CSC 446: Operations Research: Simulation

Priority Queueing to Alleviate Packet Re-ordering Problem

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1.0 Introduction

The goal of this project is to create and utilize a simulation to aid in analyzing a solution to a specific problem. The problem being explored by this project is the default project topic proposed: Priority Queuing to Alleviate Packet Re-ordering Problem [1]. The project details follow the requirements in the project topic provided, including the adjustments made in the announcement [2], and are described in section 1.2.

1.1 Background

Data packets transmitted across the internet from a source to a destination may experience a variance in delays, causing them to arrive to the destination in an order different than the source intended. One way to avoid this problem is with the addition of a priority queue between the source and destination which aids in maintaining proper packed order.

1.2 Project Description

This project investigates the extent that the inclusion of a priority queue in an intermediary router helps mitigate the problem of packets reordering from the source to the destination in a system. Each packet including a unique sequence number, and having a length of 1000 bytes. The source being a source node which transmits data along the network with exponential distribution at an average rate of 20 packets per second with a transmission speed of 10 Mbps. The packets transmitted from the source node are delayed by a normal distribution with mean x and standard deviation y on their journey to the router. The router, having a high priority queue and a low priority queue, compares the sequence number of the incoming packet to the highest packet sequence number it has seen so far, called currentSeq. The incoming packet is added to the high priority queue if its sequence number is smaller than currentSeq, or added to the low priority queue if it is larger than currentSeq. The router is only idle if both queues are empty and it is not currently transmitting a packet. If a packet arrives while the router is idle, it will immediately grab the packet. The router will take from the high priority queue first unless it is empty, where it will then grab from the low priority queue. If the router receives a high priority packet while it is in the middle of transmitting a low priority packet, it will finish transmitting the current packet before taking the high priority packet next. The priority queues each have a size of 10MB and will drop packets if they are received while at capacity. Once transmitted from the router at a speed of 10Mbps, the packet will arrive at the destination with a fixed delay of 50 ms. It is important to note the conversion between Bytes, B, and bits, b; one Byte consisting of 8 bits.

2.0 Simulation

The following section outlines the entire simulation build specifications and details.

2.1 Simulation Model

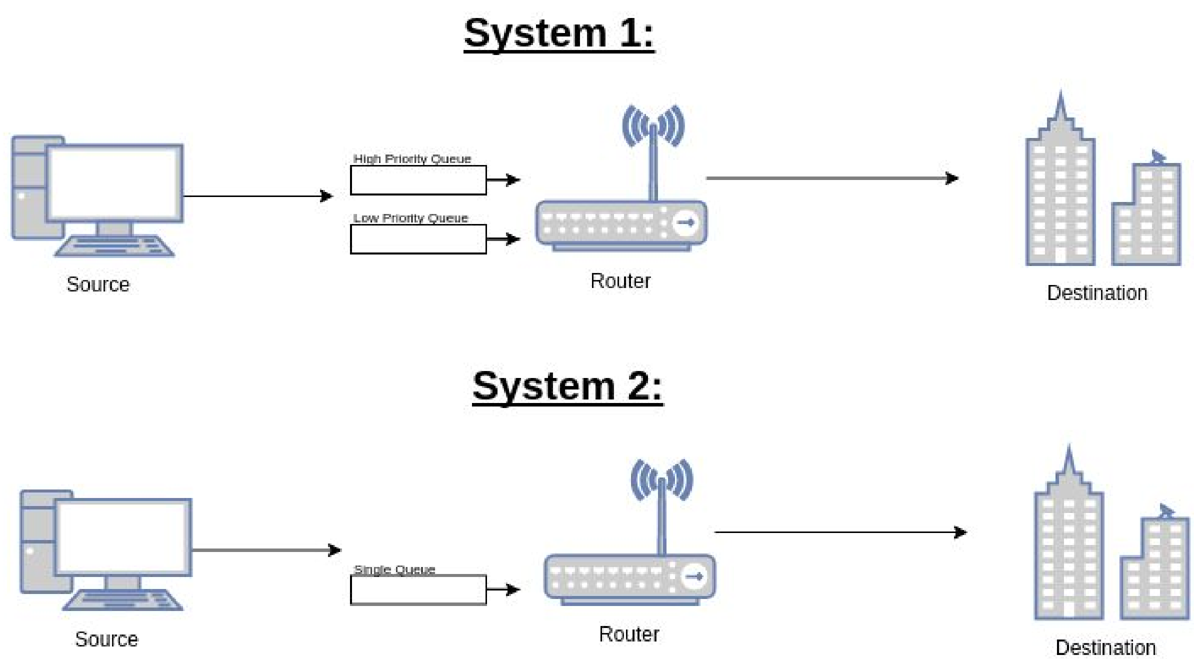


Figure 1: Overview of system models.

