CS5222 Computer Networks and Internets

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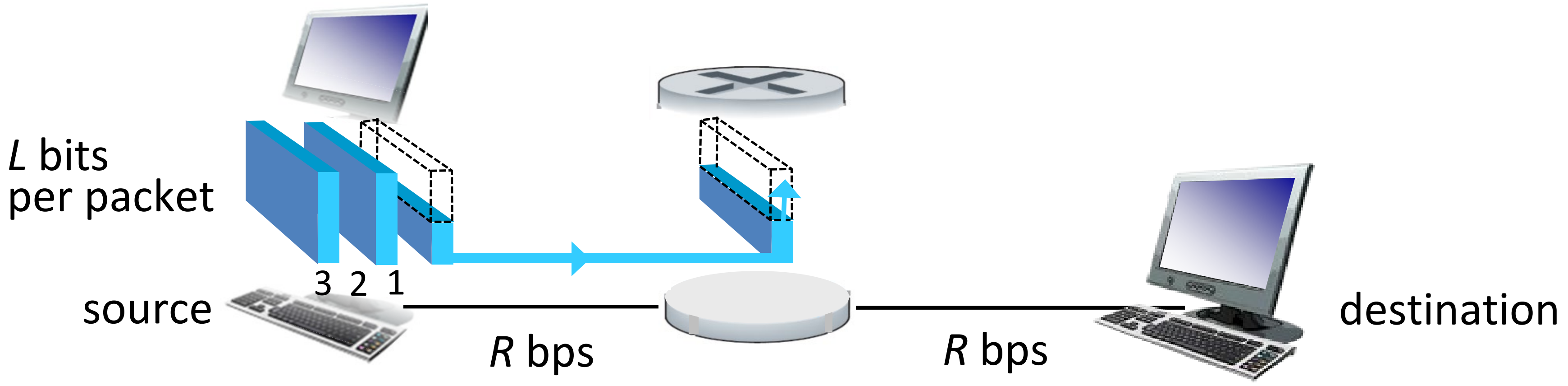
(Tutorial One)

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

Packet-switching: store-and-forward

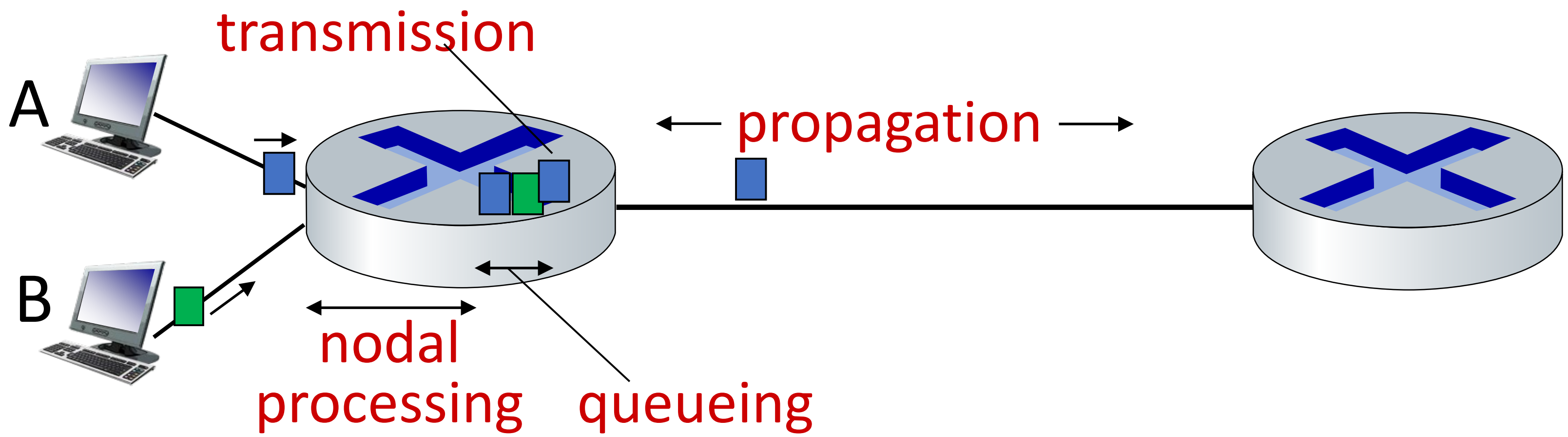


- *Store and forward: An entire* packet must arrive at a router before it can be transmitted on next link
- Transmission delay: takes L/R seconds to transmit (push out) a L-bit packet into the link at R bps
- *End-end delay:* $2L/R$ (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

