CS5222 Computer Networks and Internets
Tutorial 2 (Week 2)

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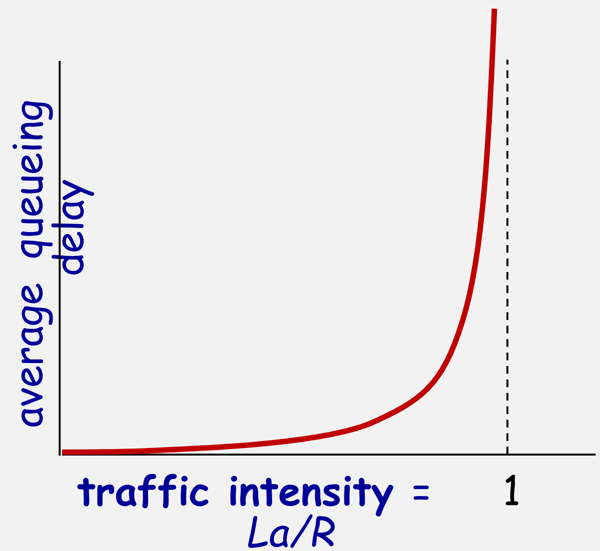
Slides based on book *Computer Networking: A Top-Down Approach.*

Packet queueing delay

- R: link bandwidth (bps)
- L: packet length (bits)
- a: average packet arrival rate



- $L*a/R \sim 0$: avg. queueing delay small
- $L*a/R$ --> 1: avg. queueing delay large
- $L*a/R > 1$: the arriving "workload" is more than the servicing workload
  => average delay infinite (in theory)!

HTTP connections: two types

Non-persistent HTTP

1. TCP connection opened
2. at most one object sent over TCP connection
3. TCP connection closed

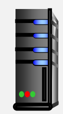
downloading multiple objects requires multiple connections

Persistent HTTP

- TCP connection opened
- multiple objects can be sent over a *single* TCP connection between a client and the server of the client
- TCP connection closed

Non-persistent HTTP: an example (requesting 10 objects)

1a. HTTP client initiates TCP connection to HTTP server (process) at www.someSchool.edu on port 80



1b. HTTP server at host www.someSchool.edu waiting for TCP connection at port 80 "accepts" connection, notifying client

2. HTTP client sends HTTP *request message* (containing URL) into TCP connection socket. Message indicates that client wants object someDepartment/home.index

3. HTTP server receives request message, forms *response message* containing requested object, and sends message into its socket

time

Non-persistent HTTP: example (cont.)

4. HTTP server closes TCP connection.

5. HTTP client receives response message containing html file, displays html. Parsing html file, finds 10 referenced jpeg objects

6. Steps 1-5 repeated for each of 10 jpeg objects

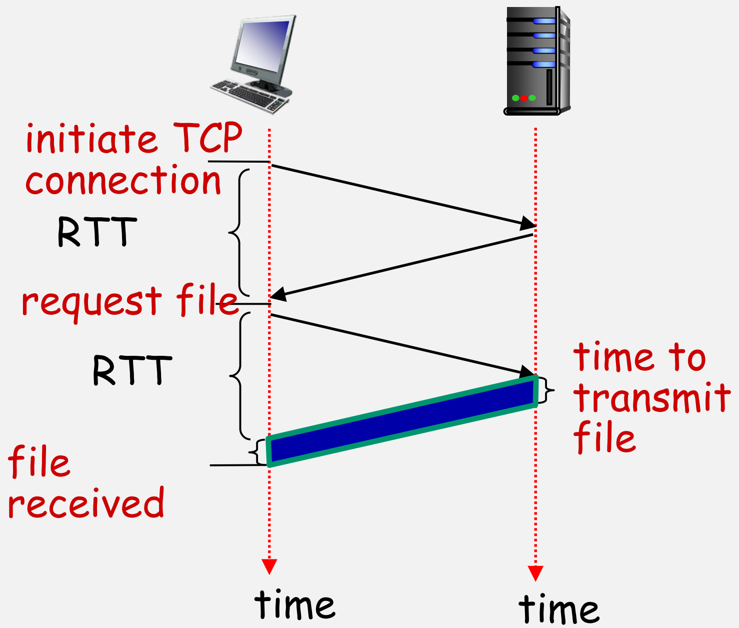
time

Non-persistent HTTP: response time

RTT (definition): time for a small packet to travel from a client to a server and back

HTTP response time (per object):

- one RTT to initiate TCP connection
- one RTT for HTTP request and first few bytes of HTTP response to return
- object/file transmission time



Non-persistent HTTP response time = 2RTT+ file transmission time

Time to work on questions…

1. Suppose that you click a URL link within a web browser to retrieve a web page. Suppose that the web page associated with that link contains **8 objects**.

Let **RTT** denote the Round Trip Time between the local host, and the server contains the base HTML and all 8 objects. Suppose that the transmission time is negligible. How long does it take before the host can receive all objects?

a) Non-persistent HTTP is used

Answer:

If non-persistent HTTP is used, it needs to setup a TCP connection for each HTTP request.

- It takes 2 RTTs to retrieve the Base HTML.
- It takes 2 RTTs to retrieve each referenced object.
- Thus, it takes 2 RTT +8 * 2 RTT=18 RTTs.

b) Persistent HTTP is used.

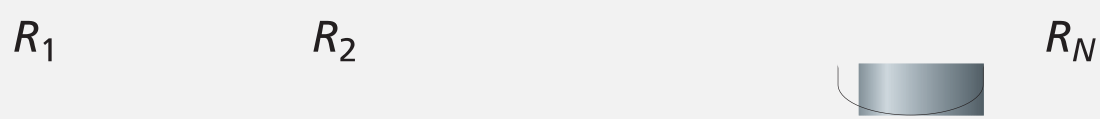
Answer:

- Only one TCP connection is established.
- It takes 2RTTs to receive the Base HTML file.
- All requests for the following 8 objects will be sent back-to-back.
- The responses for the 8 objects will be sent by the server back-to-back (in pipeline). Thus, it takes 2RTT+RTT=3RTTs.

