# Lecture 3: Internet Edge, Core, and Structure


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# Today

1. Announcements
   - Homework 1 posted, due Tuesday, Feb. 7 by 11:59p
   - Help sessions: Sun/Mon/Tues, 7-9p in Exley 638. Also virtually

2. Internet organization
   - edge vs. core
   - Internetwork: network of networks
   - IP addresses

# How do you connect to Internet?

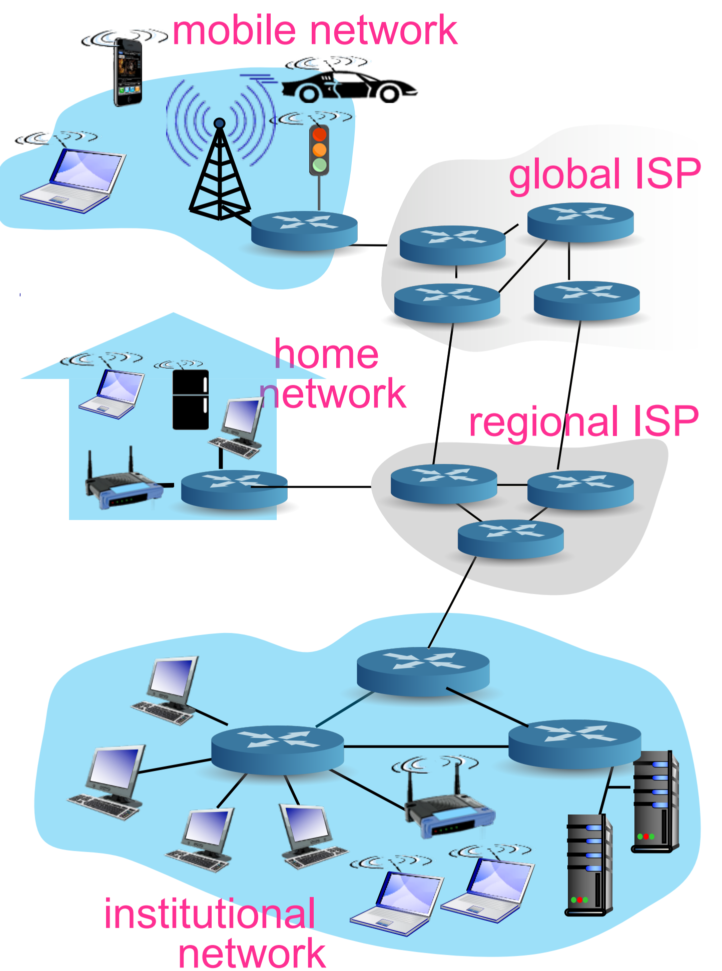
## Hosts connect to edge router

- access network/ISP

## Access networks

- **residential**
  - DSL (telephone), cable,
- **institutional**
  - school, company
- **mobile**

## Delay of getting bits into Internet?

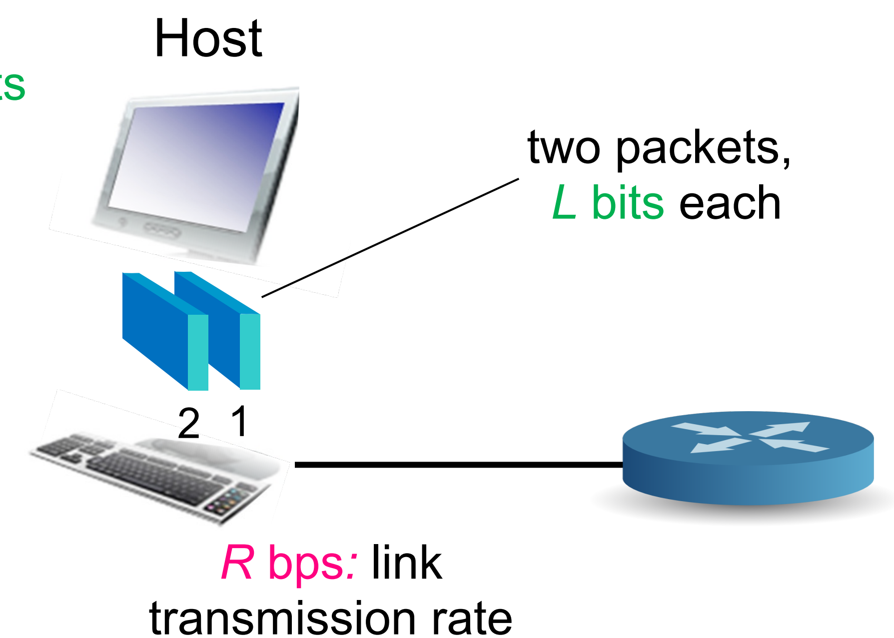



ISP: Internet Service Provider

# Host sends packets into access network

1. Given application message
   – breaks into packets
     • smaller chunks of length *L* bits

2. Transmit packets into access network
   – at transmission rate *R*
     • aka link capacity
     • aka link bandwidth




Transmission delay = Time to transmit *L*-bit packet into link = $\frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$

# Quantifying channel performance

## Delay

- time to send packet from host A to host B
  - Total Delay = **Processing** + **Transmission** + **Queu**e + **Propagation**
  - **Transmission** Delay = Packet length / Bit Rate
  - **Propagation** Delay = Distance / SpeedOfLight

- speed of light
  - $3.0 \times 10^8$ meters/second in a vacuum
  - $2.3 \times 10^8$ meters/second in a cable
  - $2.0 \times 10^8$ meters/second in a fiber

## How to compute delay accrued as packet travels through Internet?

# Internet Organization

## CORE

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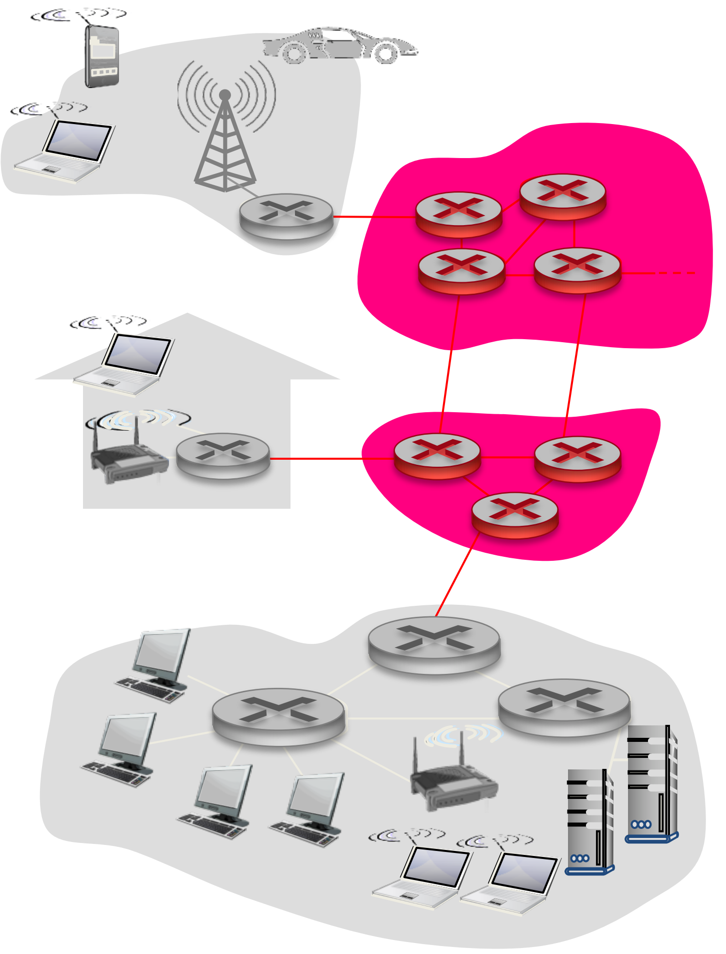
# How to move data through Internet core?

