QOS improvement for multi-media traffic, using EDF -PSO - Hybrid scheduler in Layer-2 Of 4G Wireless downlink

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ABSTRACT :

Abstract: Downlink schedulers in 4G networks need to allocate bandwidth for inputs of multiple classes of service and meet individual classes QoS requirements, which is a complex work. Conventional scheduling algorithms have limitations in providing best solutions in such vast set of solutions possible in such complex conditions in which high speed multi-media wireless networks operate. Proposed scheme namely, EDF-PSO Hybrid scheduler is a dynamic, channel aware and QoS aware, time-domain downlink scheduler, designed to work on IEEE 802.16e and 802.16m standards at MAC level. The proposed three stage EDF-PSO Hybrid scheduler consists of 1st stage of modified-EDF, 2nd stage of multi-objective PSO and final EDF rounds in that order. The performance metrics of Goodput, Packet delay and Packet Deadline Miss Ratio for real-time and non-real time connections are compared with existing best of class MAC downlink schedulers. The proposed EDF-PSO Hybrid scheduler out-performs the competing schedulers viz EDF, LWDF, FIFO and PSO comprehensively in the mentioned QoS performance metrics for both real and non-real time classes of service. It is able to maintain this best performance upto a traffic intensity of 0.9 and meet max packet deadline specifications excellently. This is simulated and tested for FDD mode of duplexing.
Key words: QoS,medium access,multimedia

INTRODUCTION

WiMAX 802.16m standard is a 4G Broadband Wireless Access Technology. WiMAX stands for Worldwide Interoperability for Microwave Access. WiMAX, which provides high speed data connections for users in last mile supporting various types of traffic, including gaming, voice, data, inter-active video, etc. [4], [6][7] and [17]. IEEE 802.16 standards allows scheduling schemes to be decided as per network operator's requirements.

MAC layer scheduling in 4G network is a NP Hard critical function that resolves contention for bandwidth and determines the transmission order of users. The function of the scheduler is critical for discrimination among classes as well as meeting the QoS requirements for each class and connection. The 802.16 standard has five Classes of Service to support and they are tabulated in Table I along with the applications and mandatory QoS parameters for the service.

TABLE I : CLASSES OF SERVICES AND QOS REQUIREMENTS FOR IEEE 802.16

Class of Service	Type of Applications Supported	Latency : maximum	Max Packet loss ratio
Unsolicited Grants Service (UGS)	Periodic, Real-time data streams. Typical : T1/E1, VoIP without silence suppression.	End-to-end latency = 200 ms max.[20]. Max Latency at Single-end Radio Interface is set as 80 ms, which is also set as deadline in the scheduler.	[23] < 3% . [20] < 1%
extended Real-Time Polling Service (ERTPS)	ERTPS meant for 'silence-suppressed' voice calls.	Deadline is same as UGS i.e. 80 ms.	[23] < 3% [20] < 1%
Real-Time Polling Service (RTPS)	Real-time streams of periodic ,variable-sized packets. Applications: MPEG video. Real time Video,	.[21]End-to-end 150 ms max Latency at Single-end Radio Interface is set as 60 ms, which is set as Deadline .	[23] < 1%
Non-Real-Time Polling Service (NRTPS)	Delay-tolerant data streams,variable-sized packets. Typical application: FTP.	[23] End to End delay 4 sec max & 2 sec pref. For one end, latency=1 sec max and 400 ms pref is set as deadlines.	
Best Effort (BE)	Data streams with no specific requirements. Typical application: HTTP	Same as NRTPS.	

OBJECTIVES OF MULTIMEDIA MAC SCHEDULING

The problem of medium access scheduling in WiMAX boils down to meeting multiple objectives which are related to each other in a complex way. The objectives are:

   i) Maximizing system throughput.
   ii) Ensuring that latencies are minimized.
   iii) Ensuring class-wise deadlines are met.

iv) Ensuring fairness among users of different Classes of Service (CoS) and Starvation is limited.

In heavily congested traffic, trade-off between these objectives is a solution. A better alternative is smart usage of resources and bandwidth. If a scheduler performs only 'channel aware' throughput maximization, it is likely that a user with a poor channel state has been disallowed the required bandwidth resources, causing starvation. In a similar way, in trying to ensure that QoS requirements are met, the scheduler may allocate many resources to the Subscriber Stations (SS) with low channel quality, ending up in a lower spectral efficiency. Similarly, a BE application may not be served for a long time because the higher classes of service are hogging the resources raising the question of fairness to the BE application user.

Single objective schedulers can easily result in either inefficient spectral or bandwidth efficiency, or low throughput or higher delays or starvation as the case maybe. These situations require that all objectives are considered in a comprehensive manner. This paper proposes a novel EDF-PSO three stage hybrid MAC scheduler algorithm that efficiently considers all these multiple objectives and conditions and produces very good results.

SCHEDULER SCHEMES AND OPTIMIZATION

Knapsack packing approach was adopted for a NP Complete scheduling problem in WiMAX by Arezou Mohammadi *et al.,* [1]. Each waiting packet is assigned a weight which is a product of the spectral efficiency of the SS's channel, Class of Service, CoS-wise traffic-mix ratio and 'deadline crossed' factor. The waiting packets are to be packed in to the knapsack which is the Wimax frame. Mass of the packet is the size of the packet in bytes. The optimization objective is to maximize the value of packets that are packed.

Particle Swarm Optimization is an optimization algorithm, belonging to the family of bio-inspired evolutionary algorithms. PSO algorithm has been able to overcome local minima in a much better way compared to other Generic Algorithms. The algorithm is inspired from the natural phenomenon of birds flocking using personal knowledge and the swarm's collective intelligence towards the best prey position. The particles fly in the solution space. Each particle or solution is altered iteratively. The particles move towards a promising area and will converge upon the optimum solution after a sufficient number of iterations.

The frequency domain resources of OFDMA, namely sub-carrier and power allocations have been covered by many research papers. Rajendrasingh *et al.,* (2012) [12] optimises sub-carrier and power to improve upon throughput and BER, using multi objective PSO where objectives were set as reaching best to Pareto-optimal and also provide diversity of solution space.

Yang Yi et al., (2011) [24] used GA and PSO algorithms to optimize OFDMA power and frequency in three different Scenarios i.e. (i) to maximize throughput in unicast scenario (ii) to maximize fairness in low rate multicast scenario and (iii) to maximize throughput rate for minimum capacity client in high rate multi-cast scenario.

Mustafa et al.,(2015) [16] has used a combination of Fuzzy rules to decide 'Channel rate – Modulation' combination and PSO for optimizing the power allocation to specific channel and sub-carriers to improve throughput in OFDMA system. This work is based on frequency & time domain.

Shubham *et al.,* (2016) [3] optimises work-floor job scheduling using work-span and resource utilisation using multi-objective PSO and achieved 10% average improvement in capacity utilisation compared to Genetic Algorithm.

Further [10], [13],[14], [15], [18], [19] can be referred for applications of PSO in other resource scheduling problems such as Cloud/Grid computing, timetable, Flow shop, Job-shop scheduling and in Power Systems . Asadollahi [5] has used a hybrid of Weighted Exponential Logarithm-Maximum Throughput algorithms in LTE downlink, but their method is restricted to homogeneous traffic wherein only one class of services is tested at a time.