- L = 10 Kbits
- R = 100 Mbps
- one-hop transmission delay = 0.1 msec

Packet delay: four sources



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

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay:

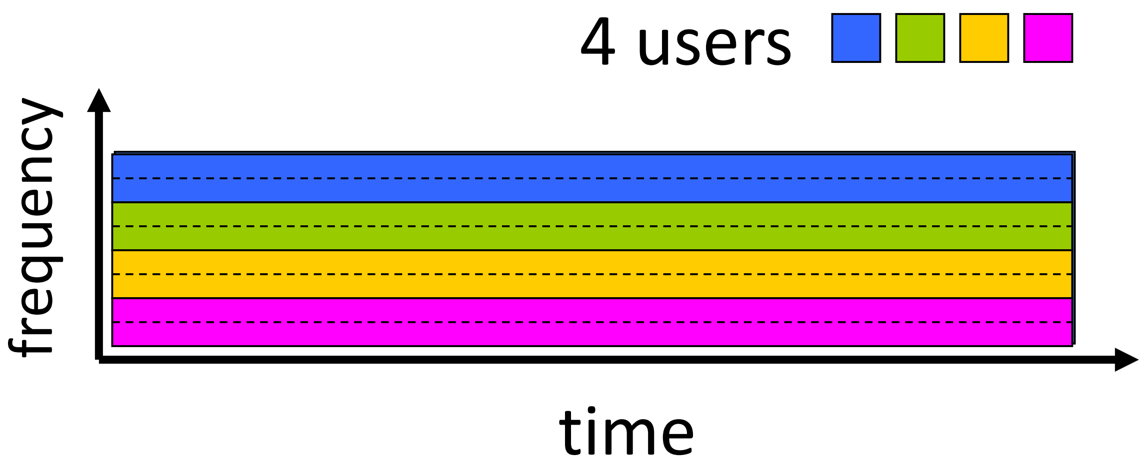
- d: length of physical link
- s: propagation speed (~$2x10^8$ m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop}
very different

Circuit switching: FDM and TDM

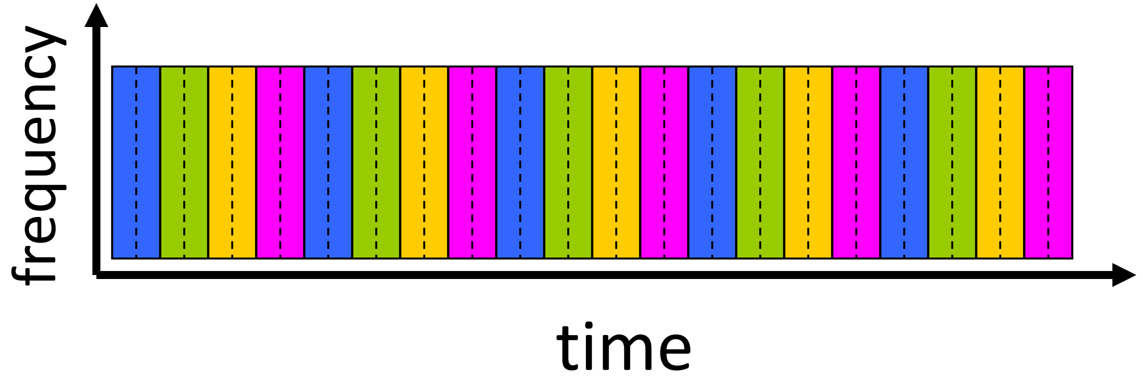
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at the max rate of that narrow band



Time Division Multiplexing (TDM)

