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A Composite Packet Scheduling Algorithm for LTE Downlink

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ABSTRACT

This paper proposes a new scheduling algorithm for Long Term Evolution (LTE) downlink systems called Composite Scheduler (CMP) for offering simultaneously Real Time (RT) and Non-Real Time (NRT) applications resources. CMP algorithm dynamically controls channel resources in a manner which reduces packet drop in an overloaded system while still guaranteeing delay bounds and high throughput of real-time services a problem inherent in the Earliest Deadline First (EDF) scheduler.TheCMP is obtained by modifying the EDF scheduling algorithm using natural logarithm, number of RT users and LTE Quality of Service (QoS) Class Identity (QCI) priority index which reduces the domino effect experienced by the scheduler during overload. Simulation was done using LTE-Sim with varying number of users ranging from 5 – 60 in a cell radius of 2km and each user receiving one video, one Voice over Internet Protocol (VoIP), one infinite buffer and one Internet Protocol (IP) Multimedia Subsystem (IMS) flow simultaneously. The proposed algorithm is evaluated against Proportional Fair (PF), EDF and Modified Largest Weighted Delay First (MLWDF) scheduling algorithms for real-time services. The result shows great increase in spectral efficiency by about 10%, 21% decrease in packet loss, an improved fairness of 12%, lowers delays by 75ms and 10 times increase in throughput for RT services when compared to normal EDF scheduler.

1.0 INTRODUCTION

In wireless communication systems, packet schedulers are employed to manage flow of traffic from user queues by assigning shared resource to users at a given time. Packet scheduler determines the order in which packets are executed. The process of assigning users' packets to appropriate shared resource to achieve some performance guarantee is called packet scheduling(Furht & Ahson, 2011). Several packet scheduling algorithms have been employed in cellular networks to handle resource allocation. Advancement in technology has seen numerous schedulers been developed for wireless cellular networks. Schedulers maybe grouped into best-effort or Quality of Service (QoS) schedulers(Furht & Ahson, 2011). In best effort schedulers, the QoS requirement of a user (e.g. delay) is not considered whereas such requirements are considered and are of utmost importance for QoS schedulers. The goal of a good resource scheduler is to achieve the required QoS and provide an optimal balance of spectral efficiency and fairness of the system (Furht & Ahson, 2011).

Long Term Evolution (LTE) is considered the successor to Universal Mobile Telecommunication System (UMTS) for wireless mobile communicationaccording to Third Generation Partnership Project (3GPP) in its Release 8 and later Release 9(Iwamura, Umesh, & Hapsari, 2009). It aims at tackling a number of problems including: increased number of data consumption, higher data rates demanded by Real Time (RT) applications, improved mobility, high delay experience etc. (Iwamura et al., 2009). LTE implements an all Internet Protocol(IP) flat network architecture which is an improvement to UMTS core network with optimization in packet switching traffic, mobility and QoS(Kurose & Ross, 2008). LTE utilizes Orthogonal Frequency Division Multiple Access (OFDMA) for its downlink communication and employs several technologies to achieve its goal: Resource allocation, Channel Quality Indicator (CQI), Adaptive Modulation and Coding (AMC), Multiple Input Multiple Output (MIMO), Hybrid Automatic Repeat Request (HARQ)(Kawamura, Kishiyama, Kakishima, & Yasukawa, 2012).Resource allocation through packet scheduling plays a key role in enabling QoS guarantees.

In this paper a new packet scheduling algorithm called Composite Scheduler (CMP) is proposed for both RT and Non-RT (NRT) applications in a mixed traffic scenario.

The remaining part of thepaper is organized as follows. Section 2 provides a background of packet scheduling and similar literatures studied. The proposed CMP scheduling algorithm for downlink LTE is presented in Section 3. Section 4 discusses the simulated parameters used in the study and section 5 discusses the simulation scenario. Results of the study is discussed in section 6 and conclusion is made in section 7.

2.0 BACKGROUND

Packet schedulers are employed in cellular networks to prioritize/sort user packets. There are two main types of packet schedulers: Uplink packet schedulers which are employed when User Equipment (UE) sends data to eNodeB (eNB) and Downlink packet schedulers which are employed when the eNB sends data to the UE. Packet scheduling in LTE involves two key aspects: first the ordering/prioritization of packets which is done in the form of assigning users' metrics based on their importance and secondly the allocation of RBs to users for transmission. Fig. 1 illustrates the procedure followed when carrying out resource allocation by the eNB.

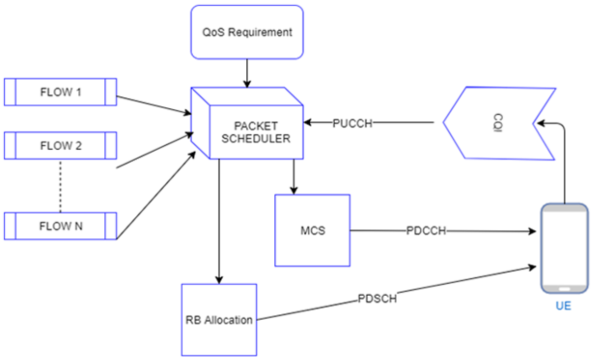

Fig. 1. Packet Scheduler Model

The UE to be scheduled and its corresponding number of RBs is selected by the packet scheduler based on channel condition and QoS requirements. The information of channel quality of each UE is available to the packet scheduler through CQI which is available to the eNB via reports of UEs through Physical Uplink Control Channel (PUCCH). This value is then used to choose the appropriate Modulation and Coding Scheme (MCS) for the UE. The eNB informs the UE on the selected MCS and allocated number of RBs through the Physical Downlink Control Channel (PDCCH) and data is transferred from the eNB through the Physical Downlink Shared Channel (PDSCH). This process is repeated for every TTI (Radhakrishnan, Neduncheliyan, & Thyagharajan, 2016).

