

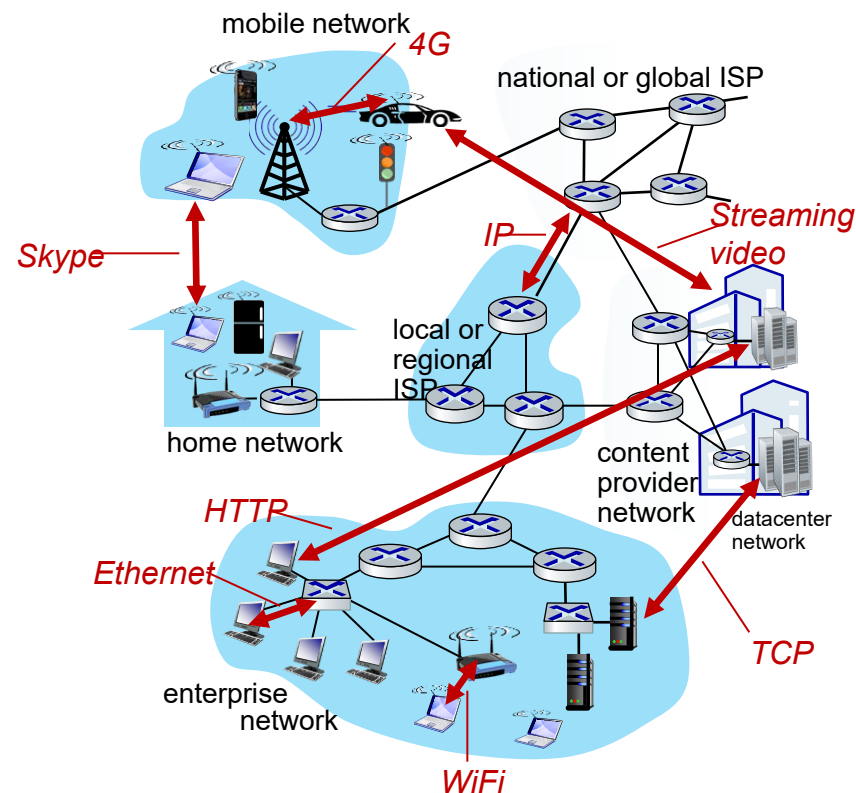
# National University of Computer & Emerging Sciences

Lecture 02  
BS(CS)  
Fall 2024

**The Network Edge and the  
Network Core**

## Recap

- *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



Introduction: 1-2

# A closer look at Internet structure

## Network edge:

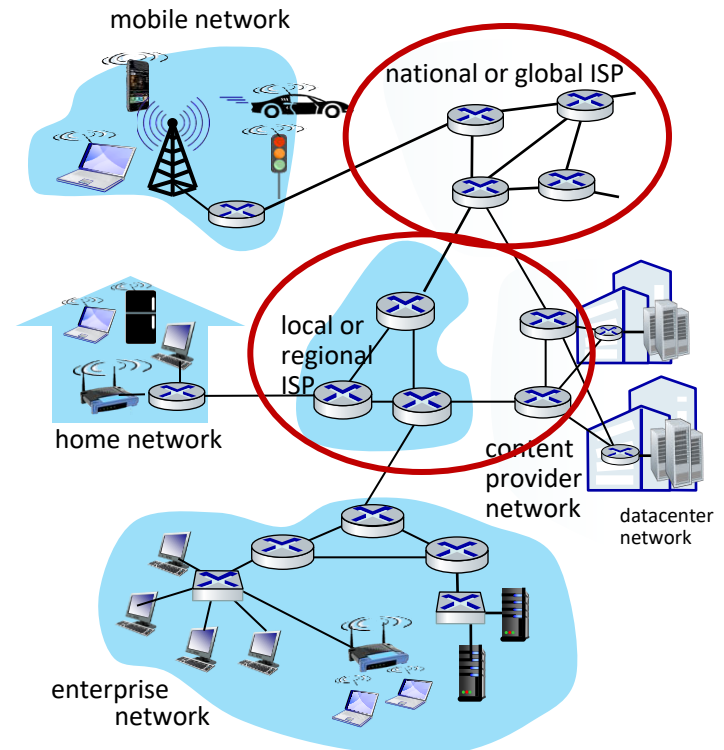
- hosts: clients and servers
- servers often in data centers

## Access networks, physical media:

- wired, wireless communication links

## Network core:

- interconnected routers
- network of networks

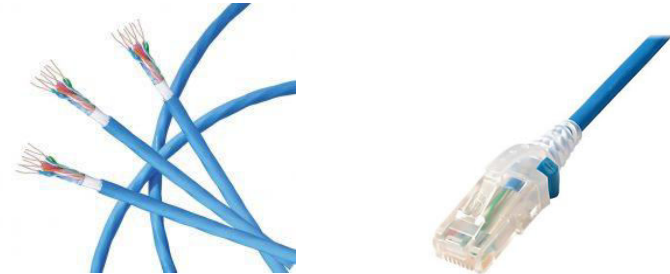


# Links: physical media

- **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 Ethernet



# Links: physical media

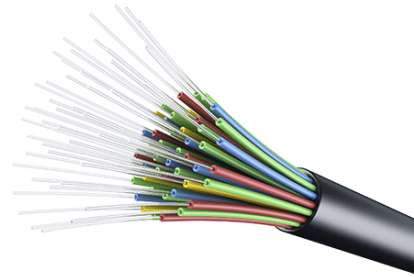
## Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel



## Fiber optic cable:

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



# Links: physical media

## Wireless radio

- signal carried in various “bands” in electromagnetic spectrum
- no physical “wire”
- broadcast, “half-duplex” (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - Interference/noise

## Radio link types:

- **Wireless LAN (WiFi)**
  - 10-100's Mbps; 10's of meters
- **wide-area** (e.g., 4G cellular)
  - 10's Mbps over ~10 Km
- **Bluetooth:** cable replacement
  - short distances, limited rates
- **terrestrial microwave**
  - point-to-point; 45 Mbps channels
- **satellite**
  - up to 45 Mbps per channel
  - 270 msec end-end delay

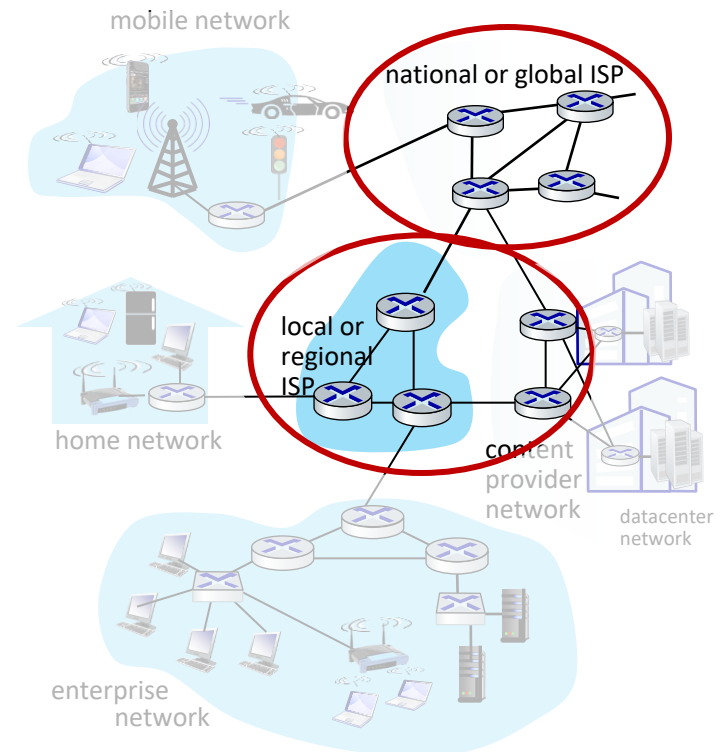
# Chapter 1: roadmap

- What *is* the Internet?
- What *is* a protocol?
- Network edge: hosts, access network, physical media
- **Network core:** packet/circuit switching, internet structure
- Performance: loss, delay, throughput
- Security
- Protocol layers, service models
- History



