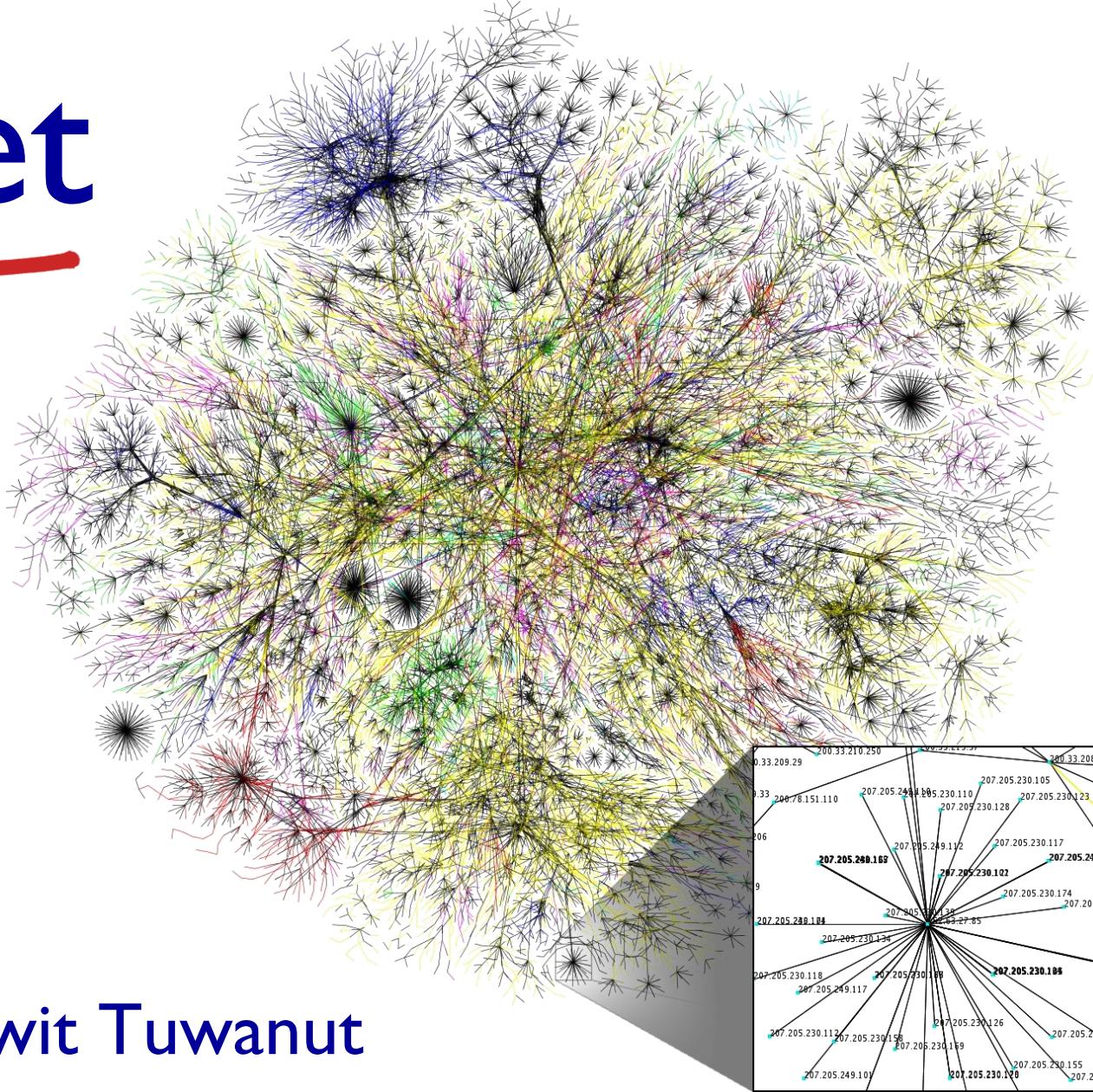


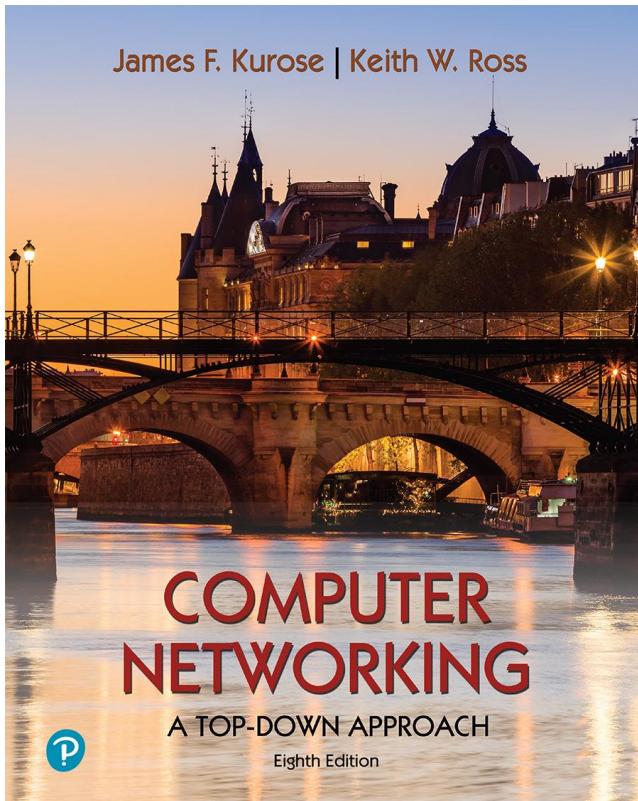
# Internet

# Assoc.Prof. Panwit Tuwanut



# Reference

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## *Computer Networking: A Top-Down Approach*

8<sup>th</sup> edition

Jim Kurose, Keith Ross  
Pearson, 2020

### Chapter 1. Introduction

# I. What *is* the Internet?

- ❖ There are a couple of ways to answer this question.