The downlink communication between eNB and UE is carried out in a channel which employs OFDMA. OFDMA is one of the multiple access schemes derived from Orthogonal Division Frequency Multiplexing (OFDM) which is a multi-carrier modulation scheme (Srikanth S, Kumaran V, & Manikandan C, 2006). In OFDMA, the shared spectrum is divided both in time and frequency domain (OFDM symbols and sub-carriers respectively) and assigned to multiple users (Srikanth S et al., 2006). Fig. 2a shows the LTE Frequency Division Duplex (FDD) (Type 1) frame structure and Fig. 2b illustrates how a frame is divided in time and frequency domain.

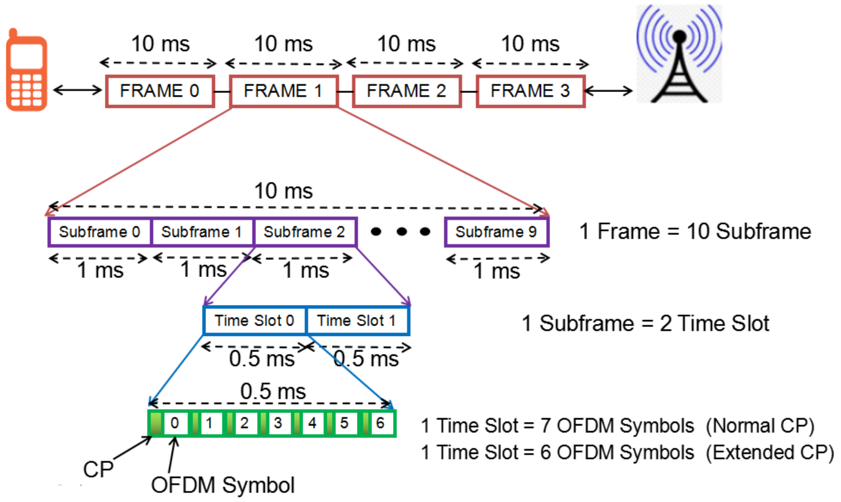

Fig. 2a. LTE FDD Frame Structure(Techplayon, 2017)

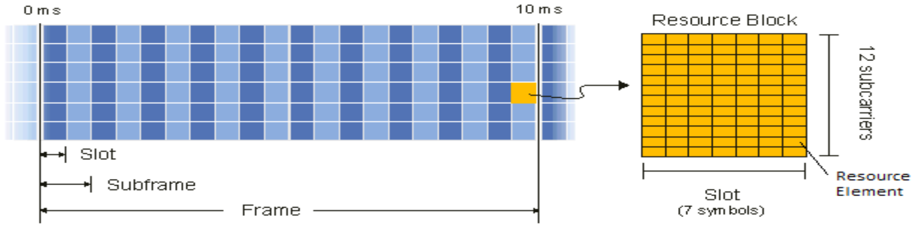

Fig. 2b. LTE Frame Resource Component(Techplayon, 2017)

At the time domain, the available spectrum is divided into frames. Each frame consist of 10 sub-frames or Transmission Time Interval (TTI) of 1ms each and each sub-frames consist of 2 time slots (Afroz, Heidery, Shehab, Sandrasegaran, & Shompa, 2015). Each time slot consists of 7 OFDM symbols (Normal Cyclic Prefix) or 6 OFDM symbol (Extended Cyclic Prefix). The available spectrum bandwidth is divided into sub-channels of 180 kHz in the frequency domain. A sub-channel consists of 12 succeeding and equally spaced sub-carrier of 15 kHz. Users are allocated a portion of this time-frequency resource known as Resource Blocks (RB) for transmission. The RB is a time-frequency radio resource spanning a time slot (0.5ms) in time domain and a sub-channel (180 kHz) in the frequency domain. However, the smallest allocable resource for transmission is a pair of Physical Resource Blocks (PRB) since the TTI in LTE last for 1ms (2 time slots) (Iacobucci, 2013). Also, LTE supports several channel bandwidths for transmission (i.e. 1.4 MHz to 20 MHz) and this dictates the number of RBs available for allocation (i.e. 6 – 100) (Anritsu, 2015). The smallest unit however is called Resource Element (RE) and it is the building block of RB. It represents a single sub-carrier during an OFDM symbol interval.

Over the years, several packet scheduling algorithms have been proposed to handle the resource sharing/prioritization in mobile networks. In (Jalali, Padovani, & Pankaj, 2000) a Proportional Fair (PF) algorithm was proposed. It is a scheduling algorithm aiming to balance a user's throughput and fairness. Using CQI and AMC, the scheduler is able to obtain the users achievable/maximum throughput and average throughput over a period of time which is then used to calculate the users' metric. The user's metric is thus computed as shown in (1) (Jalali et al., 2000):

$$PF = \frac{ri(t)}{Ri(t)} \qquad 1$$

where $ri(t)$is the user's achievable throughput and $Ri(t)$= is the average throughput over a given period.

The PF scheduler though able to offer high level of fairness to all users, fails to meet the deadline requirement of RT users especially with increasing congestion (Afroz, Sandrasegaran, & Ghosal, 2014; Nwawelu et al., 2017). Another scheduler is the Earliest Deadline First (EDF) scheduler studied in(Stankovic, Spuri, Ramamritham, & Buttazzo, 1998). It is a pre-emptive, dynamic scheduler that seeks to reduce the delay experienced by the overall system. In this scheduler, each users' packet is queued based on their delay and users with higher delay constrained services are given higher priority. User's metrics are computed as presented in (2):

$$EDF = \frac{1}{D-HOL} \qquad 2$$

whereD is the delay target of user flow, and HOL is the packet Head of Line delay. A major drawback to this scheme is the huge packet dropped experienced during congestion which greatly affects the system performance. This effect known as the domino effect is studied in (Stankovic et al., 1998)

