COMPUTER NETWORKS

Computer Networks and the Internet

Team Networks
Department of Computer Science and Engineering

PES UNIVERSITY
CELEBRATING 50 YEARS

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Unit – 1 Computer Networks and the Internet

1.1 Introduction to Computer Networks

1.2 What is the Internet?

- A nuts-and-bolts and Services description, Protocol

1.3 Network edge

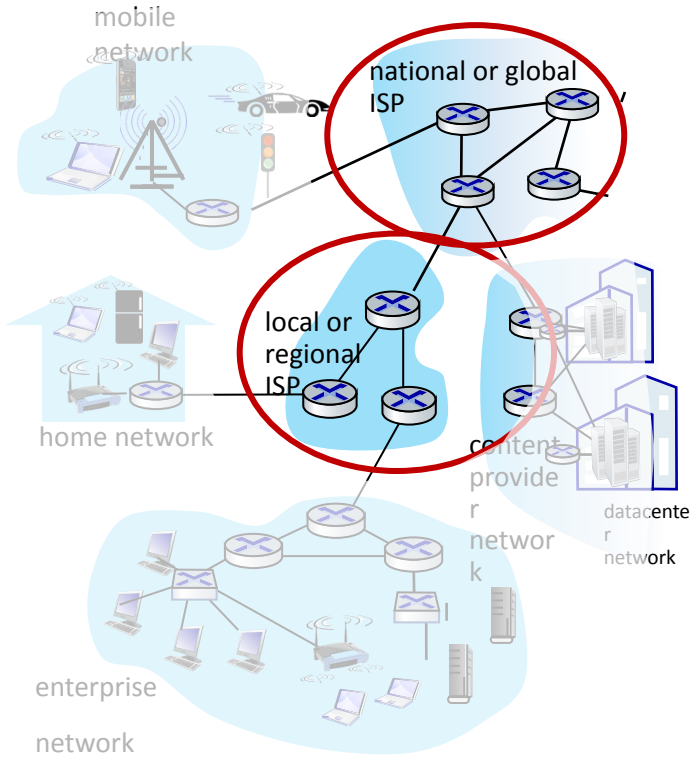
- End systems, Access networks, Physical media

1.4 Network core

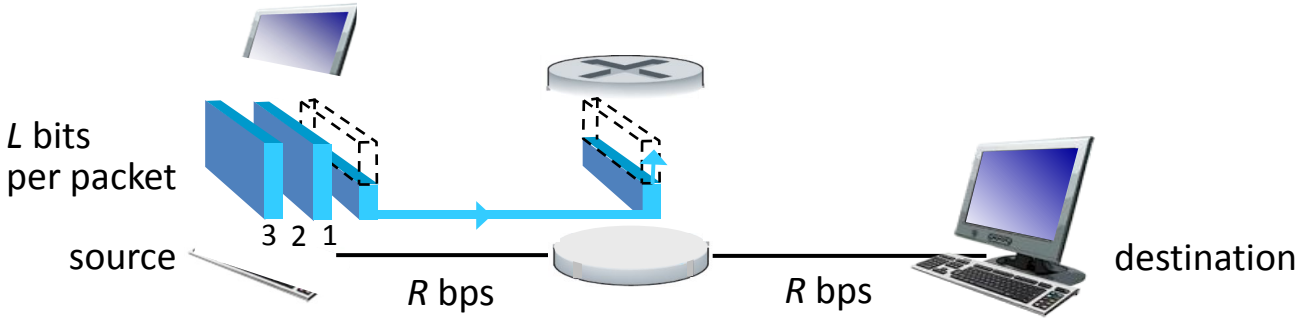
- Packet switching, Circuit switching, Network structure

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



Network Core: Packet Switching: store-and-forward

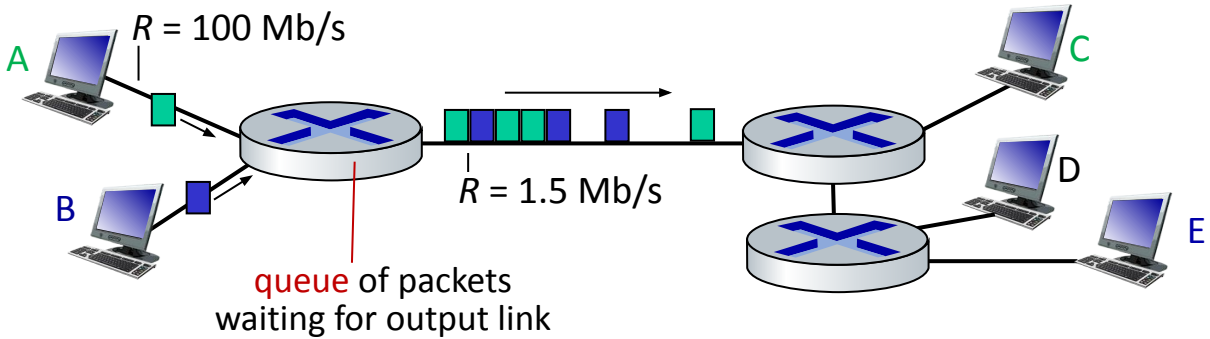


- Transmission delay: takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- *Store and forward: entire* packet must arrive at router before it can be transmitted on next link
- *End-end delay:* 2*L*/*R* (above), assuming zero propagation delay (more on delay shortly)