# The network core

- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into **packets**
  - network **forwards** packets from one router to the next, across links on path from **source to destination**

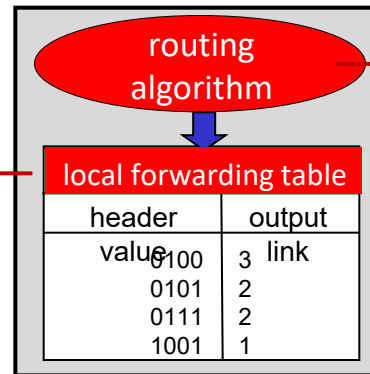




# Two key network-core functions

## Forwarding:

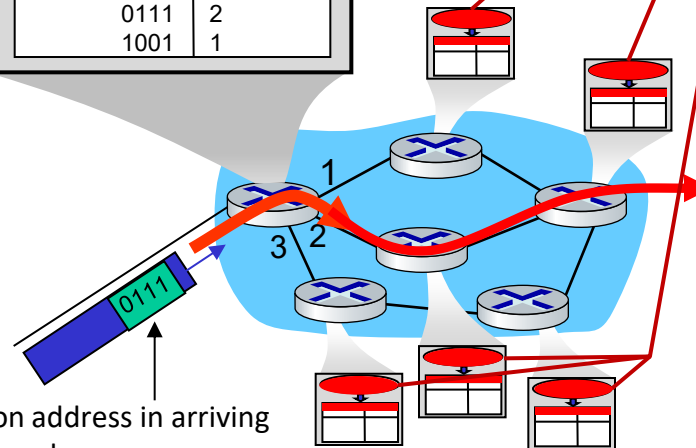
- aka “switching”
- **local** action: move arriving packets from router's input link to appropriate router output link



destination address in arriving packet's header

## Routing:

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



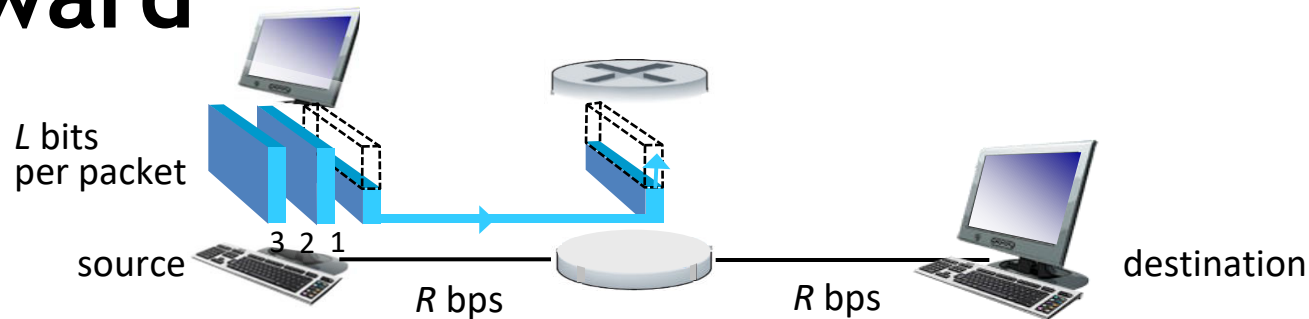
# Lecture 02: Network Edge & Core



# Lecture 02: Network Edge & Core



# Packet-switching: store-and-forward

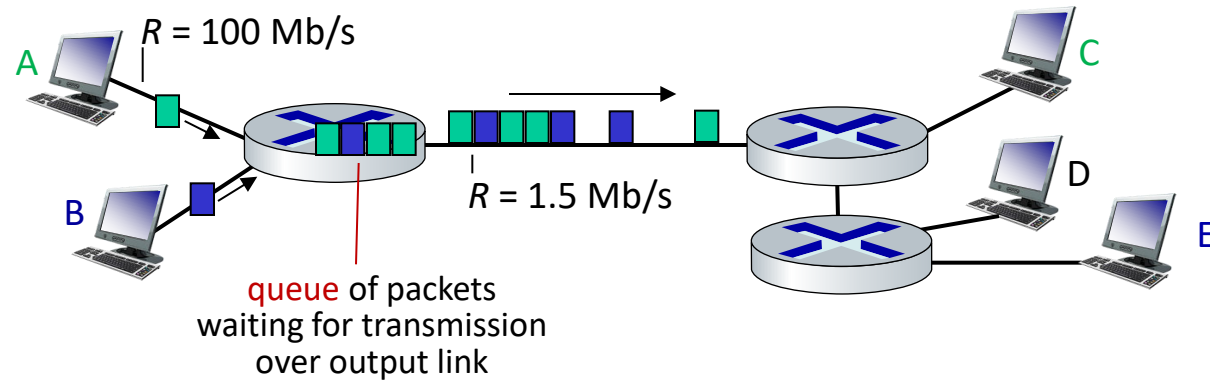


- **packet transmission delay:** takes  $L/R$  seconds to transmit (push out)  $L$ -bit packet into link at  $R$  bps
- **store and forward:** entire packet must arrive at router before it can be transmitted on next link