In (Saleh & Dong, 2010) the authors compared the traditional First Come First Serve (FCFS) scheduler with the EDF to evaluate their performance in terms of miss ratio, delay and average size of buffer. The supremacy of the EDF was ascertained under the studied conditions, however both schedulers are unsuitable for LTE due to lack of prioritization of RT flow (i.e. FCFS) and high packet drop as earlier mentioned (1) (i.e. EDF).The Modified Largest Weighted Delay First (MLWDF) scheduling algorithm proposed in(Andrews et al., 2001) was developed to handle and provide higher priority to RT applications in a view of providing QoS for these flows. It supports users of multiple services with different QoS requirements. To achieve this, it considers the users maximum and average throughput over a period like in PF together with the HOL of each packet, the maximum allowable time of a users' packet and the probability of QoS requirement violation. In this scheme a user metric is calculated in (3):

$$MLWDF = ai(t)\,wi(t)\,\frac{ri(t)}{Ri(t)} \qquad 3 \qquad (3)$$

where $ri(t)$ and $Ri(t)$ are the same as in PF algorithm. $wi(t)$represents the weight of the user which is equivalent to HOL packet in the user queue or length of user queue. $ai(t)$reflects the strictness of QoS guarantee.During system congestion, the algorithm prioritizes RT flow leading to better performance of such flows but degrading performance for NRT flows through a phenomenon known as "Starvation"(Nwawelu et al., 2017) which led to unfairness in the system. In (Xian, Tian, Xu, & Yang, 2011) the authors seek to improve the fairness problem of MLWDF. To achieve this, they provided a theoretical analysis of MLWDF fairness which showed that its fairness was affected by channel conditions, packet arrival process and the ratio of QoS requirement of users' queues. Based on their analysis an Enhanced MLWDF (EM-MLWDF) algorithm was proposed whose fairness was independent of this factors and thus improved the fairness of users but more complex.(Müller, Schwarz, & Rupp, 2013) investigated the ability to provide QoS guarantee for RT services based on the PF algorithm. In view of this, two scheduling procedures were proposed: a Two-Layer (TL) scheme in which all the RT services are first served before NRT services with both layers employing the PF algorithm for resource allocation. This scheme was able to handle a low loaded system but failed and led to starvation, low throughput and high delays in NRT services as the network grew. The second approach known as Delay-Fairing (DF) Approach employed adding an exponential factor to the PF algorithm based on the users' deadline for RT applications and an unchanged PF algorithm for NRT users which enabled the scheduler meet users' deadlines but again led to starvation in a highly loaded scenario. In (Dardouri & Bouallegue, 2014) a comparative analysis of PF, MLWF and Exponential/PF scheduling under low network load (5-20 users) was done. A mixed traffic scenario of BE, video and VoIP flow in a pedestrian and vehicular environment was used and metrics such as throughput, fairness index, delay, packet loss ratio (PLR) and spectral efficiency were considered. The MLWDF was seen to provide better performance in video flows while Exponential/PF and PF performed better in VoIP flows. It was also observed that by changing from a slower speed pedestrian environment to a higher speed vehicular environment users' performance drop as expected due to increase in multipath losses in the network. (Basukala, Ramli, & Sandrasegaran, 2009) carried out a performance analysis on EXP/PF and MLWDF algorithms in a multimedia environment with RT video streaming services and NRT web browsing services. Evaluation was done via throughput: average RT and NRT throughput, packet loss for RT services and fairness for NRT services. Result should that MLWDF performed better with fewer users (< 85) providing PLR of less than 1% and average RT throughput of 100kbps. Once users increased, MLWDF performance dropped as its means of prioritizing users via HOL alone was not sufficient and RT services deadline got missed. Conversely, EXP/PF performed better at higher users (>125 users) providing higher throughput and lower PLR at this range.

The different works been reviewed provided an understanding to the several possible parameters employed in scheduling (e.g. delay, HOL, users' average throughput over a period, channel conditions etc.). In addition, the review also highlighted their drawback e.g. EDF high packet loss during congestion, FCFS and PF lack of prioritization mechanism for RT flows and MLWDF starvation problem. In light of this a new algorithm is proposed to mitigate these weaknesses.

3.0 COMPOSITE SCHEDULER

The proposed algorithm employs a composition of deadlines, retention priority number from LTE QCI (Sheta, Zaki, & Keshk, 2013), and number of real-time users to compute the users' metric. During congestion, the earliest deadline first scheduling algorithmsis known to behave unpredictable leading to a high possibility of its packet been dropped as it is unable to meet all users' deadline. This phenomenon known as the domino effect (Stankovic et al., 1998) is caused when the system experiences transient overload leading to packet loss.To reduce this effect and thereby improve the performance of the EDF algorithm, the dependence on deadliness alone as means of prioritization need to be reduced.

To achieve this, the composite scheduler aka CMP employs a natural log on the EDF algorithm and also divides this by the logarithm to base 10 of the number of RT users as in (4) which reduces the metric dependence on user deadlines as the network grows.The choice of the log function is to allow for gradual and smooth degradation and increase of a user metric.

$$\frac{log_2(EDF)}{a} \qquad 4$$

where$a$ is a positive constant used in adjusting the strictness to QoS of the system. a is computed as in (5):

$$a = log_{10}(N_{RT}) \qquad 5$$

where N_{RT} is the number of RT users.Normally as users increases in EDF scheduler, more packets are lost due to the inability of the scheduler to meet their deadlines. By reducing theeffects of deadline-ness by means highlighted above fewer packets are lost and thus higher throughput is been achieved.

Also, as the number of users increases and the deadline of RT flow becomes less efficient due to the effect of (4), a Priority coefficient (P) is employed to increase the priority of these flows using LTE QCI priority index as shown in (6), thereby reducing packet loss both with small and large users.

$$P = a^{\left(\frac{1}{priority}\right)} \qquad 6$$

where$P$ is the Priority coefficient and$priority$ is the LTE QCI priority indexnumber. (4)

To achievethe metric of each user, (4) and (6) are combinedto compute (7):

$$CMP = \frac{log_2(EDF)}{a} \text{ x } a^{(\frac{1}{priority})} \text{ x } \frac{ri(t)}{Ri(t)} \qquad 7$$

where $ri(t)$and $Ri(t)$are as in PF algorithm and EDF is the Earliest Deadline First scheduling

(7)

algorithm.

