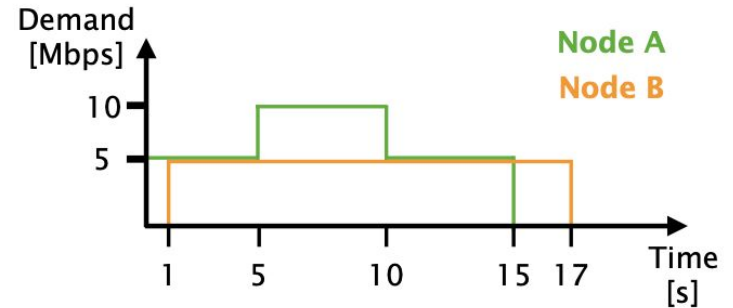
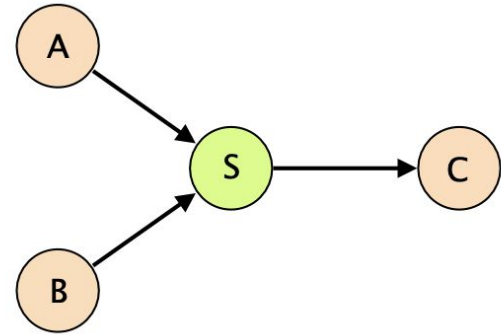


# Circuit Switching vs Packet Switching

Assume that A and B have to send data with a demand according to the diagram on the right.

- How long does it take to send all data if A and B use circuit switching (reserving for the peak demand)?
- How long does it take to send all data if A and B use packet switching (you can assume an unlimited buffer size on S)?



Demand distributions for node A and B.

# Circuit Switching vs Packet Switching

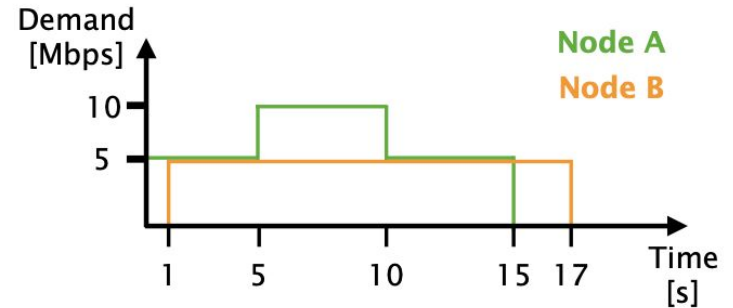
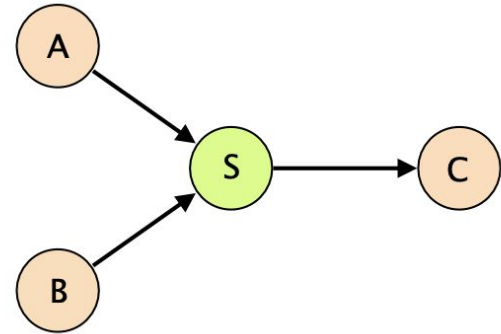
Assume that A and B have to send data with a demand according to the diagram on the right.

- How long does it take to send all data if A and B use circuit switching (reserving for the peak demand)?

*Answer: First, node A reserves 10Mbps bandwidth. During this time, node B cannot establish its circuit.  
 $0.05 + 15 + 0.05 + 0.05 + 16 + 0.05 = 31.2$  s*

- How long does it take to send all data if A and B use packet switching (you can assume an unlimited buffer size on S)?

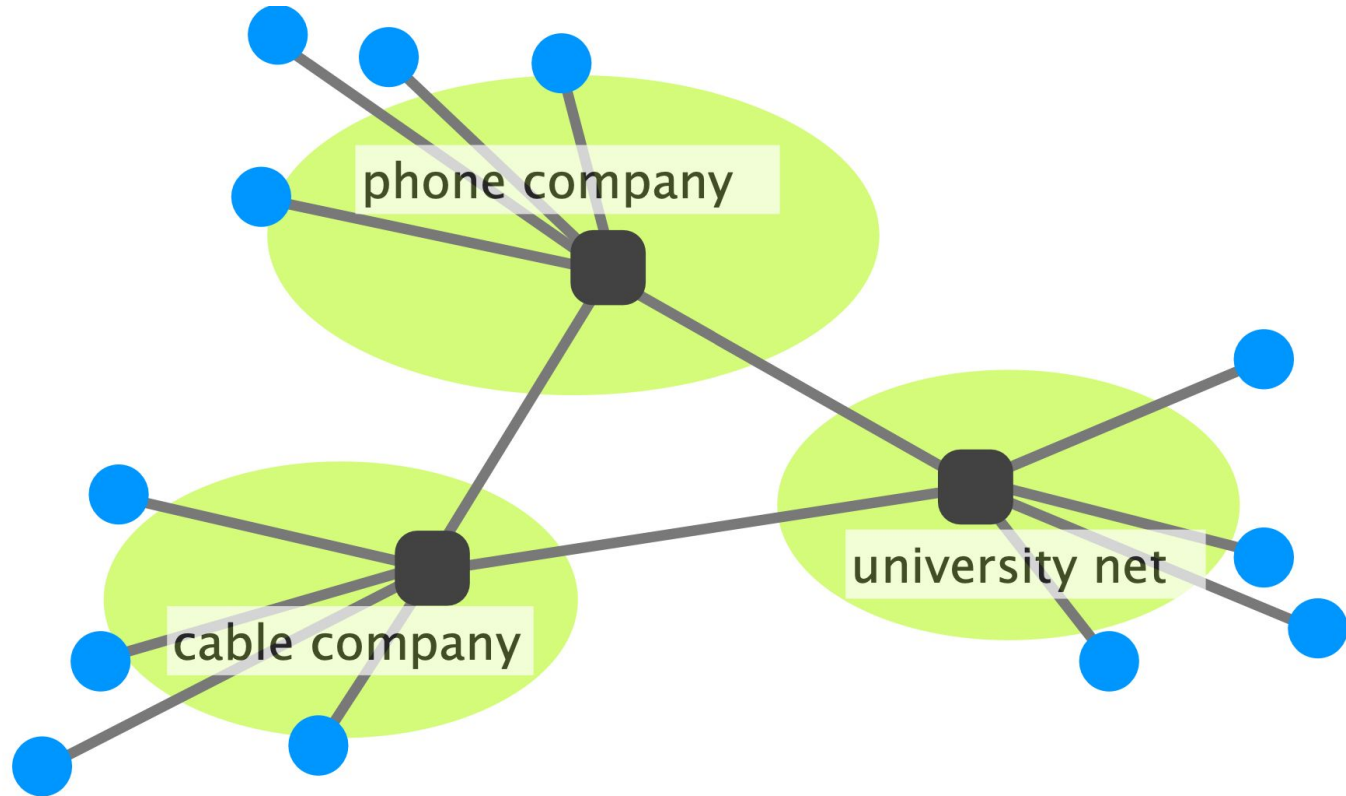
*Answer: Both nodes start to send packets immediately. From 5 to 10 s, packets are buffered. Assuming the switch always uses the full link bandwidth towards C:  
 $1 + 14 + 2 + 1.5 = 18.5$  s*