One-hop numerical example:

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

Network Core: Packet Switching: queuing delay, loss



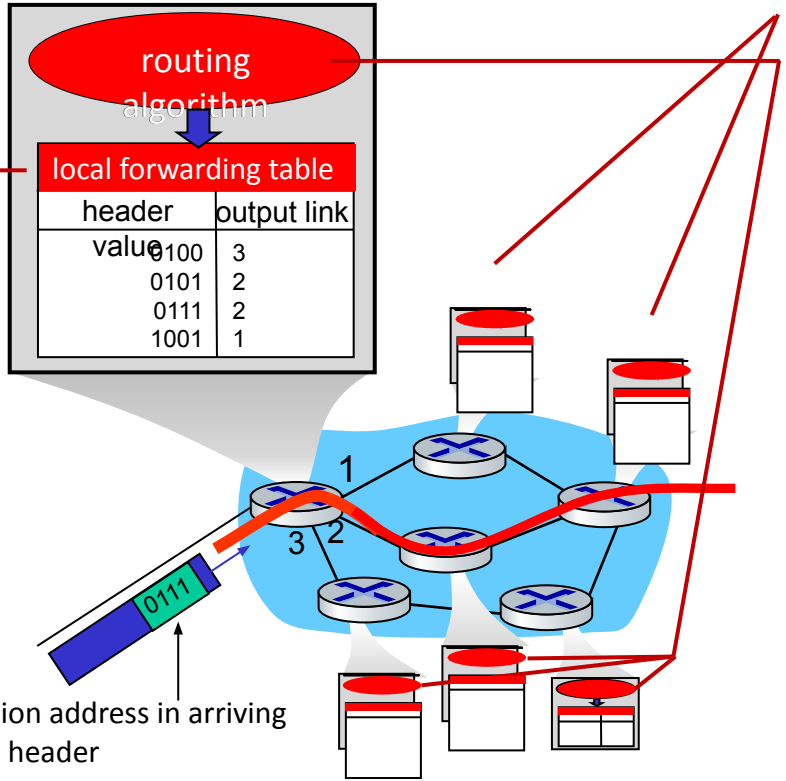
Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for a period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Network Core: Two Key Network Core Functions

Forwarding:

- *local* action: move arriving packets from router's input link to appropriate router output link



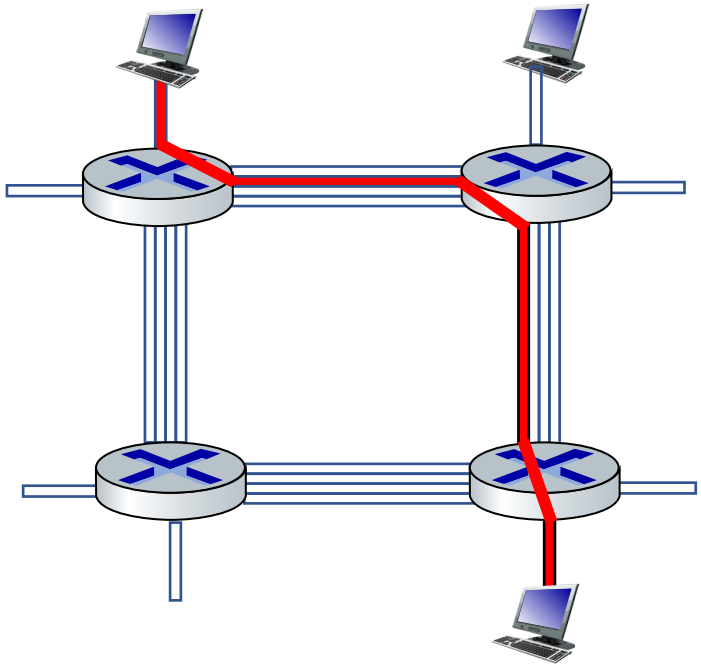
Routing:

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

Network Core: Circuit Switching

end-end resources allocated to, reserved for “call” between source and destination (eg: telephone)

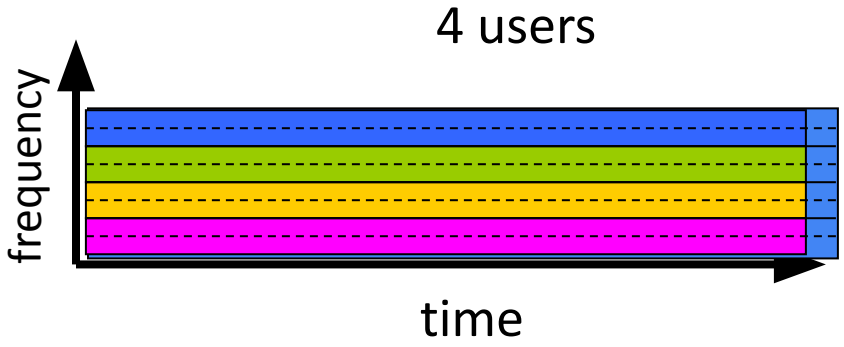
- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Multiplexing in Circuit Switched Networks: FDM & TDM

