# The Use of Hierarchical Scheduling in the Ingress Edge Router of a DiffServ Domain

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*Abstract*— **Scheduling mechanisms ensure that different type of traffics obtain their share of resources such as link bandwidth and ensure that any spare capacity is distributed fairly. In other words it can be said that scheduler is responsible in reordering the output queue. To enhance the Quality of Service (QoS) granularity in a Differentiated Services (DiffServ) QoS model, DiffServ should be facilitated with a scheduler rather than normal First In First Out (FIFO) mechanism such as Priority Queueing, Round Robin, Weighted Round Robin, Fair Queueing and many more. However, these types of schedulers have their own setbacks, thus this paper analyzes and enhances the performance of DiffServ network by deploying a hierarchical scheduling technique in the DiffServ ingress edge router.**

*Index Terms*—**DiffServ, scheduler, QoS, Network Simulator**

## I. INTRODUCTION

SCHEDULING mechanisms ensure that different type of traffics obtain their share of resources such as link bandwidth and ensure that any spare capacity is distributed fairly. In other words it can be said that scheduler is responsible in reordering the output queue. Conventional schedulers such as First In First Out (FIFO), Priority Queueing (PQ), Fair Queueing (FQ) and Weighted Round Robin (WRR) have their own drawbacks [1]. Thus, hierarchical scheduling technique is introduced in this paper to address these setbacks. The proposed cheme combines two schedulers in a hierarchy in a DiffServ ingress edge router. Recently, hierarchical scheduling method has been deployed in data communication area for QoS purpose in terms of rate control [2], Multiple Input-Queued (MIQ) switches [3], [4], scheduling latency [5] as well as in DiffServ domain [6], [7], [8].

This paper suggests the use of hierarchical scheduling in DiffServ ingress edge router where the design is based on the Diffserv network model shown in [7].

Reference [2] applied hierarchical scheduling to increase the network utilization and reduce the packet loss rate. End-to-end delay was not considered in this technique although it is an essential purpose of having a scheduler. This drawback is also stated by [5] where it is expected that this technique does not solve the weaknesses of Round Robin (RR).

Hierarchical scheduling technique is also used in Multiple Input-Queued (MIQ) switch in [3] and [4] where it is meant to provide both QoS guarantee and enhance switching throughput under bursty environment.

Minimized Cycle Round Robin (MCRR) which is the extension of Weighted Round Robin (WRR) is introduced in [5] to improve the Hierarchical Round Robin (HRR) that was introduced by [2]. This technique is introduced to improve the delay and jitter while maintaining the simplicity of WRR. In order to increase the scalability and the efficiency of the network, Hierarchical MCRR (HMCRR) is proposed. However, they did not proof that this technique will reduce the end-to-end delay particularly for real time traffic and it is expected that it will not reduce the real time delay

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as there is no element of prioritization in the scheduling technique.

A hybrid scheduling scheme known as Priority Queueing Weighted Round Robin (PQWRR) is introduced in [6] to overcome the drawback of PQ and WRR in DiffServ. PQWRR assigns Expedited Forwarding (EF) traffic with the highest priority over Assured Forwarding (AF) and Best Effort (BE) traffic which uses WRR scheduling technique. This is to ensure that the end-to-end delay of EF traffic will be minimized. Moreover, in case the network is not congested, the unused bandwidth will be used to serve the other queues. Although this technique seems to be simple to implement, however it is not scalable as it is implemented based on the output queue switch architecture compared to the input queue switch [8].

Reference [8] extends the idea of reference [3] to support DiffServ classes. However, it seems that the end-to-end delay for EF traffic is not as good as other techniques that they have compared with. This is mainly due to the lack of prioritization elements which is not included in the scheduling technique.

## II. PROPOSED TECHNIQUE

The network model used to illustrate the proposed technique is shown in Figure 1. All links is 1.554Mbps with 0.5ms delay. Traffics are classified as EF, three levels of AF named as AF3, AF2 and AF1 and finally BE.

