Computer Networks

Jong-won Lee

Handong University

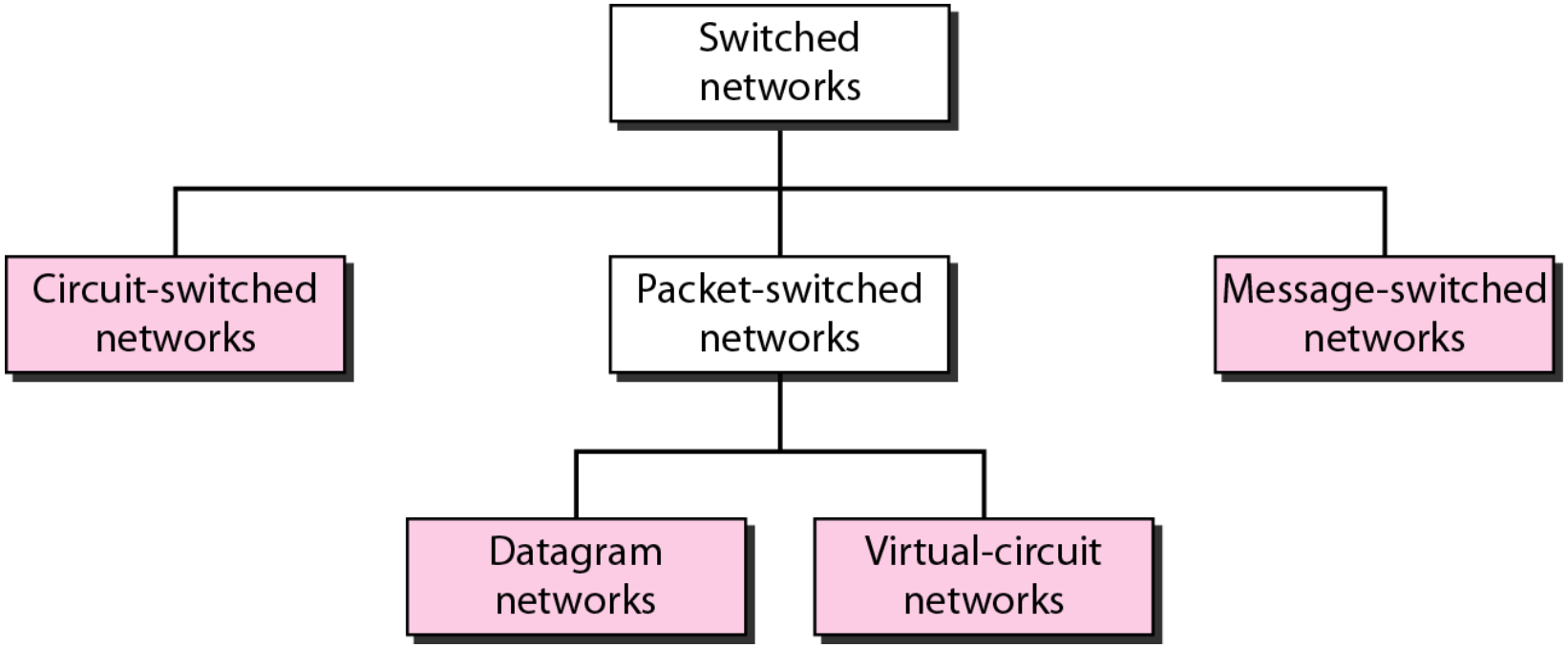
Chapter 1:

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Performance: Delay, loss throughput
1.5 Protocol layers, service models
1.6 Networks under attack
1.7 Internet history

1.3 The Network Core

- Mesh of interconnected routers/switches
- Two fundamental approaches
  - circuit switching: (telecommunication networks)
    - dedicated circuit per call
      - The sender can transfer the data to the receiver at the guaranteed rate.
  - packet-switching: (Internet)
    - data is sent through networks in packets
      - forward packets from one router to the next, across links on path from source to destination
      - each packet transmitted at full link capacity
      - The Internet makes its best effort to deliver packets in a timely manner, but it does not make any guarantees.

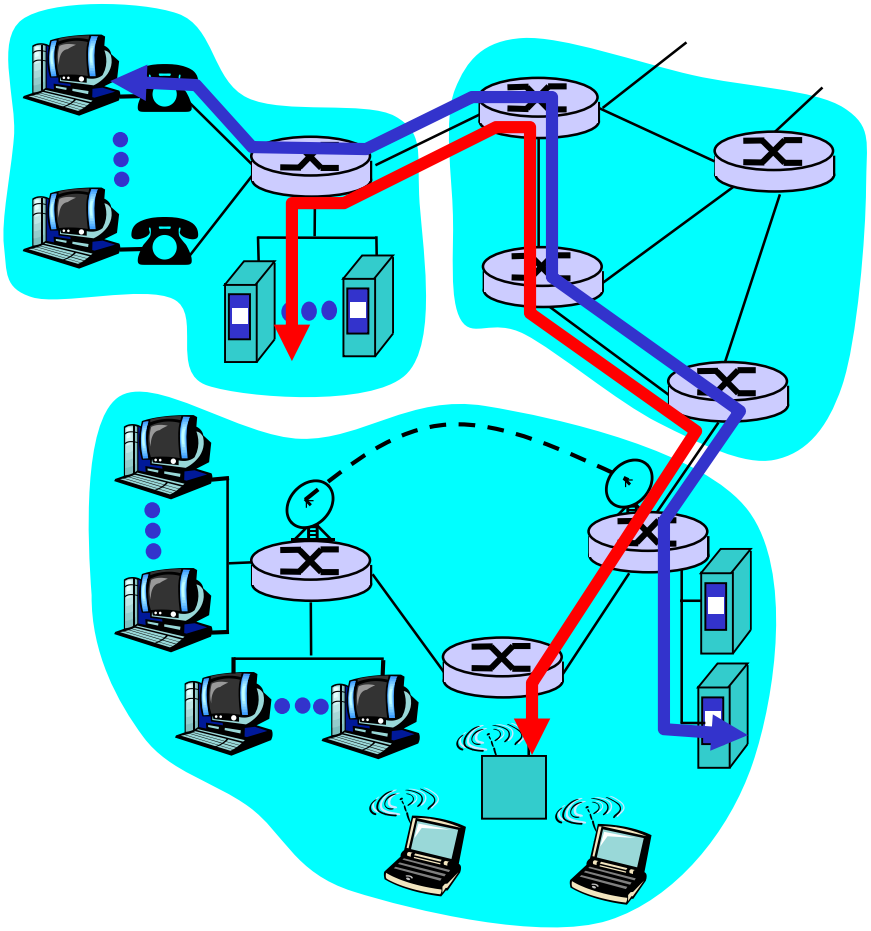
Taxonomy of Switched Networks



Circuit Switching

End-end resources reserved for "call"