Internet core
- mesh of interconnected routers

Option 1: Packet-switching
- on-demand resource allocation
- best effort service
- good bandwidth use

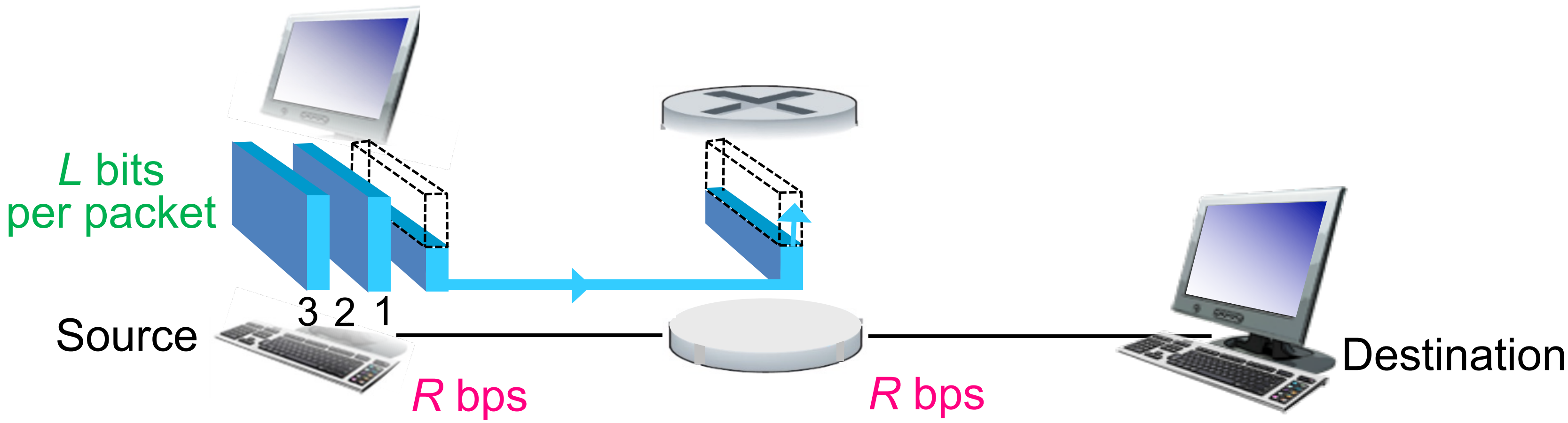
Option 2: Circuit-switching
- reserved resources
- guaranteed service
- may waste bandwidth



Q: human analogies of reserved versus on-demand allocation

# Packet switching

1. Hosts break app-layer messages into packets




2. Time to transmit (push out) *L*-bit packet into *R* bps link: *L* / *R seconds*

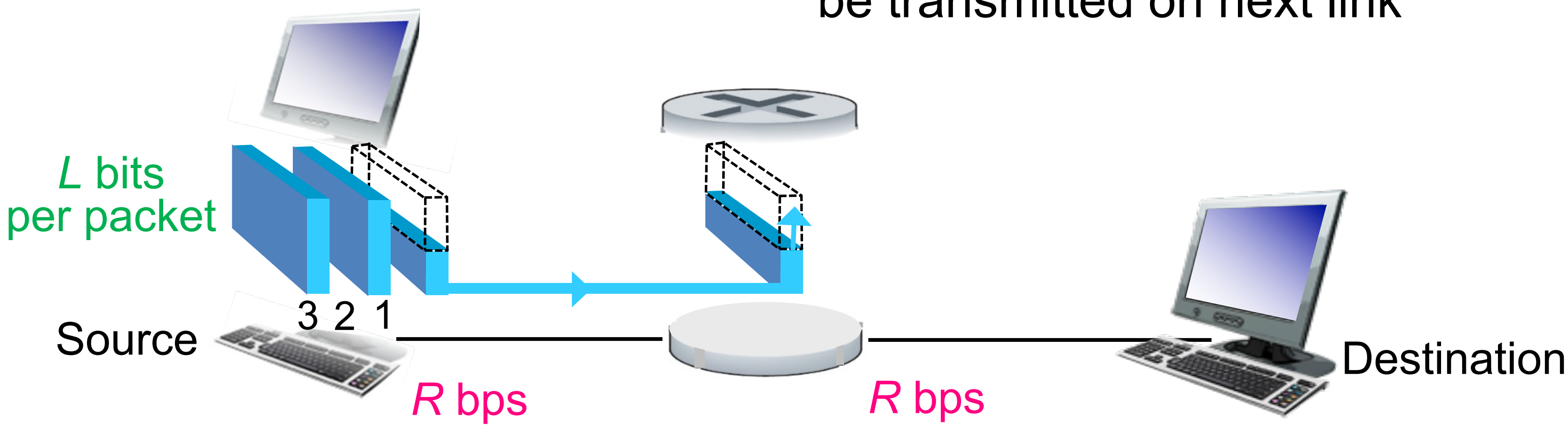
Example

- L = 7.5 Mbits
- R = 1.5 Mbps
- 1-hop transmission delay = 5s

# Packet switching

1. Hosts break app-layer messages into packets

3. Store-and-forward: entire packet must arrive at router before it can be transmitted on next link




2. Time to transmit (push out) *L*-bit packet into *R* bps link: *L* / *R* *seconds*

4. Time to transmit (push out) *L*-bit packet into *R* bps link: *L* / *R* *seconds*

**End-end transmission delay = 2 *L* / *R* *seconds***

(assuming zero propagation, queuing, processing delay… )

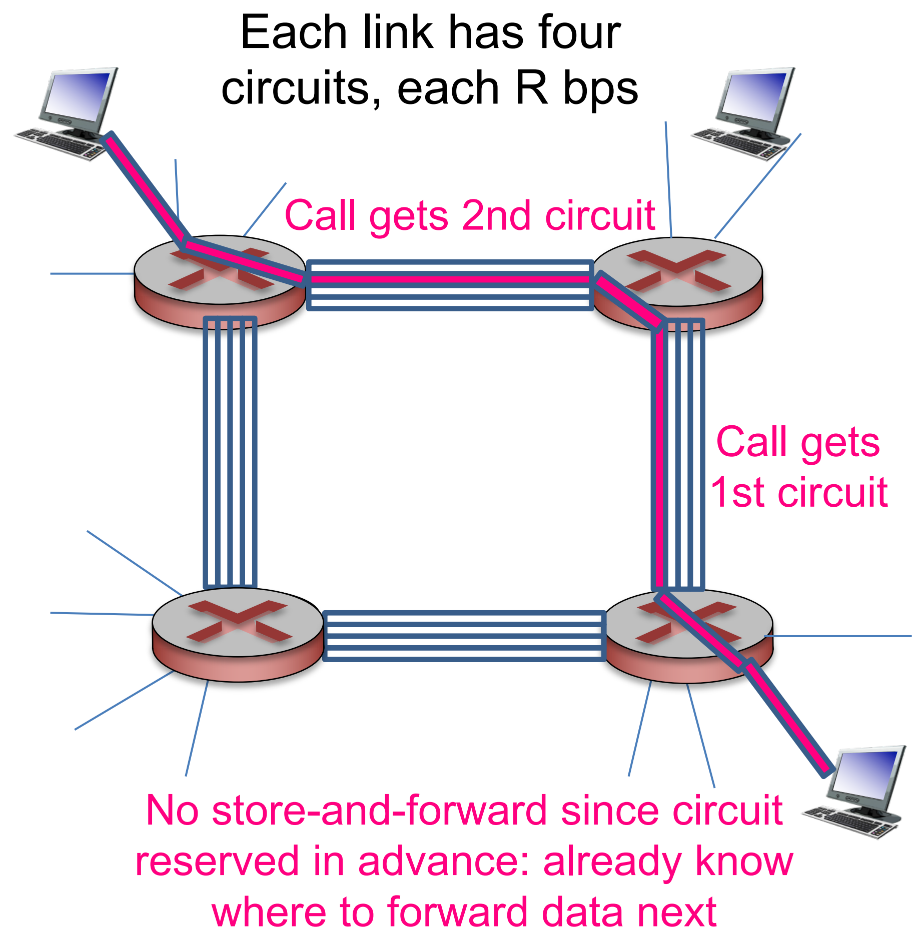
# Circuit switching

## End-end resources allocated

- reserved for "call" between source & dest
- commonly used in traditional telephone networks

