

Developed Dynamic Multilevel Feedback Queue Scheduling Algorithm with Aging Criteria for Starvation Mitigation

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Abstract—Several scheduling algorithms are discussed in this paper with a certain objective in mind, to improve the performance of the Multilevel Feedback Queue (MLFQ) algorithm including the Round Robin (RR) algorithm as the latter is used to schedule the processes present in the queues of the former. Just as any scheduling algorithm, the standard MLFQ algorithm comes with its drawbacks which stem from the methodology used to calculate each queue quantum time value and the policies used to decide whether a process should be promoted or have its priority decreased. To undertake those shortcomings, we have introduced an enhanced version of the MLFQ algorithm which computes each queue quantum value by multiplying the median of the ascendingly ordered burst time values by a factor of the queue level number, hence the increase of quantum value as priority decreases. This proposed approach also guarantees priority boosting whenever a process waiting time exceeds a certain threshold relative to its remaining time. Simulation performance analysis shows promising results in terms of decreasing the average turnaround time and the average waiting time.

Index Terms—Operating systems scheduling, Multilevel feedback queue scheduling, Average turnaround time, Average waiting time, Process Aging, Round-robin scheduling.

I. INTRODUCTION

Scheduling is a crucial part of many real-time applications such as scheduling airlines and railways communications, product manufacturing processes, data packets routing in computer networks and pipe networks. Operating systems multiprocessing environments are no different from those mediums mentioned, where processes compete over CPU utilization. This brought to existence the need for scheduling algorithms to justly assign processes to available CPUs in favour of optimizing performance measures, in particular, to maximize overall CPU utilization and throughput, and to minimize response time, waiting time and turnaround time. A scheduler could be preemptive where it can temporarily interrupt a process without its cooperation and assign the CPU resources to a different process with the intention to assign them back to the former process, such operation is called context switching, or it could be non-preemptive (cooperative) by not being able to context switch between processes. Various preemptive and non-preemptive scheduling disciplines exist such as, first come, first serve (FCFS), shortest job first (SJF), shortest remaining time first (SRTF), round-robin (RR),

multilevel queue and multilevel feedback queue. In FCFS, processes are non-preemptively executed according to their arrival time. In SJF, the CPU is assigned to the process with the smallest burst time. SRTF is a preemptive version of SJF where at each iteration, the process with the least remaining burst time takes control of the CPU. Round-robin preemptively assigns the CPU to each process in the ready queue for a static amount of time called quantum and executes them in an FCFS fashion. Multilevel queue algorithm partitions the ready queue into several queues to which processes are perpetually assigned and are executed according to another scheduling algorithm (e.g. RR). Processes cannot move from one queue to another. However, in a multilevel feedback queue algorithm, processes that don't terminate in one queue, due to having CPU burst time more than the time quantum assigned to their particular queue, are shifted to a lower priority queue. Due to the fact that long processes eventually sink to the lowest priority queue, they are conventionally carried out using FCFS to prevent starvation. Several papers discuss different methods to optimize the algorithms mentioned, each come with their set of advantages and drawbacks. One of many is [2], whose approach achieves better average response time but at the cost of hindering the scheduling process due to recalculating time quantum for each queue using a recurrent neural network. In this paper, we attempted to implement the best of all worlds.

II. RELATED WORK

Several papers proposed various types of approaches to improve the overall efficiency of the multilevel feedback queue scheduling algorithm. The chosen quantum time for each queue plays a major role. Hence, it is essential to choose a proper method to compute the time quantum value to minimize response time and maximize overall performance. In [2], an algorithm is introduced for minimizing the response time. In this algorithm, a Recurrent Neural Network (RNN) is used to determine both the number of queues and the optimized time quantum value for each queue. The RNN generates an effective model to compute the time quantum value. Their proposed intelligent version of the MLFQ offers good results, however, it suffers from a few drawbacks, the first being the direct proportionality of its network learning time and the amount

of input data, and the second is the possibility of experiencing initial overhead at the first iterations of the algorithm. Our approach proposes an improved version of MLFQ that utilizes an altered version of RR named shortest remaining burst round-robin (SRBRR) introduced in [3] which avoids the cost of learning time and overhead time in [2]. Regarding the various approaches to improve the MLFQ algorithm, those attempts dealt with starvation by assigning different quantum values to the ready queues depending on their priority. Our approach also deals with starvation by boosting processes from lower priority queues to higher ones according to certain criteria.