*One-hop numerical example:*

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

# Packet-switching: queueing

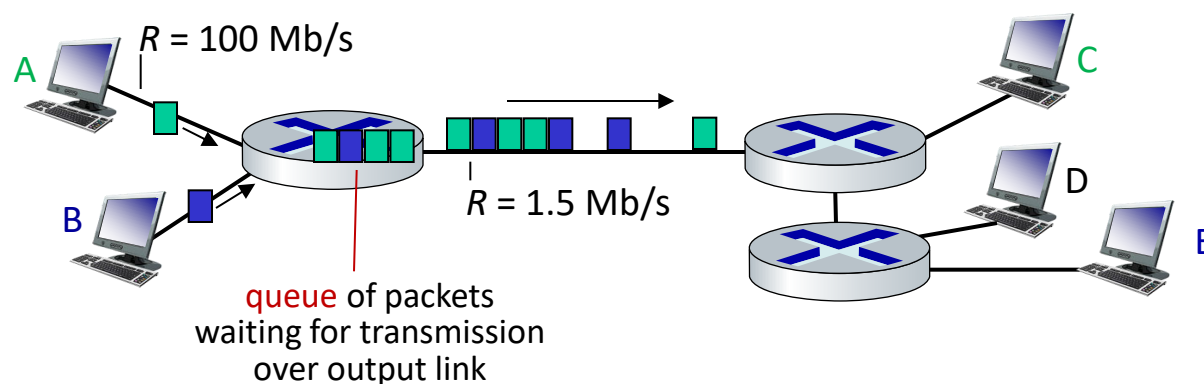


**Queueing** occurs when work arrives faster than it can be serviced:





# Packet-switching: queueing



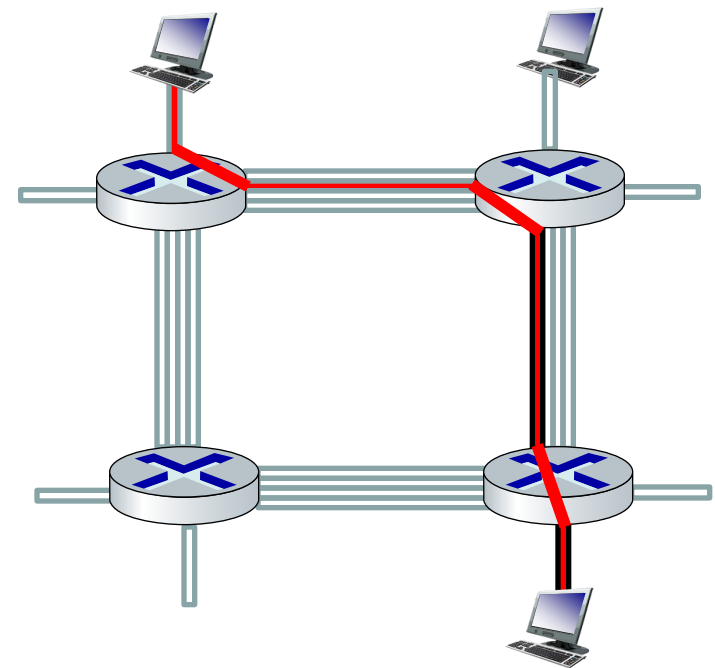
**Packet queueing and loss:** if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

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

# Alternative to packet switching: circuit switching

end-end resources  
allocated to, reserved for  
“call” between source and  
destination

- 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

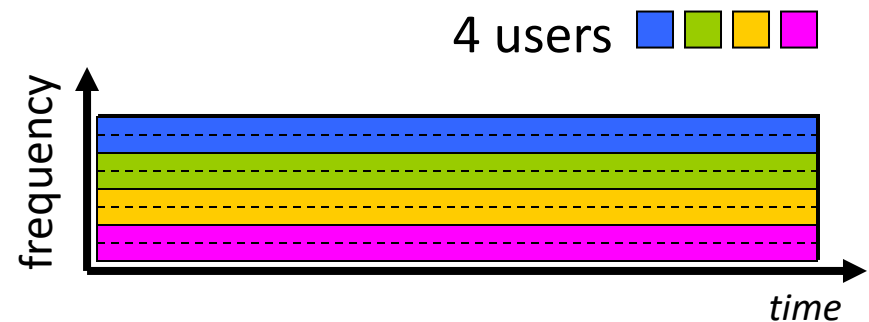


\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive](http://gaia.cs.umass.edu/kurose_ross/interactive)

# Circuit switching: FDM and TDM

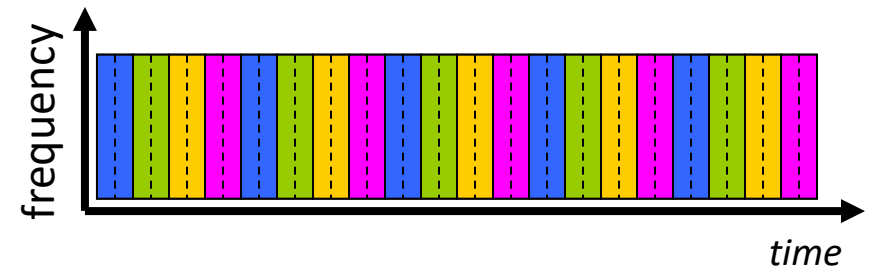
## Frequency Division Multiplexing (FDM)

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

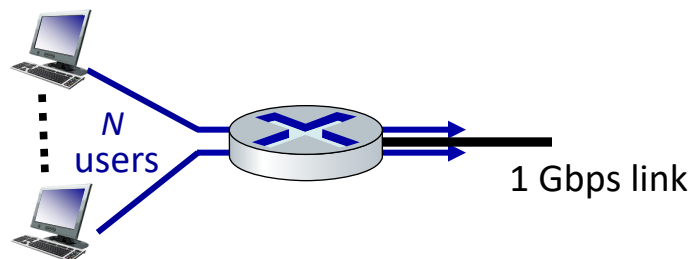




# Packet switching versus circuit switching

example:

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



**Q:** how many users can use this network under circuit-switching and packet switching?

- **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?

**A:** HW problem (for those with course in probability only)

\* Check out the online interactive exercises for more examples: [http://gaia.cs.umass.edu/kurose\\_ross/interactive](http://gaia.cs.umass.edu/kurose_ross/interactive)

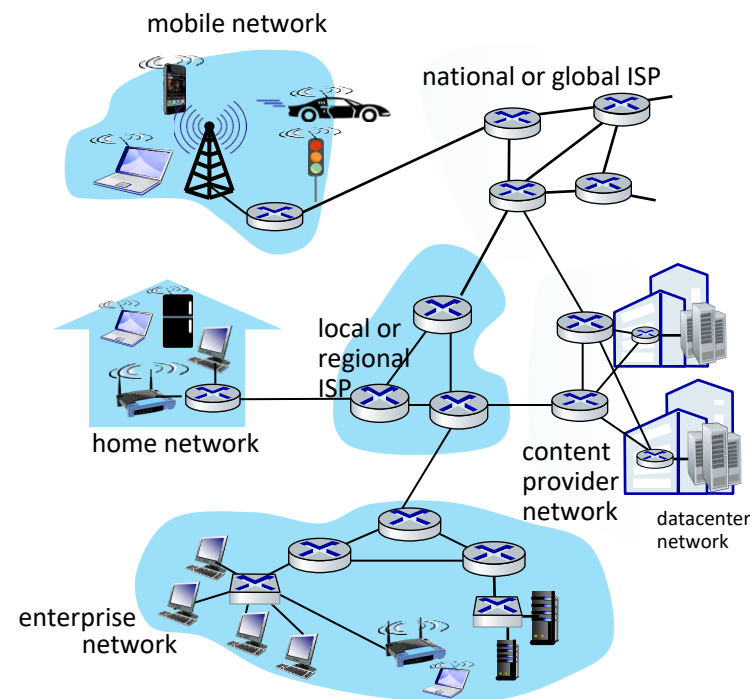
# Packet switching versus circuit switching