System Queues

Two different simulation models will be evaluated to address the packet reordering problem. System 1 will contain two queues max queue size 10,000 packets and system 2 will contain a single queue max size containing 20,000 packets. For each of the respective systems the queueing strategy is FIFO. Where the queues which will address the packets according to when they arrive to the router system.

System 1 Packet Ordering:
The system uses two queues marked high and low. An incoming packet is marked as inorder if the router current sequence number is less than the incoming packet sequence and placed into the low priority queue. The incoming packet is marked as out of order if the router current sequence number is greater than the incoming packet and placed into the high queue. The packets are ordered within the respective queues according to a FIFO.

System 2 Packet Ordering:
An incoming packet will be placed into the single queue and will be served according to a FIFO strategy.

System 1 Router service:
If there is nothing in the queues the incoming packet will be placed into service.
The router current sequence number will be updated to the packet sequence number if the incoming packet sequence number is greater than the current router sequence. The packet will be marked as an inorder packet. Otherwise, it will be marked as an out of order packet and the router current sequence number is not changed.
If there is something in either of the queues. The router will take from the high priority first, update the its' current sequence number if needed and place the packet into service. If there is nothing in the high priority queue it will take from the low priority and place into service.
The router will always take the high priority before the low priority if there are packets in both.

System 2 Router service:
If there is nothing in the single queue, the incoming packet will be place into service.
The router current sequence number is updated in the same way as system 1, however the packet will be placed into a single with no regard to an inorder or out of order packet.

2.3 Simulation Build

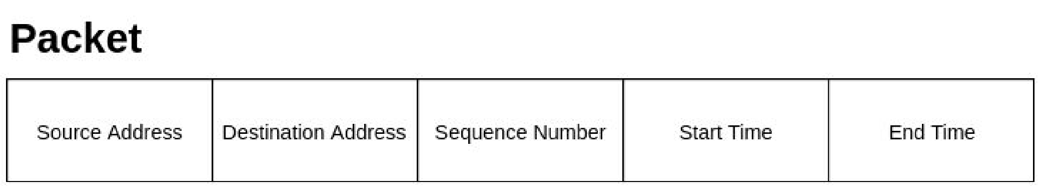


Figure 2: Objects used in system.

A packet object consists of the following:
1. **Source Address**: an integer representing one of the nodes
2. **Destination Address**: an integer representing of the nodes

3. **Sequence number**: a unique integer identifier, representing the ordering of the packet creations from the source
4. **Start time**: time that the packet leaves the source
5. **End time**: time that the packet arrives successfully at the destination

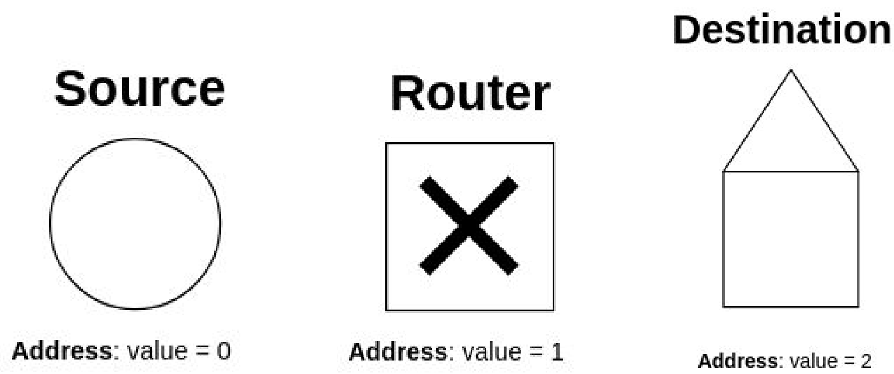


Figure 3: Addresses of interest within the system.

