

# Chapter 1: roadmap

## 1.1 what is the Internet?

## 1.2 network edge

- end systems, access networks, links

## 1.3 network core

- packet switching, circuit switching, network structure

## 1.4 delay, loss, throughput in networks

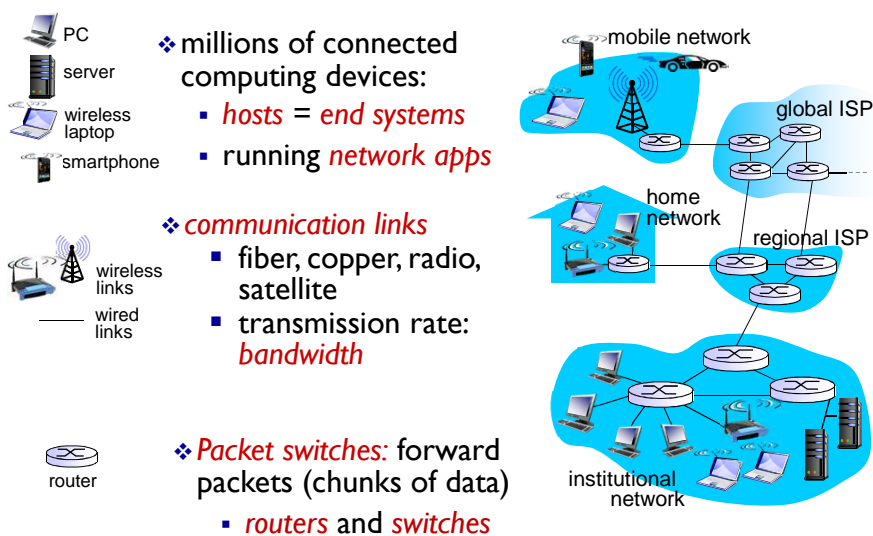
## 1.5 protocol layers, service models

## 1.6 networks under attack: security

## 1.7 history

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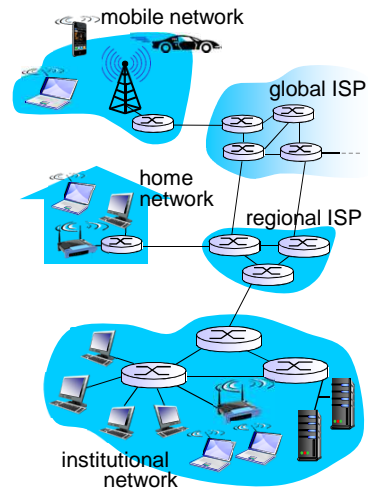
# What's the Internet: "nuts and bolts" view



Introduction 1-2

## What's the Internet: "nuts and bolts" view

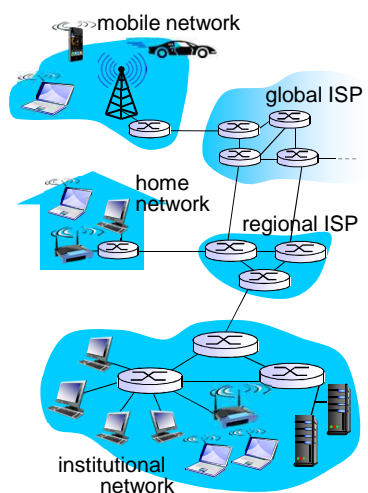
- ❖ **Internet: "network of networks"**
  - Interconnected ISPs
- ❖ **protocols** control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- ❖ **Internet standards**
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force



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## What's the Internet: a service view

- ❖ **Infrastructure that provides services to applications:**
  - Web, VoIP, email, games, e-commerce, social nets, ...
- ❖ **provides programming interface to apps**
  - hooks that allow sending and receiving app programs to "connect" to Internet
  - provides service options, analogous to postal service



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# What's a protocol?