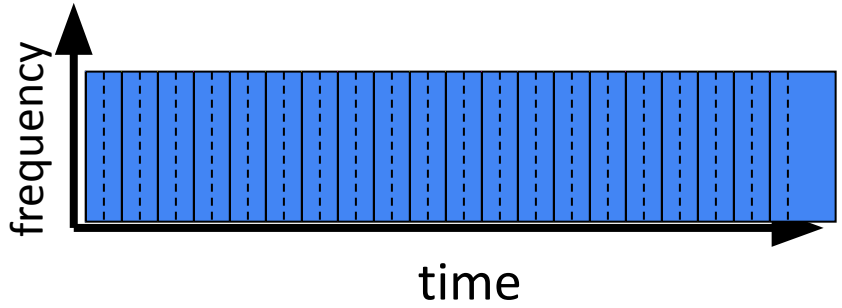
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band



Time Division Multiplexing (TDM)

- time divided into frames -> slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band, but only during its time slot(s)

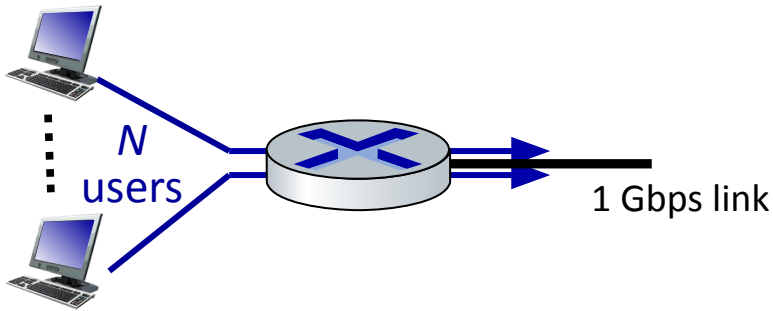


Network Core: Packet Switching vs Circuit Switching

packet switching allows more users to use network!

Example:

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



- *circuit-switching:* 10 users
- *packet switching:* with 35 users,
- probability > 10 active users at same time is less than .0004 *
- 10 or few active users, probability 0.9996

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Network Core: Packet Switching vs Circuit Switching

Is packet switching a “slam dunk winner”?

- great for “bursty” data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees traditionally used for audio/video applications

Q: human analogies of reserved resources (circuit switching) versus on-demand allocation (packet switching)?

Packet Switching vs Circuit Switching – Numerical Example

- How long does it take to send a file of 640,000 bits (1 byte = 8 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

Let's work it out!

Solution:

- Each circuit has a transmission rate of (1.536 Mbps)/24 = 64 kbps
- It takes (640,000 bits)/(64 kbps) = 10 seconds to transmit the file
- To this 10 seconds we add the circuit establishment time, giving 10.5 seconds to send the file

Network Core: Packet Switching vs Circuit Switching

- Connectionless
- Designed for data
- Flexible
- Out of order, assembled at the dest
- Forward, Store & Fwd
- Network layer
- Bandwidth is saved (dynamic)
- Transmission of data – Source, routers
- Transmission delay

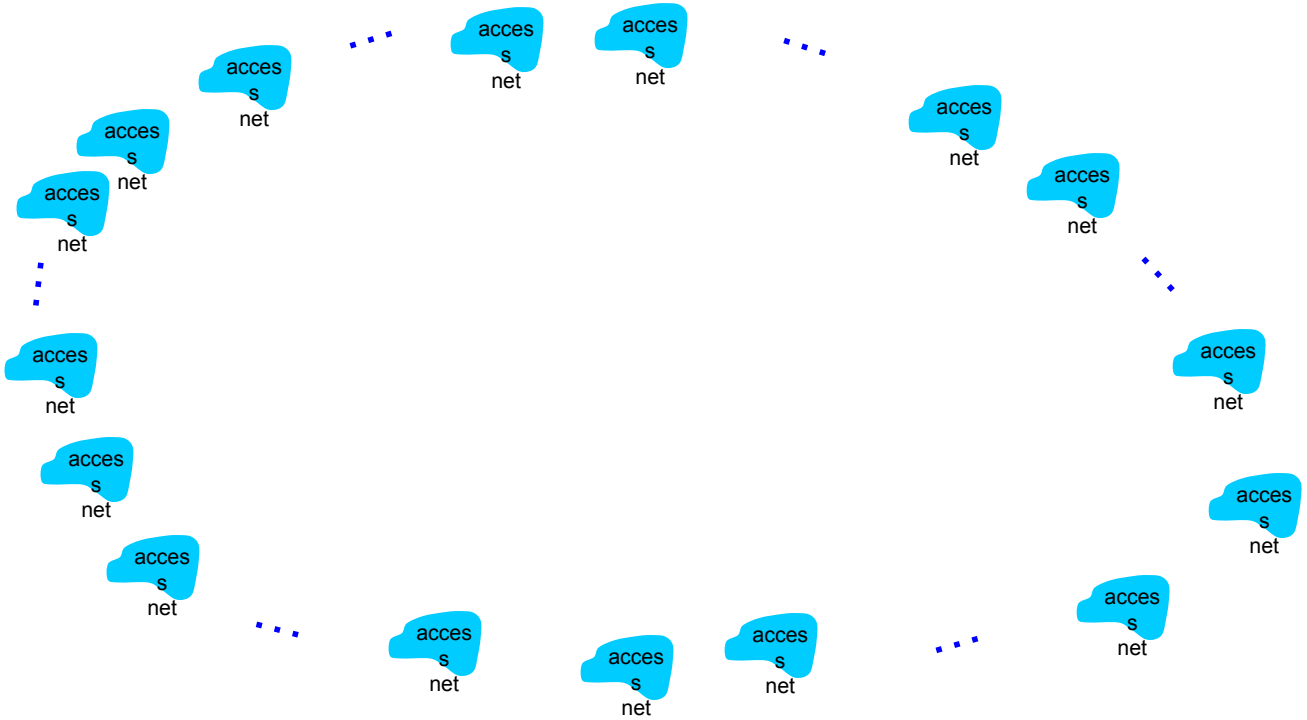
- Connection oriented
- Designed for voice
- Inflexible
- Message received in same order
- FDM & TDM
- Physical layer
- Bandwidth is wasted (fixed)
- Transmission of data – source
- Call setup delay