A survey of various Wimax downlink schedulers have been compiled at [8] by Sherry et.al., (2016), where EDF, WFQ, WRR are studied and compared. It concludes that Earliest Deadline First EDF is a simple, efficient algorithm that meets deadlines in multi-media integrated packetized networks particularly for real-time classes. But the ability of EDF to handle high traffic and congestion is limited, resulting in degraded performance across the spectrum of classes of services in case of heavy traffic. LWDF is similar to WFQ and its performance is good in dynamically changing traffic scenarios. The performance of LWDF is moderated across all metrics such as throughput, fairness and delays. Both above algorithms' performance in terms of delay and deadlines gets affected considerably in higher traffic intensity.

Our objective in this paper is to develop and test a hybrid algorithm that effectively meets all the QoS requirements in a Channel- and QoS aware manner, for mixed heterogeneous traffic consisting of five classes of services including real-time services with stringent time-constraints and non-real time services.

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DESIGN OF THE EDF-PSO HYBRID SCHEDULER

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DESCRIPTION OF THE PROPOSED SCHEME

The PSO scheme is highly efficient in searching wide solution space to reach global minima and avoiding local minima. PSO algorithms are known for its throughput efficiency. But PSO are unable to prioritise real-time traffic effectively since PSO needs extensive set of rules and it gets complicated to handle a heterogeneous mix of real-time and non-real time services, as in the case of 4G and higher order network's scheduler.. So our proposal is to design a Hybrid EDF-PSO scheme by which the effectiveness of EDF in handling real-time deadlines is utilised along with efficiency of multi-objective-PSO in balancing various QoS requirements. We also incorporated other novel efficiency-improvement methods to ensure that the proposed three stage scheduler is very effective.

The proposed EDF-PSO Hybrid scheduler is a dynamic, channel aware and QoS aware, time-domain downlink scheduler, and it is designed for IEEE 802.16e and 802.16m standards that provide for FDD duplexing with fixed downlink bandwidth of 5 Mhz and frame duration of 5 ms. But it can be modified easily to work for other versions i.e. for other bandwidth or duration also. The proposed three-stage EDF-PSO Hybrid scheduler consists of modified-EDF, Multi-Objective PSO and EDF rounds; in that order.

First Stage of ' EDF1' is a 'channel and QoS aware, packet efficient' round, which basically schedules priority packets which can be any real-time class packet or certain 'prioritized' non-real-time packets. Prioritized NRT packets are those nearing deadlines or those with high-quality RF channel Index which are also scheduled in EDF1 round. Second round of PSO is 'Channel and QoS aware, Packet-efficient-Multi-objective' one. This PSO round effectively does bulk scheduling for 'non-prioritized' non-real-time packets. This PSO round also schedules over-flowing real-time traffic from EDF1 round. Third round is Packet efficient EDF2 round to fill-up gaps left over by PSO round. This hybrid scheme results in a highly efficient scheduler that performs better than other best-of-class schedulers, when we comprehensively consider all QoS metrics and parameters such as goodput, packet delay and Deadline compliance.

By 'Channel aware', we mean that opportunistic scheduling is allowed so that data volume allocated to channels is determined based on the Channel Quality Index or SNR. In all our simulations, the channel quality for individual users, are randomly initialized and distributed across users, similar to a practical scenario where users' distances are randomly distributed. During the simulation period, the channel quality is kept fixed, indicating low or nil mobility conditions. By 'QoS –Aware' we mean the scheduler is able to differentiate between the classes and schedule them to meet deadline requirements. By 'Packet-Efficient' schedulers we mean schedulers that avoid partial packetization i.e. inefficient overhead additions. In case partial packet size is less than 12 bytes, they are carried over to next frame, since the header itself occupies 6 bytes and results in a min of 50% loss of packet scheduling efficiency.

The below given Pseudo code explains the three stages and the flow of the entire EDF-PSO hybrid scheduler.

Over-All Pseudo Code for each frame of EDF-PSO-Hybrid Scheduler

i)   Load Traffic.
ii)   Find durEDF and maxdurEDFNRT
iii)   Check if the queue fits into frame 'dur'.
      If Yes then it is the case of 'No-Contention'
- Schedule the complete queue into the frame
- Exit scheduling for the frame.

iv)   Else..
- Perform EDF1 round of scheduling

v)   If frame duration is still not filled then
- Perform PSO round.
- Consolidate the 'dur' gaps left by PSO round
- Perform EDF2 round to fill the gaps

vi)   End scheduling

The 'durEDF' and 'maxdurEDFNRT' affects the performance of the proposed EDF-PSO Hybrid algorithm to a large extent. In above code, the 'durEDF' is the maximum reserved duration limit for 'all the priority packets including RT and NRT' and 'maxdurEDFNRT' is the max reserved duration limit for 'all NRT priority packets' only. Thus the maxdurEDFNRT will be a sub-set of durEDF. Both of these are pre-determined and reserved before entering EDF1 round, and used to terminate the EDF1 round if these duration limits are exceeded during scheduling. Based on many trial runs and simulations, two sets of best performing logic and formulae were used to determine maxdurEDFNRT as described below and they are used for HYB-1 and HYB-2 algorithms respectively.

Logic and formula to reserve bandwidth for priority connections in EDF-PSO-HYB-1 algorithm:

i) Initial maxdurEDFNRT = (fdur/2) x $\frac{\text{(estimated total size for only HOL NRT connections)}}{\text{(estimated total size for all RT \& HOL NRT connections.)}}$

Note: The above limit will always be less than half of frame duration i.e.2.5 ms.
Where estimated size for HOL NRT = number of NRT connections * 1000 bytes
Where estimated size for RT = number of RT connections * 40 bytes

ii) Sum of duration required for the all the packets of each RT connection is durEDF. Only those NRT packets having RF channel rate >32 Mbps (for 5 Mhz bandwidth) OR delay>66% of deadline are allowed in EDF1 and sum of duration required for these is 'durEDFNRT' .

iii) Finally limit the maxdurEDFNRT based on actual duration required for NRT packets in queue by means of the formula: maxdurEDFNRT = minimum between durEDFNRT & maxdurEDFNRT.

iv) DurEDF is then limited to a max of fdur.

Logic and formula to reserve bandwidth for priority connections in EDF-PSO-HYB-2 algorithm:

i) Initial maxdurEDFNRT = (fdur) x $\frac{\text{(estimated total size for only HOL NRT connections)}}{\text{(estimated total size for all RT \& HOL NRT connections.)}}$

Note: The above limit will always be less than frame duration i.e 5 ms.

ii) Sum of duration required for the all the packets of each RT connection is durEDF. Only those NRT packets having RF channel rate >32 Mbps(for 5 Mhz bandwidth) OR delay>33% of deadline are allowed in EDF1 round and sum of duration required for these is 'durEDFNRT'

iii) Finally limit the maxdurEDFNRT by means of the formula:
maxdurEDFNRT = (durEDF-Ratio)x(minimum between durEDFNRT & maxdurEDFNRT.)
Where "durEDF-Ratio" =1 if durEDF < or = fdur and
durEDF-Ratio =(fdur/durEDF) if durEDF>fdur..

iv) DurEDF is then limited to a max of fdur

Pseudo code for EDF1 round :

i) Allow 'First-In' packet whose deadline is nearest AND if it meets one of following criteria.
   a. Any UGS or ERTPS or RTPS packet (i.e. any Real-Time class pkt).   OR
   b. NRTPS or BE pkt (i.e. NRT pkt) meeting priority criteria for HYB-1 OR HYB-2 explained above.

ii) Check and allow the packet or part-packet only if it meets Goodput efficiency criteria.

iii) Schedule First-In packet that meets above checks (i) and (ii).

iv) For each pkt filled , check whether the following two duration limits have crossed:
   ➤ if Total duration filled<=durEDF
   and
   ➤ durEDFNRT < maxdurEDFNRT.

v) If the duration filled exceeds the limits as above, then shift back extra-bytes into the respective queue.

vi) End EDF1

The goodput efficiency criteria check as described below allows packets to be scheduled based on the size :

i) The duration limits allow full packet be scheduled. Or

ii) If it requires pkt to be broken, then the size of part-pkt allowed should be > 6 bytes on either side.