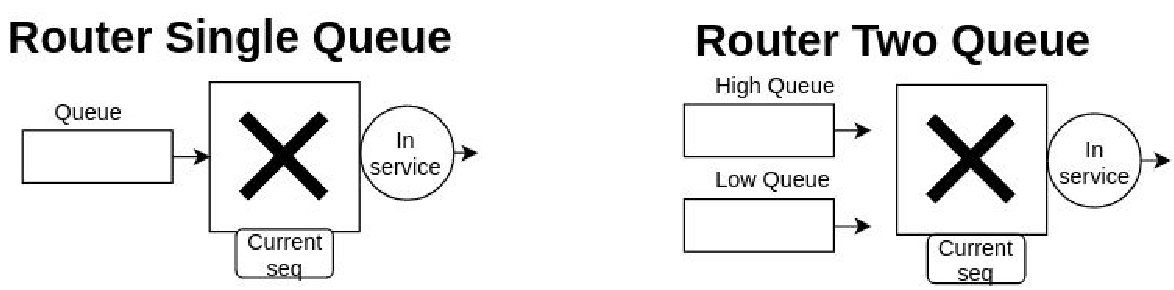


Figure 4: Router system object.

1. **Current Seq:** an integer value that changes depending on the incoming packet
2. **Queue:** holds the packets if there is a packet in service
3. **Inservice:** holds the packet that is being serviced

As the project stands there are 4 different types of the router systems that will be evaluated.

1. **RouterSingleFIFONode**: a single FIFO queue
2. **RouterTwoFIFONode:** two FIFO queues that order the packets into each respective queue based on the router current seq number. Serves from high first.

The following queueing strategies are outside of the scope of the project but evaluate how the use of priority queues for the queueing strategy change the outcomes.

3. **RouterSinglePriorityNode:** a single priority queue which orders the packets within the queue based off of the sequence number. Lower served first.
4. **RouterTwoPriorityNode:** two priority queues that order the packets within the queues based off the lowest sequence number. Lower served first. And places them into each respective queue based on the router current seq number. Serves from high first.

2.4 Initial Simulation Values

Total packets = 1,000,000
Source time to transmit per packet = 1/1250
Source mean inter departure time = exp (1/1150) or exp (1/750)
Source to router dealy = normal distribution, mean = 0, s.d = 0.1

2.5 Statistics Collection

How are the follow statistics collected:

1. **Total Packets:** calculated as the total number packets that are created and sent from the source node.
2. **Out of order router packets:** Defined as per project outline, as the number of packets that arrive with a sequence number less than the current sequence number at the router. This means that the router has already seen a packet that is larger than the one that is arriving.
3. **In order router packets:** Defined as the number of packets that arrive at the router the node that have a sequence number larger that the router current sequence number
4. **No queued packets:** Defined as the number packets that enter directly into router service spot without entering a queue.
5. **Dropped packets:** Defined as the number of packets that try to enter the router system but find their appropriate queue full. These packets are dropped from the system and will not arrive at the destination.
6. **Destination arrivals:** Defined as the number of successful packets that arrive to the destination.
7. **Out of order destination packets:** Defined as the number of packets that arrive at the destination with a sequence number less than the highest packet seen so far.
   Please consider the following example as further clarification:

Assume that the destination receives the packets in the following order:

1 4 2 3 6

```
0: -1 is set as the current highest packet
1: Examines packet 1: 1 is set as the current highest packet
2: Examines packet 4: 4 is set as the current highest packet
3: Examines packet 2: 2 is less than current highest packet
4, out of order packets increases by 1
4: Examines packet 3: 3 is less than current highest packet
4, out of order packets increases by 1
5: Examines packet 6: 6 is set as the current highest packet
```

The number of out of order packets in this sequence is **2**

3.0 Analysis

The simulation is ran in accordance with the guidelines included in the provided problem description [1]. There will be two scenarios, being two different combinations of mean x and standard deviation y for the normal distribution delay of packets transmitted from the source node to the router. Each scenario is ran with 5 different seeds and for long enough to produce sufficient data. For each run, the stats collected and compared will be the packet out-of-order rate, average packet delay, and average packet loss rate. Each metric will include a confidence interval which is calculated with a confidence level of 95%.

3.1 Analysis of average packet delay:

3.1.1 Theoretical discussion

Delay: Defined as average time from the creation of the packet to the time the packet arrives at the destination.

Packets are created with an **average inter departure time** of $1/\lambda$. Where λ is the average amount of packets created per second.
Then the packets will be **serviced** at a fixed time of 1/1250 seconds per packet at the source.

The packets have a **normally distributed delay** before they arrive at the router queueing system. If there is a queue they will wait until they may be serviced. At which time the r**outer service time** is a fixed amount. Finally, they receive a fixed delay before they reach the destination.

