Performance Evaluation of Queuing Disciplines for Multi-Class Traffic Using OPNET Simulator

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Abstract: - Queuing disciplines have now become the subject of intensive discussion in network field. There are several queuing disciplines that claim best performance. In this paper, we evaluate a hypothetical network topology based on multi-class traffic approach. Multi-class traffic provides for aggregate traffic to be classified and conditioned at the edge of the network routers on the basis of performance. We take four very popular and commercially deployed queuing disciplines (FIFO, PQ, WFQ and DWRR) for multi-class traffic and analyze their performance using a very powerful simulation tool, OPNET. We find that in general, without any specific parameter, WFQ and DWRR show best and very close performance for all considered parameters except delay jitter and end to end delay where PQ seems better.

Key-Words: - Weighted-Fair Queuing, Deficit-Weighted Round Robin, Priority Queuing, Multi-Class Traffic, OPNET Simulation

1 Introduction

As the growth of network and internetworking is rising exponentially, numerous requirements are also emerging on the screen. There are many network parameters for its performance evaluation that are required in different parts of network for different application. For example, real time applications are more sensitive to transfer delay than throughput whereas there are applications where throughput is the most important parameter to be taken care of. For last decade or so, a number of queuing disciplines have been proposed to ensure fairness between competing requests at a service point and achieve best performance. FCFS, Round Robin, Priority Queues, Fair Queuing, WFQ, WRR, DWRR etc. are some of the disciplines to name a few. In this paper, we analyze the performance of a typical network topology under different queuing disciplines. First, we develop an arbitrary network model in OPNET [1] with multi-class traffic (voice, video etc.) and then simulate it for FCFS, PQ, WFQ and DWRR queuing disciplines with drop tail and RED (random early detection) scheme. Next, we evaluate the best queuing discipline, based on simulation results, in terms of the queuing delay, delay, traffic dropped and delay jitter. There from, we finally conclude the best queuing discipline with respect to a particular parameter. Moreover, we compare the results of drop-tail and RED schemes and conclude accordingly.

The remainder of the paper is as follows. After stating problem in Section 2, Section 3 covers related work to our experiment. In section 4, we briefly describe all four selected queuing disciplines with some comments on their performance. Section 5 states our simulation-based solution strategy. We discuss and analyze simulations results to evaluate queuing disciplines performance in section 6. Section 7 contains concluding remarks.

2 Problem Statement

We evaluate a hypothetical network topology based on multi-class traffic approach. Multi-class traffic provides for aggregate traffic to be classified and conditioned at the edge of the network routers on the basis of performance. We take four very popular and commercially deployed queuing disciplines (FIFO, PQ, WFQ and DWRR) for multi-class traffic and analyze their performance using a very powerful simulation tool, OPNET.

3 Related Work

For QoS, [3] has investigated the effect of a two-priority policy when serving slotted traffic arriving with a Bernoulli statistics and also given explicit closed-form expressions for the distribution of the lengths of the high- and low-priority queue. Although our focus is on wired network performance, [4] has proposed a very nice analytical framework solution for dynamic priority queuing of handover calls in wireless networks.

Like [3], [5] proposes a modified QoS mapping that differentiates between the transmission of voice and video-telephony and a Weighted Fair Queuing scheduler to schedule the transmissions. Through a simulation study, the authors show the effect on the queuing delays of both traffic types when their WFQ weights vary and then derive an optimal weight that provides the best overall delays for multimedia telephony services. We have not considered their weights. Rather we use OPNET default weights for WFQ. [6] uses SWFQ (*Sliding Weighted Fair Queuing)* which combines priority-driven and share-driven scheduling for a real-time IPv6 network.

We find a little work on DWRR in literature. However, the study of [7] describes Dynamic Weighted Round Robin (DWRR) scheduling discipline, which is suitable for real-time variable bit rate (rtVBR) service as well as other services such as constant bit rate (CBR), non real-time VBR (nrtVBR), available bit rate (ABR) services in a high-speed network.

4 Queuing Disciplines Description

We have selected four popular queuing disciplines for our experiments: FIFO, PQ, WFQ and DWRR. We describe them one by one here.