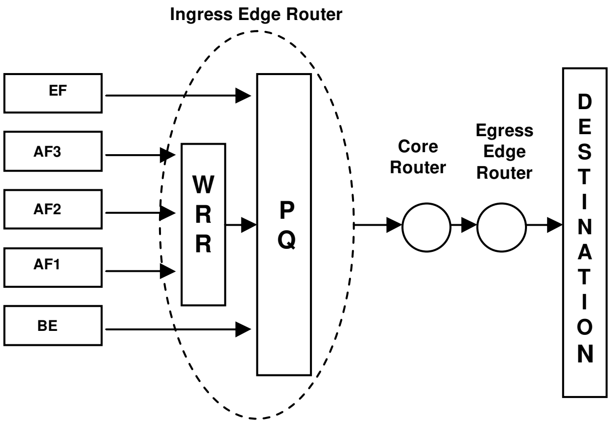


Fig. 1. Proposed WRR_PQ Hierarchical Scheduling in DiffServ Network Model

A hierarchy of a Weighted Round Robin (WRR) and Priority Queueing (PQ) is used here. WRR only schedules AF2 traffics as these traffics are not sensitive to time compared to EF traffic while BE is not included in WRR level because it is considered the lowest priority traffic. WRR is used in this work to schedule different classes of AF traffic before it is being scheduled using PQ with other EF and BE traffic. This technique is designed to address the setback of both PQ and WRR scheduler.

PQ is very useful for EF traffic where priorities can be set so that real time applications get priority over applications that are not time crucial. However, the main disadvantage of this system is that if a higher priority queue is always full, the lower priority queues will never be served [6]. Thus, a particular kind of network traffic may dominate a PQ interface and lower priority traffic may experience excessive delay as it waits for higher priority traffic to be served. If lower priority queues are dropped due to the buffer overflow, the combination of packet dropping latency will be increased and packet retransmission by host systems can lead to resource starvation for lower priority traffic.

In contrast, WRR controls the percentage of bandwidth allocated to each service class. Thus, bandwidth starvation could be avoided. WRR is also efficient in providing mechanism to support the delivery of DiffServ classes to a reasonable number of highly aggregated traffic flows. Nonetheless, the main limitation of WRR is that it gives the correct percentage of bandwidth to each service class only if all packets in all queues are in equal size or when the mean packet size is known in advance. Due to the RR nature of the algorithm, WRR tends to increase the queuing delay and jitter for EF traffic [6]. Therefore, it is envisaged that WRR_PQ technique will improve the limitations of both WRR and PQ schedulers in ingress edge router of DiffServ domain. The process of WRR_PQ hierarchical scheduler is shown in the Figure 2.

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When a new packet arrives,
Classify the packet into class EF, AF3,
AF2, AF1 and BE;
for packets classified as AF3, AF2 and AF1
  apply Weighted Round Robin with the
following weights:
    AF3 = 5
    AF2 = 3
    AF1 = 1
at the same time for packets classified
with EF and BE are scheduled together with
AF packets from the above Weighted Round
Robin using Priority Queueing as follows:
  EF = highest priority
  AF = medium priority
  BE = lowest priority
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Fig. 2. WRR_PQ Hierarchical Scheduling

## III. Results and Analysis

Network performances for the proposed WRR_PQ hierarchical scheduling are compared with performance given by the normal WRR scheduler and HMCRR which was designed by [5]. Performance given by PQ is not compared here, as referred to the work done in [9], QoS of EF is achieved but BE is seen to be starved when PQ is used. The performance metrics that will be measured are shown in Table I. The average delay and jitter are measured for EF and AF3 traffic to evaluate the performance in provisioning QoS for real time traffic. AF2, AF1 and BE traffic are assigned to different type of non real time traffic. Thus, their performance study is based on the traffic throughput and packet loss ratio. Delay for each packet is measured end-to-end which includes propagation delay, waiting time and transmission delay.

TABLE I
Metrics used for EF, AF3, AF2, AF1 and BE Performance Study

| PHB | Metrics |
|---|---|
| EF | • Average Delay<br>• Jitter |
| AF3 | • Average Delay<br>• Jitter |
| AF2 | • Throughput<br>• Packet loss ratio |
| AF1 | • Throughput<br>• Packet loss ratio |
| BE | • Throughput<br>• Packet loss ratio |

### A. *Performance Evaluation of EF Traffic*

EF traffic is assigned for highest priority traffic that is represented by a Constant Bit Rate (CBR) traffic such as voice. The QoS metrics used for EF traffic are average delay and jitter. The simulation to evaluate the performance of EF traffic is done by increasing the EF traffic load while the other traffics are kept constant. The traffic specifications for EF evaluation are shown in Table II.