4.0 SIMULATION PARAMETERS

The simulation parameters used are summarized in the Table 1.

Table 1: Simulation Parameters

Simulation Parameters	**Values**
Frame Structure	Frequency Division Duplex (FDD)
Cell Radius	2 km
Bandwidth	5 MHz
Maximum Delay	100 ms
Simulation Duration	120 sec
User speed	3 kmph
Number of Users	5 to 60
Traffic Types	Video: H264(242kbps), VoIP: G.729(8.4kbps), Infinite Buffer, IMS(8.4Kbps)

5.0 SIMULATION SCENARIO

To evaluate the proposed scheduling algorithm, we compare its performance with algorithms earlier mentioned (PF, EDF and MLWDF). The performance comparison is carried out via LTE-Sim (Piro, Grieco, Boggia, Capozzi, & Camarda, 2011) in a 5MHz single cell with interference scenario which provides a proper representation of the LTE model. The scenario is configured to compose of users ranging from 5 to 60 moving randomly in a random walk mobility model at a speed of 3 kmph and a cell radius of 2 km. Each user receives one VoIP, one Video, one Infinite Buffer and one IP Multimedia System (IMS) packet simultaneously. An IMS application is implemented by simply reusing the VoIP traffic model present in LTE-Sim. Performance metrics used are average throughput, Jain's Fairness Index (Huaizhou Shi, Prasad, Onur, & Niemegeers, 2014), delay and packet loss ratio (PLR). For delay comparisons the PF scheduler is omitted for visualization due to its extremely poor performance which hindered better evaluation of other algorithms.

6.0 SIMULATION RESULT AND DISCUSSION

The downlink throughput result is shown in Fig.3. Throughput which represents the number of successful packets transmitted shows the CMP to perform better than other schemes in all flow types. CMP better performance is as a result of its ability to meet deadlines quickly and reduce packet loss at the same time. MLWDF is next with its ability to prioritize RT while also reducing packet loss via balancing users queue using HOL. This technique is inferior to the CMP which is able to schedule packets faster via employing EDF while still reducing packet drop. EDF and PF both perform poorly. The EDF increasing packet loss due to its inability to handle channel variation especially during congestion leading to high packet loss and the PF lack of prioritization mechanism hinders their performances. Fig. 3a illustratesVoIP performance.CMP is shown to provide a considerable performance increase with a 20.7%, 35.23% and 8.07% at60 userswhen compared to the EDF, PF and MLWDF schedulers respectively. In Fig. 3b the video performance is shown withCMP providing higher performance with only MLWDF coming close when users are greater than 40. At 15 users, CMP performed better with 1761%, 38.36% and 351% against PF, MLWDF and EDF respectively. Table 2 shows the simulated result of video throughput. In Fig. 3c, IMS performance is shownwith CMP outperforming all schedulers especially above 25 users. A 46.73%, 17.25% and 31.39% improvement is observed at 60 users against PF, MLWDF and EDF schedulers respectively. Table 3 shows the throughput performance improvement of CMP to other schedulers as users increased from 15 to 60.

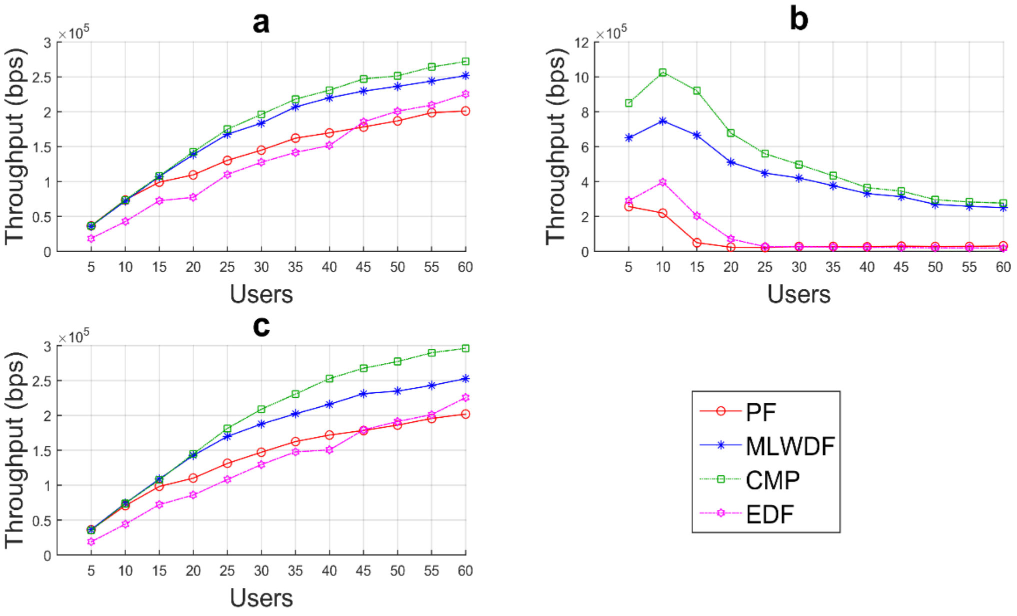

Fig.3.The Throughput of (a) VoIP (b) Video and (c) IMS

Table 2: Video Throughput Simulated Result

Users	PF	MLWDF	CMP	EDF
5	256,767.84	650,006.76	849,343.66	289,176.87
10	219,158.68	747,716.80	1,026,387.55	396,332.92
15	49,447.11	665,099.72	920,261.26	203,926.75
20	23,417.50	510,186.94	677,597.39	70,744.31
25	22,032.99	448,517.57	559,582.23	26,724.31
30	27,097.28	420,172.10	497,360.90	25,929.64
35	26,559.83	376,342.45	432,882.87	23,938.65
40	25,676.64	330,711.38	364,643.57	22,567.82
45	29,836.41	313,180.86	345,271.42	22,142.84
50	26,964.36	269,014.54	295,848.24	19,635.28
55	28,172.26	257,727.21	282,920.71	19,840.67
60	30,982.03	250,249.41	276,144.70	18,159.31

Table 3:Throughput performance comparison with respect to CMP for IMS, Video and VoIP.