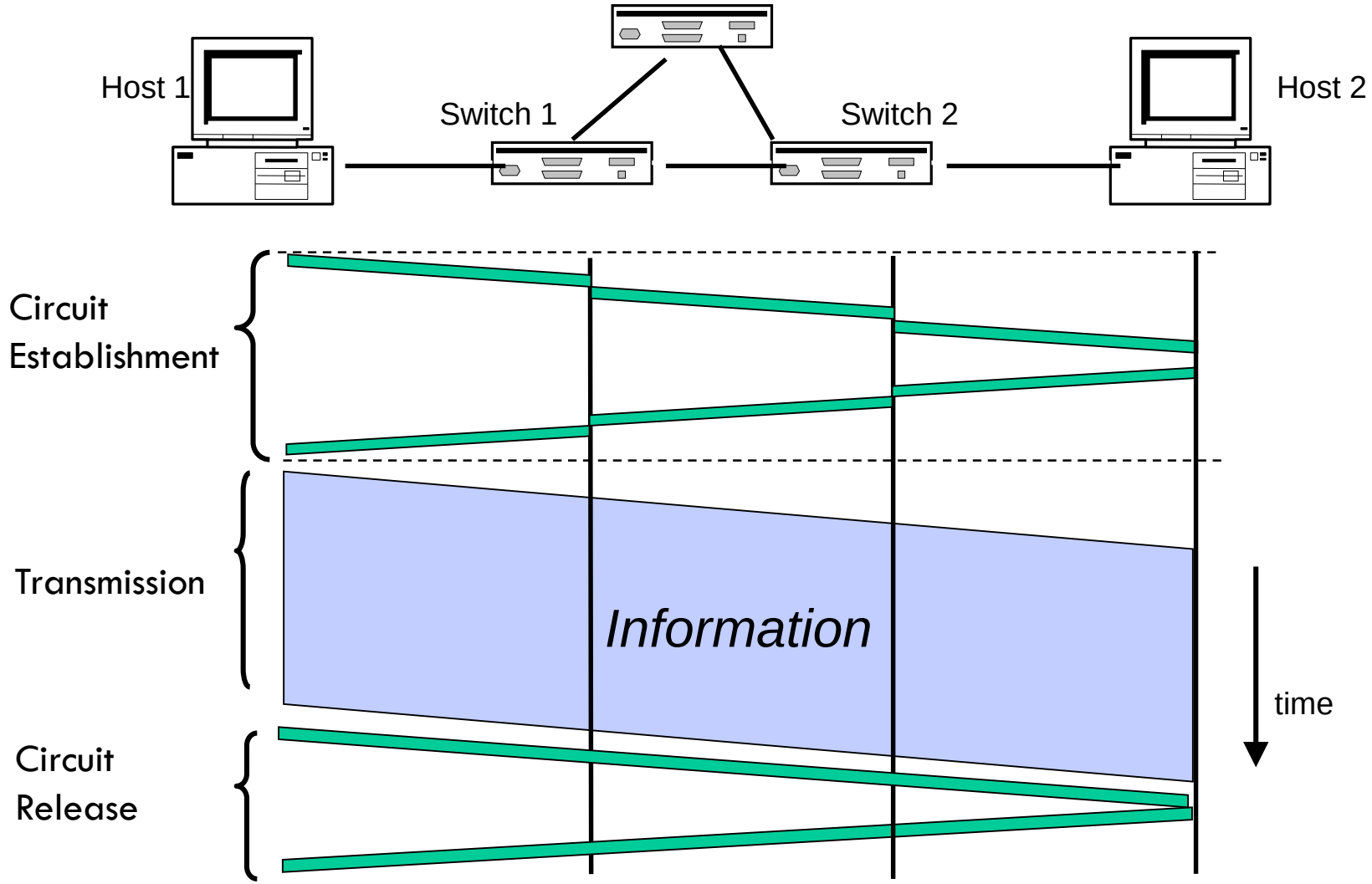
- link bandwidth, switch capacity
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- call setup required



Circuit Switching

- Circuit switching involves three phases:
  - Circuit establishment
    - Before any data is transmitted, an end-to-end circuit must be established, i.e. network resources on a path between end devices must be reserved.
  - Data transfer
  - Circuit release (disconnect)
    - After some period of data transfer, the connection should be terminated and dedicated resources are released.

Circuit Switching



Multiplexing in Circuit-switched Networks

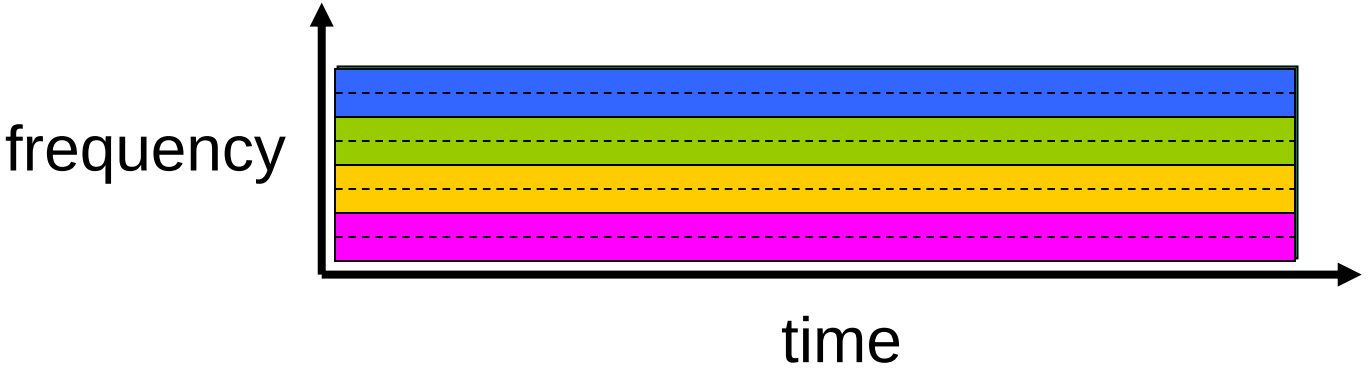
- Each link can be shared among 'N' circuits
  - Each circuit gets a fraction of 1/N of the link's bandwidth
- Multiplexing
  - Set of techniques that allows simultaneous transmission of multiple signals across a single data link
- Two basic multiplexing methods
  - Frequency division multiplexing (FDM)
    - Assign a non-overlapped frequency bandwidth to each channel through a modulation
  - Time division multiplexing (TDM)

Multiplexing: FDM and TDM

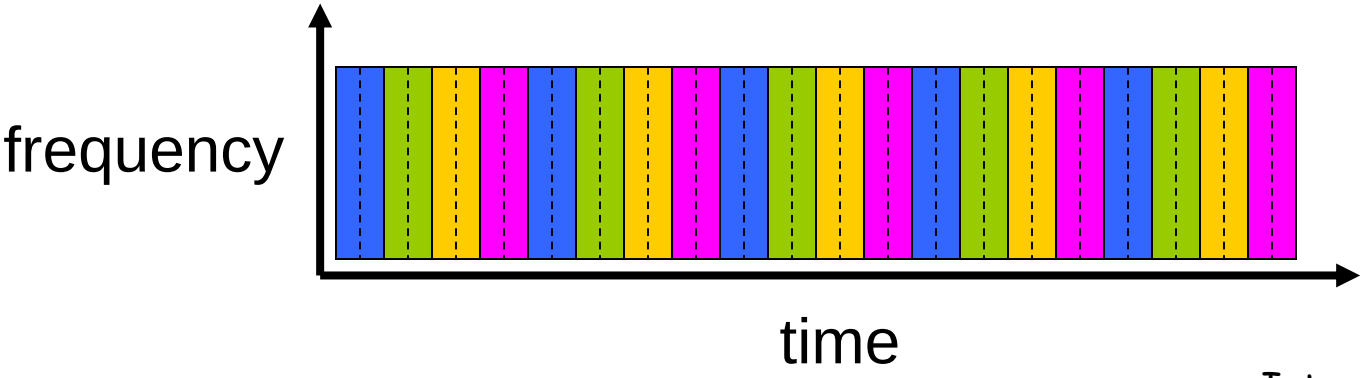
Example:

4 users

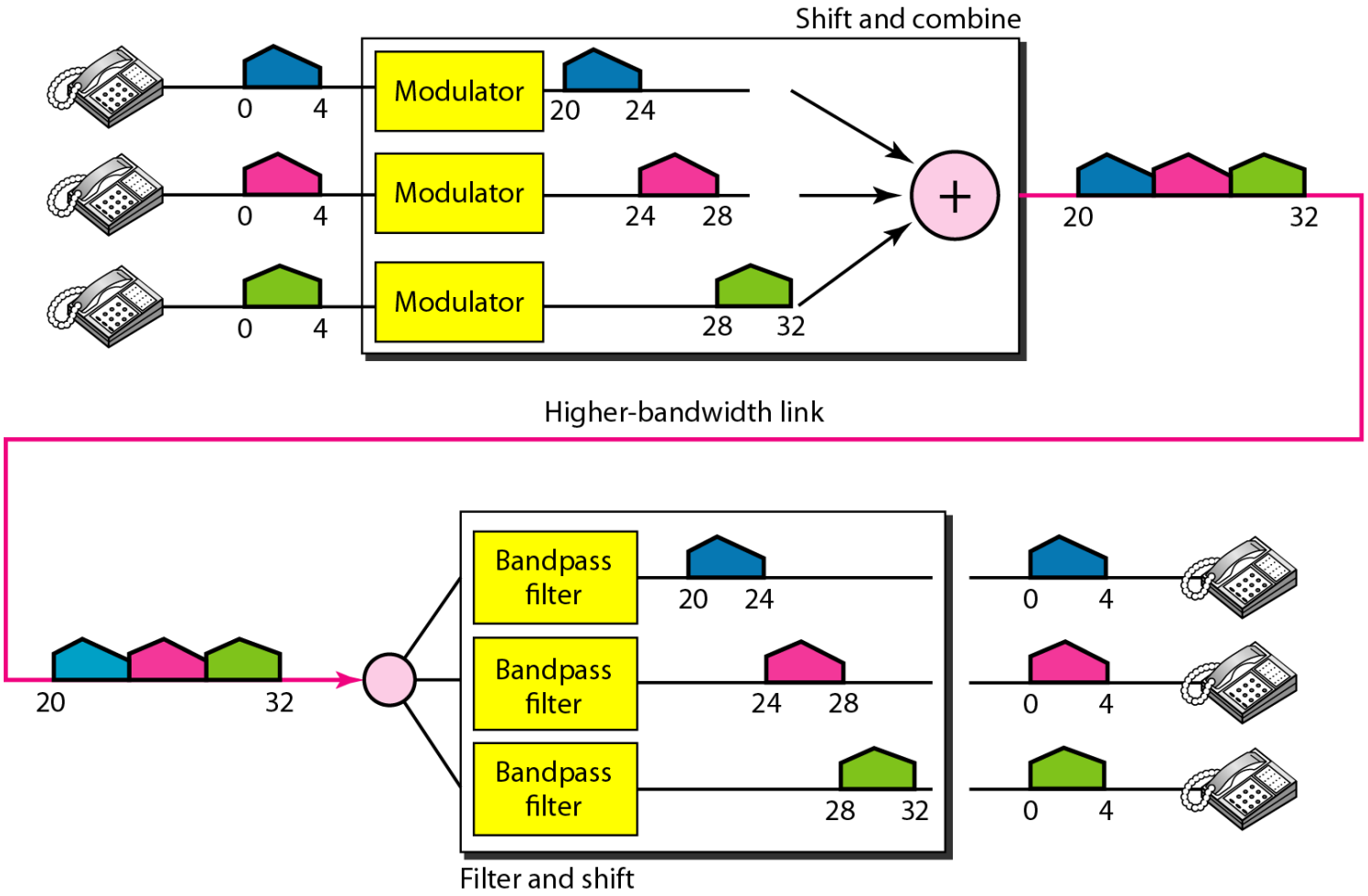
FDM



TDM

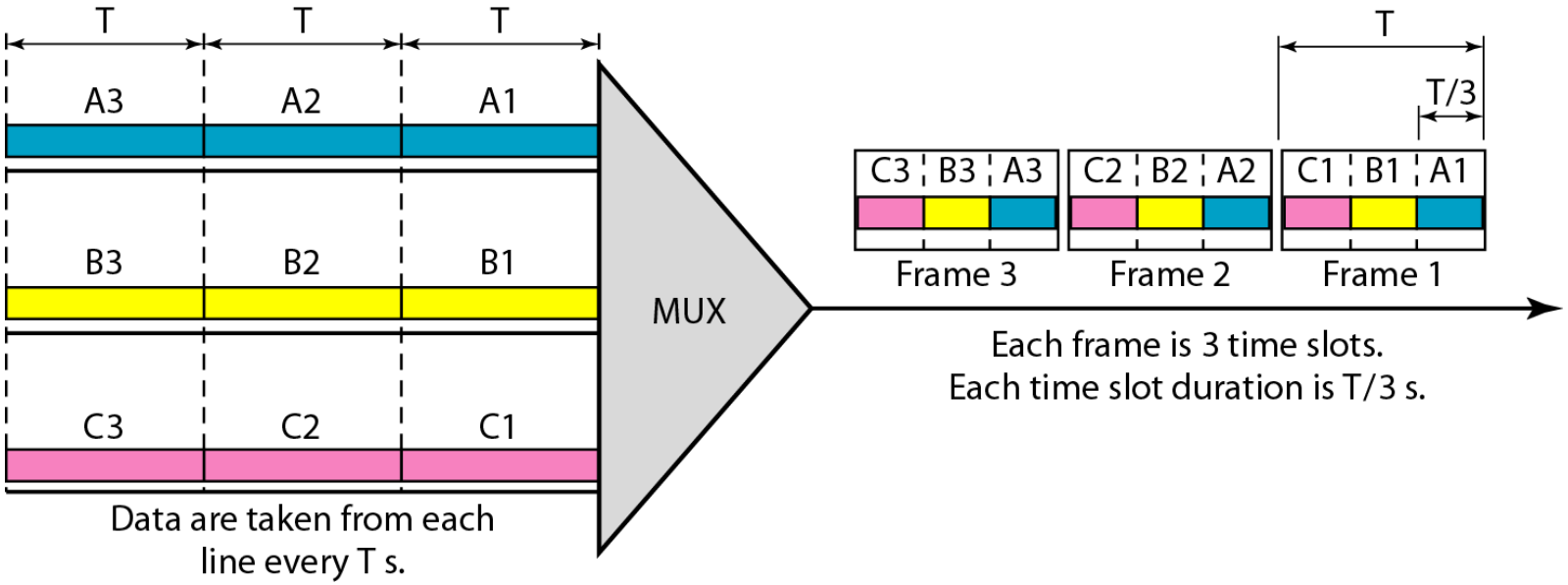


Multiplexing: FDM



Multiplexing: TDM

- TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.
  - Regularly assign time slots to each channel



Circuit Switching

- Advantages
  - Guaranteed quality of service (QoS)
- Disadvantages
  - Inefficient use of resources
  - Circuit establishment delay

Numerical example

- How long does it take to send a file of 640,000 bits from host A to host B over a circuit-switched network?
  - All links are 1.536 Mbps
  - Each link uses TDM with 24 slots
  - 500 msec to establish end-to-end circuit

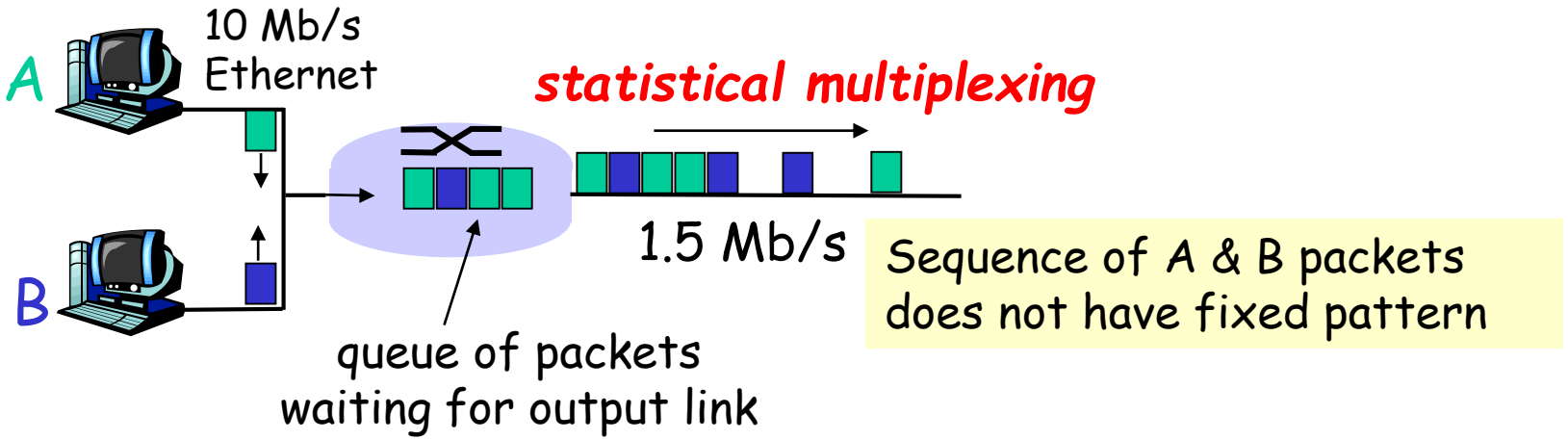
Work it out!

Packet Switching

- Each end-end data stream is divided into *packets*.
- Store the packet, and then forward the packet to the next node. (store-and-forward)
- User A, B packets *share* network resources.
- Each packet uses full link bandwidth
- Resources are used *as needed*
  - No dedicated allocation
  - Congestion may occur.
    - When aggregate demand can exceed available resource.
    - Queue packets, wait for link use

Statistical Multiplexing

- Schedule link on demand basis rather than pre-determined basis of resources
  - Link capacity is shared on packet-by-packet basis only among those users who have packets that need to be transmitted over the link
- Buffer packets that are *contending* for the link
- Congestion may occur (queueing and loss)