This criteria ensures that part-packets of less than 12 byte size, are carried over to the next frame to improve efficiency.

Pseudo code for PSO round : (Refer Para on 'Description of PSO round' for explanation).

i) Decide the Step size used to initialize 'particles' (i.e. solutions). The step size is the difference between allocation sizes between two particles for a given connection. This step size is equally spaced across the connection capacity, which is proportional to channel quality for the respective connection.

ii)   Generate Np particles spread uniformly in balance frame duration and perform following for each particle.

➤   Check fitness of particles. A Particle is considered 'fit' if it fills at least 95% of (fdur-EDF1).
➤   If it does not meet above fitness, then adjust particle size till it meets fitness criteria.

iii)   Start PSO Iterations i=1 to Ni

iv)   Process Each Particle j= 1 to Np

➤   Update Particle position based on the velocity update equation.
➤   Calculate P1,P2, P3 penalties and total penalty P for the current particle
➤   Check if P < pBest of that particle
   o   If so pBest of that particle = P
➤   Check of P < gBest
   o   If so gBest=P

v)   End PSO round.

vi)   Schedule packets based on schedule for gBest decided in PSO round, subject to Goodput efficiency check.

The final round of EDF2 scheduling is a standard earliest deadline based scheduling to fill the duration unfilled by PSO round if any.

DESCRIPTION OF PSO ROUND

Each particle or solution generated in the PSO round is an Nc - element vector where Nc is the number of TCP connections served. Each connection is one of the five classes of service. Np is the number of particles which is set as 60.

In our modified PSO algorithm, particle-initialisation process also spreads the solutions equidistant across the solution space. Fitness criteria is enforced to ensure solutions selected in PSO round fill min of 95% and max of 100% of (fdur-durEDF) i.e. left out frame duration. This is met in all cases, since only when there is contention, it enters the EDF and PSO rounds. Xiaohui Hu *et al.,* (2002) [18] introduced fitness constraint for particles before selecting the initialised particles. If the particle fails the constraint check, then they are resized in a positive or negative way until it meets the criteria.

The Velocity update equation of PSO is computed by (1)

$$v_i \leftarrow C2 * Iterf * r_p * (p_i - x_i) + C3 * Iterf * r_g * (g - x_i) \qquad (1)$$

Iterf is iteration factor that is set as 1 until iterations reach half-way mark i. e. Ni/2, beyond which Iterf will be equal to $2*(Ni-I)/Ni$. This effectively scales the velocity updates gradually when it nears the end of iterations, and thus avoids highly random variation when PSO solution search reaches the end. 'r_p' and 'r_g' are random fractional values in range 0 to 1.

Penalty Calculation in PSO round:

In the PSO round, the best fitting particle or solutions is evaluated based on the objective function value, which is the total weighted penalty P calculated as per equation below

$$Total\ P = cp1 \times P1 + cp2 \times P2 + cp3 \times P3 \qquad (2)$$

cp1, cp2 and cp3 are weighing coefficients to the sub-penalties and these are set as 1, 2 and 1 respectively.

The sub-penalty' P1 depends on 'Channel awareness' and 'queue-vs- allocation mismatch' factors and effectively P1 ensures the opportunistic scheduling is done by means of utilising connections with good RF channels to the maximum extent. P1 is calculated by eqn 3.a.

$$P1 = (pavgchdur - avgchdur)/avgchdur \qquad (3.a)$$

where

$$pavgchdur = \sum \ (\text{bytes allocation for i}^{th} \text{ connection in the particle / Channel rate for that particle}) \qquad (3.b)$$
(Sum of all bytes allocated in that particle).

$$avgchdur = \sum \ (\text{queue size in bytes for i}^{th} \text{ connection / Channel rate for that particle}) \qquad (3.c)$$
(Sum of all bytes in the queue).

Here 'avgchdur' represents mismatch between queue lengths and the respective Channel quality. 'pavgchdur' represents the mismatch between particle's allocation and the respective channel quality. So effectively, P1 penalty goes high in case of mismatches of either of the above two pairs and it is more sensitive when queue- versus-channel quality match is good. In case a particle matches the queue exactly, P1 will be zero, irrespective of either's match with the channel.

P2 sub-penalty represents the mismatch between particle's allocation and queue size, averaged over all NRT connections. P2 is computed by Equation-4 and used only for non-real time services, since the PSO round is primarily used for non-real time services in the EDF-PSO Hybrid algorithm

$$P2 = \sum (qsize(k) - alloc.size(k)) / pkt\ size(k) \tag{4}$$

'k' is the connection number.

P3 penalty is measure of unfairness and accounts for starved packets. P3 reduces deadline miss and it is computed as follows:

$$P3 = (\text{Packets starved between 140 to 280 ms}) + 3 \times (\text{Packets Starved for} > 280\ \text{ms}) \tag{5}$$

The starvation thresholds are set as per preferred values for web browsing or http applications in a radio link for one end of the network as per standards [21],[23].

SIMULATION SPECIFICATIONS

TABLE-II : Table of Network specifications considered for simulation:

Parameter	Value
Number of frames simulated for each scheduler and each run.	1200
Available downlink RF Bandwidth	5 Mhz
Available duration per frame.	5 ms.
Duplexing	FDD
Number of traffic scenarios simulated in each scheduler	21
Traffic intensity (depends on scenario selected)	0.3 to 0.96
Total number of TCP connections	55 to 250
Traffic class ratio [UGS : ERTPS : RTPS : NRTPS : BE];	Varies to 21 possible combinations. Example [10 10 10 5 20] to [75 75 75 5 20]
Channel rate for each mobile user in 5Mhz bandwidth	Channel rate is fixed, by a Randomly distribution, and takes value between 4 Mbps to 36 Mbps. The distribution is kept fixed for a scenario.

The following are the parameters used in the PSO round:
Number of particles in swarm: Np= 60
Number of iterations: Ni= 120.
- Penalty coefficients cp1, cp2 & cp3= [1, 2 1].

Goodput is considered as an effective performance metric for end-users' experience, since goodput is the volume of payload data, rather than throughput, which is the gross data volume. Goodput for any 'i' th Class is computed as follows.

$$\text{Goodput (i)} = \text{Throughput (i)}\ \text{minus}\ \frac{6 \times 8 \times \text{Pkts scheduled(i)}}{(\text{Time of observation in sec})} \tag{6}$$

The delay undergone by each packet is checked before it is loaded into current frame's queue. Those packets which are delayed beyond the deadline of their respective class, are dropped. The packet drop feature is a standard measure to stabilize the queue in case of congested traffic.

RESULTS AND ANALYSIS

The following section presents the results by means of comparison of performance metrics for EDF-PSO Hybrids with other schedulers, namely modified-PSO, LWDF, EDF and FIFO. LWDF is chosen for comparison, since it is

similar to WFQ and is reported in literature [8] to perform in a balanced manner in multi-priority and diverse traffic conditions. FIFO has been chosen as it can be used as a benchmark for fairness for Non-real time services. EDF performs well in meeting throughput and deadlines in low and medium volumes of traffic . Our well-designed EDF-PSO Hybrid algorithm is able to out-perform all other schedulers as considered above . Our proposed algorithm's overall performance ranking across metrics is better than others, even when Traffic Intensity (T.I) is 0.85 and even in congested conditions where TI goes above 1.0 once every 3 frames on an average.

