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Flow Bandwidth-based Modified Exponential MLWDF Scheduling Algorithm for LTE Wireless Systems

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***Abstract*— Flow bandwidth-based modified exponential MLWDF scheduler has been proposed in this paper with the goal of achieving improved throughput for real time (RT) services on Long Teran Evolution (LTE) network while maintaining appreciable fairness with regard to non-real time (NRT) services. The scheduler was developed by incorporating the uncertainty principle of Fuzzy Logic which accepts latency (0 – 500 ms), and throughput (0 – 50 Mbps) as input and flow weight parameter having a range 0 to 1 as output. The outcome of the Fuzzy Logic system was synergized with the original MLWDF algorithm to give a new scheduling scheme with enhanced capacity for higher throughput mainly for real time applications. A comparison of the proposed algorithm using one hundred users at the eNodeB was done with the original MLWDF, EXP/PF and PF. The results obtained showed that the new scheduler proposed consistently achieved higher throughput, dropped lesser packets and showed appreciable fairness index for RT services. However, the base MLWDF gave a better fairness for CBT flows.**

Keywords*— *Flow bandwidth; Modified Exponential MLWDF scheduler; Throughput; CBT flows; LTE.

I. INTRODUCTION

The desire for a much-improved data technology over cellular communication given the limitations associated with the previous generations of wireless communication necessitated the introduction of the fourth generation (4G) of wireless communication and Long-Term Evolution (LTE) technology [1], [2]. LTE is standard of wireless telecommunication system created by the Third Generation Partnership Project (3GPP) with the aim of providing support for a broadband connectivity over wireless communication platform capable of handling Voice over Internet Protocol (VoIP), video streaming, and online gaming [3]. Increased speed was realised through the implementation of Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and Single-Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink of the 3GPP LTE system [4]–[6]. In OFDMA, rather than sending data stream at extreme high speed over a single carrier as was employed in Universal Mobile Telecommunication Systems (UMTS), the data stream is split into several slower parallel data streams (referred to as orthogonal subcarriers) that are transported over many carriers at the same time [7], [8]. According to [9], the disparity in the technology employed in the downlink and uplink of LTE architecture stem from higher processing energy requirement of OFDMA at the base station (eNodeB) in comparison to SC-FDMA implemented on mobile devices.

In LTE downlink transmission, radio resources are organized into time domain and frequency domain which constitute transmitted resource blocks (RBs). A total of 12 subcarriers each of 15 kHz bandwidth (180 kHz in total) constitute the frequency domain while time domain is made up of time slots of 0.5 ms duration [10]. A time slot consists of a number of Orthogonal Frequency Division Multiplexing (OFDM) symbols comprising of either seven cyclic prefixes (normal) or six cyclic prefixes (extended). As reported by [11], normal cyclic prefix is adopted in urban cells and high data rate applications while extended cyclic prefix is employed in special cases like multicell broadcast and in very large cells usually deployed in rural areas as well as low data rate applications.

In order to provide optimal bandwidth and acceptable delay, radio resource allocation (scheduling) algorithms are utilized in LTE to disperse resources to connected User Equipment (UEs) [12]. As highlighted by [13], the scheduling algorithm adopted to a large extent, determines the entire system's Quality of Service (QoS). Hence, in scenarios where prioritised performance credentials are required and existing schedulers are found to exhibit limited characteristics in terms of QoS metrics, the need to develop carrier-specific scheduling algorithm becomes sacrosanct. This forms the motivation for the scheduler proposed in this paper.

This paper proposes an alternative version of combined exponential (EXP) and Modified Least Weighted Delay First (MLWDF) schedulers based on flow bandwidth integration using Fuzzy Logic (FL) technique.

II. REVIEW OF RELATED LITERATURE

The absence of standardized scheduling algorithm by 3GPP given the environment- and application-dependent nature of radio resource allocation forms the basis for the duplicity of published journals on LTE scheduling.