TABLE II
Parameters used for EF Performance Evaluation

| PHB | Packet Size | Type of Traffic | Agent | Rate | Buffer Size |
|---|---|---|---|---|---|
| EF | 256B | CBR | UDP | 80kbps | 50 packets |
| *AF3* | 1000B | Pareto | UDP | 376kbps | 50 packets |
| *AF2* | 1500B | Telnet | TCP | 320kbps | 1000 packets |
| *AF1* | 1500B | FTP | TCP | 320kbps | 1000 packets |
| *BE* | 1500B | Exponential | TCP | 320kbps | 1000 packets |

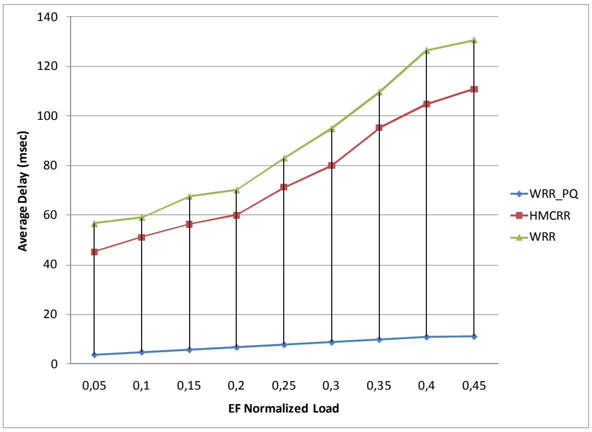


Fig. 3. Average Delay for EF Traffic

As shown in Figure 3, WRR_PQ scheduler gives the smallest average delay for the EF traffic. HMCRR gives the highest average delay which is about 20msec more than the average delay produced by WRR. By combining PQ with WRR in a hierarchy, the average seems to reduce approximately around 90% compared to normal WRR scheduler when the load is 0.45. Average delay is very important in provisioning QoS for EF traffic such as voice and it is shown here that the WRR_PQ scheme could improve the performance of EF traffic when it is deployed in a DiffServ network.

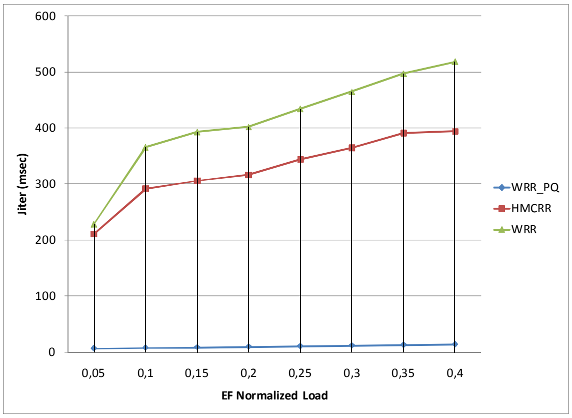


Fig. 4. Jitter for EF Traffic

Figure 4 illustrates the jitter for EF traffic given by WRR_PQ, HMCRR and WRR schedulers when these schedulers are applied in a DiffServ network. As shown in the graph, WRR_PQ gives the lowest jitter for EF traffic and this indicates that WRR_PQ could improve the jitter of EF traffic delivery. Similar to the case of average delay, HMCRR gives the highest jitter which is about 124msec more compared to WRR. The jitter produced by WRR scheduler seems to reduce approximately about 380msec when it is combined with PQ in a hierarchy for the load of 0.4. The lower jitter value will ensure that the transferred traffic such as voice is smooth.

## *B. Performance Evaluation of AF3 Traffic*

The AF3 traffic represents a Variable Bit Rate (VBR) traffic such as video streaming and same as EF, average delay and jitter are evaluated. The simulation to evaluate the performance of AF3 traffic is done by increasing the AF3 traffic while the other traffics are kept constant. Same as EF traffic, the performances are taken on load basis. The traffic specifications for AF3 evaluation are shown in Table III.