## *human protocols:*

- ❖ “what's the time?”
- ❖ “I have a question”
- ❖ introductions

... specific msgs sent

... specific actions taken when msgs received, or other events

## *network protocols:*

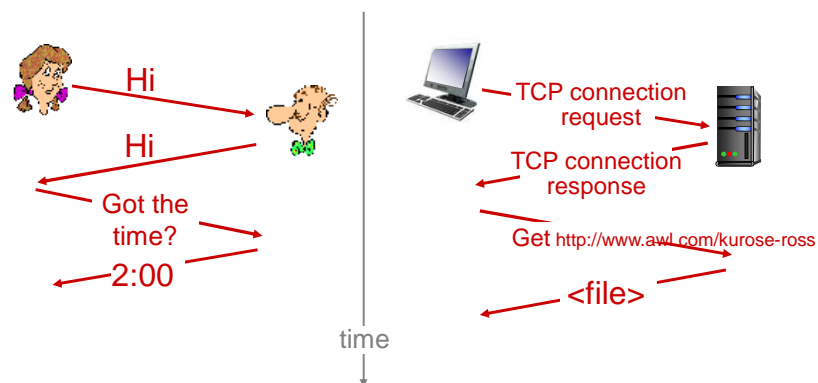
- ❖ machines rather than humans
- ❖ all communication activity in Internet governed by protocols

*protocols define format, order of msgs sent and received among network entities, and actions taken on msg transmission, receipt*

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# What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

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## A closer look at network structure:

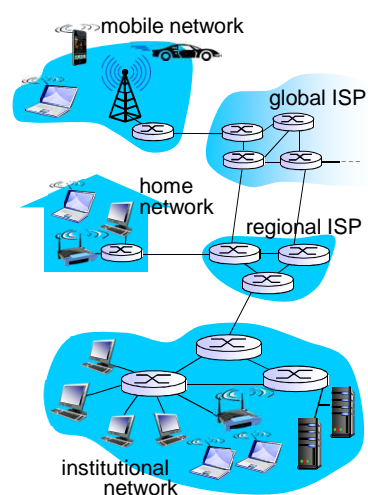
❖ *network edge:*

- hosts: clients and servers
- servers often in data centers

❖ *access networks, physical media:* wired, wireless communication links

❖ *network core:*

- interconnected routers
- network of networks



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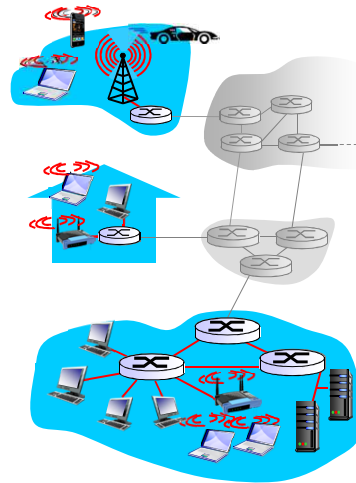
## Access networks and physical media

*Q: How to connect end systems to edge router?*

- ❖ residential access nets
- ❖ institutional access networks (school, company)
- ❖ mobile access networks

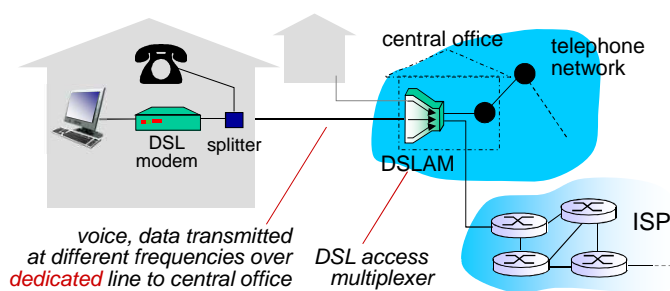
*keep in mind:*

- ❖ bandwidth (bits per second) of access network?
- ❖ shared or dedicated?



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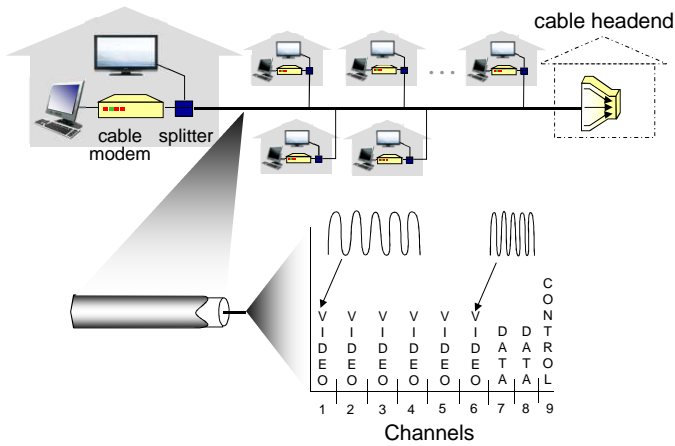
## Access net: digital subscriber line (DSL)