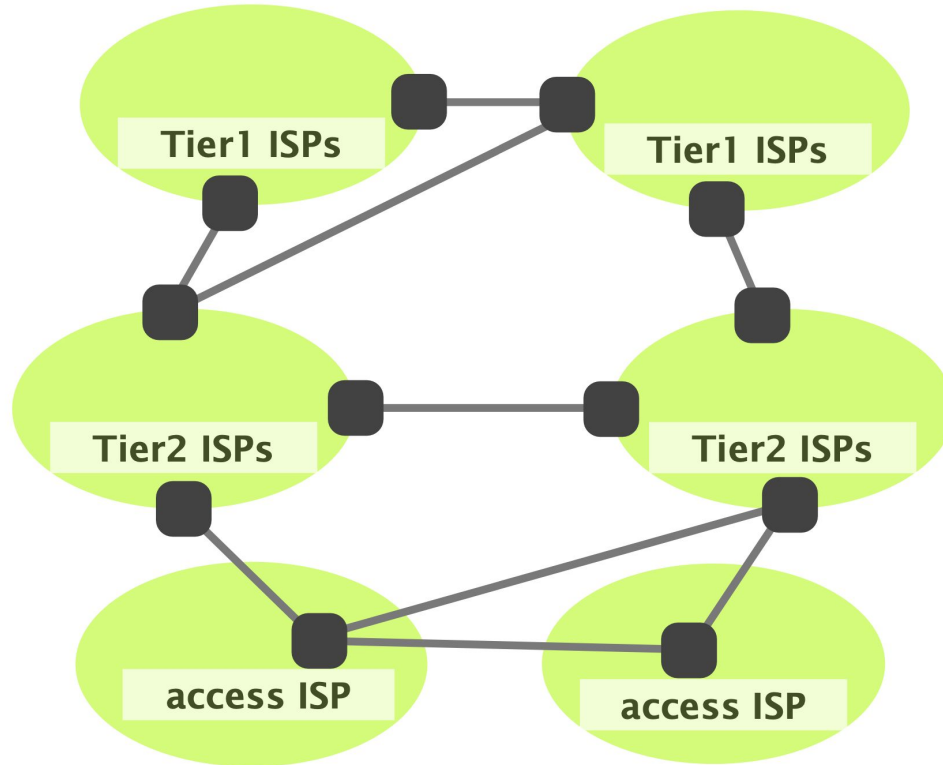
Demand distributions for node A and B.