Internet Structure: a “network of networks”

- 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
- Let’s take a stepwise approach to describe current Internet structure

Internet Structure: a “network of networks”

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



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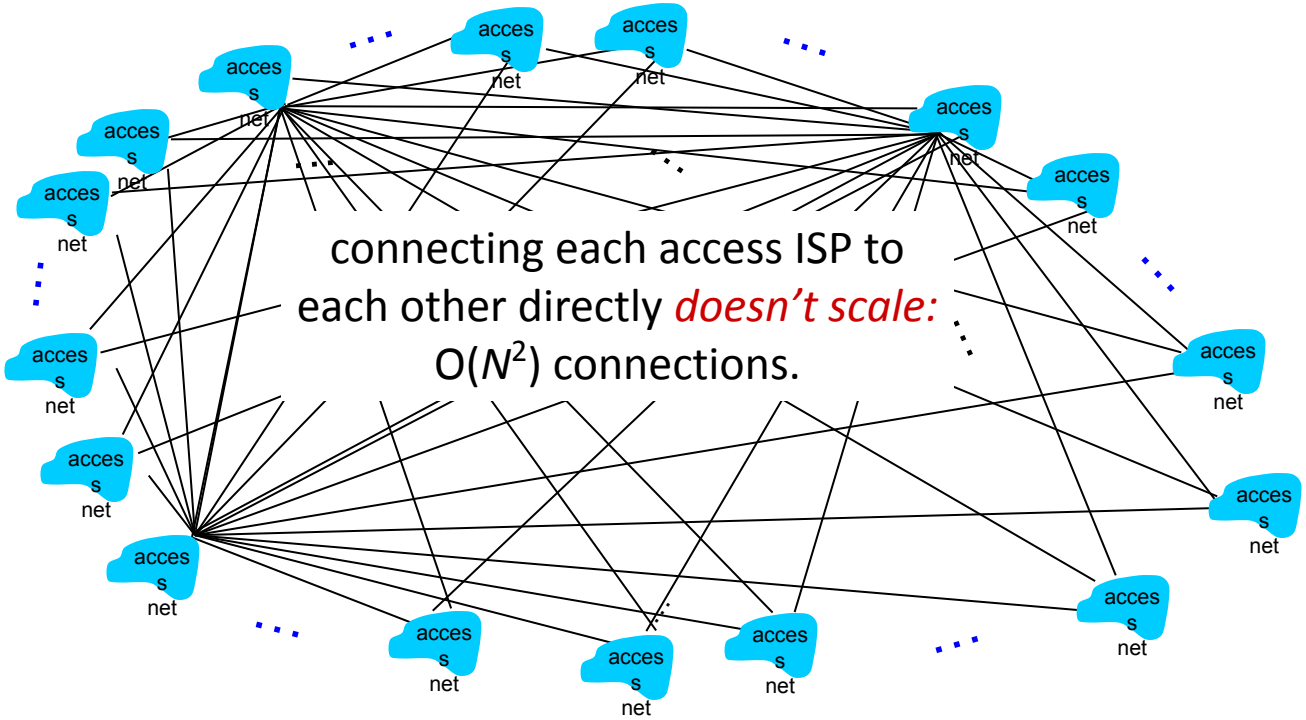
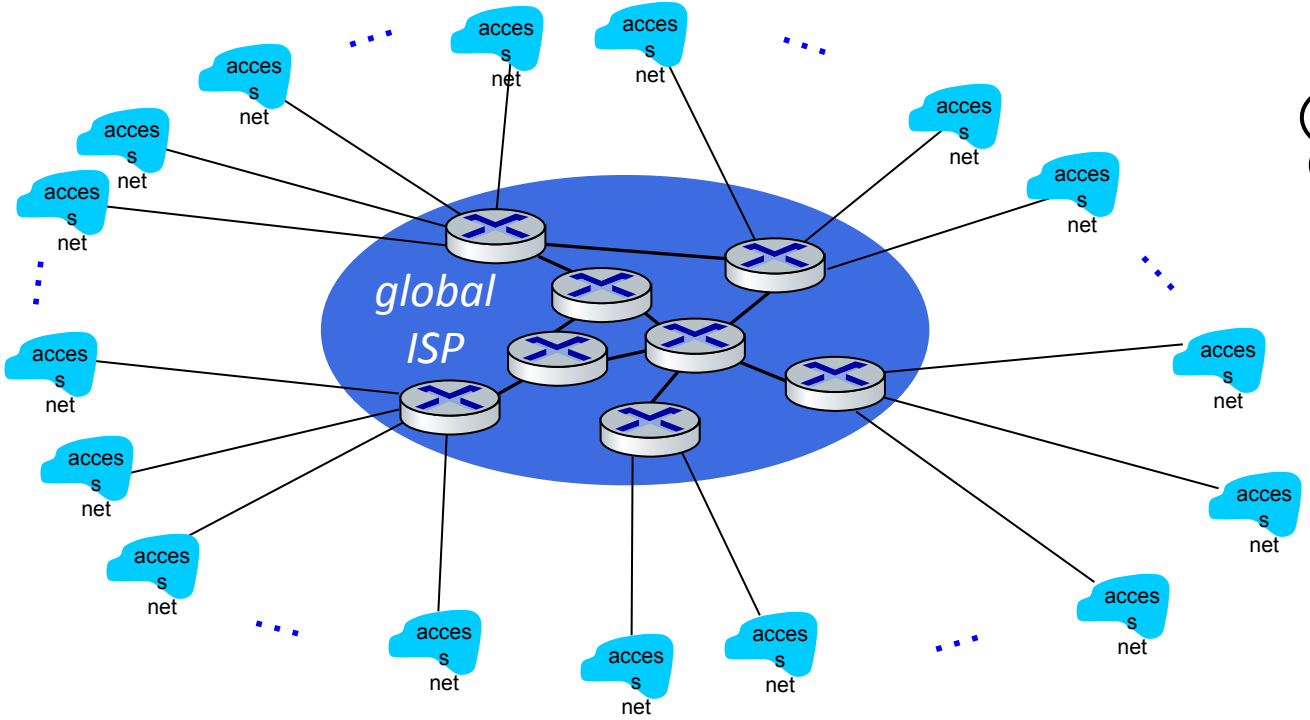
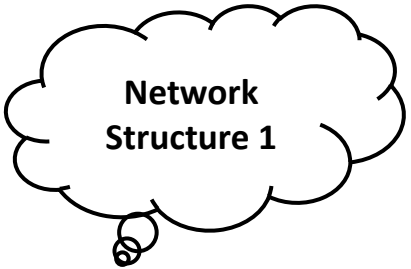


Internet Structure: a "network of networks"

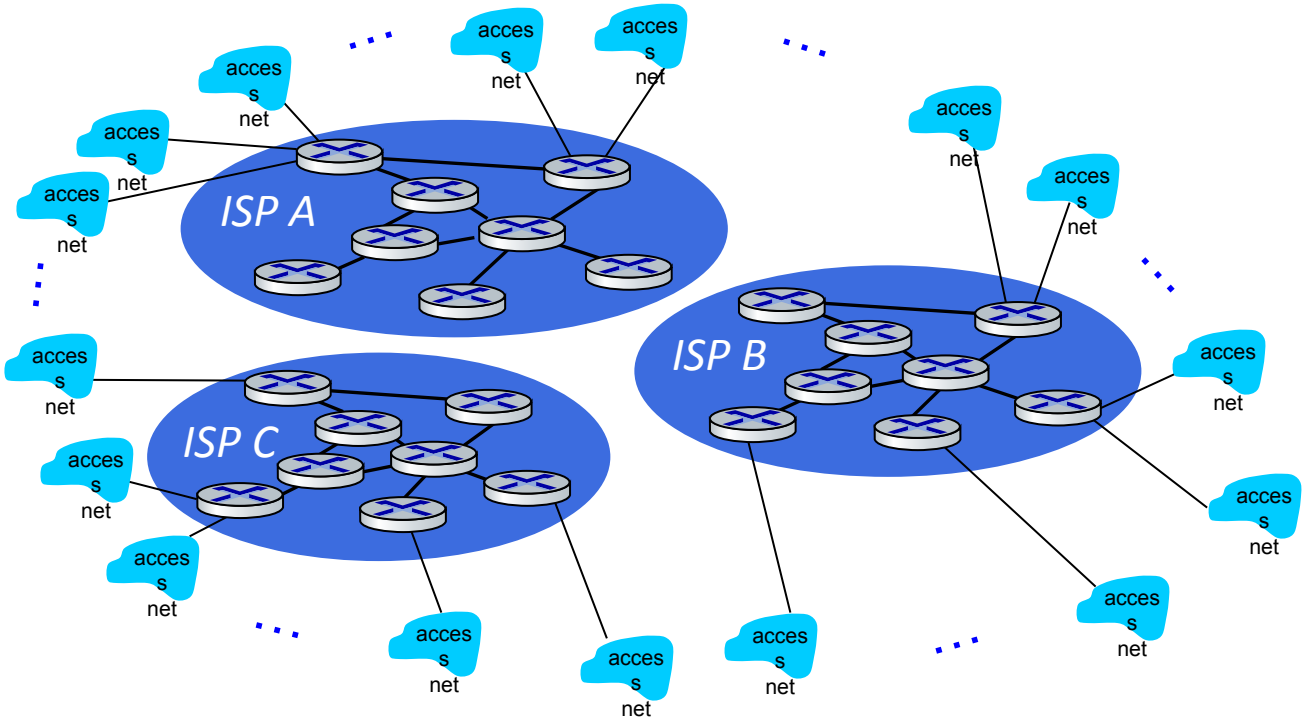
Option: connect each access ISP to one global transit ISP?
Customer and provider ISPs have economic agreement.