## Dedicated resources

- no sharing
- circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)

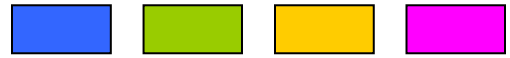


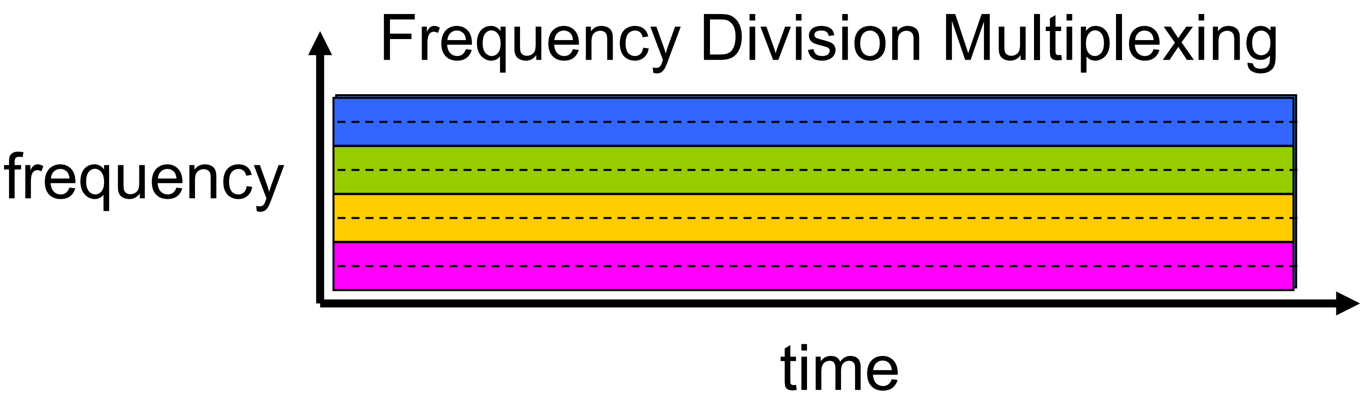

Q: what is end-end transmission delay? *L / R seconds*

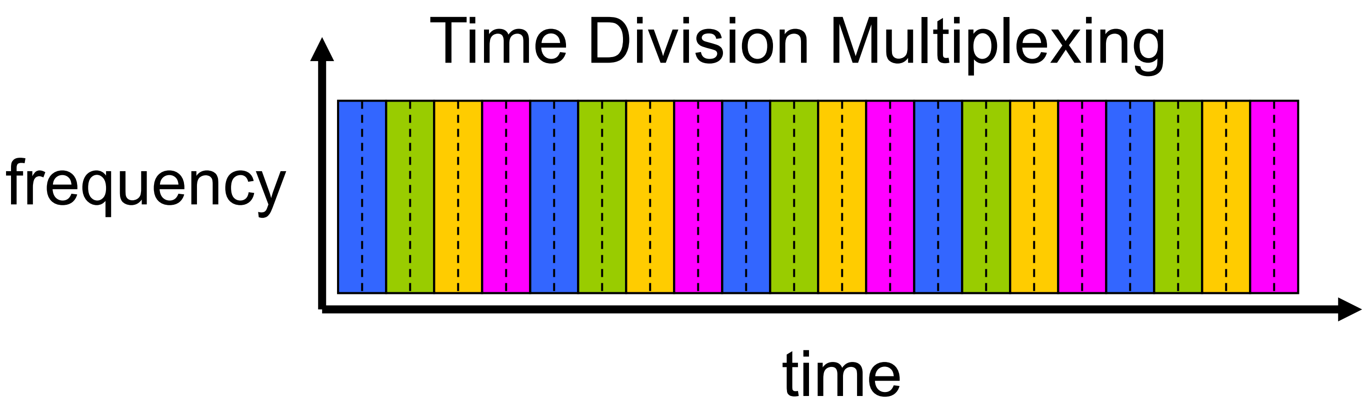
Q: what happens if there is a lull in conversation?

# Circuit switching

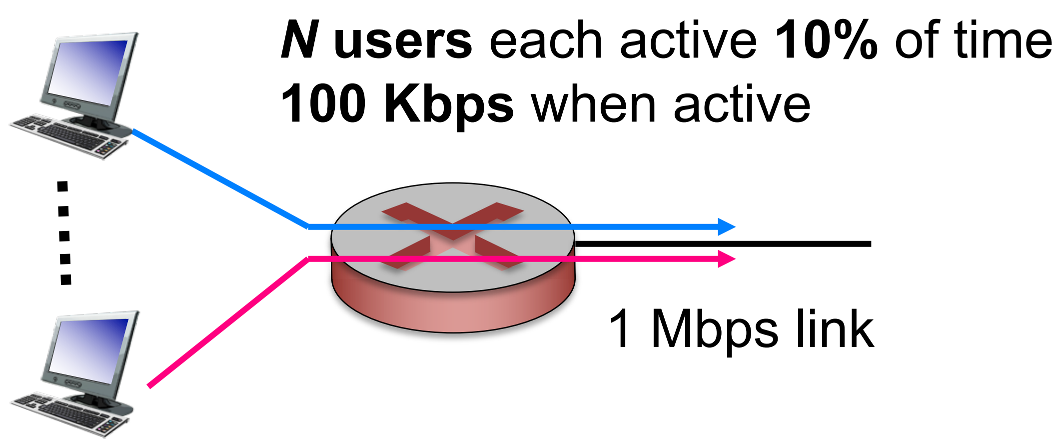
Multiplexing 4 users





# Packet switching versus circuit switching




Q: How many users can be supported?

Circuit switching

- 1 Mbps / 100 Kbps = 10
- N = 10 users

Packet switching

- N = 35 users
- prob > 10 users active simultaneously < .0004

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?

Packet switching allows more users to use network!

# Is packet switching always better?

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

Q: How to provide circuit-like behavior?