- ❖ use **existing** telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- ❖ < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- ❖ < 24 Mbps downstream transmission rate (typically < 10 Mbps)

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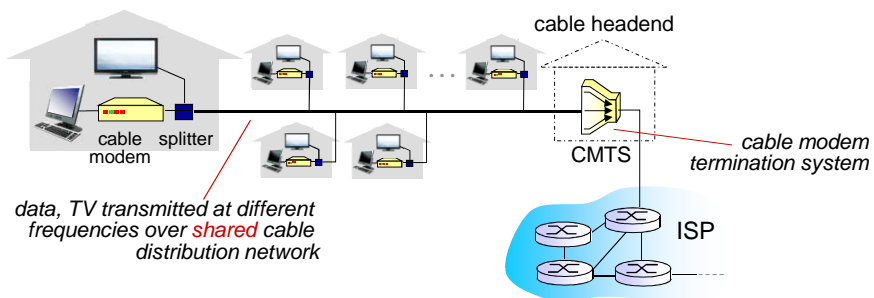
## Access net: cable network



**frequency division multiplexing:** different channels transmitted in different frequency bands

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## Access net: cable network

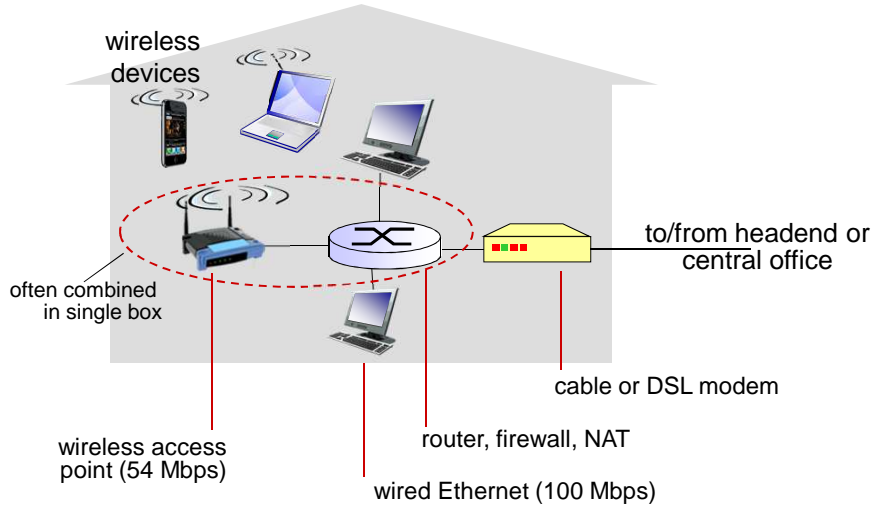


*data, TV transmitted at different frequencies over **shared** cable distribution network*

- ❖ **HFC: hybrid fiber coax**
  - asymmetric: up to 30Mbps downstream transmission rate, 2 Mbps upstream transmission rate
- ❖ **network** of cable, fiber attaches homes to ISP router
  - homes **share access network** to cable headend
  - unlike DSL, which has dedicated access to central office

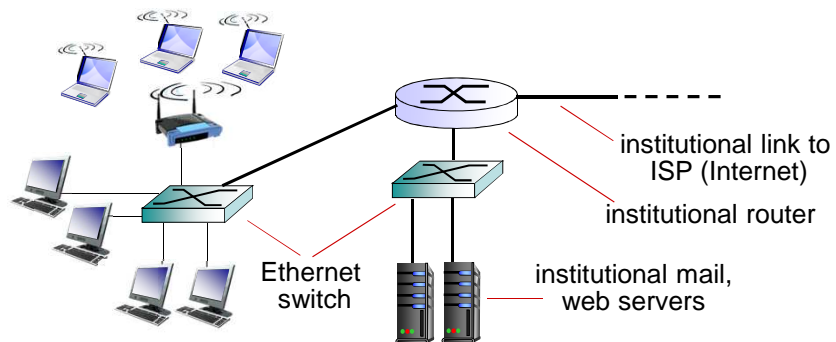
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## Access net: home network



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## Enterprise access networks (Ethernet)



- ❖ typically used in companies, universities, etc
- ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- ❖ today, end systems typically connect into Ethernet switch

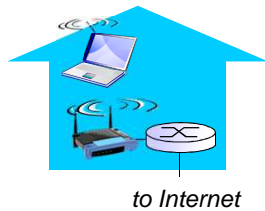
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## Wireless access networks