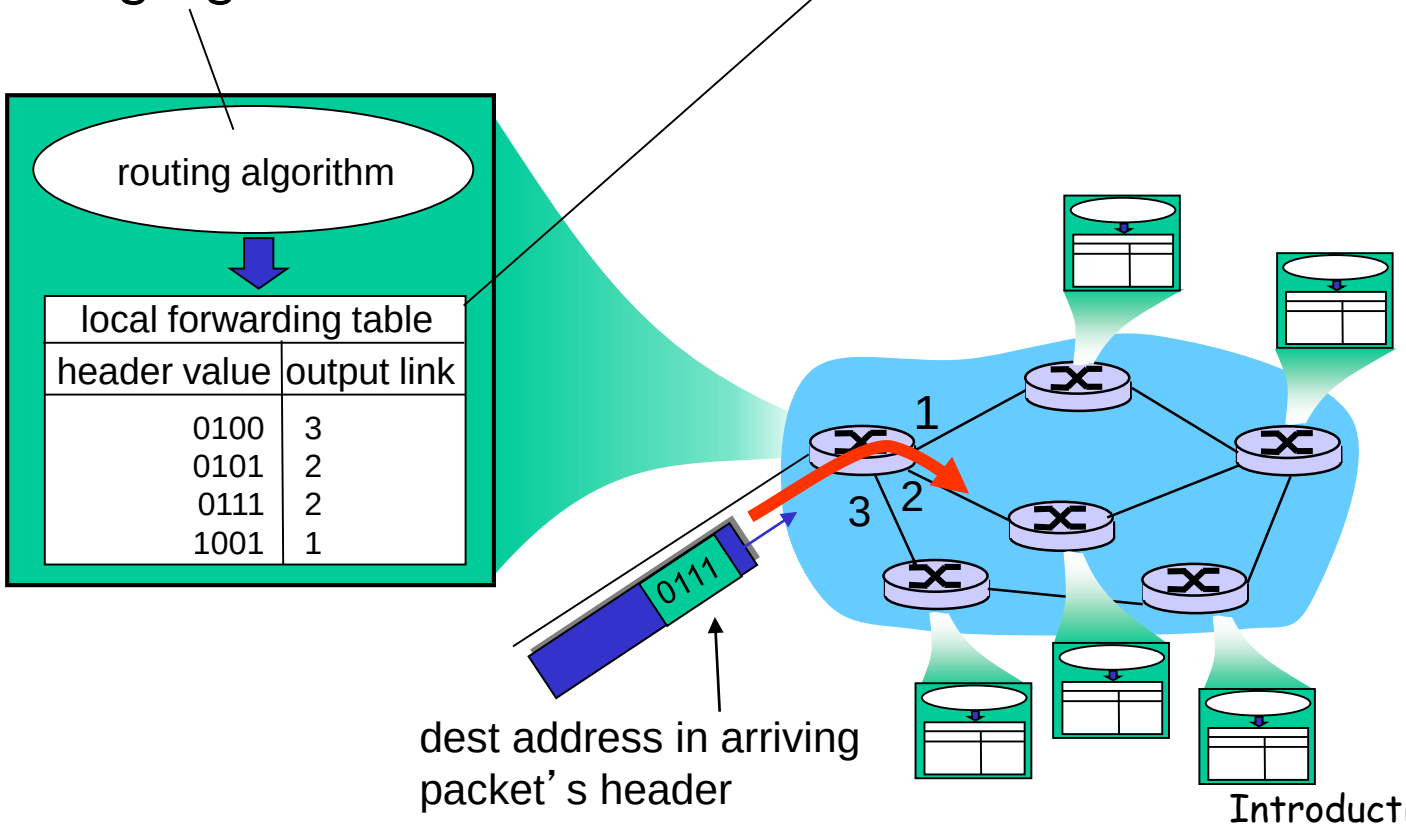


Two key network-core functions

routing: determines source-destination route taken by packets

- *routing algorithms*

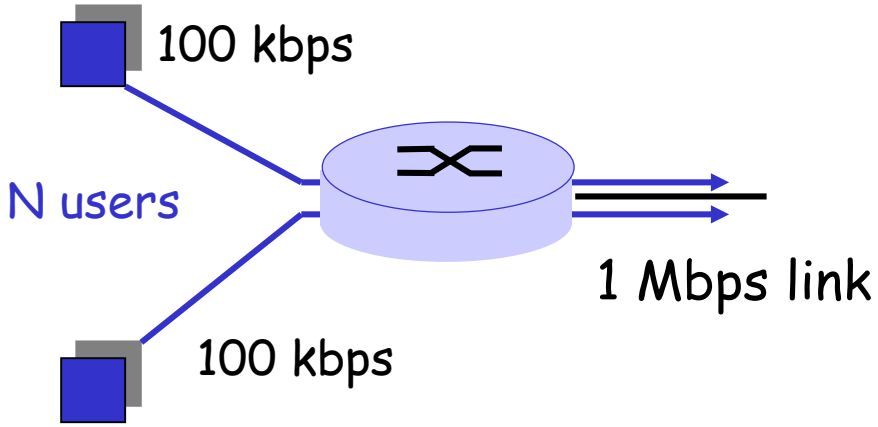
forwarding: move packets from router's input to appropriate router output



Packet switching vs circuit switching

Example

- N users share 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- Q: How many users can be supported with CS and PS?



Assumption: The probability that more than 10 users are active should be less than 0.0004.

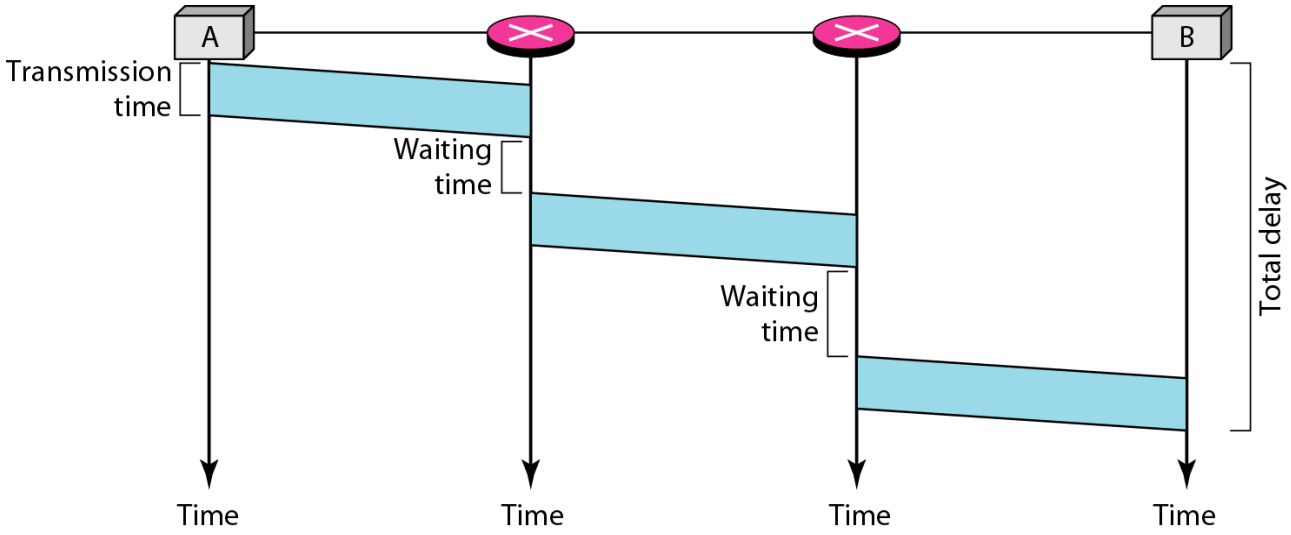
- circuit-switching:
  - 1 Mbps/100 kbps = 10 simultaneous users
- packet switching:
  - 10 or fewer simultaneous active users: aggregate rate <= 1 Mbps
  - with N users, probability > 10 active less than .0004

Packet switching allows more users to use network!

Packet switching

- Advantages
  - Efficient for bursty data
  - simpler, no call setup
- Disadvantages
  - Not guarantee QoS:
  - protocols for reliable data transfer, congestion control
- Q: How to guarantee QoS?
  - QoS needed for audio/video apps
  - still an unsolved problem (chapter 7)

Packet switching (store-and-forward)