Comparison of Performance Metrics between the proposed EDF-PSO Hybrid and other schedulers namely - EDF, LWDF, FIFO and PSO, are provided in the following figures Fig 1.a to Fig 1.f and Fig 2.a to Fig 2.f. **:In all these simulations, the traffic is a heterogeneous mix of three classes of RT and two classes of NRT services as per 802.16 standards. They are presented for two cases as follows:**

Case- (1) : Fig 1.a to Fig 1.f . Deadline time is set as 1 second, for the NRT services. For HTTP and SMTP applications, the end to end max latency is 4 sec as mentioned in ITU standards [23]. The deadline has been scaled down to 1 sec, since our scheduler accounts for only single-end downlink-BS Radio interface. This is typically 25% latency of the max end-to-end delay of 4 sec as specified in standards.

Case-(2) Fig 2.a to Fig 2.f . NRT Deadline time is set as reduced time of 400 ms, scaled down from the preferred end-to-end deadline of 2 Sec [23]. This 400 ms deadline can be applied for stringent non-real-time applications. The results in the graphs are provided in ascending order of traffic and congestion faced for 21 different traffic scenarios.

Case-(1): COMPARISON OF PERFORMANCE FOR THE SCHEDULERS FOR NRT DEADLINE = 1 Sec (for HTTP/Email applications)
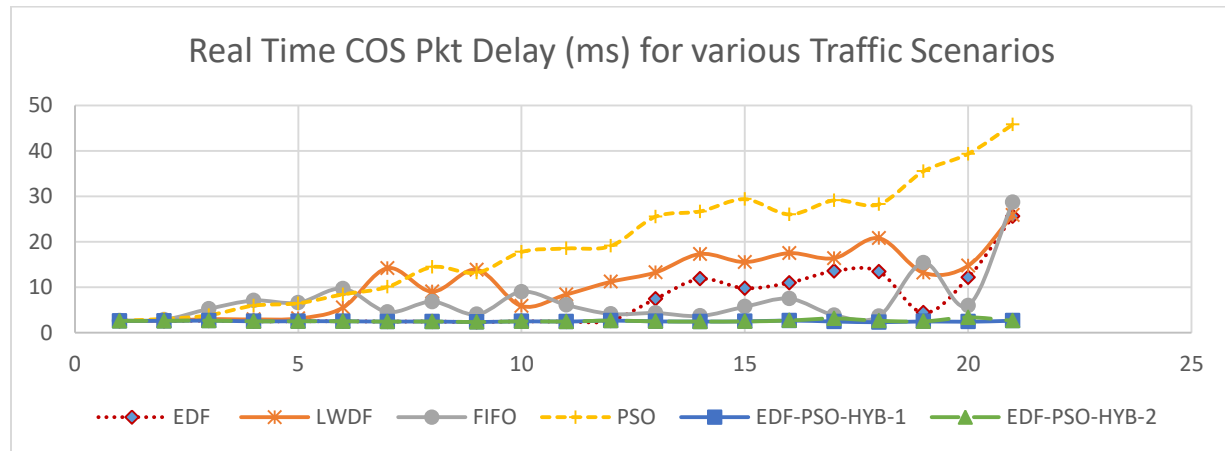

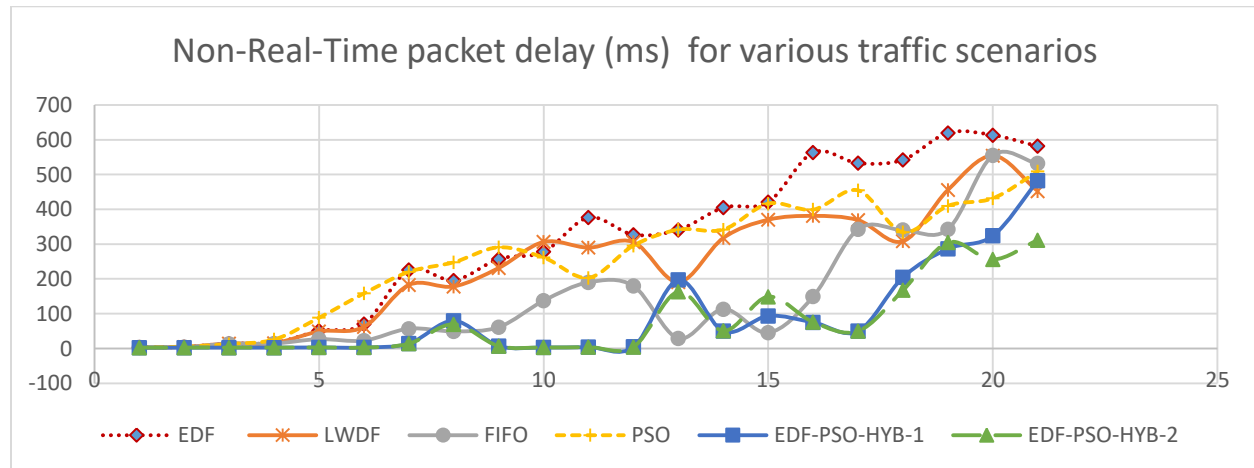**Fig-1.a.: Comparison of average Real Time Packet Delay.**

Fig-1.b.: Comparison of average Non-Real Time Packet Delay for HTTP and email applications..
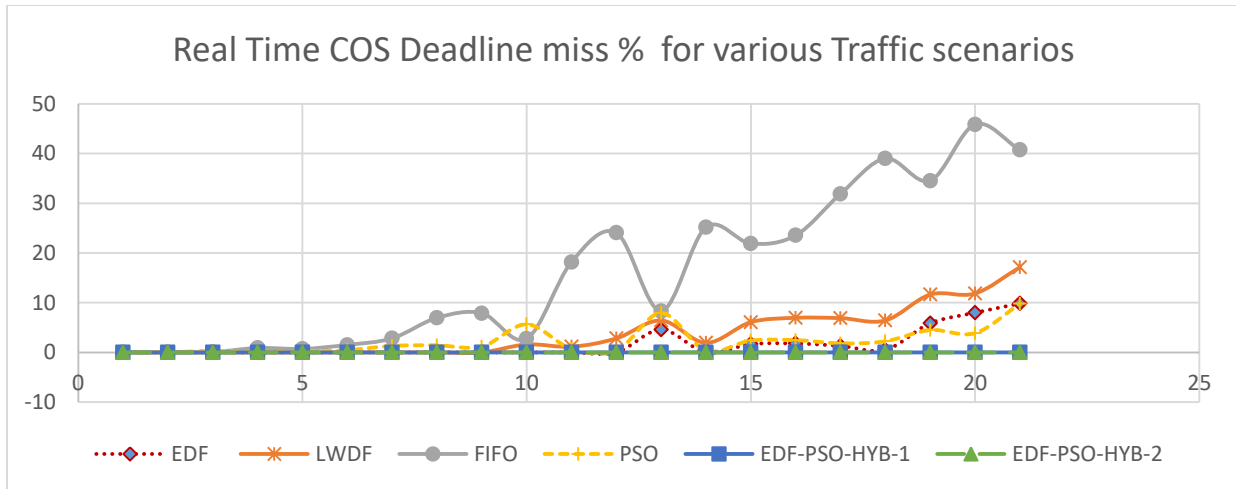
Fig-1.c: Comparison of missed deadline (in %) for Real Time Classes.
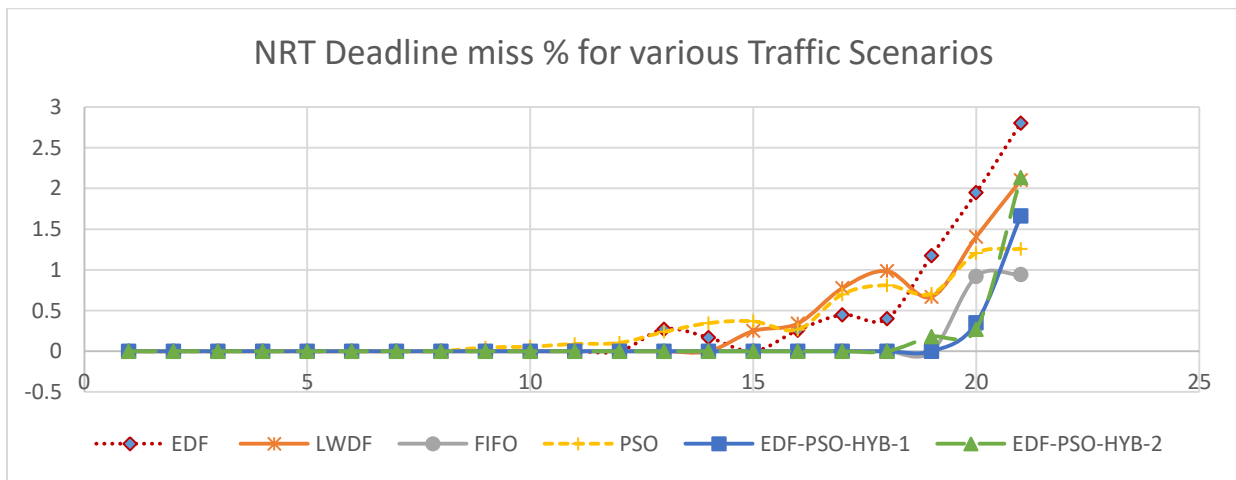

