CS144
An Introduction to Computer Networks

Packet Switching

End to End Delay

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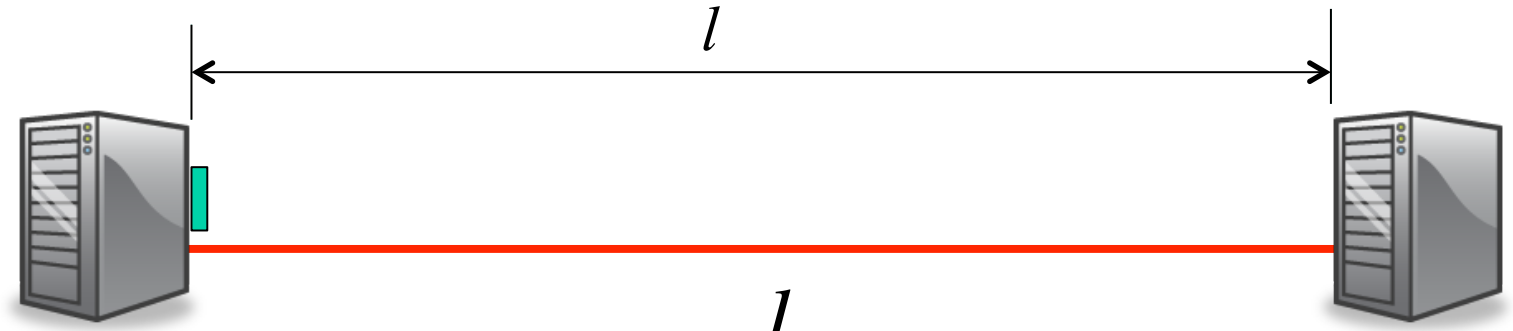
Outline

1. Useful definitions
2. End-to-end delay
3. Queueing delay

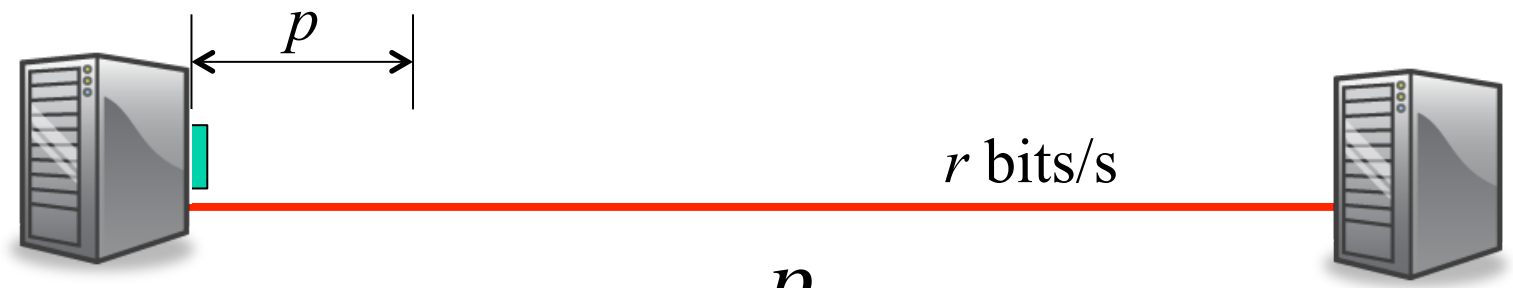
Propagation Delay, t_l: The time it takes a single bit to travel over a link at propagation speed c.



$$t_l = \frac{l}{c}$$

Example: A bit takes 5ms to travel 1,000km in an optical fiber with propagation speed 2 x 10^8 m/s.

Packetization Delay, t_p: The time from when the first to the last bit of a packet is transmitted.



$$t_p = \frac{p}{r}$$

Example 1: A 64byte packet takes 5.12μs to be transmitted onto a 100Mb/s link.
Example 2: A 1kbit packet takes 1.024s to be transmitted onto a 1kb/s link.