# Internet Organization

# The Internet is a Network of Networks

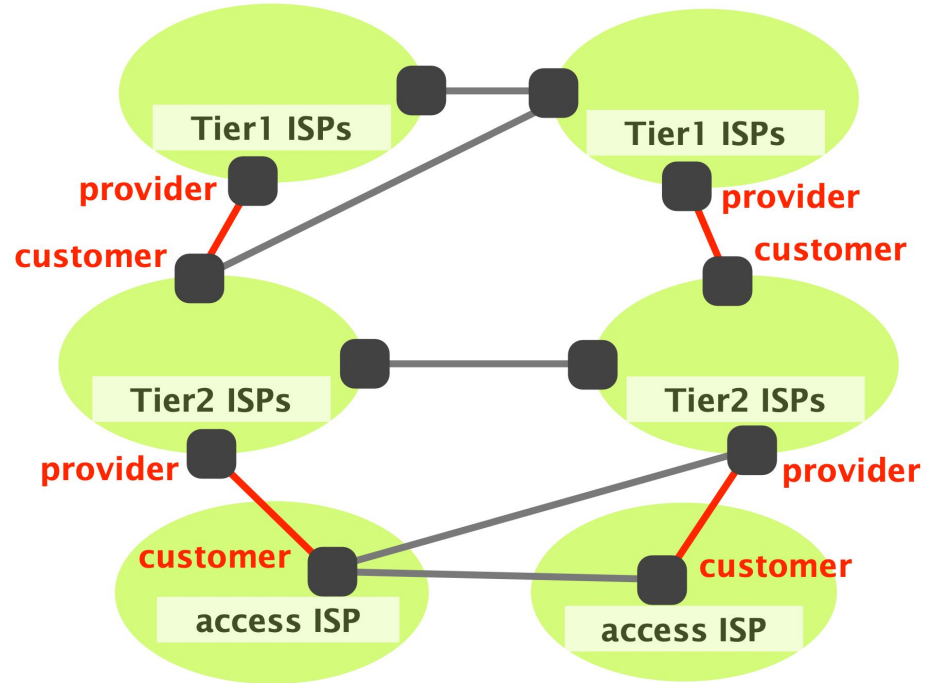


# The Internet is a Network of Networks

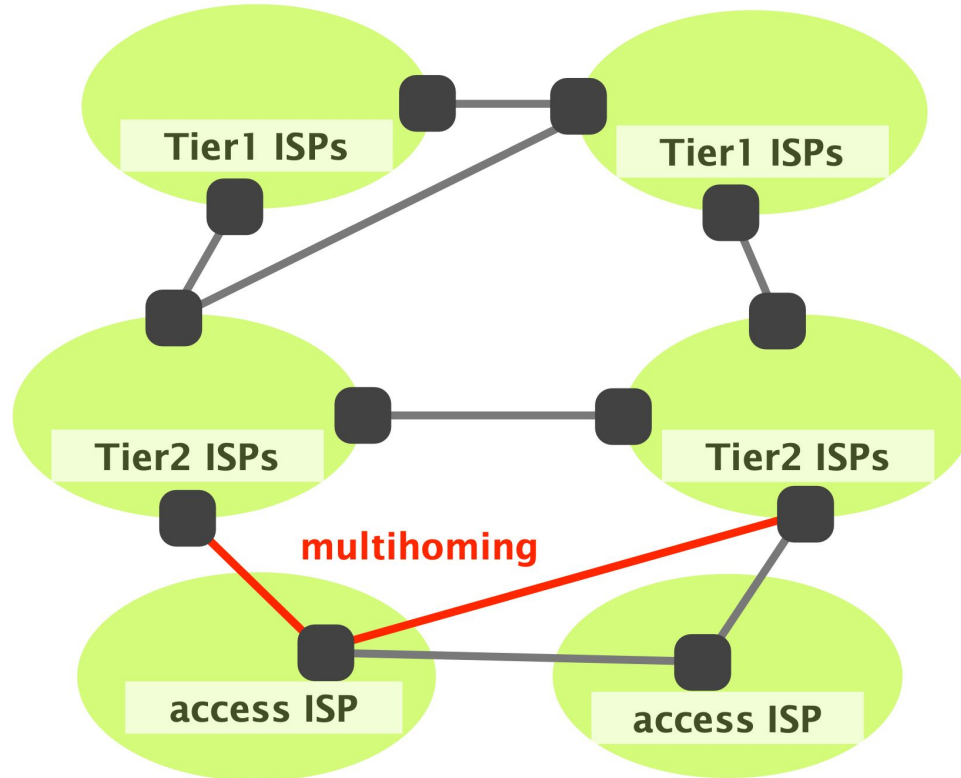


# The Internet Hierarchy

- Tier-1 (international)
  - Have no provider
- Tier-2 (national)
  - Provide transit to tier-3s
  - Have at least one provider
- Tier-3 (local)
  - Do not provide any transit
  - Have at least one provider