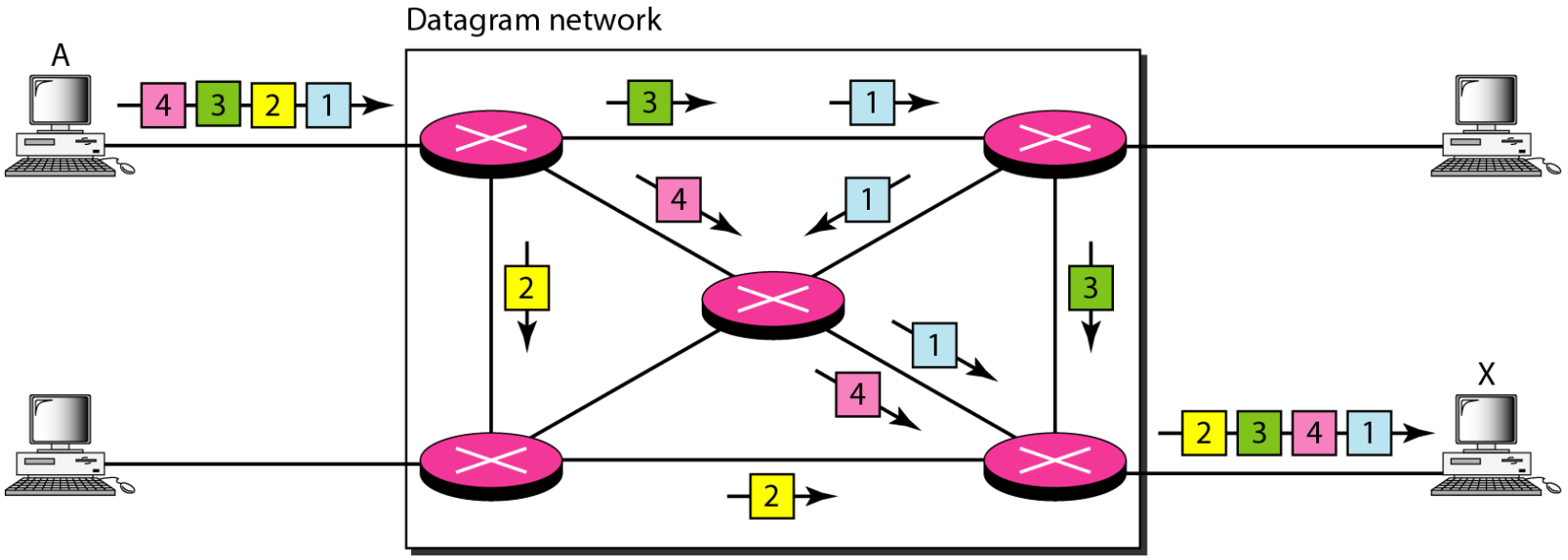
- Packet size = L bits, transmission rate = R bps
- If queueing delay and propagation delay are ignored,
  - Total delay (latency) = 3L/R

Cf) Transmission delay = L/R

Datagram Networks

- Analogy : postal service
- No connection setup phase
- Stateless switch
- Each packet is forwarded independently
  - Based on the routing table
  - Packets with the same destination address do not necessarily follow the same route.
- Each packet has the complete destination address
  - Address is a globally unique identifier
- Sometimes called *connectionless* model

Datagram Networks

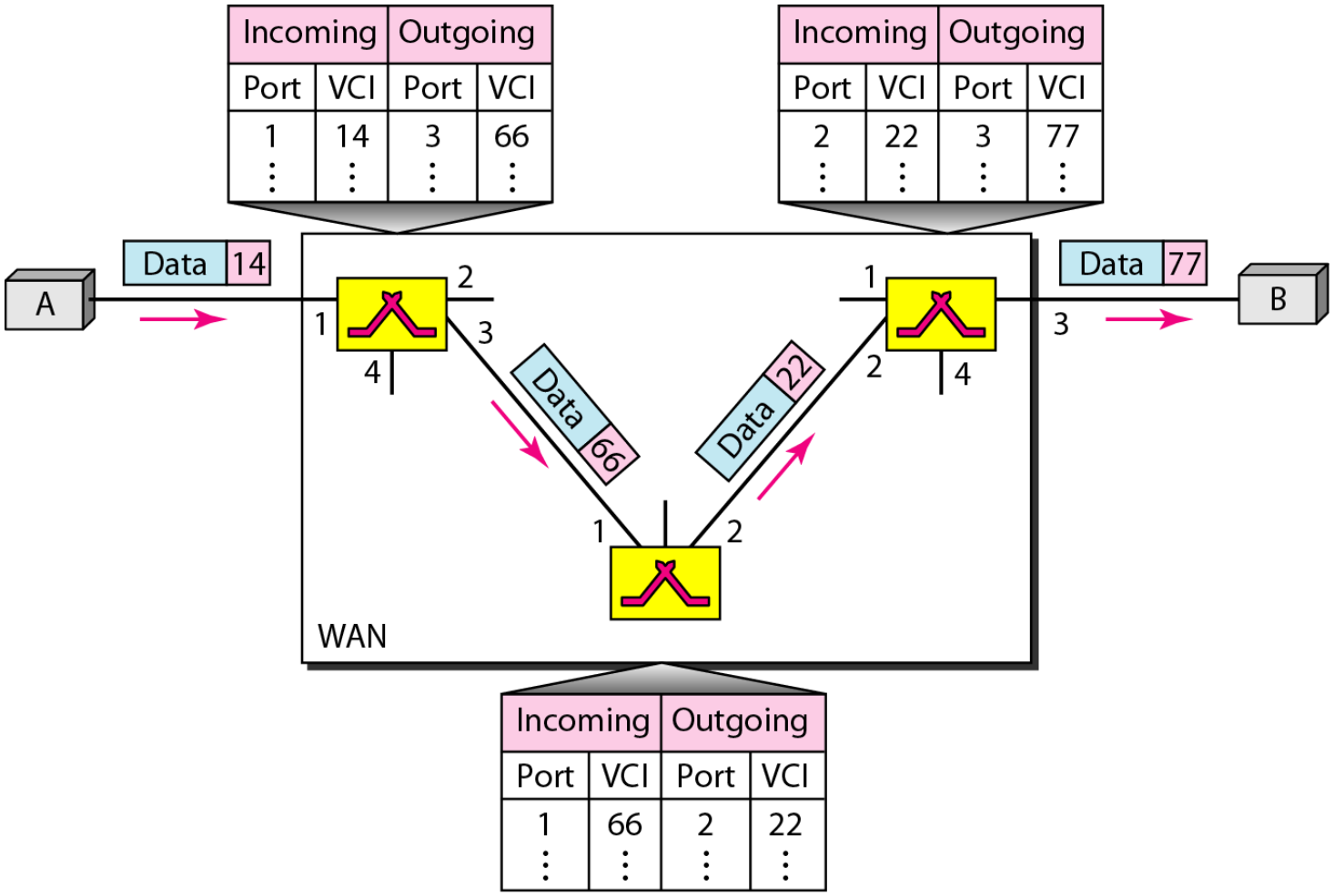


Packets with the same destination address do not necessarily follow the same route.
=> May arrive out of order

Virtual Circuit Networks

- Establish a virtual connection from the sender to the destination before data transfer.
  - A single route, so-called virtual circuit, is chosen between the sender and the destination.
  - Signaling protocol is used for connection setup
- Each switch maintains connection state
  - VC entry = < in_interface, in_VCI, out_interface, out_VCI>
  - Generally VCI is not a globally significant identifier
- Connection setup provides an opportunity to reserve resources.
  - However, a virtual circuit does not have dedicated resource.
- VC types
  - PVC : permanent VC
  - SVC : Switched VC

Virtual Circuit Networks



Virtual Circuit Networks

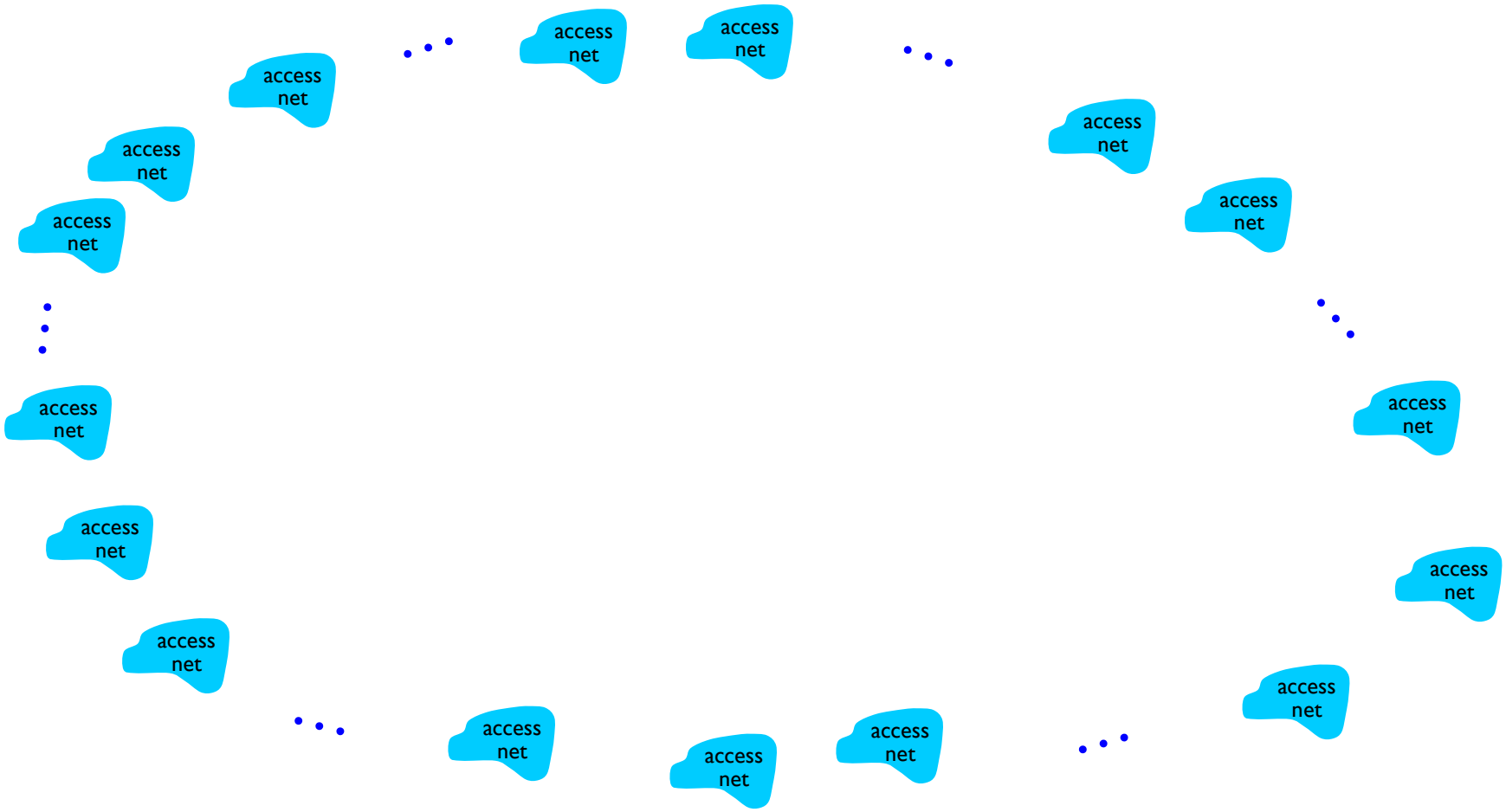
- Advantages
  -
    - Fast packet switching
  - Possibility to support QoS
    - Resource can be allocated during call setup.
  -
- Disadvantages
  - Need call setup procedure
  -