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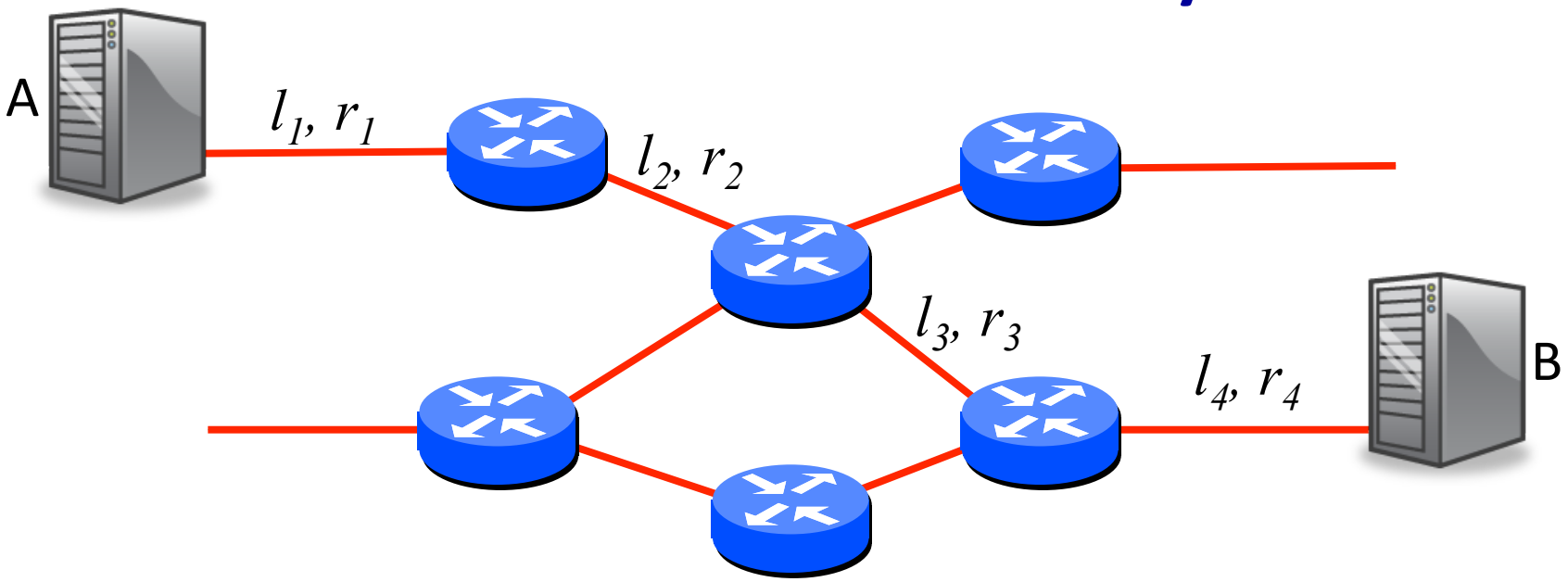
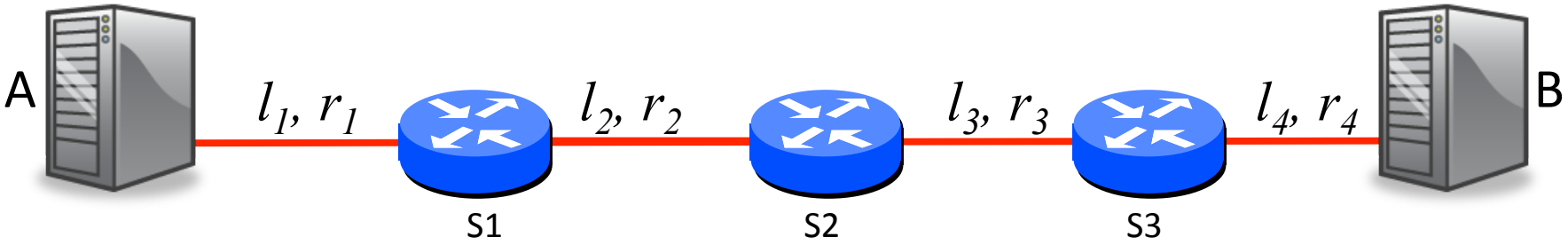
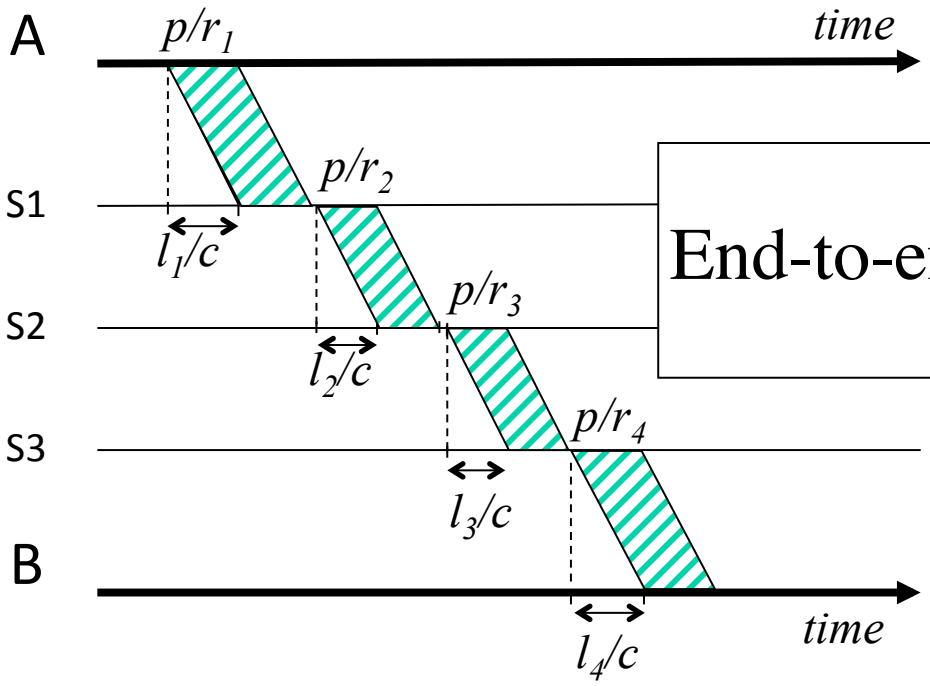
End-to-end delay