TABLE III
PARAMETERS USED FOR AF3 PERFORMANCE EVALUATION

| PHB | Packet Size | Type of Traffic | Agent | Rate | Buffer Size |
|---|---|---|---|---|---|
| EF | 256B | CBR | UDP | 640kbps | 50 packets |
| *AF3* | 1000B | Pareto | UDP | 47kbps | 50 packets |
| *AF2* | 1500B | Telnet | TCP | 320kbps | 1000 packets |
| *AF1* | 1500B | FTP | TCP | 320kbps | 1000 packets |
| *BE* | 1500B | Exponential | TCP | 320kbps | 1000 packets |

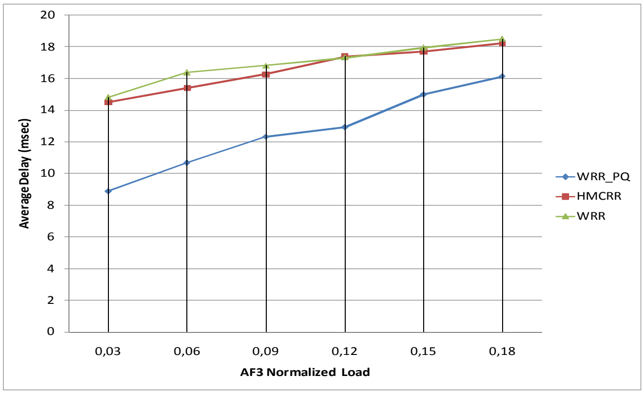


Fig. 5. Average Delay for AF3 Traffic

From Figure 5, the average delay for AF3 is reduced when WRR_PQ is applied in the DiffServ network compared to HMCRR and WRR. HMCRR and WRR more or less give the same average delay for AF3 which lies between 14msec to 18msec for the load between 0.03 to 0.18. Hence, it can be inferred from here that, HMCRR might not solve the drawback of WRR in scheduling AF3 traffic. WRR_PQ improves the average delay of AF3 approximately by 2msec when the load is 0.18.

TABLE IV

| PHB | Packet Size | Type of Traffic | Agent | Rate | Buffer Size |
|---|---|---|---|---|---|
| EF | 256B | CBR | UDP | 640kbps | 50 packets |
| *AF3* | 1000B | Pareto | UDP | 376kbps | 50 packets |
| *AF2* | 1500B | Telnet | TCP | 40kbps | 1000 packets |
| *AF1* | 1500B | FTP | TCP | 320kbps | 1000 packets |
| *BE* | 1500B | Exponential | TCP | 320kbps | 1000 packets |

PARAMETERS USED FOR AF2 PERFORMANCE EVALUATION

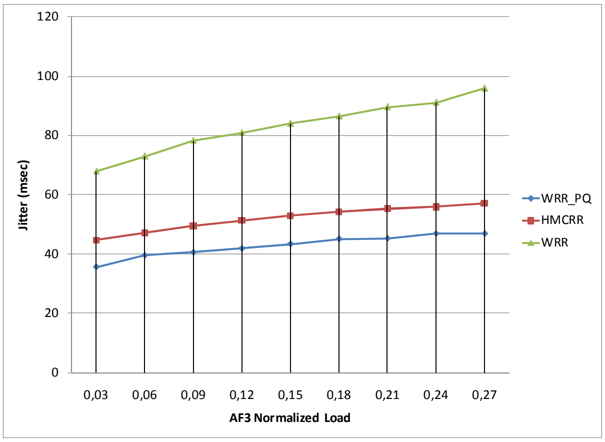


Fig. 6. Jitter for AF3 Traffic

Figure 6 shows the jitter for AF3 traffic when WRR_PQ, HMCRR and WRR schedulers are applied in a DiffServ network. As can be seen in the graph, WRR_PQ gives the lowest jitter for AF3 traffic and this indicates that WRR_PQ could improve the jitter of AF3 traffic delivery. WRR seems to give the highest jitter which is about 39msec more compared to HMCRR when the load is 0.27. The jitter of HMCRR at the load of 0.27 is reduced approximately about 18% when WRR_PQ is applied in the network. Hence, it can be concluded that, WRR_PQ improves the jitter of real time traffic as proven in EF and AF3 traffic evaluations.

### C. *Performance Evaluation of AF2 Traffic*

The AF2 traffic in the form of Telnet represents a non real time type application. Non real time traffic is not sensitive to time delay but sensitive to packet loss. Thus, the QoS metrics used for the performance analysis of the non real time traffic are throughput and packet loss ratio. The simulation to evaluate the performance of AF2 traffic is done by increasing the AF2 traffic while the other traffics are kept constant. AF2 traffic is also evaluated based on the load where the load shows the number of AF2 traffic in the network. The traffic specifications for AF2 evaluation are shown in Table IV.