# The Internet is a Network of Networks

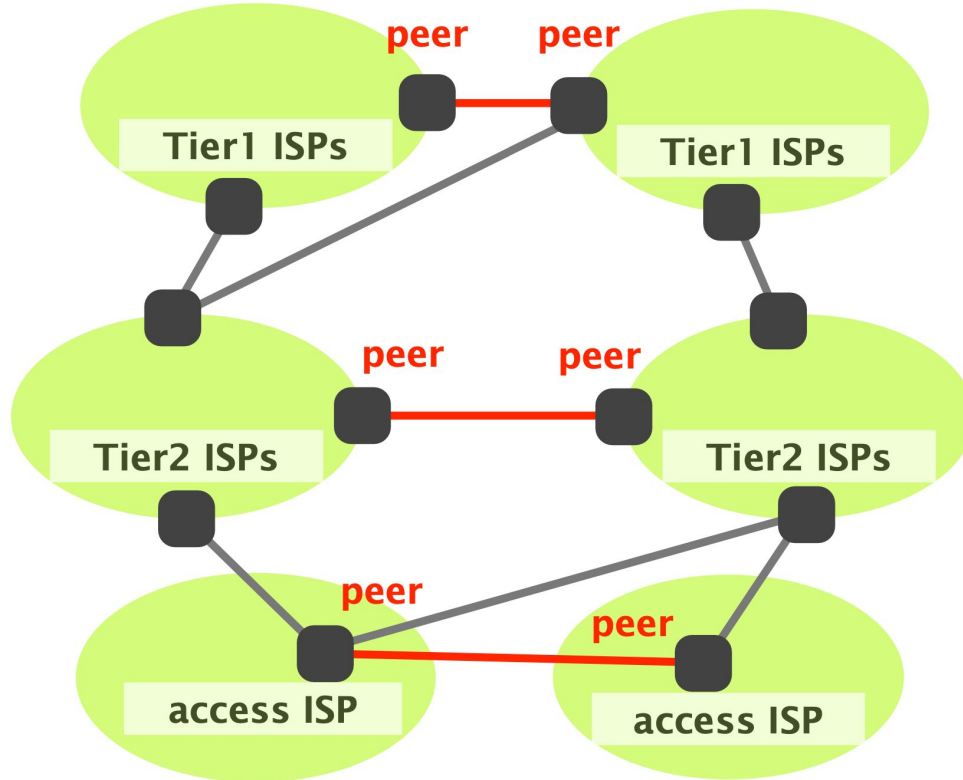


# Some Networks Connect Directly to One Another to Save \$\$\$

Known as “peering”



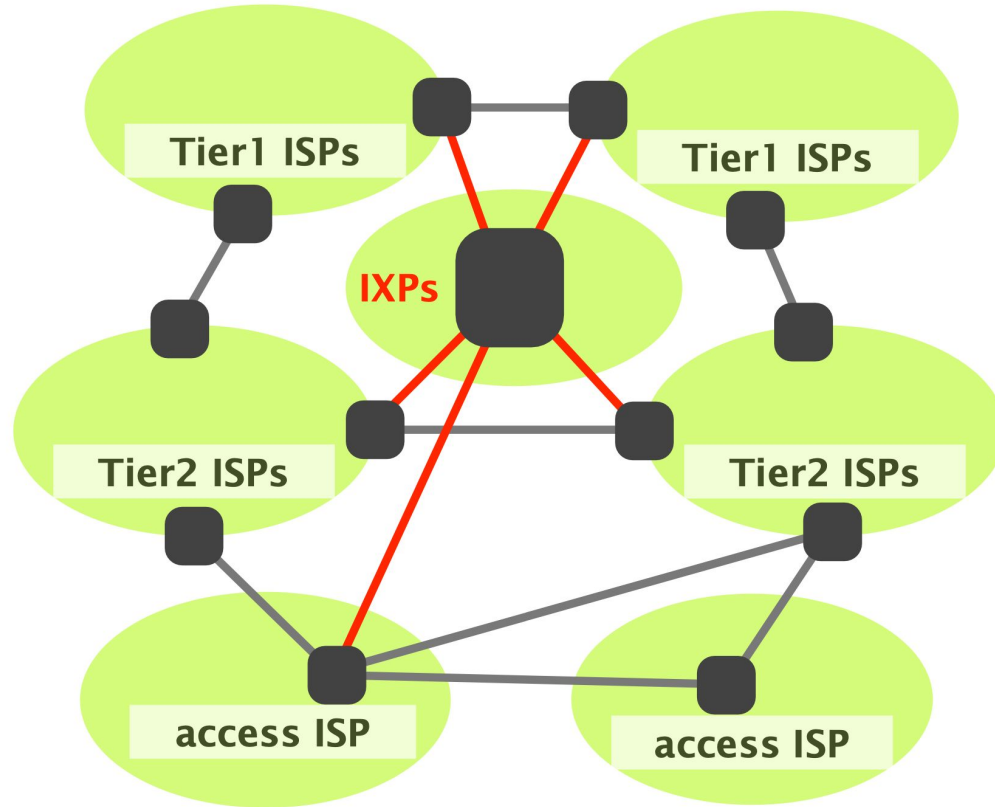
# Some Networks Connect Directly to One Another to Save \$\$\$



# Interconnecting One-by-One is not Efficient / Cost Effective

- Physical costs
  - Provisioning or renting links
- Bandwidth costs
  - Many links underutilized
- Human costs
  - Management of each connection
- Answer? Internet Exchange Points (IXPs)

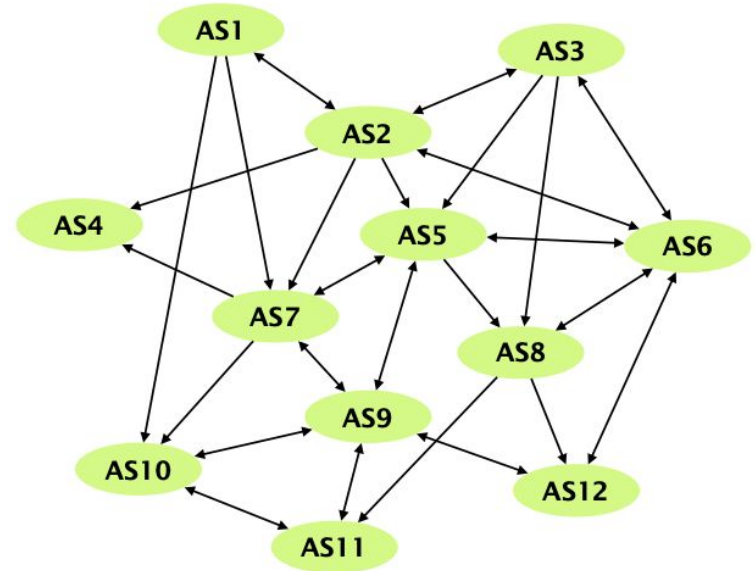
# Interconnecting One-by-One is not Efficient / Cost Effective



# Internet Hierarchy

The network on the left consists of multiple autonomous systems (AS). Single-headed arrows point from providers to their customers. Double-headed arrows represent peer connections.