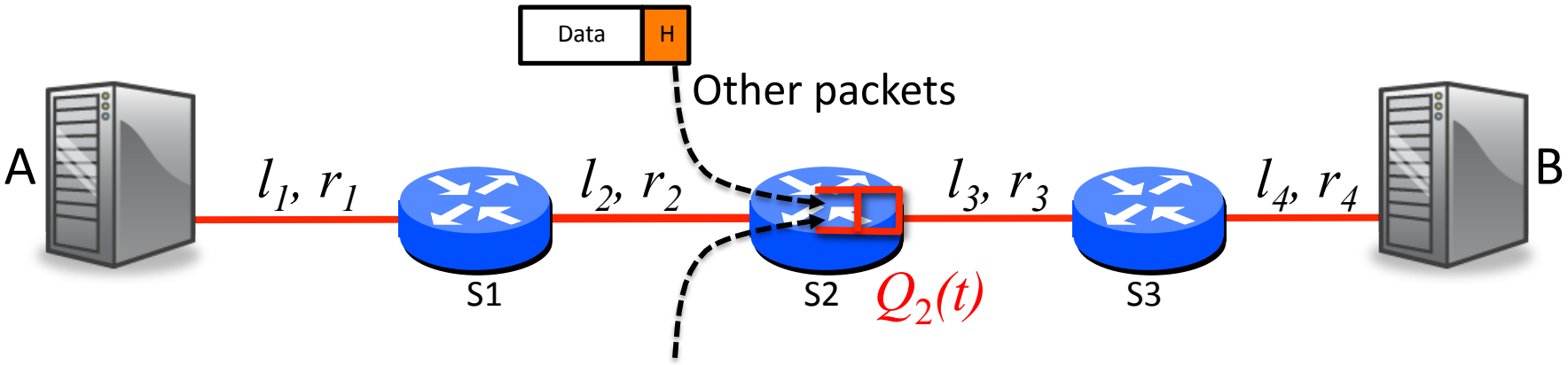
Example: How long will it take a packet of length p to travel from A to B, from when the 1st bit is sent, until the last bit arrives? Assume the switches *store-and-forward* packets along the path.

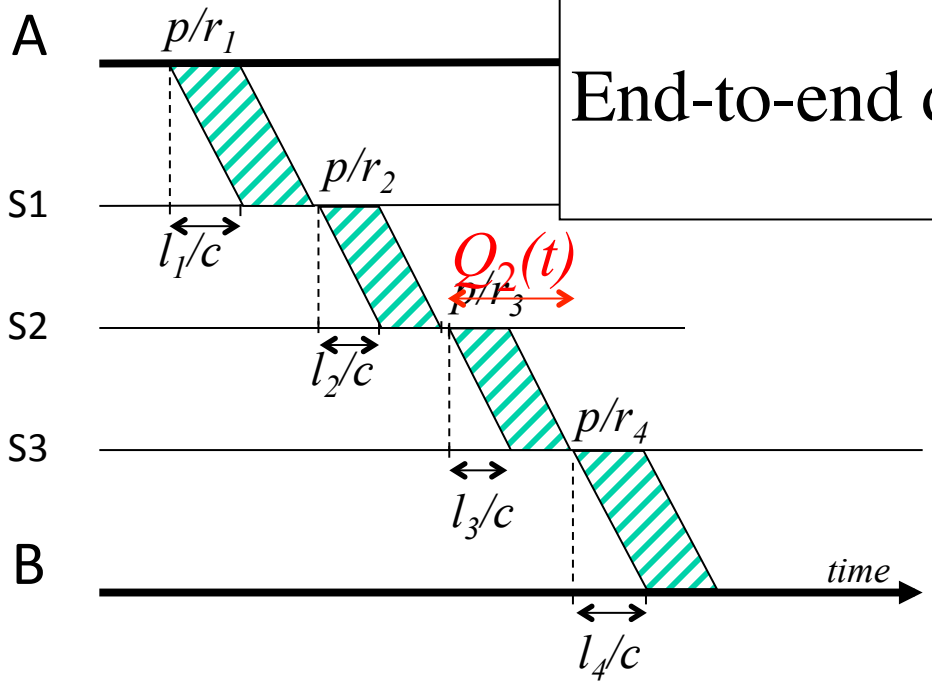
$$\text{End-to-end delay},\ t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} \right)$$