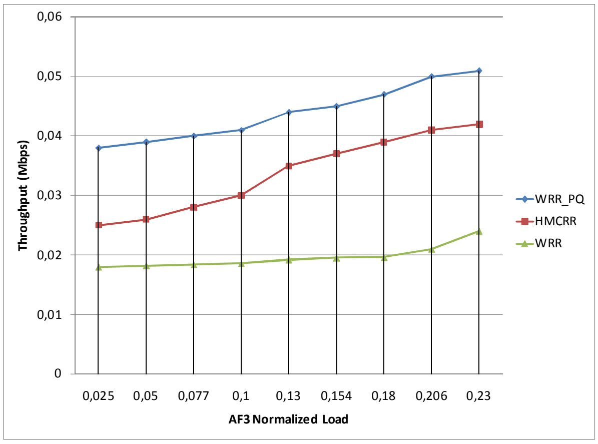


Fig. 7. Throughput for AF2 Traffic

As shown in Figure 7, WRR_PQ gives a higher throughput for AF2 traffic. The throughput improves by approximately 18% when WRR_PQ is applied compared to HMCRR for the load of 0.23. WRR seems to give the lowest throughput which is about 42% less than the throughput given by HMCRR when the load is 0.23. Theoretically, as the throughput increases, the packet loss ratio decreases. Results in Figure 8 agrees with this where packet loss ratio seems to reduce by approximately 40% when WRR_PQ is deployed in the DiffServ network compared to normal WRR for the load of 0.23.

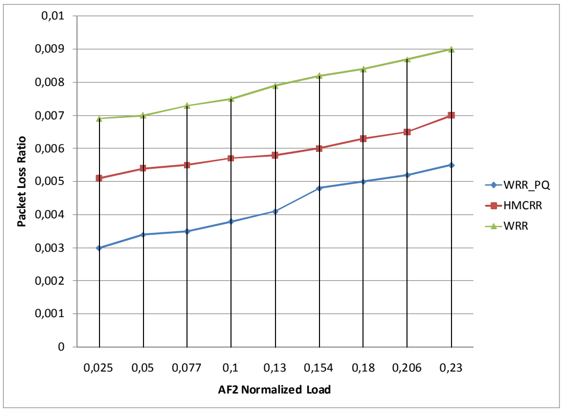


Fig. 8. Packet Loss Ratio for AF2 Traffic

### D. *Performance Evaluation of AF1 Traffic*

The File Transfer Protocol (FTP) traffic is used for AF1, which is another type of non real time traffic. Same as the AF2 traffic, the QoS metrics considered here are throughput and packet loss ratio. Similarly, the simulation to evaluate the performance of AF1 traffic is done by increasing the AF1 traffic while the other traffics are kept constant. The traffic specifications for AF1 evaluation are shown in Table V.

TABLE V
PARAMETERS USED FOR AF1 PERFORMANCE EVALUATION

| PHB | Packet Size | Type of Traffic | Agent | Rate | Buffer Size |
|---|---|---|---|---|---|
| EF | 256B | CBR | UDP | 640kbps | 50 packets |
| *AF3* | 1000B | Pareto | UDP | 376kbps | 50 packets |
| *AF2* | 1500B | Telnet | TCP | 320kbps | 1000 packets |
| *AF1* | 1500B | FTP | TCP | 40kbps | 1000 packets |
| *BE* | 1500B | Exponential | TCP | 320kbps | 1000 packets |

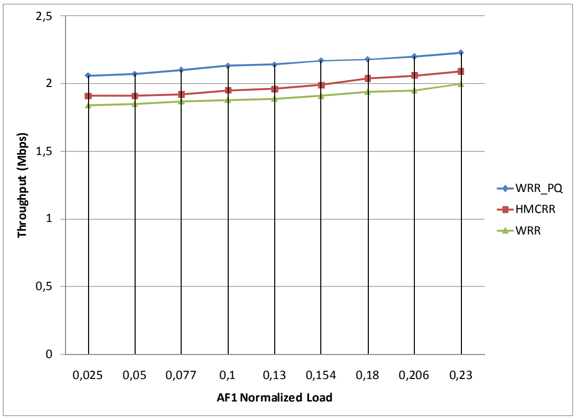


Fig. 9. Throughput for AF1 Traffic

Similar to AF2 traffic, WRR_PQ also improves the performance of the DiffServ network for AF1 traffic as shown in Figure 9 where it gives the highest throughput for AF1 traffic. The throughput for the traffic load of 0.23 increases by 0.23Mbps when WRR scheduler is combined with PQ in a hierarchy compared to applying WRR scheduler on its own. HMCRR also improves the throughput of AF1 traffic but not as much as WRR_PQ where it only increases the throughput for the AF1 traffic load of 0.23 by highest throughput, consequently the packet loss ratio is also reduced. This is proven in Figure 10, where WRR_PQ has reduced the packet loss ratio of approximately 47% compared to HMCRR and WRR when the AF1 load is 0.23.

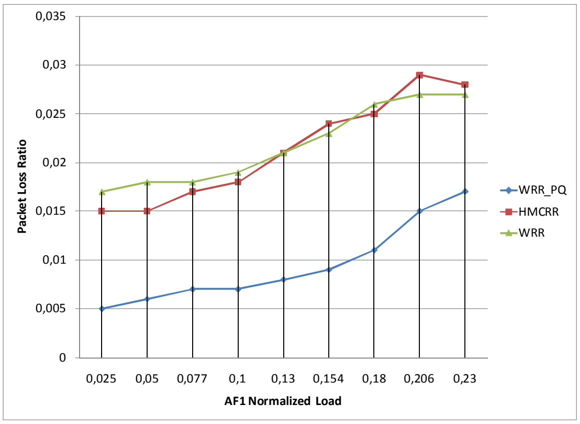


Fig. 10. Packet Loss Ratio for AF1 Traffic

## *E. Performance Evaluation of BE Traffic*

BE traffic is represented by exponential traffic which is another type of non real time traffic and here associated with the lowest priority. The simulation to evaluate the performance of BE traffic is done by increasing the BE traffic while the other traffics are kept constant. The traffic specifications for BE evaluation are shown in Table VI.

TABLE VI
PARAMETERS USED FOR BE PERFORMANCE EVALUATION

| PHB | Packet Size | Type of Traffic | Agent | Rate | Buffer Size |
|---|---|---|---|---|---|
| EF | 256B | CBR | UDP | 640kbps | 50 packets |
| *AF3* | 1000B | Pareto | UDP | 376kbps | 50 packets |
| *AF2* | 1500B | Telnet | TCP | 320kbps | 1000 packets |
| *AF1* | 1500B | FTP | TCP | 320kbps | 1000 packets |
| *BE* | 1500B | Exponential | TCP | 40kbps | 1000 packets |

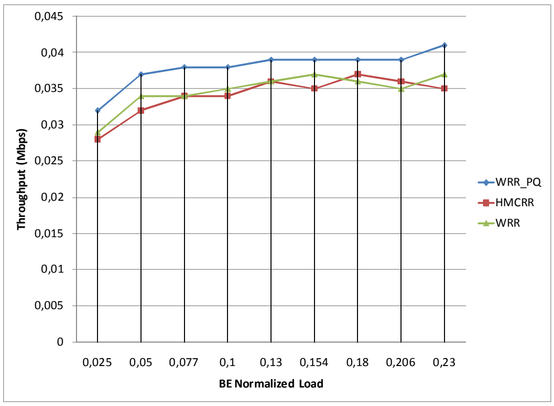


Fig. 11. Throughput for BE Traffic

The simulation shows that there are no losses that occurred for BE traffic for all types of schedulers that are considered in this work. However, as shown in Figure 11, WRR_PQ seems to give the highest throughput for BE traffic in the DiffServ network. The throughput for BE load of 0.23 increases by approximately 12% when WRR_PQ is used compared to WRR and HMCRR. This indicates that, even though PQ is included in the scheduler, BE traffic will be served relatively more compared to HMCRR and WRR schedulers.

## IV. Conclusions and Future Works

This paper discussed the use of the hierarchical scheduling scheme in a DiffServ domain. The performances given by the proposed WRR_PQ hierarchical scheduler are presented. The performances for each type of traffics are compared with the HMCRR scheduler designed by [5] and a conventional WRR scheduler. The WRR_PQ hierarchical scheme is found to give better performance for all types of traffic that are considered in this work. Potentially, the WRR_PQ hierarchical scheme can help to enhance the DiffServ domain to efficiently handle QoS requirements in the IP network.

The hierarchical scheduler can be varied by combining other types of schedulers in a hierarchy. These techniques can be compared in terms of their network performance. The granularity of the network could also be tested by adding more traffic. The work can also be further extended in a testbed environment where a DiffServ domain can be implemented and managed. The algorithm can be incorporated in ingress routers of the testbed and performance study can be made to see the viability for real implementation.

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