- ❖ shared wireless access network connects end system to router
  - via base station aka “access point”

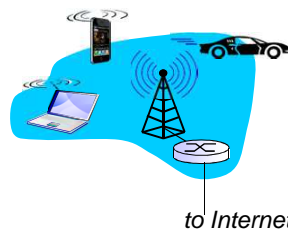
### wireless LANs:

- within building (100 ft)
- 802.11b/g (WiFi): 11, 54 Mbps transmission rate



### wide-area wireless access

- provided by telco (cellular) operator, 10's km
- between 1 and 10 Mbps
- 3G, 4G: LTE

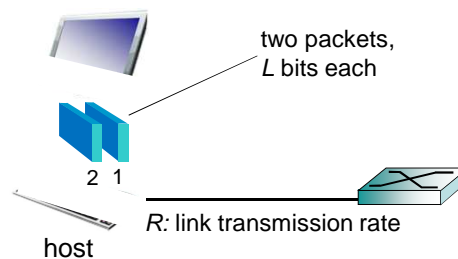


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## Host: sends packets of data

host sending function:

- ❖ takes application message
- ❖ breaks into smaller chunks, known as *packets*, of length  $L$  bits
- ❖ transmits packet into access network at *transmission rate  $R$* 
  - link transmission rate, aka link *capacity*, aka *link bandwidth*



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

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## Physical media

- ❖ **bit:** propagates between transmitter/receiver pairs
- ❖ **physical link:** what lies between transmitter & receiver
- ❖ **guided media:**
  - signals propagate in solid media: copper, fiber, coax
- ❖ **unguided media:**
  - signals propagate freely, e.g., radio

### *twisted pair (TP)*

- ❖ two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps



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## Physical media: coax, fiber

### *coaxial cable:*

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ broadband:
  - multiple channels on cable
  - HFC



### *fiber optic cable:*

- ❖ glass fiber carrying light pulses, each pulse a bit
- ❖ high-speed operation:
  - high-speed point-to-point transmission (e.g., 10's-100's Gbps transmission rate)
- ❖ low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise



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## Physical media: radio

- ❖ signal carried in electromagnetic spectrum
  - ❖ no physical “wire”
  - ❖ bidirectional
  - ❖ propagation environment effects:
    - reflection
    - obstruction by objects
    - interference
- radio link types:*
- ❖ **terrestrial microwave**
    - e.g. up to 45 Mbps channels
  - ❖ **LAN** (e.g., WiFi)
    - 11 Mbps, 54 Mbps
  - ❖ **wide-area** (e.g., cellular)
    - 3G cellular: ~ few Mbps
  - ❖ **satellite**
    - Kbps to 45Mbps channel (or multiple smaller channels)
    - 270 msec end-end delay
    - geosynchronous versus low altitude

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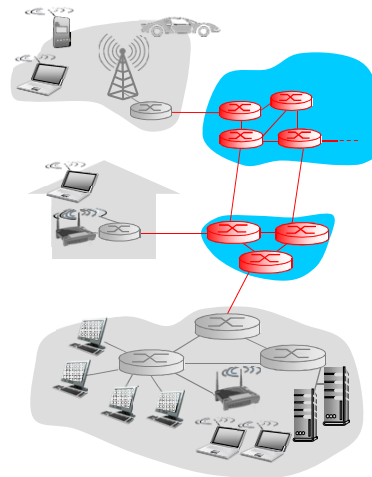
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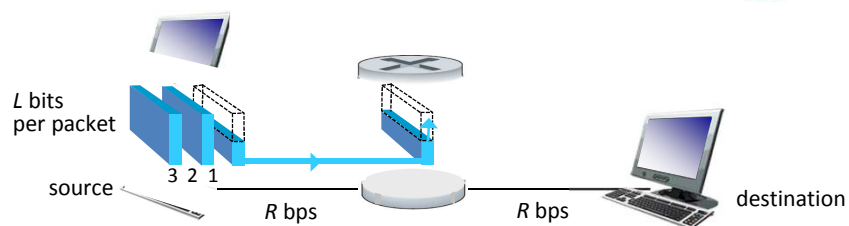
## The network core