- For each AS, identify if it is a Tier-1, Tier-2 or Tier-3 network or an IXP.
- AS7 has two different providers (AS1 and AS2). How is this type of interconnection called? What are the advantages of multiple different providers for AS7? Can you see any disadvantages?



# Internet Hierarchy

The network on the left consists of multiple autonomous systems (AS). Single-headed arrows point from providers to their customers. Double-headed arrows represent peer connections.

- For each AS, identify if it is a Tier-1, Tier-2 or Tier-3 network or an IXP.

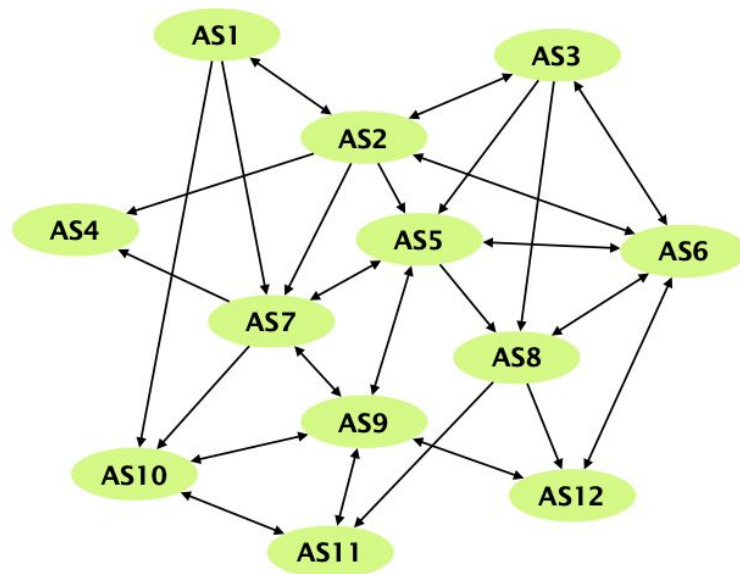
**Solution:** Tier-1 ISPs: AS1, AS2, AS3. Tier-2 ISPs: AS5, AS7, AS8. Tier-3 ISPs: AS4, AS10, AS11, AS12. IXPs: AS6, AS9.

- AS7 has two different providers (AS1 and AS2). How is this type of interconnection called? What are the advantages of multiple different providers for AS7? Can you see any disadvantages?

**Solution:** Multihoming.

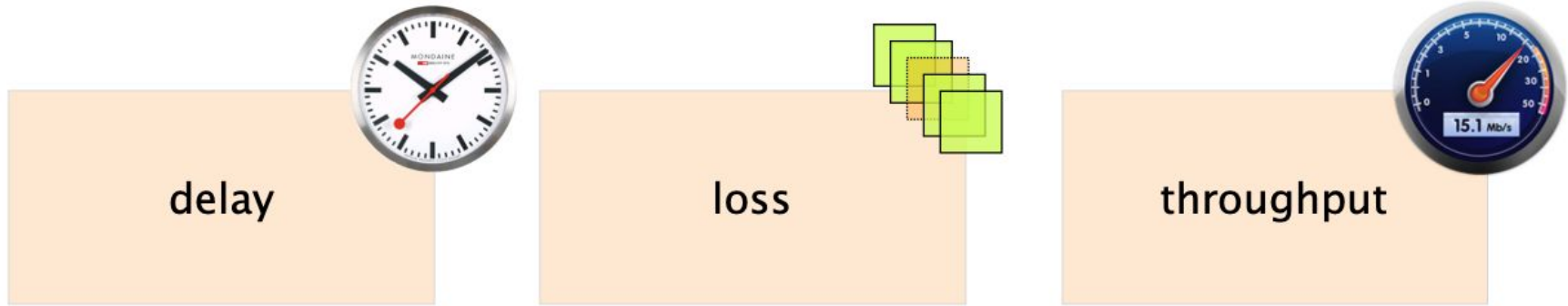
**Advantages:** Still connected if one of the provider fails. For destinations (IP prefixes) which can be reached over both providers, AS7 can choose the better one based on cost, trust, ...

**Disadvantages:** network configuration is slightly more difficult. The total cost could be higher compared to an ISP with only one provider.



