CPSC 317 – Winter 1 2025 Introduction to Computer Networking

Network Performance - Delay

Module 2.2

Norm & Ibtissem

Administration

- Programming Assignment 1 is on-going
- Quiz 1 starts Sep 22nd

READING

- Reading: 1.4

Learning Goals

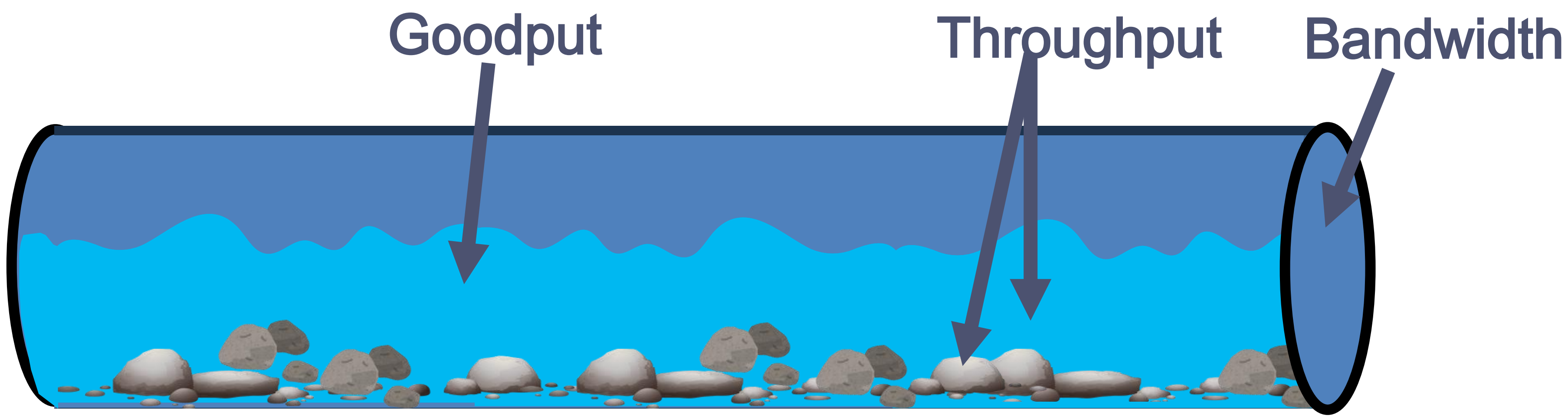
Delay

- List and define the types of delay and how they contribute to over-all delay
- Calculate the end-to-end delay in a network.
- Perform bottleneck analysis on a path
- Compute traffic intensity and relate traffic intensity to queuing delays
- Calculate link utilization
- Use the formula of Average Delay = S/(1-U) where U is the network utilization and S is the average service time for a single packet (this formula only applies to randomly arriving packets)

Recap

- Bandwidth
- Throughput
- Goodput

Rates measured in bits per second



- Latency
- RTT (Round Trip Time)
- Jitter

Times measured in seconds

Clicker Question

If lightning happens 1km from me, it takes about 3 seconds for me to hear the thunder. What time is that?

A. Latency
B. RTT
C. Bandwidth
D. Throughput
E. Goodput

Clicker Answer

If lightning happens 1km from me, it takes about 3 seconds for me to hear the thunder. What time is that?

A. Latency
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Clicker Question

Suppose you have a 5 GB movie that you want to download on a 100Mbps link. How long will it take (rounded to the nearest second)? Assume 75Mbps goodput.

