BITS Pilani
Pilani Campus

Computer Networks (CS F303)

Virendra Singh Shekhawat
Department of Computer Science and Information Systems

Today’s Agenda

- Course Overview
- Course Administration
- What is network?
- What is Internet?
- Network Structure
  – Edge, Access Network (Physical Media), Network Core
- Internet Structure

Course Objective

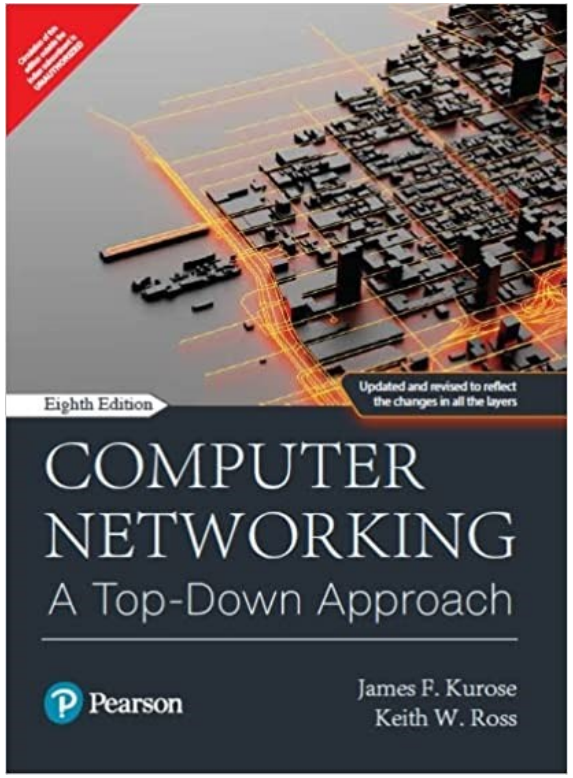
- To get familiar with the principles and working of state-of-the-art of networking
  - Routing, forwarding, data transport, addressing, naming, congestion control, reliability, security etc.
  - Design of network and services
- Learn how communication networks are put together
  - Mechanisms, Algorithms, Technology components
- To understand network internals in a hands-on way
  - Writing simple network applications, understanding and analyzing working principles of protocols

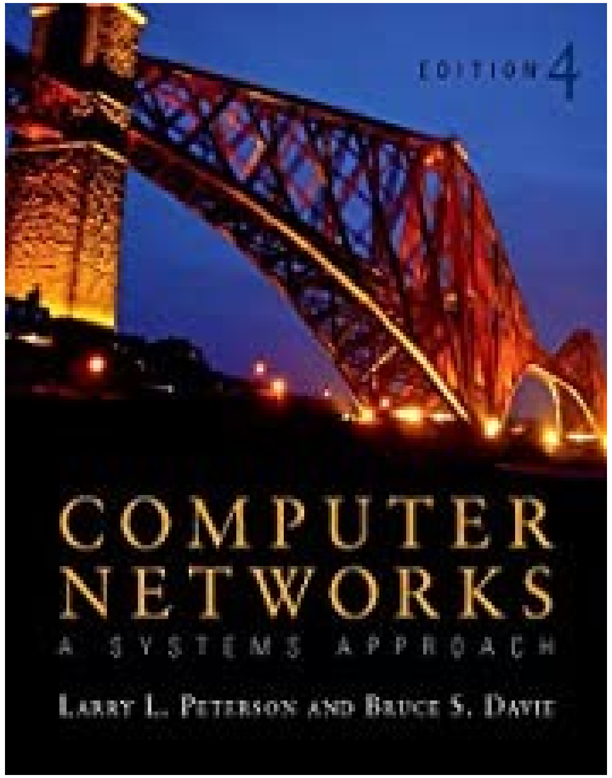
Course Overview

- Internet Architecture and Computer Network Primitives
- Network Applications (Application Layer)
- End to End Data Transfer (Transport Layer)
- Data Routing and Forwarding (Network Layer)
- Access Networks & LANs (Link Layer)
- Communication Channels (Physical Layer)
- Wireless and Mobile Networks
- Computer Network Security

Course Administration and Text Book(s)

- Instruction delivery
  - Lecture classes
    - **11:00 – 11:50 AM [MWF]**
  - Lab classes
    - **Starting from 31st Jan 2023**
- Course page Information
  - **NALANDA LMS**
- Evaluation Plan
  - Mid Semester Test @25%
  - Quiz (Two) @20% [10% each]
  - Lab Assessment @15%
  - Lab Participation @ 5%
  - Comprehensive exam @35%





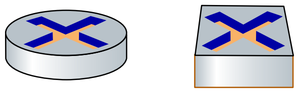
What is a Network?

- An infrastructure (shared) that allows users (distributed) to communicate with each other
  – People, devices, …
  – By means of voice, video, text, …
  – For example, Telephone n/w, Cable TV Network, Satellite network, military n/w etc. …

- Basic building blocks are
  – **Nodes** (Hosts and Forwarding devices) and **Links**

The Internet: a "nuts and bolts" view

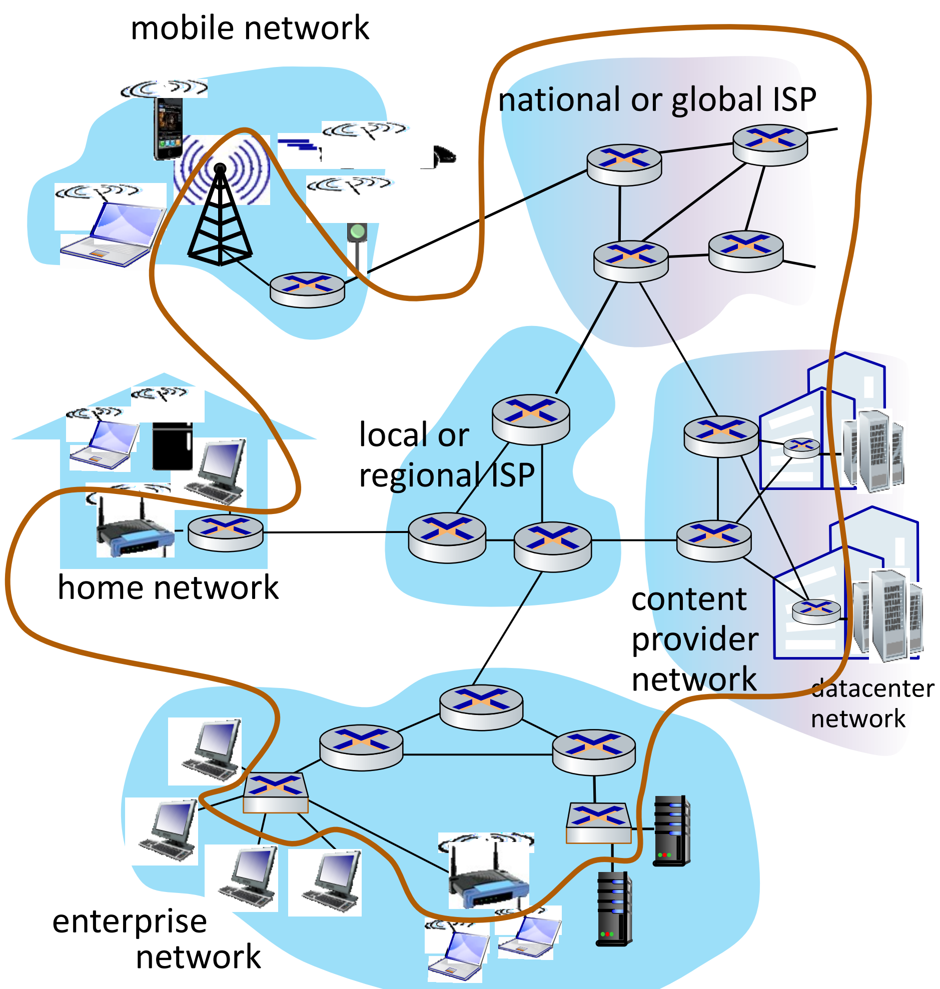
Billions of connected computing *devices*:
- *hosts = end systems*
- running *network apps* at Internet's "edge"



Packet switches: forward packets (chunks of data)
- *routers, switches*

Communication links
- fiber, copper, radio, satellite
- transmission rate: *bandwidth*

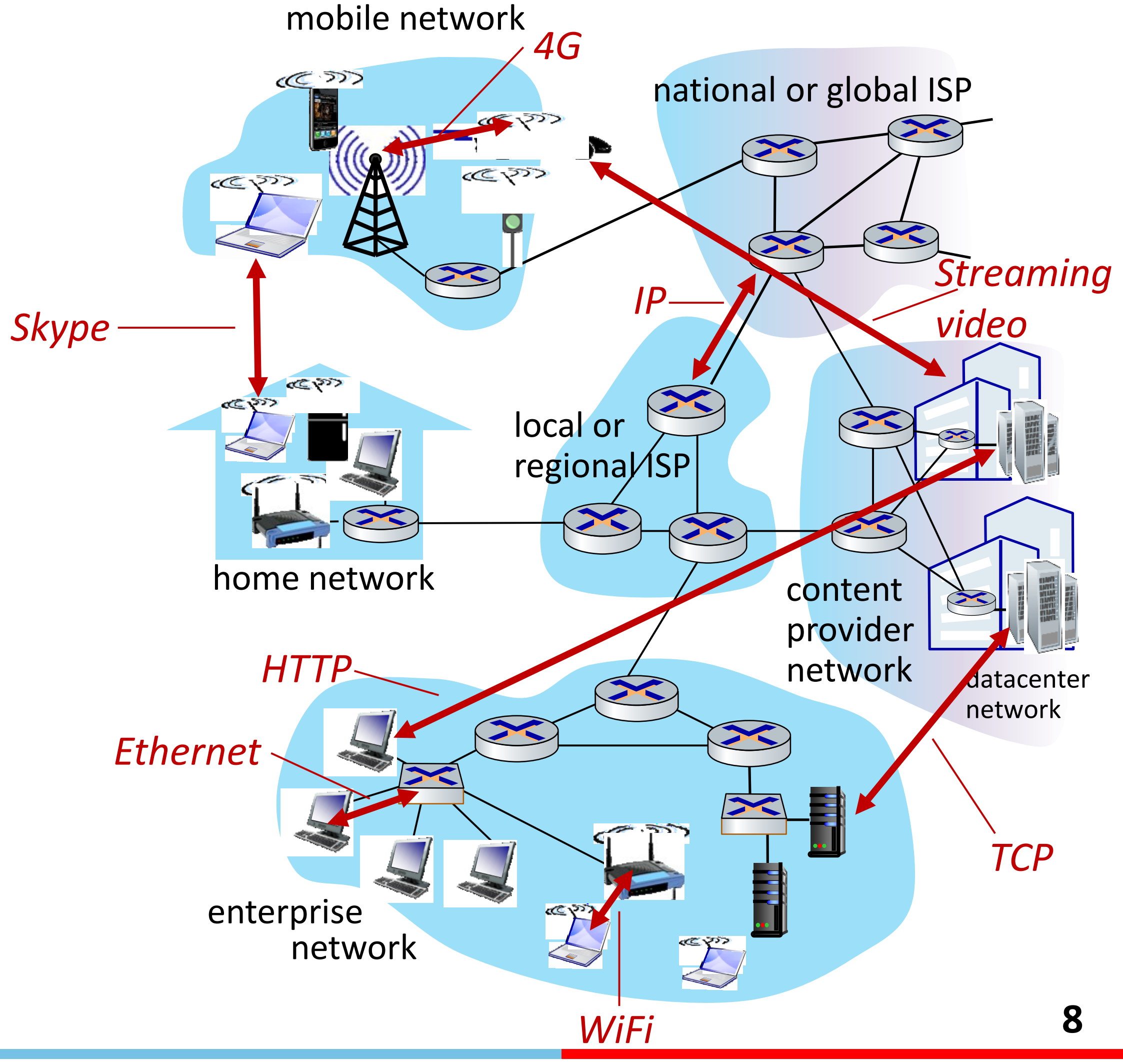
Networks
- collection of devices, routers, links: managed by an organization