Chidume et al. in [14] proposed an improved MLWDF scheduler that was developed by incorporating bandwidth of flow alongside FL uncertainty principle to estimate new weight for different traffic flows. Results obtained by the authors showed appreciable improvement in average throughput, Packet Loss Ratio (PLR), Fairness Index and delay with regard to real time (RT) services. However, the scheduler performance in terms of non-real time (NRT) traffic was poor.

Angri et al. in [15] presented an EXP-MLWDF downlink scheduling algorithm evaluated in LTE for high mobility and dense area scenario. The authors developed the proposed scheduler expression by merging the scheduler equation for both EXP and MLWDF schedulers. Performance-wise, EXP-MLWDF showed far more consistent and better performance with regard to PLR and throughput than the nominal EXP and MLWDF schedulers. NRT services was not accounted for by the authors as they only focused on video and VoIP traffic.

Iturralde et al. in [16] proposed two new schedulers developed by modifying two existing schedulers (EXP and MLWDF). The modification was done using cooperative game theory and virtual token mechanism. For multimedia traffic (video and VoIP), the achieved throughput, delay, fairness index and PLR were shown to be a lot better than the base schedulers they modified. However, the authors neglected Constant Bit Rate (CBR) traffic in the assessment of their proposed schedulers.

Delay–based and QoS–Aware Scheduling (DQAS) scheme with a low complexity overhead as an efficient solution for the resource allocation issue in LTE Medium Access Control (MAC) layer was proposed by Madi et al. in [17]. They outlined the ultimate aim of DQAS to be minimizing delay for Real-Time (RT) traffic while still offering good level of QoS. For their developed algorithm to comply with QoS of different traffic types, the authors analyzed the queue buffer of each user flow by developing an algorithm called Efficient Delay Control (EDC) that weighs each flow priority in terms of delay. The weight was utilized as a principle for the scheduling decision on the attendant flows. Furthermore, the Least Delay Increase (LDI) algorithm was introduced to tune the scheduler behavior to maintain a balance between delay and system throughput. Simulated results as reported by the authors considering different user mobility scenario revealed that DQAS significantly guaranteed a low end-to-end delay trend that is independent of increased RT load, and moreover, a reasonable throughput and data drop levels compared to other existing schedulers highlighted in the journal. Nonetheless, there was a complete disregard for fairness index in the scheduling decision of the algorithms proposed by the authors.

III. METHODOLOGY

Every QoS-aware scheduler prioritizes channel states and conditions to maximize throughput delivered to the UEs given its role in determining the data rate per time. Hence, the current data rate that can be used by the i^{th} user on the k^{th} sub-channel at the time, t is defined as $d_{i,k}(t)$. Given the inherent MLWDF characteristic of prioritising needs of users with better channel condition, the metric contained in (1) is proposed:

$$m_{i,k}^{E-MLWDF} = d_{i,k}(t) \tag{1}$$

In order not to discard traffic generated by users with bad channel condition and considering the estimated average data rate at the $(j-1)^{th}$ TTI; (1) is therefore adjusted to become (2).

$$m_{i,k}^{E-MLWDF} = \frac{d_{i,k}(t)}{R_i(t-1)} \tag{2}$$

To achieve a balance between RT and NRT streams, it is necessary to introduce and define weight parameter, α_i incorporated in the MLWDF scheduler expression into the previous expression in (2) to give (3).

$$m_{i,k}^{E-MLWDF} = \frac{\alpha_i d_{i,k}(t)}{R_i(t-1)} \tag{3}$$

Including flow bandwidth, β and multiplying it by the average throughput at the denominator of (3); the expression in (4) is derived thus;

$$m_{i,k}^{E-MLWDF} = \frac{\alpha_i d_{i,k}(t)}{R_i(t-1)\beta} \tag{4}$$

$$\beta = R_{max} * \frac{w_i}{\sum_{i=0}^{n} w_i} \tag{5}$$

for $0.01 \leq w_i \leq 1$

Alongside the QoS information received by the user from the eNodeB, it is possible to extract the Head of line Delay, $D_{HOL,i}$ for the i^{th} user. This is necessary in order to determine the allowable queue size and permitted delay length so as to properly accommodate users with bad channel conditions given that the smaller the difference between the time spent in queue, $D_{HOL,i}$ and the deadline delay, τ_i the higher the metric attained. Mathematically represented thus;

$$\alpha_i = \frac{\tau_i}{(\tau_i - D_{HOL,i})} \tag{6}$$

Applying exponential function to (6) gives the channel serviceable critical condition similar to what is obtainable with EXP scheduler.

$$\alpha_i = exp\left(\frac{\tau_i}{(\tau_i - D_{HOL,i})}\right) \tag{7}$$

Combining (4) and (7) gives (8) which is the expression for the modified EXP-MLWDF schedular proposed.

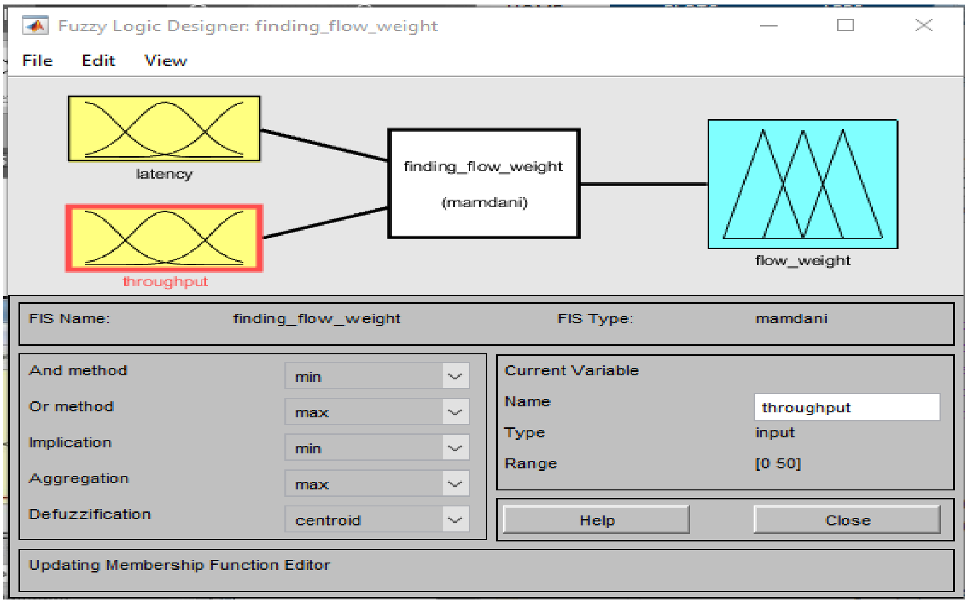
$$m_{i,k}^{E-MLWDF} = \frac{\alpha_i d_{i,k}(t)}{R_i(t-1)\beta} exp\left(\frac{\tau_i}{(\tau_i - D_{HOL,i})}\right) \qquad (8)$$

where: $d_{i,k}(t)$ = expected data rate for the i^{th} user at time t on the k^{th} RB, $R_i(t-1)$ = average throughput up to $(t-1)$ time slot, α_i = weight parameter, R_{max} = maximum user's reserved rate, w_i = weight of flow, τ_i = delay threshold for the i^{th} user and $D_{HOL,i}$ = head-of-line packet delay.

To adapt the proposed scheduler expression to use FL uncertainty principle, a similar approach applied by [14] is adopted to determine new weight for different flows over three steps (fuzzification, fuzzy reasoning and defuzzification). Latency (0 – 500 ms) for RT service requirement and throughput (0 – 50 Mbps) for NRT traffic form the input parameters to the FL with flow weight (0 – 1) being the output parameter as illustrated in Fig. 1 and Fig. 2. For the defined parameters to work with the FL system, some predefined rules (18 in all) are used as guard rails for the system to function effectively as outlined in Table 1.

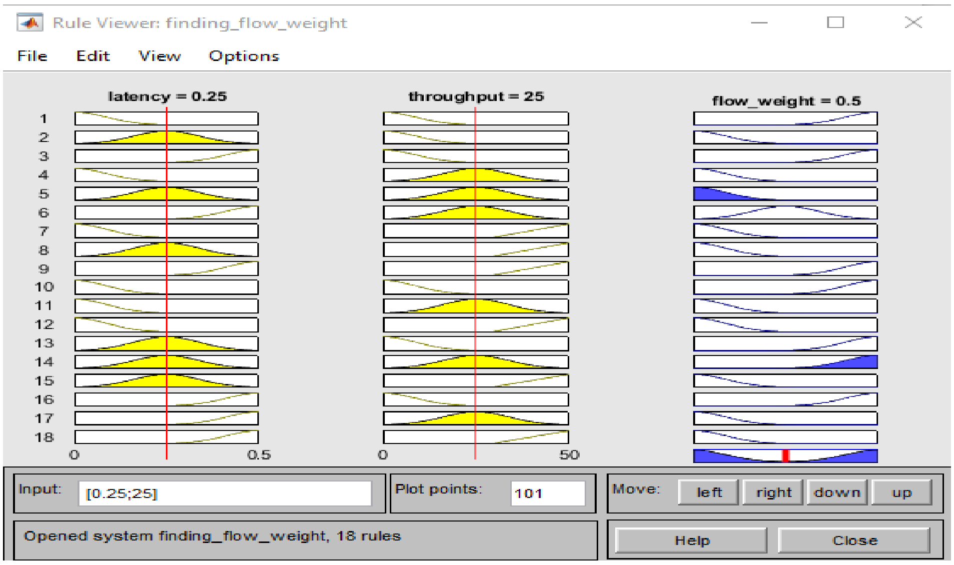
TABLE 1. FUZZY LOGIC RULES AND MEMBERSHIP FUNCTIONS

Rule No	If >> Latency is	And >> Throughput is	Then >>Flow Weight is
1	Low	Low	High
2	Average	Low	Low
3	High	Low	High
4	Low	Average	Low
5	Average	Average	Low
6	High	Average	Average
7	Low	High	Low
8	Average	High	Low
9	High	High	High
10	Low	Low	High
11	Low	Average	Low
12	Low	High	Low
13	Average	Low	High
14	Average	Average	High
15	Average	High	Low
16	High	Low	High
17	High	Average	Low
18	High	High	Low



FIS Name: finding_flow_weight
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: throughput
Type: input
Range: [0 50]
Updating Membership Function Editor

Fig. 1. *Fuzzy inputs, mamdani system and output*



Input: [0.25;25]

Plot points: 101

Opened system finding_flow_weight, 18 rules

Fig. 2. *Input and output aggregation*

Table 2 gives the simulation parameters. The proposed scheduler was simulated using C++ based LTE network simulator.

TABLE 1. SIMULATION PARAMETERS

Parameter	**Value**
Number of Users	100
Bandwidth	100 MHz
Number of RBs	50
Scheduling time (TTI)	1 ms
Number of subcarriers per RB	12
Subcarrier spacing	15 KHz
Slot duration	0.5 ms
Number of OFDM symbols per slot	7
Carrier frequency	2 GHz
Simulation duration	150 s
Flow duration	120 s
Frame structure	FDD
Radius	1 km
CQI range	1 – 15
Packet generation type	Exponential
Type of queue	FIFO
Maximum delay	0.1 s
Video bit rate	242 kbps
VoIP bit rate	8.4 kbps
CBR bit rate	20 kbps
Penetration loss	10 dB

IV. RESULTS AND DISCUSSION

Results of the simulated proposed scheduler is presented in this session in form of throughput, spectral efficiency, fairness index and PLR for video, VoIP and Constant Bit Rate traffic.

A. Average Throughput

The throughput of the proposed scheduler's video, VoIP and NRT flows is compared with some selected existing schedulers such as PF, EXP/PF and MLWDF, respectively.

a) *Video Flows:* Figure 3 gives the average throughput per UE for video flows. From Fig. 3, 21 % difference in throughput performance is noticeable between the proposed scheduler and Capozzi MLWDF. This difference is attributable to the incorporated weight parameter in that the video service possessing high bit rate, occupy a weightier flow in the network and hence larger video flow bandwidth, β justifying the considerable priority attracted in the scheduling decision.

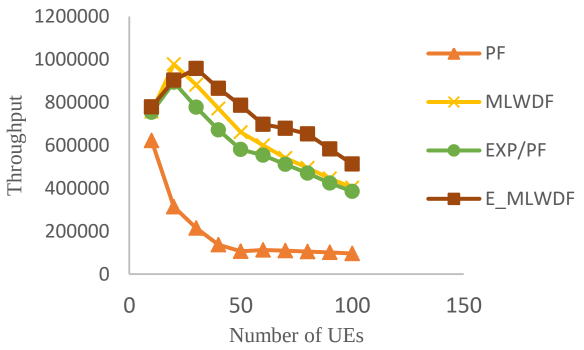


Fig. 3. *Average throughput for Video users*

b) *VoIP Flows:* Just as in the case of video flows, as users increased beyond 30, a consistent improved performance by the proposed scheduler is noticeable with PF showing slightly worst performance that is almost indistinguishable as given in Fig. 4.

c) *CBR Flows:* For non-real time flows as given in Fig. 5, very identical performance is observed. This is even more obvious with increasing UEs, however, the proposed scheduler maintained a slightly better performance at inception until the 50th user was added to the eNodeB where a slight decrease in throughput behind EXP/PF is noticed. Given the small bandwidth nature of CBR flows and its difference with video and VoIP flows, packet losses may have resulted in the overflow of buffer and hence the noticeable decrease in throughput around the 50th user.

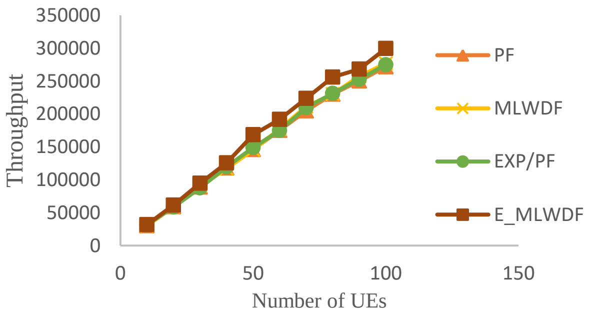


Fig. 4. *Average throughput for VoIP users*

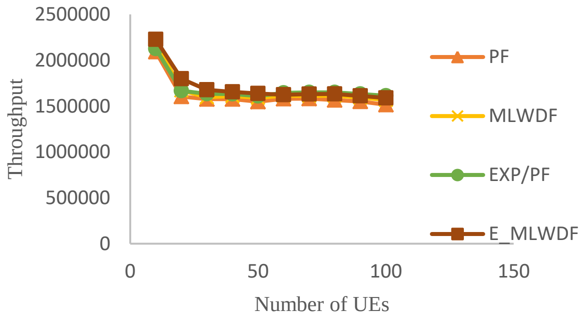


Fig. 5. *Average throughput for CBR traffic*

B. *Spectral Efficiency*

Spectral efficiency may vary from one simulation medium to another depending on the constituting elements of the simulator. However, irrespective of the simulation medium used, performance distinction is usually noticeable as demonstrated in Fig. 6. The proposed enhanced MLWDF scheduler shows superior performance with PF giving the worst performance.

Worthy of note is that the values displayed on the plot appears to be low in comparison to what is obtainable on other simulation platforms. This mainly has nothing to do the schedulers and everything to do with the configuration of the simulator employed in this research.

C. *Packet Loss Ratio (PLR)*

a) *Video Flow:* The PLR of video flows is illustrated in Fig. 7. Aside PF scheduler with a value of 0.2, every other scheduling scheme had an approximate value of 0.1 when there were only 10 video users at the eNodeB. Variation in values became apparent as the more user switched to video services at the eNodeB with a 53% difference between the amount of packet lost by the proposed scheduler in comparison to that of PF scheduler and a 36% difference when compared with MLWDF.

b) VoIP Flow: Fig. 8 gives a graphical illustration of the average packet loss ratio of VoIP users at the eNodeB. From the figure, similar performance is observed below the 50th user with far higher packets shown to be lost after the 60th user. However, the proposed scheduler is seen to retain more packets than the rest schedulers.

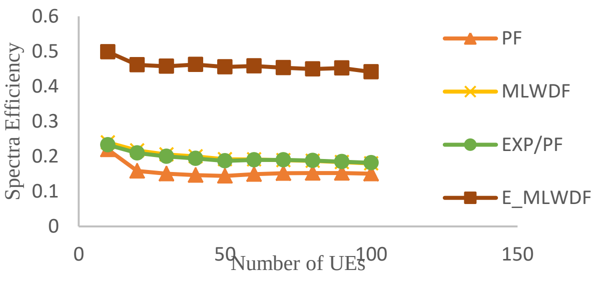


Fig. 6. *Spectra Efficiency Vs Number of Users*

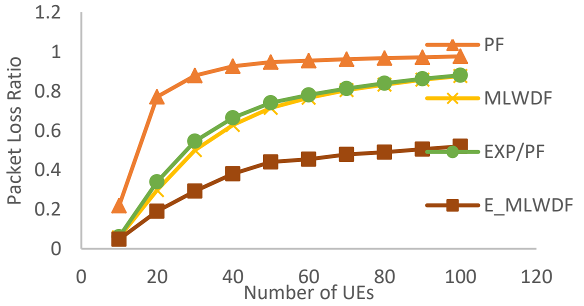


Fig. 7. *Average PLR for Video Flows*

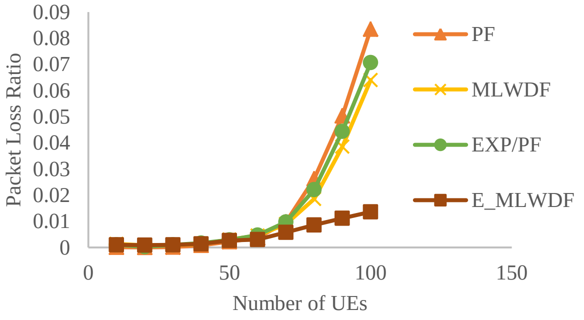


Fig. 8. *Average PLR for VoIP Flows*

c) *CBR Flows:* There is no significant distinction of PLR between the schedulers for VOIP flows as can be seen in Fig. 9. This is attributable to the ON/OFF model adopted by LTE-Sim which gave no room for transit packet; hence no packet arrives at the buffer when the state is set to OFF. Another interesting behaviour observed from the figure is the steady decline in packet loss ratio with increasing number of users for all schedulers albeit not at the same rate.

D. *Fairness Index*

a) *Video Flows:* Comparison of fairness index for 100 video users is presented in Fig. 10. MLWDF showed superior performance with less than 20 video users present at the eNodeB for scheduling. A very steep decline is however noticed after the 20th user for the rest of the schedulers considered aside the scheduler proposed which showed a far more consistent fairness till the 100th user has been served with an average fairness index value of 0.26. As usual, PF gave the worst fairness value at 0.08.

b) *VoIP Flow:* The fairness index for voice related services at the eNodeB for 100 users is illustrated in Fig. 11. There exists only a very minute difference in achieved fairness index values between the schedulers under review. The clearest distinction is at the 20th and 100 users respectively with MLWDF AND PF showing slightly smaller values.

c) *CBR Flow:* Fig. 12 shows the fairness index of constant bit rate flow for 100 users. The zigzag nature of the plot shown on the figure is attributable to the reason earlier highlighted under CBR flow for packet loss rate.

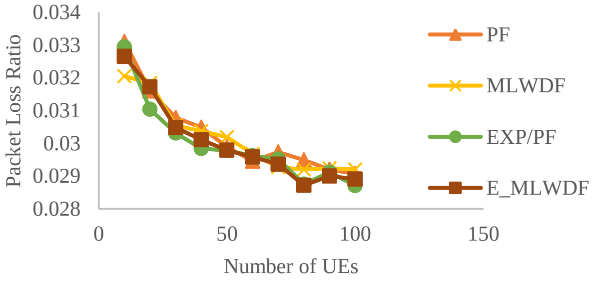


Fig. 9. *NRT Average PLR Vs Number of Users*

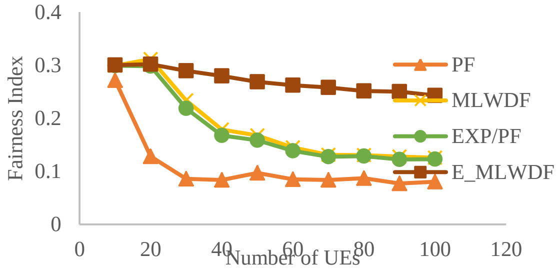


Fig. 10. *Fairness Index Vs Number of Video Users*

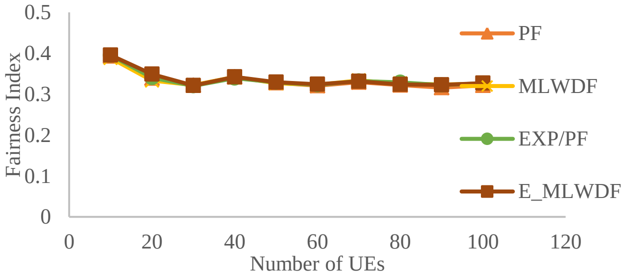


Fig. 11. *Fairness Index Vs Number of VoIP Users*

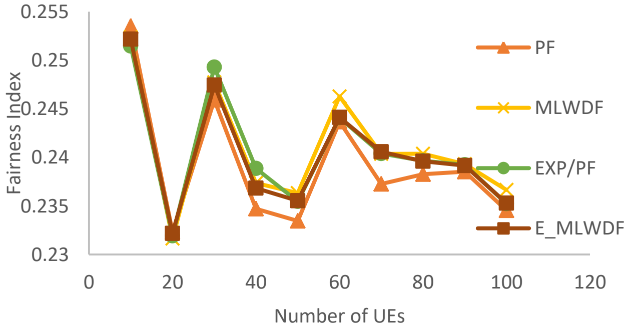


Fig. 12. *NRT Fairness Index Vs Number of Users*

V. CONCLUSION

In this paper, performance evaluation of flow bandwidth-based modified EXP MLWDF scheduling algorithm for LTE wireless systems in comparison with other existing downlink scheduling algorithms like PF, EXP/PF and MLWDF schedulers was presented. Wireless network performance indicator metrics like average throughput, fairness index, PLR and spectral efficiency was used for the proposed scheduler evaluation. From the results presented, the proposed scheduler showed far more consistent and better performance than all other scheduler compared especially for real time services. A 21 % difference in average throughput performance was noticeable between the proposed scheduler and the base MLWDF. The new scheduler was equally observed to drop less packets while maintaining high degree of fairness for video related services.

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