		IMS			VIDEO			VoIP	
Users	PF	MLWDF	EDF	PF	MLWDF	EDF	PF	MLWDF	EDF
15	9.51%	-1.17%	49.11%	1761.10%	38.36%	351.27%	8.94%	0.65%	49.02%
20	31.59%	1.59%	68.70%	2793.55%	32.81%	857.81%	30.09%	2.90%	83.98%
25	38.19%	6.74%	67.82%	2439.75%	24.76%	1993.91%	34.14%	4.25%	58.77%
30	41.89%	11.30%	61.17%	1735.46%	18.37%	1818.12%	35.36%	6.84%	53.87%
35	41.92%	14.01%	56.14%	1529.84%	15.02%	1708.30%	34.49%	5.38%	53.83%
40	47.09%	17.06%	67.97%	1320.14%	10.26%	1515.77%	36.01%	4.94%	52.27%
45	50.02%	15.76%	49.27%	1057.22%	10.25%	1459.29%	38.64%	7.63%	33.24%
50	48.95%	18.03%	44.92%	997.18%	9.97%	1406.72%	34.47%	6.34%	25.15%
55	48.11%	19.27%	44.08%	904.25%	9.78%	1325.96%	33.02%	8.28%	26.04%
60	46.73%	17.25%	31.39%	791.31%	10.35%	1420.68%	35.23%	8.07%	20.70%

The PLR is shownin Fig 4 which is a ratio of packet loss to packet sent. CMP is again seen to be superior especially when compared to the EDF scheduler. The reason for its superiority is as discussed earlier. It should be noted that the PF lack of prioritization mechanism earlier mentioned results in RT packets not scheduled on time leading to high packet loss. In Fig. 4a for VoIP, evaluation showed a performance increase of 97.64% at 5 users and 22.11% at 60 users to EDF. Also, when compared to the PF and MLWDF a performance increase of 90.86% and 43.18% at 20 users and 28.59% and 10.49% at 60 users respectively is observed. In Fig 4b the PLR of video traffic is evaluated, the superiority is again shown by CMP providing 39.35%, 12.43% and 37.13% improvement at 15 users and 5.54%, 0.46% and 6.08% at 60 users to PF, MLWDF and EDF respectively. For IMS as in Fig. 4c, CMP provides the lowest loss especially when users are greater than 15 with a 91.65%, 71.50% and 94.10% performance gain at 25 users and a 39.52%, 23.85% and 33.62% at 60 users against PF, MLWDF and EDF .

respectively. Table 4 shows the PLR performance improvement of CMP to other schedulers as users increased from 10 to 60

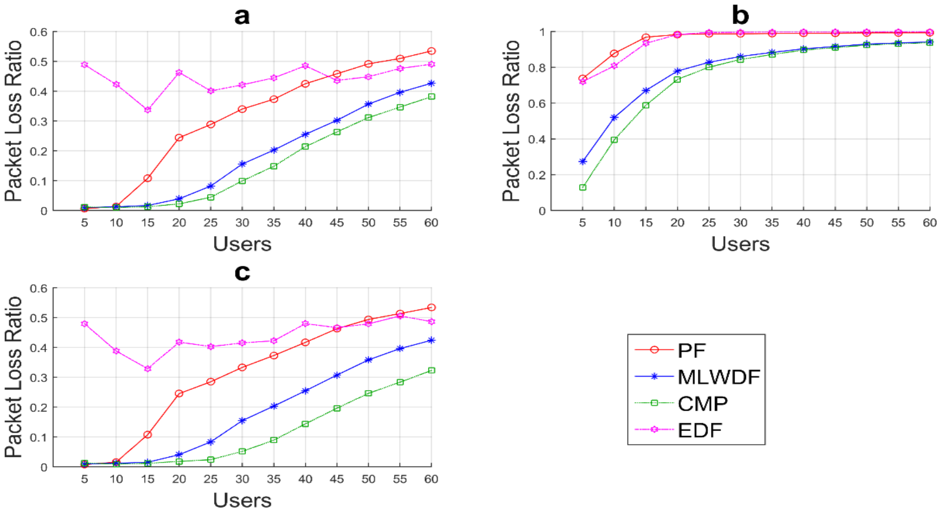

Fig.4.PLR of (a) VoIP (b) Video and (c) IMS

Table 4:PLR performance comparison with respect to CMP for IMS, Video and VoIP.

	IMS			VIDEO			VoIP		
Users	PF	MLWDF	EDF	PF	MLWDF	EDF	PF	MLWDF	EDF
10	43.66%	25.61%	97.73%	55.03%	23.94%	51.12%	22.94%	16.67%	97.53%
15	89.26%	24.01%	96.50%	39.35%	12.43%	37.13%	88.43%	25.89%	96.30%
20	92.69%	55.77%	95.71%	25.52%	6.02%	25.51%	90.86%	43.18%	95.17%
25	91.65%	71.50%	94.10%	18.84%	3.31%	19.51%	84.57%	45.73%	88.90%
30	84.56%	66.75%	87.61%	14.51%	1.97%	15.28%	70.79%	36.26%	76.41%
35	76.06%	56.12%	78.86%	11.84%	1.34%	12.54%	60.24%	26.76%	66.63%
40	65.50%	43.50%	70.02%	9.46%	0.75%	10.09%	49.61%	16.11%	55.87%
45	57.59%	36.16%	57.93%	8.12%	0.70%	8.78%	42.52%	12.86%	39.56%
50	50.14%	31.29%	48.61%	6.82%	0.57%	7.38%	36.62%	12.65%	30.52%
55	44.78%	28.43%	43.92%	6.14%	0.50%	6.67%	32.00%	12.53%	27.24%
60	39.52%	23.85%	33.62%	5.54%	0.46%	6.08%	28.59%	10.49%	22.11%