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

# Internet structure: a “network of networks”

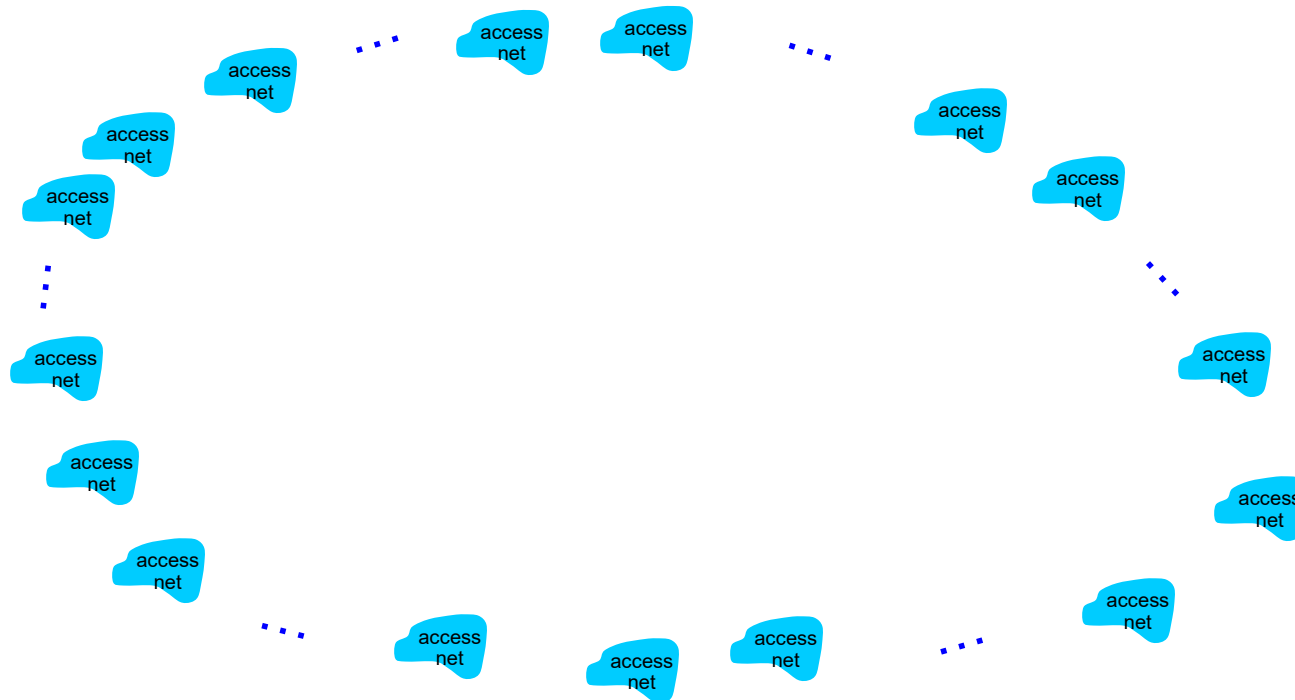
- hosts connect to Internet via **access** Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts (*anywhere!*) can send packets to each other
- resulting network of networks is very complex
  - evolution driven by **economics**, **national policies**



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

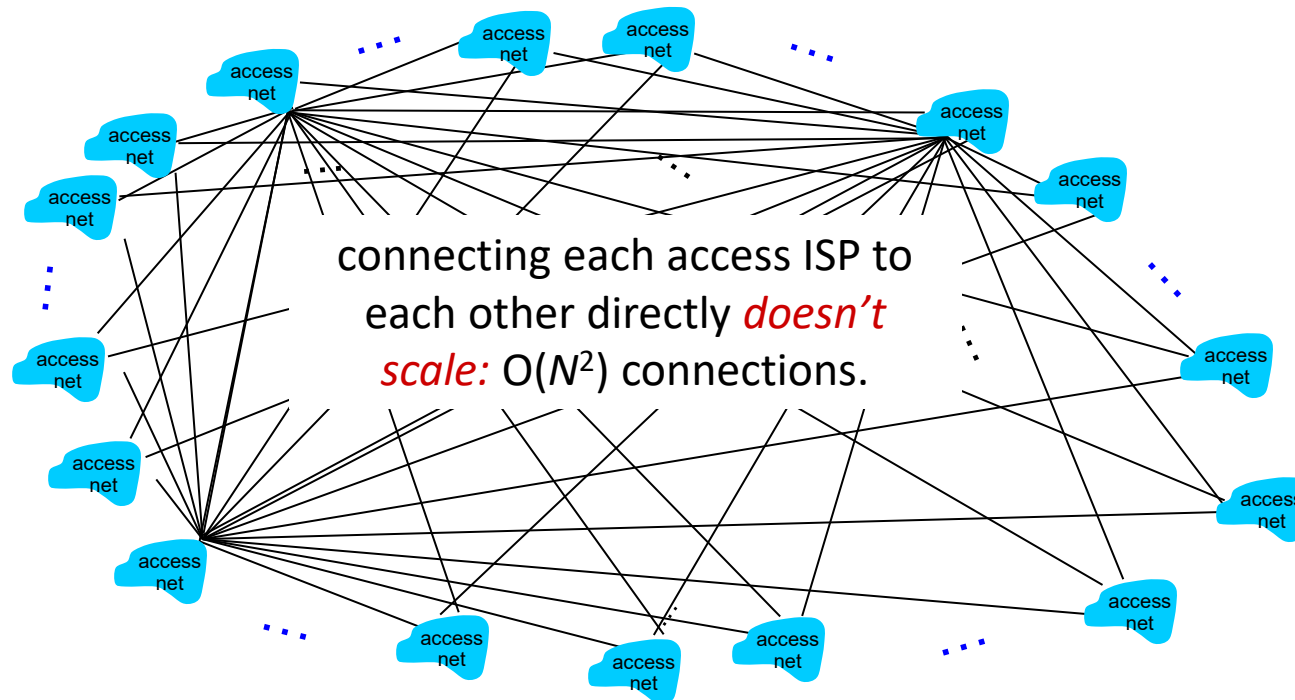
# Internet structure: a “network of networks”

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



# Internet structure: a “network of networks”

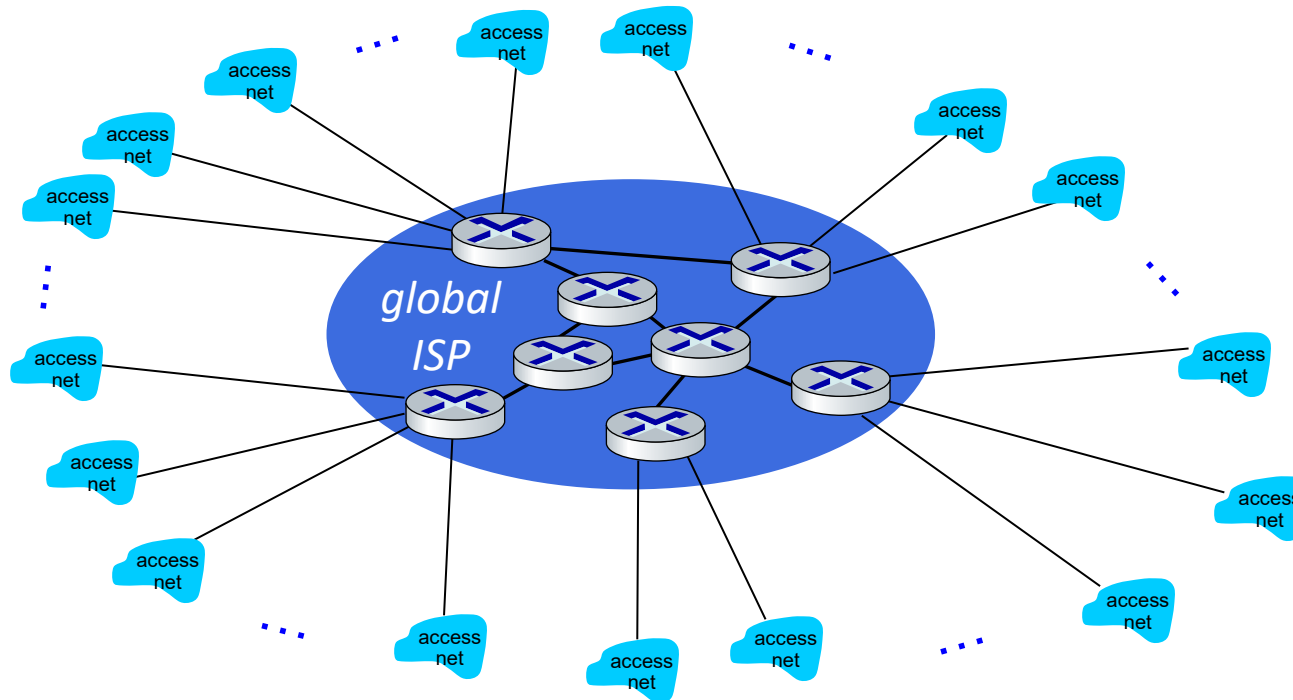
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# Internet structure: a “network of networks”

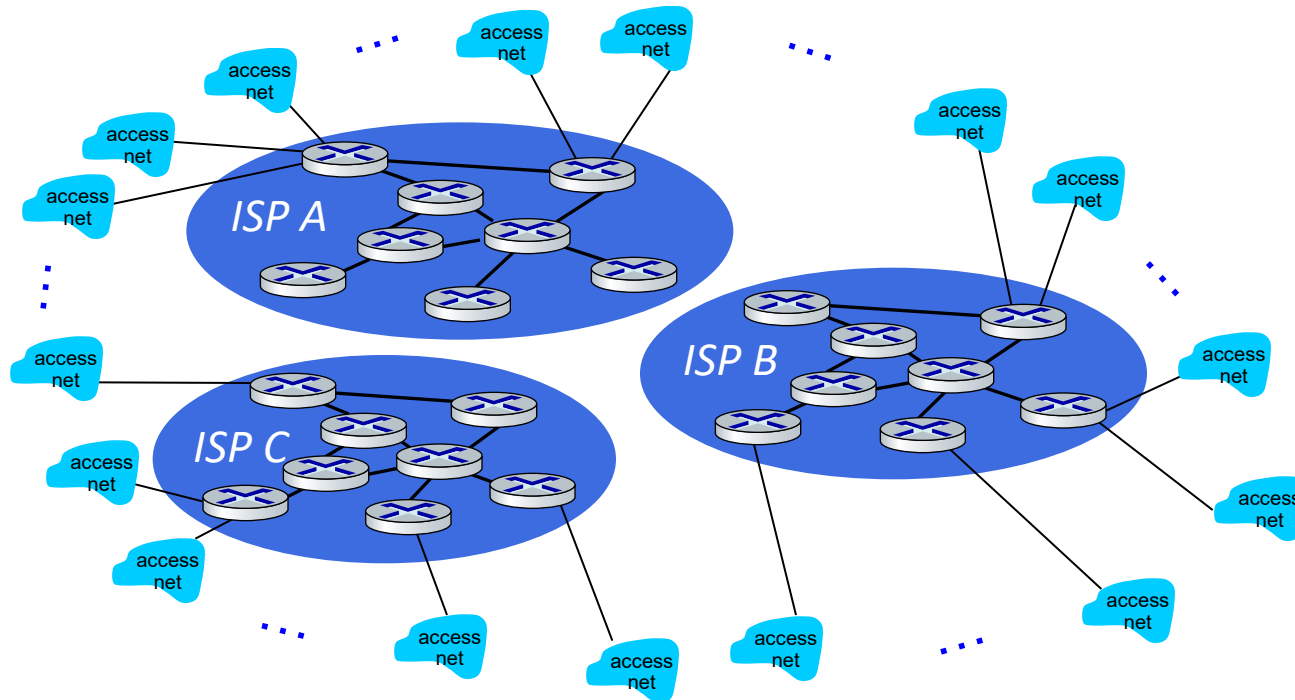
*Option: connect each access ISP to one global transit ISP?*

*Customer and provider ISPs have economic agreement.*



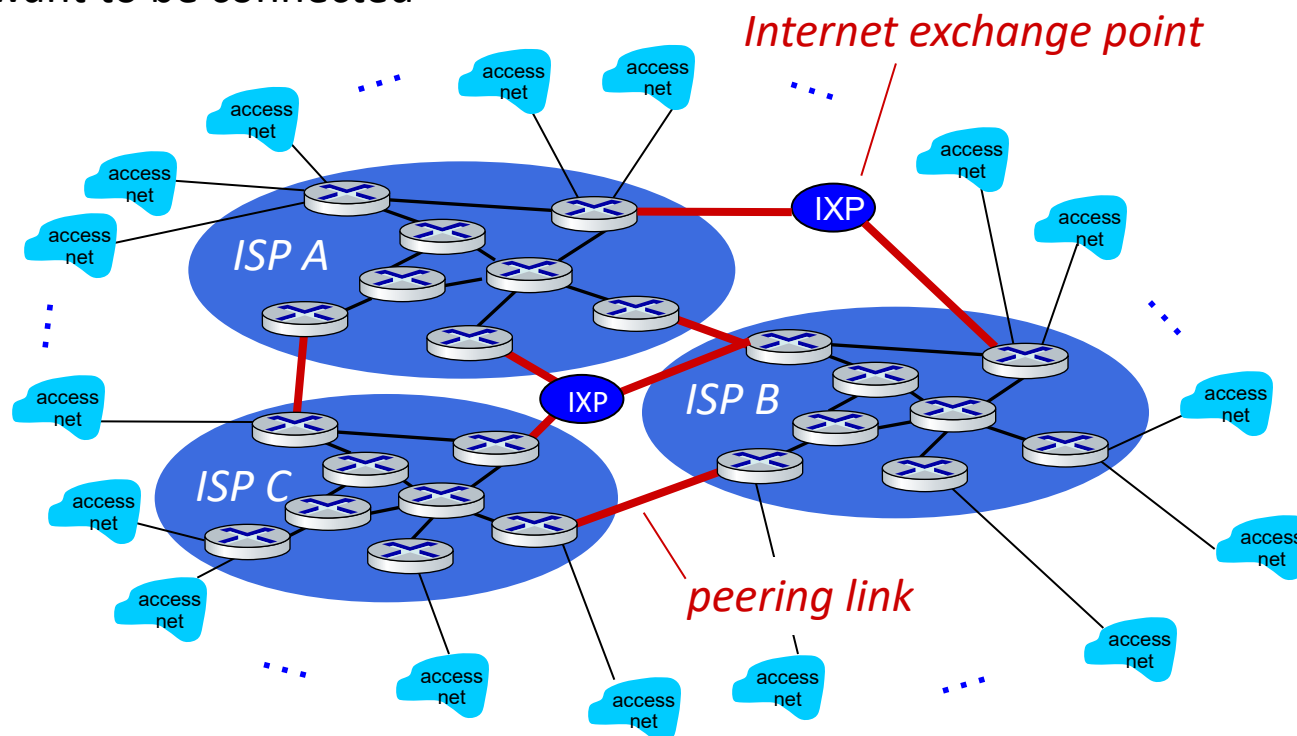
# Internet structure: a “network of networks”

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



# Internet structure: a “network of networks”

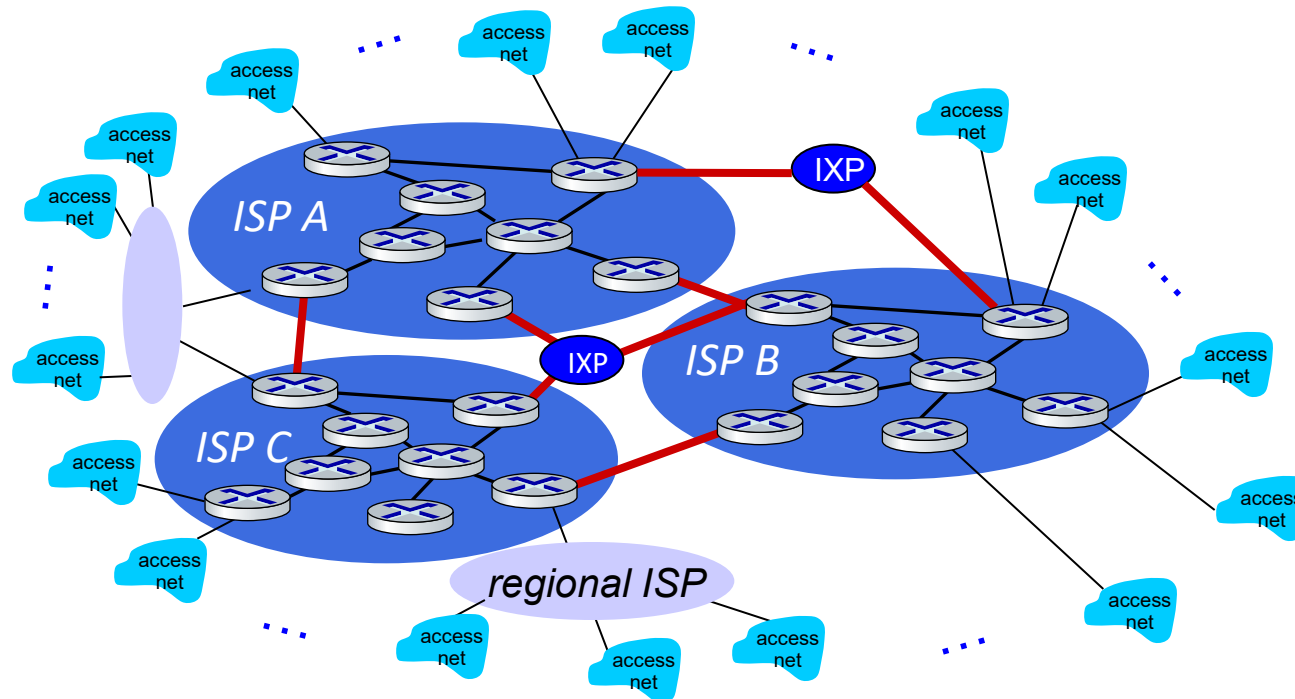
But if one global ISP is viable business, there will be competitors .... who will want to be connected





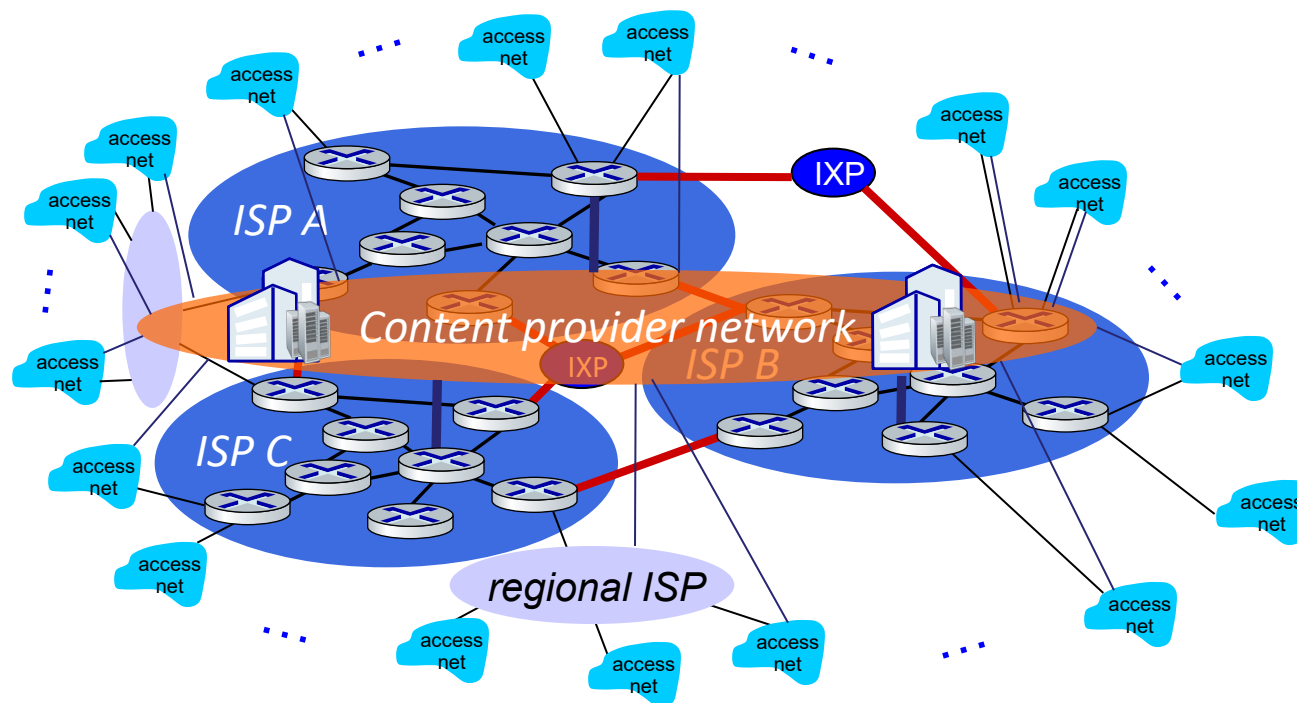
# Internet structure: a “network of networks”

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

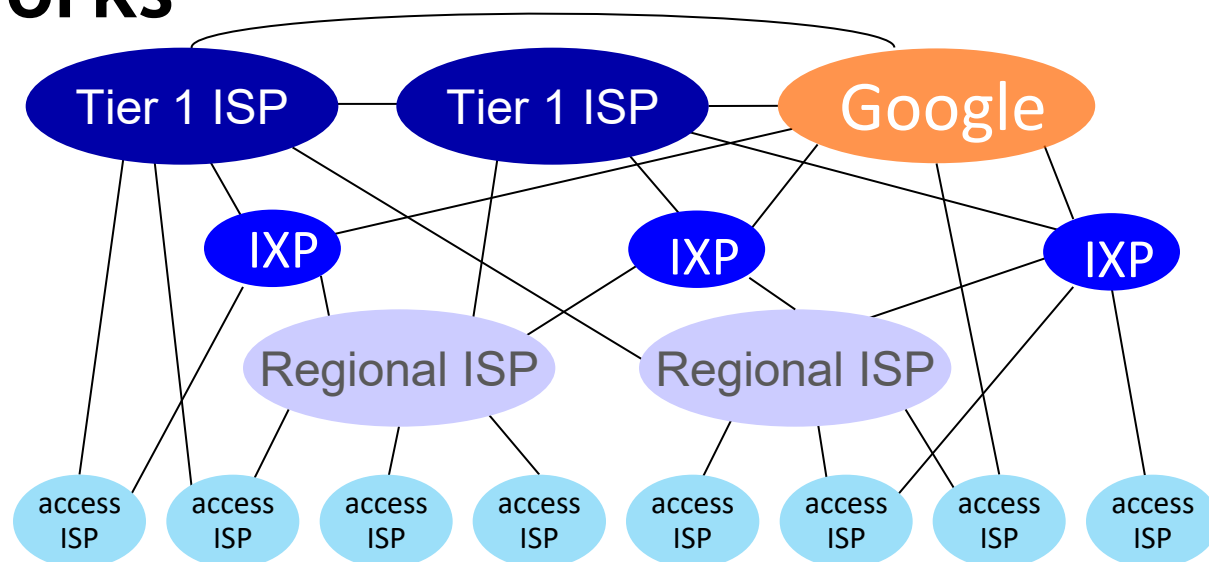


# Internet structure: a “network of networks”

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



# 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

# *Computer Networking: A Top Down Approach*

6<sup>th</sup> edition

Jim Kurose, Keith Ross

Addison-Wesley

March 2012

A note on the origin of these ppt slides:

These slides are freely provided by the book authors and it represents a *lot* of work on their part.  
We would like to thank J.F Kurose and K.W. Ross.

# Protocol “layers”

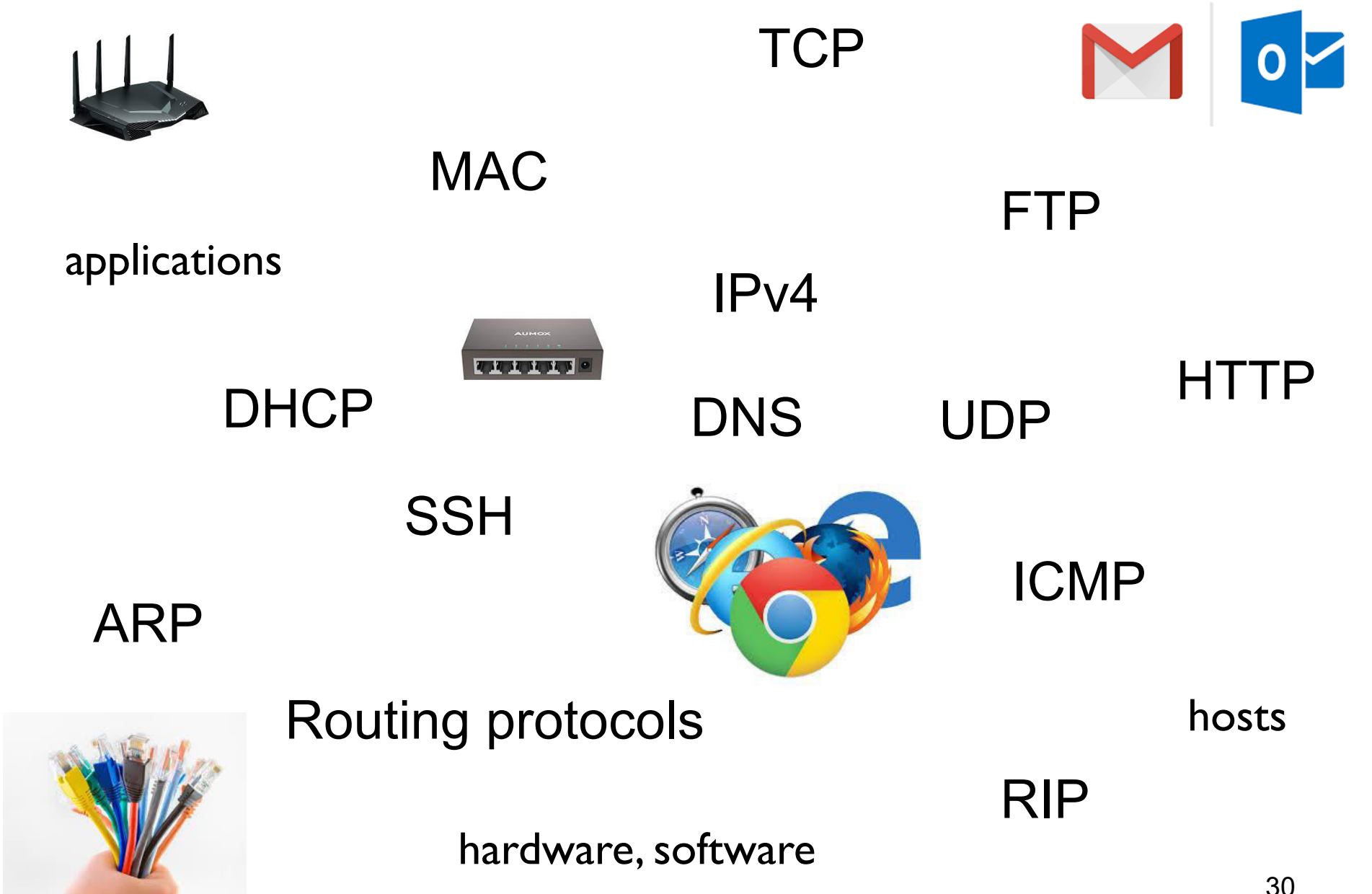
*Networks are complex,  
with many “pieces”:*

- hosts
- routers
- links of various media
- applications
- protocols
- hardware, software

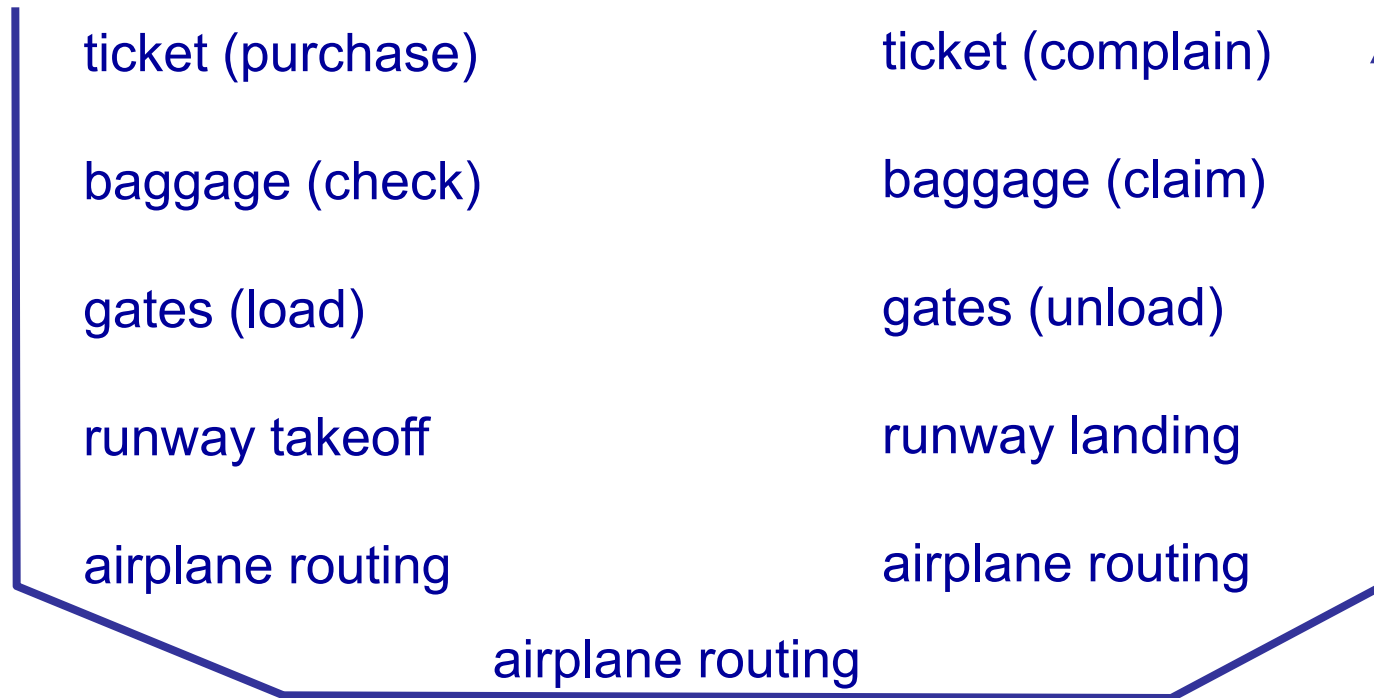
*Question:*

is there any way of  
*organizing* structure of  
network?