Firstin, Firstout (**FIFO**) queuing is the most basic queue scheduling discipline. In FIFO queuing, all packets are treated equally by placing them into a single queue, and then servicing them in the same order that they were placed into the queue. FIFO queuing is also referred to as Firstcome, Firstserved (FCFS) queuing. There is no multitasking and no preemption. The advantages of FIFO are its predictable behavior; extremely low computational load on the system, simple contention resolution, guaranteed fairness etc. but the downside of FIFO is incapability to provide priority to real time traffic, delay insensitivity due to which mean queuing delay increases rapidly.

The underlying principle of **PQ** (priority queuing) is similar to that of FIFO. In PQ, packets that arrive at the output link are classified into more than one queues based on their priorities. The packets with highest priority are then served first, next second higher priority and so on. In order to assign priority we may make use of packet header (for example, the value of the Type of Service (ToS) bits in an IPv4 packet), its source or destination IP address, its destination port number, or other criteria. Each priority class typically has its own queue. When choosing a packet to transmit, the priority queuing discipline will transmit a packet from the highest priority class that has a nonempty queue (that is, has packets waiting for transmission). The choice among packets in the same priority class is typically done in a FIFO manner. The problem with PQ is that lower-priority packets may get little attention.

WFQ (Weighted Fair Queuing) is an attractive and decent queuing technique. The main goal behind its proposal was to ensure fairness among all types of traffic and prevent bursty data to consume more bandwidth than its allocation (by the scheme) [8].It schedules interactive traffic to the front of the queue to reduce response time, and it fairly shares the remaining bandwidth between high bandwidth flows. The key to classify a flow is a conversation, this means, a numeric representation based on information taken from the packet header (source address, source port, destination address, protocol, IP precedence, etc.) for classification. Because it is not practical to have one queue for each conversation, WFQ employs a hashing algorithm which divides the traffic over a limited number of queues to be selected by the user or fixed by default. This takes care of fairness of the algorithm. The advantage of WFQ is that first WFQ provides protection to each service class by ensuring a minimum level of output port band width independent of the behavior of other service classes but even though the guaranteed delay bounds supported by WFQ may be better than for other queue scheduling disciplines, the delay bounds can still be quite large.

DWRR (Deficit weighted round robin) is a modification of the WRR algorithm (In WRR queuing, packets are first classified into various service classes and then assigned to a queue that is specifically dedicated to that service class. Each of the queues is serviced in a round-robin order. Similar to strict PQ and FQ, empty queues are skipped that enables to save the service quantum of the flow served. They do not receive packets in a round robin fashion because of variable size in order to maintain timeliness performance [9]. That is, if a packet from a flow being currently served is so long that its transmission would exceed the service quantum this round-robin, the resulting amount of service undelivered to the flow is saved until the next round-robin and is added to the service quantum. It also addresses the limitations of the WFQ model by defining a scheduling discipline that has lower computational complexity and that can be implemented in hardware. This allows DWRR to support the arbitration of output port bandwidth on high-speed interfaces in both the core and at the edges of the network. However, despite all its versatilities, DWRR does not provide end-to-end delay guarantees and delay jitter as precisely as other queue scheduling disciplines do because while maintain fairness, the overall end-to-delay may get disturbed.

5 Simulation Strategy

We have considered the following network for our simulation. We apply all the four queue disciplines on DS1 link between two routers one after the other which directly implies that we have four different scenarios, one for each queue scheme. There are three types of traffic: FTP, Voice and Video. There is a separate server for each traffic type. We use Poisson traffic for FTP, PCM quality speech for voice (ToS is *interactive voice (6)*), and low resolution video with different frame size and rates. For the application of queuing disciplines, we use QoS attribute of OPNET. All the links other than the one between two routers are 10BaseT.