Fig-1.d: Comparison of missed deadline (in %) for Non-Real Time Classes in case of HTTP or email Apps.
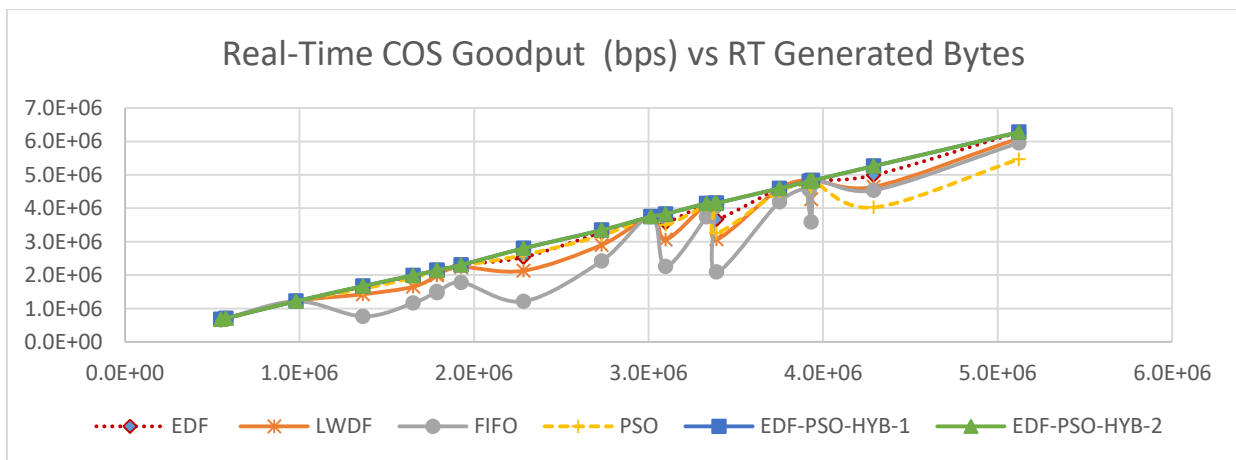

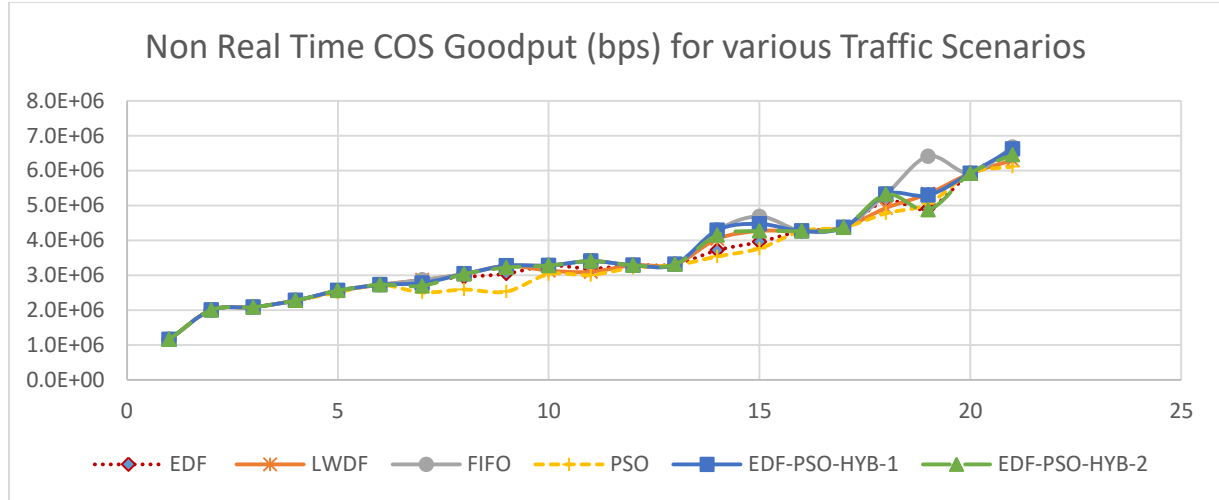**Fig-1.e: Comparison of Total Goodput for Real Time Classes.**

Fig-1.f: Comparison of Total Goodput for Non-Real Time Classes for HTTP and email applications..

By analysis of above results for Case-1, we get following Table=III, which shows the number of scenarios (out of max 21) in which given QoS metrics have gone poorer than mentioned reference levels for each scheduler.

TABLE III : Number of Scenarios where performance metric goes below reference thresholds given:Case-1

Metric and threshold	SCHEDULER					
	EDF	LWDF	FIFO	PSO	EDF-PSO HYB-1	EDF-PSO HYB-2
RT Goodput < best possible o/p	5	9	12	7	0	0
NRT Goodput < best possible o/p	6	7	2	9	3	5
RT PKT Delay > 5ms	8	16	12	14	0	0
NRT Pkt Delay > 200 ms	14	12	5	15	4	3
RT DL Miss > 1ms	7	12	16	12	0	0
NRT DL Miss > 1%	3	2	0	2	1	1

The Table IV provides the comparative performance ranks of schedulers, where deviation from the average is considered to evaluate performance for each metric. The rank for each metric is decided based on total deviation for all 21 scenarios.

TABLE IV: COMPARATIVE RANKING OF SCHEDULERS- METRIC WISE-for CASE-1.