A. 573 seconds
B. 533 seconds
C. 66 seconds
D. 50 seconds
E. None of the above

Clicker Answer

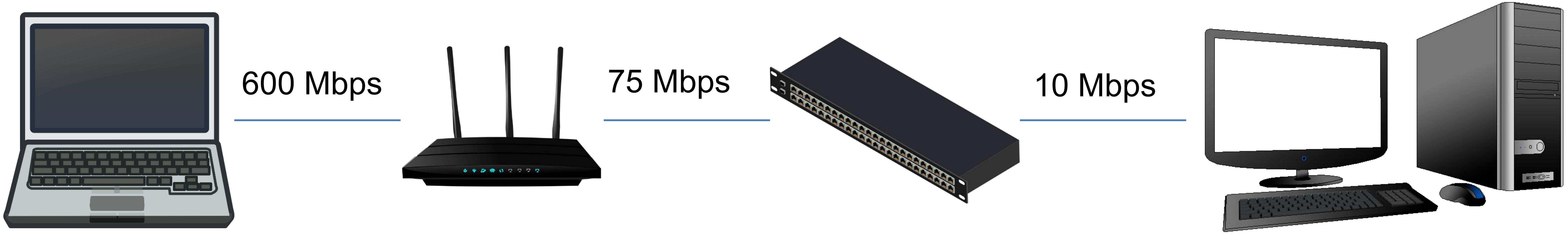
Suppose you have a 5 GB movie that you want to download on a 100Mbps link. How long will it take (rounded to the nearest second)? Assume 75Mbps goodput.

$$(5 * 2^{30} * 8) / (75 * 10^6) = 572.66 \text{ seconds}$$

A. **573 seconds**
B. 533 seconds
C. 66 seconds
D. 50 seconds
E. None of the above

Bottlenecks

- What is the maximum throughput (possible bandwidth) between two nodes connected by a network?
  - Can traffic flow at maximum bandwidth in all links?

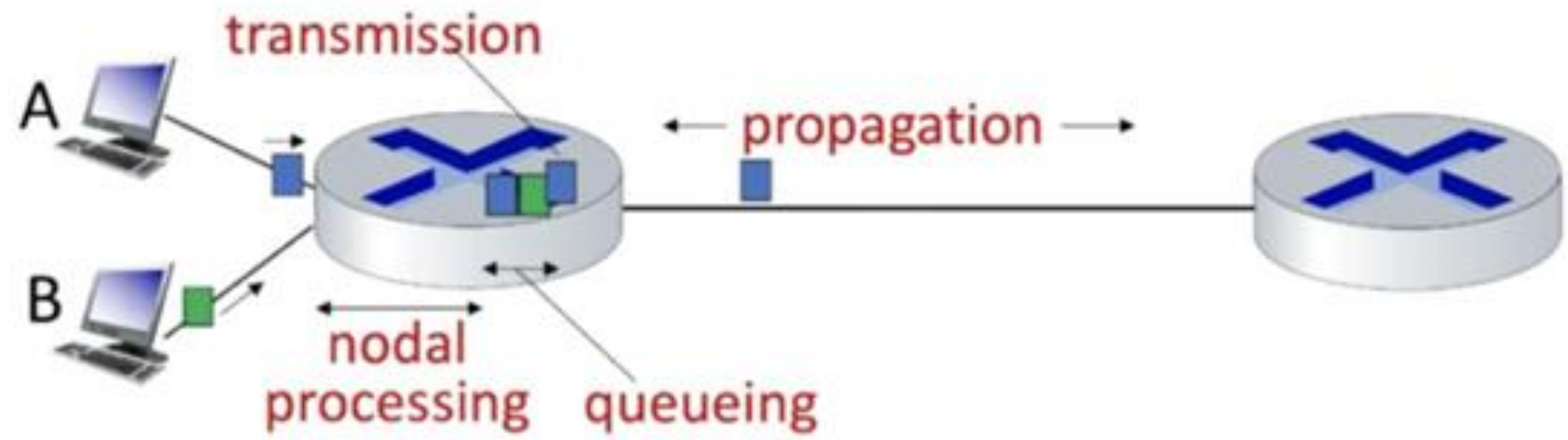


Types of Delay

- ***Processing delay***: examine packet to decide where to direct it
- ***Queueing delay:*** waiting time to get access to the link
- ***Transmission delay***: time to actually write the packet onto the medium
- ***Propagation delay:*** time spent to move each bit from source to destination on the transmission medium