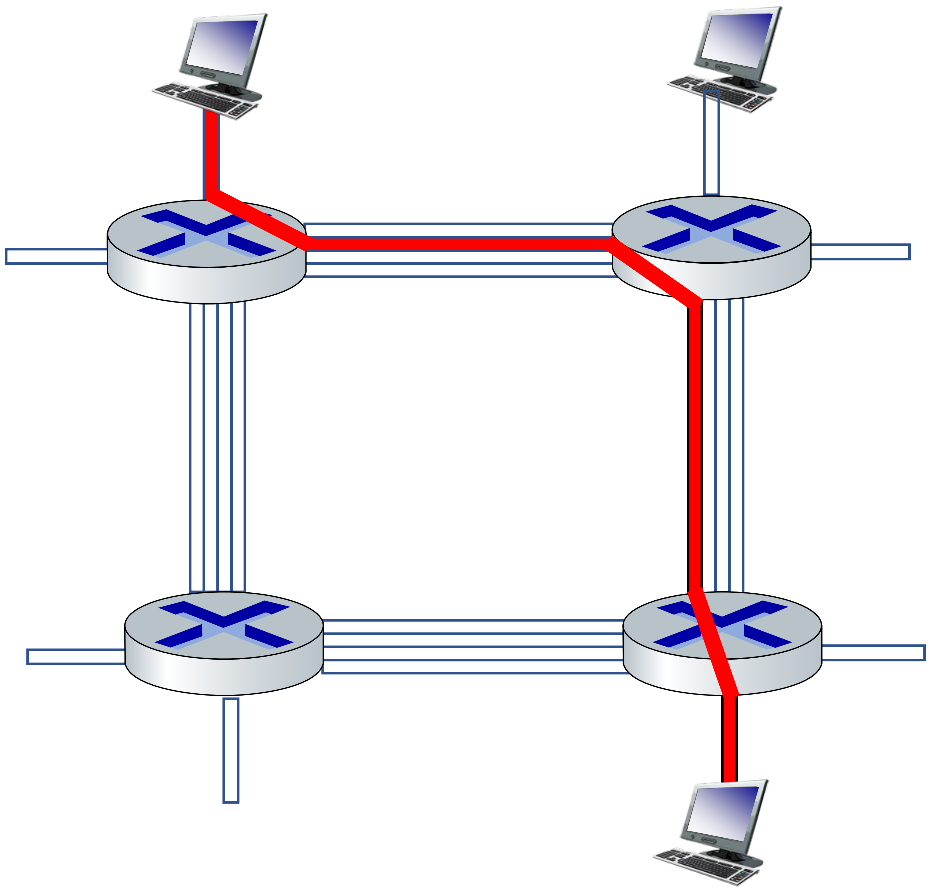
- time divided into slots
- each call allocated periodic slot(s), can transmit at the maximum rate of (wider) frequency band, but only during its time slot(s)



Circuit Switching: alternative to packet switching

end-end resources reserved for "call" between source and destination

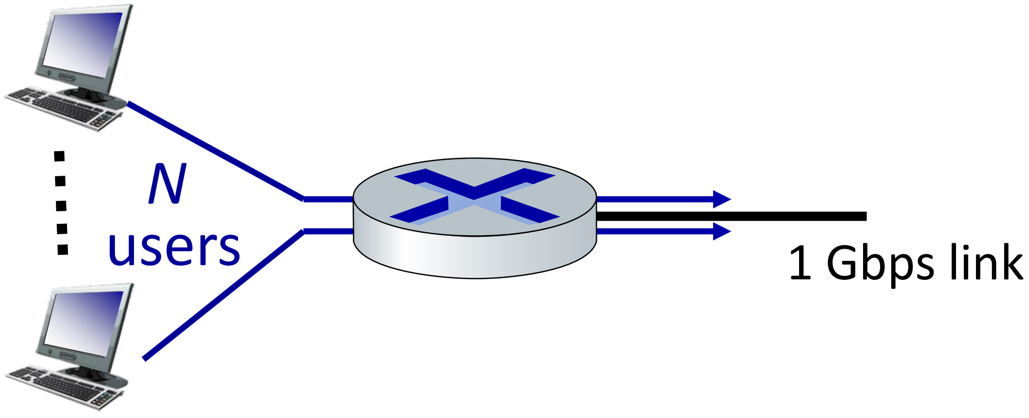
- commonly used in traditional telephone networks
- In Figure: each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - **guaranteed** performance
- circuit segment idle if not used by call (no sharing)



Packet switching versus circuit switching

Example:

- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time



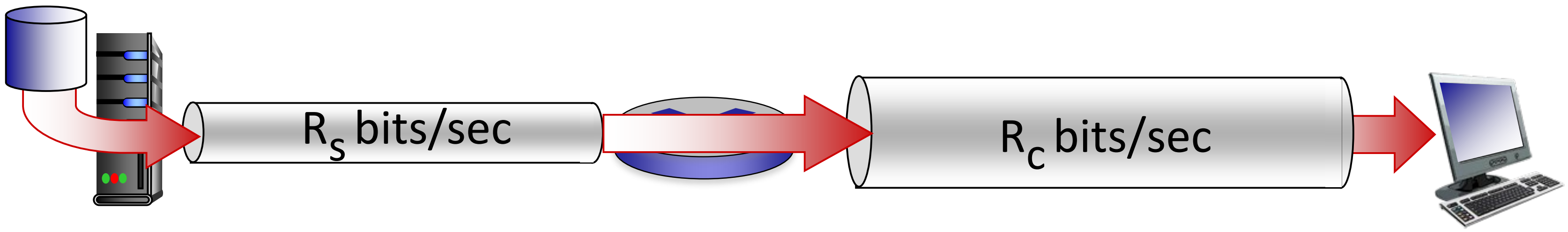
- *circuit-switching:* 10 users
- *packet switching:* with 35 users, probability > 10 active at same time is less than .0004

Q: how did we get value 0.0004?

→ *packet switching allows more users to use network!*

Throughput

$R_s < R_c$ What is the average end-end throughput?



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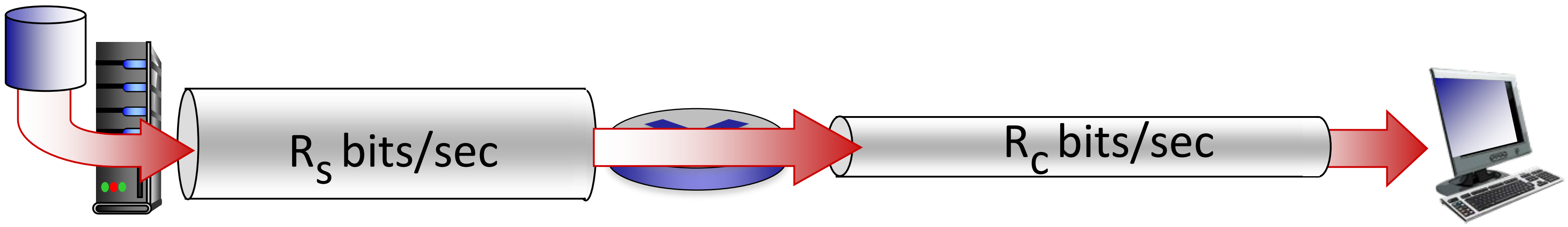
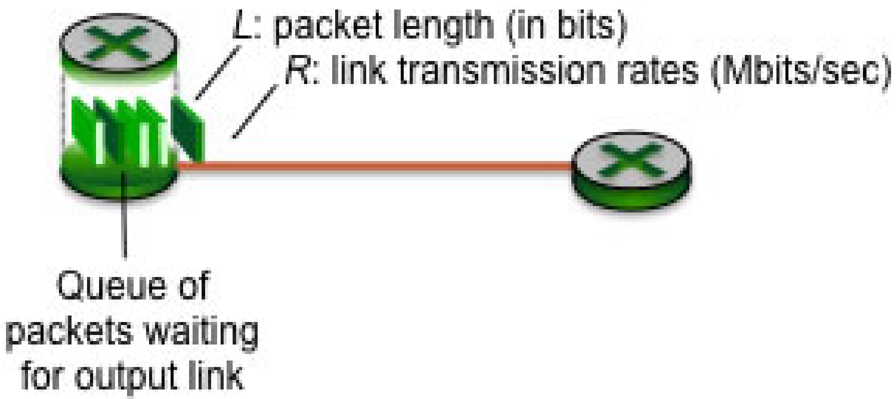


bottleneck link

link on end-end path that constrains end-end throughput

Time to work on questions…

1. Consider the figure below, in which a single router is transmitting packets over a single link with transmission rate R Mbps, to another router at the other end of the link. Suppose that the **packet length is L= 16,000 bits**, and that the link transmission rate along the link to router on the right is **R = 1,000 Mbps**.