Performance Metric	EDF	LWDF	FIFO	PSO	EDF-PSO HYB-1	EDF-PSO HYB-2
RT Goodput	2	4	5	3	1	1
NRT Goodput	5	4	1	6	2	3

RT PKT Delay	2	4	3	5	1	1
NRT Pkt Delay	5	4	3	5	2	1
RT DL Miss	2	3	5	4	1	1
NRT DL Miss	4	3	1	5	1	2
AVG Rank	**3.3**	**3.7**	**3.0**	**4.7**	**1.3**	**1.5**

Note: Where total deviation value is within 2% of each other, same rank is provided for both the schedulers.

Observation and inferences from the Results and Analysis. We find EDF-PSO HYB-1 scheduler gets the best average rank among all schedulers. It gets the top rank in 4 out of six metrics and rank 2 for remaining two metrics. While EDF-PSO HYB-2 gets the top rank for four metrics, Rank-2 and Rank-3 for one metric each. The ranking order as in Table-III can slightly vary compared to entry in Table IV , since Table –IV provides the comparative ranking, based on the total magnitude of deviation from best value, for the given metric across all 21 scenarios, while Table-III accounts for the number of Scenarios, the metric has crossed reference values.

The EDF-PSO Hybrids achieve extra-ordinary performances for all RT metrics since reserved bandwidth is provided for all real-time services. But for scenarios where the Real-time to Non-Real time connections ratio goes above 1.6 and the traffic intensity goes above 75% , the NRT performance metrics of the Hybrid gets affected.

We observe that FIFO gets good performance in all NRT metrics since it is able to drop a huge amount of RT packets as we can see from Fig 1.c that the RT Deadline miss percentage goes extra-ordinarily high. For the case of FIFO, RT DL miss (and thus PKT drop) crosses 20% for 9 out of 21 scenarios. This results in large amount of bandwidth getting freed for NRT and thus improvement of NRT metrics. The packet delays shown in Fig 1.a and 1.b are the average delay experienced by serviced packets of respective classes. Thus the delay experienced by unserved packets, which is mostly due to the DL miss and subsequent drop, are not counted in this delay graphs.

**CASE-(2): COMPARISON OF PERFORMANCE FOR ALL SCHEDULERS
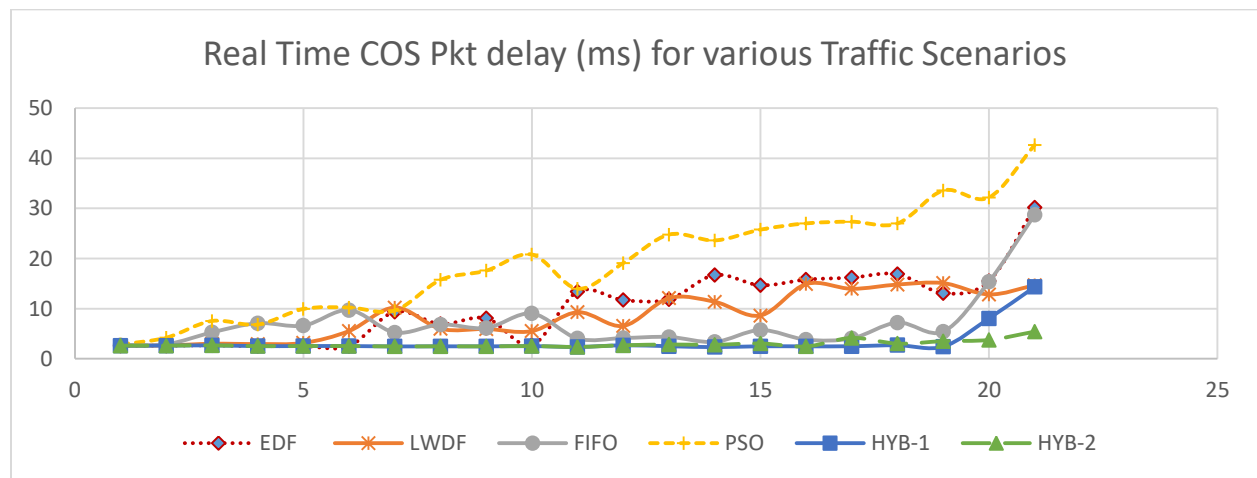FOR NRT DEADLINE = 400 Sec (for stringent delay constraints)**

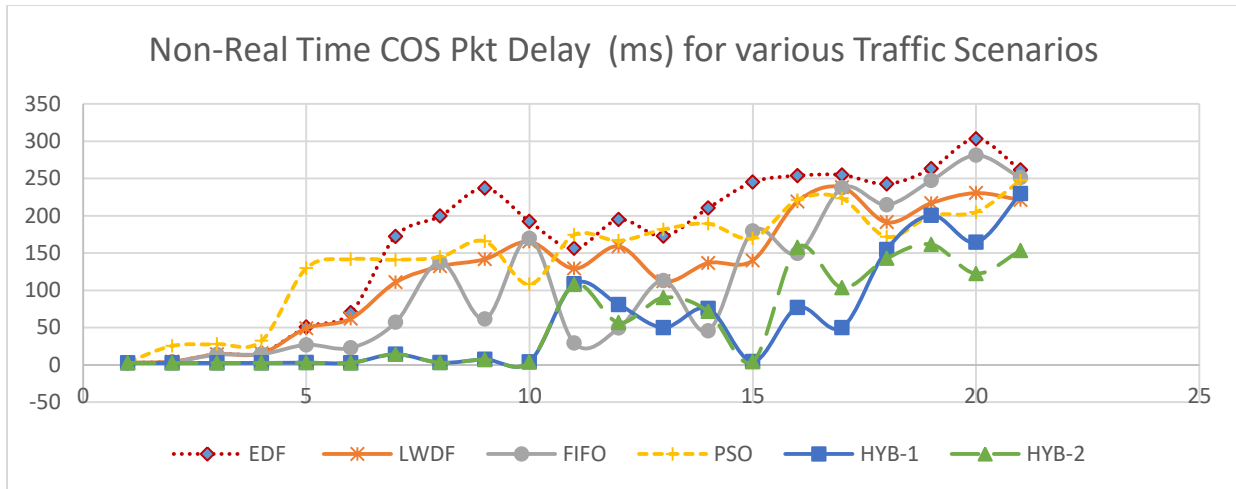**Fig-2.a.: Comparison of average Real Time Packet Delay.**

Fig-2.b.: Comparison of average Non-Real Time Packet Delay for time-constrained networks.
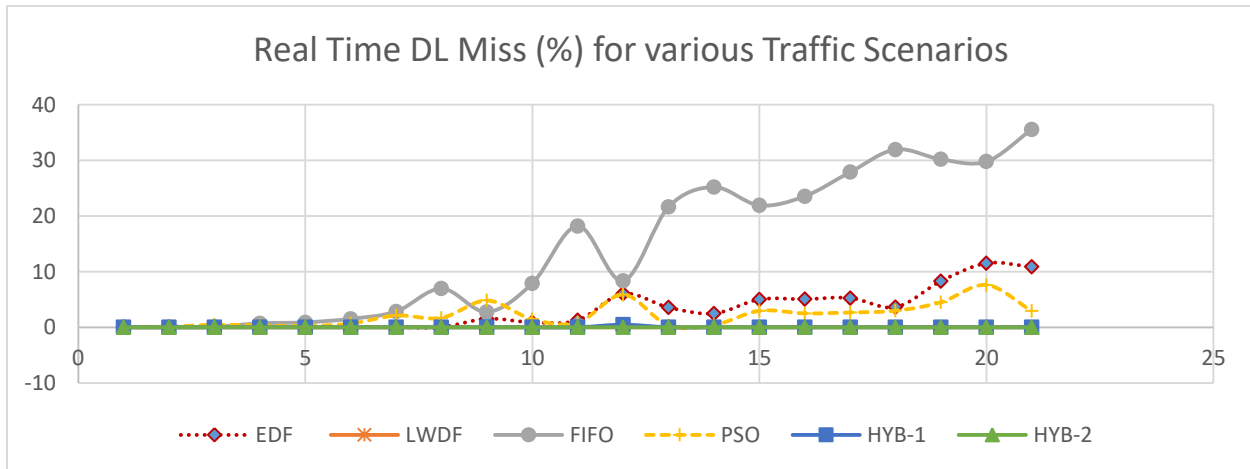