# Delay, Loss, and Throughput

# A Network Connection is Characterized by Three Metrics

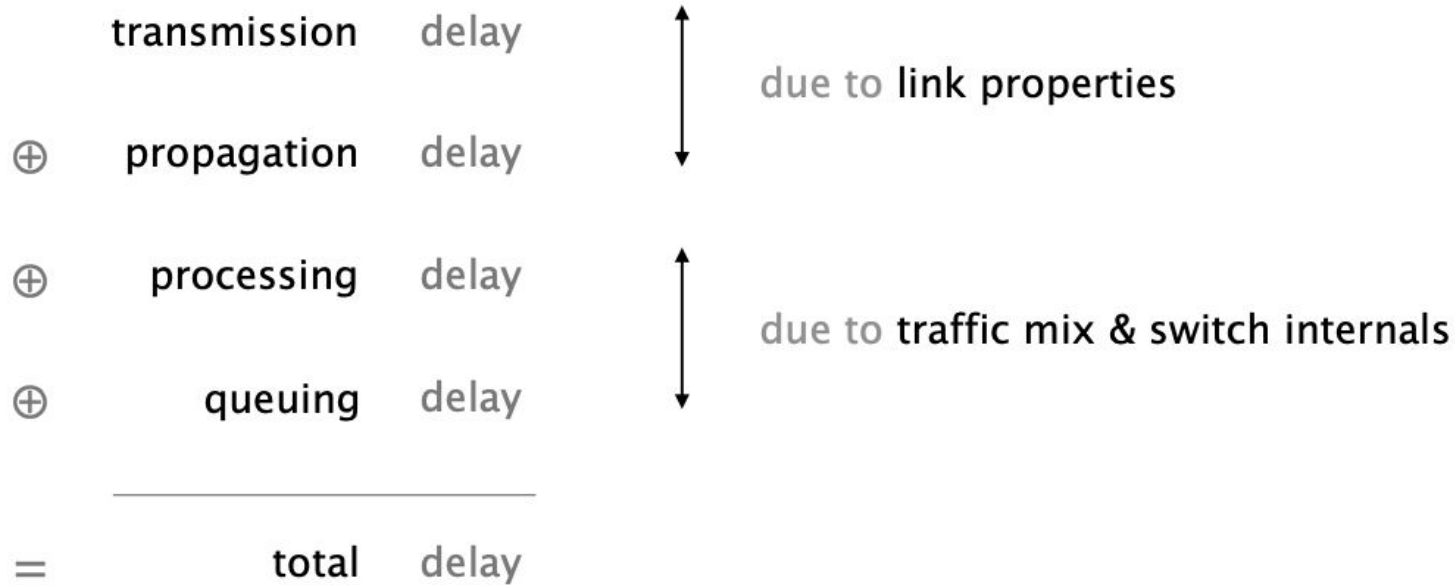


How long does it take for a packet to reach the destination

What fraction of packets sent to a destination are dropped?

At what rate is the destination receiving data from the source?

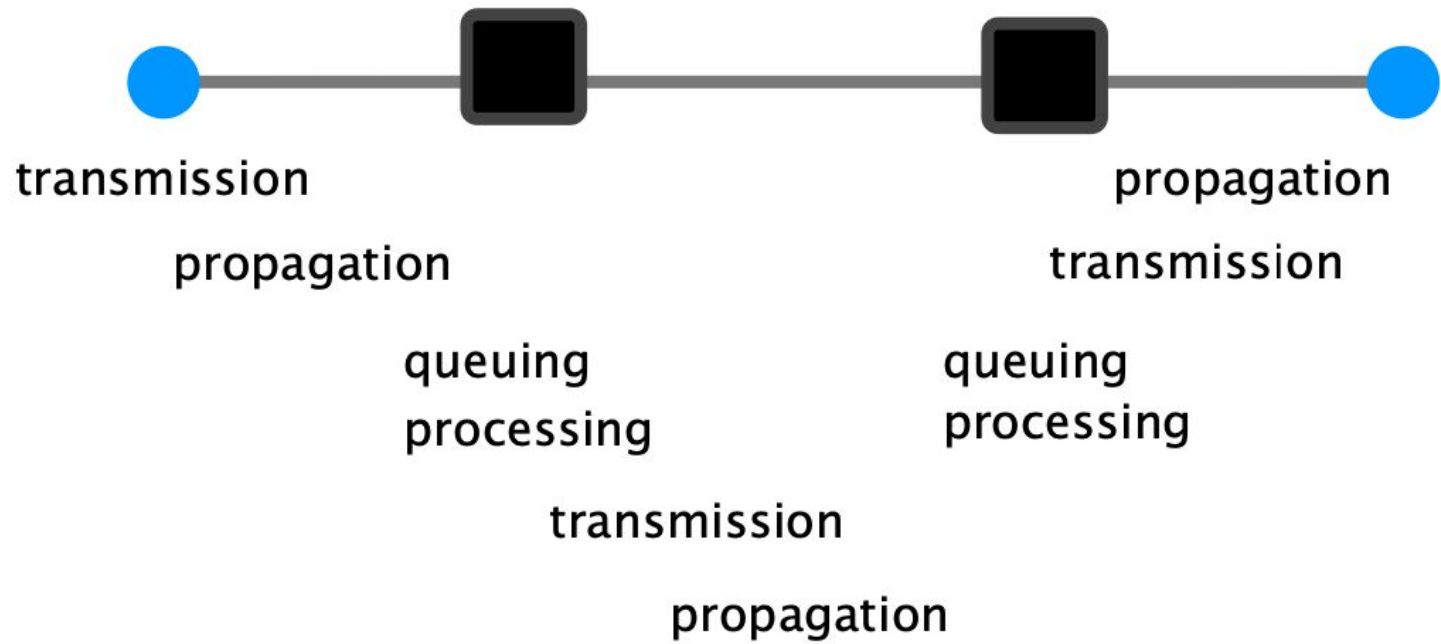
# Every Packet Suffers from Several Types of Delay at Each Node