- ❖ 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



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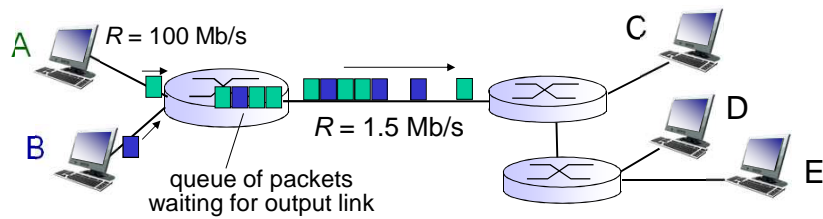
## Packet-switching: store-and-forward



- ❖ 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 =  $2L/R$  (assuming zero propagation delay)
- one-hop numerical example:*
- $L = 7.5$  Mbits
  - $R = 1.5$  Mbps
  - one-hop transmission delay = 5 sec
- } more on delay shortly ...

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## Packet Switching: queuing delay, loss



### queuing and loss:

- ❖ If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

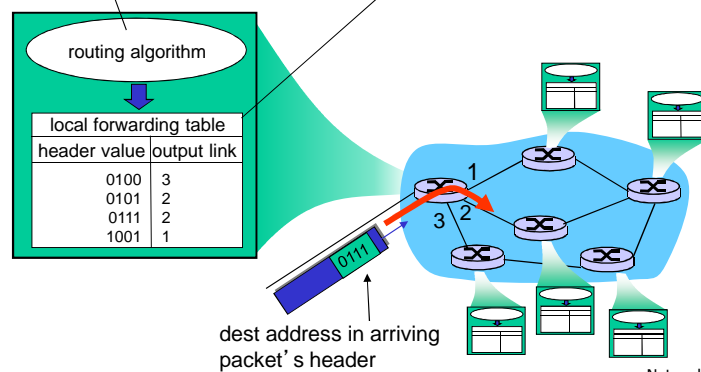
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## Two key network-core functions

**routing:** determines source-destination route taken by packets

- routing algorithms

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

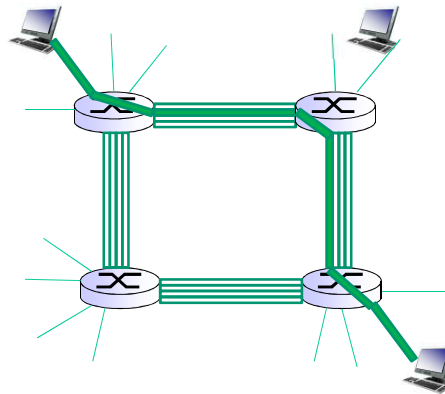


Network Layer 4-24

## Alternative core: circuit switching

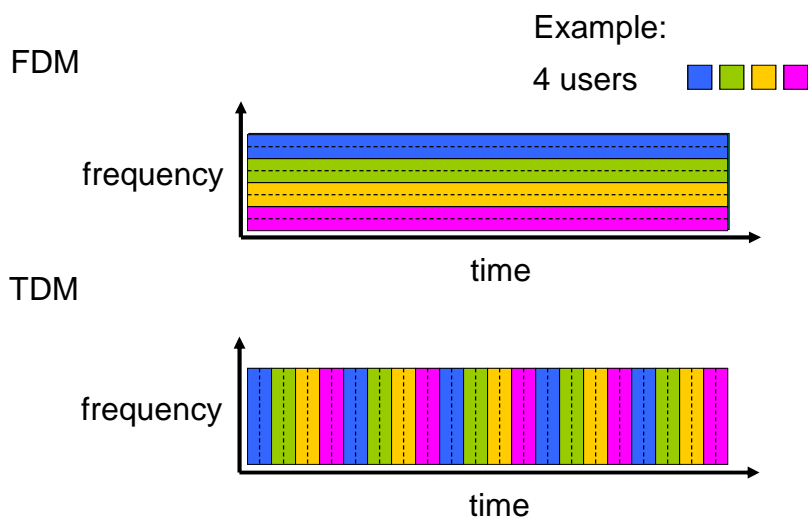
end-end resources allocated to, reserved for “call” between source & dest:

- ❖ In diagram, each link has four circuits.
  - call gets 2<sup>nd</sup> circuit in top link and 1<sup>st</sup> 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



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## Circuit switching: FDM versus TDM



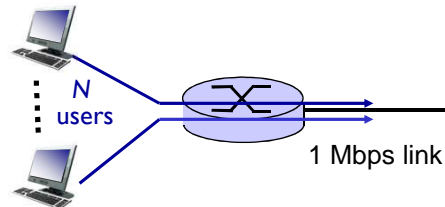
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## Packet switching versus circuit switching

*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:*

- 10 users

❖ *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

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## Packet switching versus circuit switching

*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
- ❖ 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)?