In Fig 5 the delay performance is shown. Performance shows the EDF to outperform all other schemes followed by CMP, MLWDF and PF. This performance was expected as the EDF schedules users based on their deadline alone thereby providing the lowest delay possible. CMP flows next as it also adopts the EDF though its deadline consideration is not as strict as that of the EDF. The MLWDF which balances users based on HOL performs better than the PF which has no deadline consideration at all leading to very high delays especially with increasing users. In Fig. 5aforVoIP flows, CMP performed better than PF and

MLWDF with a 64.97% and 76.20% at 20 users and 98.65% and 7.16% at 60 users respectively. Fig. 5b shows the delay in video flow. CMP provides lower delays as compared to MLWDF when users are less than 35 but slowly degrades above. Its inability to provide similar delay as in VoIP is due to the larger packet size of video flows which require more time for transmission. The delay for IMS flow is shown in Fig. 5c. CMP outperformed both PF and MLWDF with 91.11%, 82.52% at 15 users and 98.82%, 19.21% at 60 users respectively. Table 5 shows the Delay performance improvement of CMP to other schedulers as users increased from 5 to 60

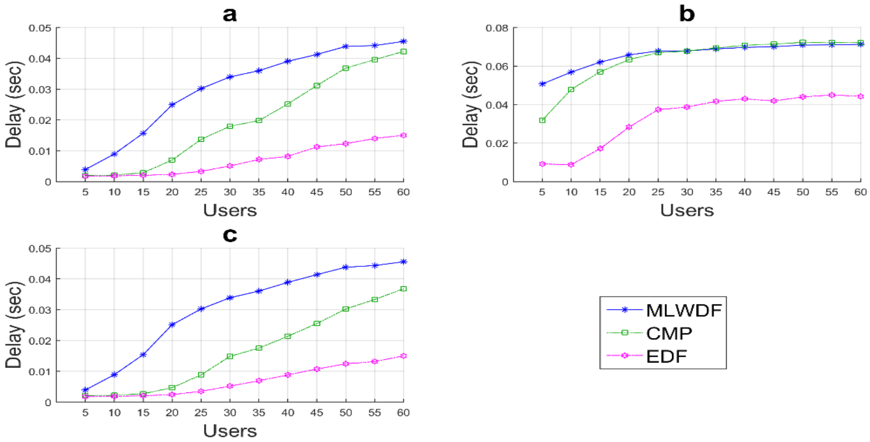

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Fig.5.Delay of (a) VoIP (b) Video and (c) IMS

Table 5:Delay performance comparison with respect to CMP for IMS, Video and VoIP.

	IMS Delay		Video Delay		VoIP Delay	
Users	PF	MLWDF	PF	MLWDF	PF	MLWDF
5	51.82%	45.78%	95.13%	37.14%	53.81%	50.26%
10	66.20%	75.34%	98.83%	15.85%	64.97%	76.20%
15	91.11%	82.52%	99.59%	8.12%	90.68%	81.73%
20	98.15%	81.39%	99.74%	3.65%	96.79%	72.02%
25	98.19%	70.85%	99.76%	1.30%	97.31%	54.59%
30	98.18%	56.16%	99.77%	0.06%	98.07%	47.13%
35	98.54%	51.39%	99.78%	-0.73%	98.31%	45.02%
40	98.57%	45.02%	99.79%	-1.59%	98.33%	35.45%
45	98.67%	38.39%	99.80%	-1.96%	98.32%	24.44%
50	98.67%	30.96%	99.81%	-2.00%	98.41%	16.07%
55	98.81%	24.90%	99.81%	-1.77%	98.57%	10.35%
60	98.82%	19.21%	99.80%	-1.21%	98.65%	7.16%

Fig. 6 shows the fairness index from the results. Fairness determines whether users or applications are receiving a fair share of system resources(Jain, R. K., Chiu, D. M. W., & Hawe, 1984) and the amount of resource allocated to a user/flow-type defines its fairness in wireless networks(Huaizhou Shi et al., 2014). The result showed CMP to largely outperform other schemes especially as users increases with an exception to video as seen in Fig. 6b. The large packet size of video hinders CMP from scheduling it on time thereby reducing the number of users served. Nonetheless it still performs slightly better than other schemes. In Fig.6a for VoIP, CMP is seen to outperform other schemes in fairness when users are above 25 with a 28.12%, 5.04% and 21.44% increase against the PF, MLWDF and EDF respectively.In Fig.6c, the IMS fairness index is evaluated. It was observed that the CMP best improvement against the PF and EDF algorithm was at 35 users providing 37.52% and 63.33% gain respectively and at 50 users for MLWDF providing 12.74% gain. Table 6 shows the Fairness Index performance improvement of CMP to other schedulers as users increased from 10 to 60.

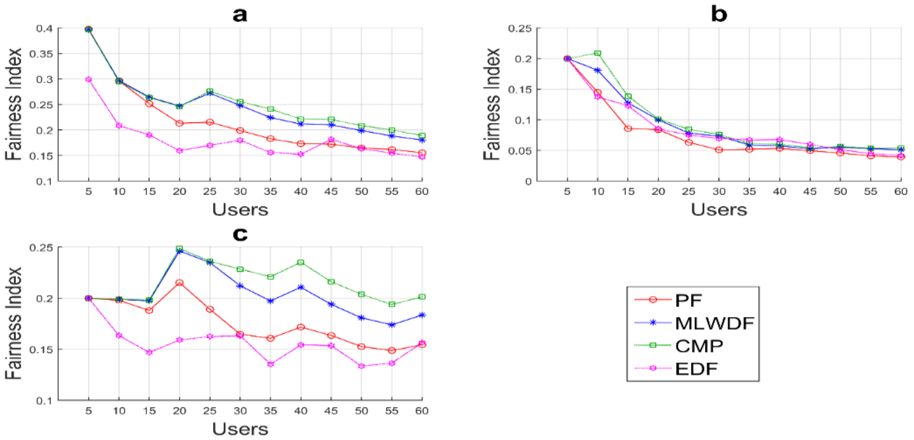

Fig.6. Fairness Index of (a) VoIP (b) Video and (c) IMS

Table 6:Fairness Index performance comparison with respect to CMP for IMS, Video and VoIP.