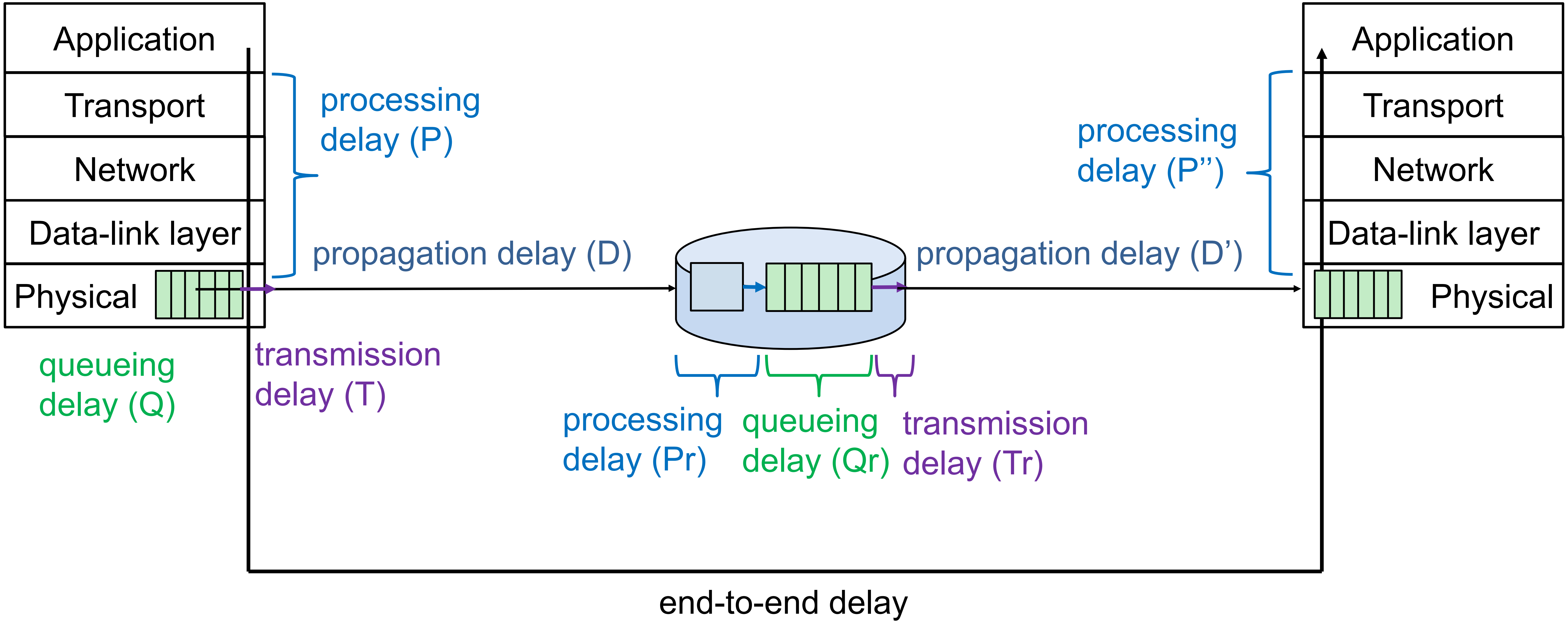
- ***End-to-end delay***: sum of all sources of delay

Types of Delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Types of Delay



Classification of Delay: fixed vs variable

• *Processing delay*		fixed or variable?	fixed (essentially)
• *Queueing delay*		fixed or variable?	variable
• *Transmission delay*	*same*	fixed or variable?	fixed (bit) variable (packet)
• *Propagation delay*	*link*	fixed or variable?	fixed (metre) variable (location)
• *End-to-end delay*		fixed or variable?	variable

Suppose ...

You are sending the same sized packets to the same destination over and over again.

- *Processing delay*: ?
- *Queueing delay*: ?
- *Transmission delay*: ?
- *Propagation delay*: ?
- *End-to-end delay*: ?