ດែលឱ្យទាំងអស់, Hw. + Sfn. នៅវគ្គបានក្រោម

- ❖ First, we can describe the nuts and bolts of the Internet, that is, the basic hardware and software components that make up the Internet.

## ການໃຫ້ຂໍ້ຕົກລາງ API

- ❖ **Second**, we can describe the Internet in terms of a networking infrastructure that provides services to distributed applications.

**nuts and bolts** เป็น สำนวน แปลว่า หลักปฏิบัติขึ้นพื้นฐาน

# What's the Internet: “nuts and bolts” view

- ❖ The Internet is a computer network that interconnects **billions of computing devices** throughout the world.
- ❖ Not too long ago, these **computing devices** were primarily traditional desktop PCs, Linux workstations, and so-called **servers that store and transmit information** such as Web pages and e-mail messages.
- ❖ Increasingly, however, **nontraditional Internet end systems** such as laptops, smart phones, tablets, TVs, gaming consoles, Web cams, automobiles, environmental sensing devices, picture frames, and home electrical and security systems are being connected to the Internet.

# “Fun” Internet-connected devices

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Amazon Echo



Internet refrigerator



Security Camera



Internet phones



IP picture frame



Slingbox: remote control cable TV



Gaming devices



Pacemaker & Monitor



Web-enabled toaster + weather forecaster



sensorized bed mattress



Fitbit



diapers



Tweet-a-watt:  
monitor energy use



bikes



cars



scooters

Others?

# What's the Internet: “nuts and bolts” view

---

Indeed, the term *computer network* is beginning to sound a bit dated, given the many nontraditional devices that are being hooked up to the Internet.

Laptop, PC, Smartphone → Hosts

- ❖ In Internet jargon, all of these devices are called **hosts** or **end systems**. As of Sep 2021, there were billions of end systems attached to the Internet, not counting smart phones, laptops, and other devices that are only intermittently connected to the Internet. Overall, more there are an estimated 2 billion Internet users.

Jargon ແປລຈ່າ ຄັ້ງທີ່ເຊີມ

# What's the Internet: “nuts and bolts” view



Billions of connected computing *devices*:

- *hosts* = end systems
  - running network *apps* at Internet's “edge”

**Packet switches:** forward packets (chunks of data)

- ### ■ *routers, switches*

## **Communication links**

- fiber, copper, radio, satellite
  - transmission rate: *bandwidth*

ခုခွန်အရဆောင်ရွက်ခဲ့သူ (Fiber Optic)

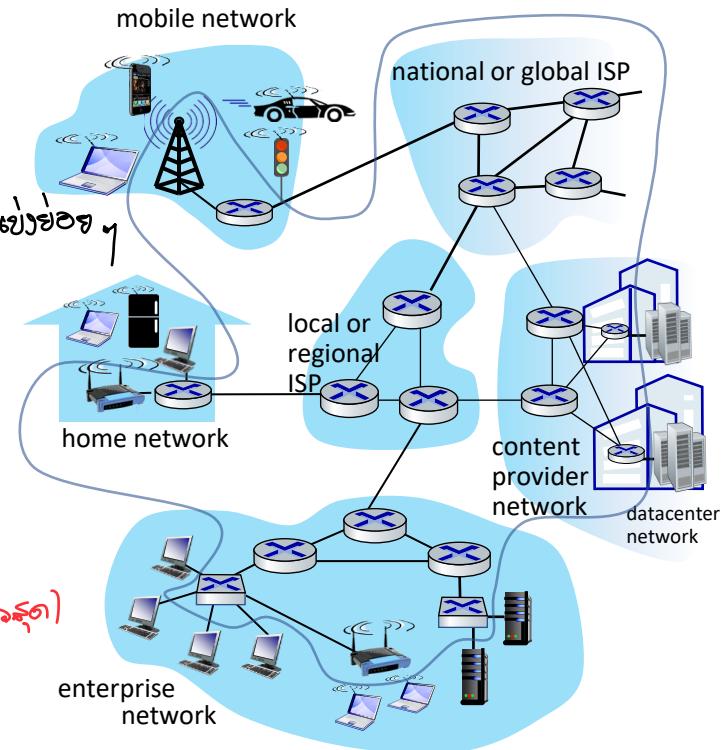
# Networks

- collection of devices, routers, links: managed by an organization

## Internet (work)

## ↓ Network ମାନ୍ୟତା

↳ computer selects



# What's the Internet: “nuts and bolts” view

- ❖ End systems are connected together by a network of **communication links** and **packet switches**. that there are many types of communication links, which are made up of different types of physical media, including **coaxial cable**, **copper wire**, **optical fiber**, and **radio spectrum**.
- ❖ Different links can transmit data at different rates, with the **transmission rate** of a link measured in bits/second.