- bandwidth guarantees needed for audio/video apps
- still an unsolved problem (chapter 7)

# Binomial random variable (homework)

Suppose we do n independent experiments

- each experiment succeeds with probability p
- each experiment fails with probability 1-p

Independent experiment

- knowledge about one experiment occurring does not affect probability of other experiment occurring: e.g., coin toss

P(A and B) = P(A) x P(B)

P(A or B) = P(A) + P(B)

P(X=4 and X=5) = P(X=4) x P(X=5)

P(X=4 or X=5) = P(X=4) + P(X=5)

# Binomial random variable (homework)

Suppose we do n independent experiments

- each experiment succeeds with probability p
- each experiment fails with probability 1-p

X = Random Variable indicating # of successes that occur in n experiments

Probability of i successes

$$P(X = i) = \binom{n}{i} p^i (1-p)^{n-i}$$

Probability of n-i failures

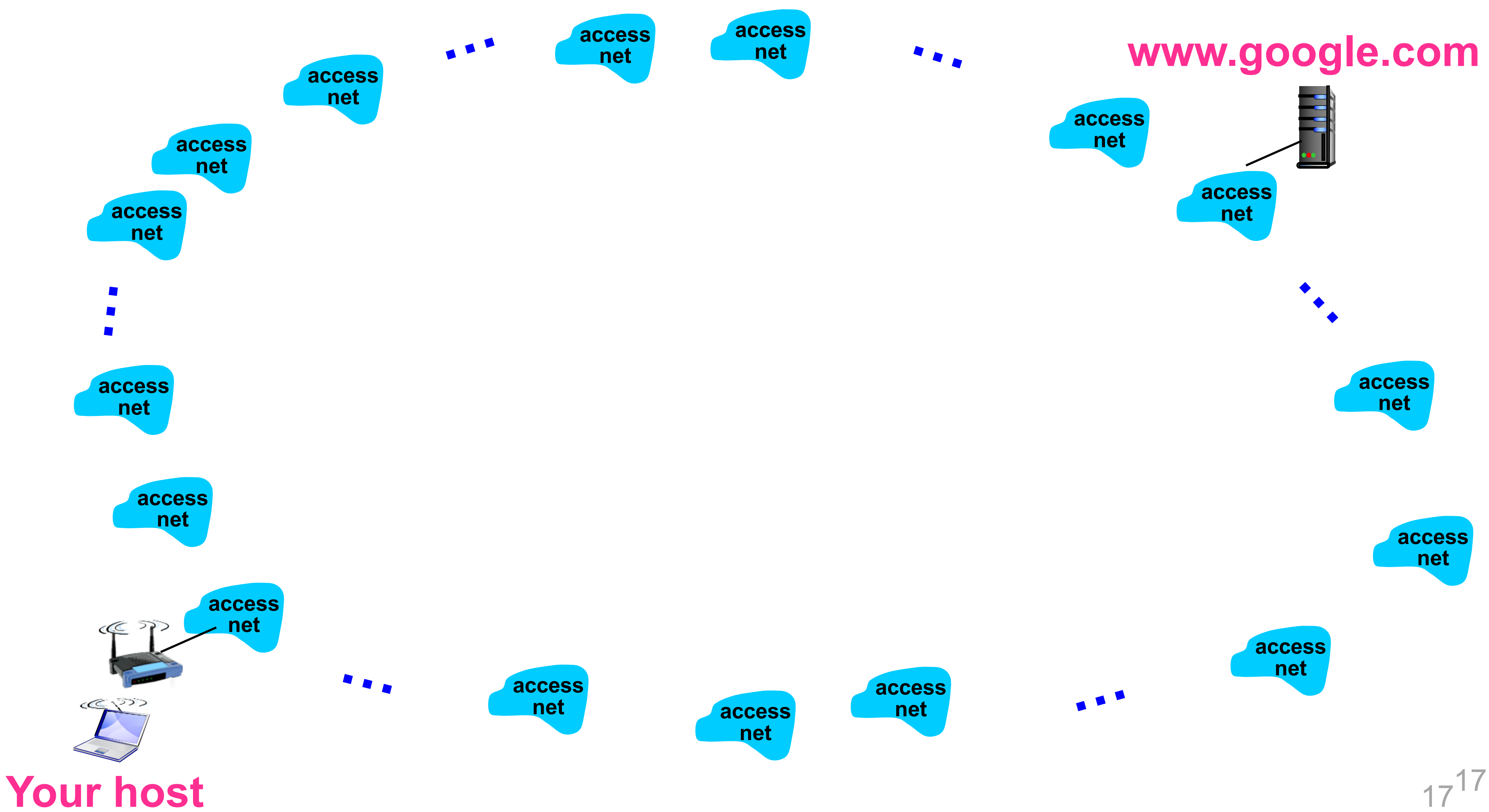
n choose i different ways to get i successful experiments

## Internet Organization

# A NETWORK OF NETWORKS

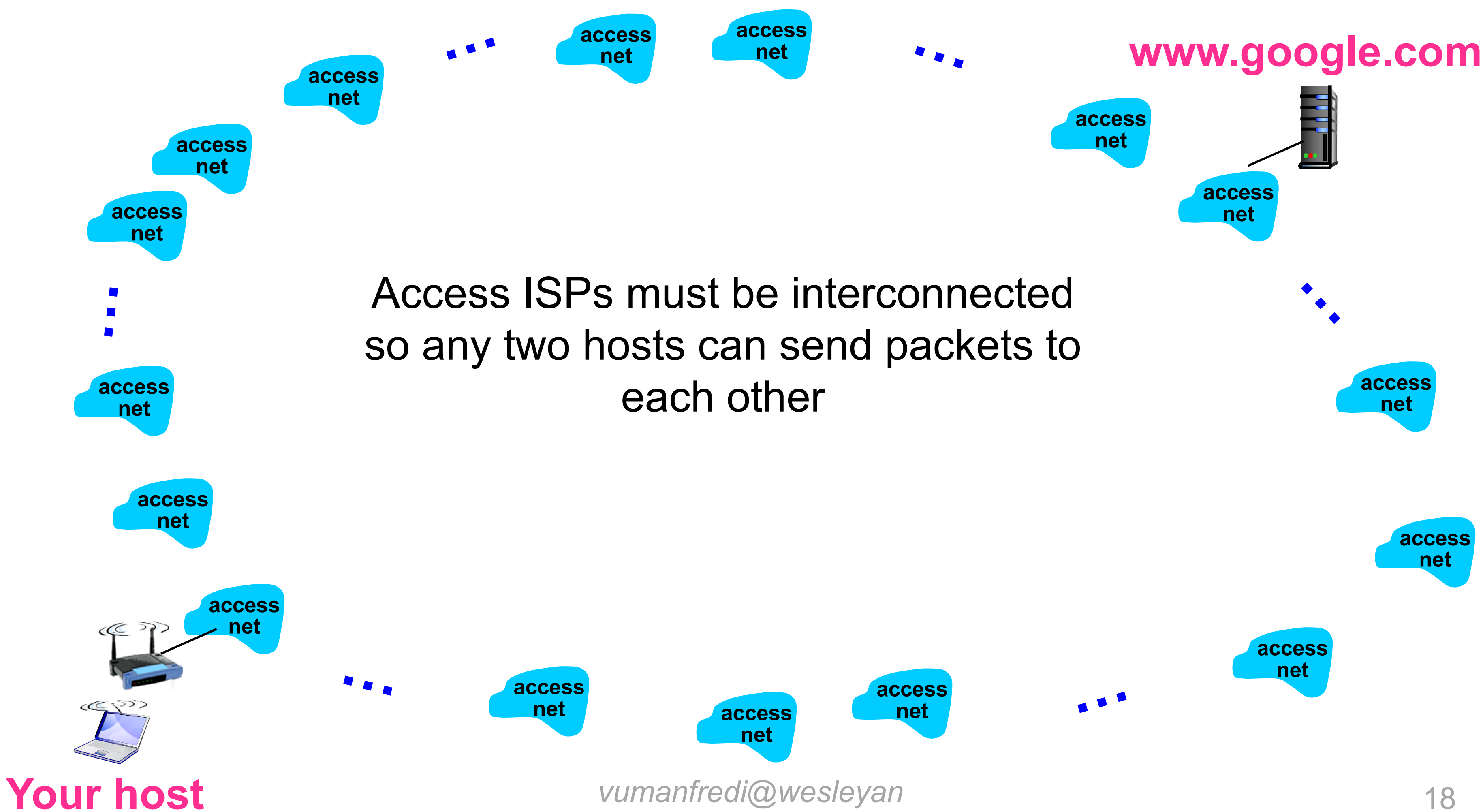
# A network of networks

- Hosts connect to Internet via access ISPs (e.g., Comcast)
  – residential, company and university ISPs