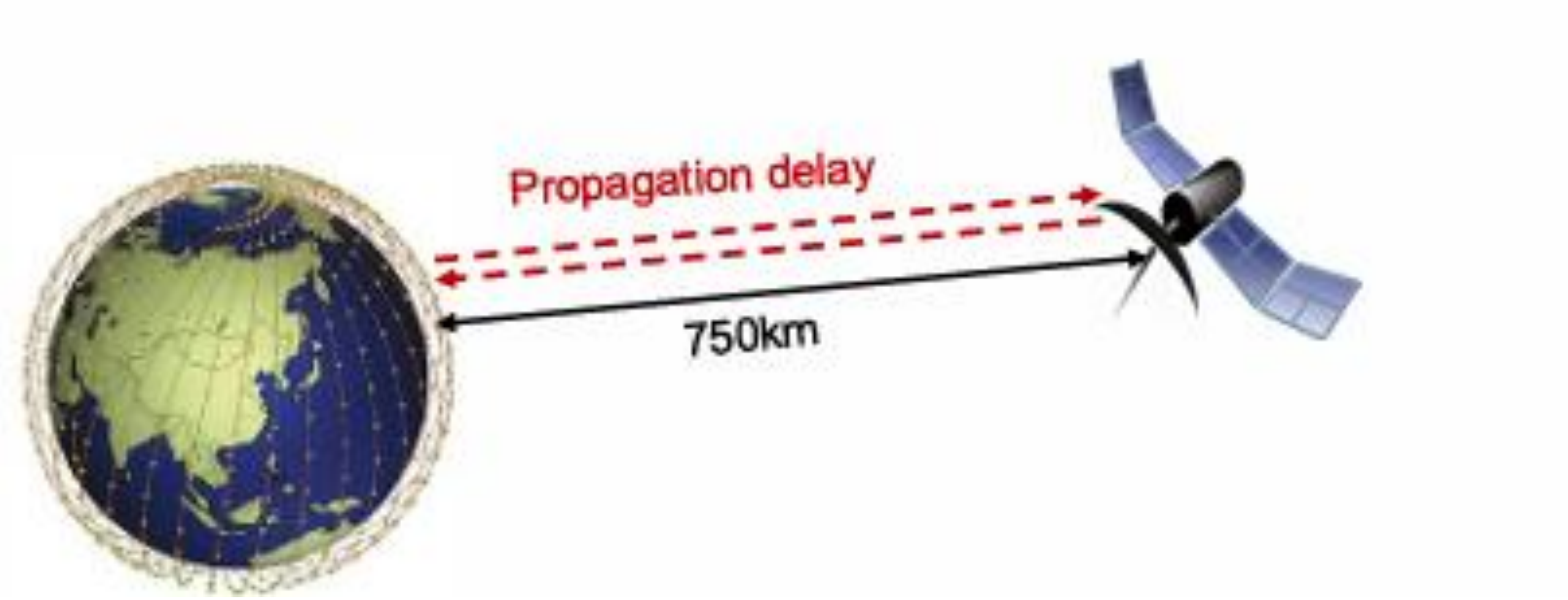
Suppose …

You are sending the same sized packets to the same destination over and over again.

- ***Processing delay***: fixed
- ***Queueing delay***: variable
- ***Transmission delay***: fixed
- ***Propagation delay***: fixed
- ***End-to-end delay***: variable

Delay Calculations – Propagation

You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is $3x10^8$ metres per second. Packets are 1250 bytes. **What is the two-way propagation delay?**