Internet structure

- End systems connect to Internet via access ISPs (Internet Service Providers)
  - Residential, company and university ISPs
- Access ISPs in turn must be interconnected.
  - So that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - Evolution was driven by economics and national policies

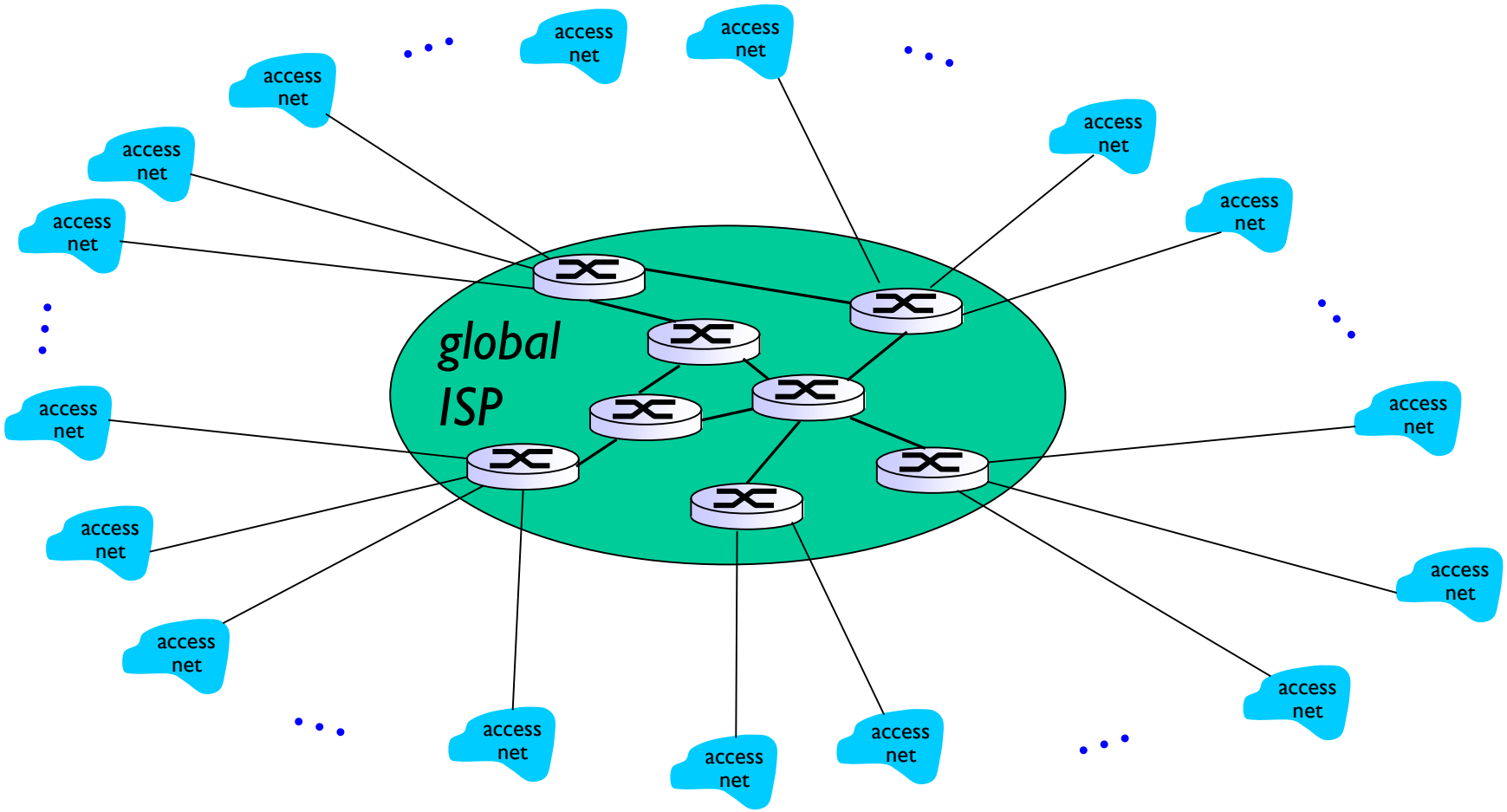
Internet structure

Question: given *millions* of access ISPs, how to connect them together?