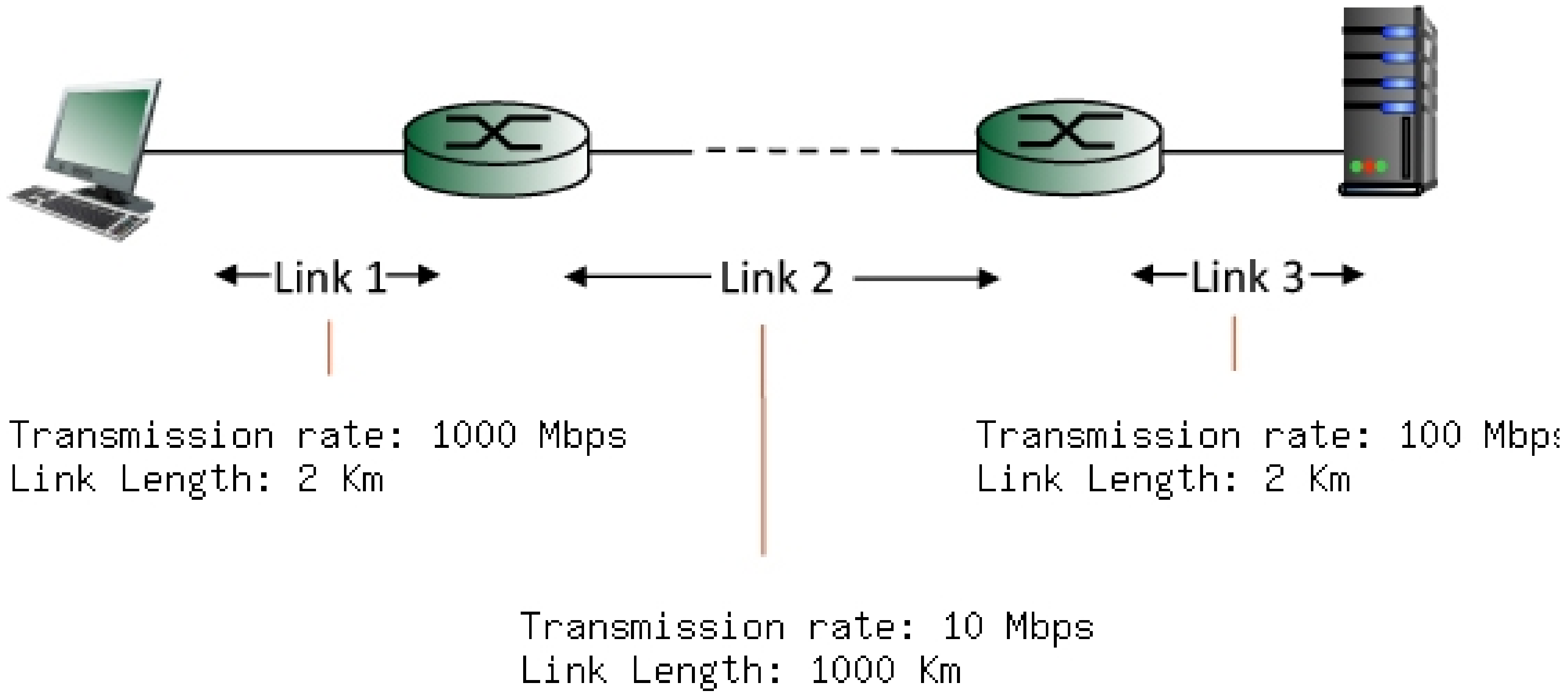


(a) What is the **transmission delay**?

(b) What is **the maximum number of packets per second** that can be transmitted by the link?

2. Consider the figure below, with three links, each with the specified transmission rate and link length. Find the **end-to-end delay** (including the transmission delay and the propagation delay on each of the three links, but ignoring queueing delays and processing delays) from when the left host begins transmitting the first bit of a packet to the time when the last bit of that packet is received at the server at the right.

The speed of light propagation delay on each link is **3×10^8 m/sec**. Note that the transmission rates are in Mbps and the link distances are in kilometers (Km). Assume a **packet length of 12,000** bits. Give your answer in milliseconds.



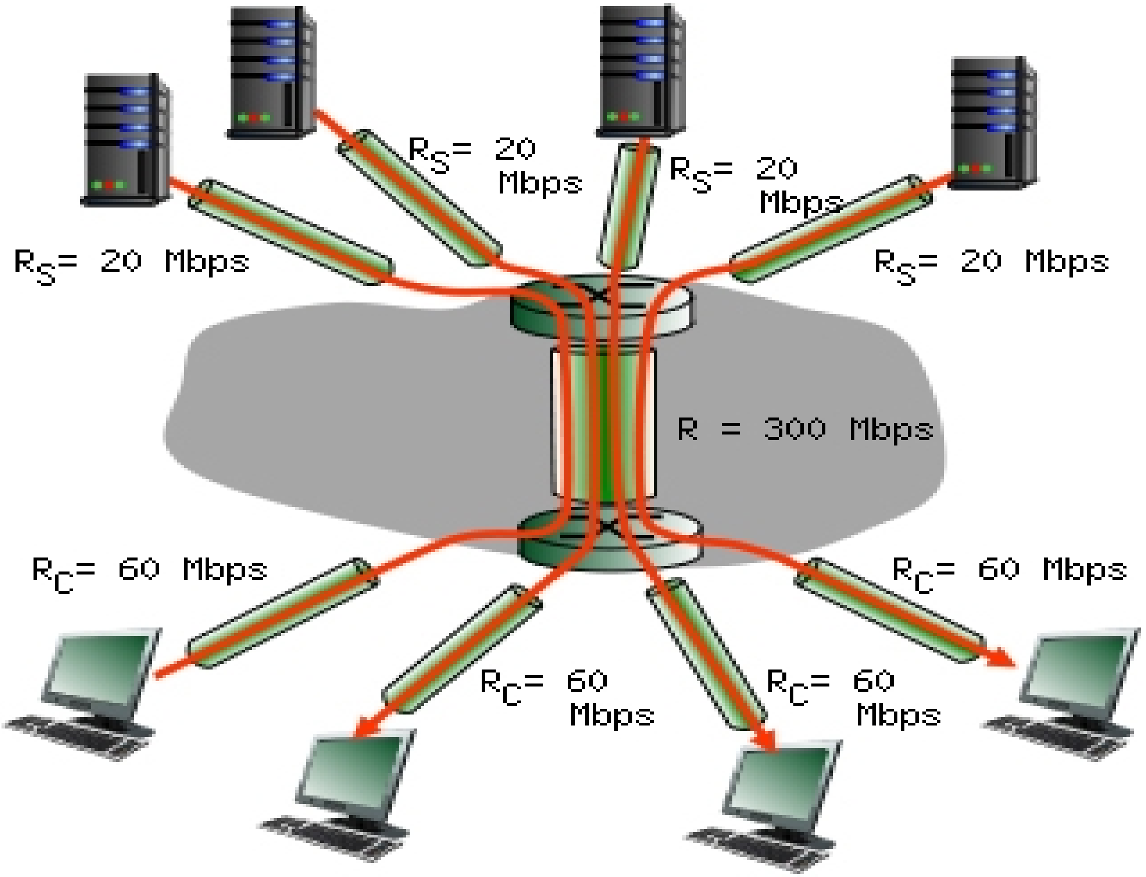
3. Suppose that **users share a 10Mbps link**, i.e., they all send traffic to a node which has a 10Mbps link to forward the traffic received from the users. Suppose that each user transmits continuously at **5Mbps when transmitting**, but each user transmits only **20% of the time**.

(a) When circuit switching is used, how many users can be supported?

(b) Suppose that there are 4 users and **packet switching** is used. What is the fraction of time that the queue at the node is not empty?

4. Consider the scenario shown below, with four different servers connected to four different clients over four three-hop paths. The four pairs share a common middle hop with a transmission capacity of R = 300 Mbps. The four links from the servers to the shared link have a transmission capacity of RS = 20 Mbps. Each of the four links from the shared middle link to a client has a transmission capacity of RC = 60 Mbps per second:

a) What is the **maximum achievable end-end throughput** (in Mbps) for each of four client-to-server pairs, assuming that the middle link is fairly shared (i.e., divides its transmission rate equally among the four pairs)?



b) Which link is the **bottleneck link** for each session?

c) Assuming that the senders are sending at the maximum rate possible, what are the link utilizations for the sender links (RS), the middle link (R), and client links (RC)?