	IMS			Video			VoIP		
Users	PF	MLWDF	EDF	PF	MLWDF	EDF	PF	MLWDF	EDF
10	0.57%	0.03%	21.77%	44.32%	15.57%	51.94%	-0.51%	-0.66%	41.30%
15	5.39%	0.36%	34.92%	61.69%	8.52%	12.67%	4.70%	-0.46%	38.34%
20	15.60%	1.03%	56.39%	20.70%	1.25%	18.59%	15.45%	-0.35%	54.41%
25	24.85%	0.52%	45.36%	33.84%	8.09%	12.58%	28.28%	1.45%	62.33%
30	38.65%	7.67%	39.99%	49.41%	3.68%	9.38%	28.51%	3.10%	42.23%
35	37.52%	11.98%	63.33%	17.52%	3.92%	-9.15%	31.79%	7.35%	54.49%
40	36.98%	11.62%	52.52%	12.82%	4.38%	-11.24%	27.93%	4.65%	45.18%
45	32.22%	11.46%	40.76%	9.88%	3.84%	-9.16%	28.12%	5.04%	21.44%
50	33.52%	12.74%	52.68%	23.31%	2.26%	10.34%	26.64%	4.92%	27.66%
55	30.31%	11.42%	42.03%	29.90%	1.21%	19.41%	23.49%	6.15%	29.18%
60	30.36%	9.73%	28.76%	36.36%	5.27%	28.91%	21.77%	5.07%	28.48%

The spectral efficiency which measures how efficient the spectrum or bandwidth is utilized is shown in Fig.7. CMP can be seen to provide the highest spectral efficiency due to its reduction in packet loss and fast scheduling as earlier discussed. It is followed by MLWDF, EDF and lastly PF scheduler. The large packet loss associated with EDF (during congestion) and PF (due to its inability to handle RT flow) largely affects their spectrum utilization.Table 7 shows the spectral efficiency performance improvement of CMP to other schedulers as users increased from 5 to 60.

Table 7:Spectral Efficiency performance comparison with respect to CMP.

Users	PF	MLWDF	EDF
5	43.85%	6.96%	-9.23%
10	73.43%	7.85%	-3.50%
15	97.60%	7.32%	8.64%
20	86.04%	4.73%	6.94%
25	72.35%	2.52%	18.71%
30	62.21%	1.55%	23.09%
35	54.77%	0.89%	22.68%
40	49.71%	0.32%	18.47%
45	47.98%	1.14%	19.90%
50	45.38%	1.41%	15.78%
55	45.12%	2.29%	13.45%
60	48.96%	2.04%	9.86%

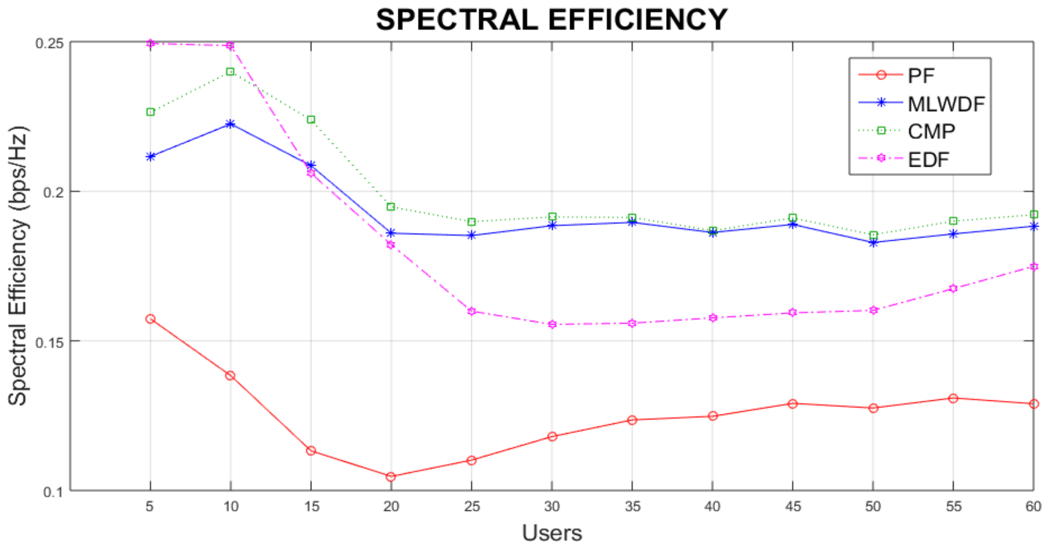

Fig.7. Spectral Efficiency

7.0 CONCLUSION

This paper has studied the scheduling of packets in LTE downlink systems. A novel scheduling algorithm named CMP have been introduced to improve overall cell throughput (spectral efficiency) of the system. The CMP scheduler is a modification of the EDF scheduling algorithm with the aim of reducing its high packet loss thereby improving performance. Simulated results show CMP to provide better throughput, PLR andfairness in all studied flow types. Also, it provides the highest cell spectral efficiency (approx. 0.24 at 10 users and 0.19 at 60 users) when compared to other schedulers. As far as delay and fairness index were concerned, the scheduler faired positively offering delay of approx. 0.07sec for video flows which had higher data packets and fairness indices of approx. 0.054 when the system was loaded with 60 users. The performance of CMP show it is more suitable for RT flows in a mixed traffic scenario compared to PF, MLWDF and EDF schedulers.Future work would consider more QoS metrics for LTE system and comparison with other schedulers such as Exponential Proportional Fair, Logarithm Rule, Earliest Based Deadline etc.