Internet Structure: a "network of networks"

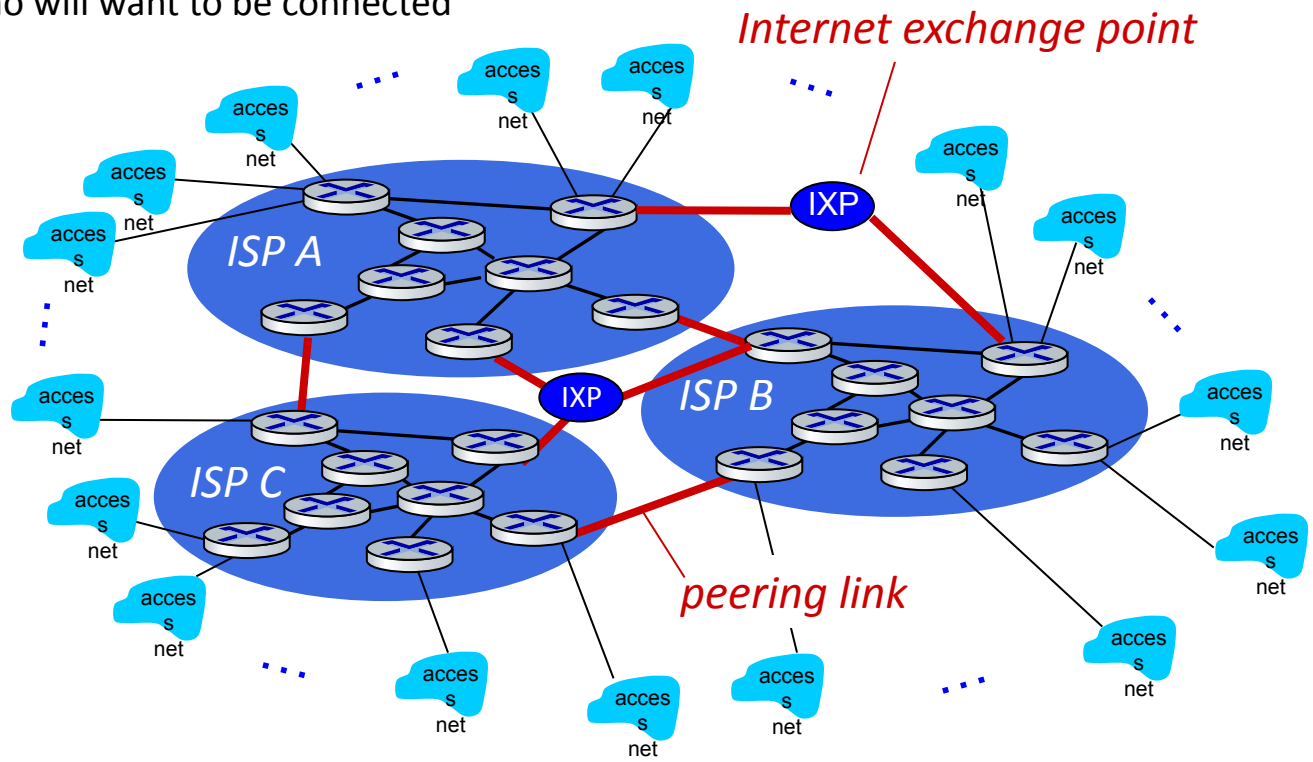
But if one global ISP is viable business, there will be competitors ….



Network Structure 2

Internet Structure: a "network of networks"

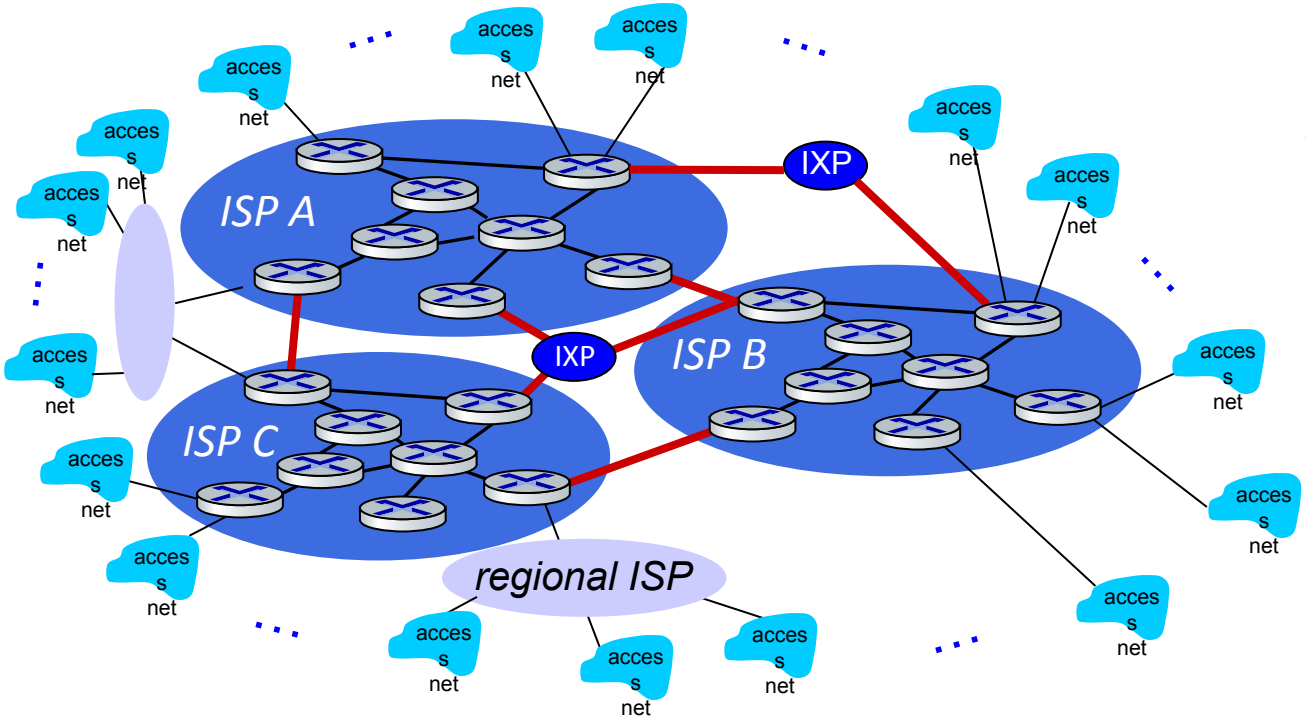
But if one global ISP is viable business, there will be competitors ….
who will want to be connected