$$\text{End-to-end delay, } t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} \right)$$





$$\text{End-to-end delay, } t = \sum_i \left(\frac{p}{r_i} + \frac{l_i}{c} + Q_i(t) \right)$$

*Queueing = UK spelling, adopted by Kleinrock at UCLA in 1960s.
Queueing and queuing (US spelling) are both widely used.

<TY>

Insert the “ping” video here.

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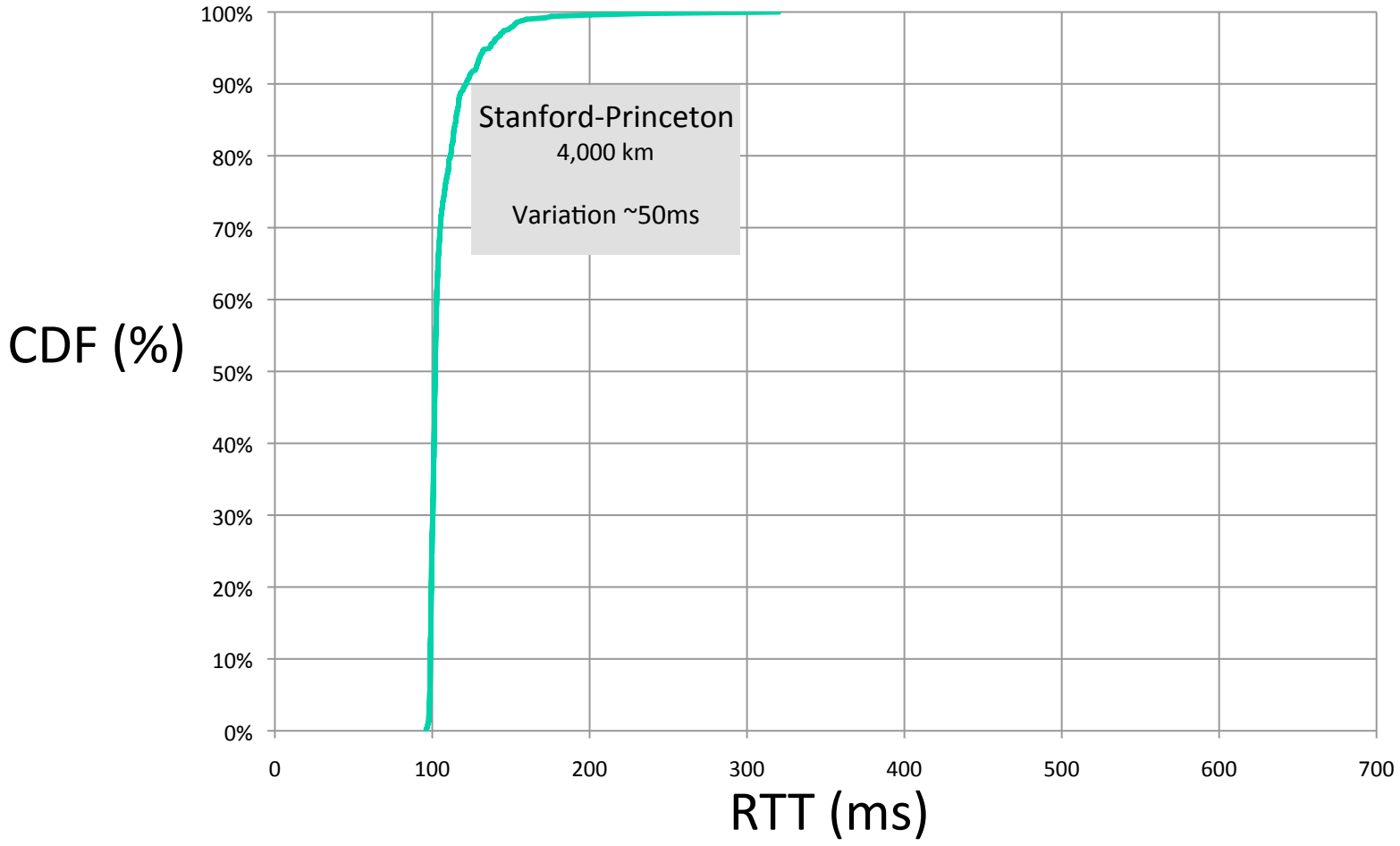
Packet delay variation



