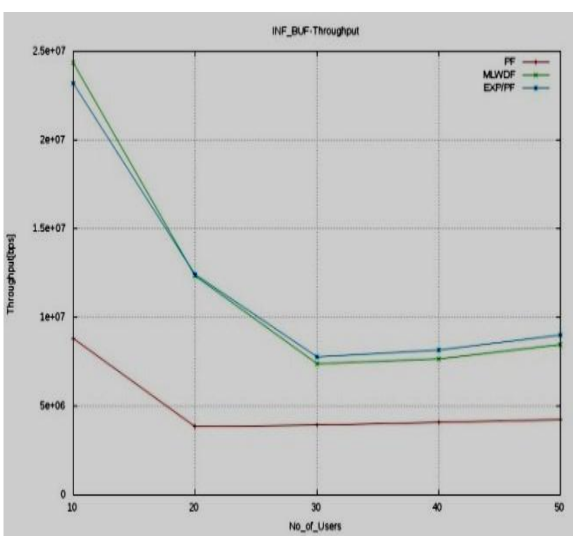

Fig.5: Throughput for infinite buffer vs. No. of User Equipments/ Cell

In best effort flows the throughput decreases because of the system saturation, it is a known effect for NRT flows. From the throughput strategy of these schedulers, one can observe the noticeable variations of the throughput provided by RT multi-user scheduler (MLWDF& EXP/PF) along with NRT scheduler (PF).

[2] Packet Loss Ratio (PLR) vs. Number of User Equipments/ Cell

The packet loss ratio for the user's application layer service flows through LTE network from source to destination can be calculated, as in

$$PLR = \left[\frac{(tx\_pkts - rx\_pkts)}{tx\_pkts} \right] *100 \quad (7)$$

Where tx_pkts denotes number of packets transmitted from the transmitter (UE or EnodeB), rx_pkts denotes the number of packets received by the receiver (UE or EnodeB).

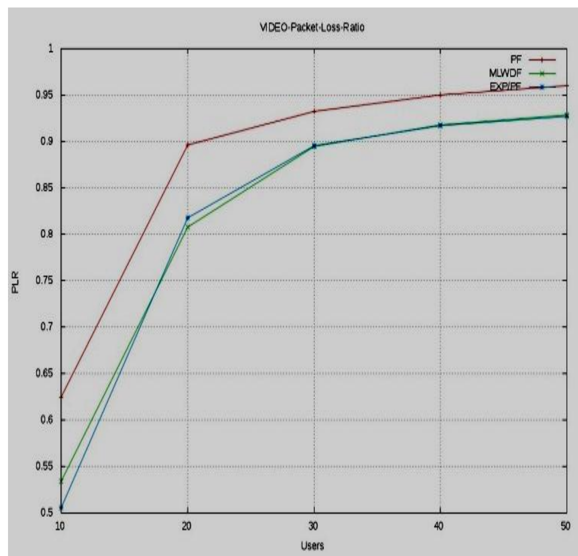

Fig. 6: Packet Loss Ratio (PLR) for video flow vs. No. of User Equipments/ Cell

The EXP/PF and M-LWDF presents an optimal behavior for delay sensitive service flow than PF and also provides better the cell supports for low variation in PLR when the number of users in the cell are ranging between (30-50) users in the cell.

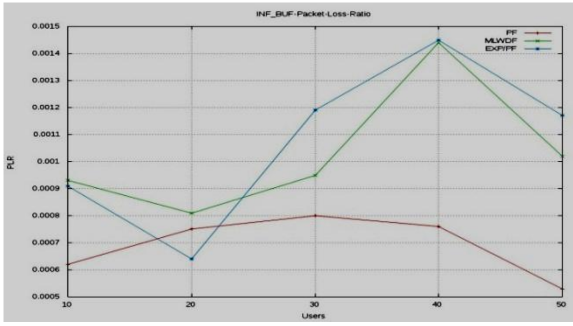

Fig.7: Packet Loss Ratio (PLR) for infinite buffer vs. No. of User Equipments/ Cell

For best effort of service application, PF shows better scheduling strategy with lowest PLR for multiple users than MLWDF & EXP/PF. This is normal in NRT flows because when the HOL packet delays for all the users do not differ a lot, the PF rule outperforms.