# A network of networks

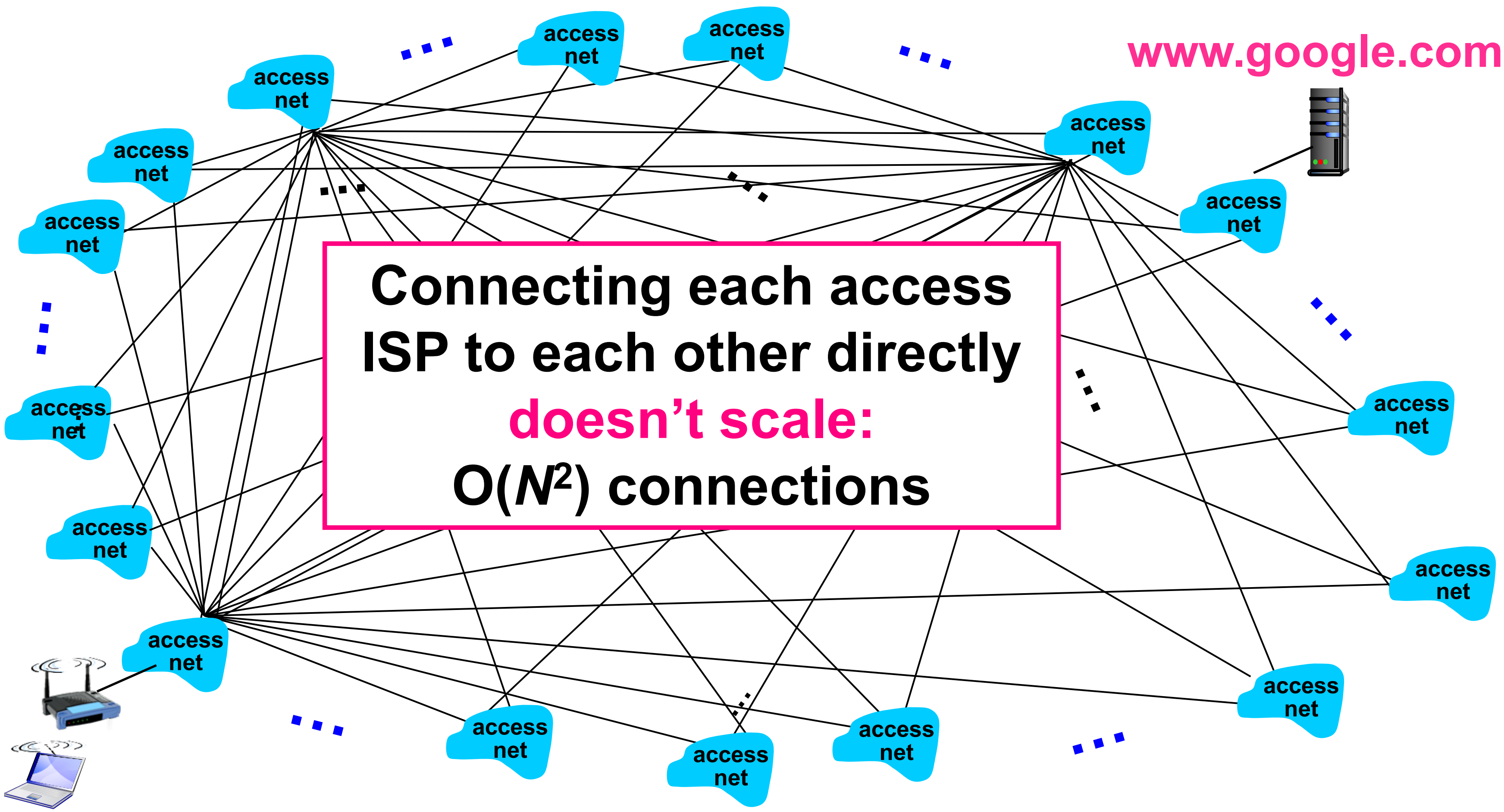
Q: given millions of access ISPs, how to connect together?




Access ISPs must be interconnected so any two hosts can send packets to each other

# A network of networks

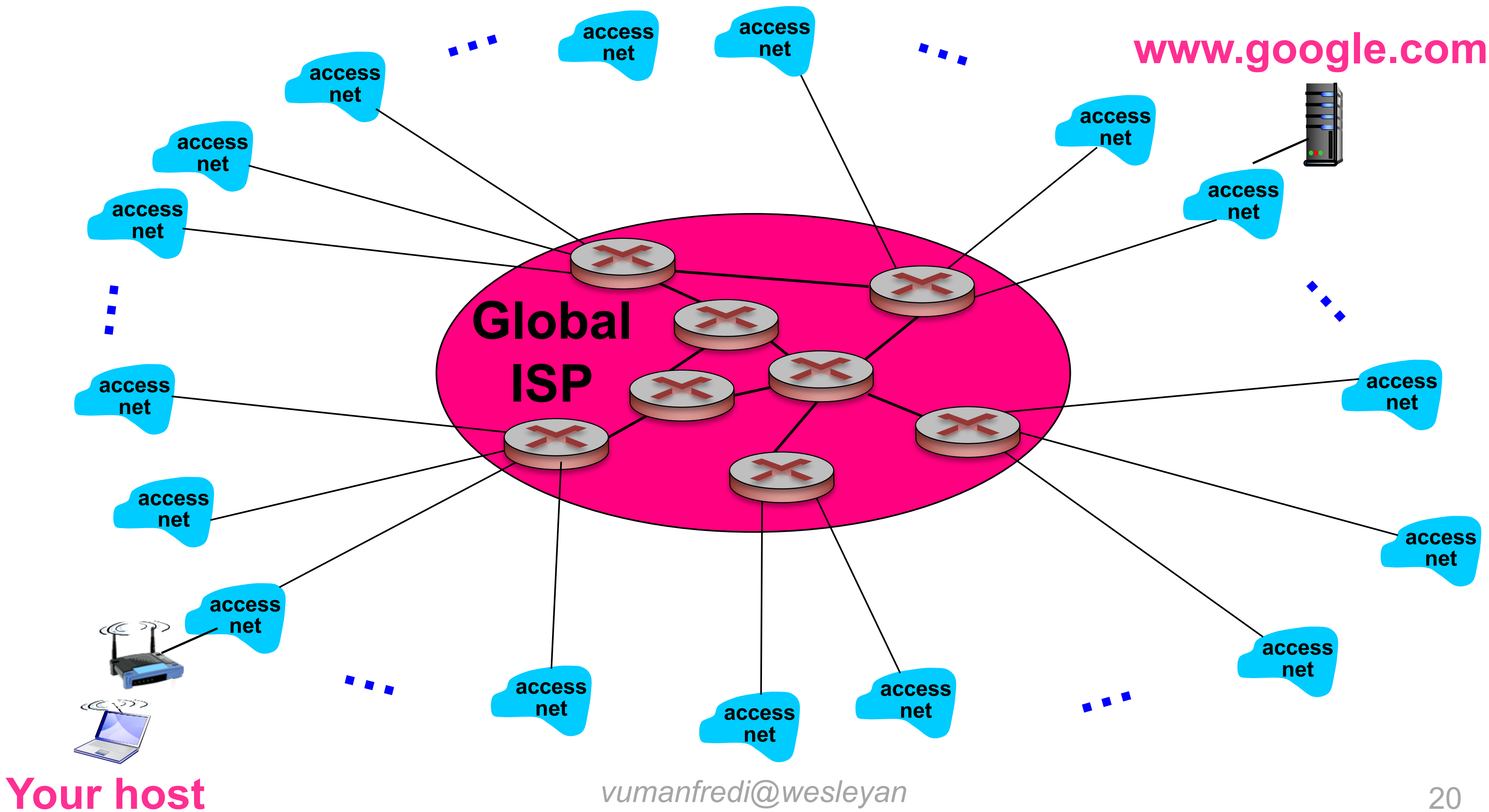
Option 1: connect each access ISP to every other access ISP?




