Exploration of the Effectiveness of a Priority Queueing Router to Re-Order Packets

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***Abstract*—This project simulates a priority queueing router in an effort to re-order packets before they arrive at their destination.**

We explore whether or not a priority queueing router has a significant effect on the order of the packets as they arrive.

Afterwards we also compare this system to a single queueing router to see, with some level of confidence, if the priority queueing is effective.

I. INTRODUCTION

THIS project is an exploration of the effects of a priority queue on the ordering of packets with a Java simulation of the system.

When a user is requesting information from a source, the packets of data sent often do not arrive in a constant time and, therefore, even if the packets are sent at a steady rate or at some fairly evenly distributed times, the variance of times in the delay between the source and the users home or office affects the order of the packets as they arrive at the router. The router may try to alleviate the cost to the destination of reordering the packets upon arrival.

Using a simulated priority queueing router we explore whether the priority queue significantly effects the order of packets to alleviate some of the cost to the destination of re-ordering packets on arrival.

II. SIMULATION MODEL

To build a matching model in the simplest way we simulate a source sending packets, a router with a priority queue, and a destination.

The source will send packets Poisson distributed at a given average. The packets will have a normally distributed delay in it's time between the departure from the source and it's arrival at the router.

Two router models will be used. One is a priority queue that prioritizes any packet that it gets that is below the highest sequence number packet it has received so far. By prioritizing those packets to be sent to the final destination it is presumed that they will become better ordered when they arrive at the destination than a single queue model router. In that regards, the second router model will be a single queue so that a comparison can be made.

The transmission rate of the router, in other words, service rate, is constant dependent on the size of the packets and the propogation from the router to the destination is considered constant. In this simulation the packets sent from the source will be constant in size giving a constant transmission time.

III. SIMULATION GOALS AND PARAMETERS

The intention of the simulation is to explore if there is a significant improvement in packet ordering at the destination with different levels of source delay for a router using a priority queue based on the sequence number of the packet compared to a router with a single queue.

The simulation will be run on different source delay means and variances and at two expected server utilization rates, those being 60% and 90%. These simulations will be run both with a priority queue model and a single queue model.

The router to destination delay will be set at a constant 50 ms.

The packet sizes will be 1000 Bytes. The transmission rate will be 15 Mbps. This gives us a service rate of 1250 packets/second.

To have a server utilization of 60% we need $1250(0.60)$ packets/second $=$ 750 packets/second $\approx$ $1/0.00133333$ packets/second. So the simulation will use 0.00133333 as the mean for the Poisson distribution to try to achive a 60% server utilization. By a similar calculation the mean for a 90% server utilization will be 0.00088889.

To get an idea of source delays UNIX's ping can be used. For example, for 20 packets the following values were calculated:

- http://www.reddit.com, mean: 18.19 ms, sd: 4.74 ms
- http://www.uvic.ca, mean: 19.08 ms, sd: 5.59 ms
- http://www.wikipedia.org, mean: 88.23 ms, sd: 6.55 ms
- http://www.amazon.ca, mean: 104.24 ms, sd: 18.74 ms

This gives an idea of the range of means and standard deviations for the source delay. The values used for this simulation are:

- Mean: 20 ms, Standard Deviation: 5 ms
- Mean: 100 ms, Standard Deviation: 25 ms
- Mean: 250 ms, Standard Deviation: 50 ms

Using these values allows exploration into the effects of packet ordering upon arrival at the router based on different source delays as well as how the priority queue effects it.

Each time the simulation it will simulate up until 5000000 packets arrive at the destination. This ensures enough packets are run so that theoretical values for server utilization and packet loss and order are met.

IV. SIMULATION METHODOLOGY

A. Validity of Simulation Model

The simulation uses discrete packet events to simulate the system. There are four different types of events in this simulation:

1) Packet departure from source
2) Packet arrival at router
3) Packet departure from router
4) Packet arrival at destination

The events are ordered in a priority queue and the next event according to the time of the events is next to be examined by the program.

When a packet i departs from the source, a new packet $i + 1$ is created and it's departure is planned according to an exponential distribution with its mean being the inverse of Poisson distributions mean. This is given by the current time on the clock plus a transformation of a uniform distribution to an exponential distribution. Given U_i, a uniformly distributed random variate, the calculation is:

$$E_i = -\mu \ln(U_i)$$

This gives us $E \sim \text{Exp}(\mu)$ where $\mu = 1/\lambda$ with lambda as the average rate of departure of packets from the source.

As well, during the departure of the packet from the source, an event is added to the events priority queue. This event is normally distributed from the current time, though only positive values of the normal will be used. Given a mean and standard distribution the Box-Muller transform [1] from a uniformly distributed variable to a normally distrubuted variable is performed. This creates two normals. The second is saved for later use.

Upon arrival of the packet the simulation checks if there is a packet in service already. If not, it's departure from the router is scheduled according to the given transmission rate. If there is it enters the queue. In the priority queue model, if the packet has a sequence number less than the highest seen so far it enters the high priority queue, and otherwise the low priority queue. In the single queue model it simply enters the queue regardless of its sequence number. It then waits until it is scheduled for departure.

When a packet leaves the router, the simulation checks if there is another queue waiting for service and services the next in priority by scheduling it's departure from the router. The packet leaving the router has an event scheduled 50 ms from the current time for it's arrival at the destination.

These events are discrete and occur in order of time. An event can also schedule other events after it which ensures that no events are missed since a priority queue is used.

B. Setting Up Parameters for Simulations

The parameters are initialized at the start of the simulation. The code user can adjust the the total number of users that need to run through the simulation. The packet size, router to destination delay and transmission rate can be changed, but, for the purposes of this report, are not.

The user can also adjust the average interarrival time and mean and standard deviation for the source delay. These are used by a random variate class that also uses the random stream and makes it's calculations based on these values to plan future events.

C. Collection of Statistics

Many different statistics are calculated over the run of the simulation. Each packets time in system, queue, total in the router, and interarrival time is counted. These are averaged at the end of the simulation. The source delay and router utilization are calculated for posterity and comparison to the true means.

Everytime a packet arrives at the router the dropped and in order counters are incremented according to if there is no room in the router or if the sequence number is larger than the largest seen so far, respectively. A percentage is calculated based on the number of total packets that made it to the router.

Every time a packet arrives at the destination the in order count is incremented if the packet is the largest to have made it to the destination so far. A percentage calculated based on the number of total packets that made it to the destination.

V. Analysis

A. Statistics Collected

Five different seeds were used for each scenario with three different parameters for the normally distributed source delay. The first is a priority queueing model with a source packet rate of 750 packets per second as shown in Table I.

TABLE I
PRIORITY QUEUE WITH 750 PACKETS PER SECOND.

Delay	Statistic Calculated	Seed				
μ, σ		50	100	150	200	250
20,5	Out of order rate (%)	64.64	64.65	64.63	64.65	64.63
	Avg system time (ms)	21.4	21.4	21.4	21.4	21.4
100,25	Out of order rate (%)	89.33	89.31	89.32	89.34	89.34
	Avg system time (ms)	101.4	101.4	101.4	101.4	101.4
250,50	Out of order rate (%)	94.04	94.04	94.04	94.04	94.04
	Avg system time (ms)	251.4	251.4	251.4	251.4	251.4

With 1125 packets per second and a theoretical 90% server utilization the values in Table II were calculated.

TABLE II
PRIORITY QUEUE WITH 1125 PACKETS PER SECOND.

Delay	Statistic Calculated	Seed				
μ, σ		50	100	150	200	250
20,5	Out of order rate (%)	69.29	69.29	69.27	69.29	69.26
	Avg system time (ms)	24.4	24.4	24.4	24.4	24.4
100,25	Out of order rate (%)	90.56	90.54	90.55	90.56	90.55
	Avg system time (ms)	104.4	104.4	104.4	104.4	104.4
250,50	Out of order rate (%)	94.79	94.80	94.78	94.81	94.80
	Avg system time (ms)	254.4	254.4	254.4	254.3	254.4

With 750 packets per second and a theoretical 60% server utilization with a single queue router the values in Table III were calculated.

With 1125 packets per second and a theoretical 90% server utilization with a single queue router the values in Table IV were calculated.

TABLE III
SINGLE QUEUE WITH 750 PACKETS PER SECOND.

Delay	Statistic Calculated	Seed				
μ, σ		50	100	150	200	250
20,5	Out of order rate (%)	67.19	67.21	67.20	67.20	67.19
	Avg system time (ms)	21.4	21.4	21.4	21.4	21.4
100,25	Out of order rate (%)	89.86	89.83	89.85	89.87	89.86
	Avg system time (ms)	101.4	101.4	101.4	101.4	101.4
250,50	Out of order rate (%)	94.25	94.25	94.26	94.26	94.26
	Avg system time (ms)	251.4	251.4	251.4	251.4	251.4

TABLE IV
SINGLE QUEUE WITH 1125 PACKETS PER SECOND.