# The Main Culprits for Overall Delay are Transmission, Propagation, and Queuing

	transmission	delay	
⊕	propagation	delay	
⊕	processing	delay	<i>tend to be tiny</i>
⊕	queuing	delay	
<hr/>			
=	total	delay	



# Transmission Delay is the Time Required to Push all Bits onto the Link

$$\begin{array}{l} \text{Transmission delay} \\ \text{[sec]} \end{array} = \frac{\begin{array}{l} \text{packet size} \\ \text{[#bits]} \end{array}}{\begin{array}{l} \text{link bandwidth} \\ \text{[#bits/sec]} \end{array}}$$

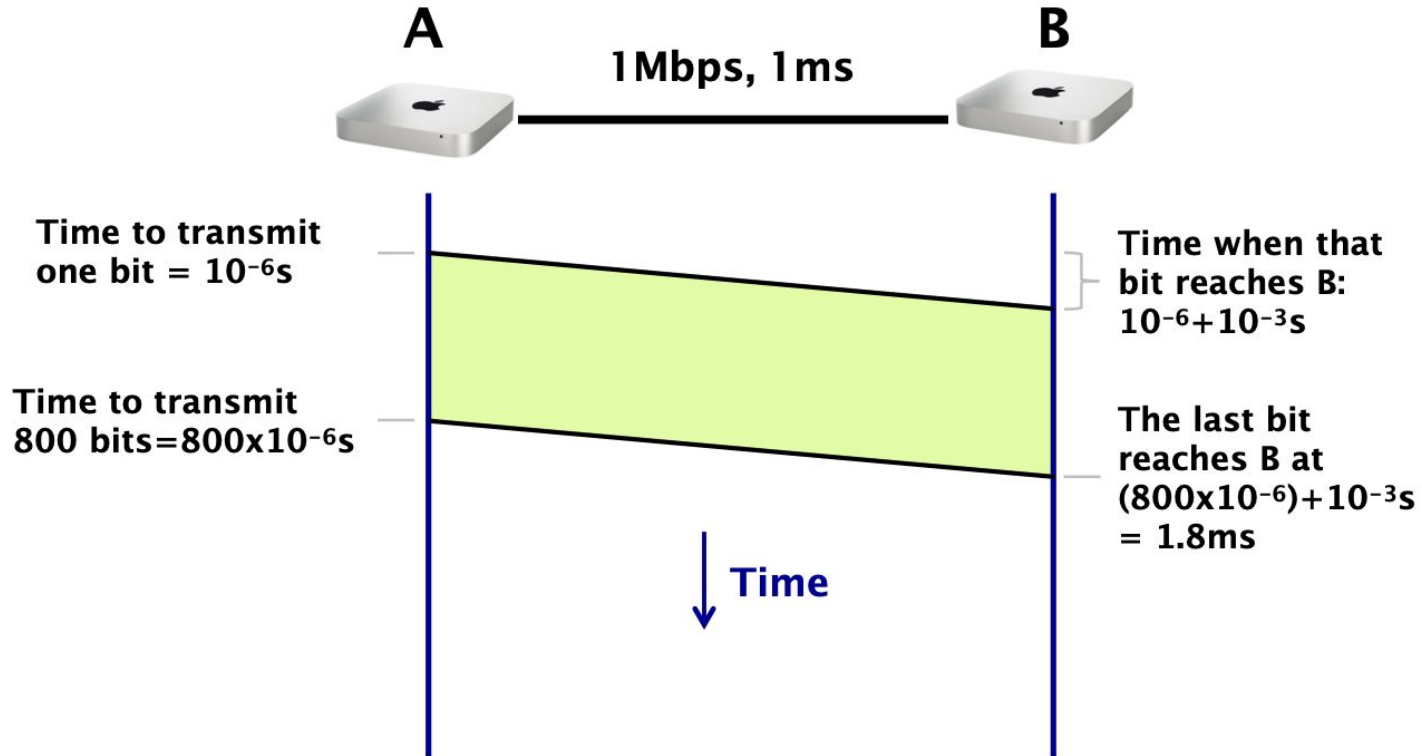
$$\begin{array}{l} \text{Example} \\ \end{array} \frac{\begin{array}{l} 1000 \text{ bits} \\ \end{array}}{\begin{array}{l} 100 \text{ Gbps} \end{array}} = \begin{array}{l} 10 \text{ ns} \\ \end{array}$$