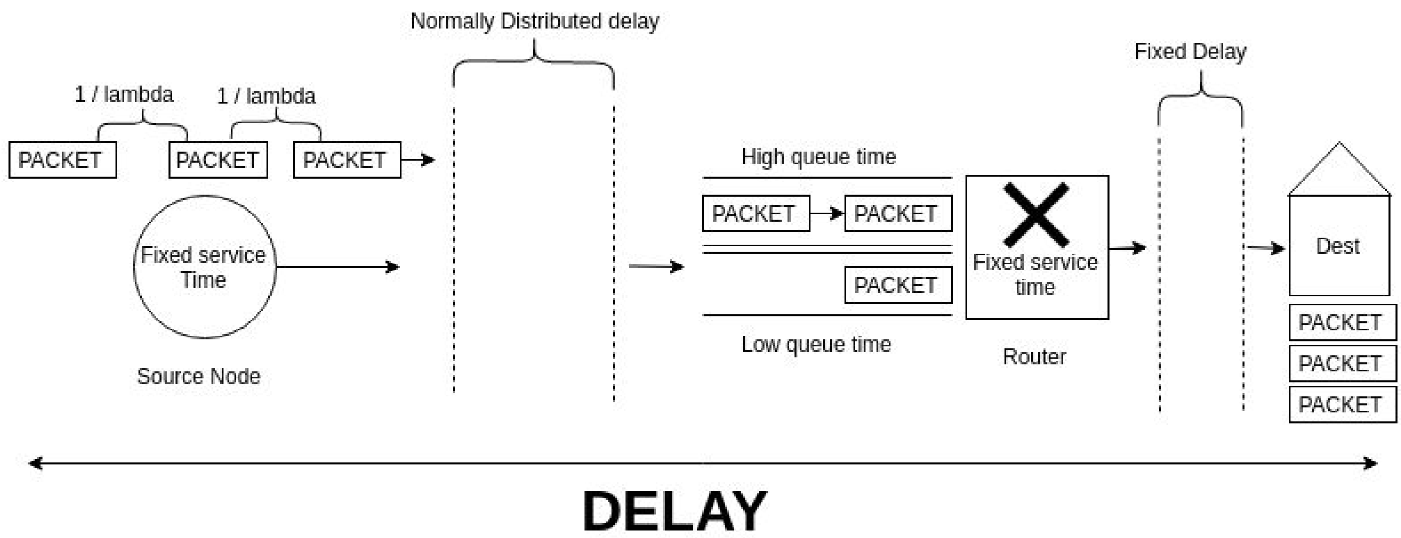


Figure 5: Illustration of delay across system.

$$Delay\ = source\ service\ +\ normal\ delay\ +\ time\ in\ queueing\ system\ +\ router\ service\ time\ +\ fixed\ delay$$

Let:

x : mean of normal distribution

h : size of the high queue

l : size of the low queue

f : fixed destination delay

r : service time of router

These calculations are assuming 2 FIFO queues:

<u>Case of out order packet:</u>

$$DelayOut\ =\ 1/\lambda\ +\ x\ + h(r) + r\ +\ f$$

Packet enters high priority queue

<u>Case of in order packet</u>

$$DelayIn\ =\ 1/\lambda\ +\ x\ + h(r)\ +\ l(r) + r\ +\ f$$

Packet enters low priority queue

The amount of inorder and out of order packets at the router will be determine by the normally distributed delay.

3.1.2 Simulated Claims

Let's consider a simple case:

Case: Consider the case that all of the packets arrive at the router with in order, meaning that the normally distributed delay standard deviation is 0:

The packets arriving at the router should not queue with X = 0, and Y= 0, since the service time of the source and router is 1/1250 and 1/1250 respectively.
So theoretically our delay for this example should be

Claim: Never queue, since service packets arrive to router after previous packet had already been served. (1/1250 + 1/1250) > 1/1250

$$= 1/1250 + 0 + 0 + 1/1250 + 0.05 = 0.516$$

Simulation Parameters Used

Statistic	**Value**
X	0
Y	0
Router service	1/1250
Source interdeparture + source service	1/1250 + 1/1250