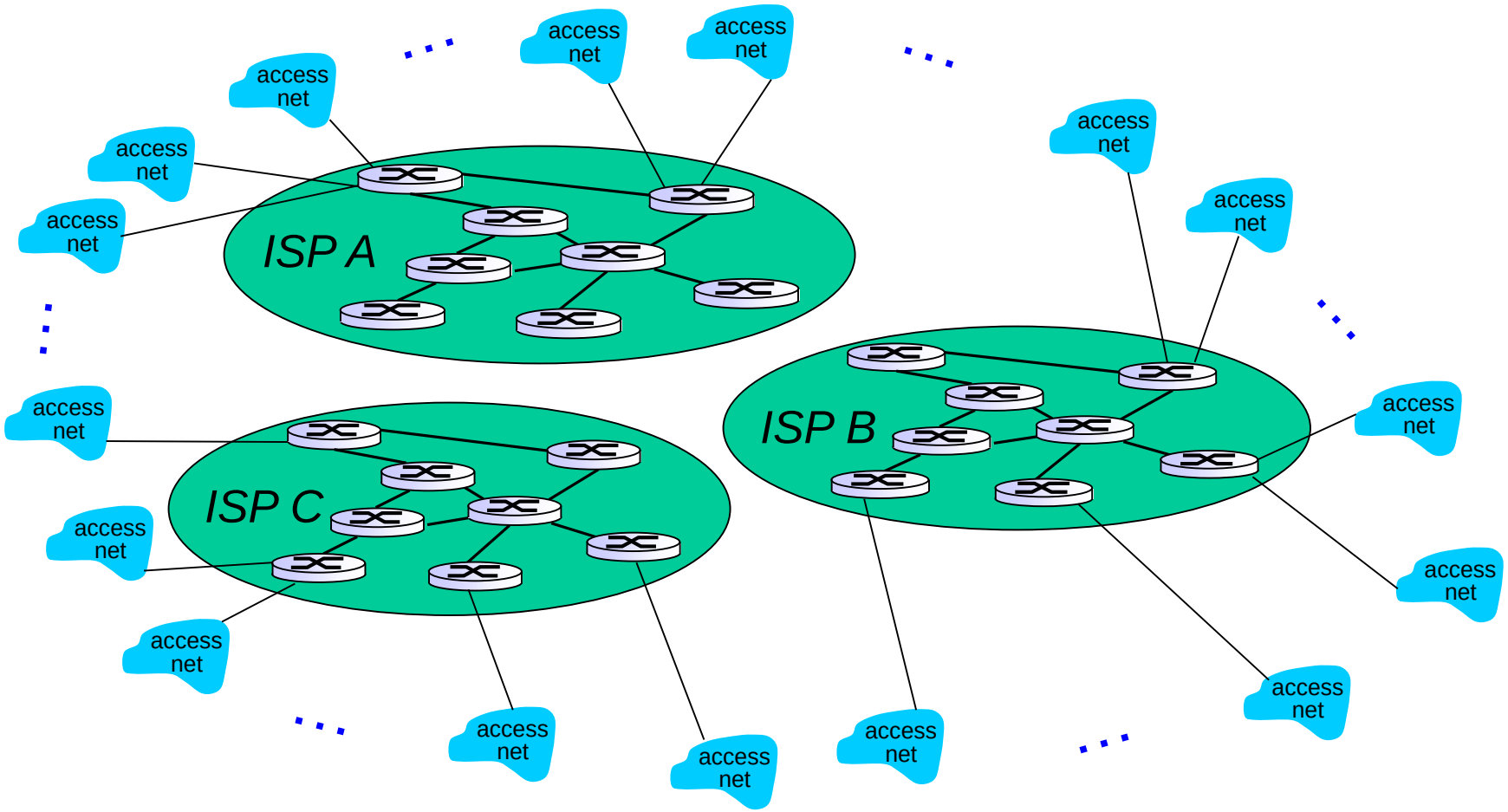
Internet structure

Option: connect each access ISP to a global transit ISP? Customer and provider ISPs have economic agreement.



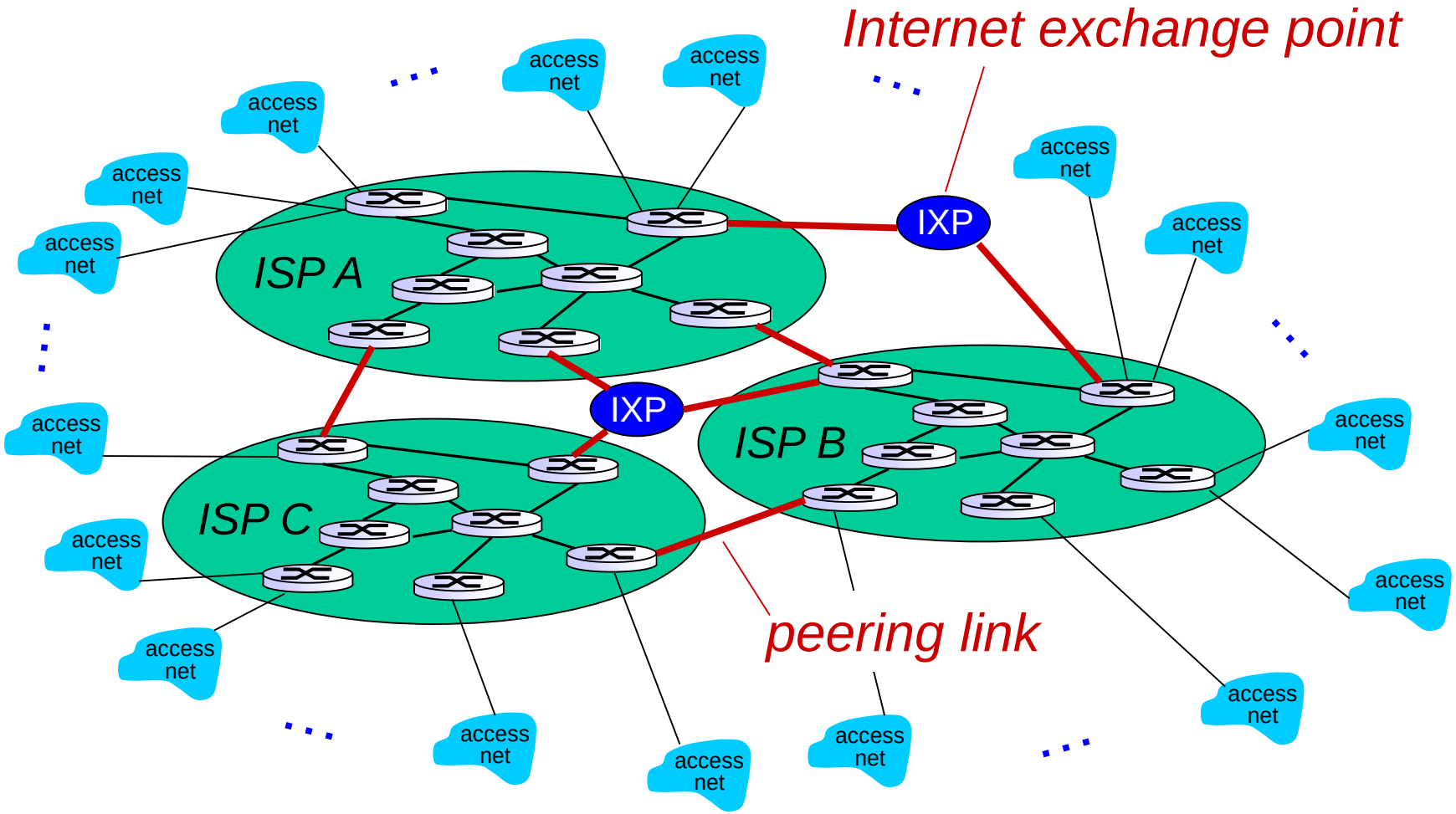
Internet structure

But if one global ISP is viable business, there will be competitors ….



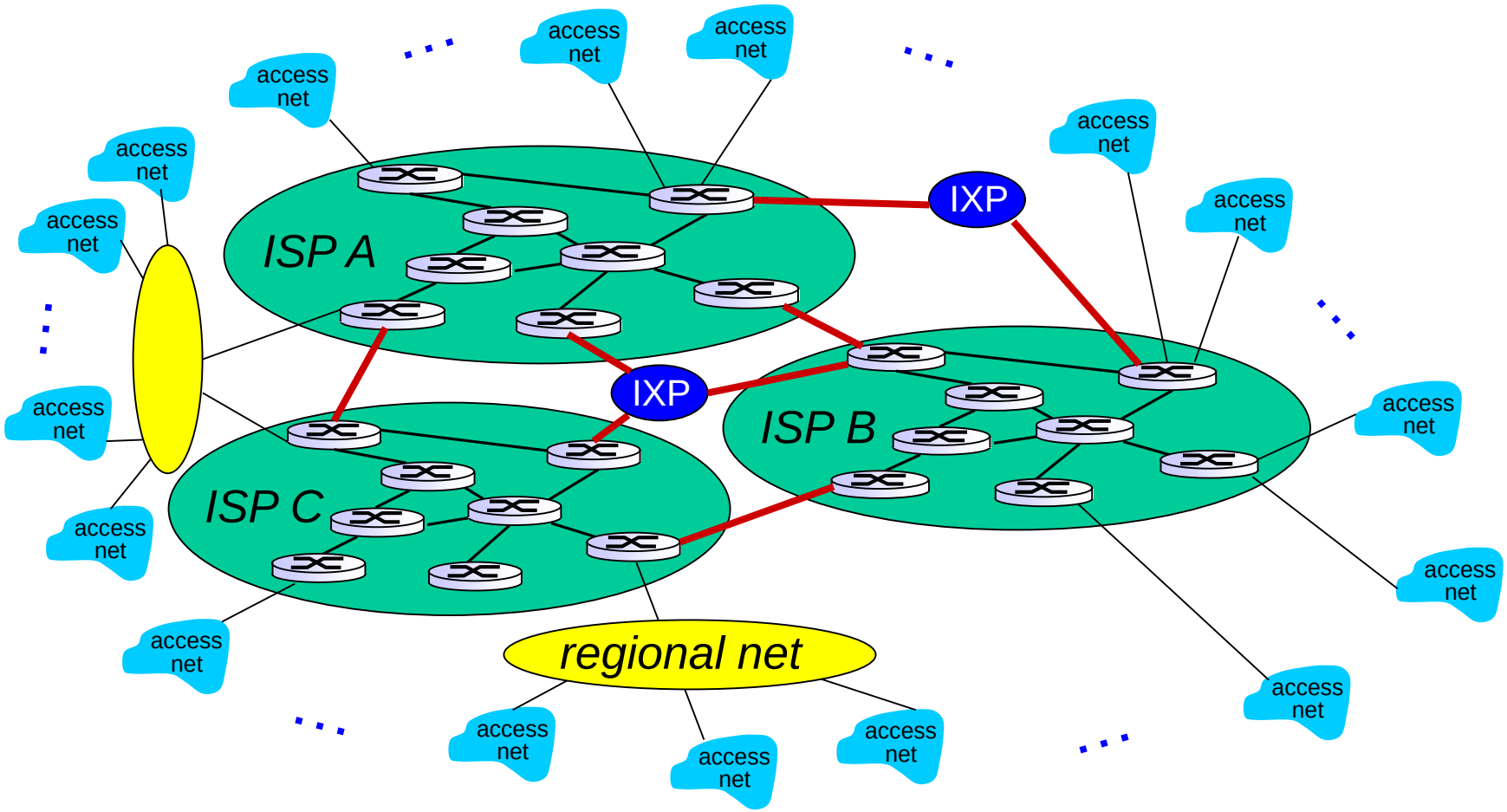
Internet structure

But if one global ISP is viable business, there will be competitors …. which must be interconnected