The Internet: : "nuts and bolts" view

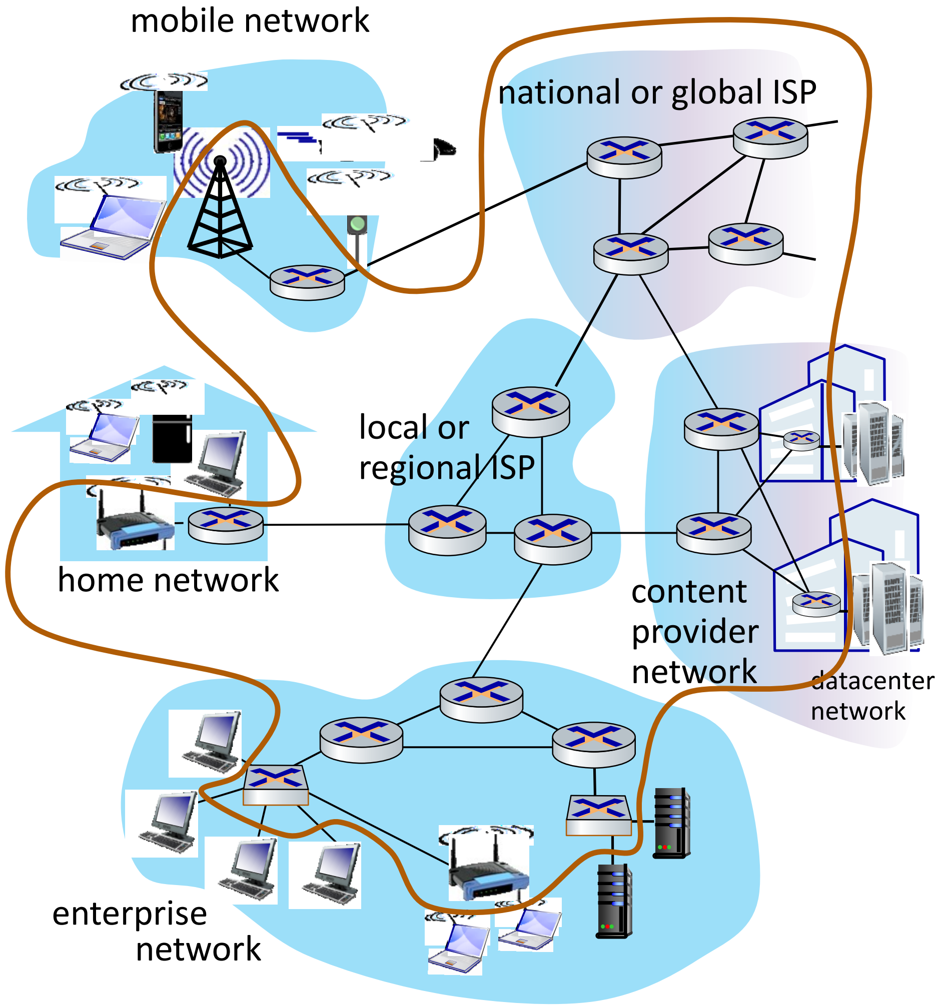
- **Internet:** "network of networks"
- *Protocols are everywhere*
  - Control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4G, Ethernet

- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



The Internet: “nuts and bolts” view

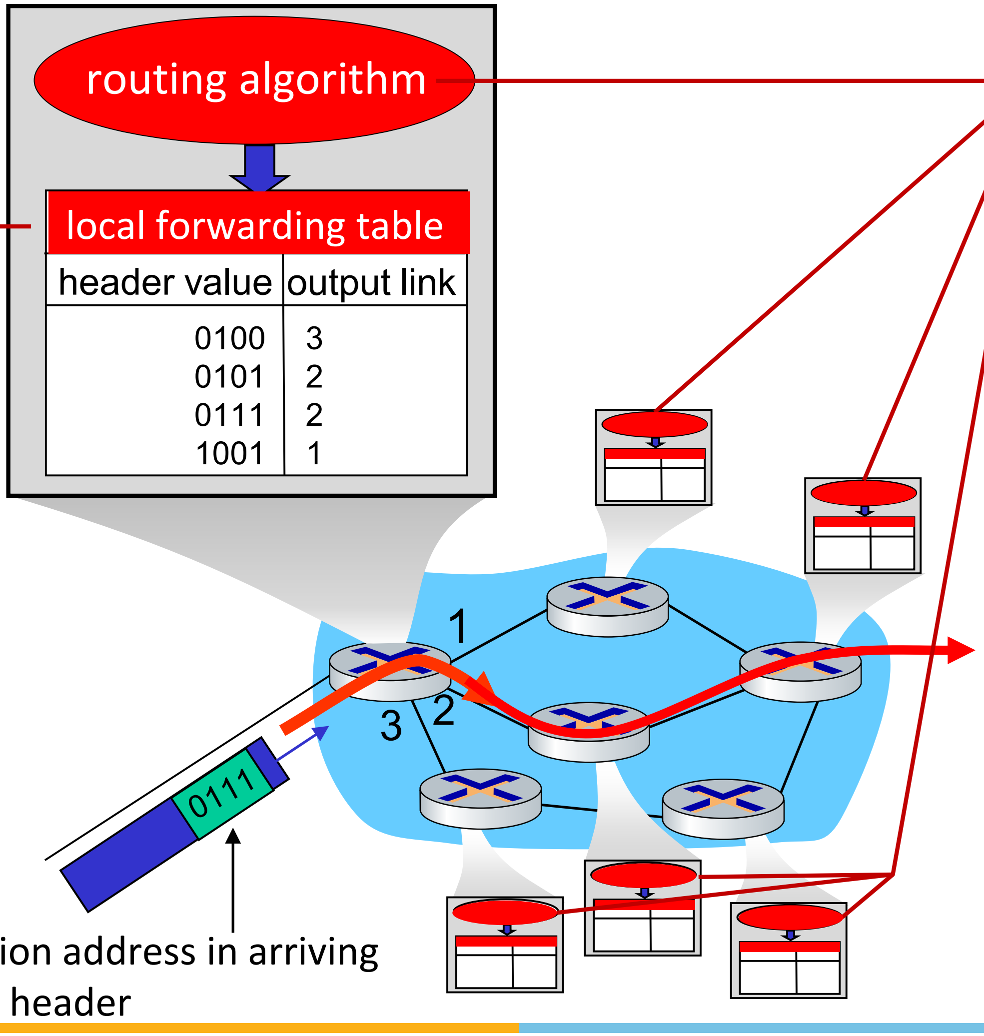
- Network edge: applications and hosts
- Network core: interconnected routers
- Access networks: The network that physically connects an host
- Physical media: wired, wireless communication links



Two key **network-core** functions

Forwarding:

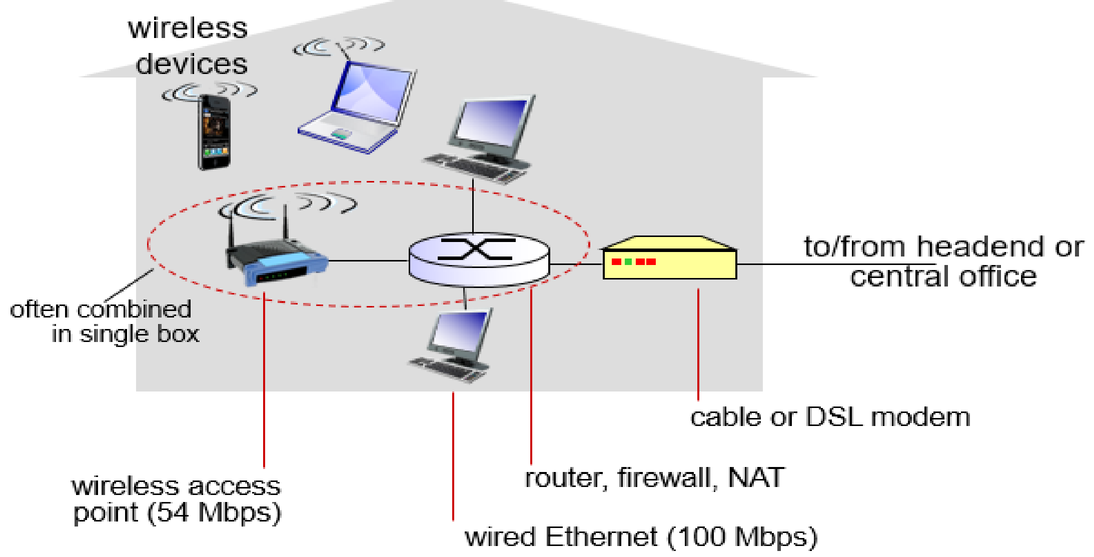
- aka “switching”
- *local* action: move arriving packets from router’s input link to appropriate router output link

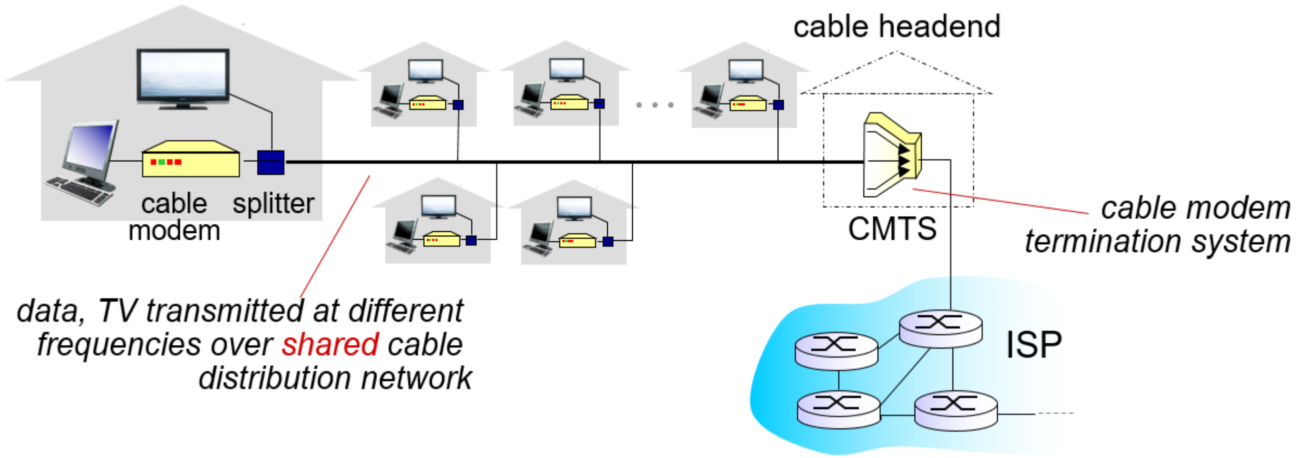


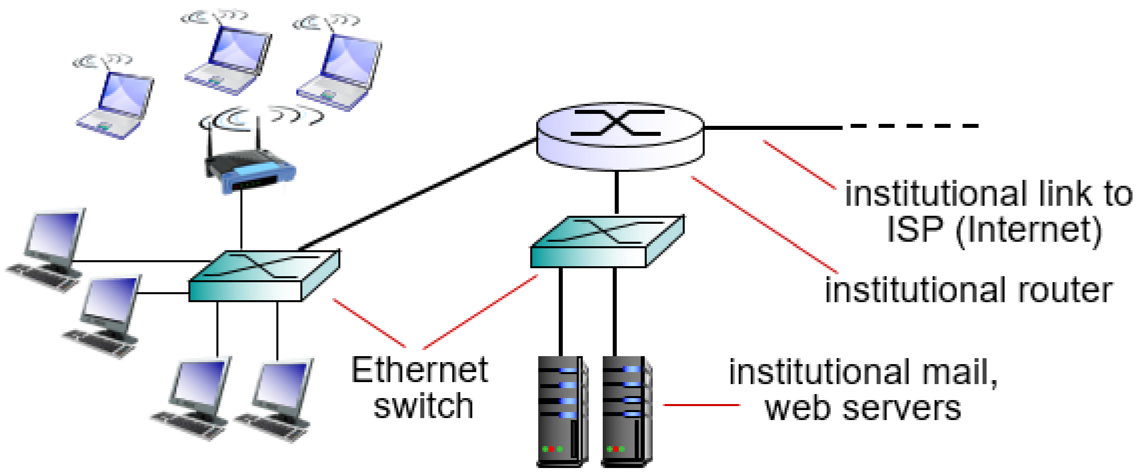
Routing:

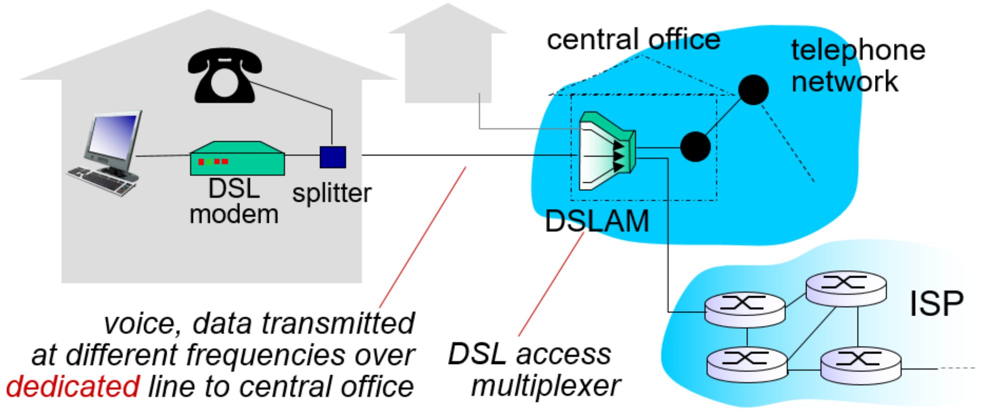
- *global* action: determine source-destination paths taken by packets
- routing algorithms

Access Networks Example





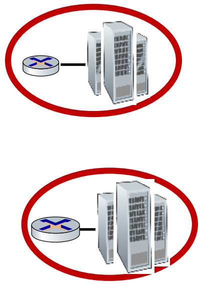




Access networks: Data Center Networks

- High-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet

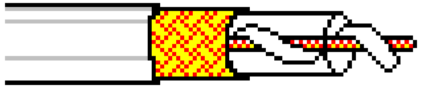
Courtesy: Massachusetts Green High Performance Computing Center (mghpcc.org)



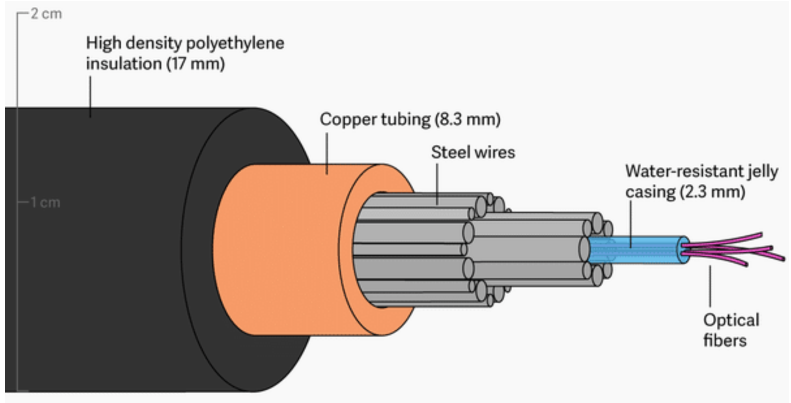
Physical Media-Guided

- Twisted pair
  - Two insulated copper wires
  - Transmission rates supported are 100 Mbps, 1 Gbps, 10 Gbps

- Coaxial Cable
  - Two concentric copper conductors
  - Multiple channels on cable



- Fiber Optic Cable
  - Glass fiber carrying light pulses, each pulse a bit
  - High speed operation (10 Gbps to 100 Gbps)
  - Low error rate

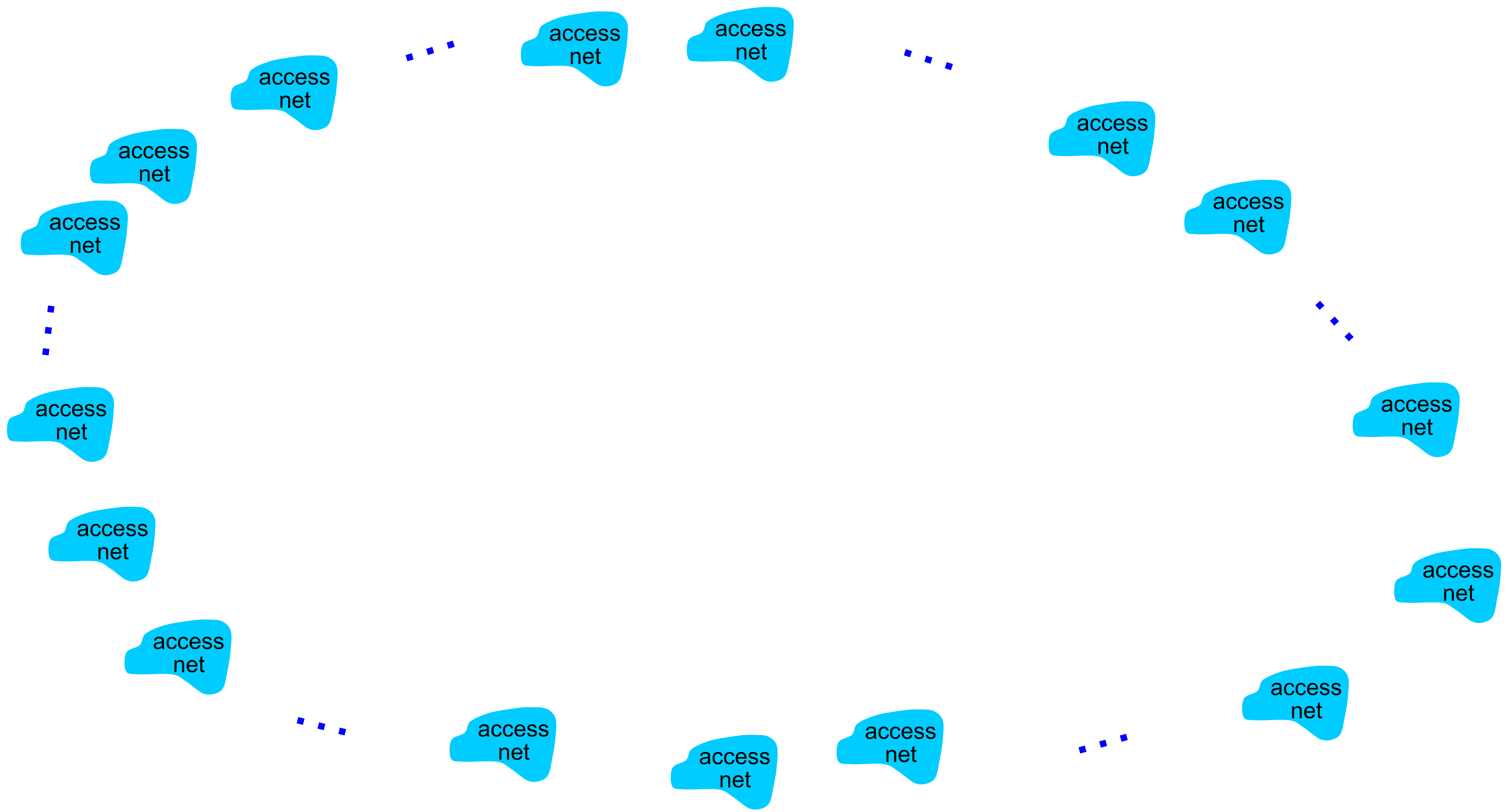


Physical Media-Unguided

- Radio link types:
  - terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 11Mbps, 54 Mbps, 10 Gbps (2020)
- Wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
  - 4G cellular: ~100 Mbps
  - 5G cellular: ~20 Gbps
- Satellite
  - Kbps to 45Mbps channel (or multiple smaller channels)

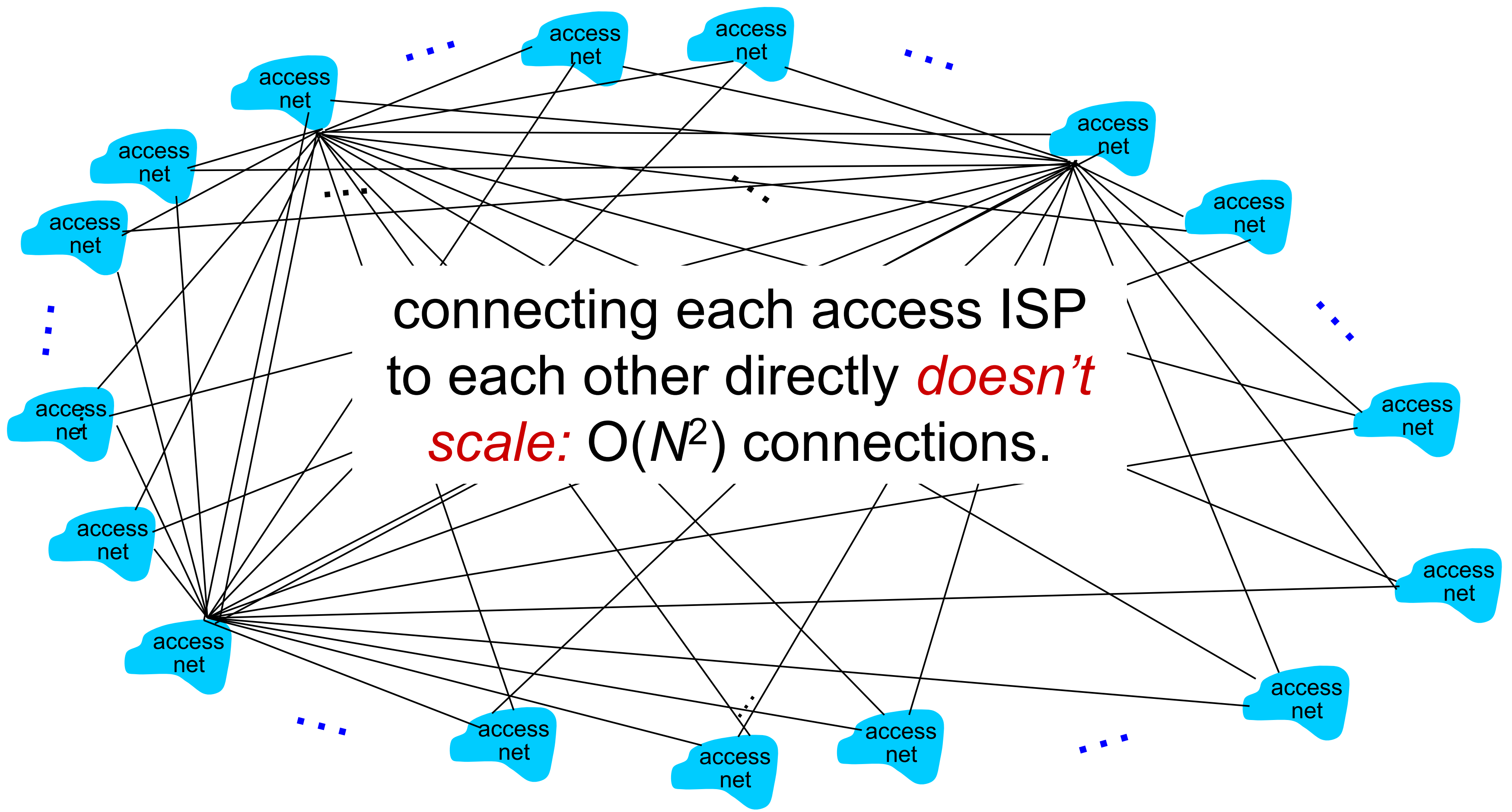
Internet structure: **network of networks**