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

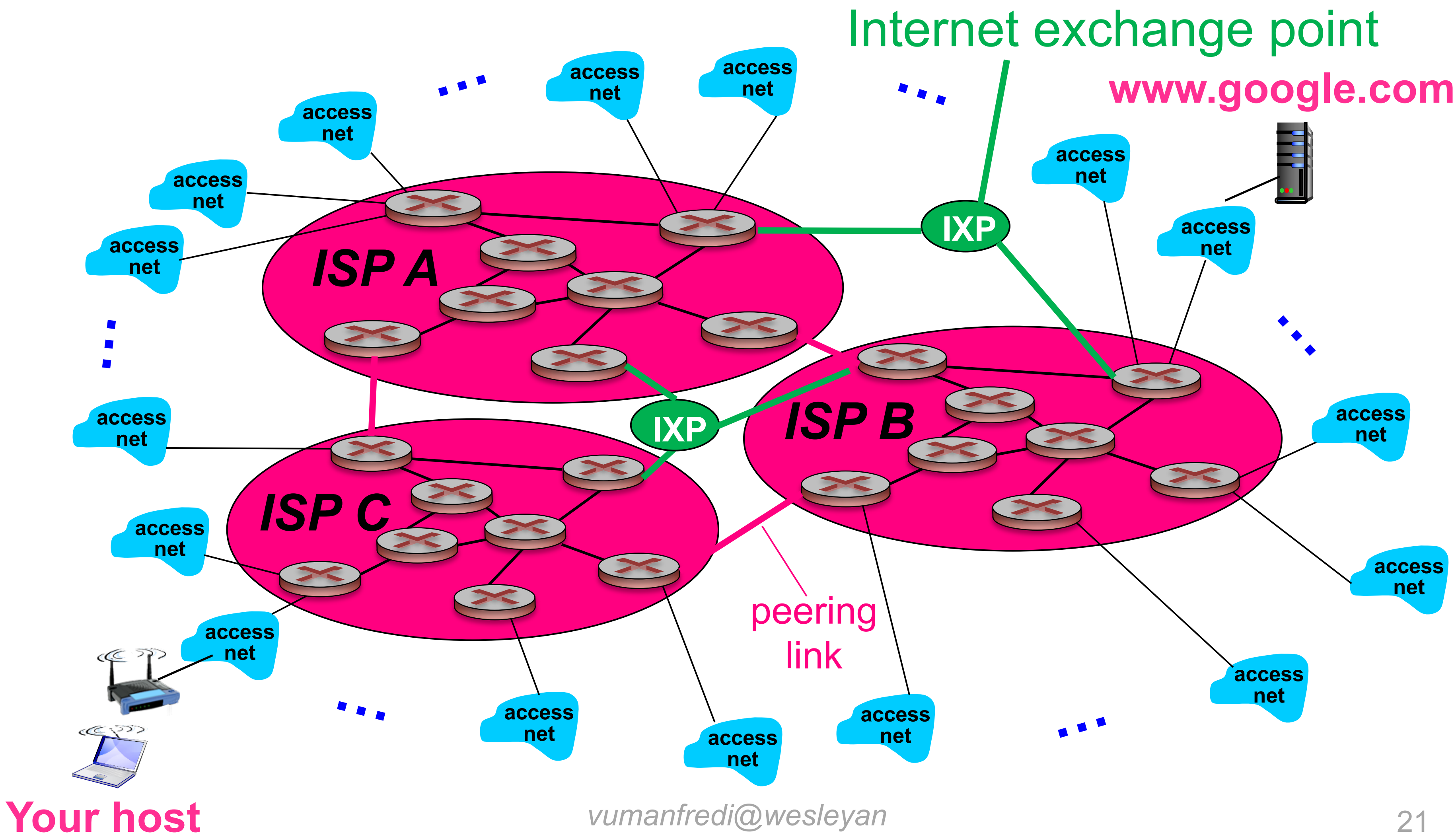
# A network of networks

Option 2: connect each access ISP to one global transit ISP?
Customer and provider ISPs have economic agreement.



# A network of networks

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



# IXP: Internet Exchange Point

Room full of routers

- meeting point where multiple ISPs can peer together

Peer

- let Internet traffic cross/transit your computer network without fee

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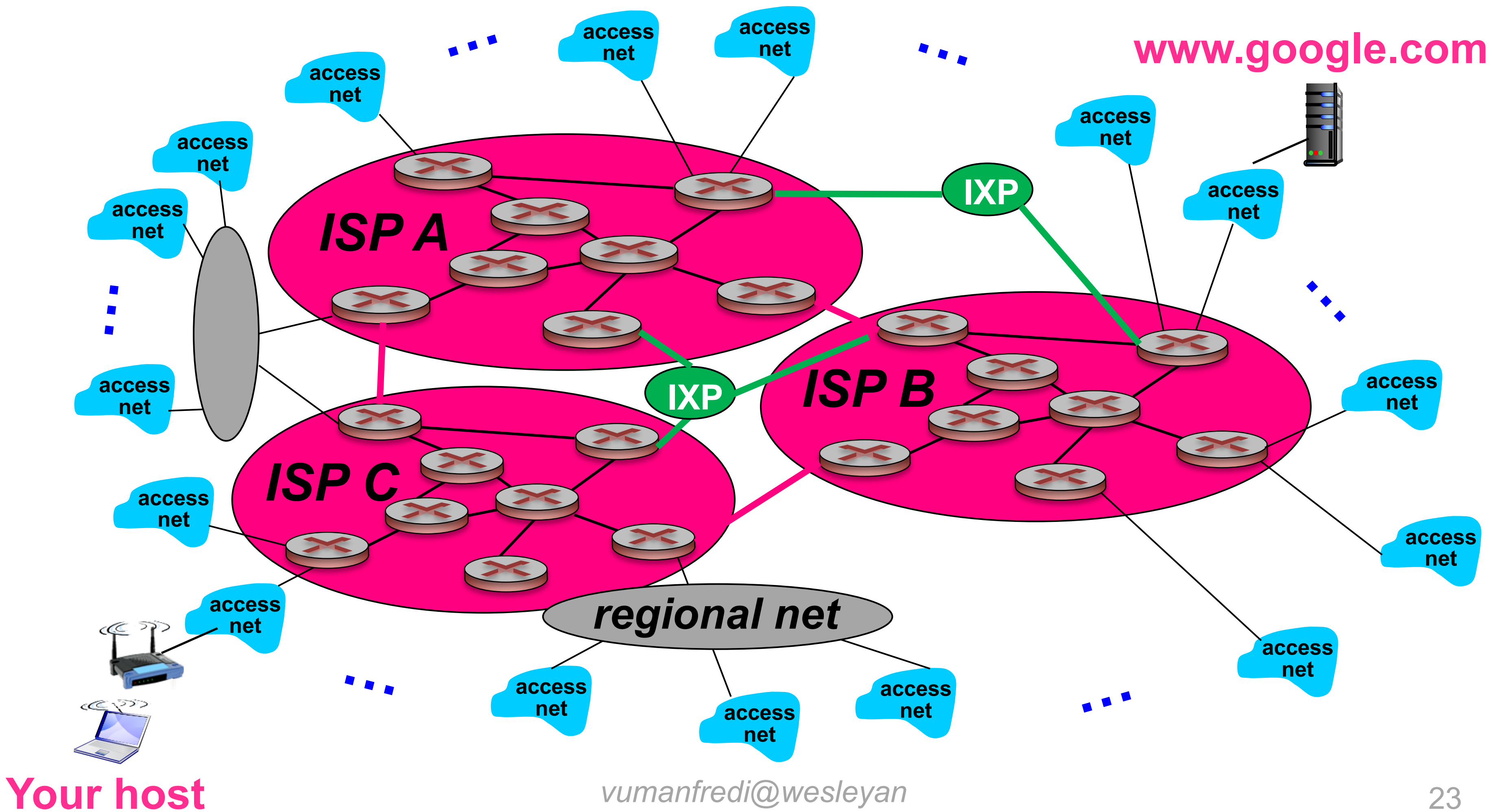
Amsterdam IXP