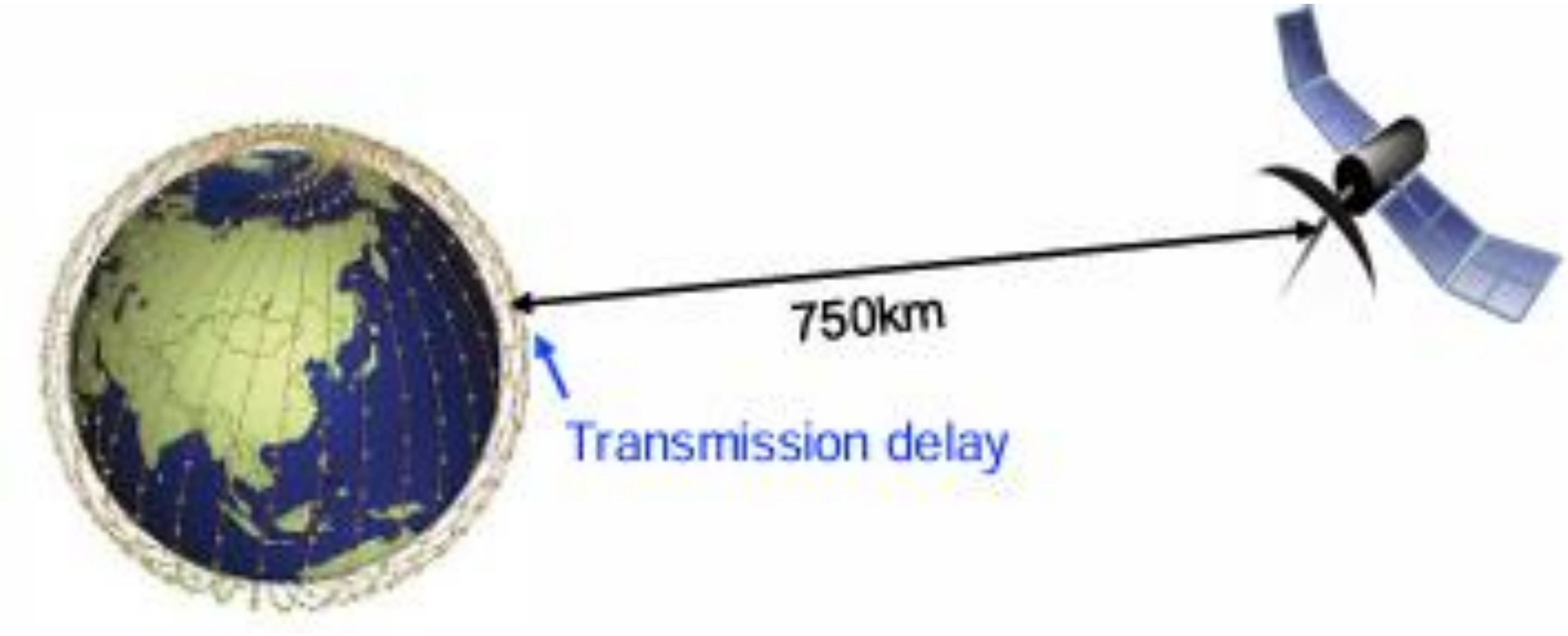


Delay Calculations – Propagation

- You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 Bytes. What is the two-way propagation delay?
- Two-way propagation delay = 2 * one-way propagation delay
- One-way propagation delay= distance / speed
- $= (750 * 10^3) / (3 \times 10^8)$
- = 0.0025 seconds *1000 = 2.5 ms
- Two-way propagation delay = 2 *2.5 = 5 ms

Delay Calculations – Transmission

You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 bytes. The network has a transfer rate (bandwidth) of 100Mbps. **What is the transmission delay (one-way)?**



Delay Calculations – Transmission

- You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 Bytes. The network has a transfer rate (bandwidth) of 100Mbps. What is the transmission delay (one-way)?

- **Transmission delay = packet size / Transmission rate**
- **$= (1250*8) / (100*10^6)$**
- **= 0.0001 seconds**
- **= 0.1 ms**

Delay Calculations – End-to-end

You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 bytes. The network has a transfer rate (bandwidth) of 100Mbps. Assume the transmission delay for the ACK is 0ms, and that the processing and queueing delays are 0. **What is the total round-trip delay for one packet?**

Delay Calculations – End-to-end

- You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is $3x10^8$ metres per second. Packets are 1250 Bytes. The network has a transfer rate (bandwidth) of 100Mbps. Assume the transmission delay for the ACK is 0ms, and that the processing and queueing delays are 0. **What is the total round-trip delay for one packet?**

- **RTT = 2*propagationDelay + $\text{transmissionDelay}_{\text{packet}}$**
- **= 2* 2.5 + 0.1**
- **=5.1 ms**

More Calculations – Throughput

You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 bytes. The network has a transfer rate (bandwidth) of 100Mbps. Assume that the processing and queueing delays are 0. Assume also that you can transmit packets back-to-back.

What is the throughput?

More Calculations – Throughput

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- **Throughput = 100 Mbps**

More Calculations – Throughput

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More Calculations – Throughput