Case	**Simulated delay**	**Theoretical delay**
0	0.5159999	0.516

```
---------------Data--------------------

OCCURENCES OF IMPORTANT EVENTS
       Total packets sent:           100000
       Out of order router packets:  0
       In order router packets:      100000
       No Queued packets:            100000
       Dropped packets:              0
       Destination arrivals:         100000

RATIOS OF IMPORTANT EVENTS
       Packet out of order Router rate:
0.0
       Packet in router order rate:
1.0
       No queued packet rated:
1.0
       Average packet loss rate:
0.0
       Average packet success rate:  1.0
       Average packet delay rate:
0.05159999999987024

ROUTER INFORMATION
       Max L queue: 0
       Max H queue: 0
```

```
DESTINATION INFORMATION                                     Packet out of order ratio:
       Out of order destination packets:           0.0
0
```

Notice that the queue max queue size is 0 as expected:

Average packet delay with normally distributed router arrival delay:
Mean delay X = 0.1

Standard Deviation	**Packet delay one queue**	**Packet delay two queues**
0	0.05159999999987024	0.05159999999987024
0.1	0.13139881589454663	0.1313988158945461
0.2	0.21095975437461217	0.2109597543746116
0.3	0.29051931560754973	0.29051931560755007
0.4	0.37008168561340715	0.37008168561340693
0.5	0.44964298259988944	0.44964298259988983
-	-	-
1.0	0.8474464128736532	0.8474464128736494
2.0	1.6430485943732798	1.6430485943732722
3.0	2.438656284071667	2.4386562840716617
4.0	3.234268654641571	3.234268654641581
5.0	4.029874563101231	4.029874563101232

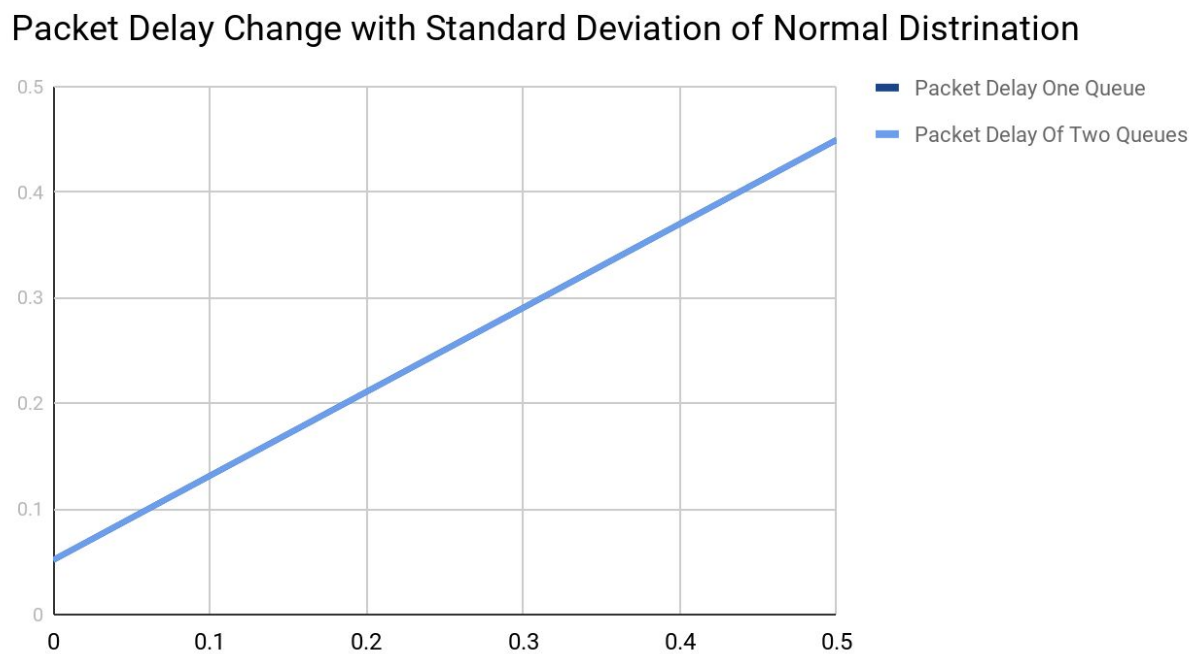


Figure 6: Packet Delay Change with Standard Deviation of Normal

Average packet delay: The above graph illustrates that as we increase standard deviation of the router delay, the packet delay increases at a linear rate. With no difference in a one or two queueing system.