# What's the Internet: “nuts and bolts” view

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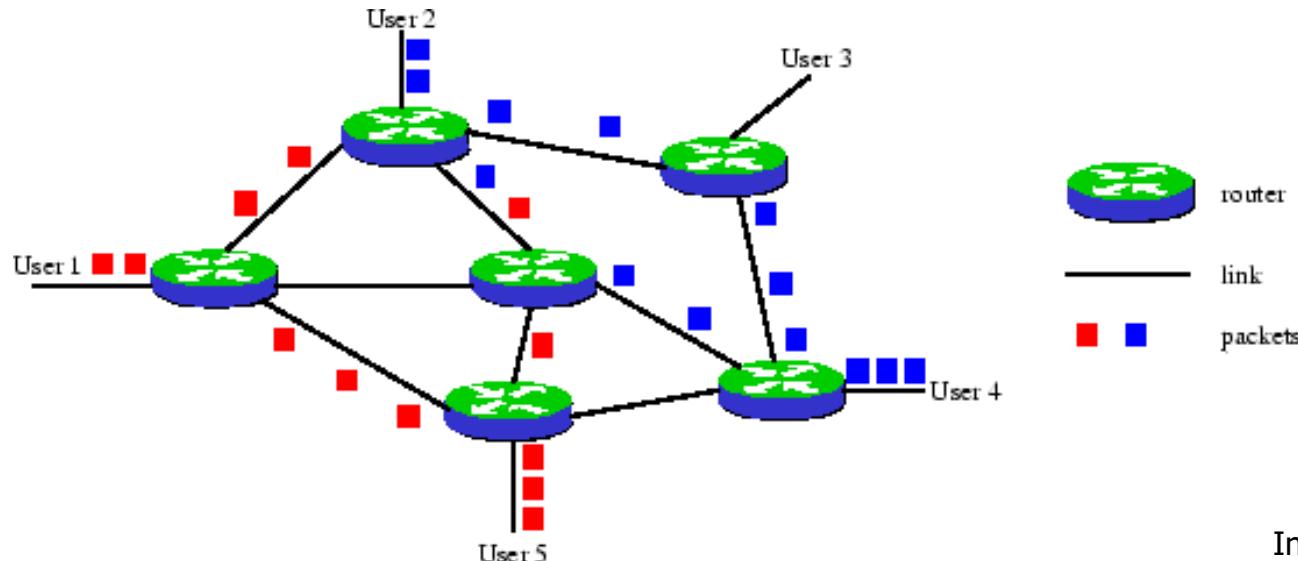
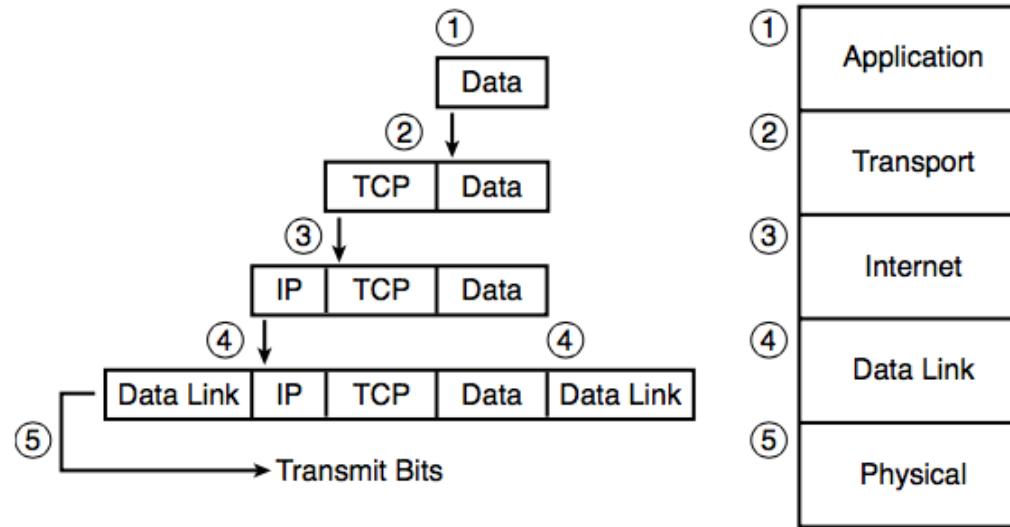
- ❖ When one end system has data to send to another end system, the sending end system segments the data and adds header bytes to each segment.

ແນວ **header** ຖະການສ້າງຈົມຂຶ້ນ ເລີ່ມຕົ້ນໄຕ  $\rightarrow$  ເຮັດວຽກວິທະຍາ **Packet**

- ❖ The resulting packages of information, known as **packets** in the jargon of computer networks, are then sent through the network to the destination end system, where they are reassembled into the original data.