Delay	Statistic Calculated	Seed				
μ, σ		50	100	150	200	250
20,5	Out of order rate (%)	74.93	74.93	74.92	74.93	74.93
	Avg system time (ms)	24.4	24.4	24.4	24.4	24.4
100,25	Out of order rate (%)	92.71	92.68	92.69	92.71	92.69
	Avg system time (ms)	104.4	104.4	104.4	104.4	104.4
250,50	Out of order rate (%)	95.92	95.93	95.91	95.92	95.93
	Avg system time (ms)	254.4	254.4	254.4	254.3	254.4

B. Output Analysis for Priority Queue Model

To calculate confidence intervals of 95% for each experiment we perform the following calculations as exemplified with case of 750 packets/second and source delay average of 20 ms and standard deviation of 5 ms. Here Y is the package out of order rate as a function of source departure time, source delay mean, and source delay standard deviation:

$$\begin{aligned}\overline{Y}_1(750, 20, 5) &= 64.64\\ S &= 0.01\\ \text{s.e.}(\overline{Y}_1(750, 20, 5)) &= S/\sqrt{5}\\ &= 0.0045\\ t_{0.025,4} &= 2.13\\ 64.63 \leq Y_1&(750, 20, 5) \leq 64.65\end{aligned}$$

Using the same method we calculate the following confidence intervals:

$$\begin{aligned}89.32 &\leq Y_1(750, 100, 25) \leq 89.34\\ 94.04 &\leq Y_1(750, 250, 50) \leq 94.04\\ 69.27 &\leq Y_1(1125, 20, 5) \leq 69.29\\ 90.54 &\leq Y_1(1125, 100, 25) \leq 90.56\\ 94.78 &\leq Y_1(1125, 250, 50) \leq 94.81\end{aligned}$$

C. Output Analysis for Single Queue Model

Doing the same calculation for the single queue model we get:

$$\begin{aligned}67.19 &\leq Y_2(750, 20, 5) \leq 67.21\\ 89.84 &\leq Y_2(750, 100, 25) \leq 89.87\\ 94.25 &\leq Y_2(750, 250, 50) \leq 94.26\\ 74.92 &\leq Y_2(1125, 20, 5) \leq 74.93\\ 92.68 &\leq Y_2(1125, 100, 25) \leq 92.71\\ 95.91 &\leq Y_2(1125, 250, 50) \leq 95.93\end{aligned}$$

D. Comparison of Priority and Single Queue Models

We assume the priority queue will have a smaller out of order rate so our hypotheses are as follows:
H_0: $Y_1 - Y_2 > 0$
H_0: $Y_1 - Y_2 \leq 0$

We calculate $\overline{Y}_{\bullet 1} = 83.77$ and $\overline{Y}_{\bullet 2} = 85.81$. Given the above values we have $S^2_{\bullet i} = 11.626$ and $S^2_p = 11.626 = 3.410^2$.

So:

$$\text{s.e.}(\overline{Y}_{\bullet 1} - \overline{Y}_{\bullet 2}) = S_p\sqrt{\frac{1}{R_1} + \frac{1}{R_2}} = 0.8804$$

With $v = R_1 + R_2 - 2 = 58$ degrees of freedom, for $\alpha = 0.05$, $t_{0.025,58} = 2.3011$

So our confidence interval for the performance difference is:

$$(\overline{Y}_{\bullet 1} - \overline{Y}_{\bullet 2}) \pm t_{0.025,58}\text{s.e.}(\overline{Y}_{\bullet 1} - \overline{Y}_{\bullet 2})$$

$$-2.07 \leq Y_1 - Y_2 \leq -0.01$$

So at this level of confidence we do not reject the null hypothesis and continue to predict that the out of order rate is higher for the priority queueing system than the single queue system.

VI. CONCLUSION

We predict, with a 95% level of confidence, that the priority queueing router improves the out of order rate. In the future this study can be repeated with different server utilizations, more significant jitter or more significantly, a different priority queueing method. In future exploration there can also be a comparison of queueing time for packets and overall system time for packets compared with different queueing methods.

REFERENCES

[1] T. Shinzato. *Box Muller Method*. http://http://www.lmpt.univ-tours.fr/~nicolis/Licence_NEW/08-09/boxmuller.pdf.
[2] J. Banks *et al.*, *Discrete-Event System Simulation*, 4th ed., Pearson, 2005.