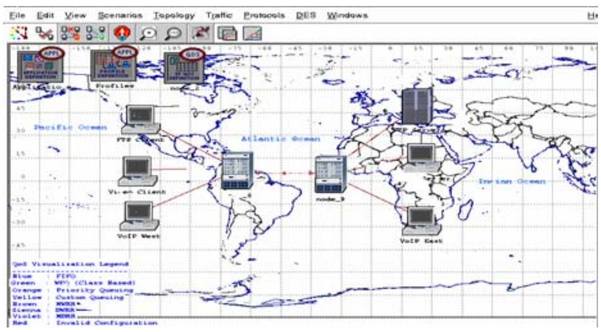

Fig. 1 Network topology for simulation

In order to evaluate queue performance, we collect mean queuing delay, end to end delay, packet drop rate and delay jitter for each kind of queue scheme. Furthermore, we also see the effect of RED and observe its dominance over drop tail policy.

6 Simulation Results

6.1 Queuing delay

The first figure shows the comparison of queuing delay of all the queue disciplines (with drop-tail policy). We can see that FIFO shows the worst behavior (2.5 msec) on account of non-prioritized nature. The packets coming from voice and video client are relatively large so they suffer more delay thus resulting in overall large queuing delay.

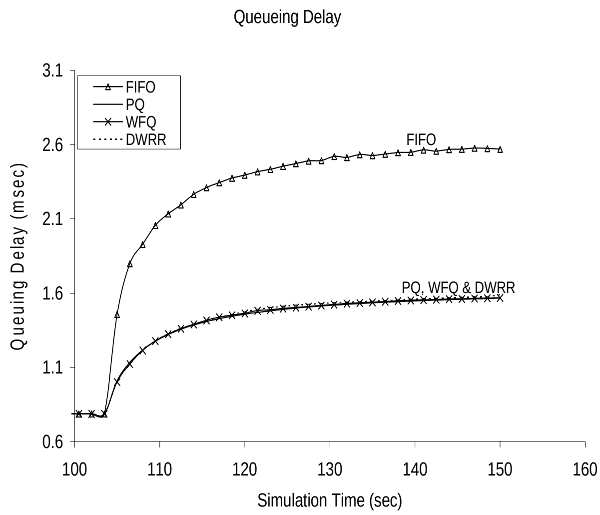

Fig.2 Queuing delay with drop-tail policy

The next figure is similar to the previous but if we decrease our interval gap, we can easily see the relative performance of PQ, WFQ and DWRR. We can see that DWRR shows best performance as shown in the following figure.

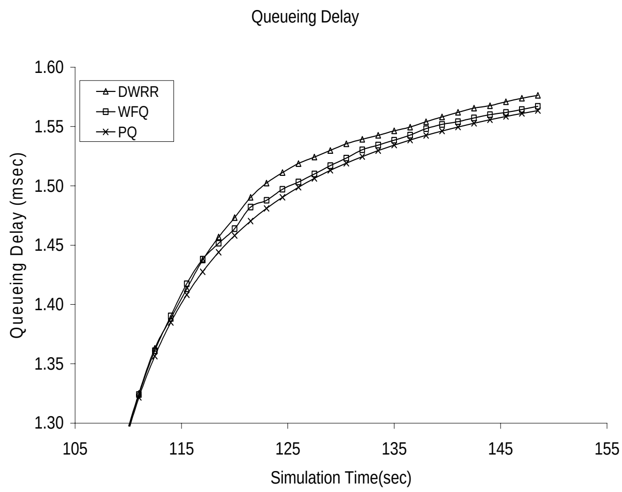

Fig.3 Queuing delay with drop-tail policy on expanded scale

While the above two figures compare queuing delay versus simulation time, the following Fig. shows the queuing delay variation versus load. We change load by changing IAT (inter arrival time) in FTP client and fame size and frame rate in video client. This now verifies completely that DWRR is the most reliable to achieve minimum queue delay (This is totally in agreement with what we discussed in section 3).