2. Consider the figure below. Suppose that each link between the server and the client has a packet loss probability *p*, and the packet loss probability for these links is independent.

a) What is the probability that a packet (sent by the server) is successfully received by the client?

b) If a packet is lost in the path, then the server will eventually re-transmit the packet. On average, how many times will the server have to transmit a packet until the client successfully receives the packet?



Solution:

a) Probability that the i-th link does not fail: $(1 - p)$.

This is the same for all i.

Since a packet is successfully received only if none of the links fails, we thus have

$$
\begin{aligned}
\Pr[\text{ no link fails }] &= \Pr[\ 1^{st} \text{ link doesn't fail }] \ldots \Pr[\ n\text{-th link doesn't fail}] \\
&= (1 - p)^n
\end{aligned}
$$

b) The server "succeeds" if the packet is not lost; otherwise it "fails" if the packet is lost on some link.

We know from part a) that

$\Pr[\text{ server succeeds }] = (1 - p)^n$

What we want to compute is the expected number of times that the server has to transmit until the event that "server succeeds" happens. This quantity is the expected value of the **geometric distribution** with parameter Pr[server succeeds] and thus its expected value is $1 / (1 - p)^n$.

3. A packet switch receives a packet *P* and determines the outbound link to which the packet should be forwarded. When packet *P* arrives, another packet is halfway done being transmitted on this outbound link and four other packets are in the waiting queue of the switch waiting to be transmitted. Packets are transmitted in order of arrival. Suppose all packets have a length of 1,500 bits and the transmission rate of the outbound link is 2 Mbps. What is the queueing delay for packet *P* ?

Answer:

(a) The delay due to the packet that is on a halfway is:

$750 / (2*10^6)$ sec = 0.000375 seconds

(b) The delay due to the 4 packets that are ahead of the arriving packet *P* is:

$4 * 1500 / (2 * 10^6)$ sec = 0.003 seconds

In total, there is a queueing delay of 0.003375 seconds.

4. [**Harder**] Consider a sequence of N packets with each having a length of L bits, and a router with an outbound link with the transmission rate R. Suppose that, at time 0, the first $N/2$ packets arrive simultaneously at the router and, after (L/R) seconds, the remaining $N/2$ packets arrive. Apart from these N packets, no other packets are currently being queued or transmitted by the router. (You can assume that N is even, i.e., $N/2$ is an integer.)

a) What is the queueing delay for the i-th packet, if $i \leq N/2$?

b) What is the queueing delay for the i-th packet, if $i > N/2$?

c) What is the average queueing delay for these N packets?

Solution:

a) We number the packets 1,…,N.

- Here we are looking at the first $N/2$ packets that arrive at the router at time 0.
- The 1st packet has 0 delay.
- The 2nd packet has delay of L/R.
- → The i-th packet will have a delay of (i-1)(L/R) sec.

- b) We now are looking at the second group, i.e., the remaining $N/2$ packets, that simultaneously arrive at the router at time L/R.
- At time L/R, the router has just finished sending one packet of the first group of packets, therefore:
- The ($N/2+1$)-th packet will have a delay of:
- ($N/2$ – 1)(L/R) sec.
- The ($N/2+2$)-th packet will have a delay of:
- ($N/2$)(L/R) sec.
- ($N/2+3$)-th packet will have a delay of;
- ($N/2$ + 1)(L/R) sec.
- → The i-th packet (i> $N/2$) will have a delay of (i – 2)(L/R) sec.

Solution: c) To compute the average delay, we will first compute the total delay of all *N* packets and then divide by the number of packets. The total delay is calculated as follows (assuming *N* is even):

- $\sum_{i=1}^{N/2}\left(\frac{L}{R}\right)(i-1)+\ \sum_{i=N/2+1}^{N}\left(\frac{L}{R}\right)(i-2)$
- $=\sum_{i=1}^{N/2}\left(\frac{L}{R}\right)(i-1)+\ \sum_{i=1}^{N/2}\left(\frac{L}{R}\right)\left(\frac{N}{2}+i-2\right)$
- $=\left(\frac{L}{R}\right)\sum_{i=1}^{N/2}\left((i-1)+\frac{N}{2}+i-2\right)$
- $=\ \left(\frac{L}{R}\right)\sum_{i=1}^{N/2}\left(2i-3+\frac{N}{2}\right)$
- $=\left(\frac{L}{R}\right)\left(2\sum_{i=1}^{N/2}i-\sum_{i=1}^{N/2}3+\ \sum_{i=1}^{N/2}\frac{N}{2}\right)$
- $=\ \left(\frac{L}{R}\right)\left(2(\sum_{i=1}^{N/2}i)-\frac{3N}{2}+\frac{N}{2}\frac{N}{2}\right)$
- $=\left(\frac{L}{R}\right)\left(\frac{N}{2}\left(\frac{N}{2}+1\right)-\frac{3N}{2}+\frac{N^2}{4}\right)$
- $=\ \left(\frac{L}{R}\right)\left(\frac{N^2}{4}+\frac{N}{2}-\frac{3N}{2}+\frac{N^2}{4}\right)\ =\left(\frac{L}{R}\right)(\frac{N^2}{2}-\boldsymbol{N})$
- Therefore, the average queueing delay is $\left(\frac{L}{R}\right)$ (*N*/2 – 1).