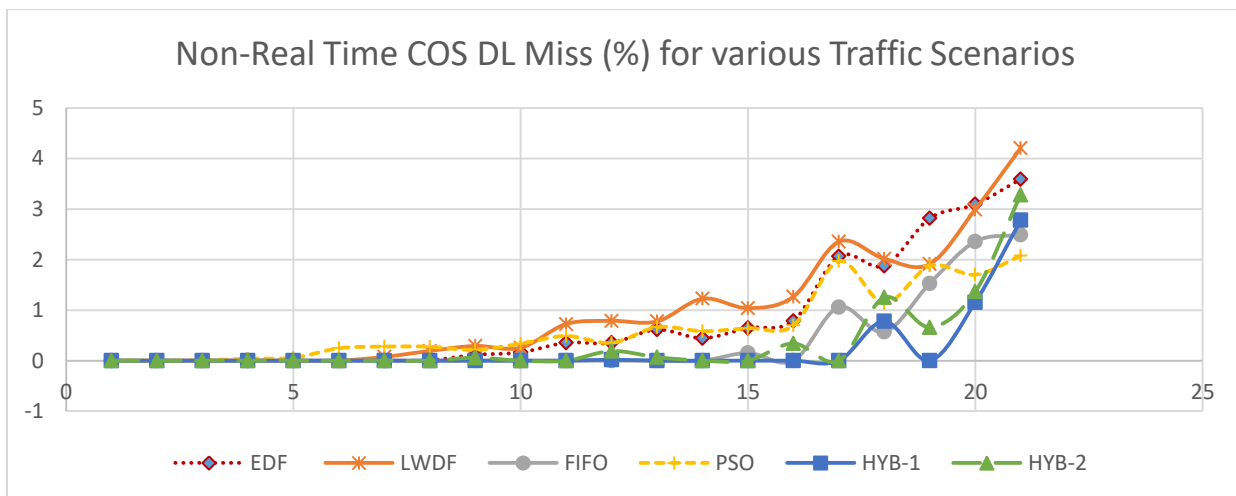**Fig-2.c: Comparison of missed deadline (in %) for Real Time Classes.**

Fig-2.d: Comparison of missed deadline (in %) for Non-Real Time Classes in Time constrained networks.
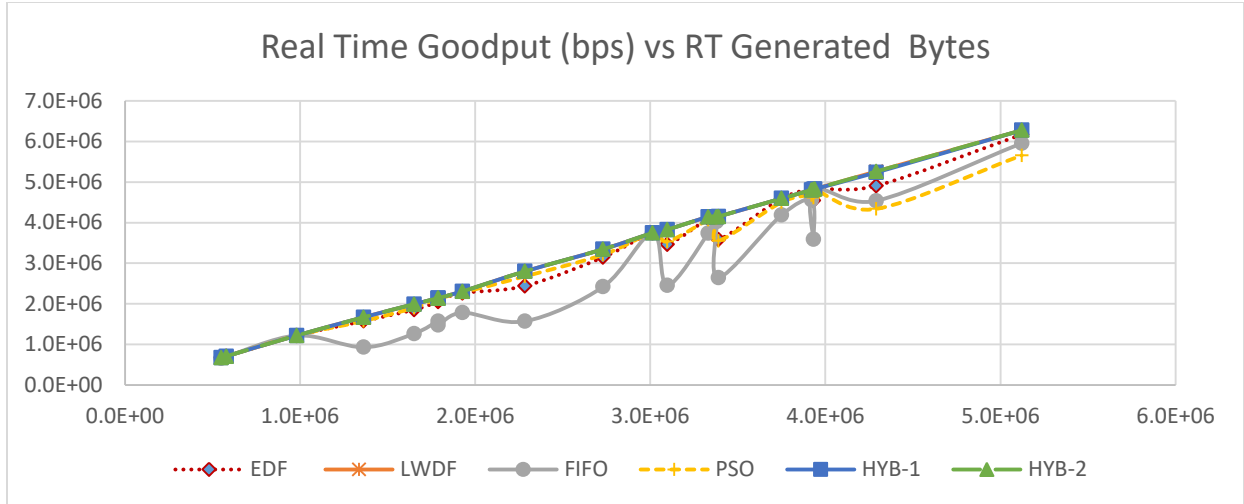
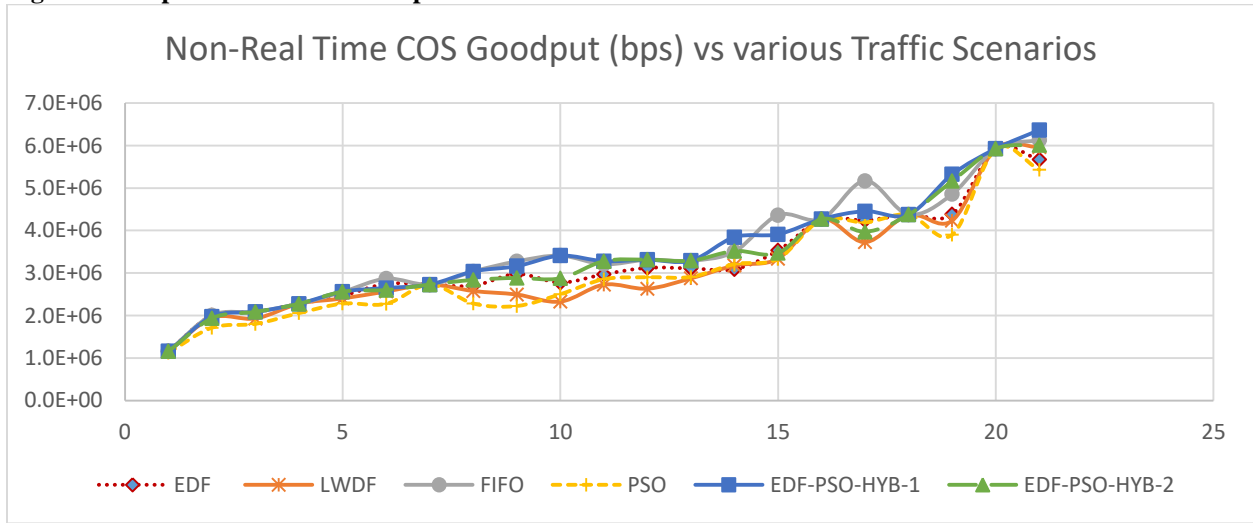**Fig-2.e: Comparison of Total Goodput for Real Time Classes .**

Fig-2.f: Comparison of Total Goodput for Non-Real Time Classes for time-constrained networks.

By analysis of above results for Case-2, we get following Table V, which shows the number of scenarios (out of max 21) in which QoS metrics have gone poorer than mentioned reference levels for each scheduler.

TABLE V : Number of Scenarios in which performance goes below reference thresholds.- Case-2.