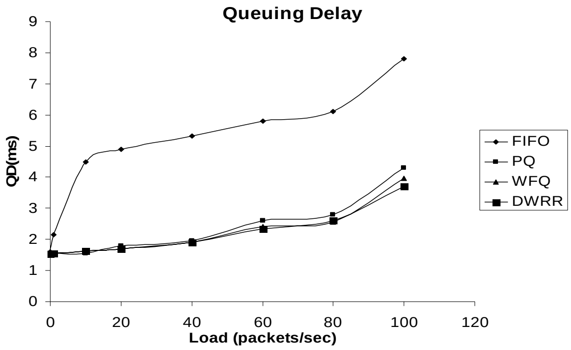

Fig.4 Queuing delay versus load

Next, the results with RED scheme have been shown. We can clearly examine that FIFO behaves far better now (queuing delay is less.i.e.1.5 msec compared to the previous one). There is no much improvement for other queuing disciplines but while discussing delay jitter and end to end delay, we shall clearly see the role of RED for these disciplines as well.

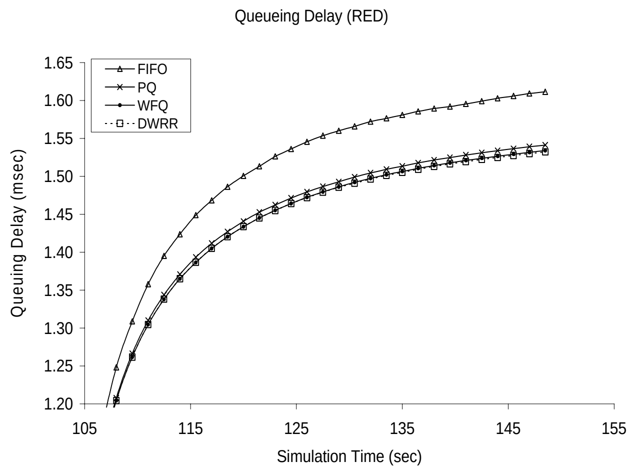

Fig.5 Queuing delay with RED policy

The following Fig. shows RED enabled queuing delay versus load variation. The analysis is as described earlier.

6.2 Packet drop rate

As there is no buffer management, no multiple queues in FIFO, the packet drop rate is too high in its case. Like other parameters, PQ, WFQ and DWRR almost give better (although on finer scale, DWRR wins once again) and similar results in this case too (clearer when scaled well). Of course, RED gives better results relative to drop tail in all four disciplines as far instantaneous value is concerned.

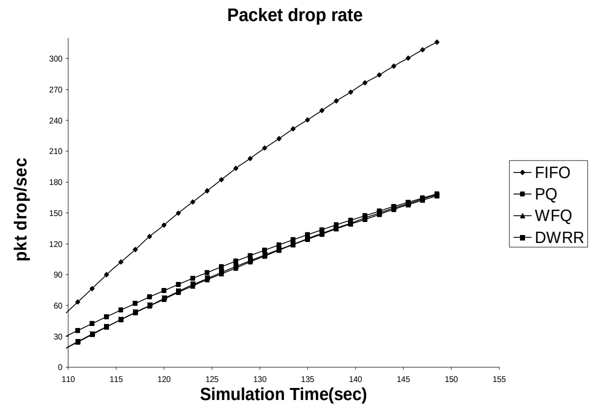

Fig.6 Packet drop rate with drop-tail policy

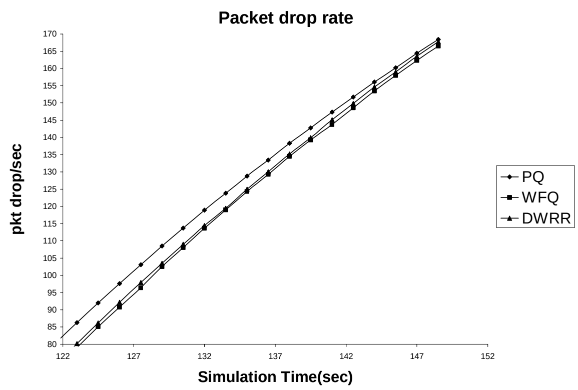

Fig.7 Packet drop rate on expanded scale

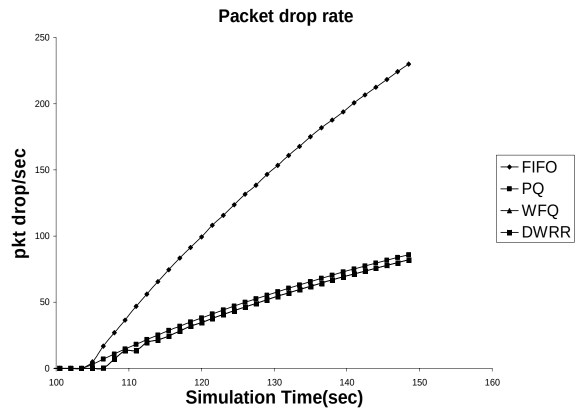

Fig.8 Packet drop rate with RED policy

The next is the same thing but versus load. This ensures our instantaneous observation. It is very interesting to compare drop-tail and RED results. At some points, packet drop rate is more in case RED which sounds logical as RED relies merely on probabilistic packet drop to avoid congestion and starvation problem.

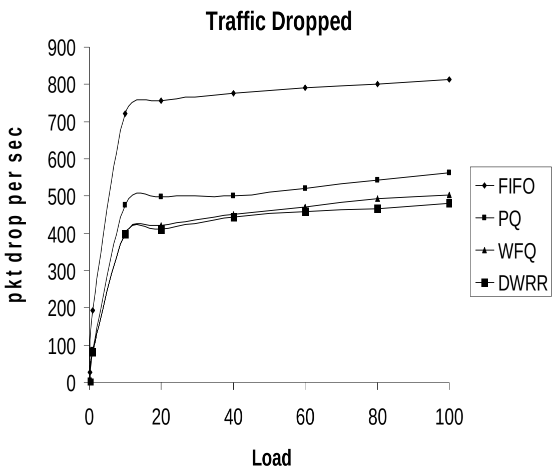

Fig.9 Packet drop rate versus load with drop-tail policy

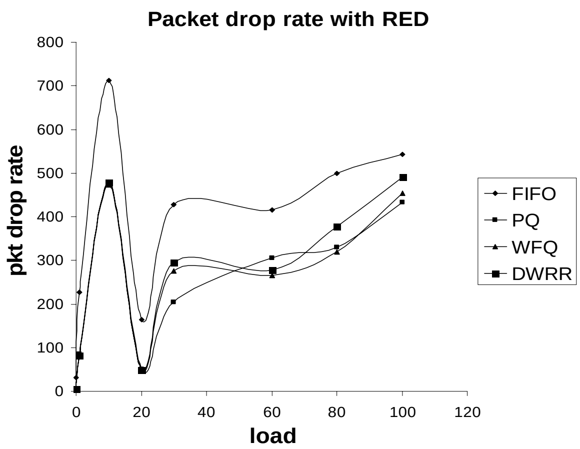

Fig.10 Packet drop rate versus load with RED policy

6.3 End-to-end delay & delay jitter

The importance of RED can be best illustrated by looking at the end-to-end delay and delay jitter of video traffic for drop tail and RED schemes respectively. The following first two graphs (fig.11 and fig.12) for end-to-end delay clearly show that (1) WFQ and DWRR do not produce good results for this type of delay. Instead they show longer delay when compared with even FIFO. (2) The compensation can be made if we make use of RED scheme [18] (also see the results) and we can verify this statement by looking at the improvement that FIFO shows in RED result for end-to-end delay (and similarly in delay jitter too). Note that in end-to-end delay with RED, DWRR overlaps with WFQ result.

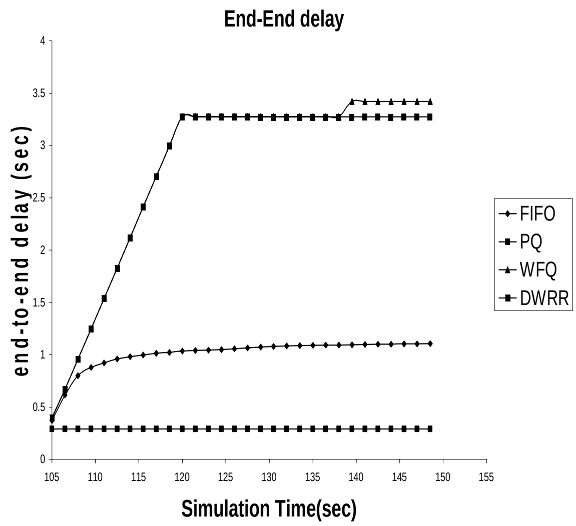

Fig.11 End-to-End delay with drop-tail policy

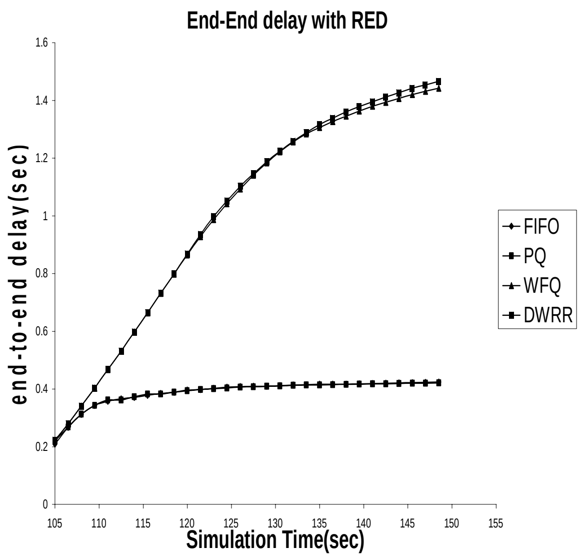

Fig.12 End-to-end delay with RED policy

The next two figures show delay jitter for video traffic. Like end-to-end delay, WFQ and DWRR again show poor performance because they try to avoid congestion and maintain fairness and in doing so delay jitter and end-to-end has become guarantee less which means that they may and may not perform well and the results show exactly what we get from theory. In our simulation model, PQ outperforms all other queuing disciplines for delay jitter.

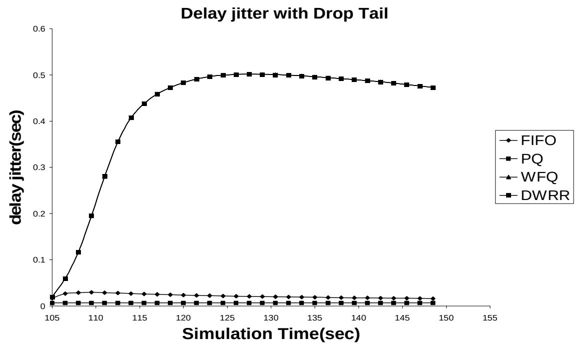

Fig.13 Delay jitter with drop-tail policy

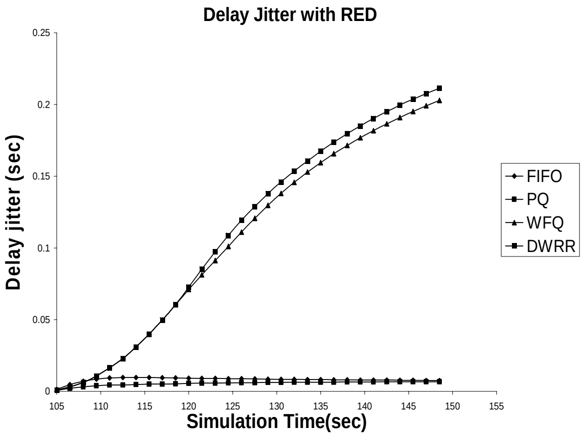

Fig.14 Delay jitter with RED policy

7 Conclusion

We end up with the conclusion that DWRR gives the minimum queuing delay for multi-class traffic. Moreover, the packet drop rate is also minimal in case DWRR although PQ and WFQ are also very close to it. DWRR and WFQ queuing schemes maintain fairness well, as already discussed in Section 6, which is also in agreement with [10]. However, these schemes fail to produce acceptable results with respect to delay jitter and end-to-end delay as they offer no guarantee to be within the minimum threshold. We admit that there is further work required to extrapolate all the advantages of DWRR over other queuing disciplines. OPNET provides a very impressive and real environment like picture what happens to the network performance when we change the queuing discipline.

8 Acknowledgment

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