REFERENCES

Afroz, F., Barua, S., & Sandrasegaran, K. (2014). PERFORMANCE ANALYSIS OF FLS , EXP , LOG AND M-LWDF PACKET SCHEDULING ALGORITHMS IN DOWNLINK 3GPP LTE SYSTEM. *International Journal of Wireless & Mobile Networks (IJWMN)*, *6*(5), 77–91.

Afroz, F., Heidery, R., Shehab, M., Sandrasegaran, K., & Shompa, S. S. (2015). COMPARATIVE ANALYSIS OF DOWNLINK PACKET SCHEDULING ALGORITHMS IN 3GPP LTE NETWORKS. *International Journal of Wireless & Mobile Networks (IJWMN)*, *7*(3), 1–21.

Afroz, F., Sandrasegaran, K., & Ghosal, P. (2014). Performance Analysis of PF, M-LWDF and EXP/PF Packet Scheduling Algorithms in 3GPP LTE Downlink. *Australasian Telecommunication Networks and Applications Conference (ATNAC)*, 87–92.

Andrews, M., Kumaran, K., Ramanan, K., Stolyar, A., Whiting, P., & Vijayakumar, R. (2001). Providing quality of service over a shared wireless link. *IEEE Communications Magazine*, *39*(2), 150–153.

Anritsu. (2015). *LTE Resource Guide*.

Basukala, R., Ramli, H. A. M., & Sandrasegaran, K. (2009). Performance Analysis of EXP/PF and M-LWDF in Downlink 3GPP LTE System. *AH-ICI 2009*, 1–5.

Dardouri, S., & Bouallegue, R. (2014). *Comparative Study of Scheduling Algorithms for LTE Networks*. *8*(3), 467–472.

Furht, B., & Ahson, S. (2011). *HSDPA/HSUPA handbook*.

Huaizhou Shi, Prasad, R. V., Onur, E., & Niemegeers, I. G. M. M. (2014). Fairness in Wireless Networks:Issues, Measures and Challenges. *IEEE Communications Surveys & Tutorials*, *16*(1), 5–24.

Iacobucci, M. S. (2013). *Reconfigurable radio systems : network architectures and standards.*

Iwamura, M., Umesh, A., & Hapsari, W. A. (2009). Further Enhancements of LTE LTE Release 9. *NTT DOCOMO Technical Journal*, *2*(1).

Jain, R. K., Chiu, D. M. W., & Hawe, W. R. (1984). A quantitative measure of fairness and discrimination. *Eastern Research Laboratory, Digital Equipment Corporation*, pp. 2–7.

Jalali, A., Padovani, R., & Pankaj, R. (2000). Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system. *VTC2000-Spring. 2000 IEEE 51st Vehicular Technology Conference Proceedings (Cat. No.00CH37026), 3,* 1854–1858. IEEE.

Kawamura, T., Kishiyama, Y., Kakishima, Y., & Yasukawa, S. (2012). LTE-Advanced—Evolution of LTE—Radio Transmission Experiments. *NTT DOCOMO Technical Journal*, *14*(2).

Kurose, J. F., & Ross, K. W. (2008).

Computer networking : A Top-down Approach.

Müller, M. K., Schwarz, S., & Rupp, M. (2013). QoS Investigation of Proportional Fair Scheduling in LTE Networks. *IEEE*.

Nwawelu, U. ., Anil, C. ., & Ahaneku, M. . (2017). COMPARATIVE ANALYSIS OF THE PERFORMANCE OF RESOURCE ALLOCATION ALGORITHMS IN LONG TERM EVOLUTION NETWORKS. *Nigerian Journal of Technology (NIJOTECH)*, *36*(1), 163–171.

Piro, G., Grieco, L. A., Boggia, G., Capozzi, F., & Camarda, P. (2011). Simulating LTE Cellular Systems : an Open Source Framework. *IEEE Transactions on Vehicular Technology*, *60*(2), 498–513.

Radhakrishnan, S., Neduncheliyan, S., & Thyagharajan, K. K. (2016). A Review of Downlink Packet Scheduling Algorithms for Real Time Traffic in LTE-Advanced Networks. *Indian Journal of Science and Technology*, *9*(4).

Saleh, M., & Dong, L. (2010). Comparing FCFS & EDF scheduling algorithms for real-time packet switching networks. *2010 International Conference on Networking, Sensing and Control, ICNSC 2010*, 698–703.

Sheta, N., Zaki, F. W., & Keshk, S. (2013). Packet scheduling in LTE mobile network. *International Journal of Scientific & Engineering Research*, *4*(6).

Srikanth S, Kumaran V, & Manikandan C. (2006). Orthogonal Frequency Division Multiple Access : Is it the Multiple Access System of the Future? *AU-KBC Research Center, Anna University, India*.

Stankovic, J. A., Spuri, M., Ramamritham, K., & Buttazzo, G. C. (1998). *Deadline Scheduling for Real-Time Systems : EDF and Related Algorithms*. Springer US.

Sulthana, S. F., & Nakkeeran, R. (2014). Performance Evaluation of Downlink Packet Scheduling Algorithms in LTE. *Proceeding of International Conference on Advances in Communication Networks and Computing, CNC*, 38–44.

Techplayon. (2017). LTE Frame Structure. Retrieved September 12, 2018, from http://www.techplayon.com/wp-content/uploads/2018/04/LTE-Frame-1.png

Xian, Y. J., Tian, F. C., Xu, C. B., & Yang, Y. (2011). Analysis of M-LWDF fairness and an enhanced M-LWDF packet scheduling mechanism. *Journal of China Universities of Posts and Telecommunications*, *18*(4), 82–88.