National University of Singapore
School of Computing
CS5229: Advanced Computer Networks
Semester I, 2021/2022

Lecture 3 Training
Buffer sizing and AQMs

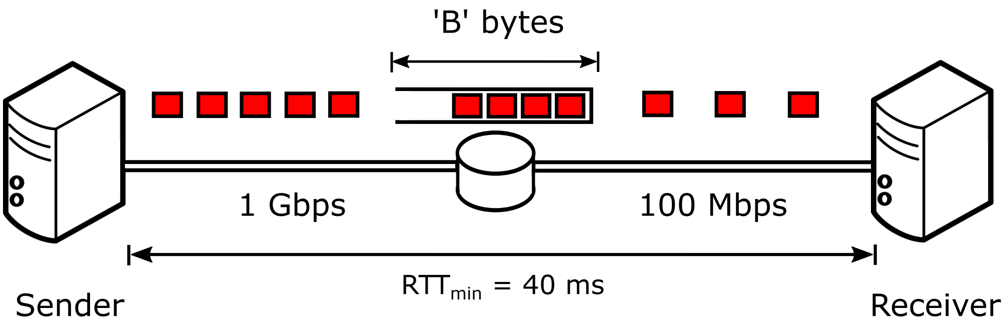

Figure 1: A simple network with a 100 Mbps bottleneck

In Lecture 3, you learnt how sizing the router buffer is crucial to ensuring link utilization with loss-based congestion control algorithms like Reno. In this training, we will explore the effects of buffer sizes on the throughput and RTT a little more.

Let's look at a simple network with 2 hosts with a 100 Mbps bottleneck link between them (Figure 1). Let the bottleneck buffer have a maximum capacity of B bytes and let RTT when the buffer is empty (RTT_{min}) be 40 ms. From the lecture, we know that if B is too small, we risk underutilizing the bottleneck. On the other hand if B is too large, there will be buffer bloat, which will increase the RTT of the connection (see Figure 2).

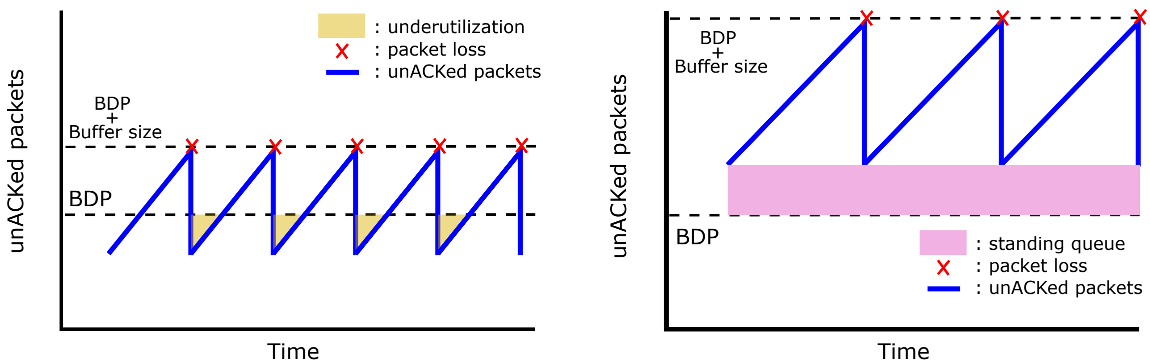

Figure 2: unACKed packets vs. time in different buffer sizes.

Assuming the sender starts a long flow (long enough for the slow start to be negligible) and uses Reno to do congestion control, answer the following questions. For simplicity sake, you can assume the time taken to drain the queue is negligible and the `cwnd` always matched the number of unACKed packets. Each packet is 1,000 bytes.

Questions

1. Calculate the average throughput and the minimum and maximum RTT when the bottleneck buffer is:
   (a) 100 Kilobytes
   (b) 500 Kilobytes
   (c) 1 Megabyte
2. In your opinion, which of the above mentioned buffer sizes is most suitable for this network, and why?

Solutions

Before answering the questions, we will first calculate the BDP of the network. This will make working easier later on:
BDP = Bandwidth × RTT = 100 Mbps × 40 ms
BDP = $500,000$ bytes

1. The average throughput whenever there is atleast 1 packet in the buffer is going to be 100 Mbps. However, when the buffer is empty, we will need to use the packets in the pipe to calculate the throughput. For calculalting the minimum and maximum RTTs, we will need to calculate the minimum and maximum queue size. If the queue size is zero, the minimum RTT will simply be 40 ms.
   (a) When the buffer size is 100 KB, the sender will be able to have a maximum cwnd of 600 KB and a minimum cwnd of $\frac{600}{2} = 300$ KB. Since Reno increases its cwnd by 1 packet every RTT, it will take $(500 - 300) = 200$ RTTs to fill the pipe again after a backoff. After this, the cwnd will continue to rise for 100 more RTTs after which there will be a packet loss in the 301^{st} RTT and the cycle will continue again.