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



Internet structure: network of networks

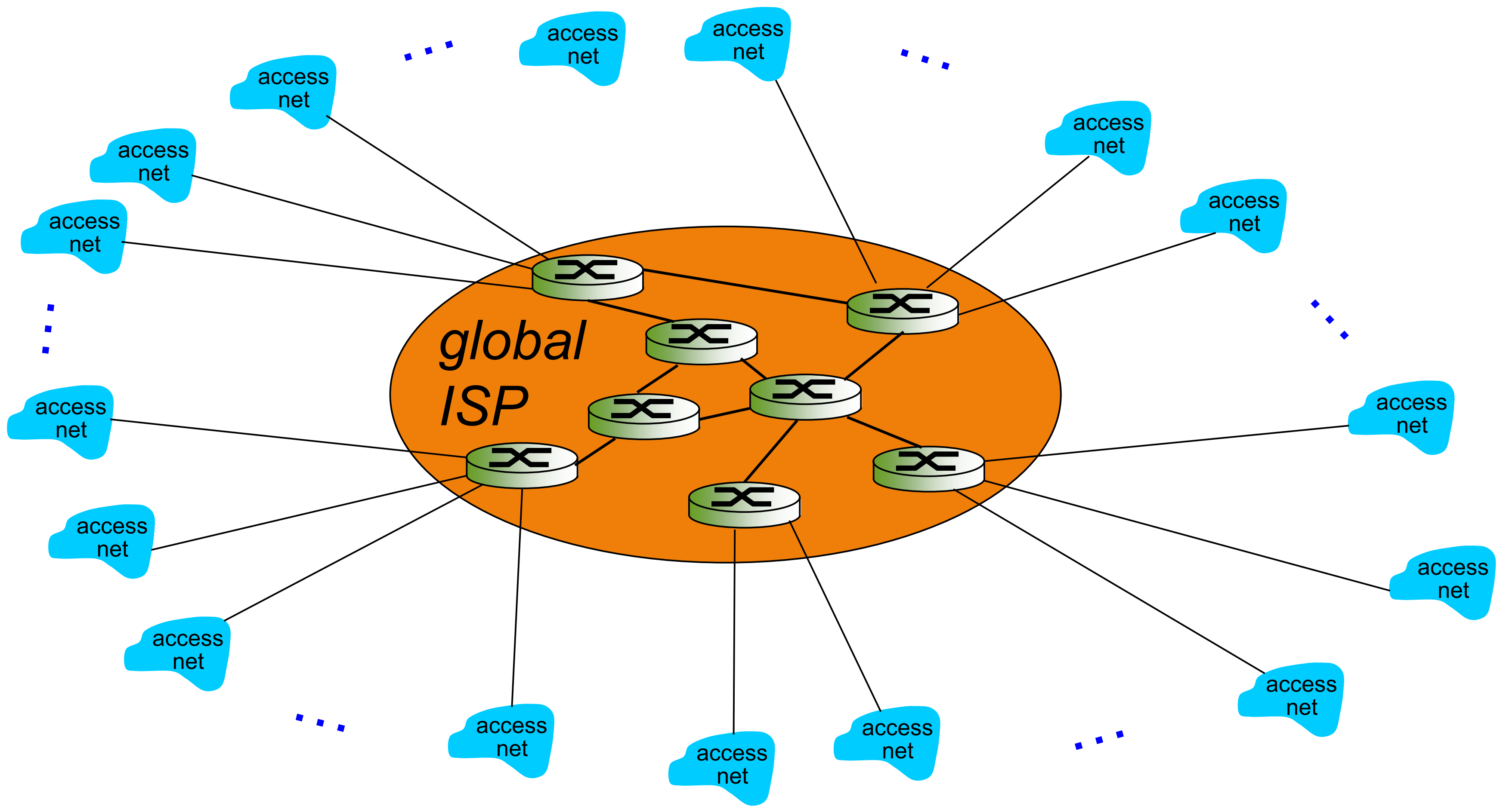
Option: connect each access ISP to every other access ISP?



connecting each access ISP to each other directly *doesn't scale:* $O(N^2)$ connections.

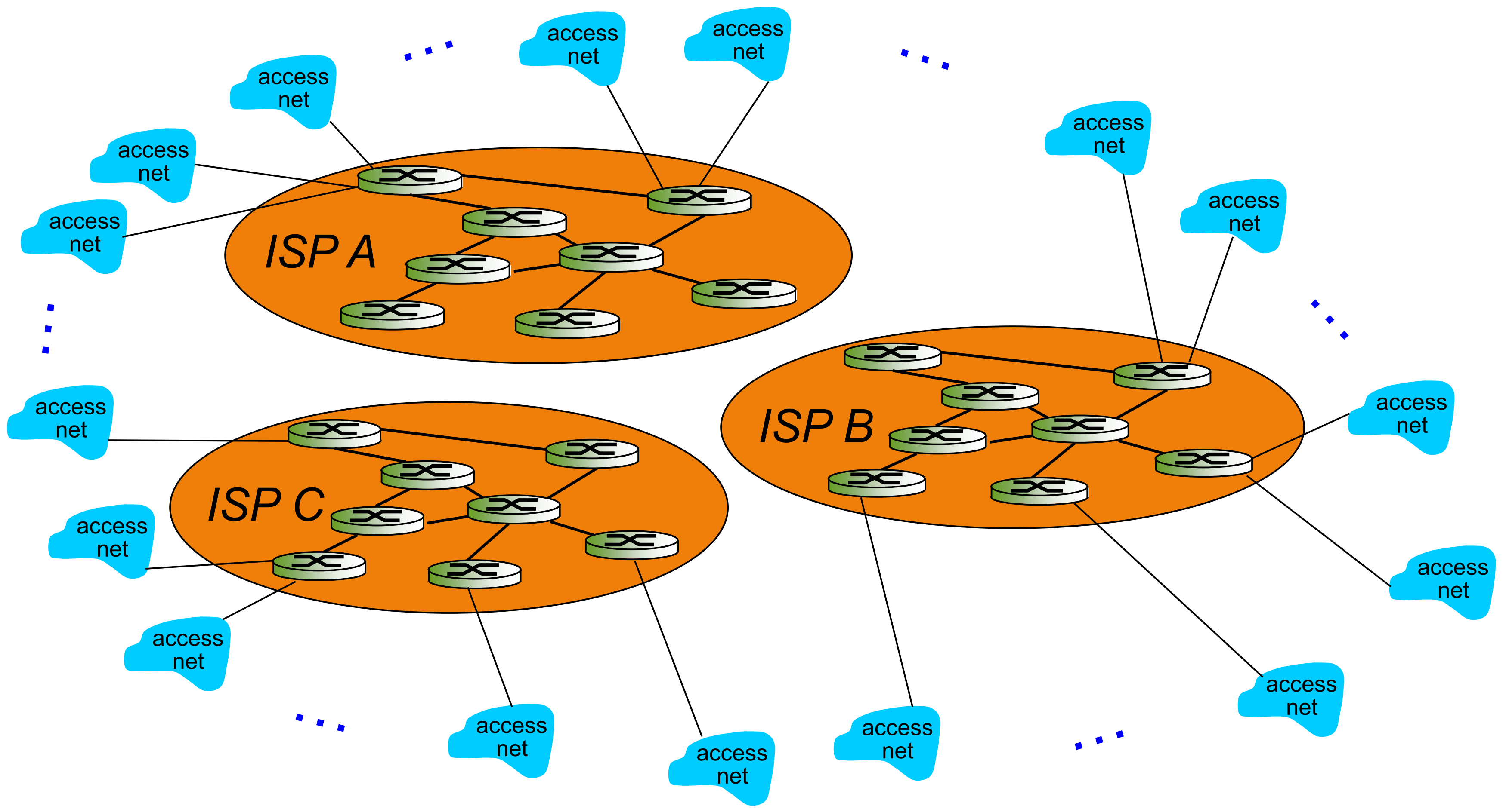
Internet structure: network of networks

Option: Connect each access ISP to a global transit ISP?



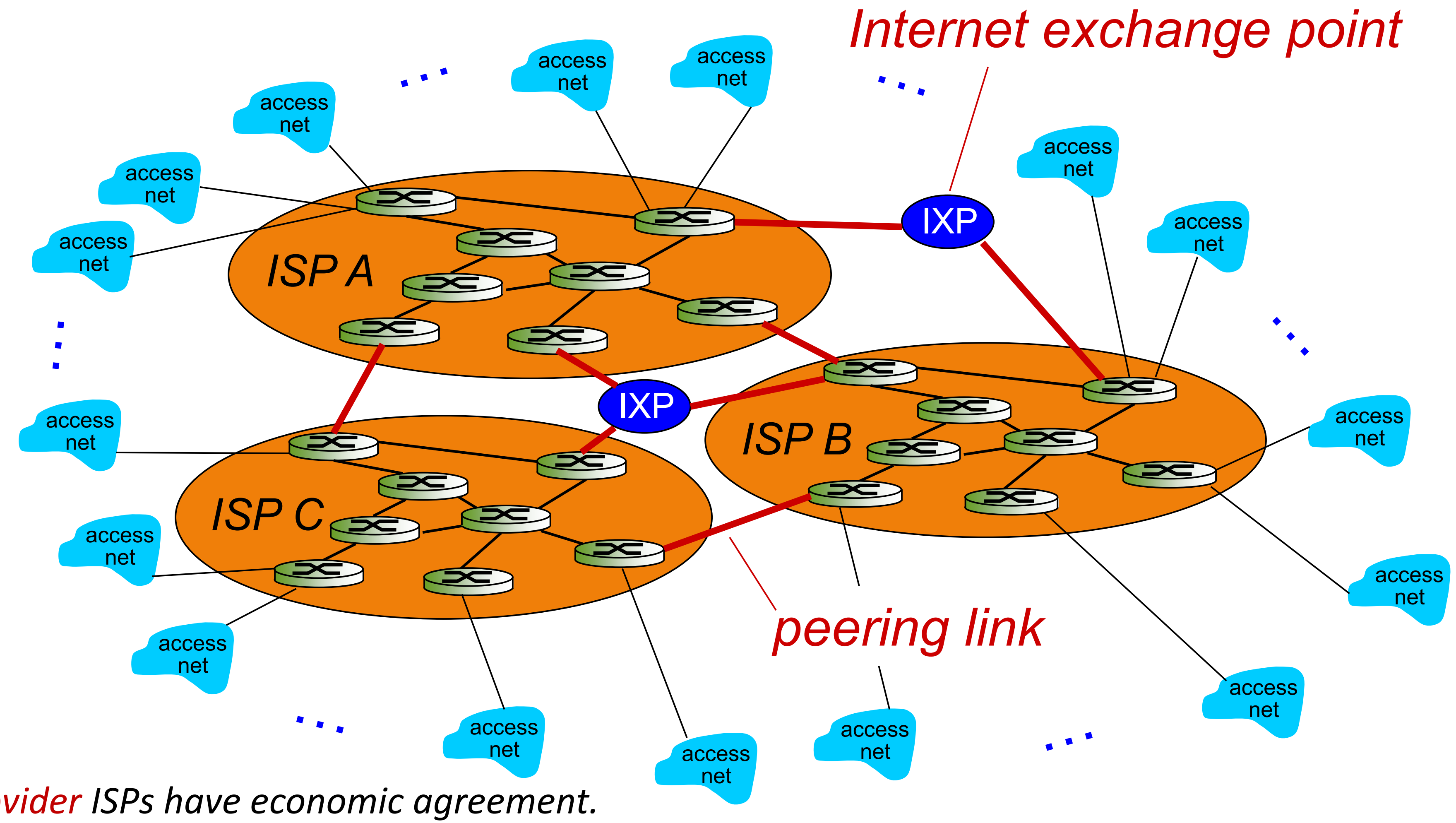
Internet structure: network of networks

Single global ISP does not scale, there are multiple global ISPs ….



Internet structure: network of networks

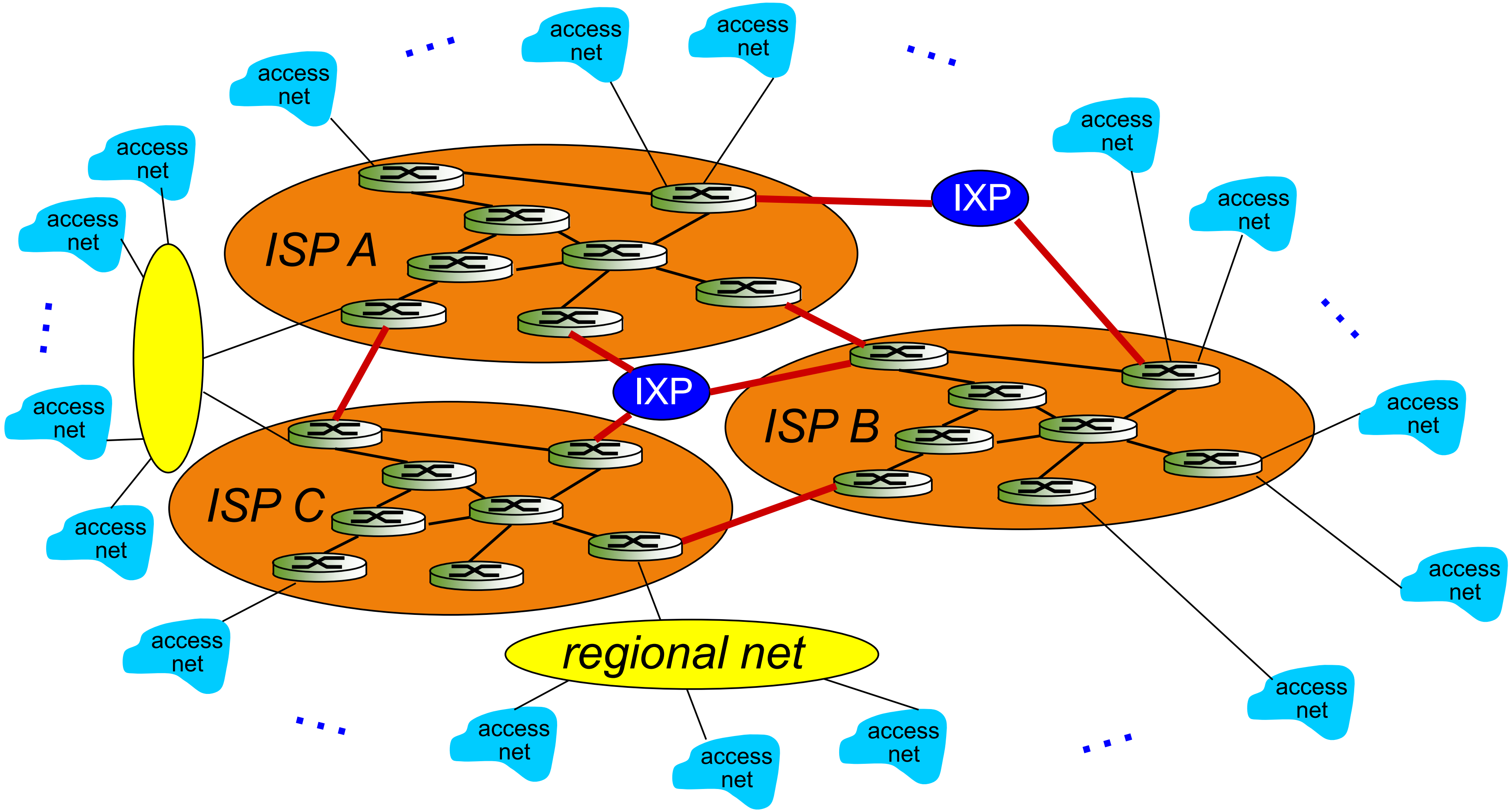
Multiple global ISPs must be interconnected.



Customer and provider ISPs have economic agreement.

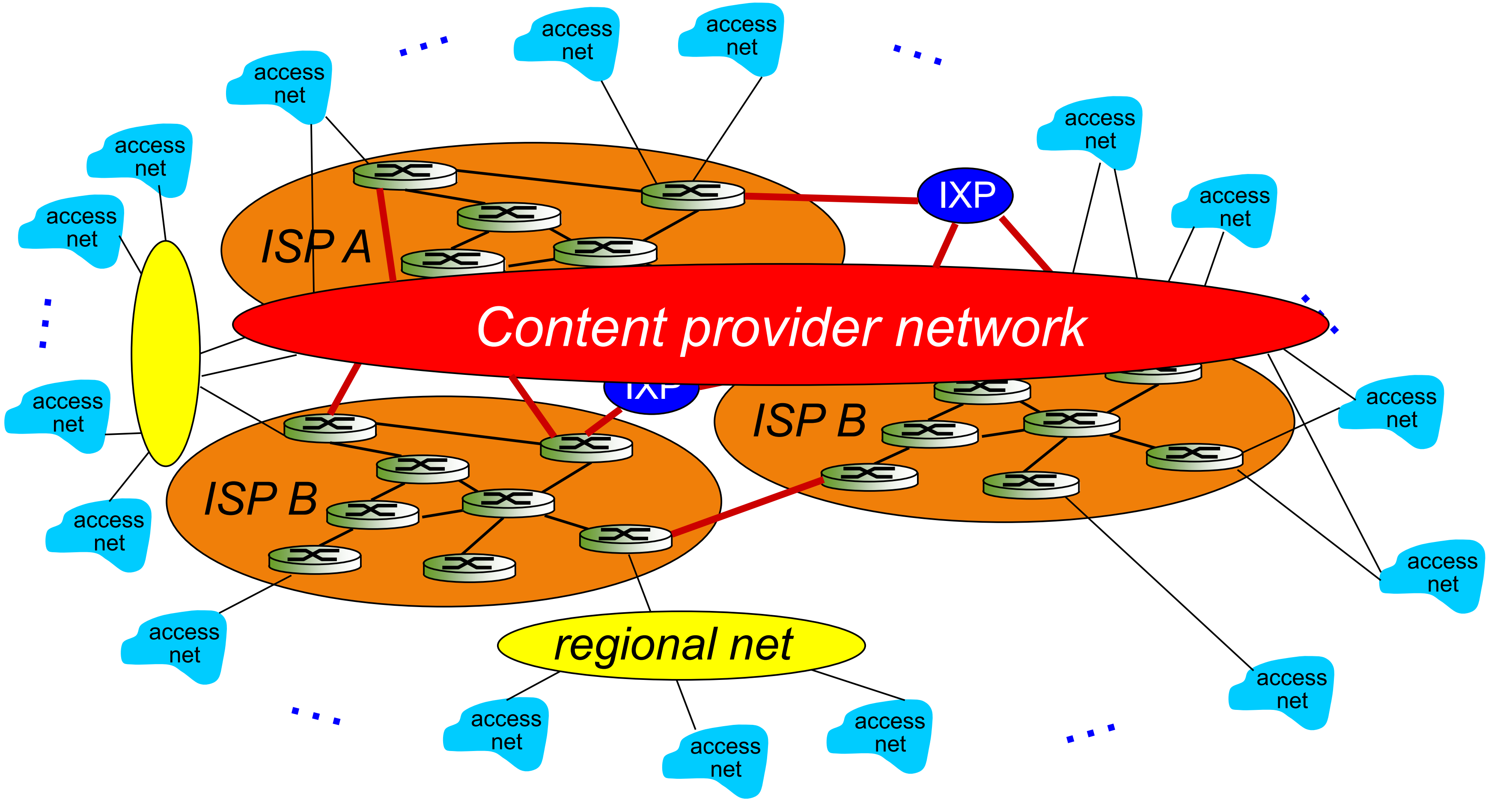
Internet structure: network of networks

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

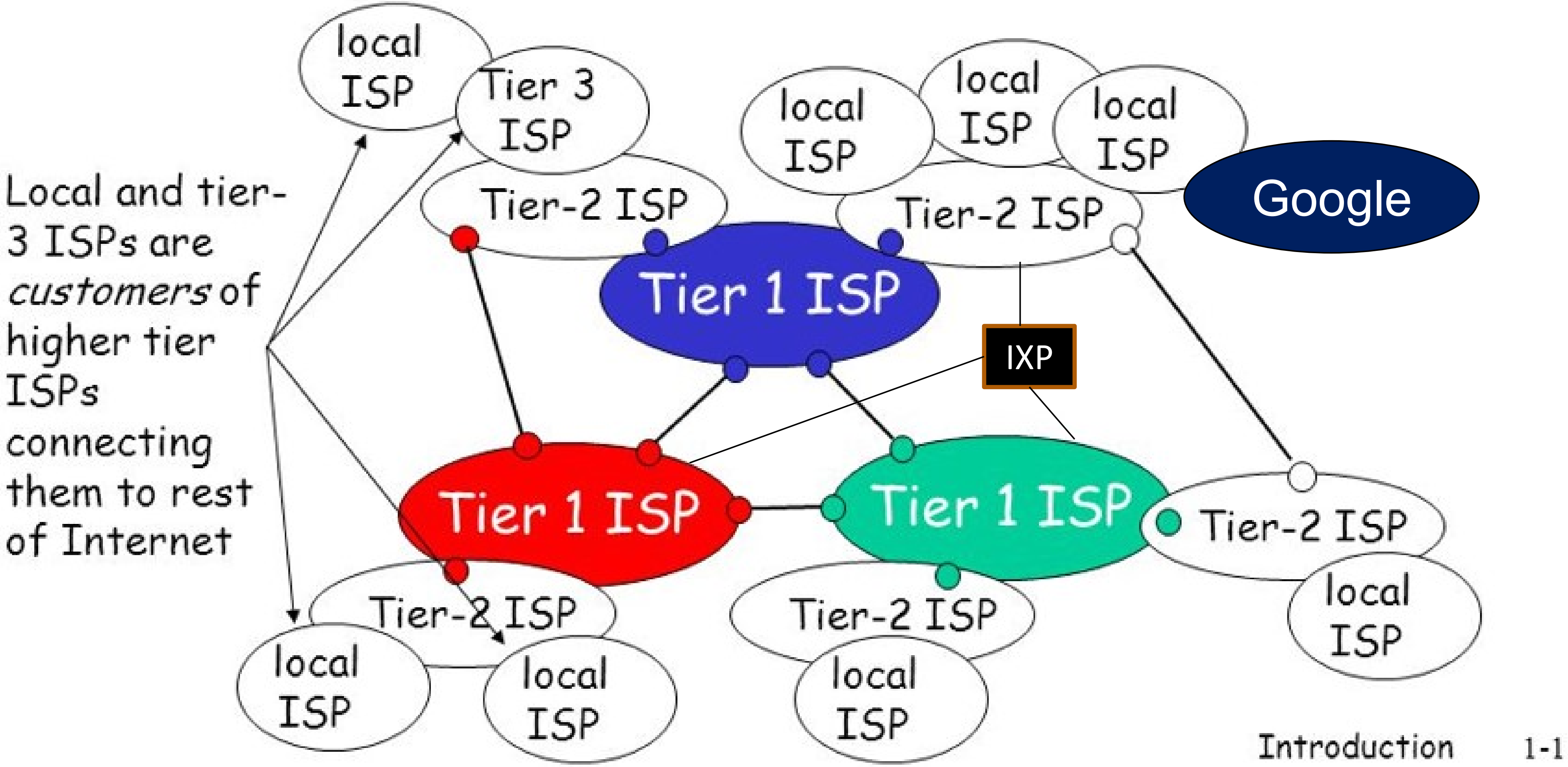


Internet structure: network of networks

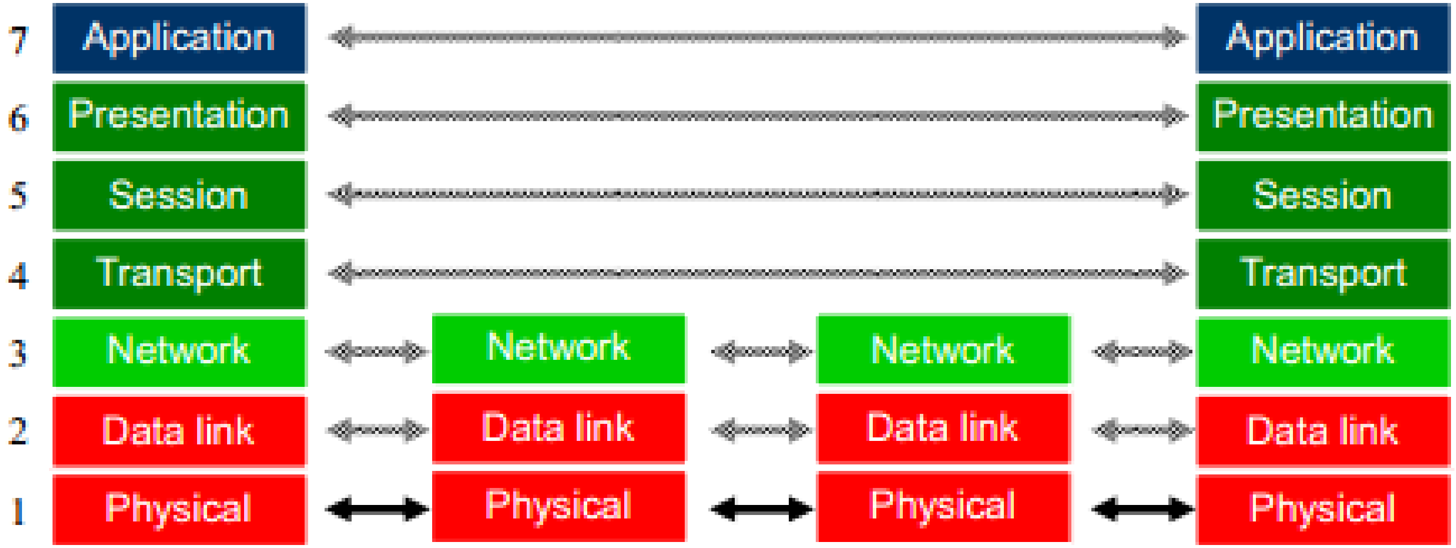
… and content provider networks (e.g., Google, Microsoft, Akamai) may run their own network, to bring services, content close to end users



Internet structure: network of networks

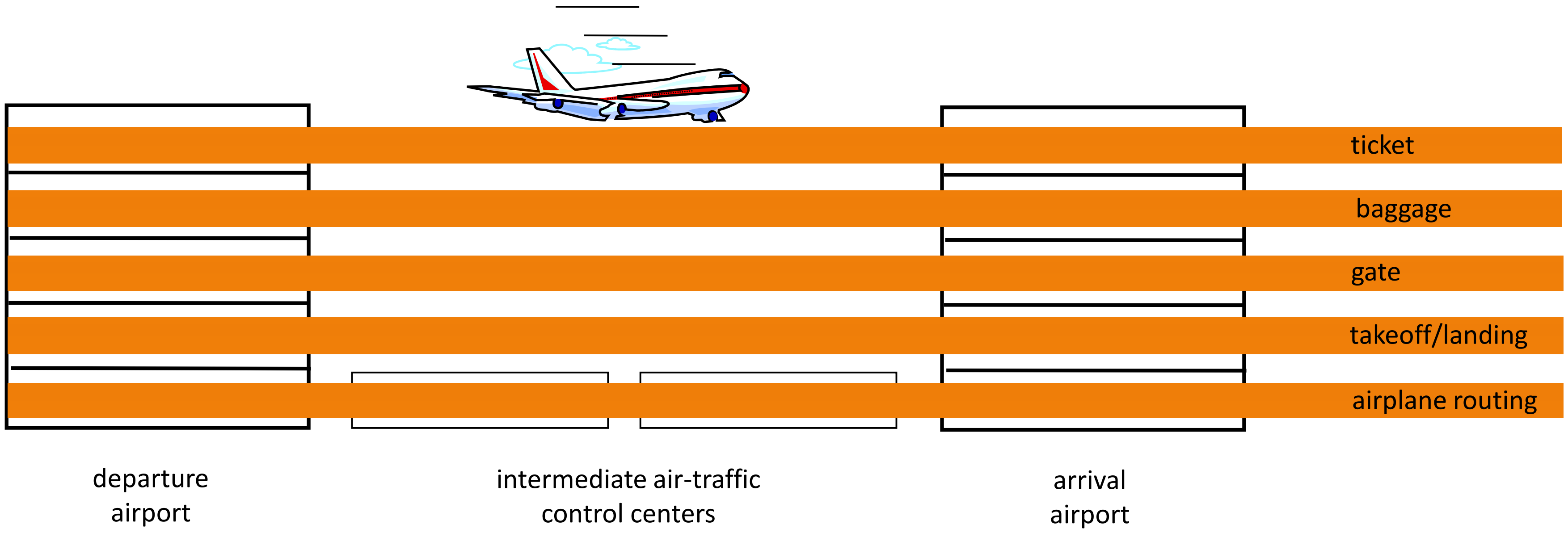


Layered (Modular) Network Model (OSI)



Each layer performs specific operations.
Implementation of a layer can change by keeping interfaces intact.

Layering of Airline Functionality

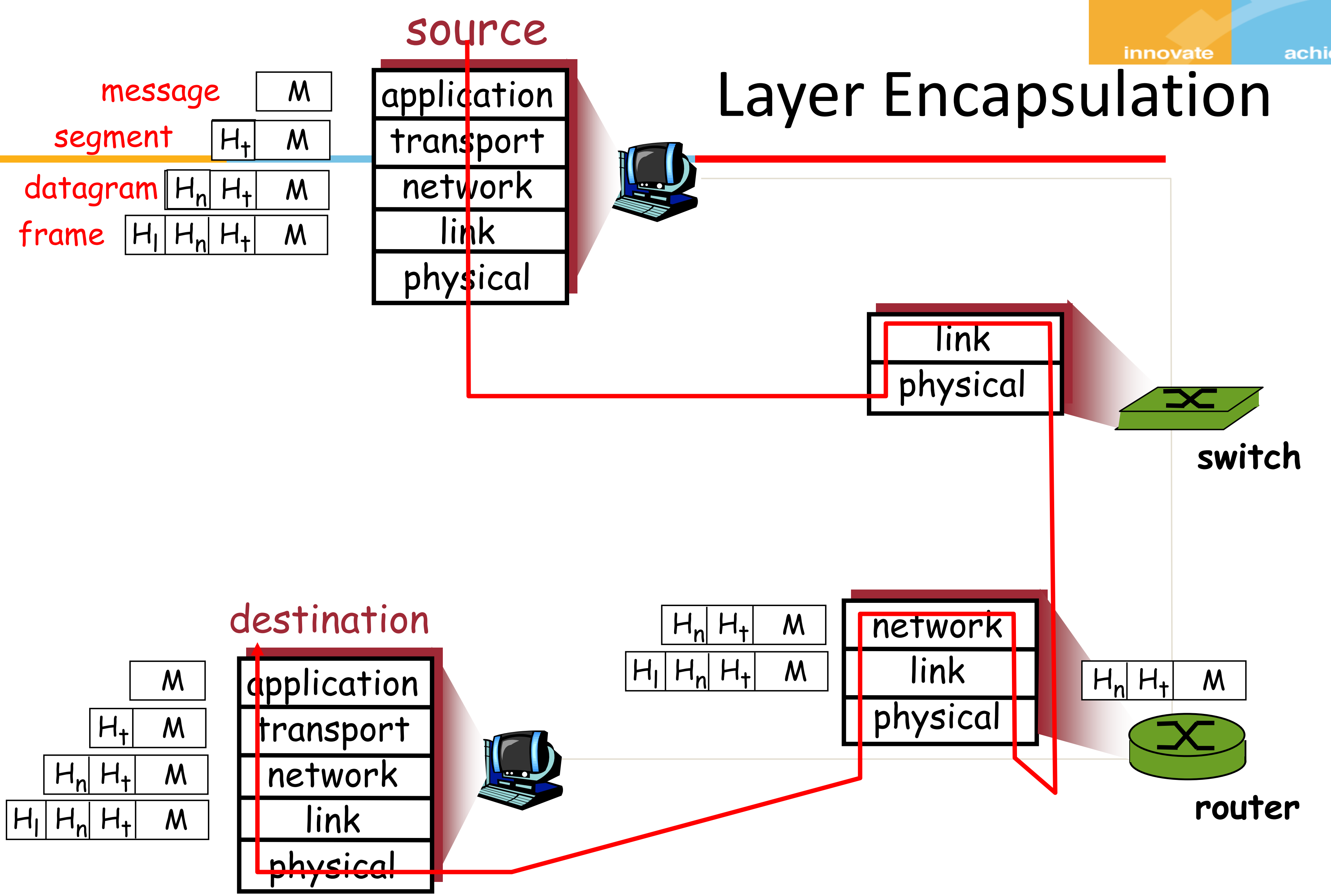


Layers: Each layer implements a service

– Via its own internal-layer actions

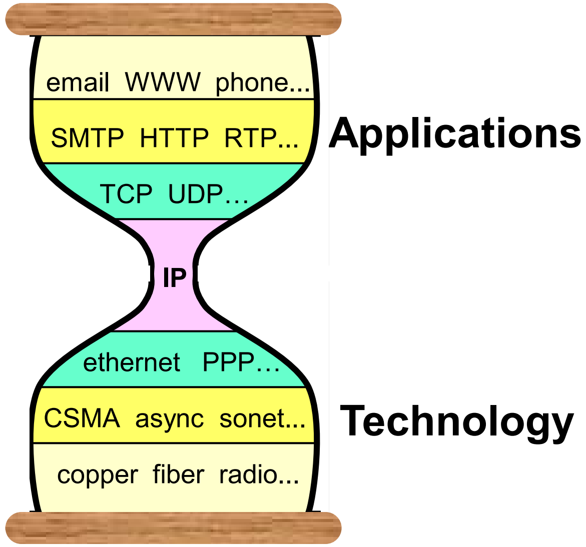
– Relying on services provided by layer below

Layer Encapsulation



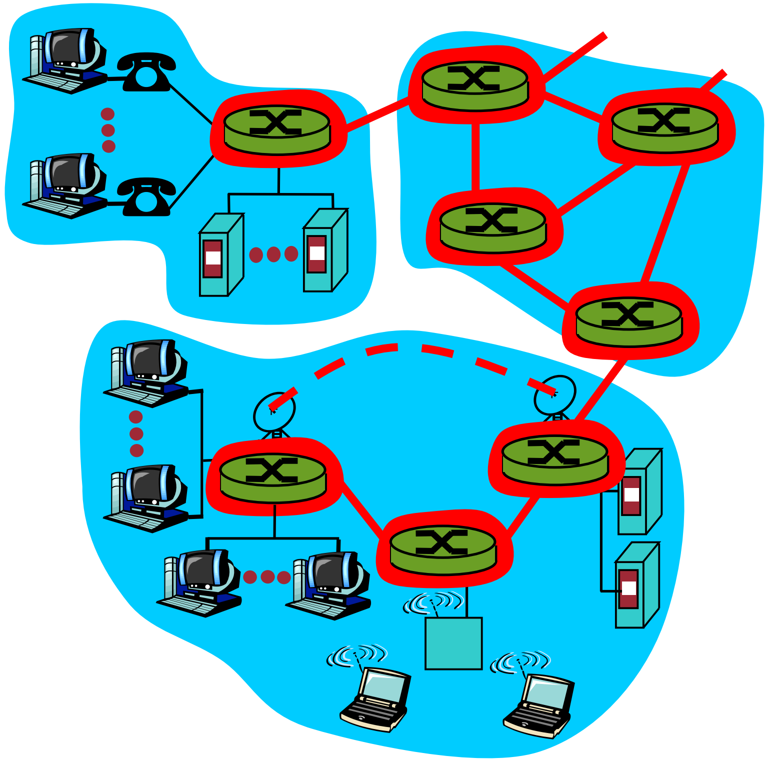
Internet Hourglass Architecture

- Need to interconnect many existing networks
- Hide underlying technology from applications
- Decisions:
  - Network provides minimal functionality
  - “Narrow waist”
  - ***Best Effort Service…!***
  - Tradeoff→ No assumptions no guarantee



The Network Core

- Mesh of interconnected routers
- How is data transferred through network?
  - Circuit switching: Dedicated circuit per call ex: telephone net
  - Packet-switching: Data Sent through net in discrete "chunks" ex: Internet

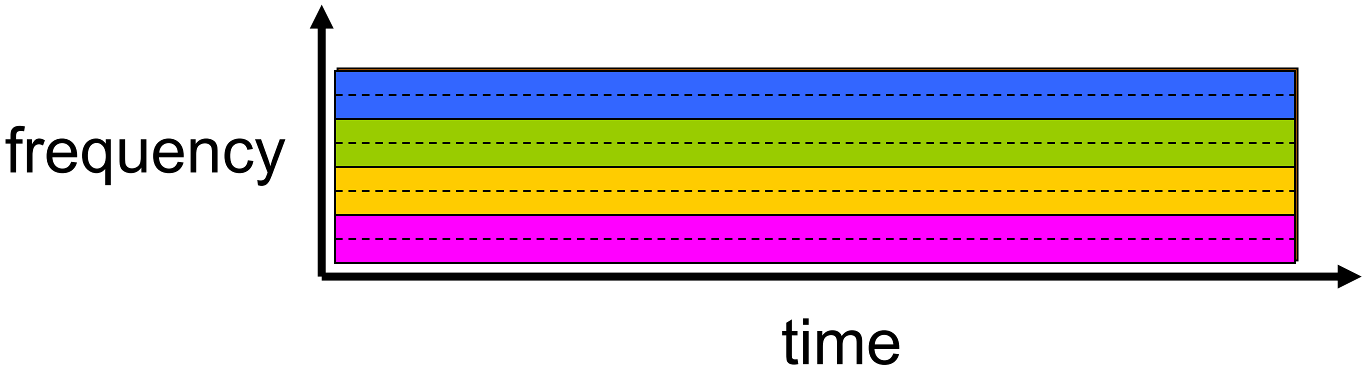


Circuit Switching: FDM and TDM

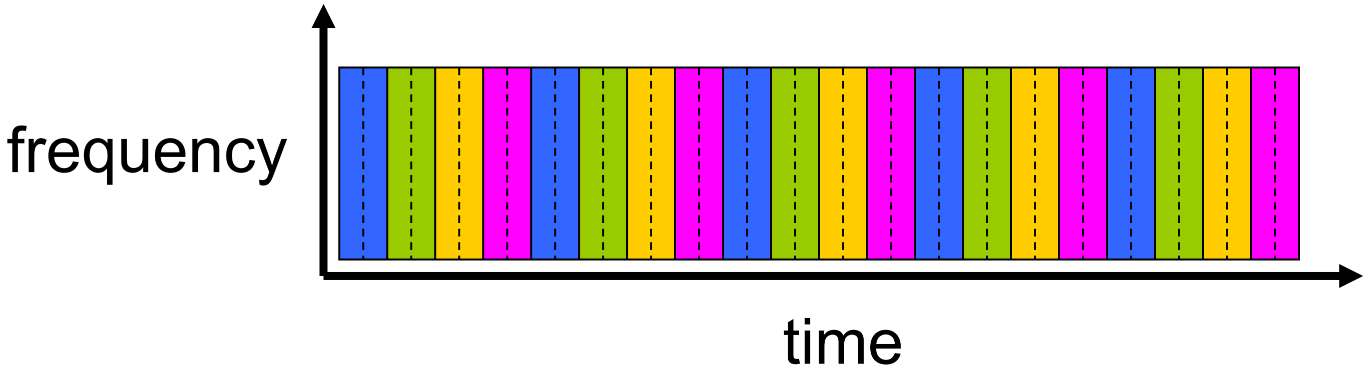
Example:

4 users

FDM



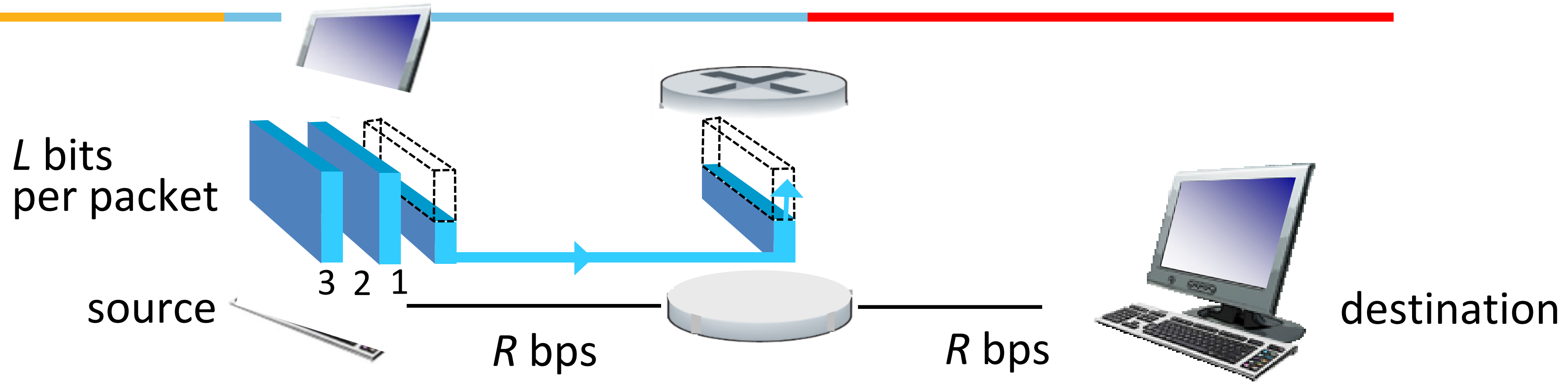
TDM



Circuit Switch: 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/sec
  - 500 msec to establish end-to-end circuit

Packet-switching: store-and-forward

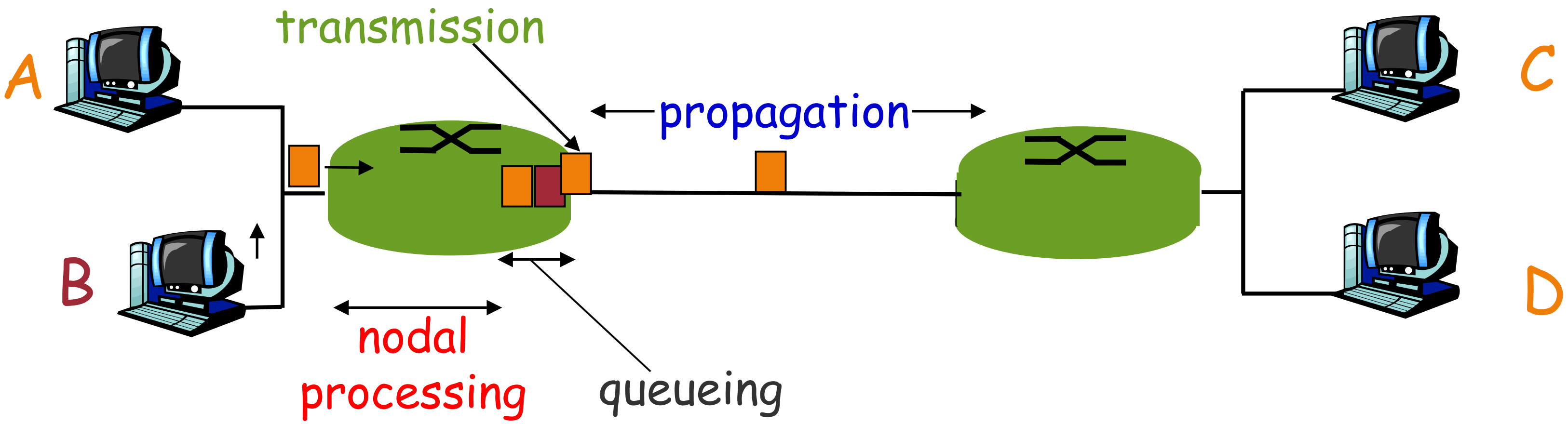


- Packet transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps
- *Store and forward: entire* packet must arrive at router before it can be transmitted on next link

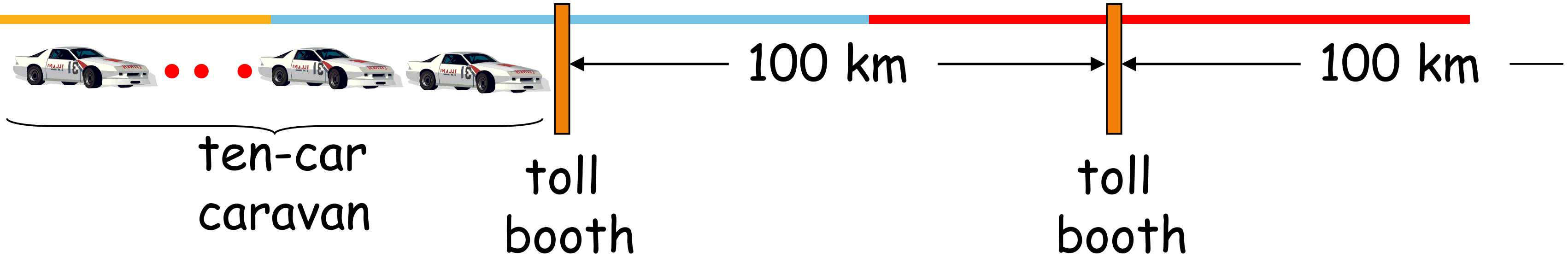
One-hop numerical example:

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

End-to-End Delay



Transmission Delay vs. Propagation Delay - Caravan Analogy

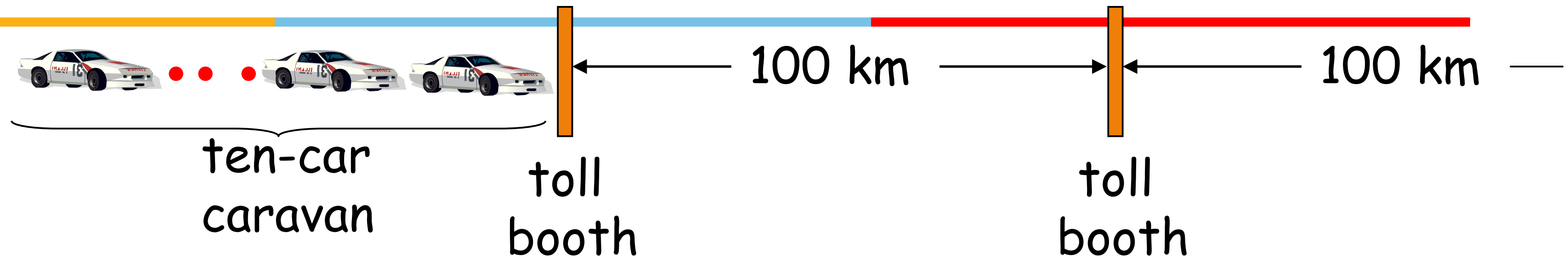


- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (car transmission time)
- Car is analogous to **bit**; caravan is analogous to **packet**

Questions???

1. Once a car enters service at the tollbooth, how long does it take until it leaves service?
2. How long does it take for the entire caravan to receive service at the tollbooth (that is the time from when the first car enters service until the last car leaves the tollbooth)?
3. Once the first car leaves the tollbooth, how long does it take until it arrives at the next tollbooth?
4. Once the first car leaves the tollbooth, how long does it take until it enters service at the next tollbooth?
5. Are there ever two cars in service at the same time, one at the first toll booth and one at the second toll booth? Yes or No.
6. Are there ever zero cars in service at the same time, i.e., the caravan of cars has finished at the first toll both but not yet arrived at the second tollbooth? Yes or No
7. How much time does it take to lined up the caravan before the next tollbooth?

Caravan analogy [..2]

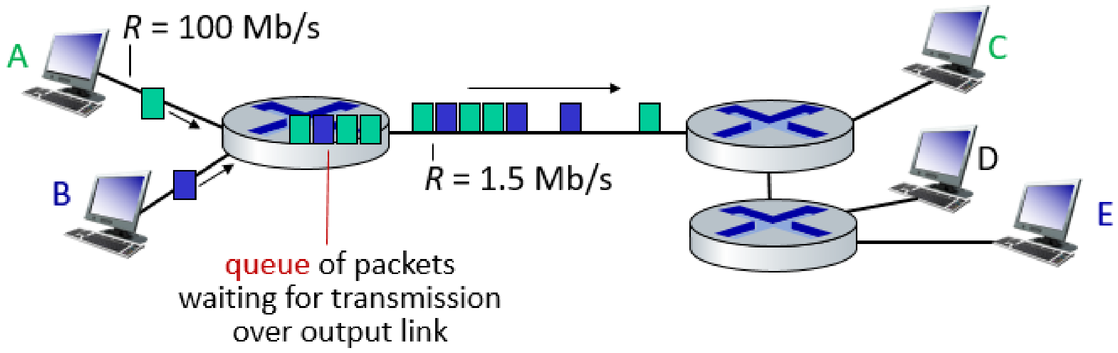


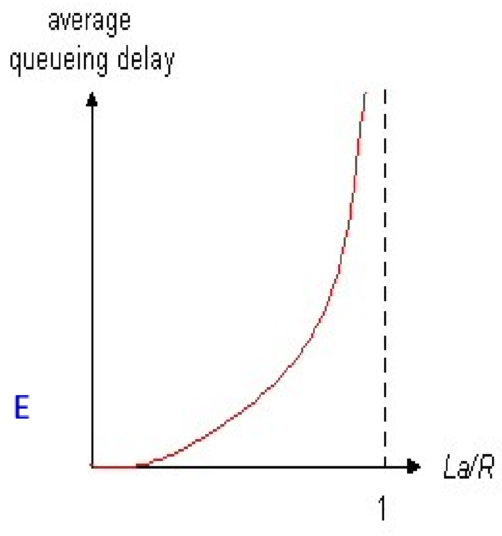
- Cars now “propagate” at 1000 km/hr
- Toll booth now takes 1 min to service a car

Queuing Delay

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

traffic intensity = La/R

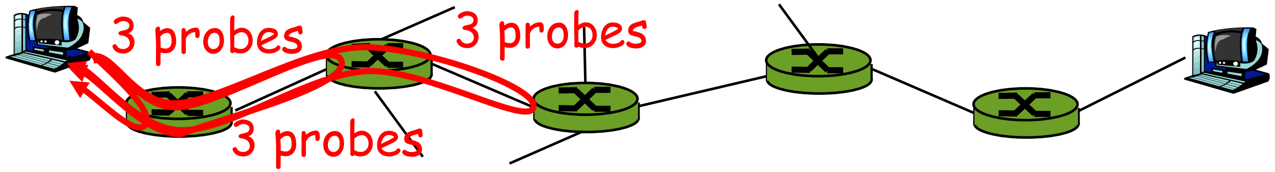




- La/R > 1: more “work” arriving than can be serviced, average delay infinite!
- La/R <= 1: delays become large
- La/R ~ 0: average queueing delay small

"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- **Traceroute** program: provides delay measurement from source to router along end-to-end Internet path towards destination. For all *i:*
  - Sends three packets that will reach router *i* on path towards destination
  - Router *i* will return packets to sender
  - Sender times interval between transmission and reply.
  - Read RFC 1393 for more detail !!!
- http://traceroute.org



Real Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

3 delay measurements to border1-rt-fa5-1-0.gw.umass.edu

1 (128.119.240.254) 1 ms 1 ms 2 ms
2 (128.119.3.145) 1 ms 1 ms 2 ms
3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
7 (198.32.8.46) 22 ms 22 ms
8 (62.40.103.253) 104 ms 109 ms
9 de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
10 de.fr1.fr.geant.net (62.40.96.50) 113 ms 121 ms 114 ms
11 renater-gw.fr1.fr.geant.net (62.40.103.54) 112 ms 114 ms
12 nio-n2.cssi.renater.fr (193.51.206.13) 111 ms 114 ms
13 nice.cssi.renater.fr (195.220.98.102) 123 ms 125 ms 124 ms
14 r3t2-nice.cssi.renater.fr (195.220.98.110) 126 ms 126 ms 124 ms
15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
17 * * *
18 * * *
19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms

trans-oceanic link

looks like delays *decrease*! Why?

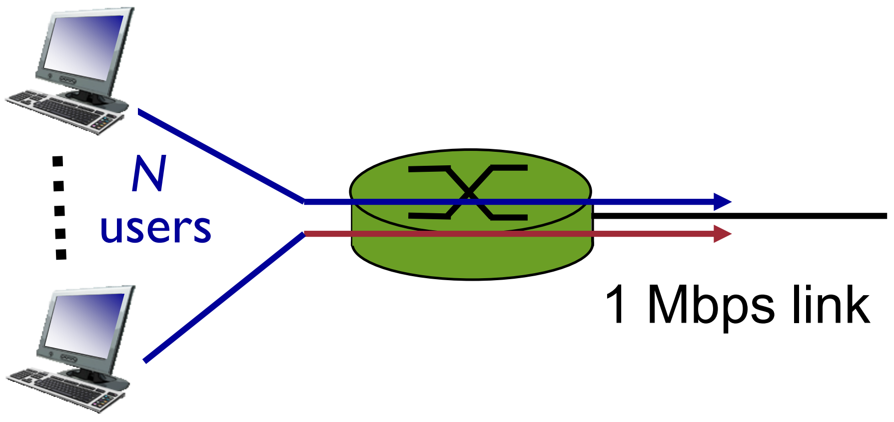
* means no response (probe lost, router not replying)

Packet switching vs. 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

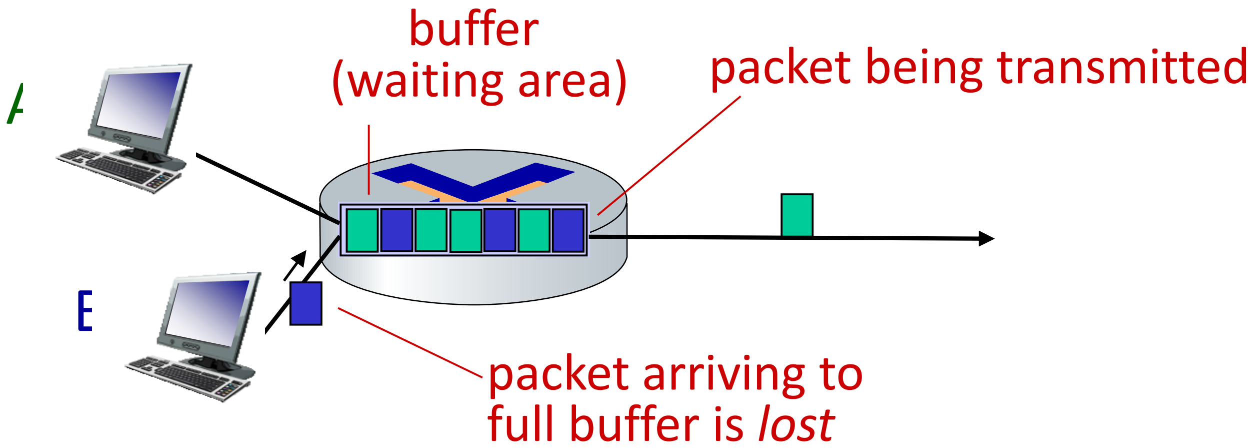


- *Circuit-switching:*
  - **How many users are supported?**
- *Packet switching:*
  - With 35 users, probability > 10 active at same time is less than .0004

Exercise: How did we get value 0.0004?

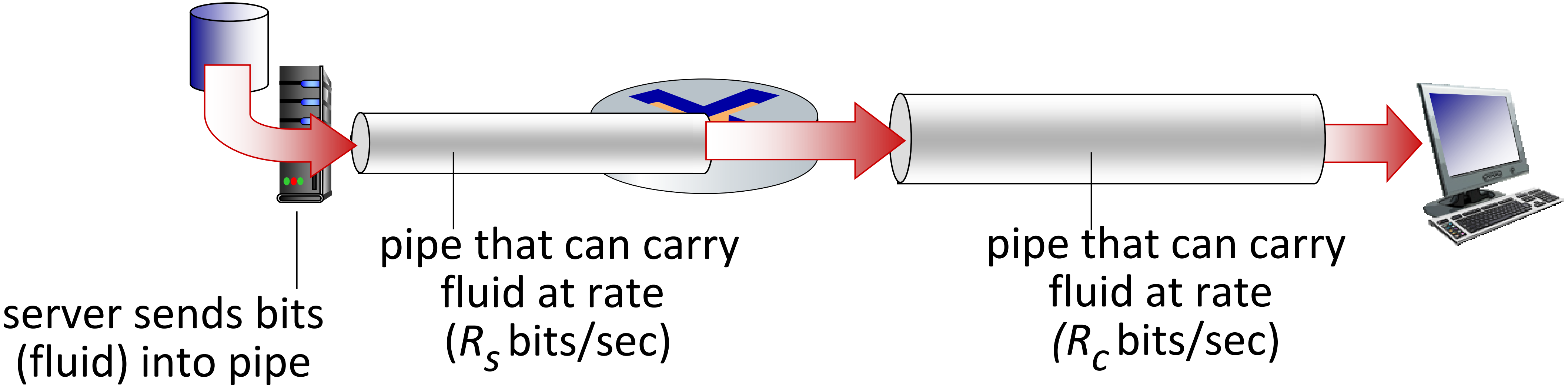
Packet loss

- Queue (aka buffer) preceding link in buffer has finite capacity
- Packet arriving to full queue dropped (aka lost)
- Lost packet may be retransmitted by previous node, by source end system, or not at all

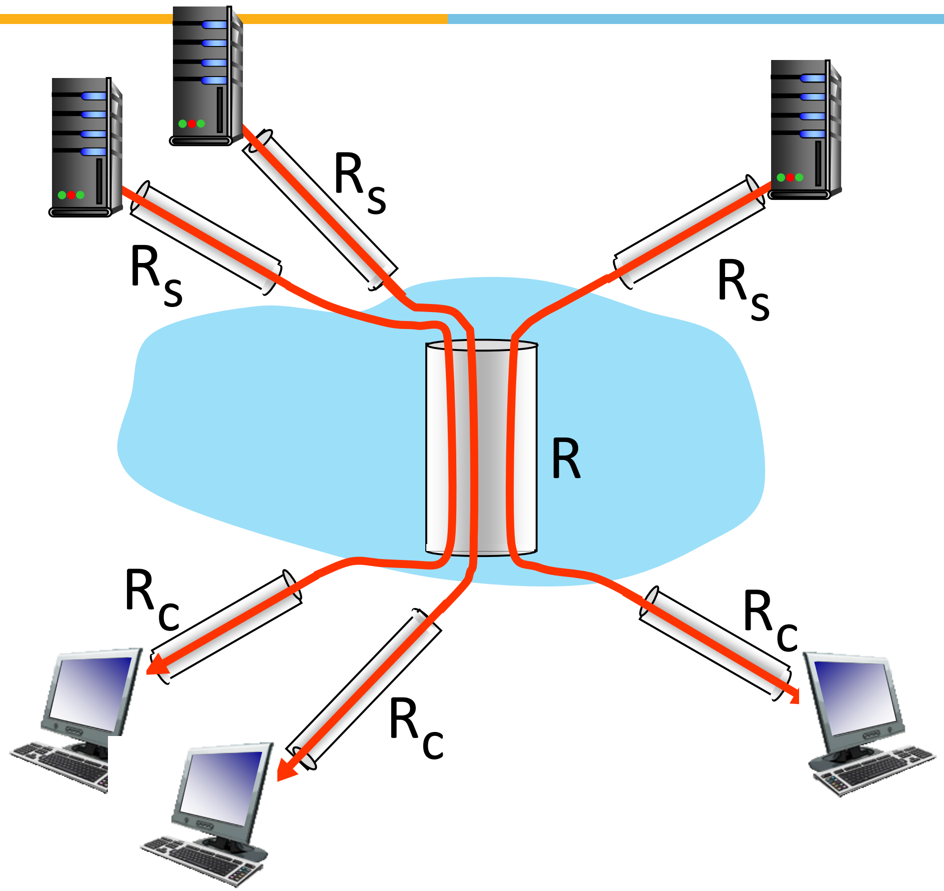


Throughput

- *Throughput:* rate (bits/time) at which bits are being sent from sender to receiver
  - *Instantaneous:* rate at given point in time
  - *Average:* rate over longer period of time

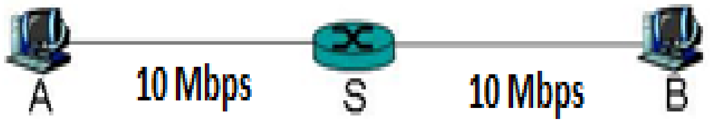


Throughput: network scenario



10 connections (fairly) share
backbone bottleneck link *R* bits/sec

Exercise



We have learned so far…

- Components of computer networks and Internet.
  - Edge, network core, access networks, communication channels.
  - Hosts, links, routers, switches, protocols, etc.
- Layered architecture of computer networks
  - OSI model vs. TCP/IP models
- Network core design
  - Packet switched networks vs. circuit switched networks
- Network performance measurement parameters
  - Delay, throughput, bandwidth

Thank You!