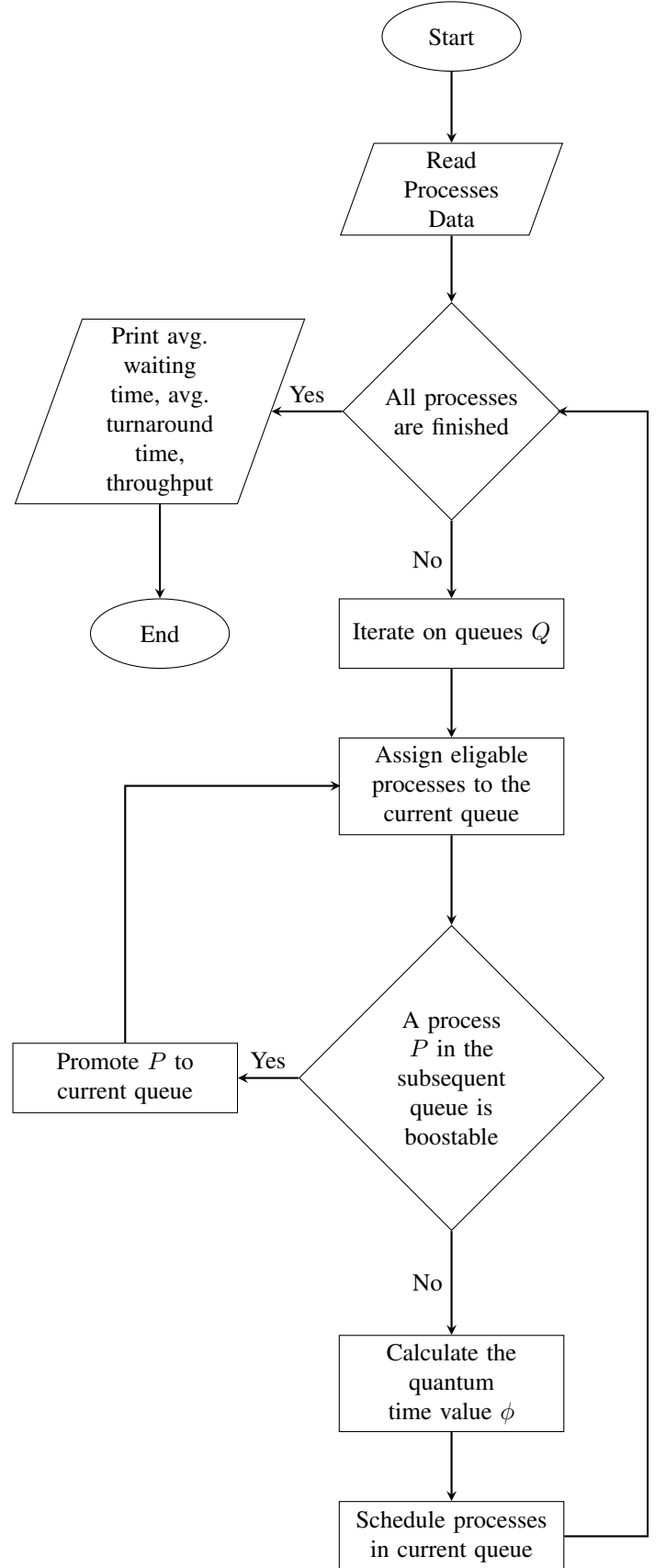
III. PROPOSED APPROACH

For a multilevel feedback queue scheduling algorithm, three parameters are considered. The first is the chosen scheduling algorithm for each queue, especially the last queue as its scheduling algorithm is expected to treat starvation. The second is the criteria according to which a process is promoted, this technique is also known as Aging. The third is the criteria according to which a process is demoted. In our proposed algorithm, there are 5 queues sorted in ascending order in line with their priority number, 1 being the highest priority and 5 being the lowest. Each queue uses a modified version of the round-robin scheduling algorithm stated in [3]. In [3], processes are sorted in ascending order according to their burst time and are assigned a time quantum that equals the median burst time of those processes. This algorithm provides better turnaround time and waiting time than the standard static quantum RR algorithm whose quantum, if set too short, leads to many context switches and, if set too long, morphs the algorithm into an FCFS algorithm. The proposed alteration on the stated algorithm in [3] is that each queue quantum time equals the median burst time multiplied by a factor matching the queue number. Hence, the gradual increase of quantum time as priority decreases. For clarification, a queue with priority equal 2 has the following processes denoted by their burst time: 100, 300, 550, 600, 620, 700, 720, 900 and 1200, the median value is 620, since we are in a queue whose priority equals 2, therefore the quantum slice value according to the proposed approach equals 1240 as in $620 * 2$. If processes of a certain queue didn't terminate after assigning the quantum time value, they are shifted to the next lower priority queue. After introducing new processes into a queue, the quantum time slice is recalculated. Processes age whenever they are in a queue whose priority is one less than that currently getting scheduled and satisfies the following inequality:

$$\frac{\text{waiting time of } P}{\text{burst time of } P} > 1 \quad (1)$$

Those procedures are repeated for all the generated queues until all processes reach the lowest priority queue where they are rescheduled until their completion.

A. Pseudocode Flowchart of the Proposed Approach



Algorithm 1 Developed Multilevel Feedback Queue Scheduling Algorithm

Input: Number of processes n , processes priority α
burst time values β , arrival time values σ ,
context switching cost ϵ
Output: Average turnaround time, average waiting time,
throughput

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1: procedure DMLFQ
  Declaration and Initialisation:
2:   Queue  $Q_i$  where  $i \in \{1, 2, 3, 4, 5\}$ 
3:   Turnaround time values  $\tau$ 
4:   Finish time values  $\lambda$ 
5:   Waiting time values  $\theta$ 
6:   Remaining time values  $\mu = \beta$ 
7:   Quantum time value  $\phi$ 
8:   Number of context switches  $\delta$ 
9:    $time = 0$ 
10:  while  $\exists P \in Q$  do
11:    for  $i = 1$  to 5 do
12:      for  $j = 1$  to  $n$  do
13:        if  $\sigma_j \leq time$  and  $\alpha_j$  equals  $i$  then
14:          Assign  $P_j$  to  $Q_i$ 
15:        end if
16:         $waitingTime = time - \sigma_j$ 
17:        if  $i < 5$  and  $waitingTime/\mu_j \geq 1$  and
           $\alpha_j$  equals  $i + 1$  and  $\sigma_j \leq time$  then
18:          Assign  $P_j$  to  $Q_i$ 
19:        end if
20:      end for
21:      Sort  $Q_i$  in ascending order according to re-
        maining time values
22:       $\phi = \text{median value of } Q_i * i$ 
23:      foreach  $P_j \in Q_i$  do
24:        if  $\mu_j \leq \phi$  then
25:           $time = time + \mu_j$ 
26:           $\lambda_j = time$ 
27:          Remove  $P_j$  from  $Q_i$ 
28:        else
29:           $time = time + \phi$ 
30:           $\mu_j = \mu_j - \phi$ 
31:          if  $i < 5$  then
32:             $\alpha_j = \alpha_j + 1$ 
33:          end if
34:        end if
35:        if Previous process  $\neq P_j$  then
36:           $time = time + \epsilon$ 
37:           $\delta = \delta + 1$ 
38:        end if
39:      end foreach
40:    end for
41:  end while
42:  for  $i = 1$  to  $n$  do  $\tau_j = \lambda_j - \sigma_j$ ,  $\theta_j = \tau_j - \beta_j$ 
43:  end for
44:  return average of  $\theta$ , average of  $\tau$ ,  $n/time$ 
45: end procedure

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A. Assumptions

The proposed scheduling algorithm is software simulated using a Python script which simulates scheduling independent CPU-bound processes on a single processor environment which guarantees that no more than a single process is getting scheduled at any arbitrary moment. Each process is assumed to have its own predetermined burst time, arrival time and the queue to which each one belongs. The proposed approach is non-preemptive. For the sake of giving an example, if a process was lately introduced to a queue denoted by Q_i prior to the current queue getting scheduled, it won't get scheduled until the current queue, its subsequent queues and the queues prior to Q_i get scheduled.

B. Experimental Scheme

On one hand, the input arguments to the proposed algorithm implementation are the number of processes to be scheduled, their burst time, their arrival time and the queue where each one belongs. On the other hand, output parameters are the average waiting time, average turnaround time and throughput. The following equations are used to calculate the previously mentioned output parameters:

$$\text{Average Waiting Time} = \frac{\text{Total Waiting Time}}{\text{Number of Processes}} \quad (2)$$

$$\text{Average Turnaround Time} = \frac{\text{Total Turnaround Time}}{\text{Number of Processes}} \quad (3)$$

$$\text{Throughput} = \frac{\text{Number of Executed Processes}}{\text{Total Execution Time}} \quad (4)$$

C. Performance Metrics

As a means to have a concrete, viable evaluation of either the proposed algorithm or any other scheduling algorithm, the output parameters are taken into consideration for analysis. Since the average waiting time indicates the average time that a process had to starve for, therefore the lower the average waiting time is the better. The same principle applies to the average turnaround time and the number of context switches, as the former implies the average time spent by the process since its arrival time to its completion and the latter costs time as the CPU is assigned back and forth between different processes. Contrarily to the prior metrics, the larger the throughput is the better as it indicates the number of processes that are completely executed per unit time.

D. Simulation

For the sake of showcasing the proposed algorithm, a number of processes, their predetermined burst time values and their arrival time values are taken as input to the Python simulation script. Suppose that the input to the script is according to the following table:

TABLE I

Process	Arrival Time	Burst Time	Queue
1	0	60	1
2	0	50	1
3	0	40	2
4	0	30	2
5	0	10	3
6	0	210	3
7	0	200	3

According to the proposed algorithm, the time quanta calculated are as follows:

TABLE II

Queue	Quantum Value
1	55
2	40
3	615
4	0
5	0

All processes are sorted in ascending order according to their remaining time and are scheduled by assigning the time quantum calculated for their respective queue. The time spent scheduling a particular queue is the waiting time for its subsequent queues.

The scheduling process goes as follows:

P_2	P_1	
0	50	105

Fig. 1. Q_1 Gantt Chart

Considering that each process in Q_1 is assigned a quantum value of 50, as we reach the last process in Q_1 , the total time elapsed equals 105, which happens to be the time that all the other processes in the subsequent queues had to wait for, hence the addition of their waiting time by a value of 105 units of time.

P_1	P_5	P_4	P_3	
105	110	120	150	190

Fig. 2. Q_2 Gantt Chart

Even though P_5 is initially assigned to Q_3 as in Table I, it was promoted to Q_2 due to satisfying inequality (1).

P_7	P_6
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190 390 600

Fig. 3. Q_3 Gantt Chart

Whenever processes reach the lowest queue precompletion, they are scheduled using the RR scheduling algorithm with a relatively large quantum time value which is in most cases similar to using the FCFS algorithm because, as the time quantum value of an RR algorithm tends to infinity which could practically be a very large number relative to the available processes remaining time values, the algorithm tends to morph into the FCFS algorithm. This procedure is iterated until all the processes are finished. Simulation results are shown in the table below:

TABLE III

Avg. Turnaround Time	Avg. Waiting Time	Throughput
230	144.3	0.011667

E. Performance Comparisons

To assess the performance of the proposed algorithm implementation, multiple test cases are addressed and analyzed in seven different experiments. In each experiment, the output of the proposed algorithm implementation is compared to the output of another scheduling algorithm implementation addressed in a different paper, such as standard MLFQ algorithm with static quantum RR and other variants of MLFQ algorithms and RR algorithms.

1) *Experiment 1:* In this experiment, the proposed algorithm is compared against two MLFQ algorithm variants stated in [4]. The first uses a static version of the RR algorithm for scheduling each queue, while the second variant uses a dynamic version of the RR algorithm for doing so.

TABLE IV
EXPERIMENT 1 INPUT

Process	Arrival Time	Burst Time	Queue
1	1	25	1
2	5	70	1
3	6	84	1
4	7	17	1
5	8	35	1

TABLE V
EXPERIMENT 1 RESULTS

Algorithm	Avg. Turnaround Time	Avg. Waiting Time
Proposed Algorithm	115	68.8
Dynamic RR MLFQ	150.8	107.6
Static RR MLFQ	161.4	116.2

2) *Experiment 2*: In this experiment, the proposed algorithm is compared against two MLFQ algorithm variants stated in [4]. The first uses a static version of the SJFRR algorithm for scheduling each queue, while the second variant uses a dynamic version of the SJFRR algorithm for doing so.

TABLE VI
EXPERIMENT 2 INPUT

<i>Process</i>	<i>Arrival Time</i>	<i>Burst Time</i>	<i>Queue</i>
1	1	25	1
2	5	70	1
3	6	84	1
4	7	17	1
5	8	35	1

TABLE VII
EXPERIMENT 2 RESULTS

<i>Algorithm</i>	<i>Avg. Turnaround Time</i>	<i>Avg. Waiting Time</i>
Proposed Algorithm	115	68.8
Dyn. SJFRR MLFQ	134	91.8
Stat. SJFRRMLFQ	143.4	98.2

3) *Experiment 3*: In this experiment, the proposed algorithm is compared against two MLFQ algorithm variants stated in [5]. The first uses a static version of the SJFRR algorithm for scheduling each queue, while the second variant uses a dynamic version of the SJFRR algorithm for doing so.

TABLE VIII
EXPERIMENT 3 INPUT

<i>Process</i>	<i>Arrival Time</i>	<i>Burst Time</i>	<i>Queue</i>
1	0	8	1
2	3	133	3
3	2	21	2
4	8	39	2
5	19	67	2
6	33	114	3
7	33	54	2

TABLE IX
EXPERIMENT 3 RESULTS

<i>Algorithm</i>	<i>Avg. Turnaround Time</i>	<i>Avg. Waiting Time</i>
Proposed Algorithm	151	88.7
Dyn. SJFRR MLFQ	252	119
Stat. SJFRR MLFQ	351	228

4) *Experiment 4*: In this experiment, the proposed algorithm is compared against multiple variants of the MLFQ

algorithm that are stated in [6]: standard MLFQ algorithm, a priority-based MLFQ algorithm and a vague logic-based MLFQ algorithm.

TABLE X
EXPERIMENT 4 INPUT

<i>Process</i>	<i>Arrival Time</i>	<i>Burst Time</i>	<i>Queue</i>
1	0	40	1
2	0	30	1
3	0	50	1
4	2	70	1
5	4	25	1
6	6	60	1
7	7	45	1

TABLE XI
EXPERIMENT 4 RESULTS

<i>Algorithm</i>	<i>Avg. Turnaround Time</i>	<i>Avg. Waiting Time</i>
Proposed Algorithm	185.85	140.14
VMLFQ	190	170
MLFQ	232.14	175
PMLFQ	240	180

5) *Experiment 5*: This experiment is the same as the previous one, but with a different input test case.