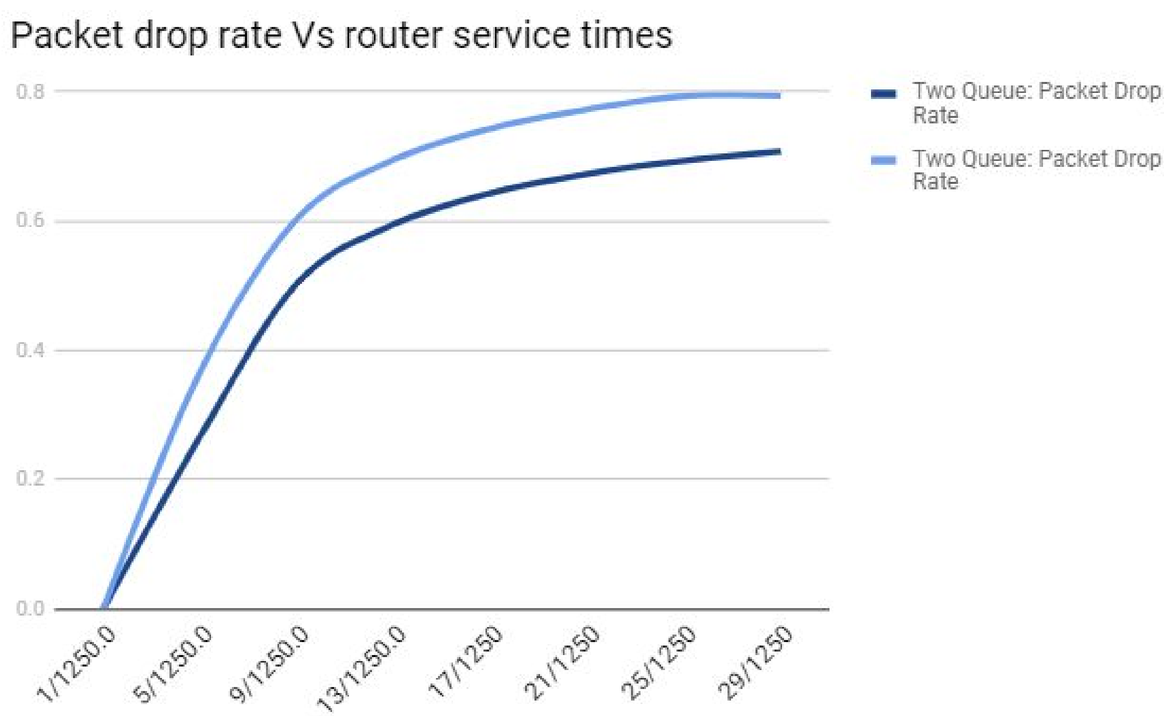
3.2 Analyzing Data Against Changing Router Server Times

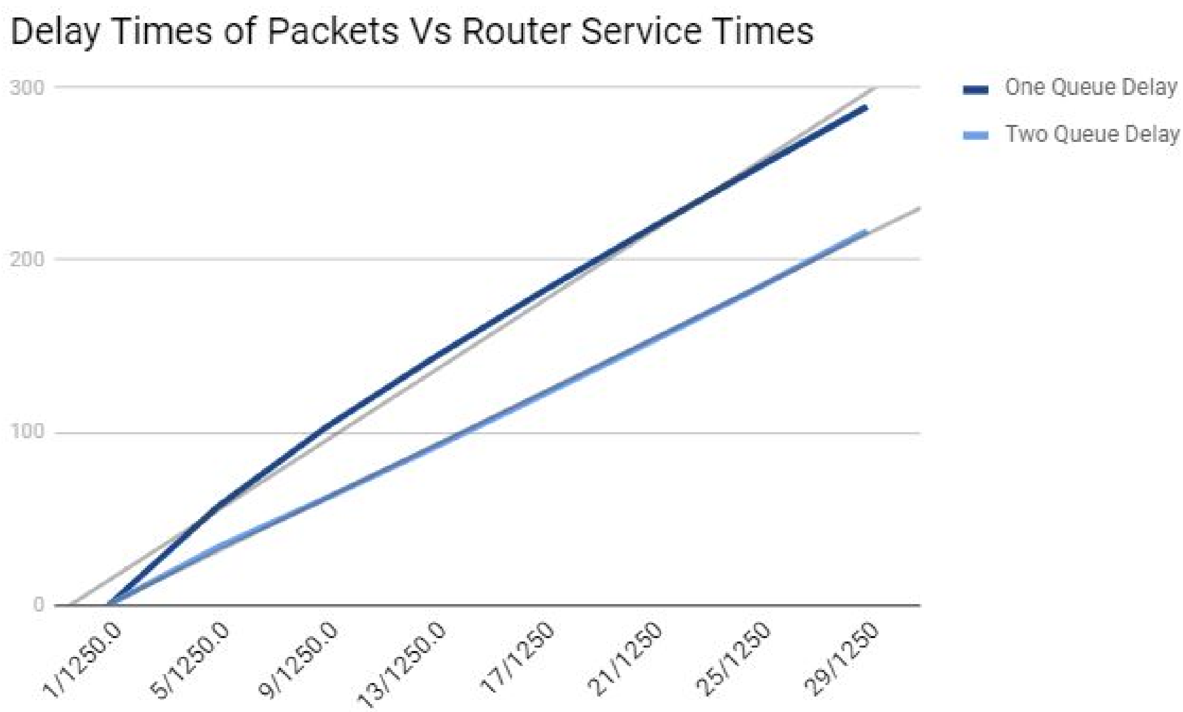
The following section will analyze the drop rate of packets as the service time at the router increases from the base 10MBps, 1/1250 packets per second.