- where 100s of ISPs connect
- optical fiber patch panel connecting different ISPs

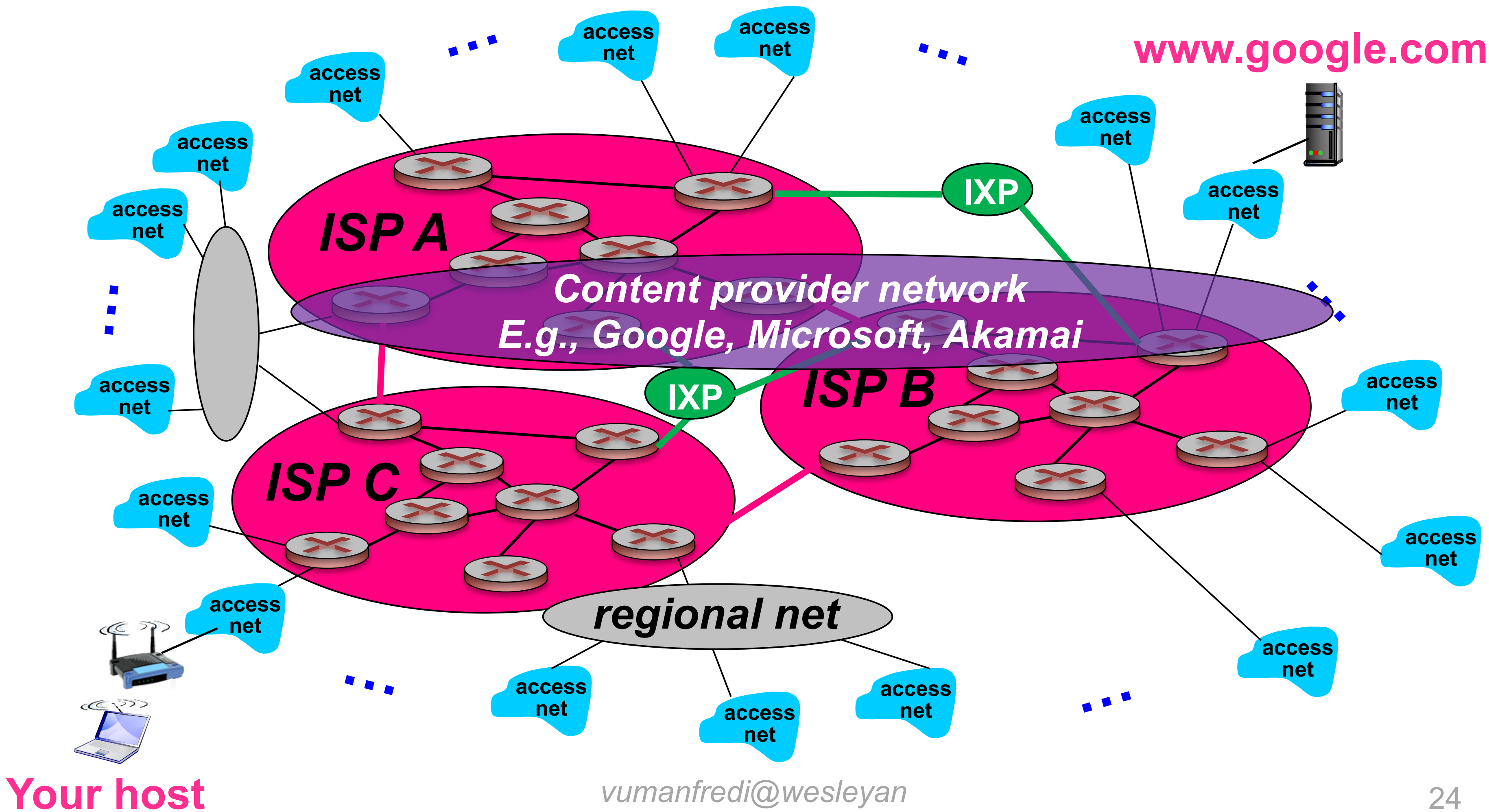
# A network of networks

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



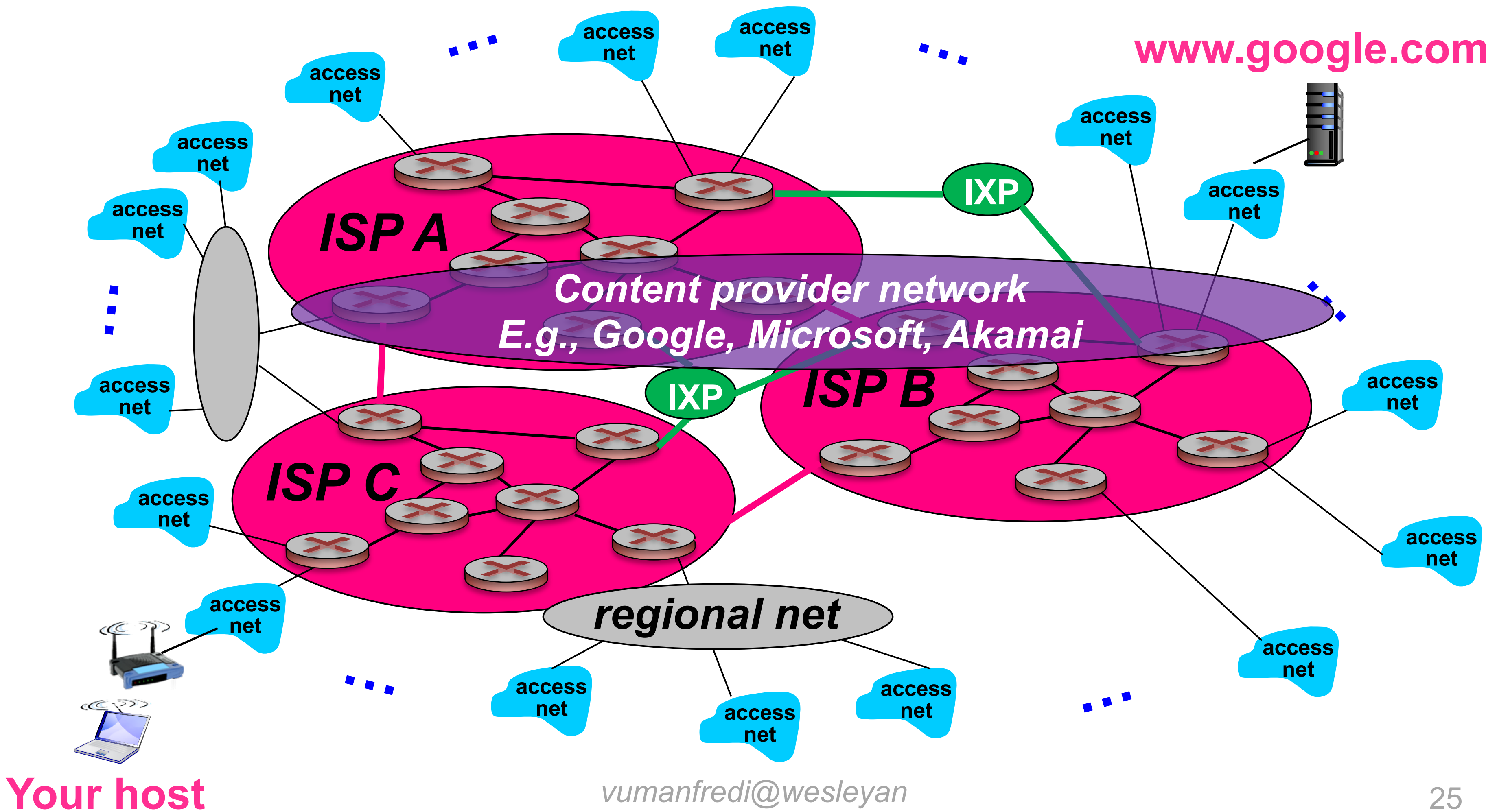
# A network of networks

… and content provider networks may run their own network, to bring services, content close to end users



# A network of networks

**Resulting network of networks is very complex: evolution was driven by economics and national policies**



# Different kinds of ISPs

Tier-1commercial ISPs: e.g., Level 3, Sprint, AT&T, NTT

- national & international coverage, peer with other tier 1 ISPs
- can reach all of Internet via peering only, peering typically payment free

Content provider network: e.g., Google (YouTube benefits)

- private network that connects its data centers to Internet
- often bypasses tier-1, regional ISPs, may buy transit
- by not paying provider ISP, save money and better control QoS for traffic

Regional ISP: e.g., Comcast