TABLE XII
EXPERIMENT 5 INPUT

<i>Process</i>	<i>Arrival Time</i>	<i>Burst Time</i>	<i>Queue</i>
1	0	90	1
2	0	30	1
3	0	28	1
4	0	57	1
5	0	73	1
6	0	19	1
7	0	42	1
8	0	67	1

TABLE XIII
EXPERIMENT 5 RESULTS

<i>Algorithm</i>	<i>Avg. Turnaround Time</i>	<i>Avg. Waiting Time</i>
Proposed Algorithm	212.5	161.75
VMLFQ	260	225
MLFQ	290	240
PMLFQ	300	245

6) *Experiment 6*: In this experiment, the proposed algorithm is compared against two variants of the RR algorithm stated in [3]. The first is a static version of the RR algorithm with a constant quantum value of 25 for scheduling each queue while the second uses a dynamic version of the RR algorithm called SRBRR for doing so.

TABLE XIV
EXPERIMENT 6 INPUT

Process	Arrival Time	Burst Time	Queue
1	0	13	1
2	0	35	1
3	0	46	1
4	0	63	1
5	0	97	1

TABLE XV
EXPERIMENT 6 RESULTS

Algorithm	Avg. Turnaround Time	Avg. Waiting Time
Proposed Algorithm	113.2	62.4
Dynamic SRBRR	122.4	71.6
Static RR	148.2	97.4

7) *Experiment 7*: This experiment is the same as the previous one, but with a different input test case. Note that for this test case, a process queue number is irrelevant to both the RR algorithm and the SRBRR algorithm mentioned in [3].

TABLE XVI
EXPERIMENT 7 INPUT

Process	Arrival Time	Burst Time	Queue
1	0	54	1
2	0	99	3
3	0	5	2
4	0	27	2
5	0	32	2

TABLE XVII
EXPERIMENT 7 RESULTS

Algorithm	Avg. Turnaround Time	Avg. Waiting Time
Dynamic SRBRR	93.6	50.2
Proposed Algorithm	106.8	63.4
Static RR	152.2	108.8

F. Observation

From the above simulations of different test cases and multiple performance comparisons that involved as many as 11 different scheduling algorithms not including this paper

algorithm, it is clear that the average turnaround time and the average waiting time of the proposed algorithm is less than or in few occasions nearly equal to those of the stated algorithms. With that said, the proposed algorithm is arguably advantageous over those algorithms, considering even the case in which it underperformed compared to the SRBRR algorithm, it is still favourable due to the capability to separate processes into categories based on their need for the processor and other advantages of the MLFQ algorithm. The performance of the proposed algorithm compared to other algorithms is further illustrated in the following graphs:

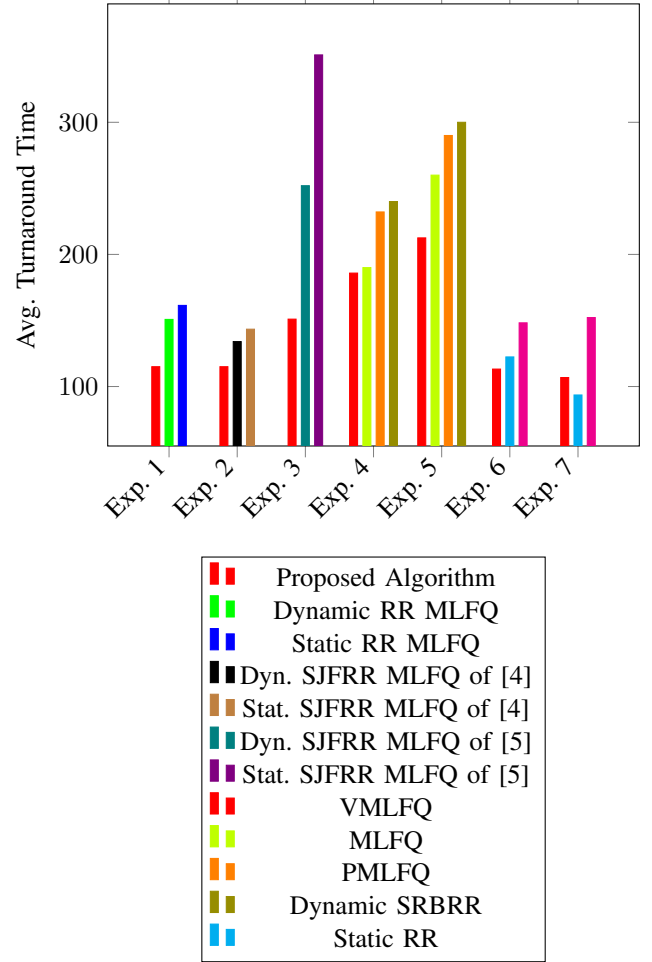


Fig. 4. Comparison graph for average turnaround time

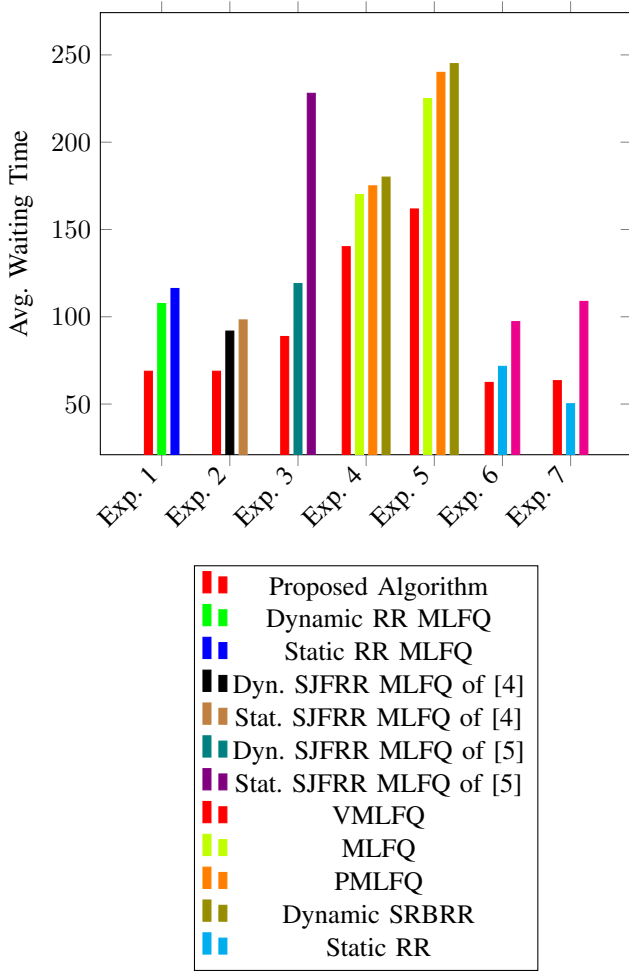


Fig. 5. Comparison graph for average waiting time

V. CONCLUSION AND FUTURE WORK

The goal of this paper is to tackle different shortcomings associated with the standard MLFQ scheduling algorithm as well as its variants discussed in several papers. To resolve these deficiencies, we introduced different adjustable policies and techniques. It is evidently clear that those methods yield better CPU performance and optimize utilization by reducing the average waiting time as well as the average turnaround time. Despite experimenting numerous combinations of the parameters and scheduling policies by which the proposed MLFQ algorithm operates, we can say that there is yet a large room for experiment and improvement through finding better methods and policies which would make the algorithm more adaptable to the nature of the submitted processes and overall more enhanced. For instance, adjusting the criteria by which the scheduler decides whether to promote a process might further lessen starvation. Making the proposed algorithm preemptive might also aid mitigating starvation and render overall better performance. The possibilities are limitless.

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