CS 168 Fall 2017	Introduction to the Internet Scott Shenker	Discussion 2: Packets in Flight

1 True or False

(1) On a fast cross-continental link ($\approx$ 100Gbps), *propagation delay* usually dominates *end-to-end packet delay*.

Solution: True. On a 100Gbps link, even a 1GB file download would only take 0.01 seconds to get on the wire, compared to 0.02 seconds propagation delay from New York to London. Most communications dont come close to 1GB.

(2) On the same cross-continental link ($\approx$ 100Gbps), when transferring a 100GB file, *propagation delay* still dominates end-to-end file delivery.

Solution: False. Sending a 100GB file over a 100Gbps link will have at least 8 seconds transmission delay.

(3) On-demand circuit-switching is adopted by the Internet.

Solution: False. Circuit-switching shares bandwidth through reservation. Packet-switching shares bandwidth on demand. Packet-switching is adopted by the Internet.

(4) The aggregate (i.e., sum) of peaks is usually much larger than peak of aggregates in terms of bandwidth usage.

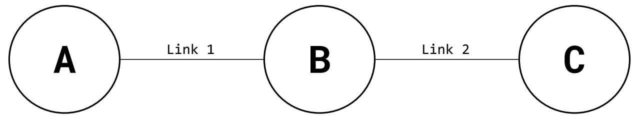
Solution: True. This is the definition of statistical multiplexing.

(5) Bursty traffic (i.e., when packet arrivals are not evenly spaced in time) always leads to queuing delays.

Solution: False. Queuing delay happens when arrival rate is larger than transmission rate (ignoring processing delays). Bursty traffic does not necessarily imply arrival rate is larger than transmission rate. Queuing delay depends on traffic patterns, router internals, and link properties.

2 End-to-End Delay

Consider the diagram below. Link 1 has length L_1 m (where m stands for meters) and allows packets to be propagated at speed $S_1 \frac{\text{m}}{\text{sec}}$, while Link 2 has length L_2 m but it only allows packets to be propagated at speed $S_2 \frac{\text{m}}{\text{sec}}$ (because two links are made of different materials). Link 1 has transmission rate $T_1 \frac{\text{bits}}{\text{sec}}$ and Link 2 has transmission rate $T_2 \frac{\text{bits}}{\text{sec}}$.



Assuming nodes can send and receive bits at full rate and ignoring processing delay, consider the following scenarios:

(1) How long would it take to send a packet of 500 Bytes from Node A to Node B given $T_1 = 10000$, $L_1 = 100000$, and $S_1 = 2.5 \cdot 10^8$?

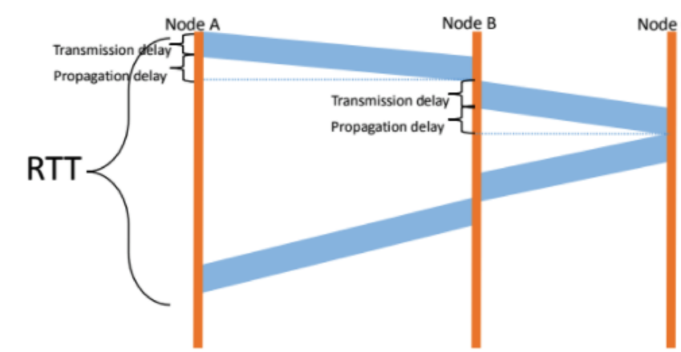
Solution: The total time needed is the sum of the transmission delay to push the packet onto Link 1 and the propagation delay for the packet to travel from Node A to Node B.

$$\begin{aligned} t_{\text{total}} &= t_{\text{transmission}} + t_{\text{propagation}} \\ &= \frac{\text{packet size}}{\text{transmission rate of Link 1}} + \frac{\text{distance between A and B}}{\text{propagation speed}} \\ &= \frac{500B \cdot 8\frac{b}{B}}{10000\frac{b}{s}} + \frac{100000m}{2.5 \cdot 10^8 \frac{m}{s}} \\ &= 0.4s + 0.0004s = \boxed{0.4004s} \end{aligned}$$

Notice that transmission delay dominates more than 99.9% in this case.

(2) Compute RTT (round trip time) for a packet of B Bytes sent from Node A to Node C (packet gets transmitted back from Node C immediately after Node C receives it).

Solution: There is only one packet so no need to worry about queuing delays. Consider the diagram below:



Note the sequence of delays the packet experiences during its route from A to C:

1. Transmission delay to push the packet onto Link 1.
2. Propagation delay as the packet travels from Node A to Node B.
3. Transmission delay to push the packet onto Link 2.
4. Propagation delay as the packet travels from Node B to Node C.
5. Transmission delay to push the packet onto Link 2.

6. Propagation delay as the packet travels from Node C to Node B.
7. Transmission delay to push the packet onto Link 1.
8. Propagation delay as the packet travels from Node B to Node A.