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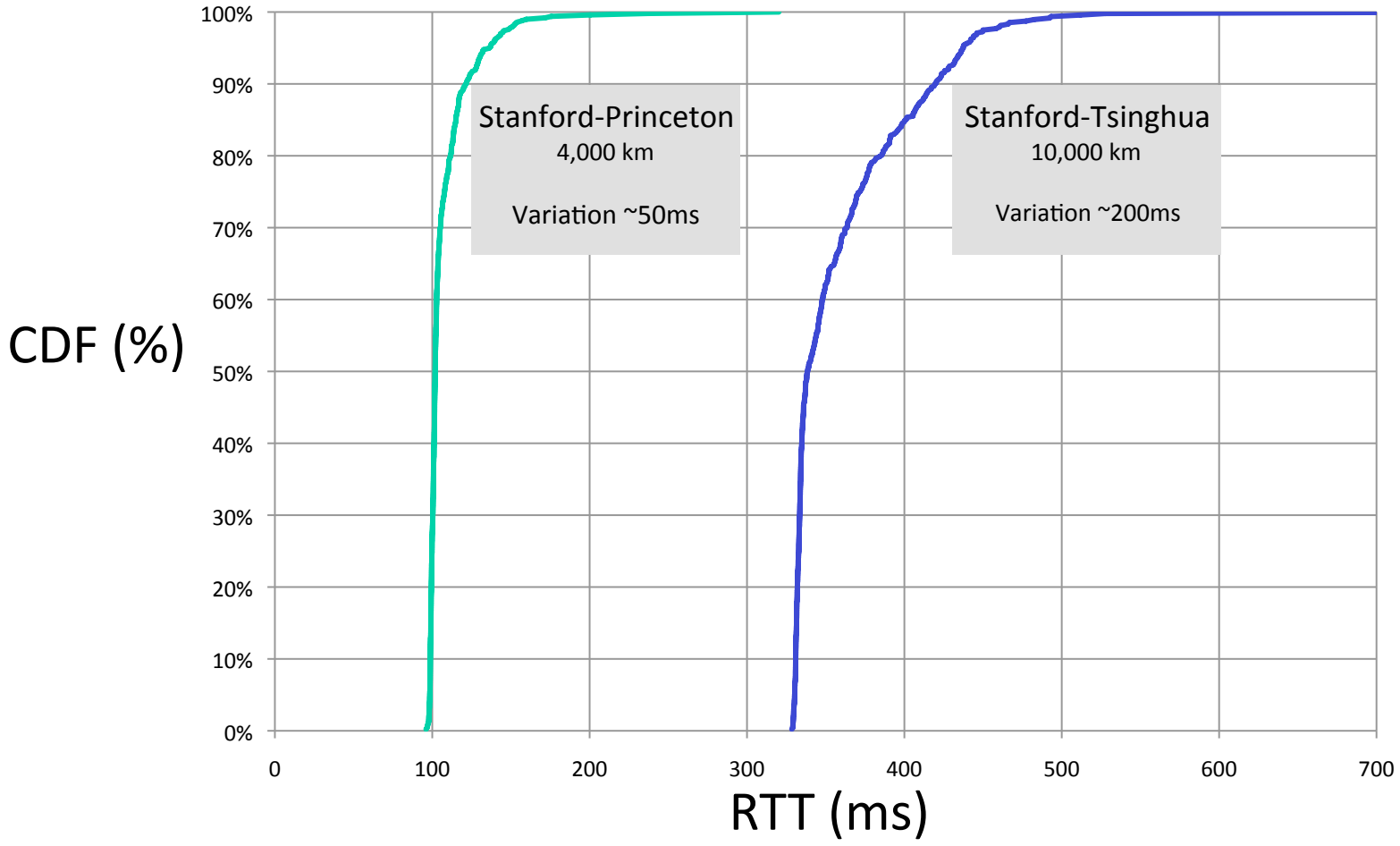

Summary

End to end delay is made up of three main components:

- Propagation delay along the links (fixed)
- Packetization delay to place packets onto links (fixed)
- Queueing delay in the packet buffers of the routers (variable)