PERF METRIC & THRESHOLD	EDF	LWDF	FIFO	PSO	EDF-PSO HYB-1	EDF-PSO HYB-2
RT Goodput < best possible	8	0	13	8	0	0
NRT Goodput < best possible	11	12	5	15	4	9
RT PKT Delay > 5 ms	14	16	13	19	2	1
NRT Pkt Delay > 100 ms	15	15	10	17	5	7

RT DL Miss > 1%	12	0	16	12	0	0
NRT DL Miss > 1%	5	8	4	5	2	3

We can see that even in highly time constrained NRT application or network conditions, the Hybrids are able to maintain the top rank as compared to other four schedulers.

TABLE VI: COMPARATIVE RANKING OF SCHEDULERS- METRIC WISE-for CASE-2.

PERF METRIC	EDF	LWDF	FIFO	PSO	EDF-PSO HYB-1	EDF-PSO HYB-2
RT Goodput	2	1	4	3	1	1
NRT Goodput	4	5	1	6	2	3
RT PKT Delay	5	4	3	6	2	1
NRT Pkt Delay	4	3	2	5	1	1
RT DL Miss	2	1	4	3	1	1
NRT DL Miss	4	5	2	6	1	3
AVG Rank	**3.5**	**3.2**	**2.7**	**4.8**	**1.3**	**1.7**

CONCLUSION:

As shown in the results, EDF's NRT performances are affected considerably in traffic intensity above 0.75. EDF's real-time performance is also not the best. LWDF is able to achieve top ranks in two RT metrics and moderate or poor NRT performance ranking in other metrics. FIFO is poor in all real-time metrics and get good rank in non-real-time metrics. PSO is below the average in all metrics. By means of a well-designed combination of EDF and PSO, we are able to out-perform EDF, PSO and even LWDF. The performance of WFQ schedulers will be similar to LWDF. The proposed EDF-PSO Hybrids are able to achieve the highest overall performance metric and top ranks among the compared best schedulers.

The proposed EDF-PSO Hybrid-1 is able to meet the stringent deadline-miss criteria of 1% for NRT services for traffic intensity up to 0.85. The Real Time services are anyway the best forming metrics for the proposed Hybrid.

The scope of application of EDF-PSO Hybrid scheduler goes beyond the 4G/WiMAX networks and can be extended to 5G or any packet switched scheduler for heterogeneous multimedia multi-priority diverse traffic conditions.

REFERENCES

[1]. Arezou Mohammadi, Selim G. Akl, Firouz Behnamfar (2008), "QoS-based Optimal Logarithmic-TimeUplink Scheduling Algorithmfor Packets," Proceedings of the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Cannes, France.

[2]. Chakchai So-In, Raj Jain, Abdel-Karim Tamimi, (2009), "Scheduling in IEEE 802.16e Mobile WiMAX Networks: Key Issues and a Survey", IEEE Journal on Selected Areas in Communication, vol. 27, issue 2.

[3]. Shubham, Rishabh Gupta, Vatsal Gajera, Prasanta K. Jana (2016) "An Effective Multi-Objective Workflow Scheduling in Cloud Computing: A PSO based Approach." Ninth International Conference on Contemporary Computing.

[4]. Davoud Sedighizadeh Ellips Masehian (2009), "Particle Swarm Optimization Methods, Taxonomy and Applications", International Journal of Computer Theory and Engineering, Vol. 1, No. 5, pp. 486-502.

[5]. Faezeh Asadollahi, Ramin Dehdasht-Heydari (2017) Introduction of a Novel Hybrid Weighted Exponential   Logarithm-Maximum Throughput (HWEL-MT) Scheduler for   QoS Improvement of LTE/4G Cellular Networks, Wireless Personal Communication, 2017.

[6]. IEEE 802.16m Evaluation Methodology Document (2008), IEEE 802.16 Broadband Wireless Access Working Group.

[7]. IEEE Std. 802.16 Document (2004), IEEE Standard for Local and Metropolitan Area Networks, Part 16: Air Interface for Fixed Broadband Wireless Access Systems.

[8]. Ashlin Sherry, Manikandan (2016) "Survey on MAC Scheduling Algorithms for WiMax(IEEE 802.16) Networks". IJARC. pp 100-103.

[9]. Jinchang Lu, Maode Ma (2011), "Cross-layer QoS support framework and holistic opportunistic scheduling for QoS in single carrier WiMAX system", Journal of Network and Computer Applications, vol. 34, pp. 765–773.

[10]. Kennedy J., Eberhart R. (1995), "Particle Swarm Optimization", IEEE International Conference on Neural Networks Proceedings, vol.4, pp. 1942- 1948, Perth, WA.

[11]. Pratik Dhrona (2007), "A Performance Study of Uplink Scheduling Algorithms in Point to Multipoint WiMAX Networks" Master of Science Thesis, Queen's University Kingston, Ontario, Canada.

[12]. Rajendrasingh Annauth and Harry Rughooputh C.S. (2012), "OFDM Systems Resource Allocation using Multi-Objective Particle Swarm Optimization", International Journal of Computer Networks & Communications (IJCNC), vol. 4.

[13]. Riccardo Poli (2008), "Analysis of the Publications on the Applications of Particle Swarm Optimization", Journal of Artificial Evolution and Applications, vol. 2008, article ID 685175.

[14]. Shu-Chuan Chu, Yi-Tin Chen and Jiun-Huei Ho (2006), "Timetable Scheduling Using Particle Swarm Optimization", IEEE International Conference on Innovative Computing, Information and Control, Beijing.

[15]. Suraj Pandey, Linlin Wu, Siddeswara Mayura Guru , Rajkumar Buyya (2010) , "A Particle Swarm Optimization-based Heuristic for Scheduling Workflow Applications in Cloud Computing Environments", 24th IEEE International Conference on Advanced Information Networking and Applications, Perth, Western Australia.

[16]. Farhana Mustafa, Padma Lohiya,(2015)"Optimum Resource Allocation in Orthogonal Frequency Division Multiplexing Communication System using Fuzzy Rule Base System and Particle Swarm Optimization and Comparison with Conventional other Techniques . I.J. Wireless and Microwave Technologies. Online at http://www.mecs-press.net/ijwmt

[17]. WiMAX System Evaluation Methodology, Version 2.1, (2008), WiMAX Forum.

[18]. Xiaohui Hu and Russell Eberhart (2002), "Solving Constrained Nonlinear Optimization Problems with Particle Swarm Optimization", 6th World Multi-conference on Systemics, Cybernetics and Informatics, Orlando, Florida, USA.

[19]. Yue-Jiao Gong, Jun Zang, Henry Shu-Hung Chung, Wei-Neng Chen, Zhi-Hui Zhan, Yun Li, Yu-Hui (2012), "An Efficient Resource Allocation Scheme Using Particle Swarm Optimization", IEEE Transactions on Evolutionary Computation, vol. 16, issue 6.

[20]. Wimax Forum White Paper: "Wimax VoIP Solutions for 4G Networks" WMF-M14-v01 , 30th August 2010.

[21]. Cisco : Enterprise QoS Solution Reference Network Design Guide. 8th April 2014.

[22]. 3GPP Technical Specifications TS 23.203 V14.0.0 (2016-06)

[23]. ITU-T Recommendation G.1010 for end-user multimedia QOS catergories- 11/2001

[24]. Yang Yi, Zhang Qin Yu and Wang Ye, (2011)," Modified Particle Swarm optimization and Genetic Algorithm based Resources Allocation algorithm for Multi-user orthogonal Frequency Division Multiplexing system., Information Technology Journal.