[3] Fairness Index vs. Number of User Equipments/ cell

Fairness index has been computed using Jain's fairness index method considering the throughput achieved by each flow at the end of each simulation.

$$Fairness = \frac{\left(\sum x_i\right)^2}{\left(n.\sum x_i\right)^2} \qquad (8)$$

Where n denotes number of users and x_i is the throughput for the i^{th} connection.

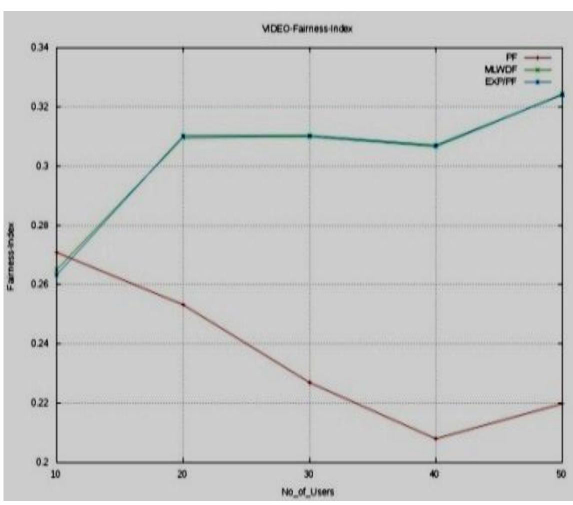

Fig.8: Fairness Index of video flow vs. No. of User Equipments/ Cell

The fairness level of MLWDF and EXP/PF schedulers is greater than the PF scheduler when the number users in the access network increases demanding access in the shared channel.

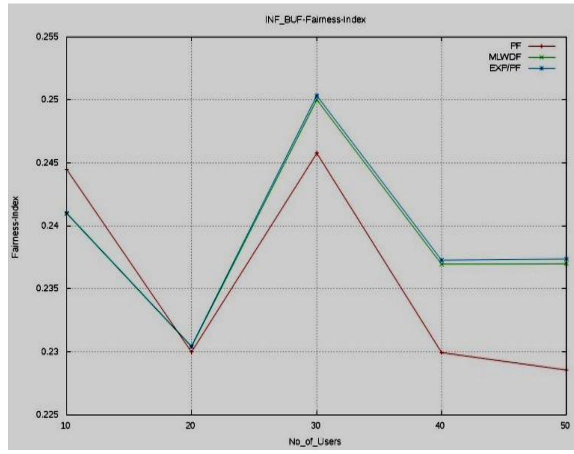

Fig.9: Fairness Index of Infinite Buffer vs. No. of User Equipments/ Cell

[4] Average Packet Delays vs. Number of User Equipments/ Cell

MLWDF and EXP/PF algorithms show a high level of fairness value closer to 0.3. Fairness in best effort of service flow increases when user's number decreases the NRT service flows because of their low priority level.

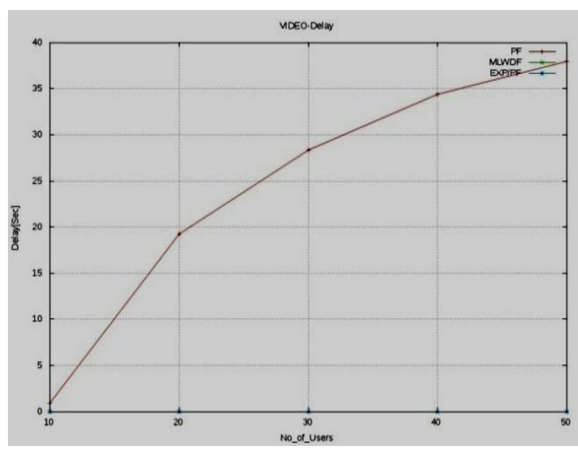

Fig.10: Average Packet Delays for video flow vs. No. of User Equipments/ Cell

For Video service, EXP/PF, M-LWDF presents a stable delay close to 0.02ms. When the number of user increase in the cell simultaneously the average delay among the current users serviced by the access network also increases.