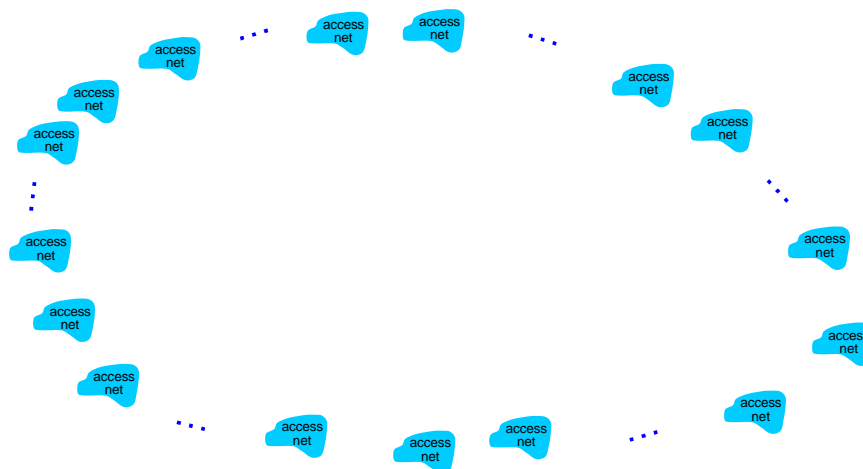
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## Internet structure: network of networks

- ❖ 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

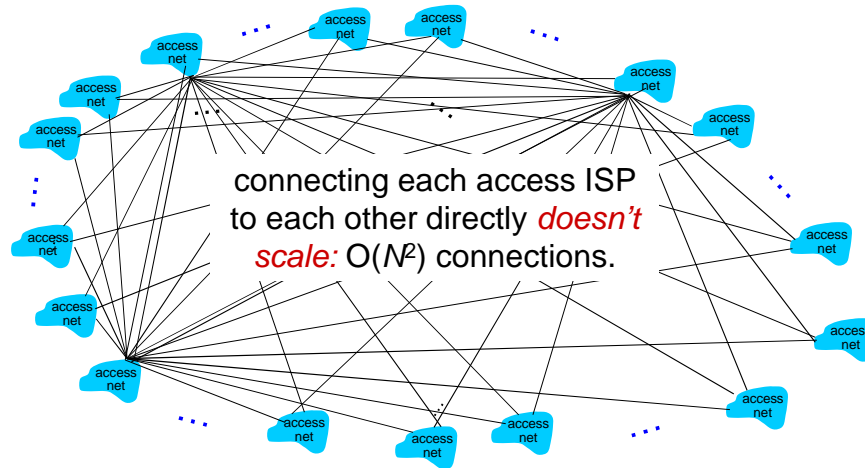
## Internet structure: network of networks

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



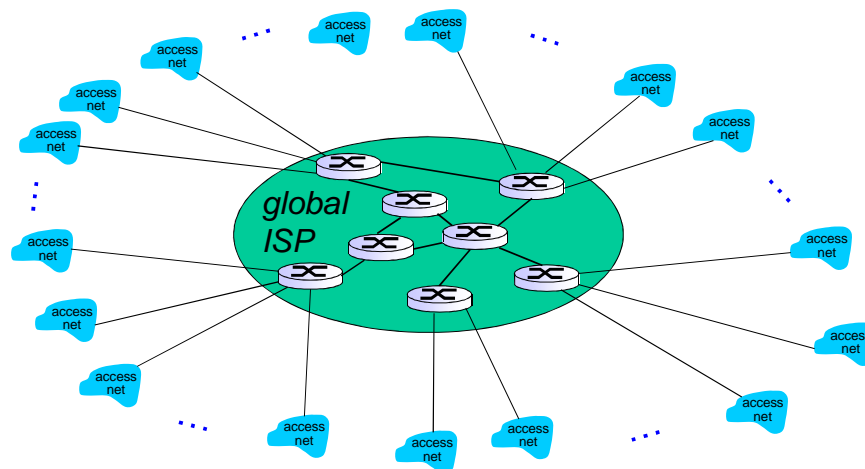
## Internet structure: network of networks