Summing these delays yields the total RTT:

$$\boxed{\text{RTT} = \frac{8B}{T_1} + \frac{L_1}{S_1} + \frac{8B}{T_2} + \frac{L_2}{S_2} + \frac{8B}{T_2} + \frac{L_2}{S_2} + \frac{8B}{T_1} + \frac{L_1}{S_1}}$$

(3) At time 0, Node A sends packet P_1 with D_1 Bytes and then it sends another packet P_2 with D_2 Bytes immediately after it pushes all bits of P_1 onto Link 1. When will Node C receive the last bit of P_2?

Solution: There are two packets, and so we might need to consider queueing delays. There will be a queueing delay at Node B if P_2 arrives at B before P_1 is finished being pushed onto Link 2.

Let's start by computing the time at which P_1 finishes being pushed onto Link 2. P_1 takes $\frac{8D_1}{T_1}$ seconds to be pushed onto Link 1, $\frac{L_1}{S_1}$ seconds to propagate from Node A to Node B, and then $\frac{8D_1}{T_2}$ seconds to be pushed onto Link 2. Hence P_1 leaves Node B at time

$$t_1 = \frac{8D_1}{T_1} + \frac{L_1}{S_1} + \frac{8D_1}{T_2}$$

Next, let's figure out the time when P_2 arrives at Node B. It first waits $\frac{8D_1}{T_1}$ seconds for P_1 to be completely pushed onto Link 1, then takes $\frac{8D_2}{T_1}$ seconds of transmission delay to be pushed onto Link 1 itself, before finally needing $\frac{L_1}{S_1}$ seconds of propagation delay to reach Node B. With this, we know that P_2 reaches Node B at time

$$t_2 = \frac{8D_1}{T_1} + \frac{8D_2}{T_1} + \frac{L_1}{S_1}$$

There's queueing delay if $t_1 > t_2$, and the length of the delay can be expressed as

$$t_1 - t_2 = \left(\frac{8D_1}{T_1} + \frac{L_1}{S_1} + \frac{8D_1}{T_2}\right) - \left(\frac{8D_1}{T_1} + \frac{8D_2}{T_1} + \frac{L_1}{S_1}\right) = \frac{8D_1}{T_2} - \frac{8D_2}{T_1}$$

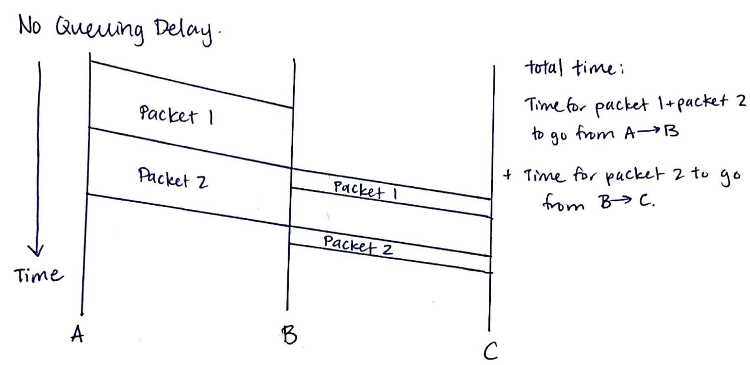
With this analysis in hand, we can express the time at which Node C receives the last bit of P_2 as follows:

$$\boxed{t_{\text{total}} = \frac{8D_1}{T_1} + \frac{8D_2}{T_1} + \frac{L_1}{S_1} + \max\left(\frac{8D_1}{T_2} - \frac{8D_2}{T_1}, 0\right) + \frac{8D_2}{T_2} + \frac{L_2}{S_2}}$$

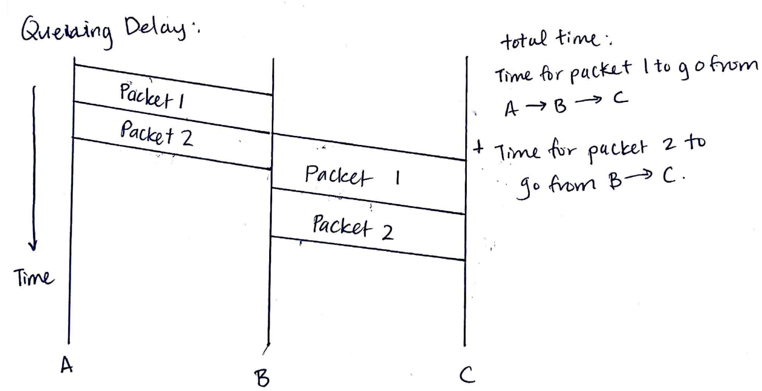
From left to right, the terms in this sum are:

1. The transmission delay to push P_1 onto Link 1.
2. The transmission delay to push P_2 onto Link 1.
3. The propagation delay as P_2 travels from Node A to Node B.
4. The queueing delay at Node B. Note that the use of the max operator allows us to express the two cases when there is and when there isn't queueing delay compactly.
5. The transmission delay to push P_2 onto Link 2.
6. The propagation delay as P_2 travels from Node B to Node C.