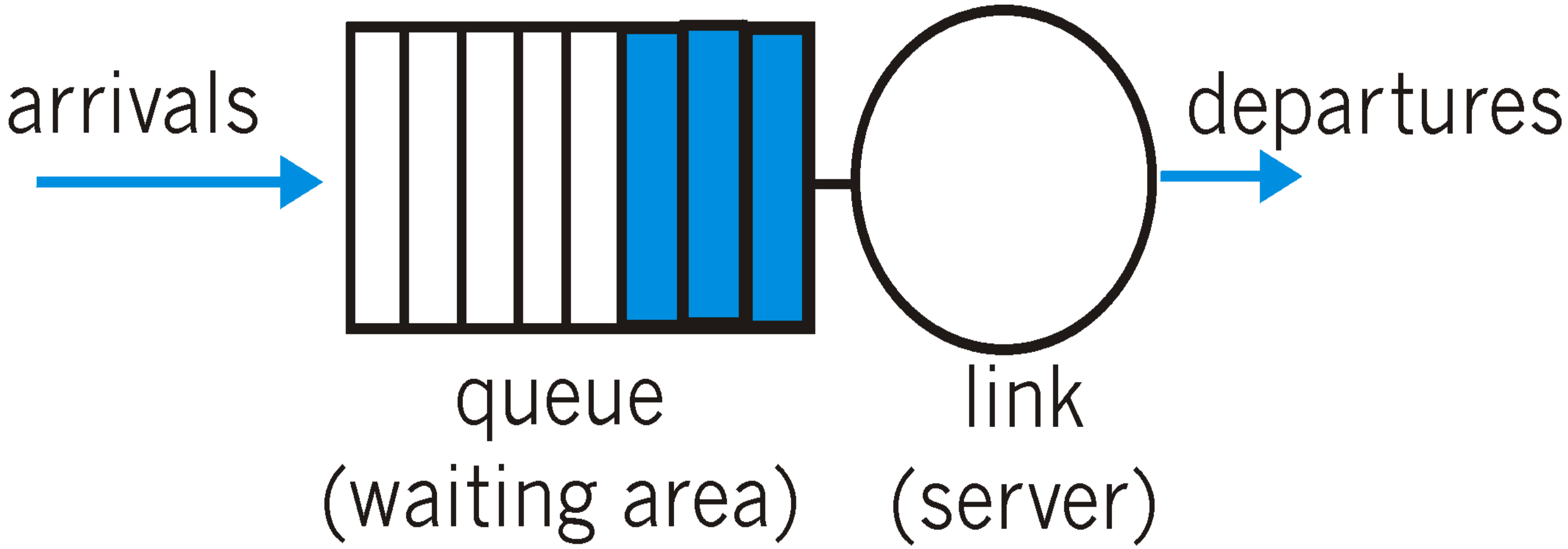
- You are designing a satellite network. The satellites are 750km from the surface of the earth. The speed of light is 3×10^8 metres per second. Packets are 1250 Bytes. The network has a transfer rate (bandwidth) of 100Mbps. Assume that the processing and queueing delays are 0. Assume also that you don't transmit the $(n+1)^{th}$ packet until you get a (very short) ACK for the n^{th} packet (assume 0ms transmission delay for the ACK). What is the throughput?

- We transmit 1250 Bytes every RTT time
- Throughput = $(1250 * 8) / (5.1 * 10^{-3}) = 1\,960\,784.31$ bps = 1.96 Mbps

Traffic Intensity

- How much data is arriving at the router?
- How much data can a router handle?
  - At what rate can the router forward data out?
- Queueing: when a router receives data faster than it can forward it

Traffic Intensity



Arrival Rate of 100 packets/second

Packets depart every 1 millisecond

Traffic Intensity Calculation

- Traffic intensity is determined by
  - Number of packets arriving per second (a)
  - Average packet size (L) in bits
  - Transmission rate: rate at which bits are disposed off per second (R)
- Traffic intensity: ${}^{La}/_{R}$
- Example:
  - Suppose a router is connected to a 1Mbps link. The router receives an average of 100 packets per second, averaging 500 bytes per packet. What is the traffic intensity?

Clicker Question

Suppose a router is connected to a 1Mbps link. The router receives an average of 100 packets per second, averaging 500 bytes per packet. What is the traffic intensity?

A. 0.05
B. 0.125
C. 0.2
D. 0.4
E. 0.8

Clicker Answer

Suppose a router is connected to a 1 Mbps link. The router receives an average of 100 packets per second, averaging 500 bytes per packet. What is the traffic intensity?

Traffic intensity = $(L*a)/R = (500*8 * 100)/(1*10^6) = 0.4$

A. 0.05
B. 0.125
C. 0.2
D. 0.4
E. 0.8

Traffic Intensity Rationale

- Traffic intensity helps us understand how busy a link is
- Queueing delay is related to the intensity
  - Queueing delay is delay caused by waiting for the queue to clear
  - Packets arriving must wait for packets already there to leave

Traffic Intensity vs Queueing Delay

- Suppose La bits/second arrive randomly for an outgoing link in a router
- Suppose that the router can transmit R bits/second
- Draw a graph of queueing delay vs traffic intensity
  - What does $La = R$ mean?
  - What does $La > R$ mean?
  - What does $La < R$ mean?
  - What does $La \ll R$ mean?

Queueing Problem

- **Packets are not spaced out evenly**
  - Spacing between packets is not deterministic
- Packets may not be served evenly
  - Link may be busy at times
  - Particularly for shared medium (e.g., radio signals)
- Higher intensity means higher probability that there is one or more packets in the queue

Traffic Intensity vs Queueing Delay

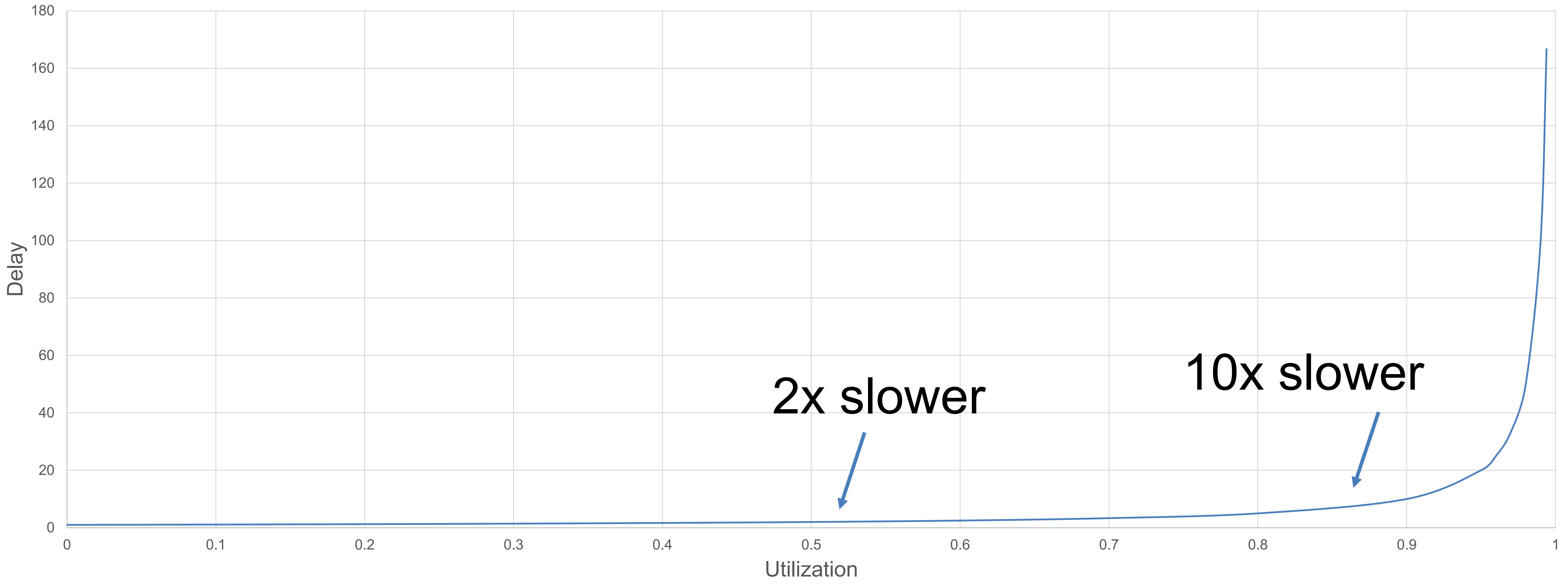
- Assuming packets arrive at an exponential distribution, delay is given by:

$$Total\ Delay = \frac{S}{1-U}$$

- Where:
  - S is average service time when server is idle
  - U is server utilization (usually traffic intensity)
- Queueing delay is then:

$$Queueing\ delay = \frac{S}{1-U} - S\ or\ \frac{US}{1-U}$$

Delay vs Utilization



Some Observations

- Routers don't have infinite buffer space
- If packets arrive faster than they can be disposed off, they may have to be dropped
- Packets may also be corrupted in transit
  - These packets must be discarded, since their content is no longer valid
  - Even routing information (e.g., destination IP) may be corrupted

In-class Activity

- ICA22

Next Topic:
Application Layer Protocols