Basic Network Organisation

A/PROF. DUY NGO

Learning Objectives

1.3 network core

- packet switching
- circuit switching
- network structure

1.4 Performance:

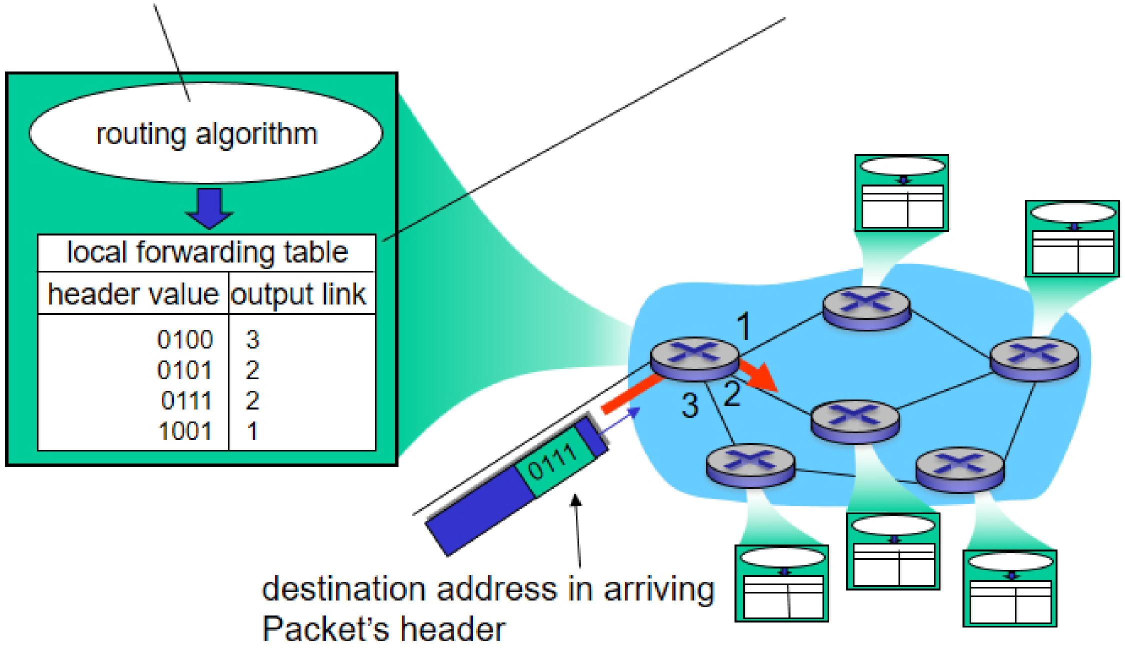
- **delay,**
- **loss,**
- **throughput in networks**

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



Alternative Core: Circuit Switching (1 of 2)

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

in diagram, each link has four circuits.

- call gets 2^{nd} circuit in top link and 1^{st} circuit in right link.

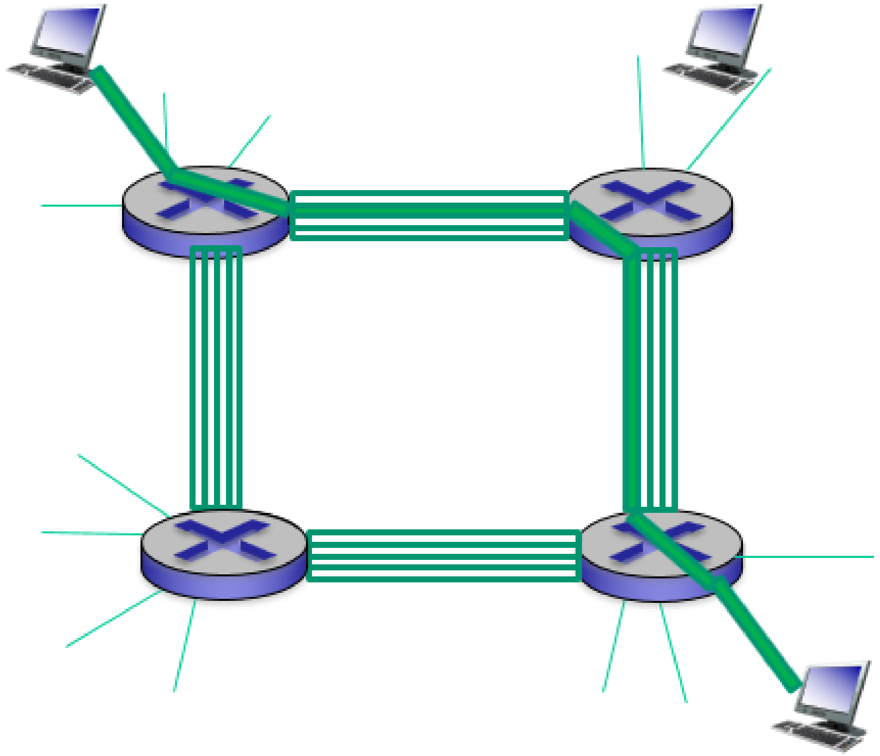
dedicated resources: no sharing

- circuit-like (guaranteed) performance

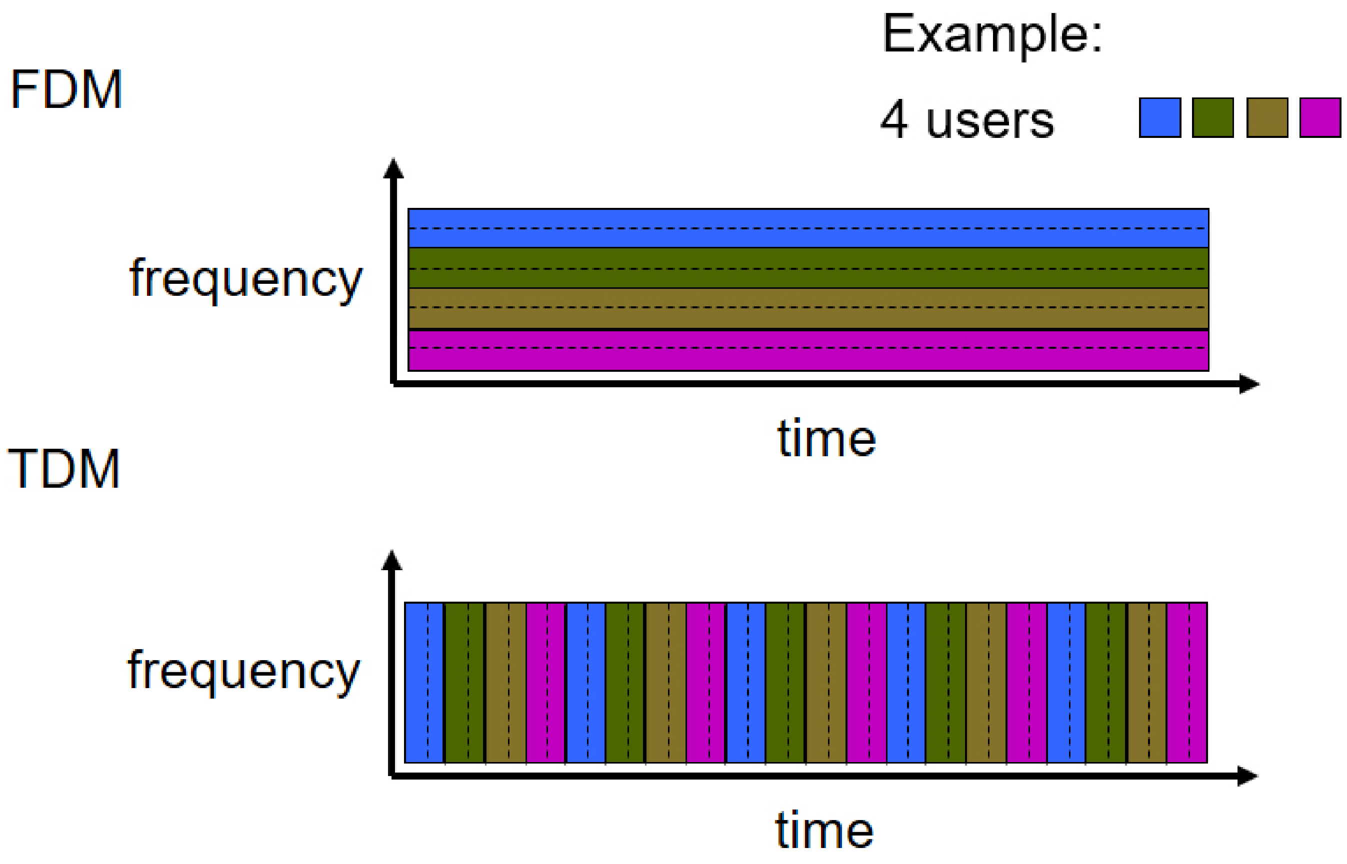
circuit segment idle if not used by call **(no sharing)**

commonly used in traditional telephone networks

Alternative Core: Circuit Switching (2 of 2)



Circuit Switching: FDM Versus TDM



Packet Switching Versus Circuit Switching (1 of 4)

packet switching allows more users to use network!

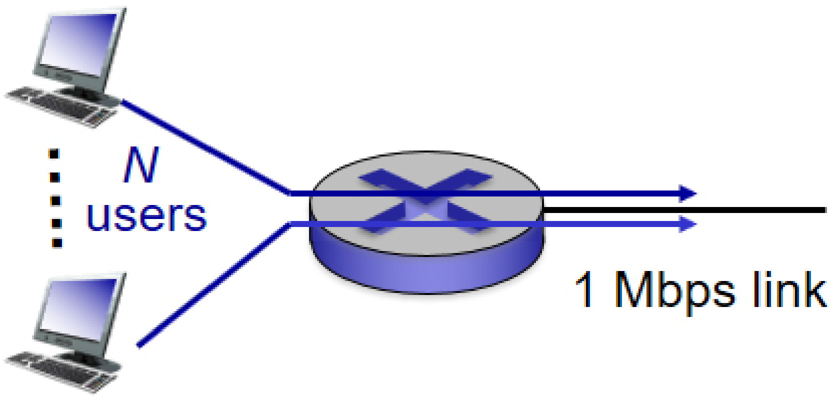
example:

- 1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time
- **circuit-switching:**
  - 10 users

Packet Switching Versus Circuit Switching (2 of 4)

packet switching:

- with 35 users, probability > 10 active at same time is less than .0004 *



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/

Packet Switching Versus Circuit Switching (3 of 4)

is packet switching a “slam dunk winner?”

- great for bursty data
  - resource sharing
  - simpler, no call setup
- **excessive congestion possible:** packet delay and loss
  - protocols needed for reliable data transfer, congestion control

Packet Switching Versus Circuit Switching (4 of 4)

- **Q: How to provide circuit-like behavior?**
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 7)

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

Internet Structure: Network of Networks (1 of 10)

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

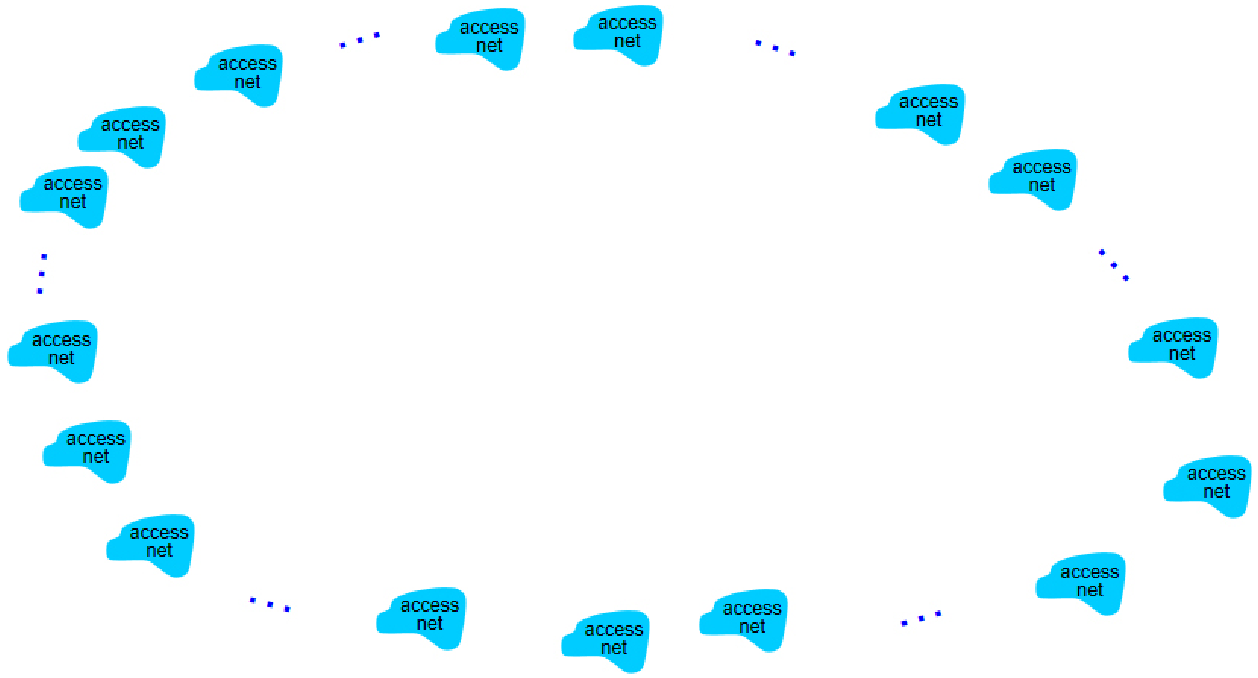
Resulting network of networks is very complex

- evolution was driven by **economics** and **national policies**

Let's take a stepwise approach to describe current Internet structure

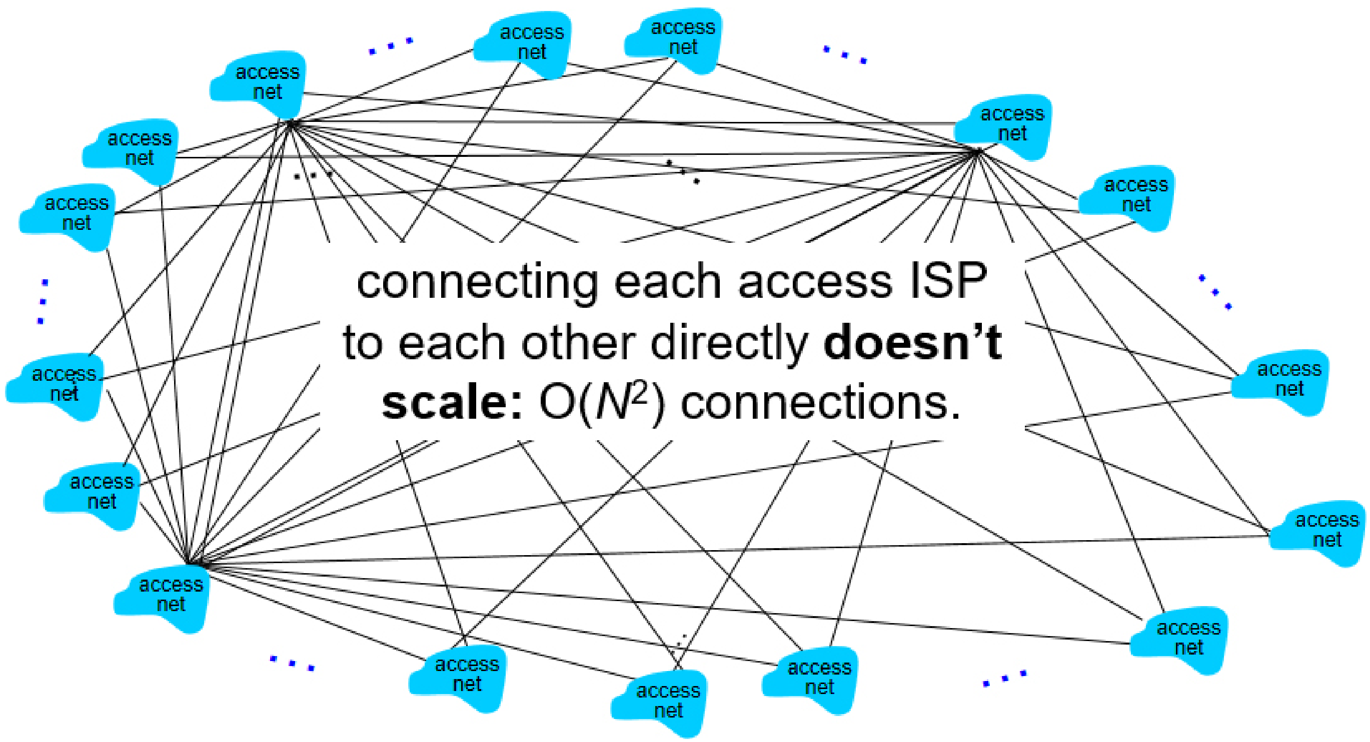
Internet Structure: Network of Networks (2 of 10)

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



Internet Structure: Network of Networks (3 of 10)

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

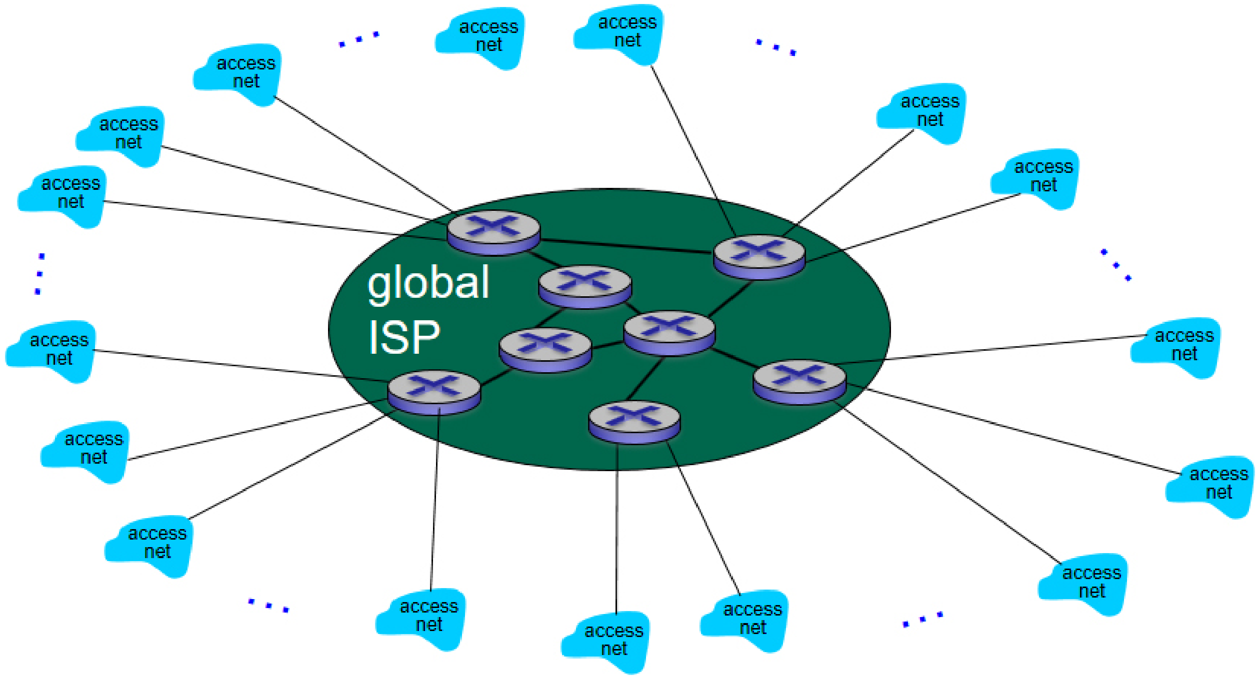


connecting each access ISP to each other directly **doesn't scale:** O(N^2) connections.

Internet Structure: Network of Networks (4 of 10)

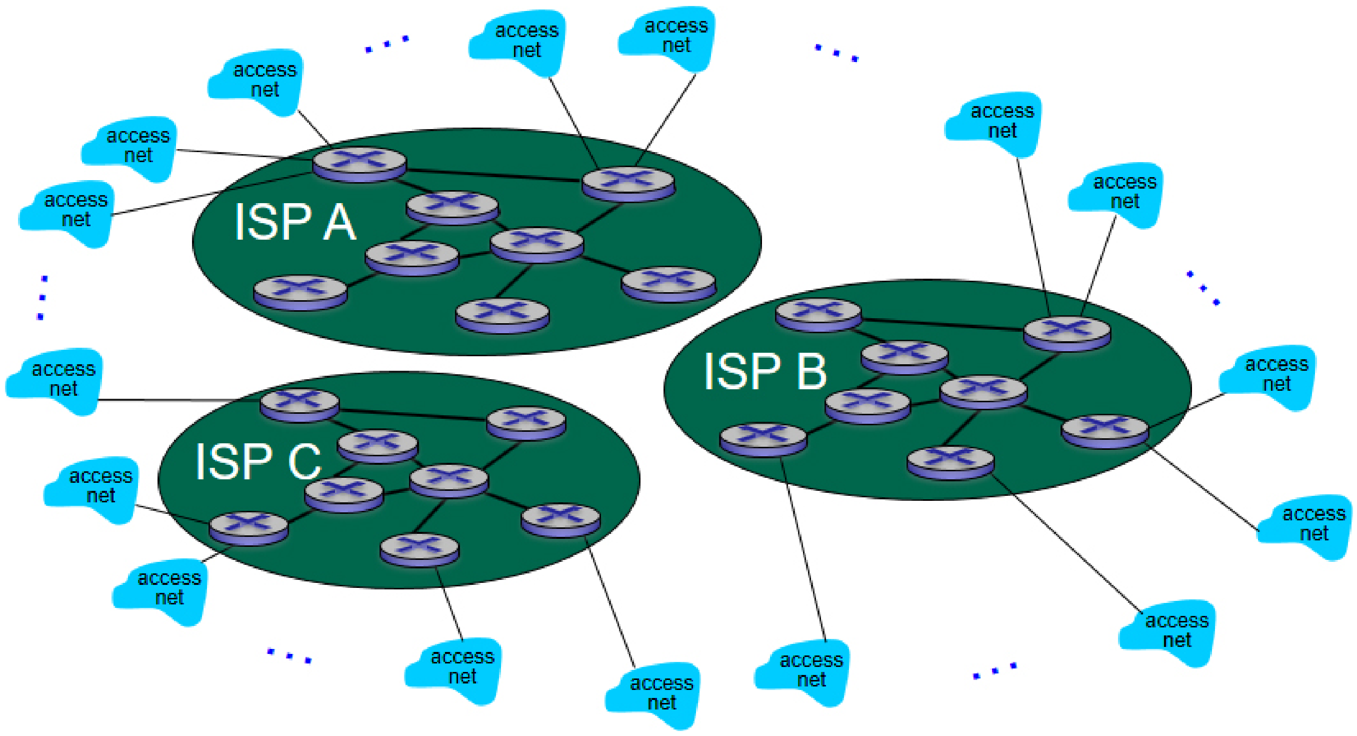
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



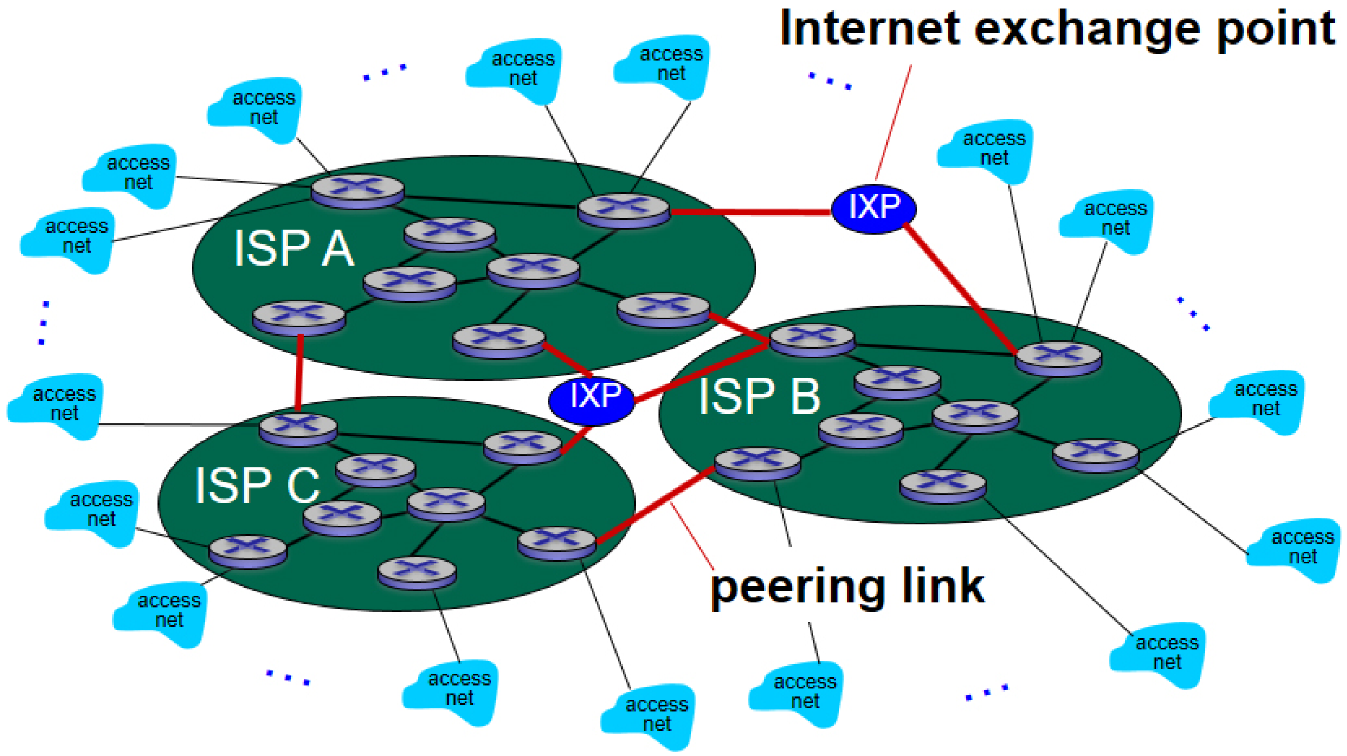
Internet Structure: Network of Networks (5 of 10)

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



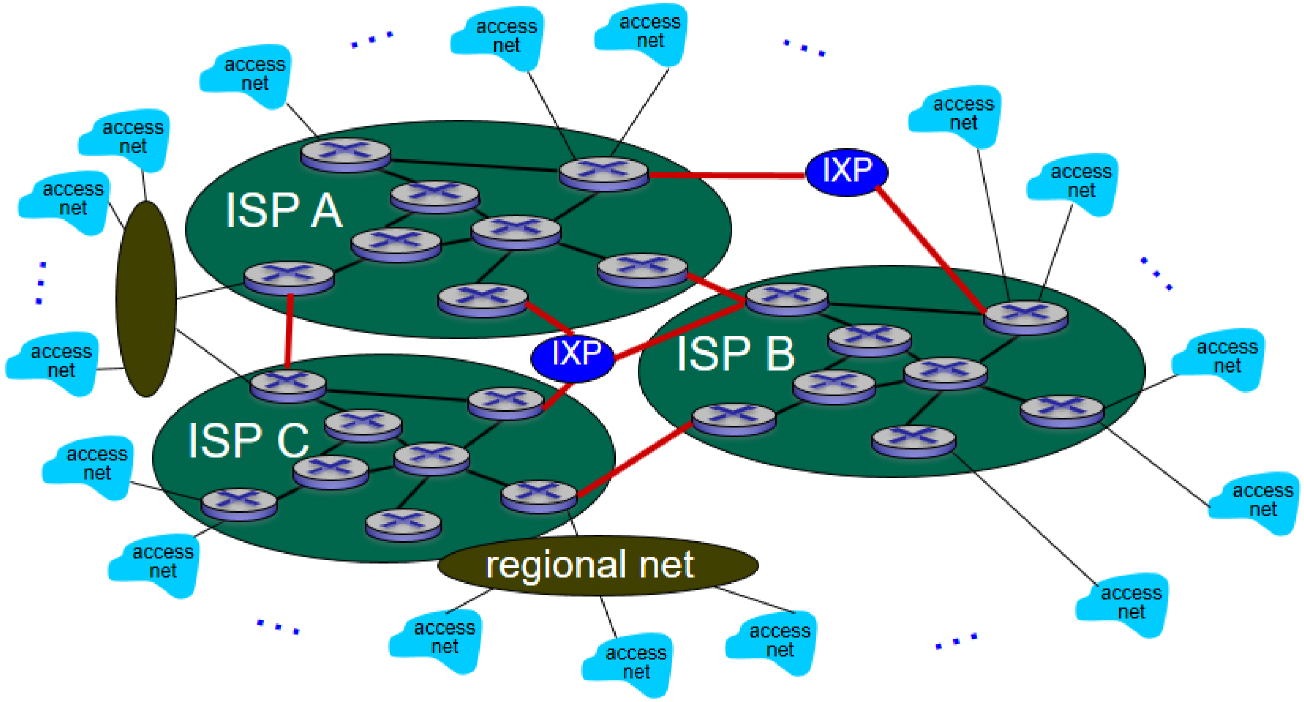
Internet Structure: Network of Networks (6 of 10)

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



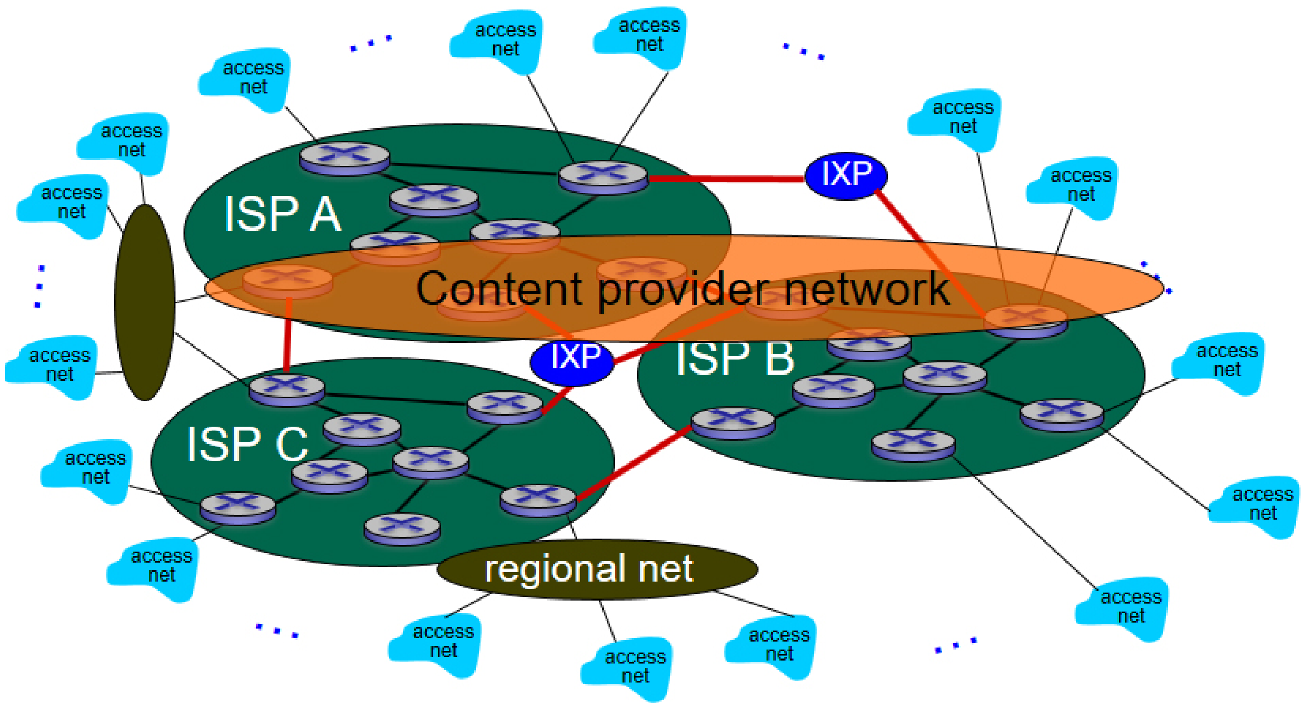
Internet Structure: Network of Networks (7 of 10)

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

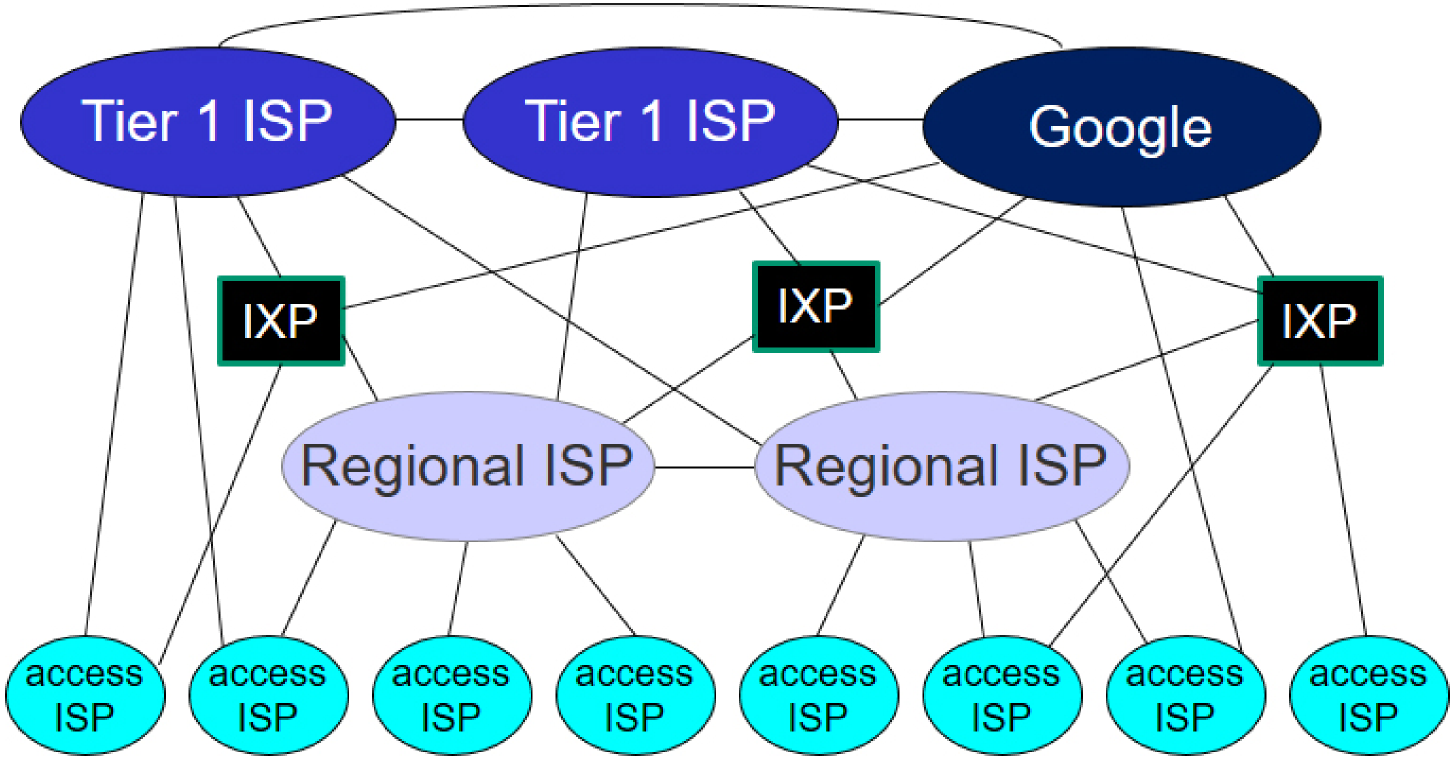


Internet Structure: Network of Networks (8 of 10)

… 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 (9 of 10)

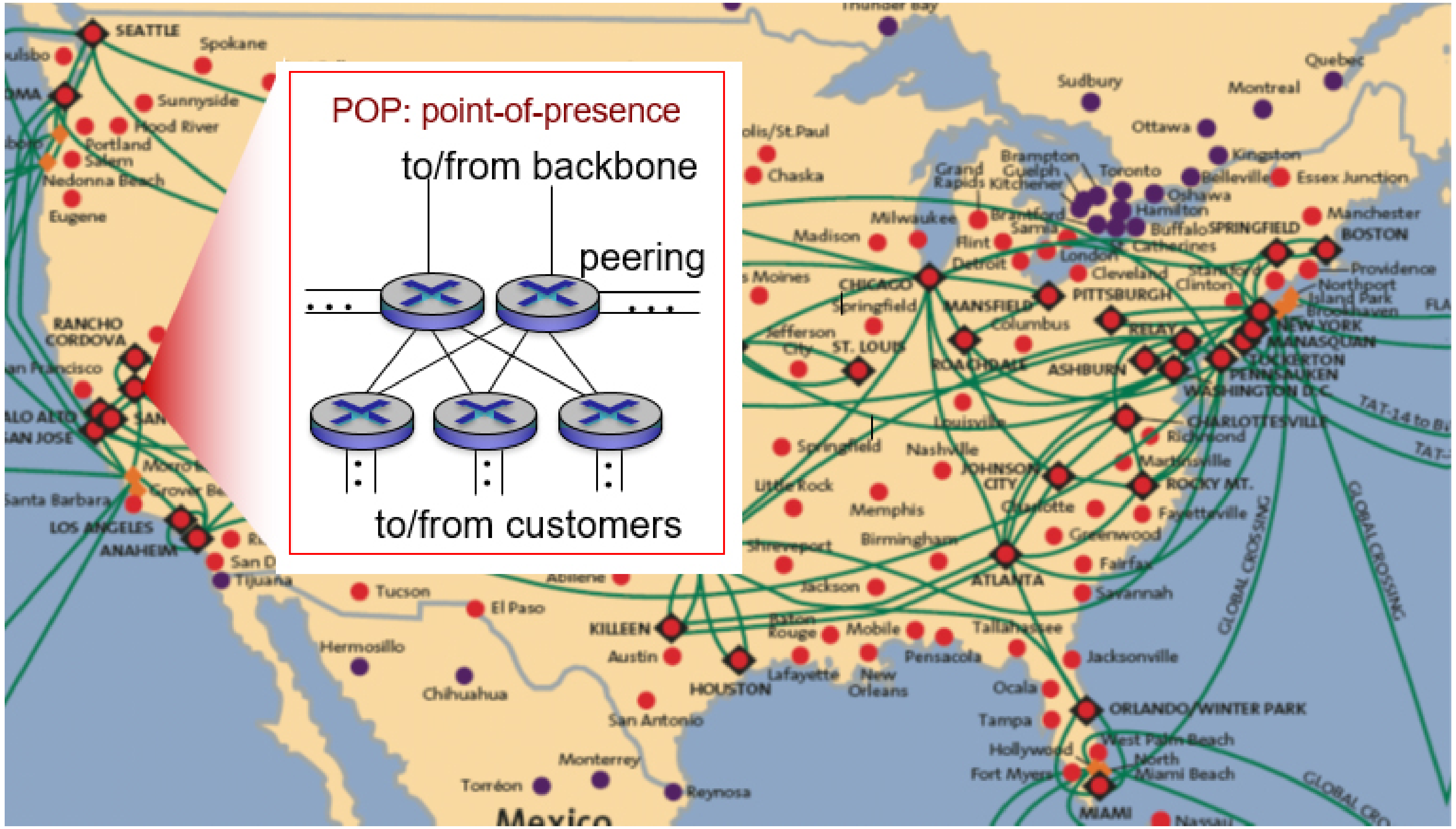


Internet Structure: Network of Networks (10 of 10)

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 network** (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

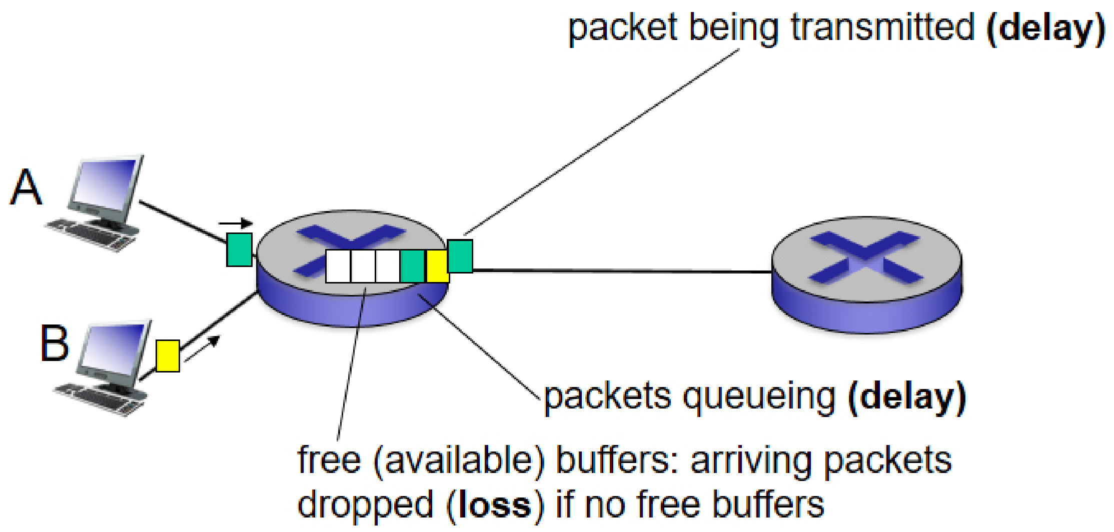
Tier-I ISP: e.g., Sprint



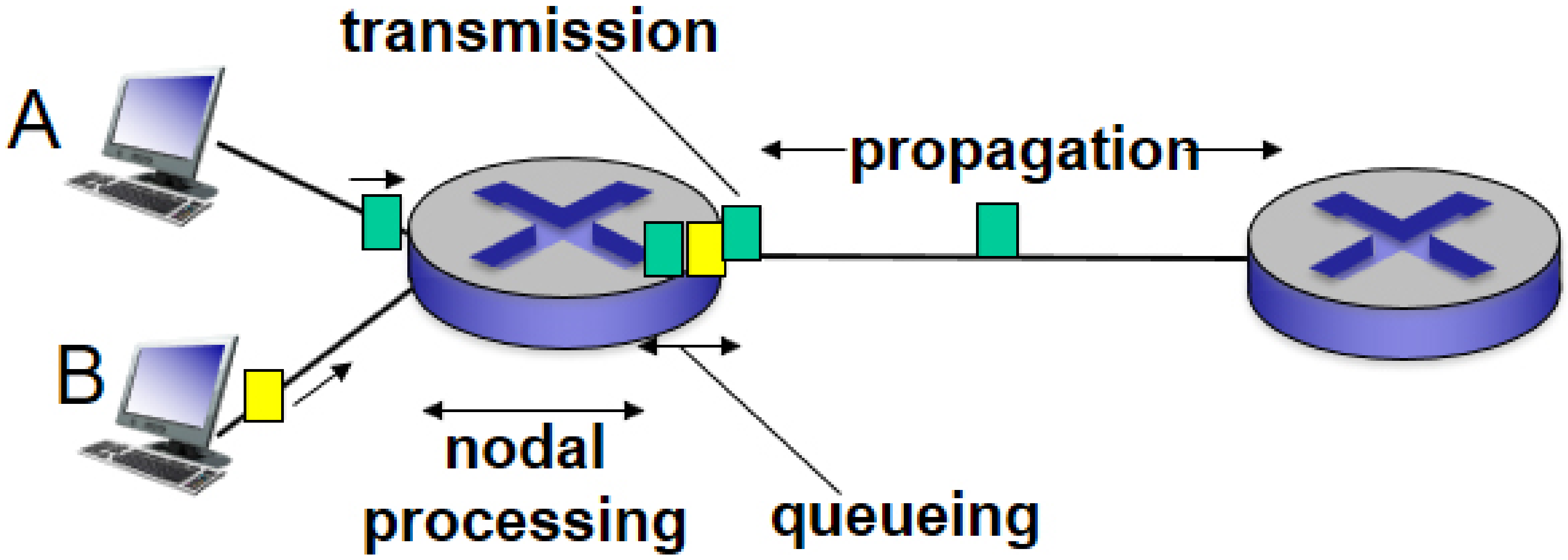
How Do Loss and Delay Occur?

packets **queue** in router buffers

- **packet arrival rate to link (temporarily) exceeds output link capacity**
- packets queue, wait for turn



Four Sources of Packet Delay (1 of 4)



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

Four Sources of Packet Delay (2 of 4)

d_{proc}: nodal processing

check bit errors

determine output link

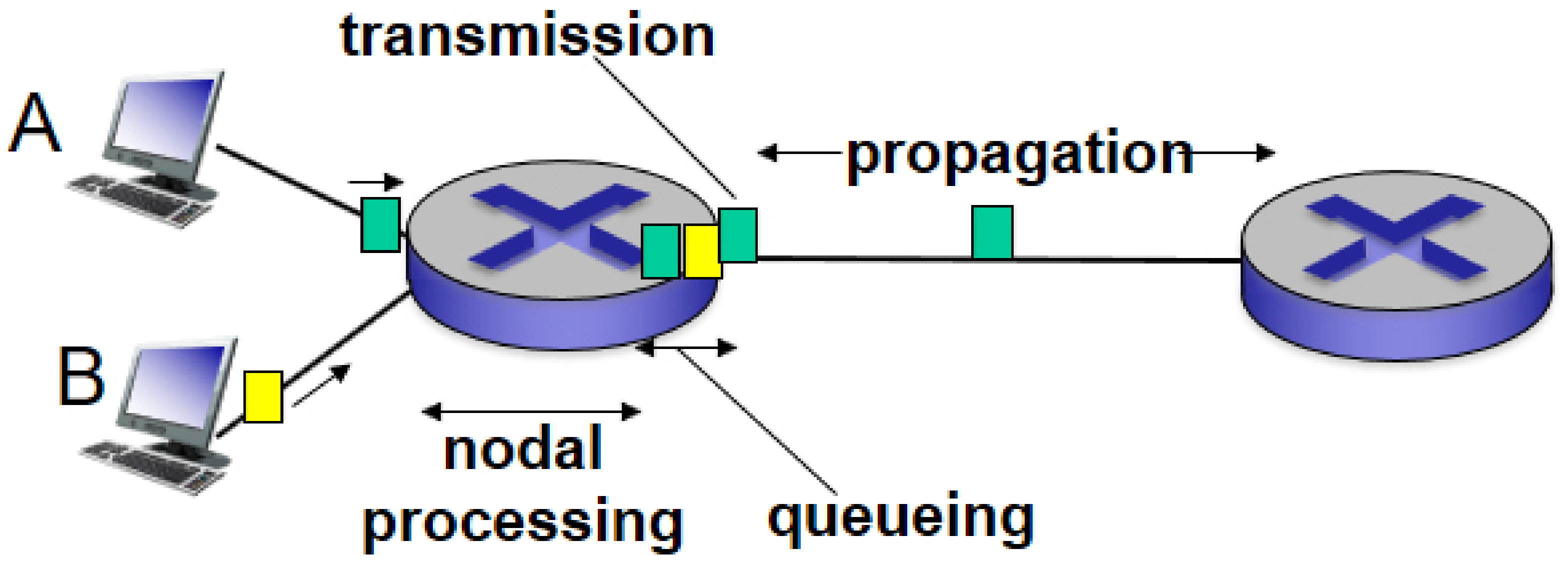
typically < msec

d_{queue}: queueing delay

time waiting at output link for transmission

depends on congestion level of router

Four Sources of Packet Delay (3 of 4)



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

Four Sources of Packet Delay (4 of 4)

d_{trans}: transmission delay:

L: packet length (bits)

R: link **bandwidth (bps)**

- $d_{trans} = \frac{L}{R} \leftarrow d_{trans}$ and $d_{prop} \rightarrow$ very different

d_{prop}: propagation delay:

d: length of physical link

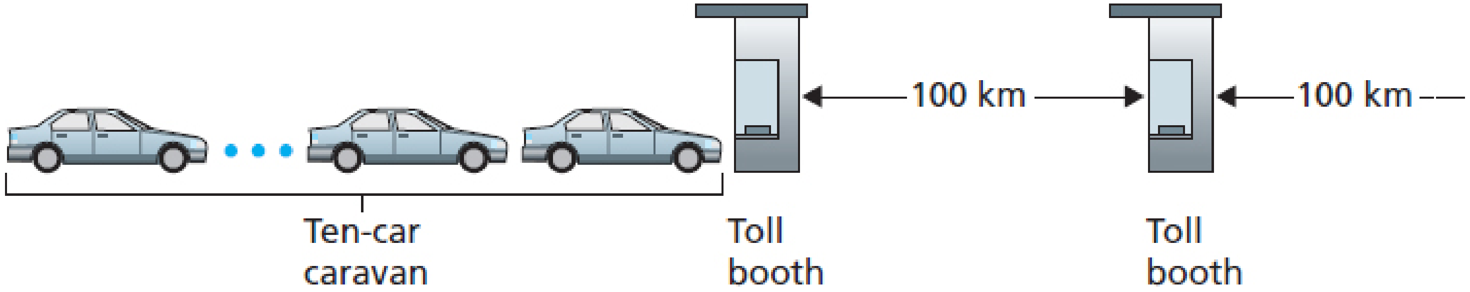
s: propagation speed $\left(\sim 2 \times 10^8 \frac{\text{m}}{\text{sec}}\right)$

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

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

* Check out the Java applet for an interactive animation on trans vs prop delay

Caravan Analogy (1 of 3)



cars "propagate" at $100 \dfrac{km}{hr}$

toll booth takes 12 sec to service car (bit transmission time)

car ~ bit; caravan ~ packet

Q: How long until caravan is lined up before 2nd toll booth?

Caravan Analogy (2 of 3)

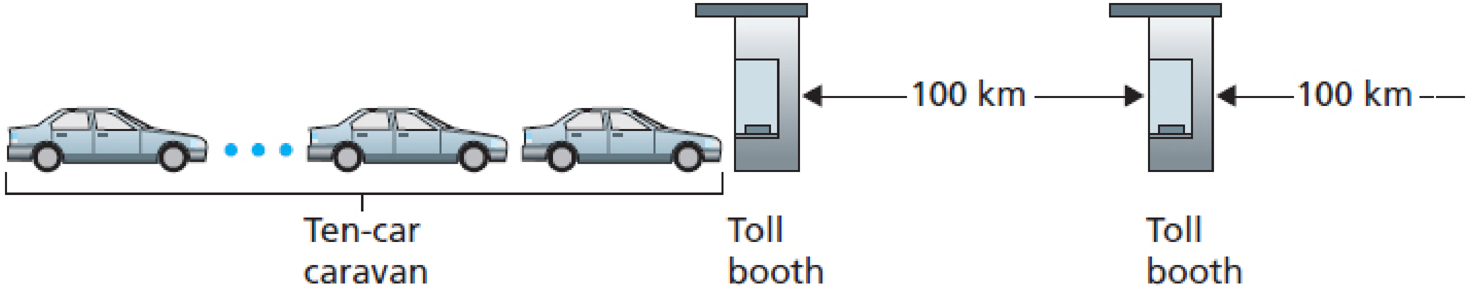
time to “push” entire caravan through toll booth onto highway = $12 \times 10 = 120$ sec

time for last car to propagate from 1st to 2nd toll both:

$$\frac{100\text{km}}{\left(\frac{100\text{km}}{\text{hr}}\right)} = 1\text{hr}$$

A: 62 minutes

Caravan Analogy (3 of 3)



suppose cars now "propagate" at $\frac{1000\,km}{hr}$

and suppose toll booth now takes one min to service a car

Q: Will cars arrive to 2nd booth before all cars serviced at first booth?

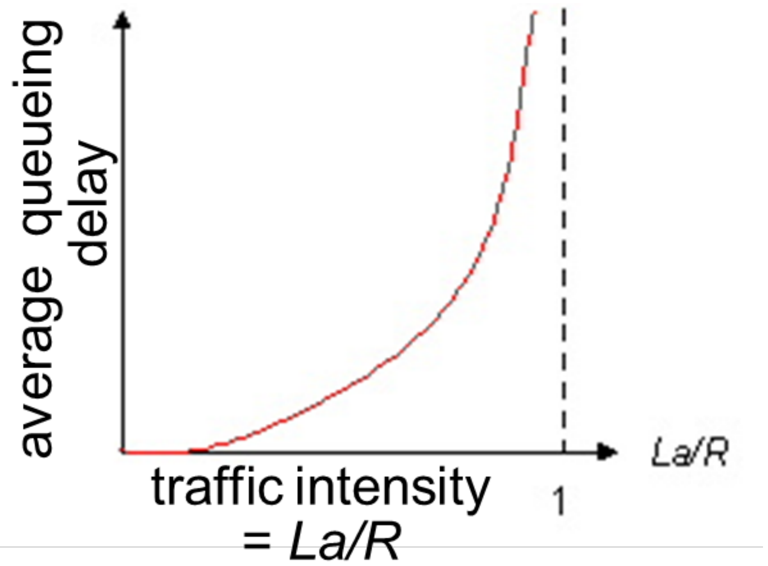
- **A: Yes!** after 7 min, first car arrives at second booth; three cars still at first booth

Queueing Delay (Revisited) (1 of 2)

R: link bandwidth (bps)

L: packet length (bits)

a: average packet arrival rate



Queueing Delay (Revisited) (2 of 2)

$\frac{La}{R} \sim 0$: avg. queueing delay small

$\frac{La}{R} -> 1$: avg. queueing delay large

$\frac{La}{R} > 1$: more "work" arriving

than can be serviced, average delay infinite!

$\frac{La}{R} \sim 0$

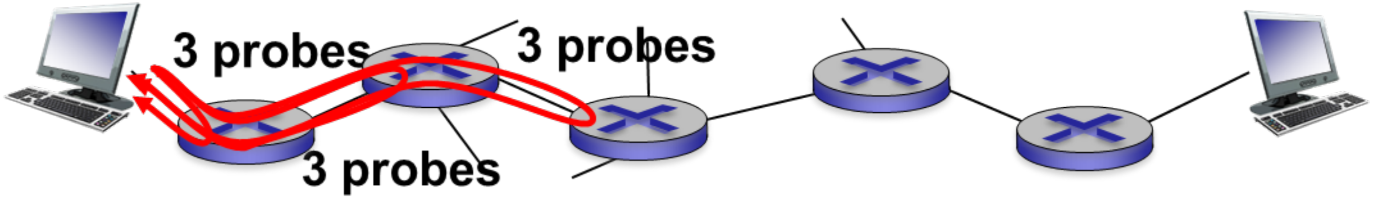
$\frac{La}{R} -> 1$

"Real" Internet Delays and Routes

what do "real" Internet delay & loss look like?

traceroute program: provides delay measurement from source to router along end-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.



"Real" Internet Delays, Routes

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

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

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (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  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 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  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 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

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

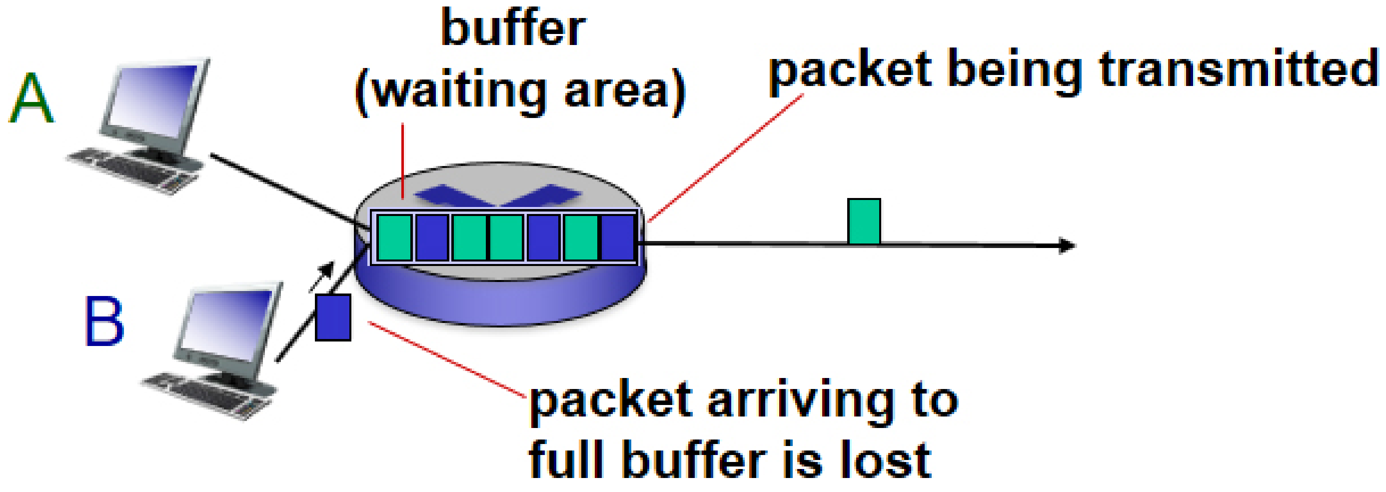
* Do some traceroutes from exotic countries at www.traceroute.org

Packet Loss

queue (aka buffer) preceding link in buffer has finite capacity

packet arriving to full queue dropped (aka lost)

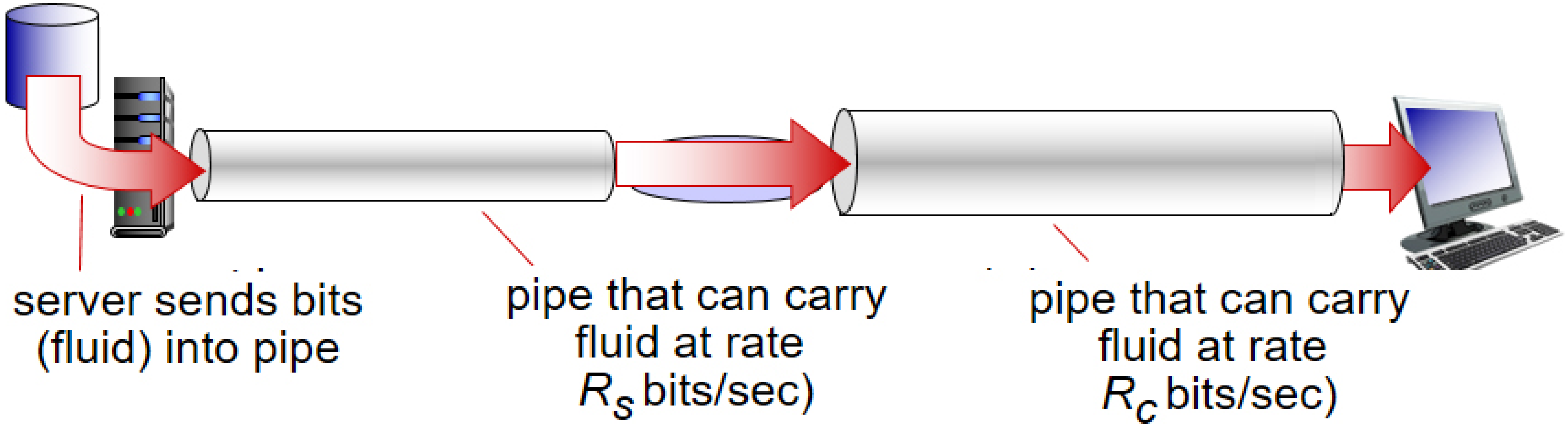
lost packet may be retransmitted by previous node, by source end system, or not at all



Throughput (1 of 2)

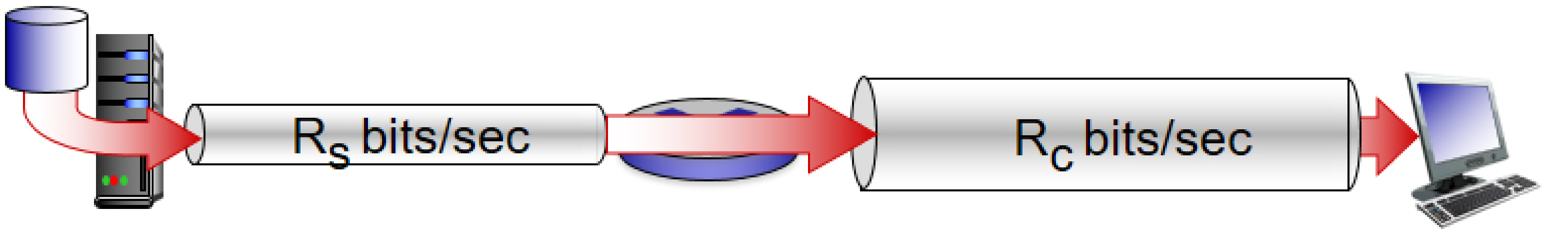
throughput: rate (bits/time unit) at which bits transferred between sender/receiver

- **instantaneous:** rate at given point in time
- **average:** rate over longer period of time

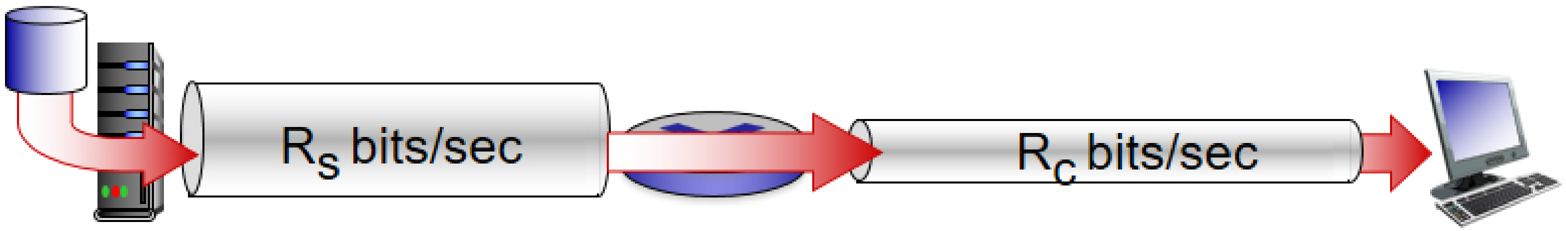


Throughput (2 of 2)

R_s < R_c What is average end-end throughput?



R_s > R_c What is average end-end throughput?



bottleneck link

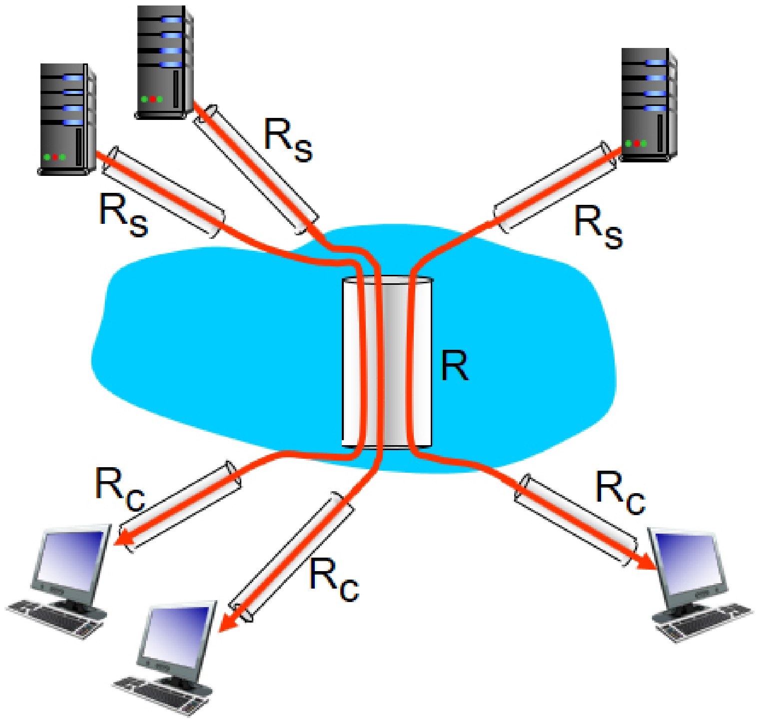
link on end-end path that constrains end-end throughput

Throughput: Internet Scenario

per-connection end-end throughput:

$$min\left(\frac{R_c, R_s, R}{10}\right)$$

- in practice: R_c or R_s is often bottleneck



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

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