Below is the time-graph of a packet in flight without queuing delay:



And with queuing delay:



(4) Find the variable relations that need to be satisfied in order to have no queuing delays for part (c).

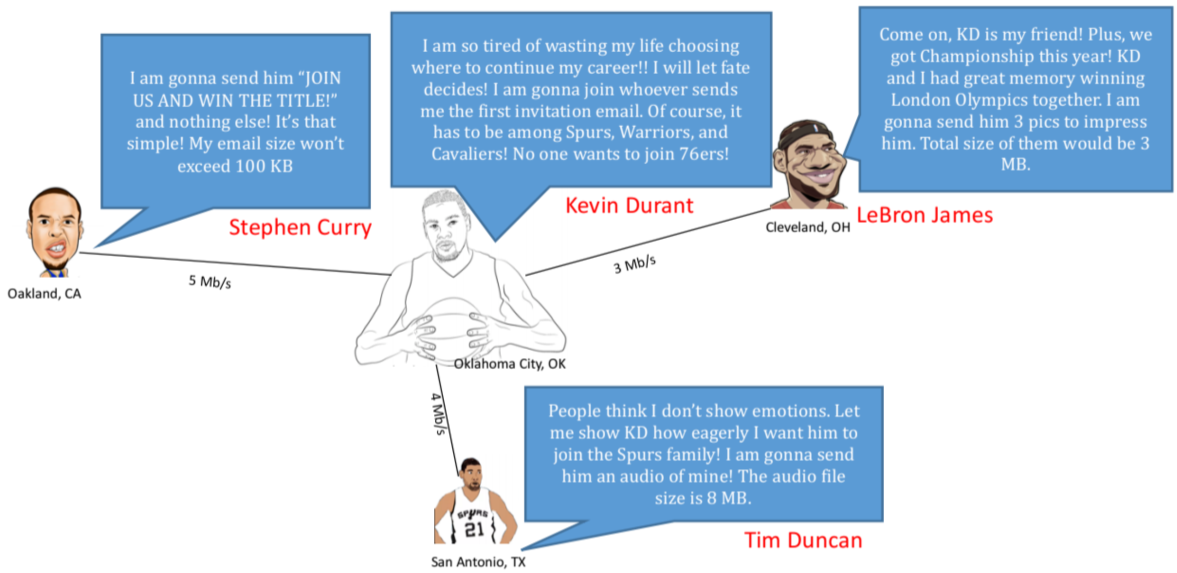
Solution: From the analysis we conducted in part (c), we know there will be queueing delays if $t_1 > t_2$, or $\frac{8D_1}{T_2} > \frac{8D_2}{T_1}$. Hence, there's no queueing delays if $\frac{8D_1}{T_2} \leq \frac{8D_2}{T_1}$. After simplifying it, we see the relation that must be satisfied is

$$\boxed{\frac{D_1}{T_2} \leq \frac{D_2}{T_1}}$$

3 You Have No Clue Why Kevin Durant Joined Us

This summer Golden State Warriors got Oklahoma Thunder superstar Kevin Durant onboard. Exciting, huh?! Lots of rumors have already been spread across the Internet about KDs motivation. Luckily, we got one league source insider in our TA crew. Lets follow the leaked information (this question) to explore why Kevin Durant chose us!

Tim Duncan, LeBron James, and Stephen Curry all sent invitation email to KD, trying to persuade him to join their team (Spurs, Cavaliers, and Warriors).



Source insiders told us that they are all old school players and use very slow internet speed at home (transmission rate provided in the diagram above), when KD announced that he would love to receive invitation emails to help him make the decision. Stephen, Tim, and LeBron all got notified and decided to send their prepared invitation emails. They clicked Send button almost at the same time (within a 5-second range). Given it takes magically no time for emails to propagate so we only need to consider transmission times, explain why KD signed the contract with Golden State Warriors.

Solution: Lets first compute the transmission time for the emails sent:

Stephen's text email wont exceed 100KB (that would be a long, long email with thousands of words) and it takes at maximum

$$\frac{100\text{KB}}{1000\frac{\text{KB}}{MB}} \cdot 8\frac{\text{bits}}{\text{byte}} \div 5\frac{Mb}{s} = \boxed{0.16 \text{ seconds}}$$

to push all bits of that email onto the link.

LeBron's email with photo attachment would need around

$$3\text{MB} \cdot 8\frac{\text{bits}}{\text{byte}} \div 3\frac{Mb}{s} = \boxed{8 \text{ seconds}}$$

to be put onto the link.

Tim's email with audio attachment would need around

$$8\text{MB} \cdot 8\frac{\text{bits}}{\text{byte}} \div 4\frac{Mb}{s} = \boxed{16 \text{ seconds}}$$

to be put onto the link.

Stephen sends his email (pure text email) no more than 5 seconds later than LeBron and Tim send their emails (with attachment). Because their transmission times are more than five seconds longer than Steph's transmission time, Steph wins! This is a case where 1000 words is better than a picture (or audio).....