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



## Internet structure: network of networks

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

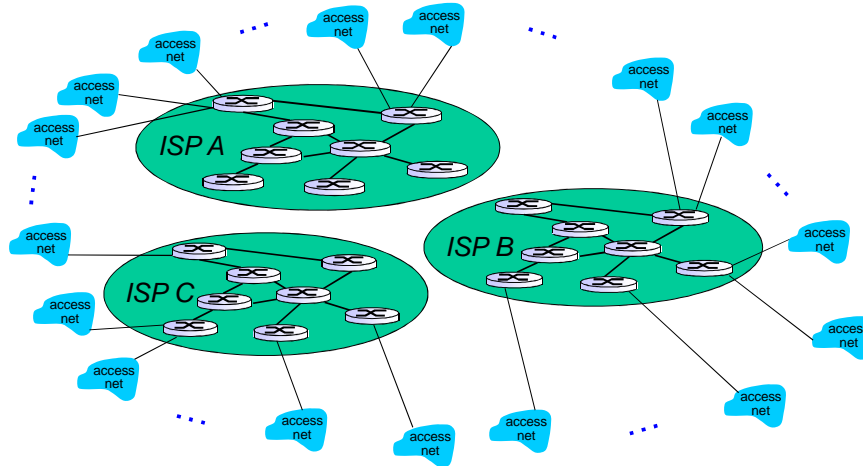




## Internet structure: network of networks

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

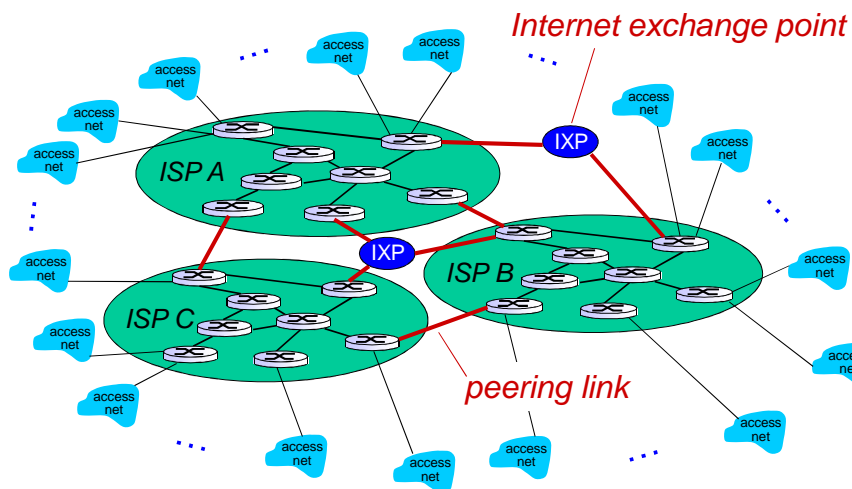
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## Internet structure: network of networks

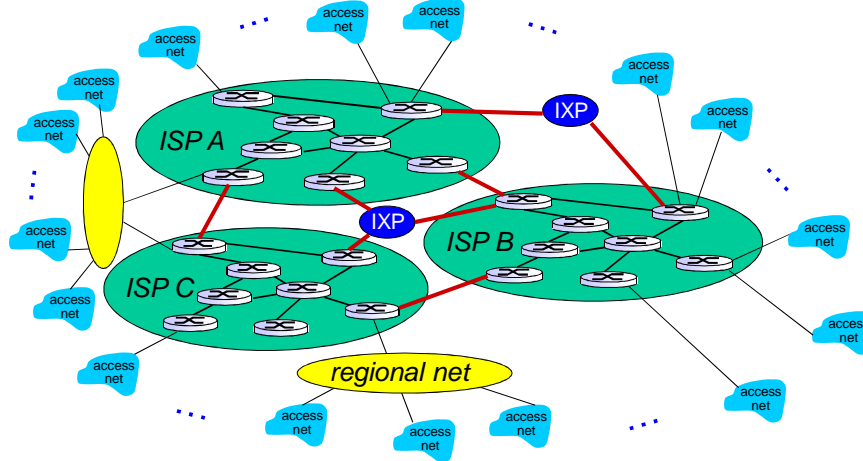
But if one global ISP is viable business, there will be competitors

.... which must be interconnected



## 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