Network Structure 3

Internet Structure: a “network of networks”

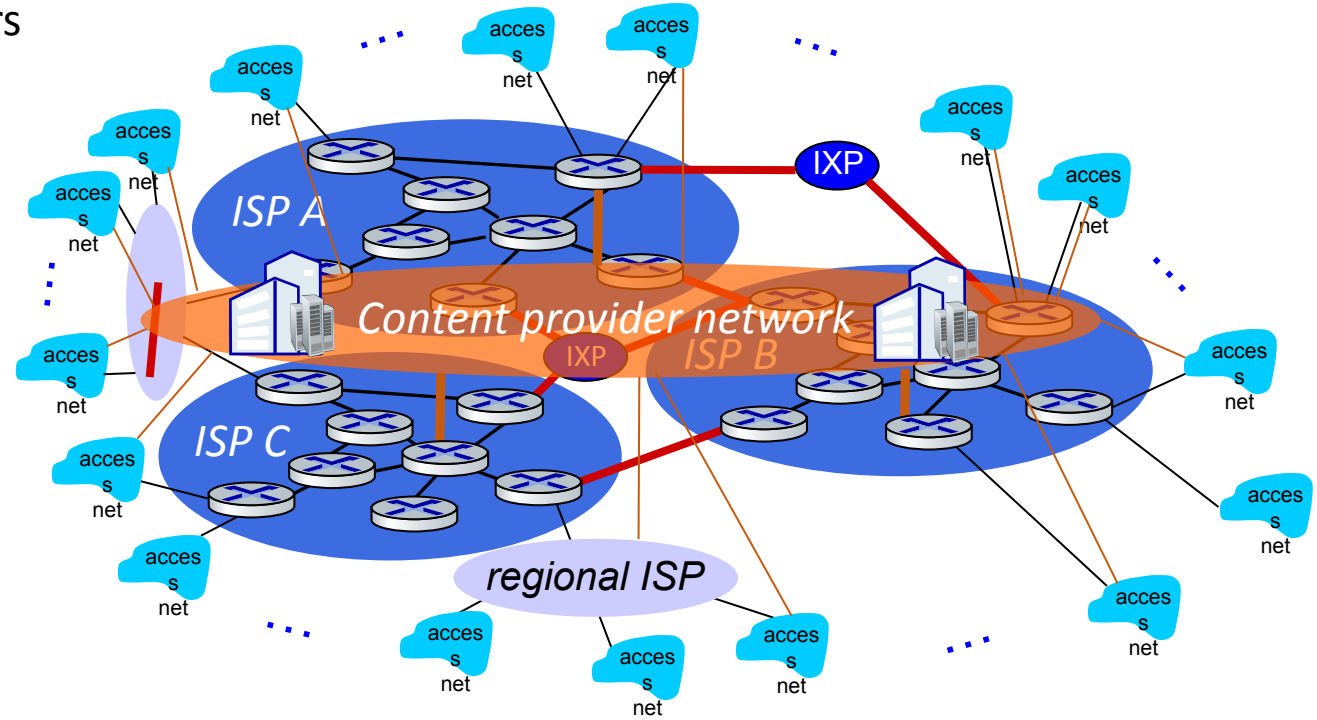
… and regional networks may arise to connect access nets to ISPs



