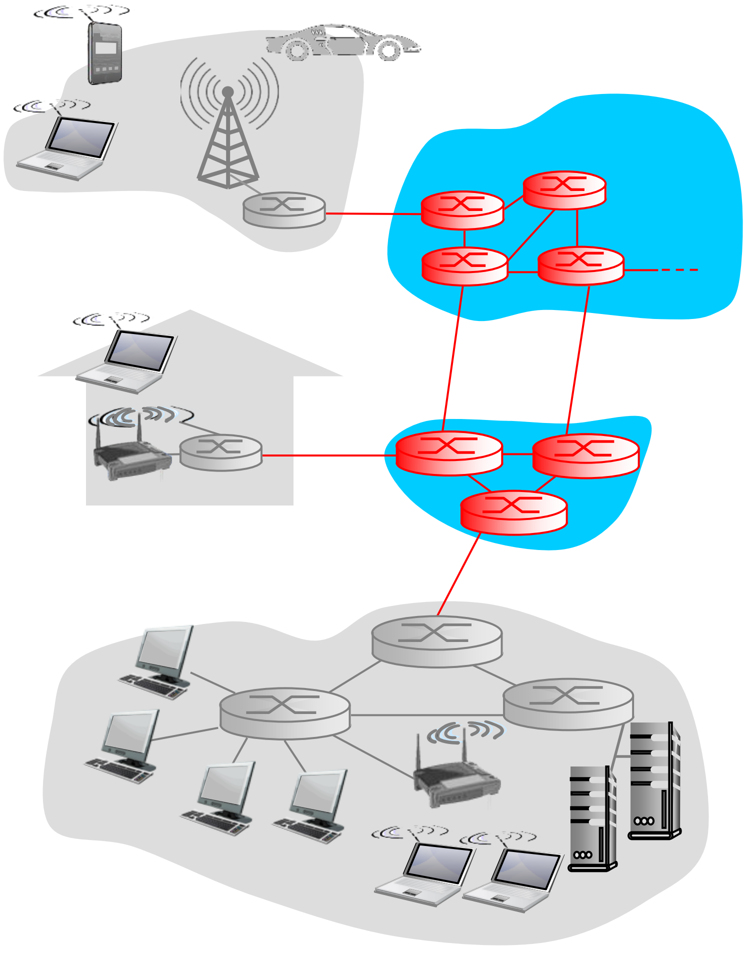
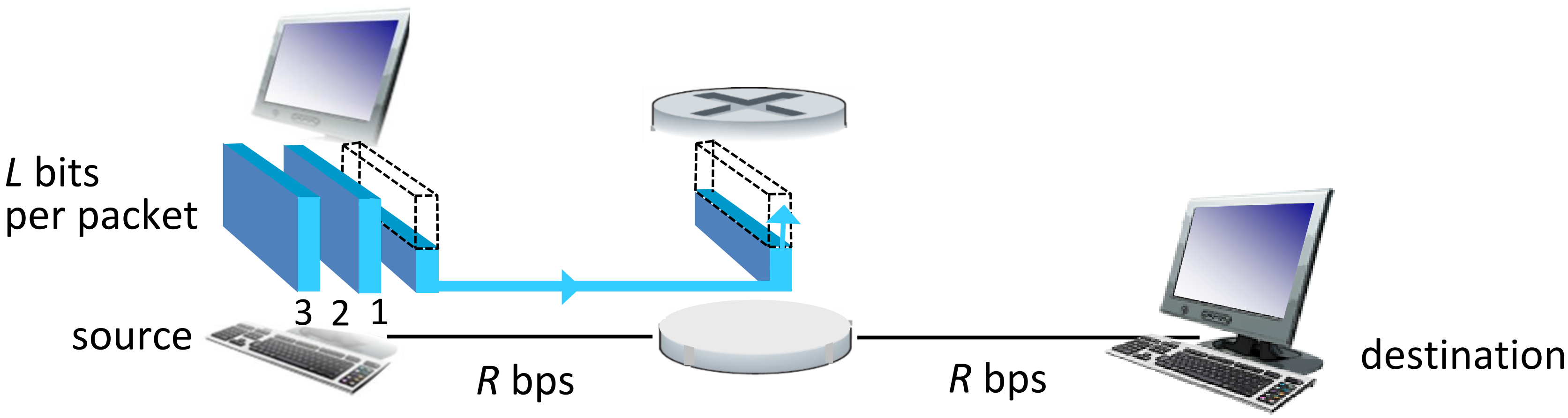
The network core

- mesh of interconnected routers
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity



Packet-switching: store-and-forward



- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

more on delay shortly …

one-hop numerical example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec

Q1

- a) At time t_0 the sending host begins to transmit. At time $t_1 = L/R_1$, the sending host completes transmission and the entire packet is received at the router (no propagation delay). Because the router has the entire packet at time t_1, it can begin to transmit the packet to the receiving host at time t_1. At time $t_2 = t_1 + L/R_2$, the router completes transmission and the entire packet is received at the receiving host (again, no propagation delay). Thus, the end-to-end delay is $L/R_1 + L/R_2$.

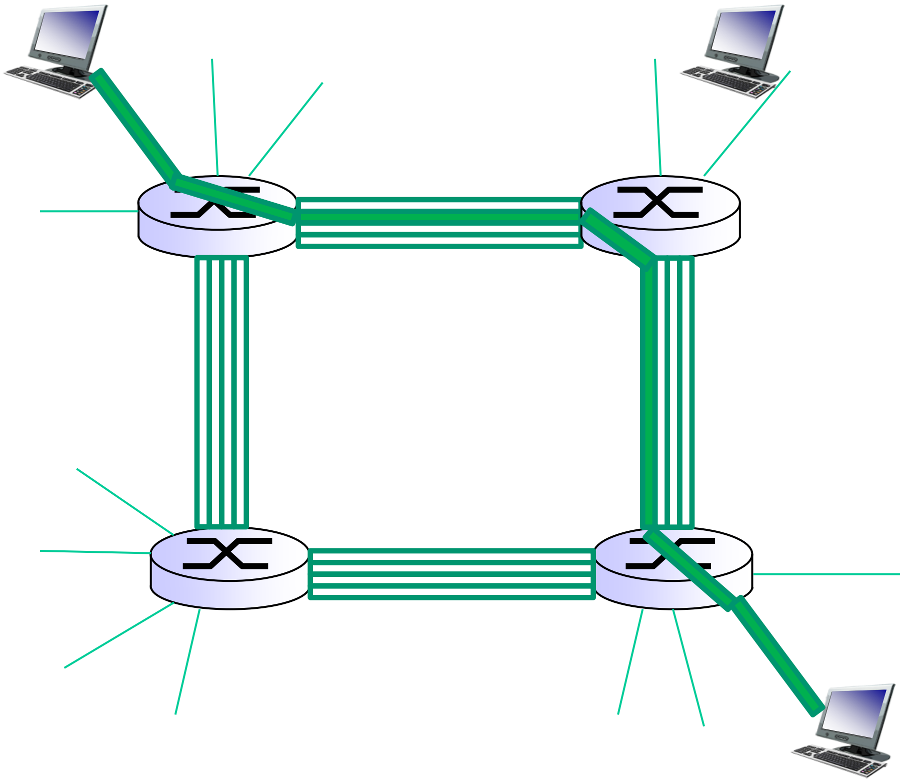
Q1

- b)Case of 2 links: When the first node sends the P-th packet to the second node, thereby incurring a net delay of PL/R, the second node sends the
(P-1)-th packet to the third node. Hence an additional delay of L/R would be incurred for sending the P-th packet from the second node to the third node. Thus, the net delay would be (P+1)L/R.

Alternative core: circuit switching

end-end resources allocated to, reserved for "call" between source & dest:

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



Q2

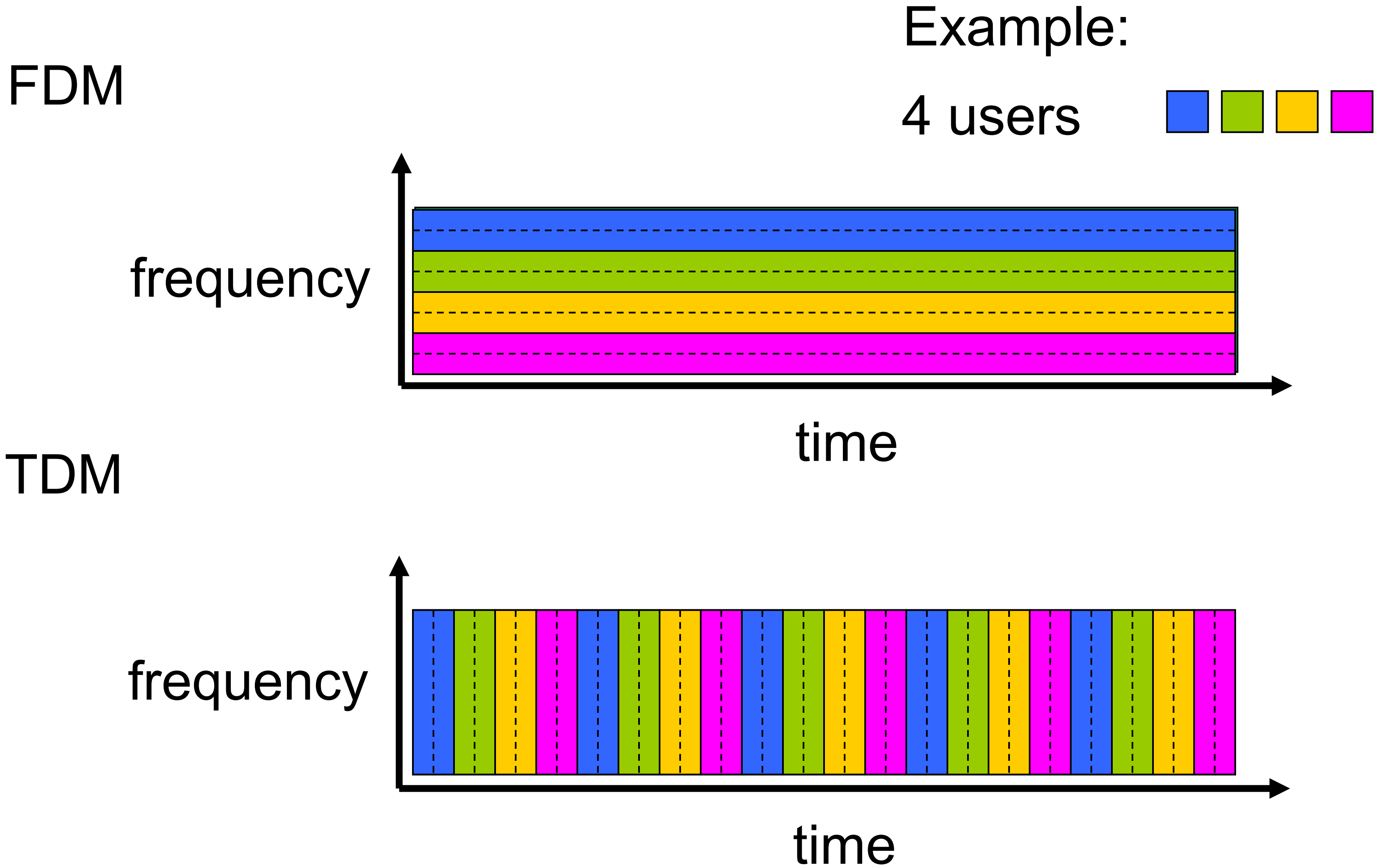
- a) Between the switch in the upper left and the switch in the upper right we can have 4 connections. Similarly we can have four connections between each of the 3 other pairs of adjacent switches. Thus, this network can support up to 16 connections.

- b) We can *4* connections passing through the switch in the upper-right-hand corner and another *4* connections passing through the switch in the lower-left-hand corner, giving a total of *8* connections.

Q2

- C) Yes. For the connections between A and C, we route two connections through B and two connections through D. For the connections between B and D, we route two connections through A and two connections through C. In this manner, there are at most 4 connections passing through any link.

Circuit switching: FDM versus TDM



Q3

- Each circuit has a transmission rate of (1.536 Mbps)/12 = 128 kbps, so it takes (160,000 bits)/(128 kbps) = 1.25 seconds to transmit the file. To this, we add the circuit establishment time of 0.6 seconds, giving a total of 1.85 seconds to send the file.

Q4

- a) 3Mbps/150 kbps = 20 users can be supported.
- b) p = 0.1
- c) $\binom{120}{n} p^n (1-p)^{120-n}$

- Binomial distribution B(*N, p*): assume the success probability of an independent trial is p, then the probability of getting exactly *n* successes in *N* trials is

$$\binom{N}{n} p^n (1-p)^{N-n}$$