   In this scenario since the buffer empties, the average throughput will not be the bottleneck bandwidth. We will need to use the packets in the pipe to calculate the throughput.

$$\text{Total data sent}(D) = \sum_{i=0}^{300} 300,000 + 1000i = 135,450,000 \text{ bytes}$$

   The amount of data calculated above is sent for 301 RTTs. In the first 201 of those RTTs, the buffer is empty and therefore the RTT = 40 ms. However, for the next 100 RTTs, there is a queue in the bottleneck buffer. This queue rises from 0 to 100 KB in those 100 RTTs. We can calculate the total time elapsed during the last 100 RTTs as follows:

$$= \sum_{i=1}^{100} 0.04 + i \times (0.00008) = 4.404 \text{ seconds}$$

   Therefore, the total time will be

$$\text{Total time}(t) = 201 \times 0.04 + 4.404 = 12.444 \text{ seconds}$$

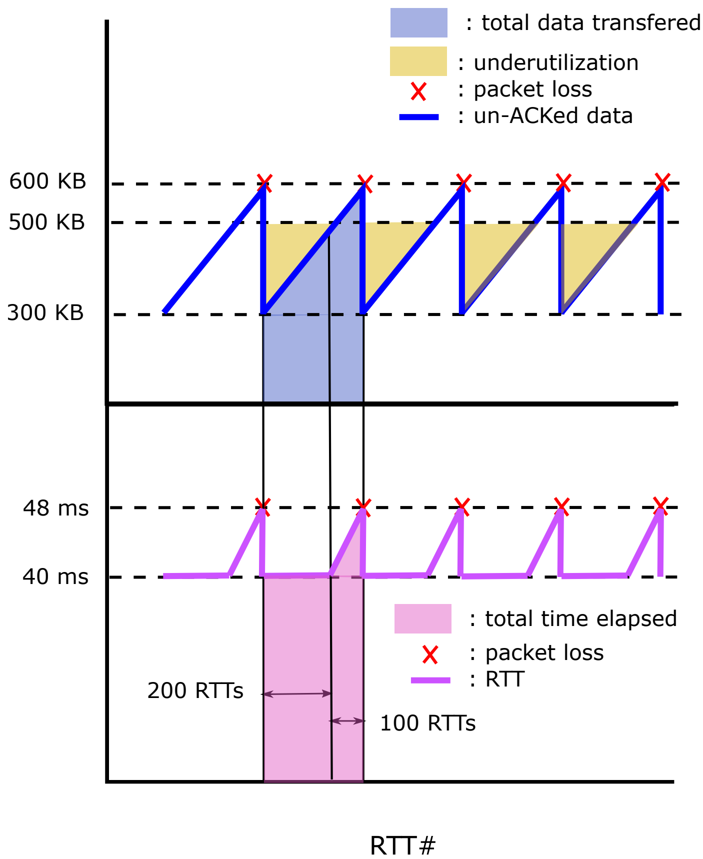

Figure 3: Variation in cwnd and RTT

$$\textbf{Avg. Throughput}(\frac{D}{t}) = \textbf{87.078 Mbps} \sim 87.08\text{Mbps}$$

Since the buffer empties in this scenario, **Minimum RTT = 40 ms**

The maximum queue size in this network will be 100KB, which will cause $\frac{100\times1000\times8}{100\times1{,}000{,}000} = 0.008$. Therefore, **Maximum RTT = 48 ms.**

(b) When the buffer size is 500 KB, the sender will be able to have a maximum cwnd of 1,000 KB and a minimum cwnd of $\frac{1{,}000}{2} = 500$ KB. Therefore, the pipe will always be full. Hence, **Avg. Throughput =100 Mbps**

Since the buffer also (just) empties in this scenario, **Minimum RTT = 40 ms**

The maximum queue size in this network will be 500KB, which will cause $\frac{500\times1000\times8}{100\times1{,}000{,}000} = 0.04$. Therefore, **Maximum RTT = 80 ms.**

(c) When the buffer size is 1 MB, the sender will be able to have a maximum cwnd of 1,500 KB and a minimum cwnd of $\frac{1{,}500}{2} = 750$ KB. Again, the pipe will always be full. Hence, **Avg. Throughput =100 Mbps**

The minimum queue size in this network will be 250KB, which will cause $\frac{250\times1000\times8}{100\times1{,}000{,}000} = 0.02$. Therefore, **Minimum RTT = 60 ms.**

The maximum queue size in this network will be 1000KB, which will cause $\frac{1000\times1000\times8}{100\times1{,}000{,}000} = 0.08$. Therefore, **Maximum RTT = 120 ms.**

2. A buffer size of 500 KB is clearly the best buffer size for this network. It ensures that the link is fully utilized and does not cause buffer bloat.