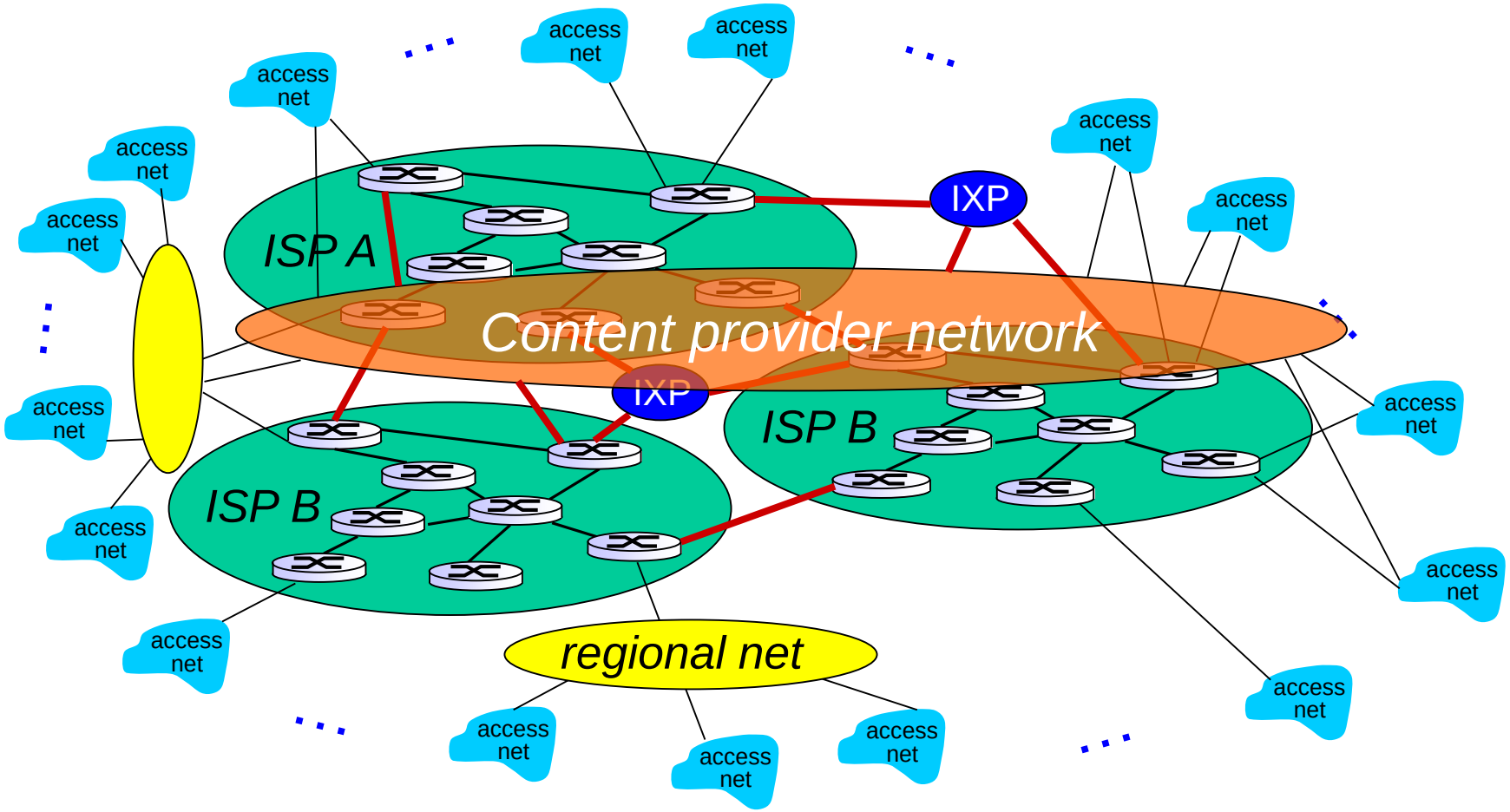
Internet structure

… and regional networks may arise to connect access nets to ISPS

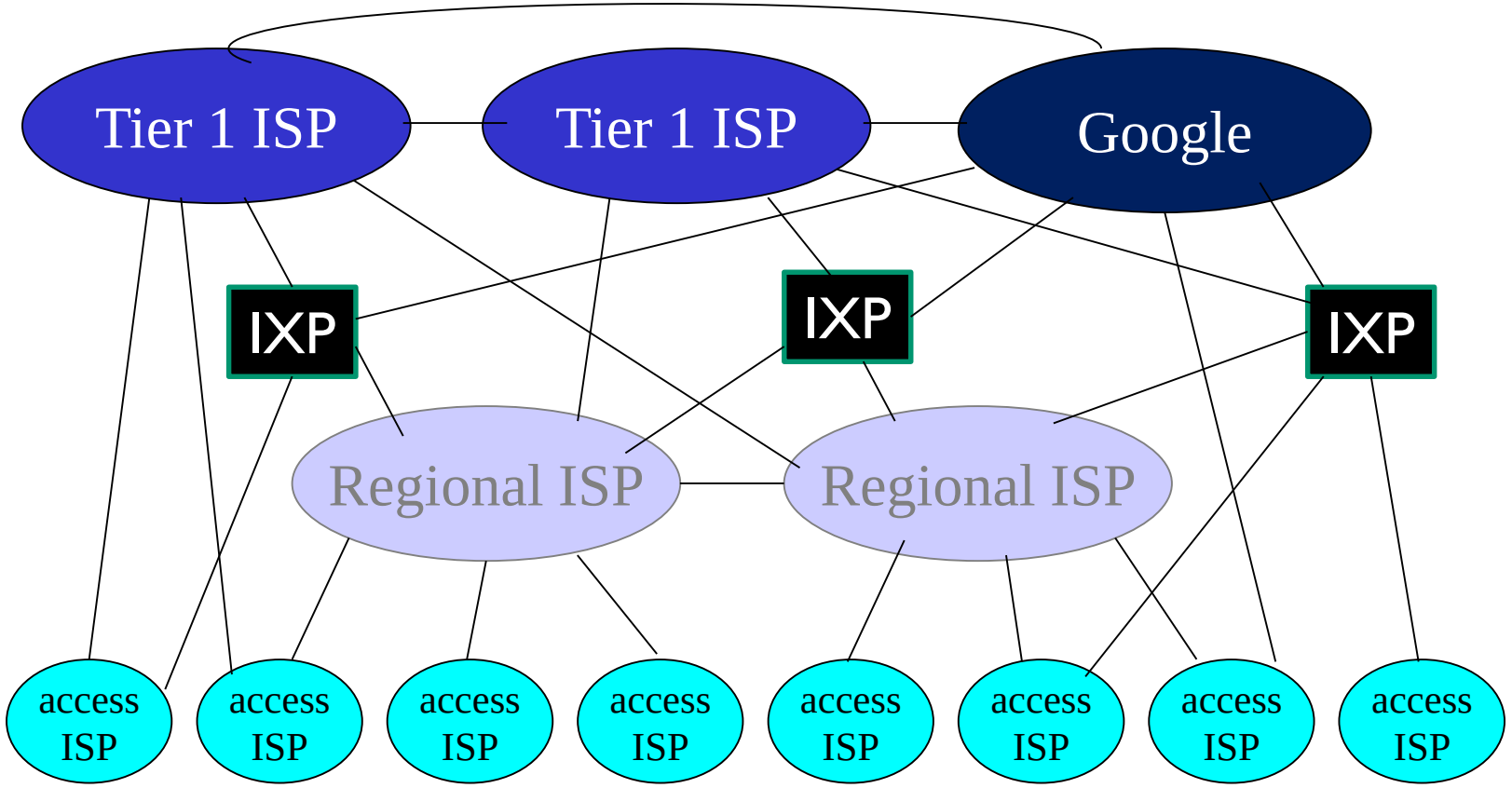


Internet structure

… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



Internet structure



- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., AT&T, KT), national & international coverage
  - content provider network (e.g, Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs