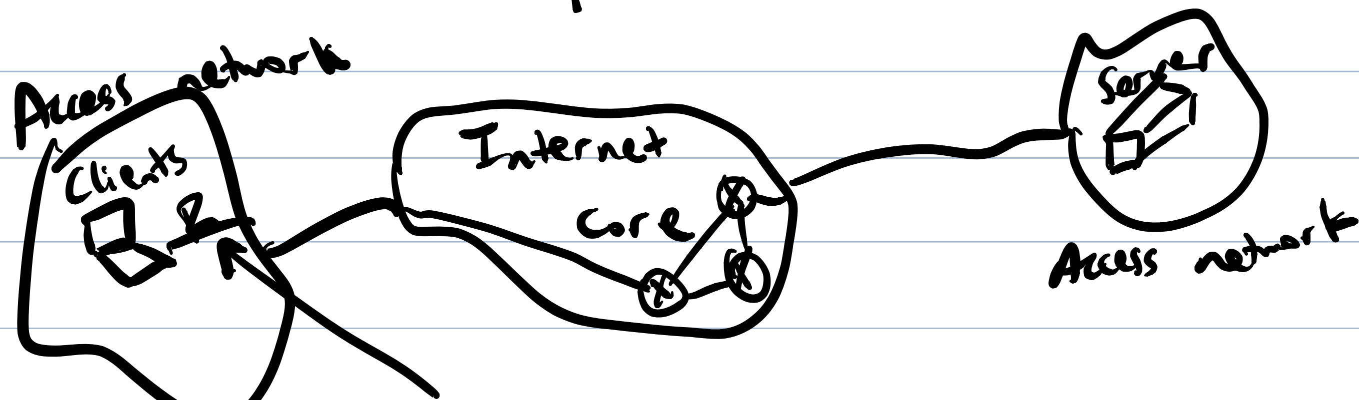
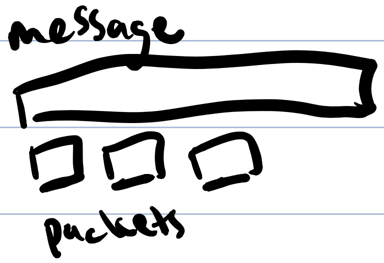
Packet Switching: queueing delay, loss

queueing and loss:

- if arrival rate (in bits) to link exceeds the transmission rate of link for a period of time:
  - → packets will queue, wait to be transmitted on link
  - → packets can be dropped (lost) if memory (buffer) fills up



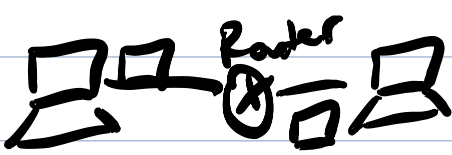
Transmission delay = $\frac{L}{R}$



Network Core

Packet switching

store-and-forward



receive packet before retransmit

Circuit switching

- requires "call" setup
- reserves resources for the call between src and dst
- doesn't allow sharing

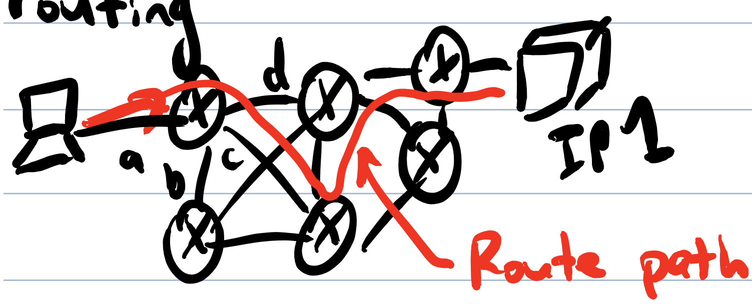
- each packet uses the full link speed
- most dominant
- suffers from queueing delay + packet loss

- common for traditional telephone networks
- circuit segment idle if not used by call (e.g. no data to transmit)

+ No delay (QoS guarantee)
- Wasted resources (no sharing)

2 key network core functions:

routing

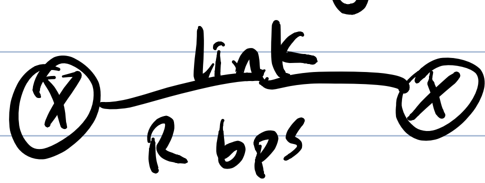


- planning of route from src to dest
→ routing algorithms
- planning the whole route
- result is a forwarding table

forwarding

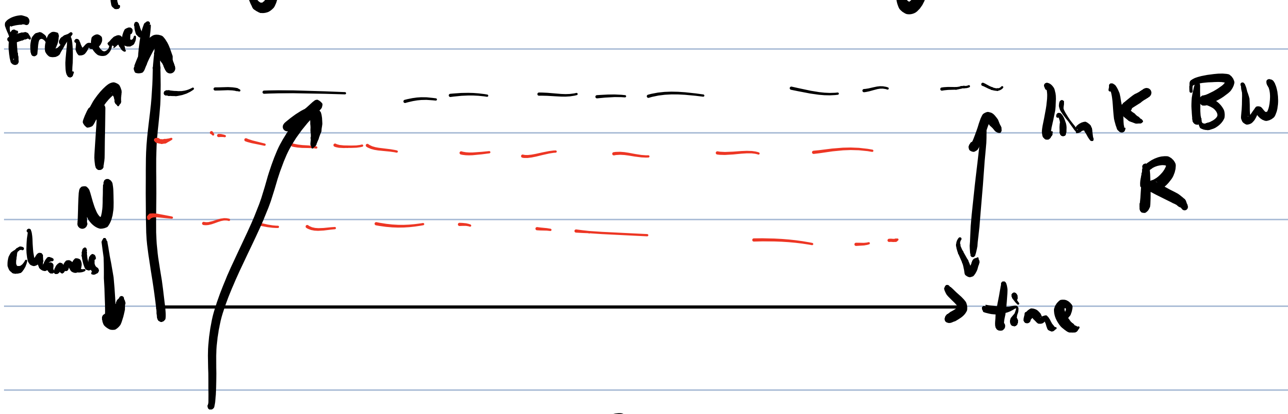
- router receiving a packet at port A with addr IP1. which port should be used to forward the packet? b, c, d?
- determining the output port
- local to the router
- consequence of routing

Circuit Switching: FDM vs. TDM



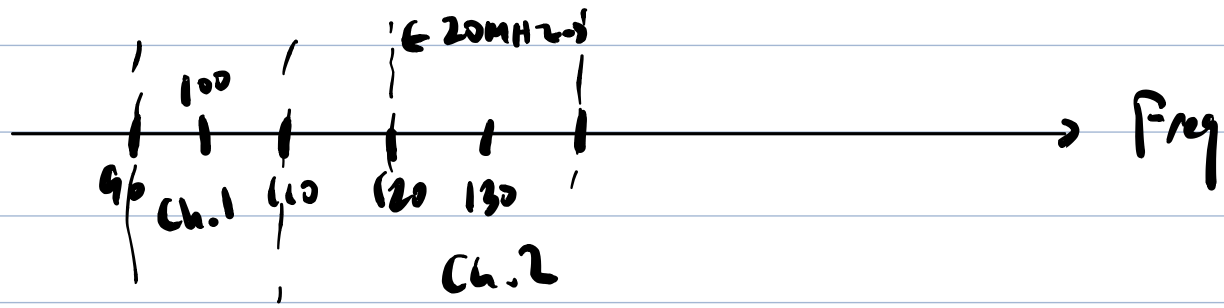
How to divide a link into multiple circuits or channels?

Frequency division multiplexing:



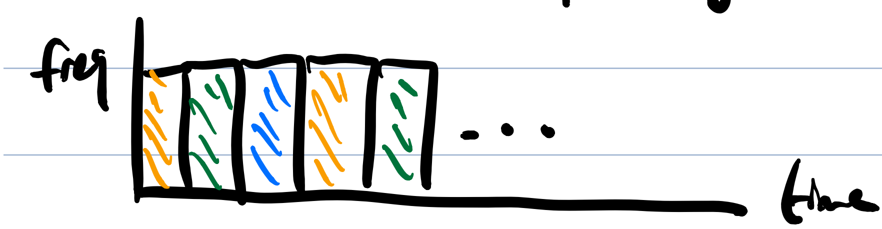
Channel rate $= \frac{R}{N}$

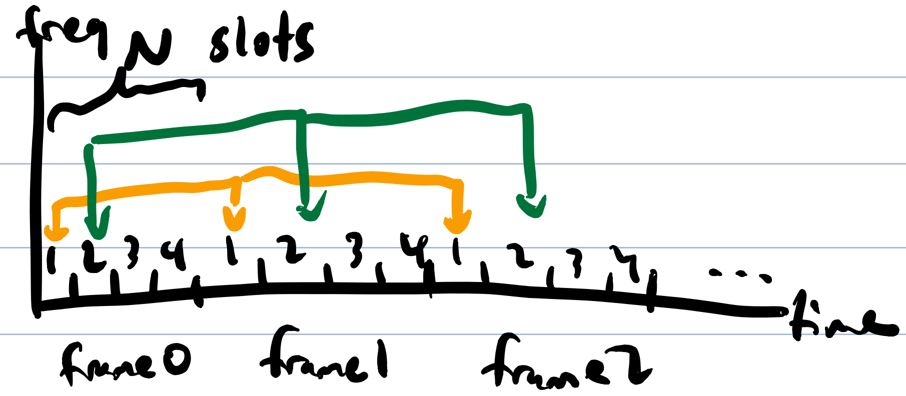
e.g. 80 MHz
N=4
each user = 20 MHz



- each user can transmit all the time but using a smaller chunk of bandwidth

Time division multiplexing



- 

→ frames divided into timeslot

- assigned timeslot in certain frame, must wait for same timeslot in a subsequent frame to keep transmitting
- number of users known in advance

still $\frac{R}{N}$ bps

e.g. 1 Mbps link, N users active 10% of the time, 100 kb/s when active

P(> 10 users active at the same time)

Suppose N = 35

$$P(\leq 10 \text{ users active}) = \sum_{i=0}^{10} \binom{35}{i} (0.1)^i (0.9)^{35-i}$$

$$= 0.996$$

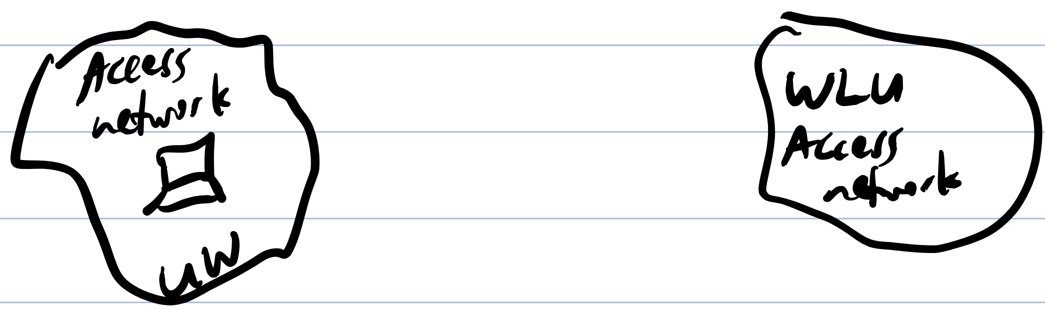
$$P(> 10 \text{ users active}) = 1 - 0.996 = 0.004$$

∴ packet switching supports more users

circuit switching supports $\leq \frac{1\text{Mbps}}{100\text{kbps}} = 10$ users packet switching:

- great for bursty data (users become silent and suddenly transmit many pkts)
  - → resource sharing
  - → simpler, no call sharing
- excessive congestion possible: packet delay + loss
  - → protocols needed for reliable data transfer, congestion control
- how to provide circuit-like behavior?
  - → bandwidth guarantees needed for video/audio apps
  - → still an unsolved problem (Ch. 7)

Internet as network of networks



connecting each access ISP to another: $\Theta(n^2)$ connections

global ISP: each access net. connects to a router in the global ISP

→ competitors for global ISPs crop up
ISP A, B, C disjoint!

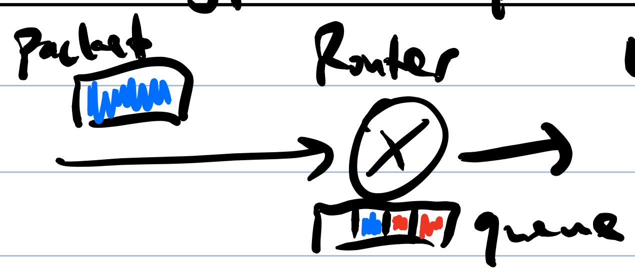
→ global ISPs must be connected
  ↳ peering link (mutual agreement)
  ↳ IXP: internet exchange point – meeting point for ISPs to peer together

→ regional nets (ISPs) – smaller companies with limited coverage within a country
  ↳ connected to tier 1 ISPs to connect to Internet
  ↳ charge money for this service

→ Content Provider Network: companies may run their own network for faster, better service

How do loss and delay occur?
From now on we only study packet switching.
packets queue in router buffers
- packet arrival rate to link (temporarily) exceed output link capacity

Four types of packet delay:



1. processing delay
d_{proc}

- check for bit errors (error ⇒ request retransmit)
- forwarding (determine output link)

- typically $<$ msec.

2. queueing delay, d_{queue}
- time a packet has to wait in a queue before being transmitted

3. transmission delay, d_{trans}

L: pkt length (bits)
R: link bw (bps)

$$d_{trans} = \frac{L}{R}$$

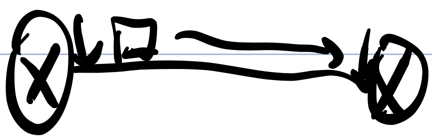
- time required to put a packet of size L bits on a link of rate R bps.

4. propagation delay

d: length of physical link (m)
s: propagation speed in medium ($\sim 2 \times 10^8$ m/s)
↳ copper wire

$$d_{prop} = \frac{d}{s}$$

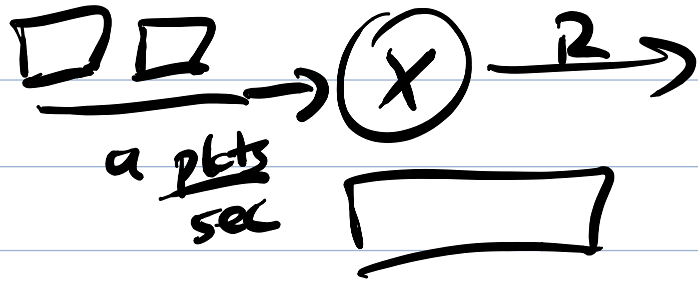
- time required for a packet to travel from one end of a link to the other end of the link



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

we can't really control this one

Queueing delay revisited



Traffic utilization = traffic intensity = offered traffic

$$= \frac{\text{Incoming data rate}}{\text{Outgoing data rate}} = \frac{aL}{R}$$

↳ very important for traffic designers