The following test is conducted with x = 0, and y = 0.01

Router service time per packet (seconds)	One Queue Delay	One Queue: Packet Drop rate:	Two Queue Delay	Two Queue: Packet Drop Rate
1/1250.0	0.05976007175703615	0	0.05976007175703606	0
5/1250.0	56.716998833526155	0.26681	33.309534184940595	0.3668
9/1250.0	102.84778105077712	0.50378	61.782761732529586	0.60376
13/1250.0	143.48761266968	0.59492	91.3506249	0.69491

	614			
17/1250	181.68196240788353	0.64317	121.7204148	0.74317
21/1250	218.38163583435212	0.67304	152.6910948	0.77304
25/1250	254.0758043194636	0.69336	184.1225594	0.79335
29/1250	289.0634436273835	0.70807	217.0147182	0.79408





The delay times and router service times seems to increase at a linear rate.
The packet drop rate and router service times seem to increase at a logarithmic rate.

3.3 Scenario 1: Priority Queue at 60% Utilization

The first scenario will simulate the case where the router is running at 60% utilization and will be ran with the following values:

x	0
y	0.01
Average Router Arrival Rate	750 packets/second
Packets Sent	1,000,000

Scenario 1	Packet Out of Order Rate at Router	Packet Out of Order Rate at Destination	Average Packet Delay	Average Packet Loss Rate
Run 1	0.512221	0.505265	0.05978509553	0

Run 2	0.512437	0.505508	0.05978647252	0
Run 3	0.512695	0.505565	0.05979077337	0
Run 4	0.512972	0.50597	0.05979248976	0
Run 5	0.512612	0.505601	0.05977993673	0
Average	0.5125874	0.5055818	0.05978695358	0
Standard Deviation	0.0002815000888	0.0002535541362	0.000004953789243	0
Confidence Interval	±0.000349976	±0.000315232	±0.00000615882	0

3.4 Scenario 2: Priority Queue at 90% Utilization

The second scenario will simulate the case where the router is running at 90% utilization and will be ran with the following values:

x	0
y	0.01
Average Router Arrival Rate	1125 packets/second
Packets Sent	1000000

Scenario 2	Packet Out of Order Rate at Router	Packet Out of Order Rate at Destination	Average Packet Delay	Average Packet Loss Rate
Run 1	0.556868	0.545568	0.05987539656	0
Run 2	0.557091	0.545403	0.05987698165	0
Run 3	0.557324	0.545849	0.05988101493	0
Run 4	0.557145	0.545484	0.05988329888	0
Run 5	0.556982	0.545512	0.05986999565	0
Average	0.557082	0.5455632	0.05987733753	0
Standard Deviation	0.0001720537707	0.0001704866564	0.000005168611111	0
Confidence Interval	±0.000213907	±0.000211959	±0.00000642589	0

3.5 FIFO Queue at 60% Utilization

This section will simulate the scenario of 60% utilization on a router using a FIFO queue instead of a priority queuing system. For comparison purposes, this scenario will use the same values as scenario 1:

x	0
y	0.01
Average Router Arrival Rate	750 packets/second
Packets Sent	1000000

FIFO Queue at 60% Utilization	Packet Out-of-Order Rate at Destination	Average packet delay	Average Packet Loss Rate
Run 1	0.512221	0.05978509553	0
Run 2	0.512437	0.05978647252	0
Run 3	0.512695	0.05979077337	0
Run 4	0.512972	0.05979248976	0
Run 5	0.512612	0.05977993673	0
Average	0.5125874	0.05978695358	0
Standard Deviation	0.0002815000888	0.000004953789242	0
Confidence Interval	±0.000349976	±0.00000615882	0

