T1: Introduction

1.1 What is computer network?

Examples of computer network

The Internet

Network structure: edge and core

1.2 Why computer networks

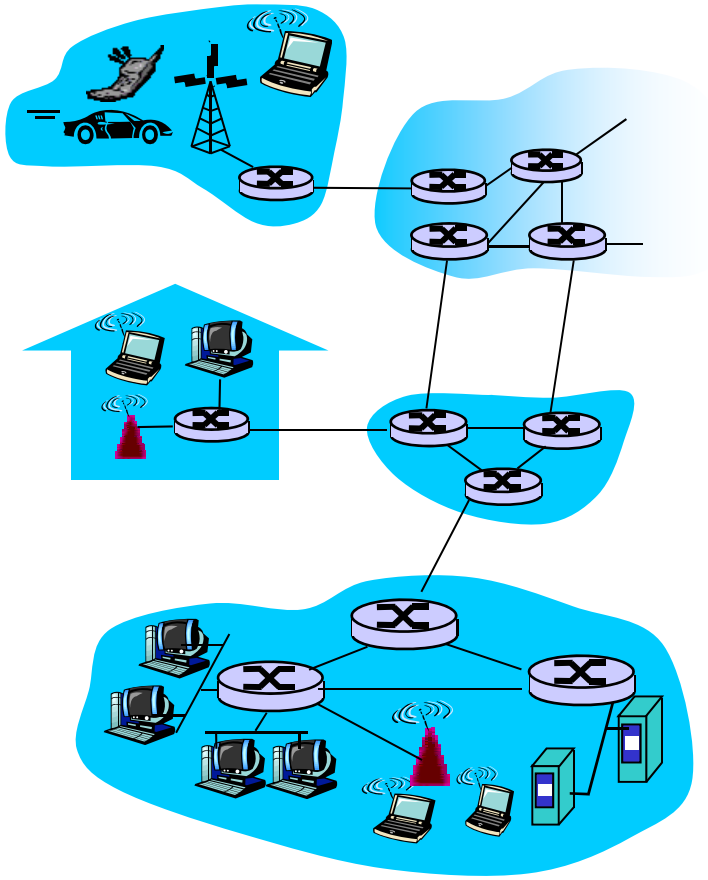
1.3 The way networks work

1.4 Performance metrics:

Delay, loss and throughput in packet-switched networks

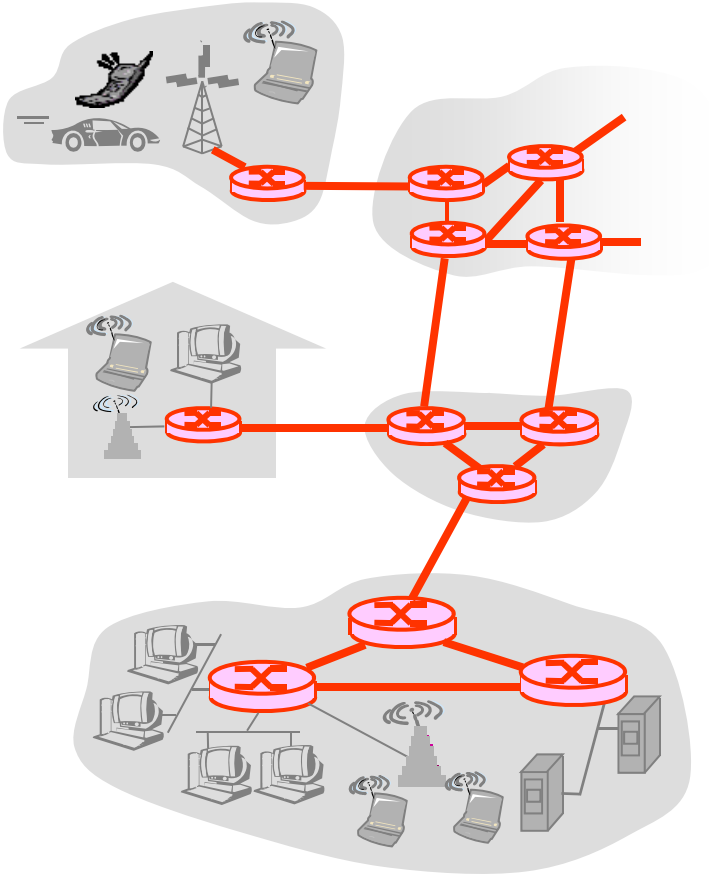
A closer look at network structure:

- **Network edge:**
  applications and hosts
- **Access networks, physical media:**
  wired, wireless communication links
- **Network core:**
  - interconnected routers
  - network of networks

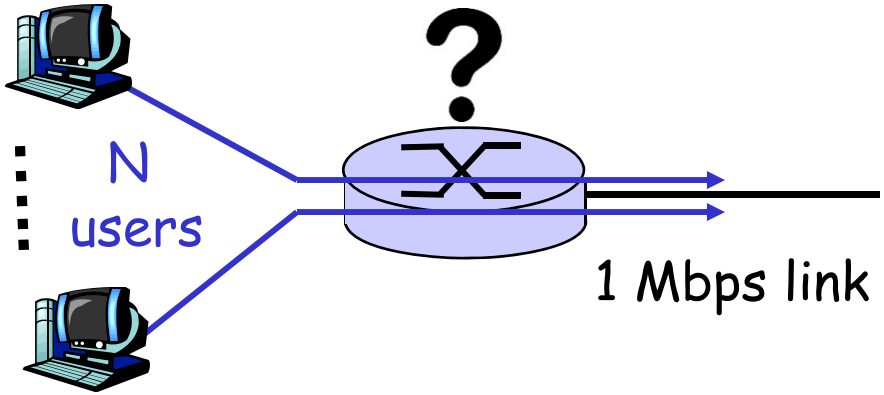


The Network Core

- Mesh of interconnected routers



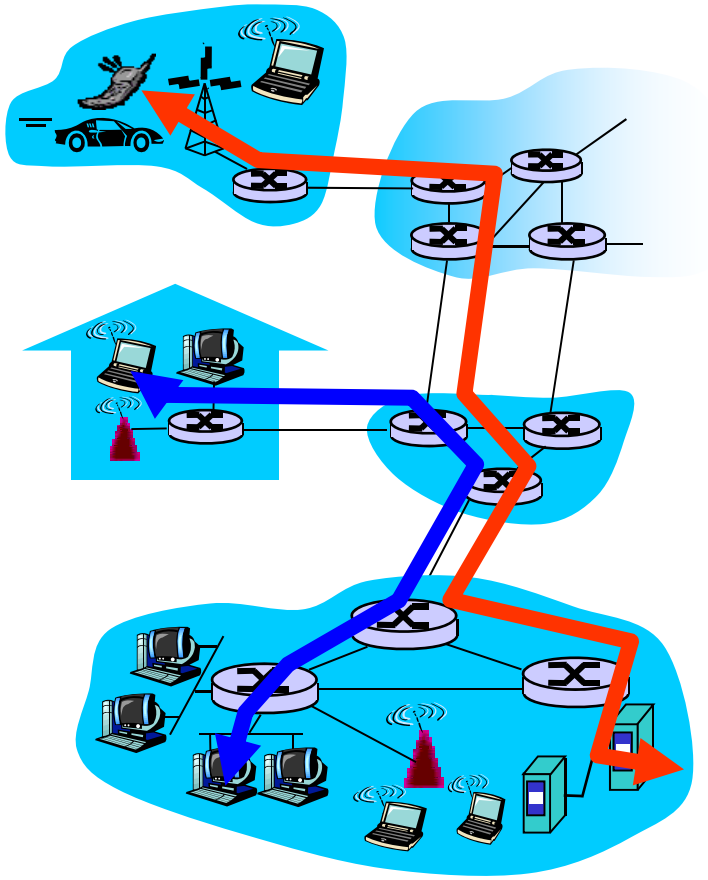
The fundamental question:
how is data (from multiple users) transferred through net?



Network Core: Circuit Switching

End-end resources reserved for "call"

- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required
- Example: telephone net



Network Core: Circuit Switching

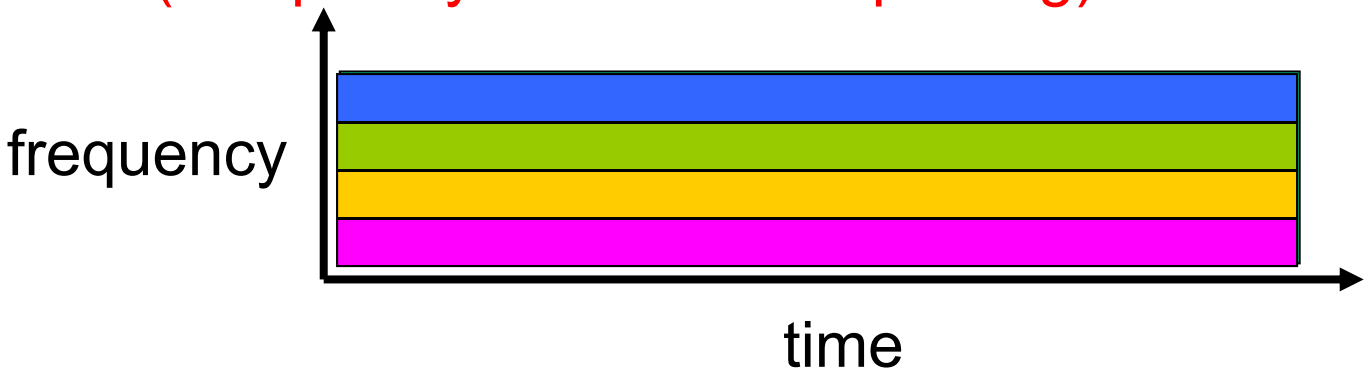
Network resources (e.g., bandwidth) divided into "pieces"

- pieces allocated to calls
- resource piece idle if not used by owning call (no sharing)
- dividing link bandwidth into "pieces"
  - frequency division
  - time division

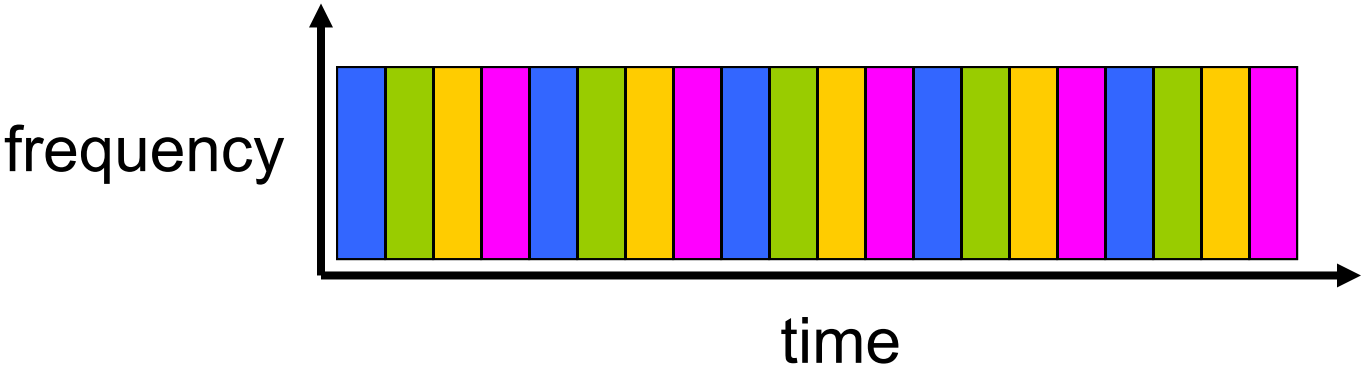
Circuit Switching: FDM and TDM

Example: 4 users 

FDM (Frequency Division Multiplexing):



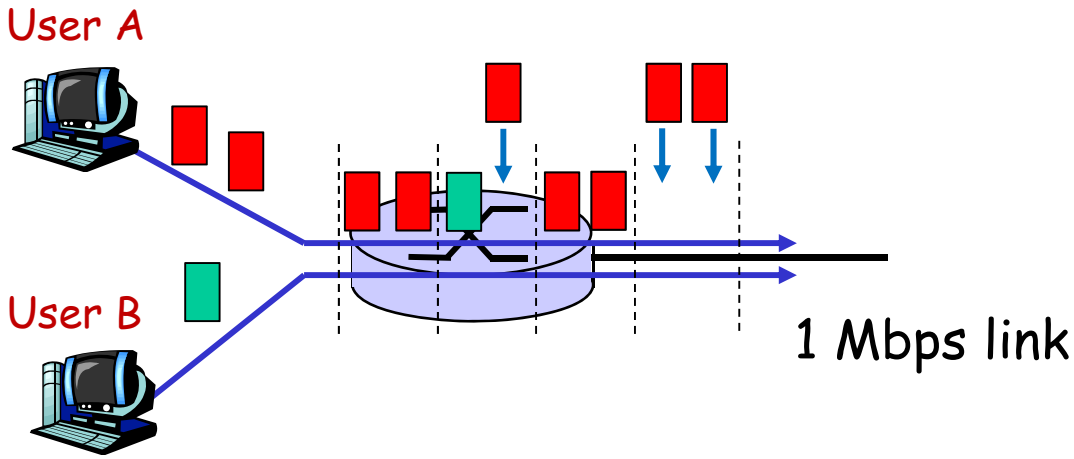
TDM (Time Division Multiplexing):



Network Core: Packet Switching

Dynamic sharing

- Multiple sessions can share one link
- Resources used as needed



Packetizing/Data segmentation statistical multiplexing

Queueing

Packet Switching: Packetizing

- A message is segmented into blocks of data called packets. A packet is a group of bits, typically from a few hundreds to thousands.

- A packet consists of a header, user information, and a trailer. The header usually contains the addresses of the destination and of the source of the packet; it may also include a sequence number that the destination users to verify that all the packets were received or to reorder them. The trailer contains error control bits that the nodes use to verify that they received the packet correctly.

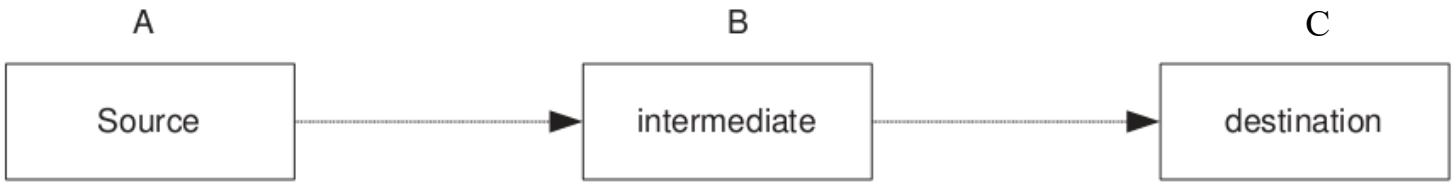
Packetizing: Pipelining gain

- Packets are transmitted without prior reservation of link capacity. When a packet is received at a switch, it is inspected to determine the appropriate output link. If the output link is available, it is transmitted. Otherwise, it is stored and then forwarded to the next switch on its way to the destination (store & forward network)

- The transmission of messages as small packets is called store-and-forward packet switching. The store-and-forward packet switching can reduce the message delivery time. The reduction in the delivery time is called the pipelining gain .

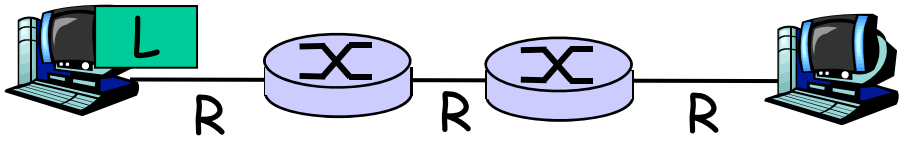
Packetizing: Pipelining gain

- Example: Transmission of a message on a direct link from A to B or B to C takes 1 minute. The total transmission time takes 2 minutes.



If the message is decomposed into 60 packets that takes 1 second each to be transmitted on a direct link, then during the first second packet 1 is sent from A to B , during the next second packet 2 is sent from A to B and packet 1 is sent from B to C , and so on. After 1 minute and 1 second, the complete message is received by C .

Packetizing: store-and-forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- store and forward: entire packet must arrive at router before it can be transmitted on next link
- delay = 3L/R (assuming zero propagation delay)

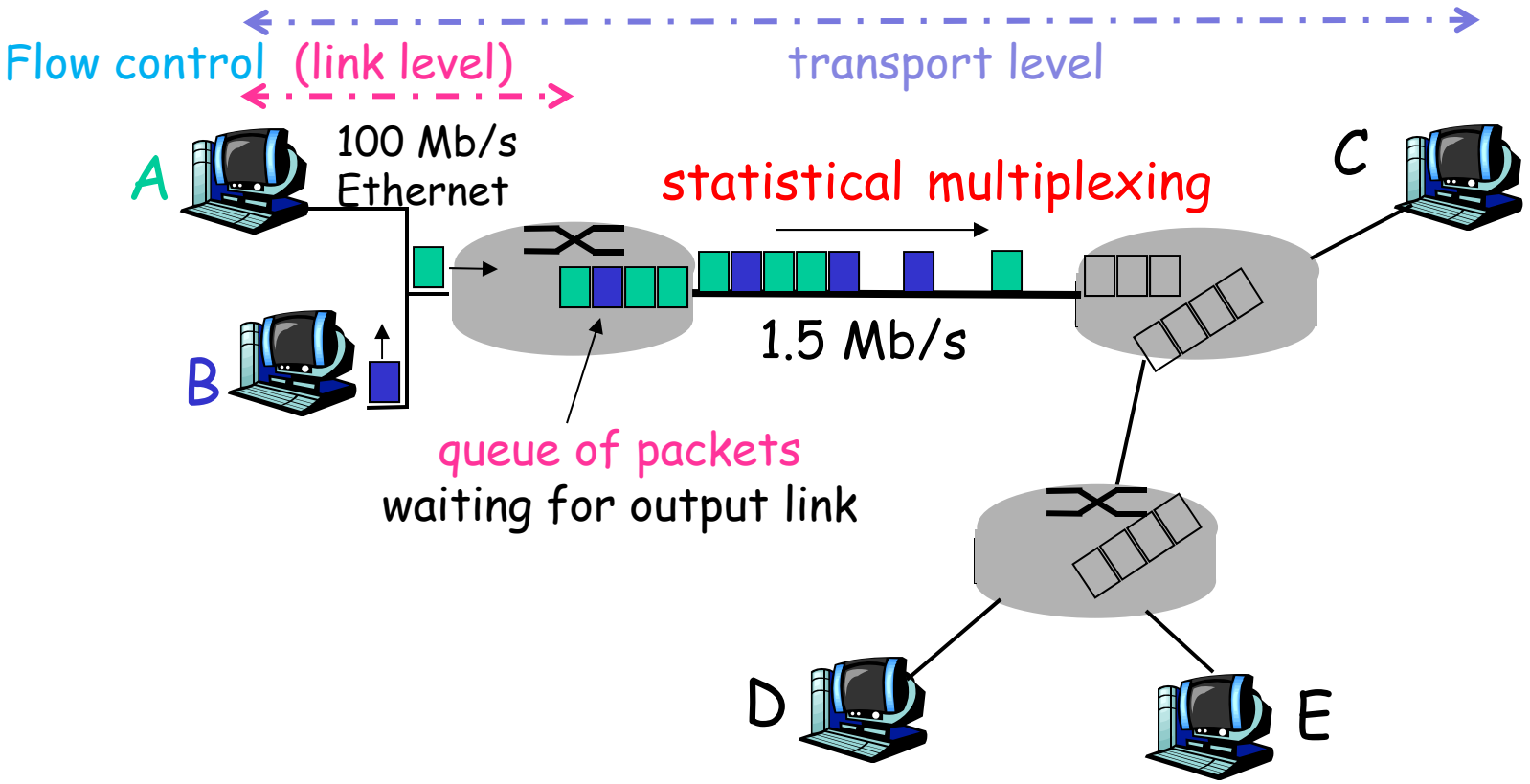
more on delay shortly …

Example:

- L = 7.5 Mbits

  (Note: packets are not that long! ~1.5KB is very common)
- R = 1.5 Mbps
- transmission delay (3L/R) = 15 sec