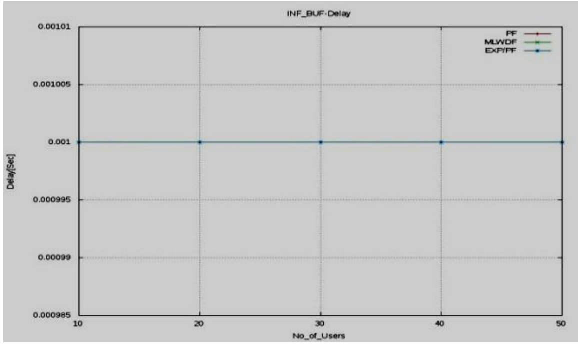

Fig.11: Average Packet Delays of infinite buffer vs. No. of user Equipments/ Cell

As best effort of service flows uses an infinite buffer model, the delay will always be a constant value of 0.001 ms. Therefore three downlink schedulers schedules all the best effort of service flow in similar manner and hence there exhibits a common delay.

[5] Spectral Efficiency vs. Number of User Equipments/ Cell

The Cell Spectral Efficiency (CSE) can be calculated from this equation for the LTE radio access network.

$$\mathrm{CSE} = \left[\frac{\left(\frac{\mathrm{Total\_Goodput}}{\mathrm{Time}} \right)}{\mathrm{AVAILABLE\ BANDWIDTH}} \right] \quad (7)$$

Where Total_Goodput denotes the application level error transmission rate otherwise can be called as application layer level throughput.

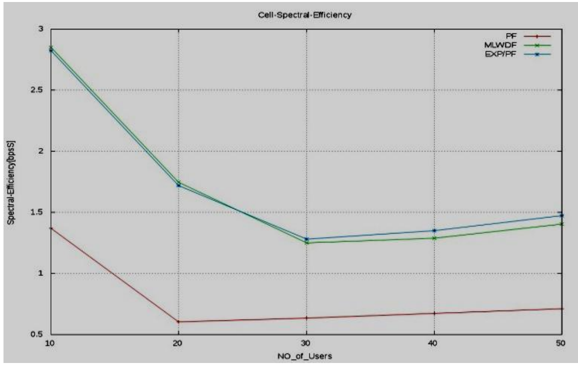

Fig 12: Cell Spectral Efficiency vs. number of User Equipments/ Cell

The QoS-aware scheduler (M-LWDF and EXP/PF) provides guarantee QoS constraints to a high number of flows than the PF scheduler. Here the initially the cell spectral efficiency at initial stage promote greater spectral efficiency in bps/ Hz.

5. Conclusion

The performance of the proposed scheduling algorithm with respect to the video and data services along with cross layer feature compared with other packet scheduling algorithm is observed and studied. From the result obtained, the M-LWDF scheduling algorithm has greater performance for increasing load applied on comparison with other scheduling algorithm. When the number of users in the cell increases, the QoS-aware schedulers (M-LWDF and EXP) still try to guarantee QoS constraints to a high number of flows, with a consequent negative impact on the system efficiency. In this study, the PF, M-LWDF, and EXP rules were investigated in the case of video, VoIP, and best effort services in LTE. The simulations-based comparison indicated that the modified M-LWDF and EXP rules outperform PF, especially when using RT flows. In all simulations, the EXP/PF held an advantage over M-LWDF and PF. But as stated, the EXP/PF and M-LWDF are able to adapt to increasing user diversity and channel variation much better than PF. Clearly PF algorithm is not considered as good solution for RT services. Packet loss ratio value is the highest one, the throughput achieved is the lowest one, and the delay is high when the cell is charged, therefore this algorithm is a good solution only for NRT flows. M-LWDF is an algorithm that aims at satisfying the transfer delay of multimedia packets while utilizing the fast channel quality information represents an interesting solution for providing RT services. It is concluded that the M-LWDF algorithm is a rather unfair scheduling principle where the users with poor average radio propagation conditions suffer from higher delays than the remaining users in the cell and are not able to fulfill the QoS criterion during high load situations. In order to provide a significant cell user throughput gain, a low delay, a high fairness index, and a low packet loss ratio, the EXP/PF scheduling algorithm seems an optimal possible solution for guaranteeing a good QoS level.