- customer ISP of Tier 1ISP, provider ISP to access ISP
- peers with some networks but needs to purchase some IP transit to reach some parts of Internet

Access ISPs: connect end systems to Internet

- any of these could be access ISP
- company or Wesleyan may connect directly into Tier 1 or Regional ISP

# Internet terminology

## Internet transit

- service of letting Internet traffic cross or transit a computer network
- usually used to connect a smaller ISP to larger Internet

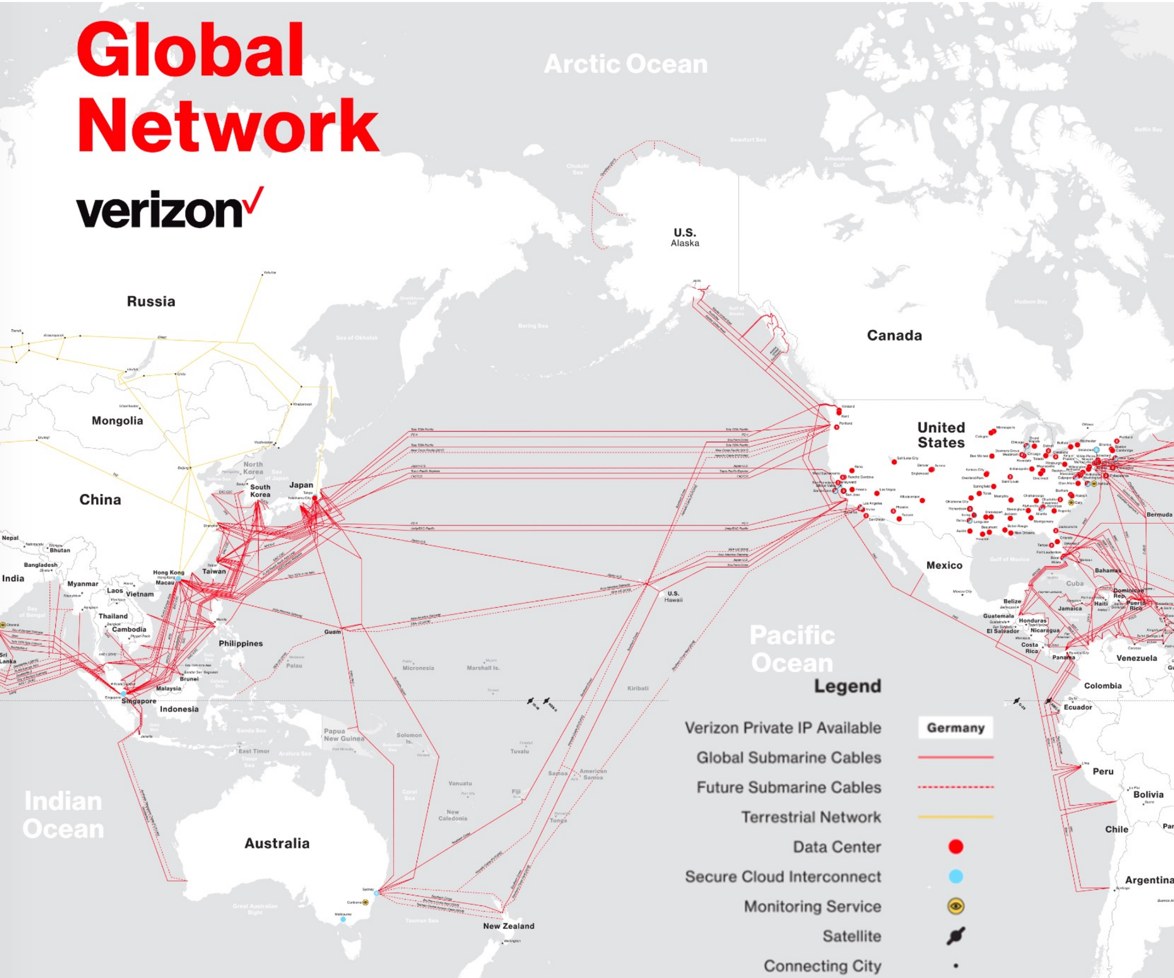
## Multi-home

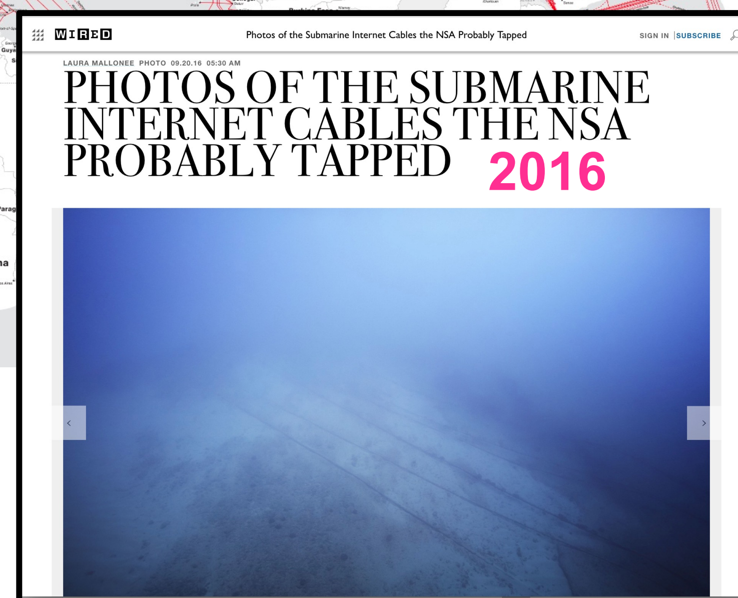
- customer ISP connects to 2 or more provider ISPs
- Why? For robustness. Can also multi-home your home network

## PoP: Point-of-Presence

- where customer packets enter network
- e.g., you connecting to access ISP or ISP connecting to provider ISP

# Tier-1 ISP has global reach

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Photos of the Submarine Internet Cables the NSA Probably Tapped

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