Packet Switching: Statistical Multiplexing

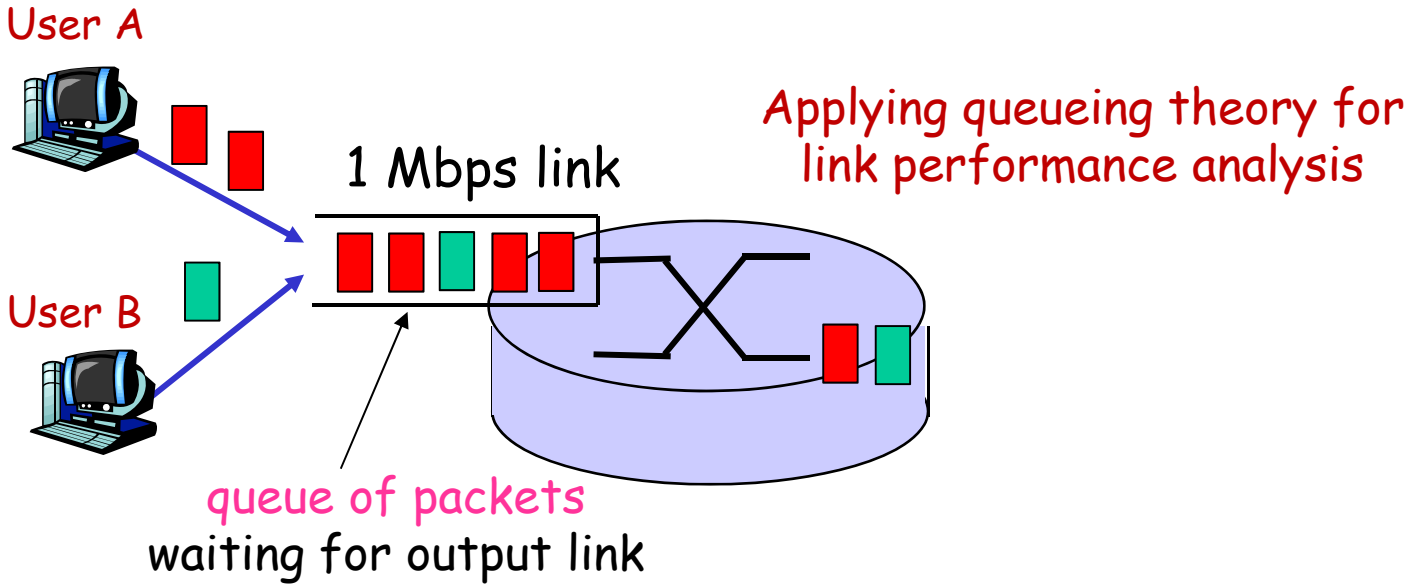


- sequence of A & B packets has no fixed timing pattern
  - bandwidth shared on demand: statistical multiplexing.

Packet Switching: Resource contention

Resource contention:

- Aggregate resource demand can exceed amount available
- Congestion: packets queue, wait for link use



Packet switching versus circuit switching

Packet switching allows more users to use network!

Example:

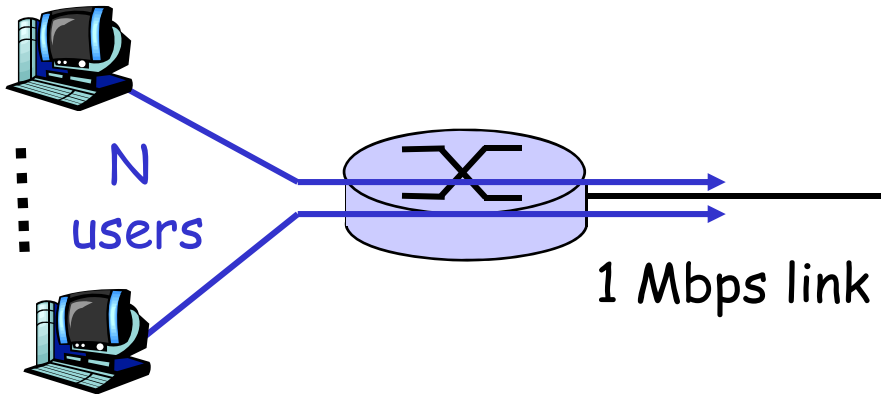
- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time

❖ circuit-switching:

- 10 users

❖ packet switching:

- with 35 users, probability > 10 active at same time is less than .0004



Circuit Switching Advantages

- Debate runs far and deep
  - Guarantee of Quality
- Circuit switching
  - Each session has a dedicated circuit
  - Throughput and delay performance will not change
- Packet switching
  - Best-effort service: no guarantees
  - Links get congested, messages arrive out of order, …

Packet Switching Advantages

- Ease of connectivity
  - No need to allocate resources first
  - Transmit at will, as long as protocols are allowed
- Scalability
  - Large number of diverse sessions
  - Obtained through high efficiency
    - Statistical multiplexing

A comparison of circuit-switched and packet-switched networks

Item	Circuit switching	Packet switching
Dedicated path	Yes	No
Bandwidth available	Fixed	Dynamic
Potentially wasted	Yes	No
Store-and-forward trans.	No	Yes
Call setup	Yes	Not needed
When can congestion occur	At setup time	On every packet
Charging	Per minute	Per packet
Each packet follows the same route	Yes	No