Network Structure 4

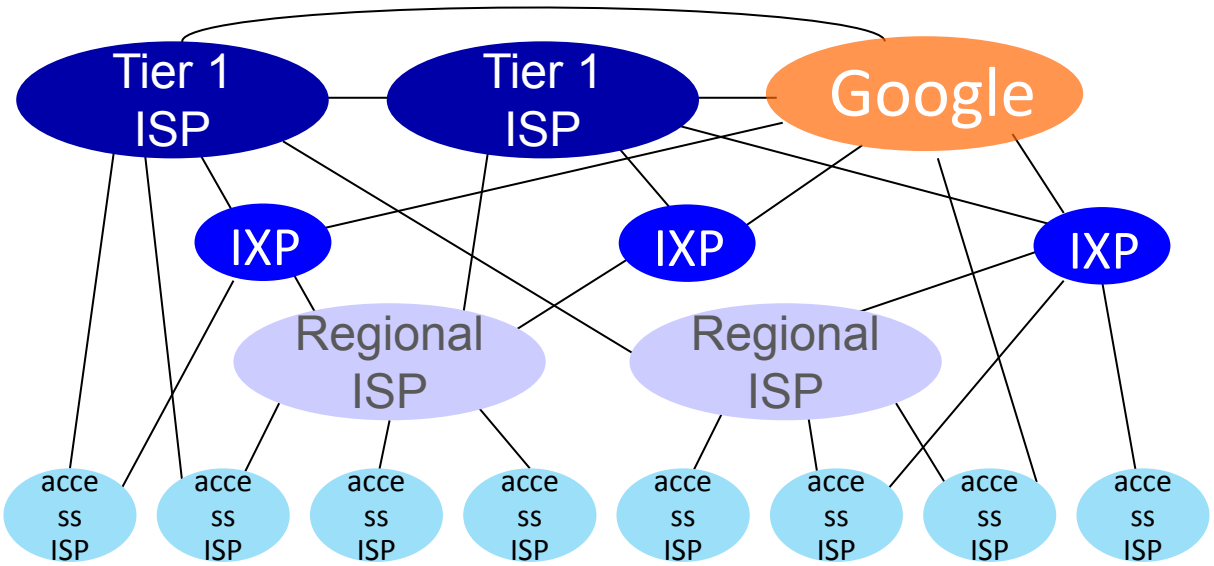
Internet Structure: a "network of networks"

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



Network Structure 5

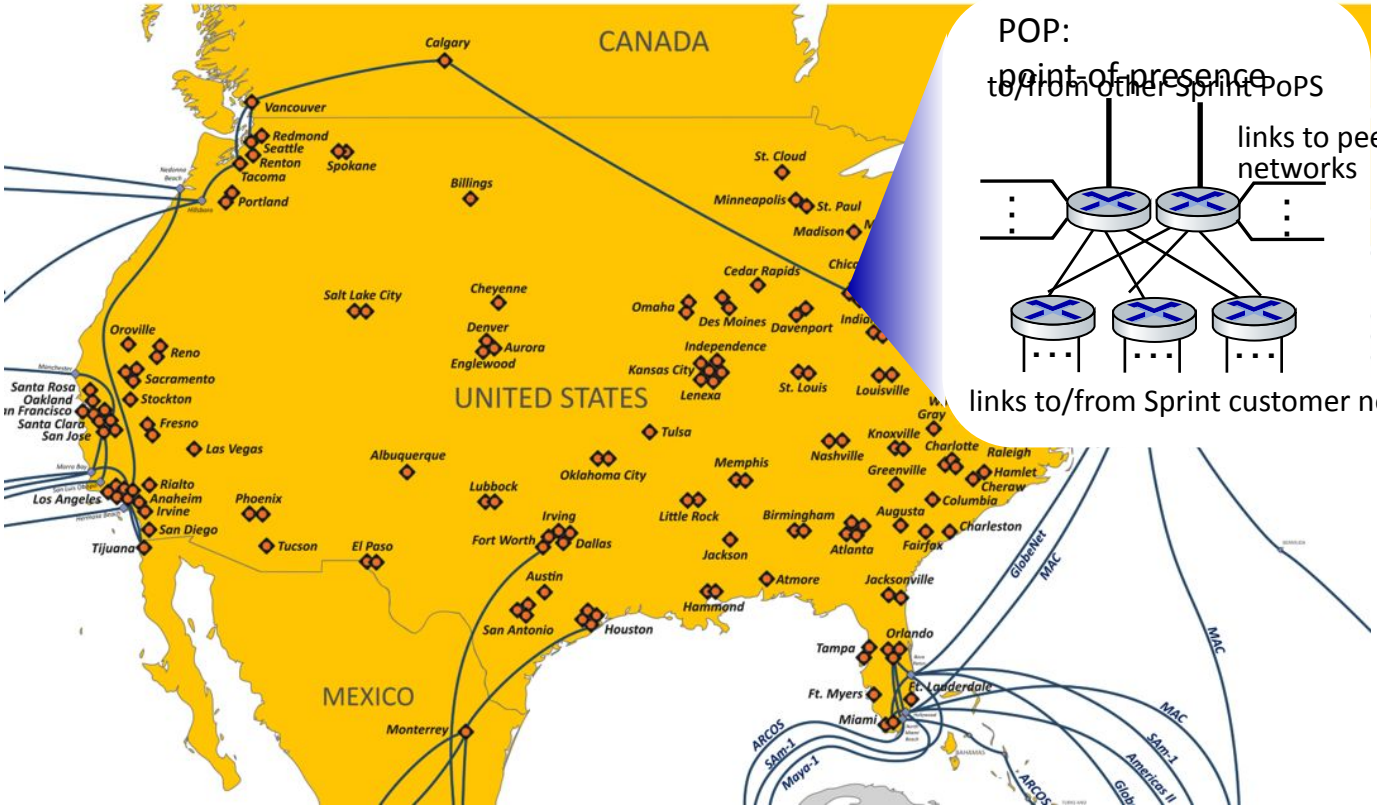
Internet Structure: a "network of networks"



At "center": small # of well-connected large networks

- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

Network Core: Tier 1 ISP Network Map: Sprint 2019



THANK YOU

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