3.6 FIFO Queue at 90% Utilization

This section will simulate the scenario of 90% utilization on a router using a FIFO queue instead of a priority queuing system. For comparison purposes, this scenario will use the same values as scenario 2:

x	0
y	0.01
Average Router Arrival Rate	1125 packets/second
Packets Sent	1000000

FIFO Queue at 90% Utilization	Packet Out-of-Order rate at Destination	Average Packet Delay	Average Packet Loss Rate
Run 1	0.556868	0.05987539656	0
Run 2	0.557091	0.05987698165	0

Run 3	0.557324	0.05988101493	0
Run 4	0.557145	0.05988329888	0
Run 5	0.556982	0.05986999565	0
Average	0.557082	0.05987733753	0
Standard Deviation	0.0001720537707	0.000005168611111	0
Confidence Interval	±0.000213907	±0.00000642589	0

3.7 Comparison of Results

60% Utilization	Average Packet Out-of-Order rate at Destination
Priority Queues	0.5055818±0.000315232
FIFO Queue	0.5125874±0.000349976
Difference	0.0070056±4.28563×10^-8

90% Utilization	Average Packet Out-of-Order rate at Destination
Priority Queues	0.5455632±0.000211959
FIFO Queue	0.557082±0.000213907
Difference	0.0115188±1.15771×10^-7

Comparing the results between the priority queuing router and the single FIFO queuing router, it is noticed that there is no difference between packet out-of-order rate at the router and average packet delay, within 60% 90% utilization cases due to the use of the same seeds on each run. The interesting values to compare are the average packet out-of-order rates at the destination. In the 60% utilization case, the priority queueing router improved on the simple FIFO router by ~0.7%. In the 90% utilization case, the priority queuing router made an improvement of ~1.2% on the FIFO router. This makes sense, since the priority queues are only affecting order when they have a chance to fill and partially sort packets. Since 60% router utilization is lower than 90%, packets don't accumulate at the router as much, and therefore experience less sorting. If the queues are always empty, the priority queuing router will not affect packet order, since it would effectively act the same as a single FIFO queue.

A priority queuing router is superior to a single FIFO queuing router in alleviating the problem of packets reaching the destination out of order; most significantly in a busier system, where the router is reaching its full utilization.

4.0 Conclusion

Since there is a variance in delay when sending packets along a network, the problem arises where packets may reach their destination in an unintended order. A basic router which essentially acts as a FIFO queue will not aid in resolving the issue. However, improvements can be made to the router to help alleviate the disorder of packet arrivals at the destination. This project simulated a modified router which has two FIFO queues which aid in prioritizing packets arriving from the source. This minor modification was able to help alleviate the problem by 0.7% when running at 60% of its utilization, and 1.2% when at 90% of its utilization. Although a seemingly minor improvement, when looking at the volume of packets sent, is significant enough to consider upgrading to a prioritizing router. Cases in which the FIFO router should not be upgraded are when they are not being taken near their full utilization, as the prioritizing router would show minimal improvement, essentially acting as a single FIFO queue router.

Although the priority queuing router made an improvement on the FIFO router, there still seems to be major room for improvement considering 51% of packets reached their destination out-of-order in the 60% utilization scenario, and 56% in the 90% utilization scenario. Possible future improvements on the router which should be explored are the addition of queues, smart queues which can order packets within, and the ability for the router to add a delay to packets which would allow it to sort packets before sending to the destination (in the case where order is more important than delay from source to destination).

5.0 References

[1] "Priority Queueing to Alleviate Packet Re-ordering Problem," *Project.pdf*, [Online]. Available: https://connex.csc.uvic.ca/access/content/group/b734f8c1-6466-48c4-9f77-0f979ba6b5c9/Project.pdf, [Accessed: November 25, 2018].

[2] K. Wu, "Important, Please Read: server utilization and due date," *Connex Announcement*, [Online]. Available: https://connex.csc.uvic.ca/portal/tool/8300078c-9633-4074-b8ea-fff2c26e92f0?panel=Main, November 22, 2018 [Accessed: November 25, 2018].