.... or at least our  
discussion of networks?

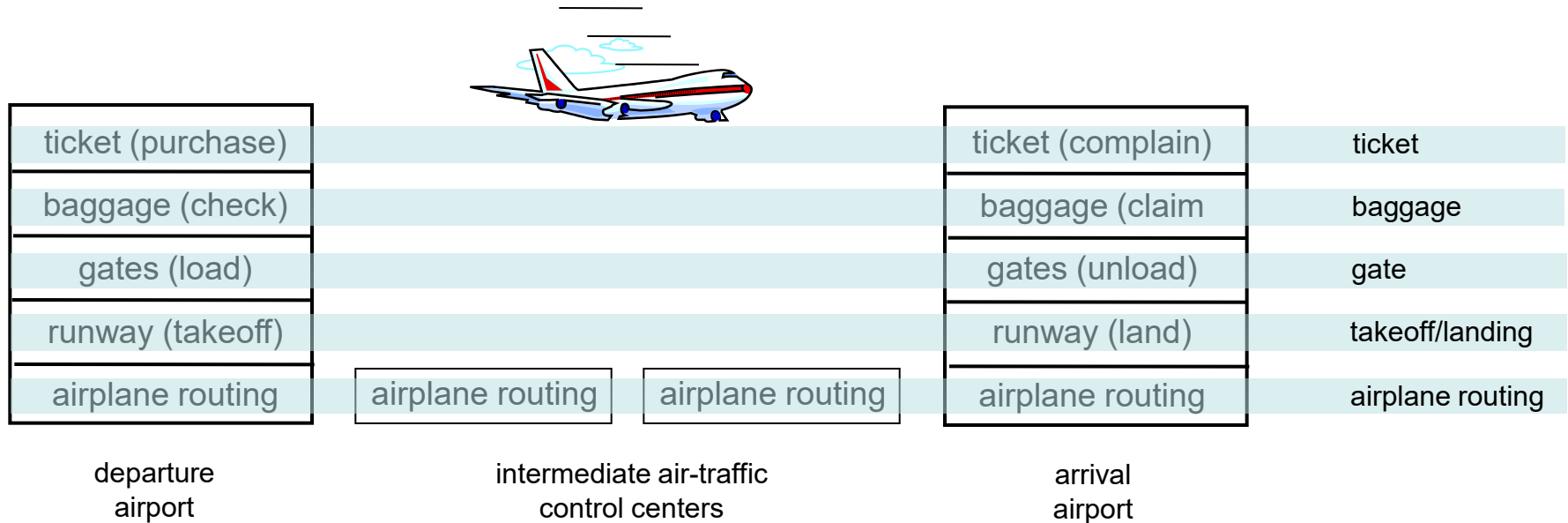


# Organization of air travel



- a series of steps

# Layering of airline functionality



**layers:** each layer implements a service

- via its own internal-layer actions
- relying on services provided by layer below



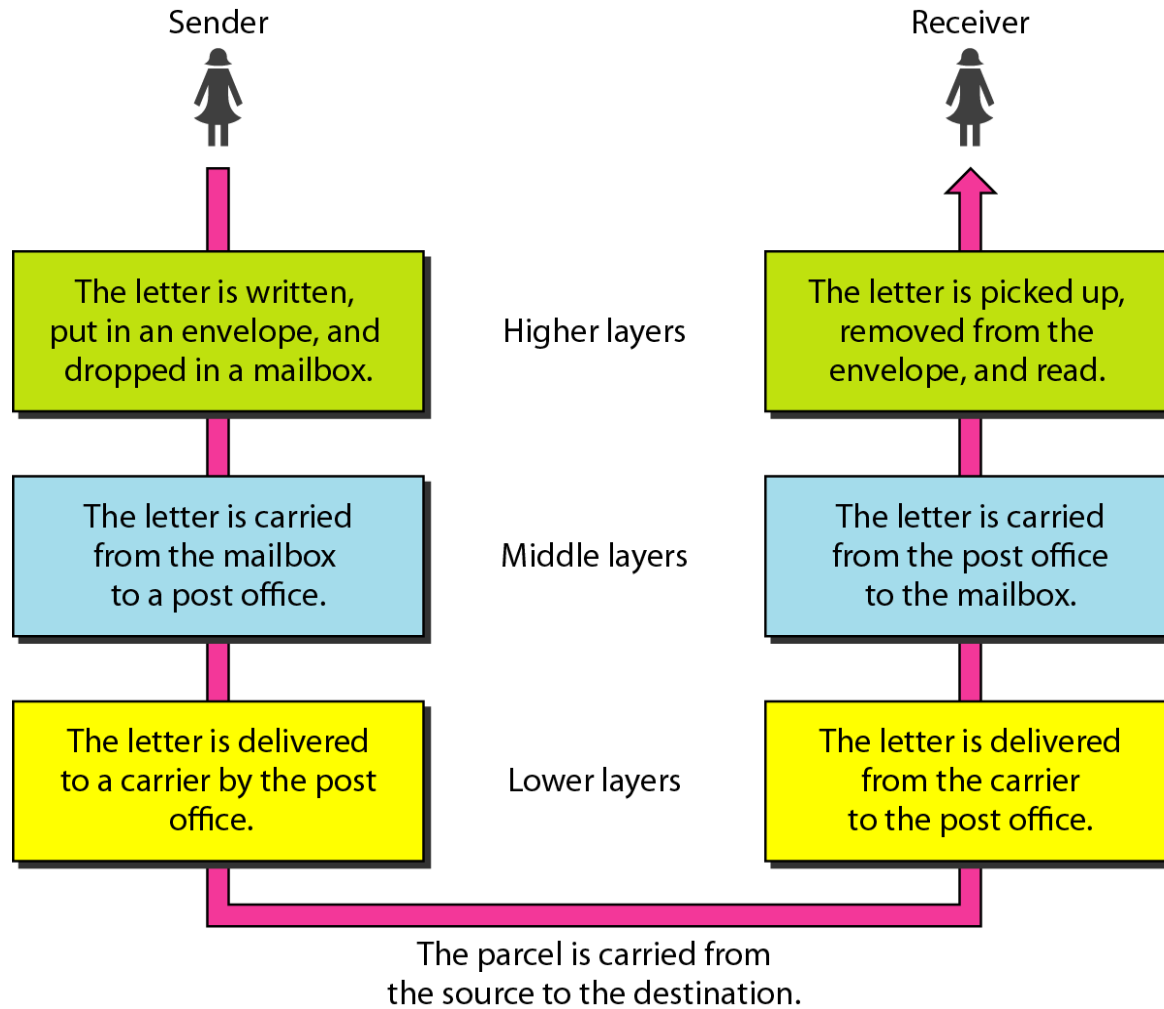
# Why layering?

dealing with complex systems:

- modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g., change in gate procedure doesn't affect rest of system
- Led to flexibility in modifying and developing network architectures.
- Accommodates incremental changes.

*We use the concept of **layers** in our daily life. As an example, let us consider two friends who communicate through postal mail. The process of sending a letter to a friend would be complex if there were no services available from the post office.*

# Tasks involved in sending a letter



# Internet protocol stack

- *application*: supporting network applications
  - FTP, SMTP, HTTP
- *transport*: process-process data transfer
  - TCP, UDP
- *network*: routing of datagrams from source to destination
  - IP, routing protocols
- *link*: data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical*: bits “on the wire”