6. Appendix

From the 3GPP specification, the throughput calculation of LTE release 8 can be calculated. 1 Radio Frame = 10 Sub-frame, 1 Sub-frame = 2 Time-slots, 1 Time-slot = 0.5 ms (i.e1 Sub-frame = 1 ms), 1 Time-slot = 7 Modulation Symbols (when normal CP length is used). 1 Modulation Symbols = 6 bits; if 64 QAM is used as modulation scheme. Radio resource is managed in LTE as resource grid. 1 Resource Block (RB) = 12 Sub-carriers Assume 20 MHz channel bandwidth (100 RBs), normal CP“."Therefore,” number of bits in a sub-frame = 100RBs x 12 sub-carriers x 2 slots x 7 modulation symbols x 6 bits = 100800 bits. "Hence, data rate = 100800 bits / 1 ms = 100.8 Mbps“. "If 4x4 MIMO is used, then the peak data rate would be 4 x 100.8 Mbps = 403 Mbps.""If 3/4 coding is used to protect the data, we still get 0.75 x 403 Mbps = 302 Mbps as data rate”.

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D. Vinayagam was born in Puducherry, India, August 7, 1988. He received his Bachelor degree (B.Tech.) in Electronic & Communication Engineering (ECE) by the year 2010 at Regency Institute of Technology, Affiliated to Pondicherry University, Yanam, U.T. of Puducherry, INDIA. He received his Master degree (M. Tech.) in Electronic & Communication Engineering (ECE) by the year 2012 at Sri Manakula Vinayagar Engineering College, Affiliated to Pondicherry University, Pondicherry, INDIA. His research interests are in the areas of mobile communication, cross layering, Quality of Service (QoS), downlink scheduling in Long Term Evolution (LTE) Network and recent emerging technologies in wireless networks. He has published his recent work along with his co-authors in CiiT International Journal of Automation and Autonomous System on the Title: “Analysis of Security in Mobile Phone Payment Method using Near Field Communication” on July 2012. At present, he is working as a Lecturer in IFET College of Engineering, [Affiliated to Anna University, Chennai], Villupuram, Tamilnadu, India.

R. Kurinjimalar received the B.E. (ECE) degree from Bharadhidasan University, Thiruchirapalli, Tamilnadu, INDIA, in 1997, then joined as Plant Manager in VENUS INDUSTRIES, Hosur, Tamilnadu, INDIA. Then joined as Lecturer in Bharathiyar College of Engineering & Technology, Karaikal, Puducherry State, INDIA by 1999. She completed MBA (HR) by 2005 and M.E (Communication Systems) degree from Vinayaga Mission University, Salem, Tamilnadu, INDIA, in 2007. She is currently Assistant Professor with Sri Manakula Vinayagar Engineering College, Puducherry State, INDIA. Her current interests include Wireless Communication Networks and Security. She serves as a member of ISTE & Organized two FDPs.

D. Srinivasan was born in Puducherry, INDIA. Currently, he is pursuing final year B.Tech. degree in Electronic & Communication Engineering at Sri Manakula Vinayagar Engineering College, Affiliated to Pondicherry University, Pondicherry, INDIA. He has participated in the workshops related to Next Generation Wireless Networks. His current research interests are 3G wireless networks and mobile communication.