# Propagation Delay is the Time Required a Bit to Travel to the End of the Link

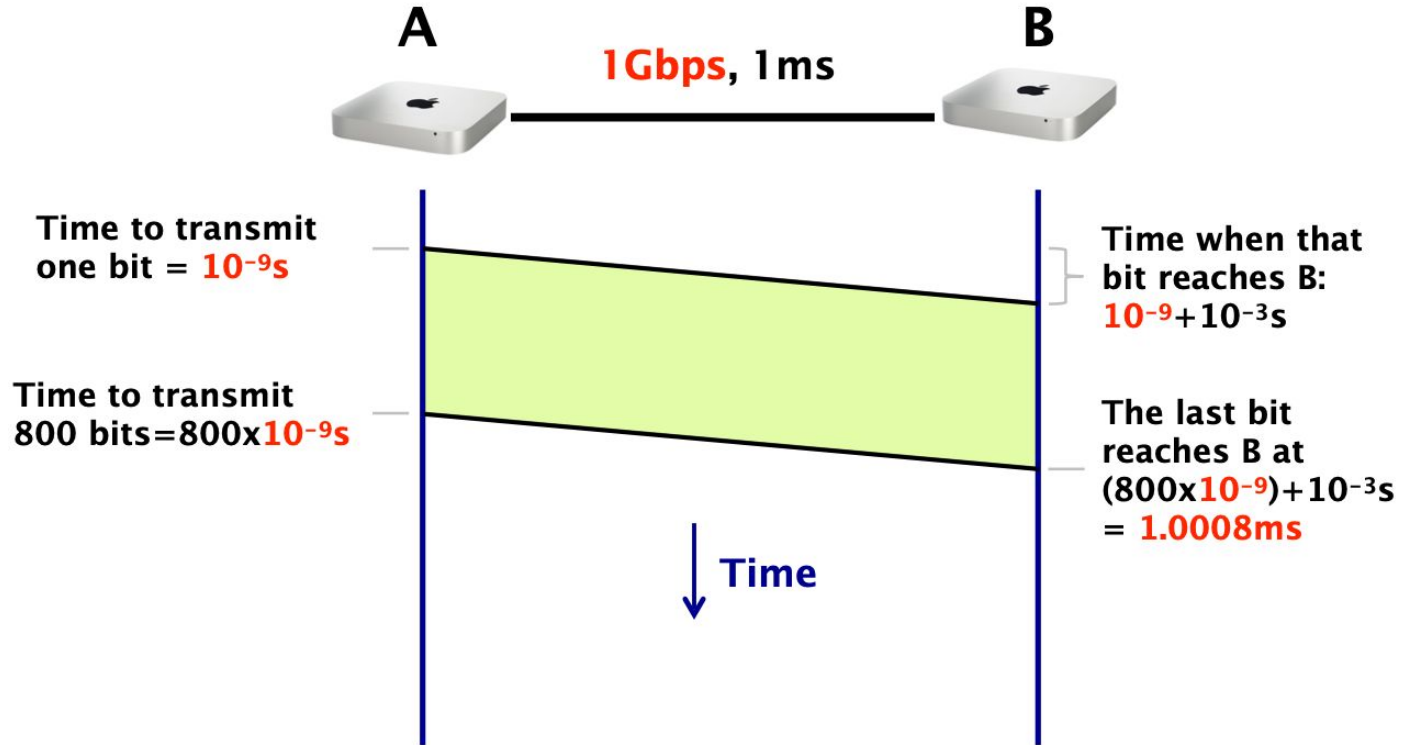
$$\begin{array}{l} \text{Propagation delay} \\ \text{[sec]} \end{array} = \frac{\begin{array}{l} \text{link length} \\ \text{[m]} \end{array}}{\begin{array}{l} \text{propagation speed} \\ \text{[m/sec]} \\ \text{(fraction of speed of light)} \end{array}}$$

$$\begin{array}{l} \text{Example} \end{array} = \frac{\begin{array}{l} 30\,000 \text{ m} \\ \text{[m]} \end{array}}{\begin{array}{l} 2 \times 10^8 \text{ m/sec} \\ \text{[m/sec]} \\ \text{(speed of light in fiber)} \end{array}} = 150 \mu\text{sec}$$

# How Long Does it Take to Send a 100 Byte (800 bits) Packet?



# If We Have a 1Gbps Link



## Different Transmission Characteristics Imply Different Tradeoffs in Terms of Which Delay Dominates

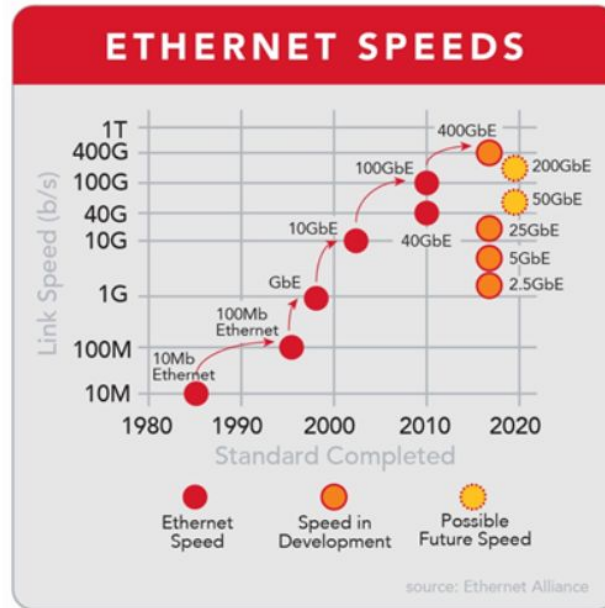
$10^7 \times 100\text{B}$  pkt      1 Gbps link      transmission delay dominates

$1 \times 100\text{B}$  pkt      1 Gbps link      propagation delay dominates

$1 \times 100\text{B}$  pkt      1 Mbps link      both matter

**In the Internet, we can't know in advance which one matters!**

# As Technology Improves, Throughputs Increase and Delays Decrease (except for propagation)



source: ciena.com



# What To Do About Propagation Delays?



Put the content physically near people using CDNs