# Encapsulation

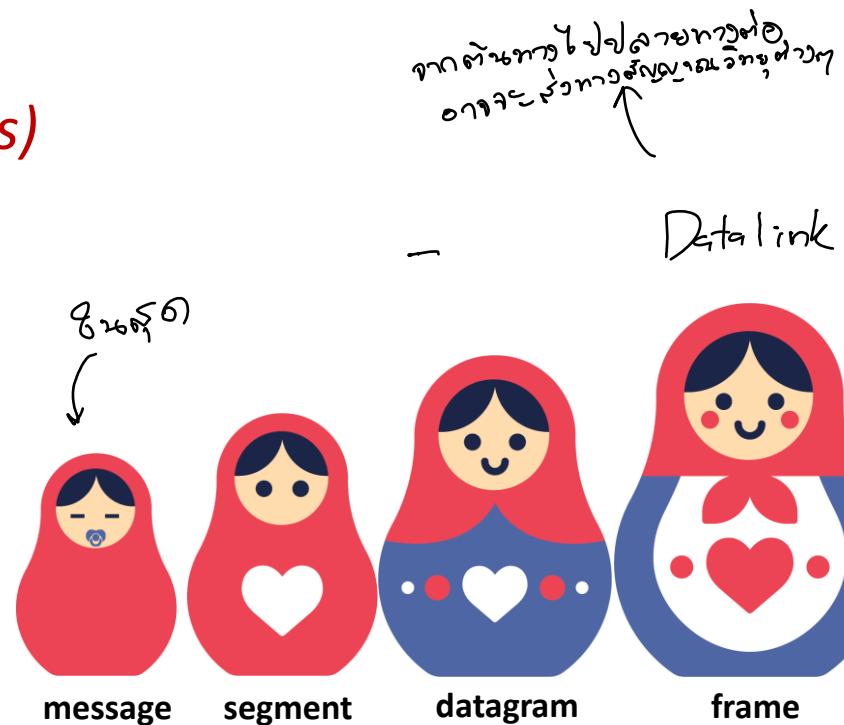
ក្រឡាសំណង់ទិន្នន័យ  
header និង body



# Encapsulation

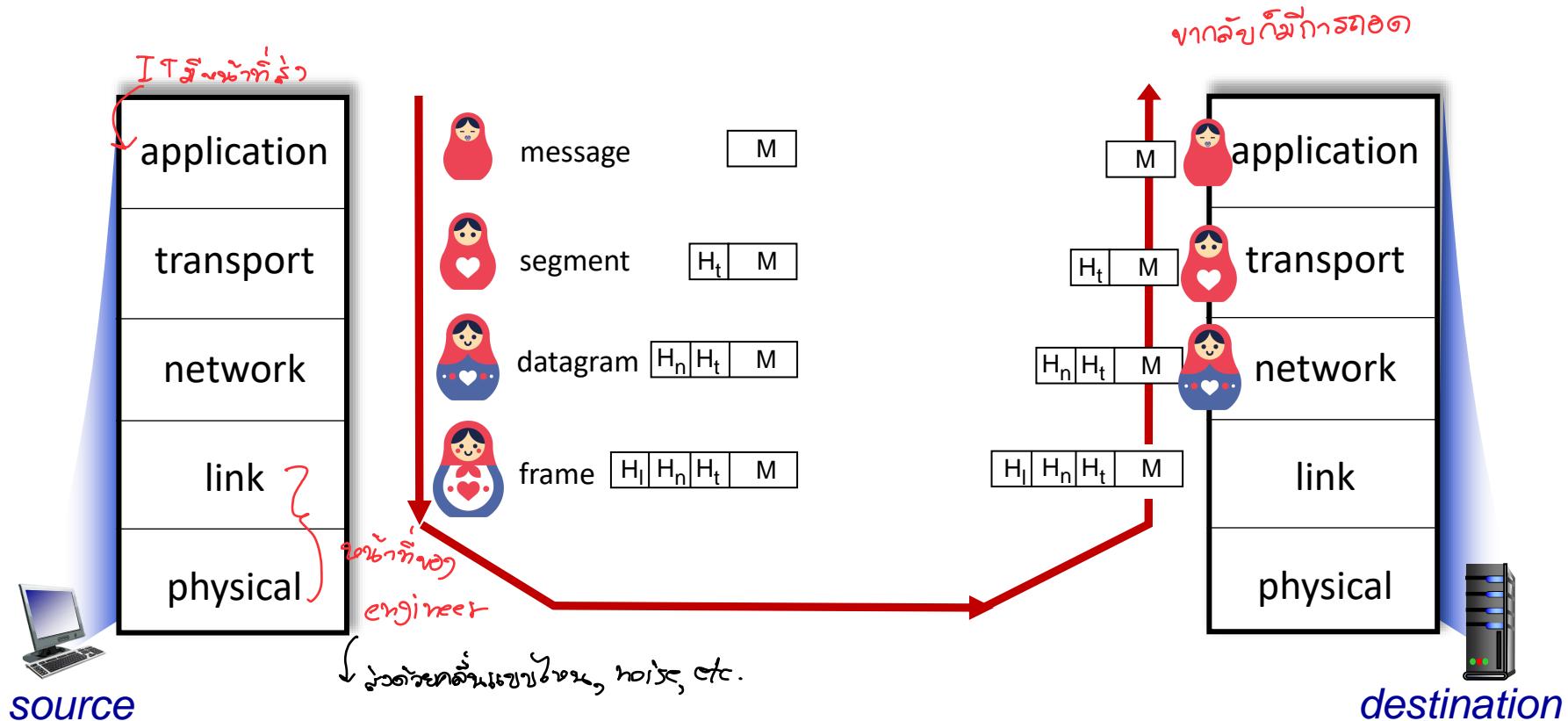
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*Matryoshka dolls (stacking dolls)*



Credit: <https://dribbble.com/shots/7182188-Babushka-Boi>

# Services, Layering and Encapsulation



# What's the Internet: “nuts and bolts” view

A switch & Router

ຫຼັບ Packet ແລະ ລັດຕ່າງຈະສ້າງໄປໄກຂີ

A packet switch takes a packet arriving on one of its incoming communication links and forwards that packet on one of its outgoing communication links.

Packet switches come in many shapes and flavors, but the two most prominent types in today's Internet are **routers** and **link-layer switches**.

- ❖ Both types of switches forward packets toward their ultimate destinations. **Link-layer switches** are typically used in **access networks**, while **routers** are typically used in the **network core**. \*\*

# What's the Internet: “nuts and bolts” view

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The sequence of communication links and packet switches traversed by a packet from the sending end system to the receiving end system is known as a **route or path** through the network.

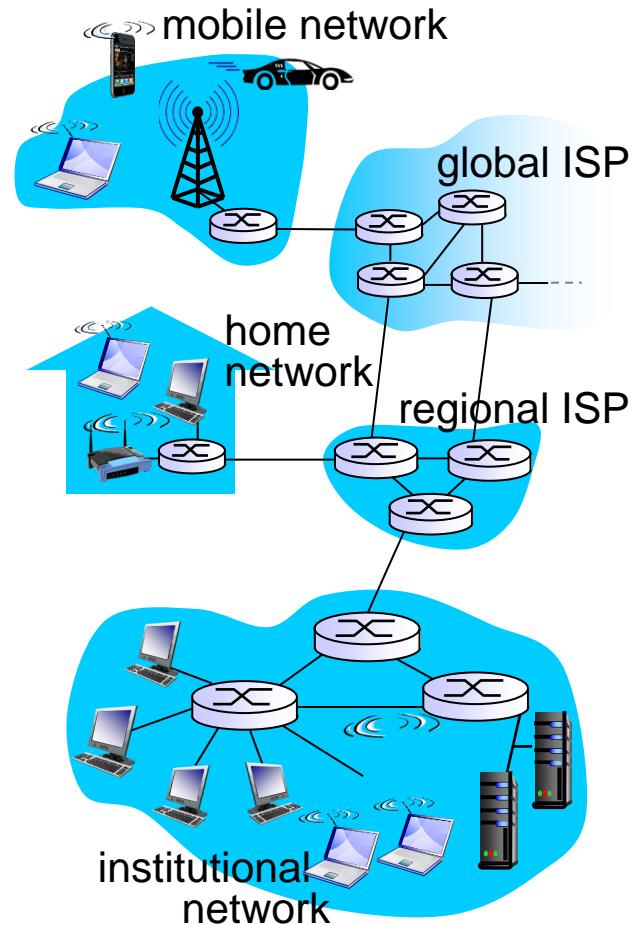
ISPs; → True, 3BB, etc.

- ❖ End systems access the Internet through **Internet Service Providers (ISPs)**, including residential ISPs such as local cable or telephone companies; Corporate ISPs; university ISPs; and ISPs that provide WiFi access in airports, hotels, coffee shops, and other public places.

# What's the Internet: “nuts and bolts” view

Each ISP is in itself a network of packet switches and communication links. ISPs provide a variety of types of network access to the end systems, including residential broadband access such as cable modem or DSL, high-speed local area network access, wireless access, and 56 kbps dial-up modem access.

- ❖ ISPs also provide Internet access to **content providers**, connecting Web sites directly to the Internet. The Internet is all about connecting end systems to each other, so the ISPs that provide access to end systems must also be interconnected.

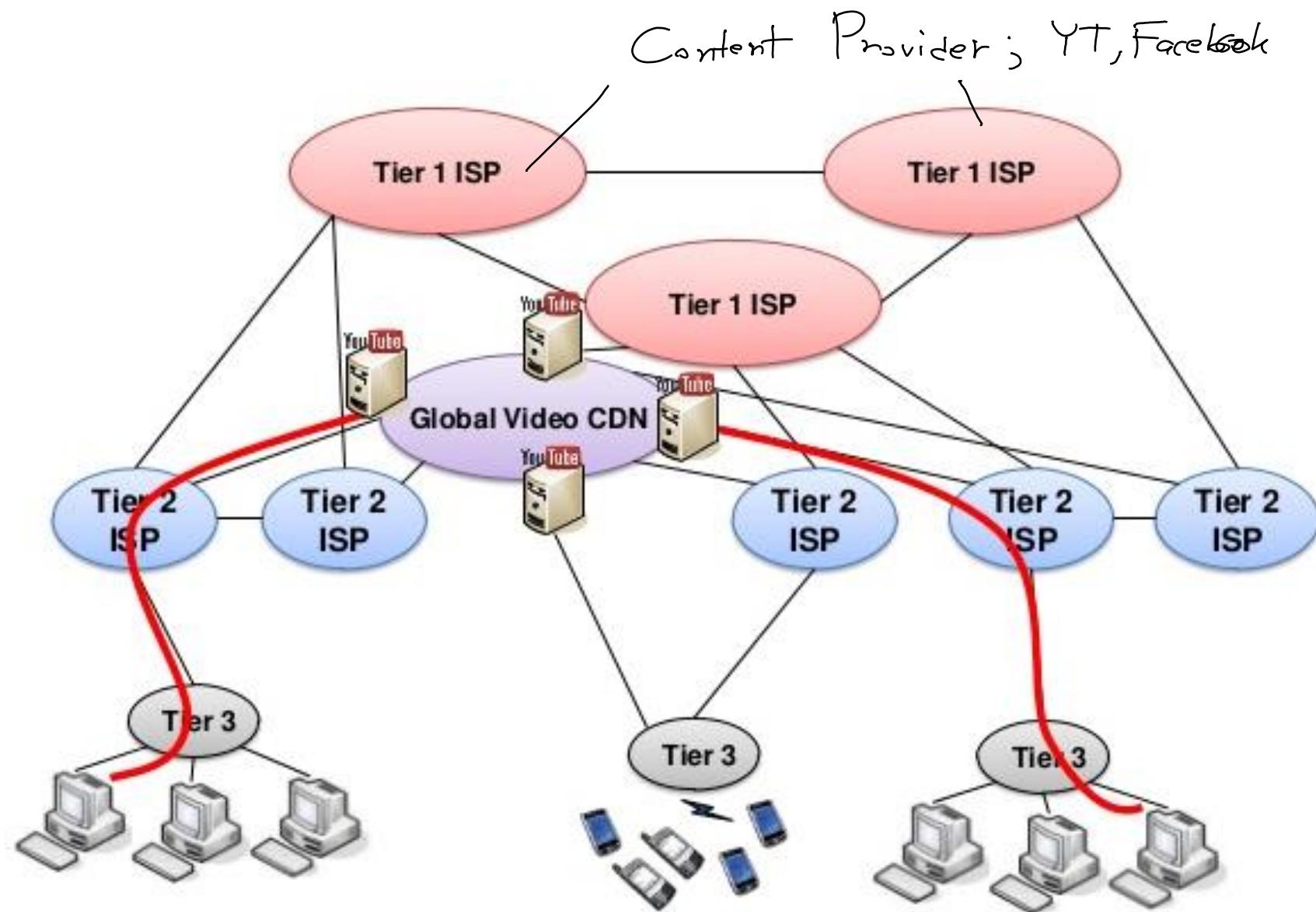


# What's the Internet: “nuts and bolts” view

- ❖ These lower-tier ISPs are interconnected through national and international upper-tier ISPs such as Level 3 Communications (USA), AT&T (USA), Sprint (USA), and NTT(Japan).
- ❖ An upper-tier ISP consists of high-speed routers interconnected with high-speed fiber-optic links. Each ISP network, whether upper-tier or lower-tier, is managed independently, runs the **IP protocol**, and conforms to certain naming and address conventions.

protocol = វិធានក្រោងកំណត់របៀបទាមរឿងដែលបានគេប្រើប្រាស់

e.g. ធនធានអាមេរិក, protocol កំណត់របៀបទាមរឿងដែលបានគេប្រើប្រាស់  
នៅពេលសេវាអ៊ីនេर៉ង, ឥឡូវ, AT&T, NTT, etc.



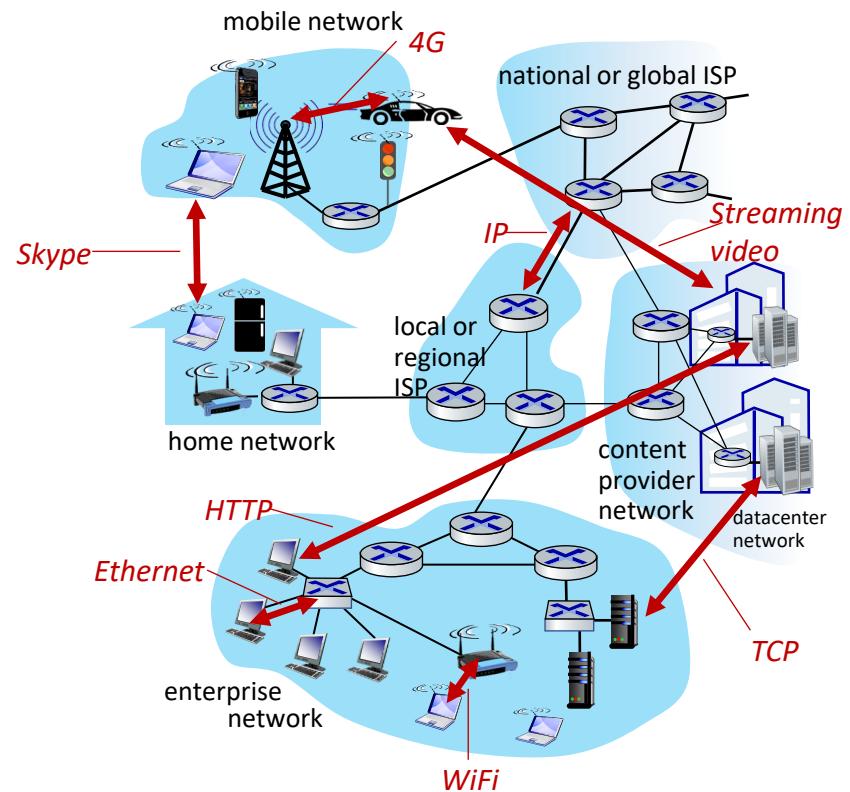
# List of Tier 1 networks

Name	Headquarters	AS number	CAIDA AS rank <sup>[10]</sup>	Fiber route (km)	Peering policy
AT&T <sup>[11]</sup>	United States	7018	26	660,000 <sup>[12]</sup>	AT&T Peering policy ↗
Comcast <sup>[13]</sup>	United States	7922	31	150,000 <sup>[14]</sup>	Comcast Interconnection Policy ↗
Deutsche Telekom Global Carrier <sup>[15]</sup>	Germany	3320	19	250,000 <sup>[16]</sup>	DTAG Peering Details ↗
GTT Communications	United States	3257	7	232,934 <sup>[17][18]</sup>	GTT Peering Policy ↗
Liberty Global <sup>[19][20]</sup>	The Netherlands <sup>[21]</sup>	6830	21	800,000 <sup>[22]</sup>	Peering Principles ↗
Lumen Technologies (formerly CenturyLink, formerly Level 3) <sup>[23][24][25]</sup>	United States	3356	1	885,139 <sup>[26][27]</sup>	Lumen Peering Policy ↗
NTT Communications (formerly Verio) <sup>[28]</sup>	Japan	2914	6	?	Global Peering Policy ↗
Orange <sup>[29]</sup>	France	5511	13	495,000 <sup>[30]</sup>	OTI peering policy ↗
PCCW Global	Hong Kong	3491	10	?	Peering policy ↗
T-Mobile US (formerly Sprint) <sup>[31]</sup>	United States	1239	20	30,000 <sup>[32]</sup>	Peering policy ↗
Tata Communications (formerly Teleglobe) <sup>[33]</sup>	India	6453	9	700,000 <sup>[34]</sup>	Peering Policy ↗
Telecom Italia Sparkle (Seabone) <sup>[35]</sup>	Italy	6762	5	560,000	Peering Policy ↗
Arelion (formerly Telia Carrier) <sup>[36]</sup>	Sweden	1299	2	70,000 <sup>[37]</sup>	Arelion's IP Network Peering Policy ↗
Telxius (Subsidiary of Telefónica) <sup>[38]</sup>	Spain	12956	15	65,000 <sup>[39]</sup>	Peering Policy ↗
Verizon Enterprise Solutions (formerly UUNET) <sup>[44]</sup>	United States	701	24	805,000 <sup>[45]</sup>	Verizon UUNET Peering policy 701, 702, 703 ↗
Zayo Group (formerly AboveNet) <sup>[46]</sup>	United States	6461	8	196,339 <sup>[47]</sup>	Zayo Peering Policy ↗

# What's the Internet: “nuts and bolts” view

---

- *Internet: “network of networks”*
  - Interconnected ISPs
- *protocols are everywhere*
  - control sending, receiving of messages
  - e.g., HTTP (Web), streaming video, Skype, TCP, IP, WiFi, 4/5G, Ethernet
- *Internet standards*
  - RFC: Request for Comments
  - IETF: Internet Engineering Task Force



# What's the Internet: “nuts and bolts” view

End Device

- ❖ End systems, packet switches, and other pieces of the Internet run **protocols** that control the sending and receiving of information within the Internet. The **Transmission Control Protocol (TCP)** and the **Internet Protocol (IP)** are two of the most important protocols in the Internet.
- ❖ The IP protocol specifies the format of the packets that are sent and received among routers and end systems.
- ❖ The Internet's principal protocols are collectively known as **TCP/IP**.

# What's the Internet: “nuts and bolts” view

---

- ❖ **Internet standards** are developed by the **Internet Engineering Task Force (IETF)** [IETF 2012].
- ❖ The IETF standards documents are called **requests for comments (RFCs)**. RFCs started out as general requests for comments (hence the name) to resolve network and protocol design problems that faced the precursor to the Internet [Allman 2011].
- ❖ RFCs tend to be quite technical and detailed. They define protocols such as TCP, IP, HTTP (for the Web), and SMTP (for e-mail). There are currently more than 6,000 RFCs.

# Review

- ❖ อุปกรณ์ใดไม่ถือว่าเป็น End systems

Desktop devices

Workstation

Web Server

Environmental sensing

Link-Layer Switch

- ❖ ข้อใดไม่ใช่ Communication Link

Coaxial cable

Copper wire

Optical fiber

Router

Radio wave

- ❖ เอกสาร Requests for comments ออกโดยหน่วยงานใด

IEEE

ITU

IETF

IFET

ANSI

- ❖ จงยกตัวอย่าง Content Provider *FB, YT*

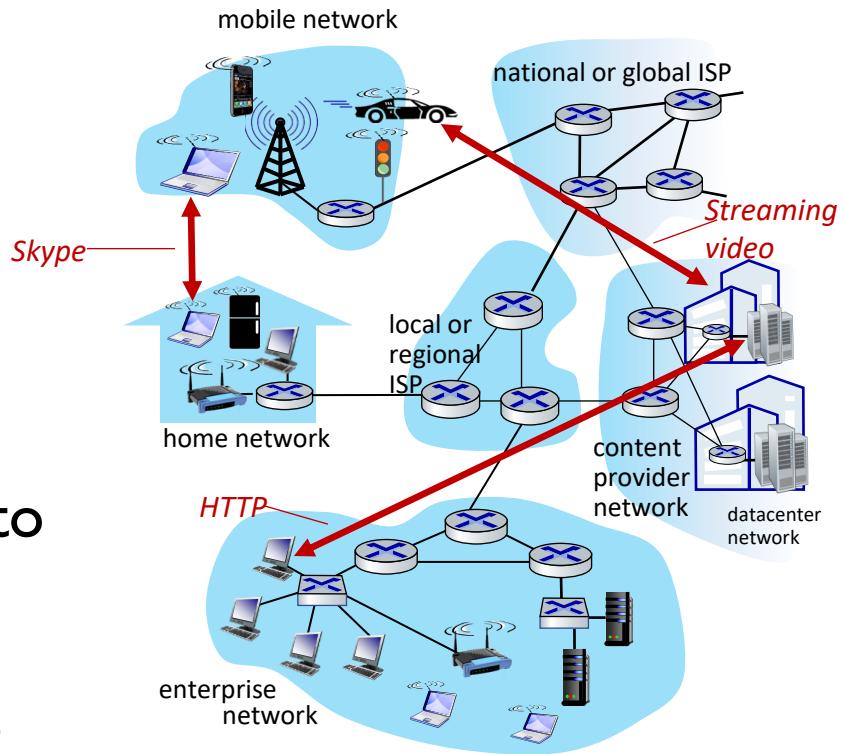
- ❖ What is the difference between a host and an end system? *ตอบเฉลี่ยอีกนึง*

- ❖ List several different types of end systems. *smart phone, laptop*

- ❖ Is a Web server an end system? *Yes  
end device*

# What's the Internet: a service view

- **Infrastructure** that provides services to applications:
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, ...
- provides **programming interface** to distributed applications:
  - “hooks” allowing sending/receiving apps to “connect” to, use Internet transport service
  - provides service options, analogous to postal service

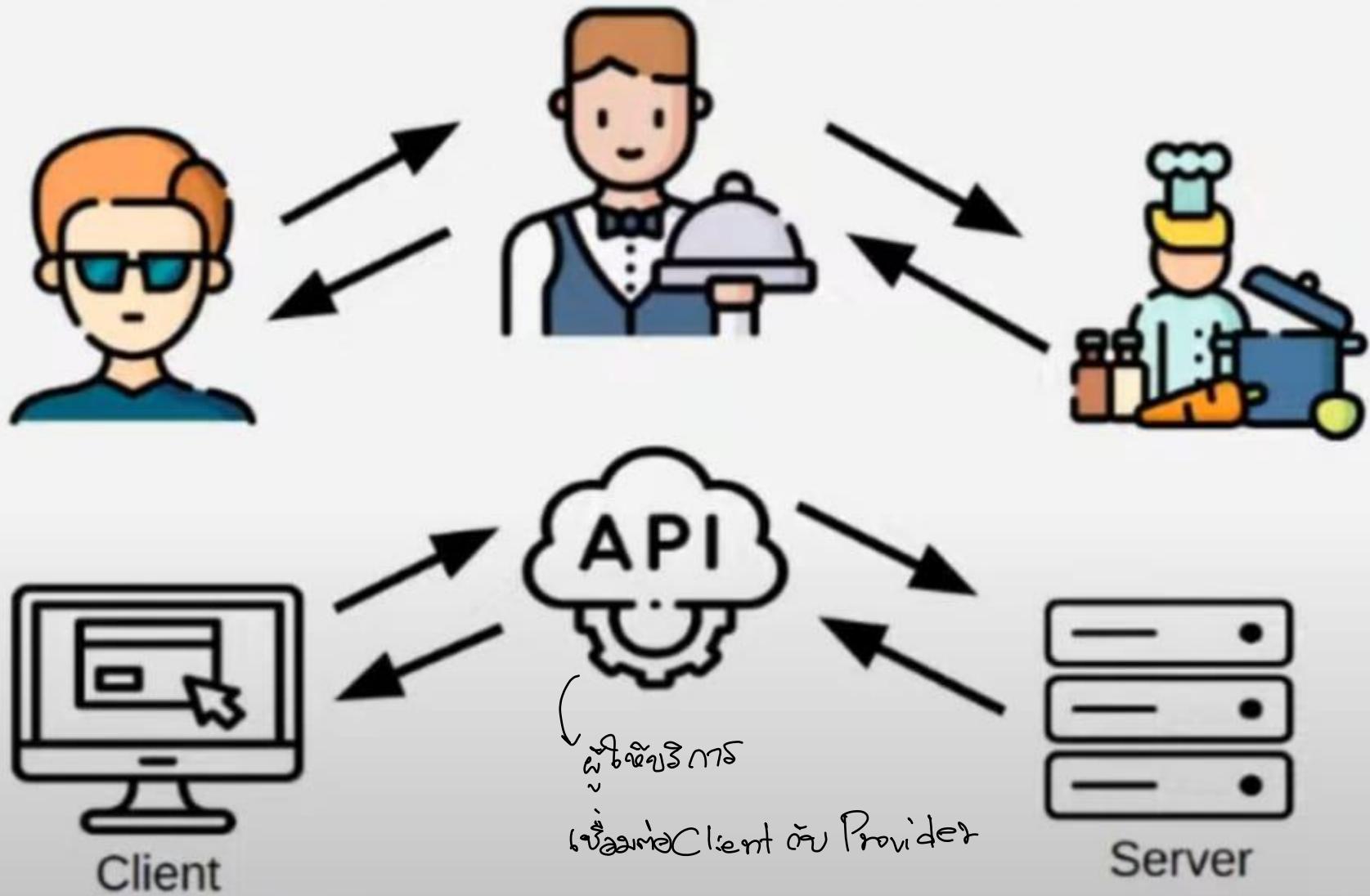


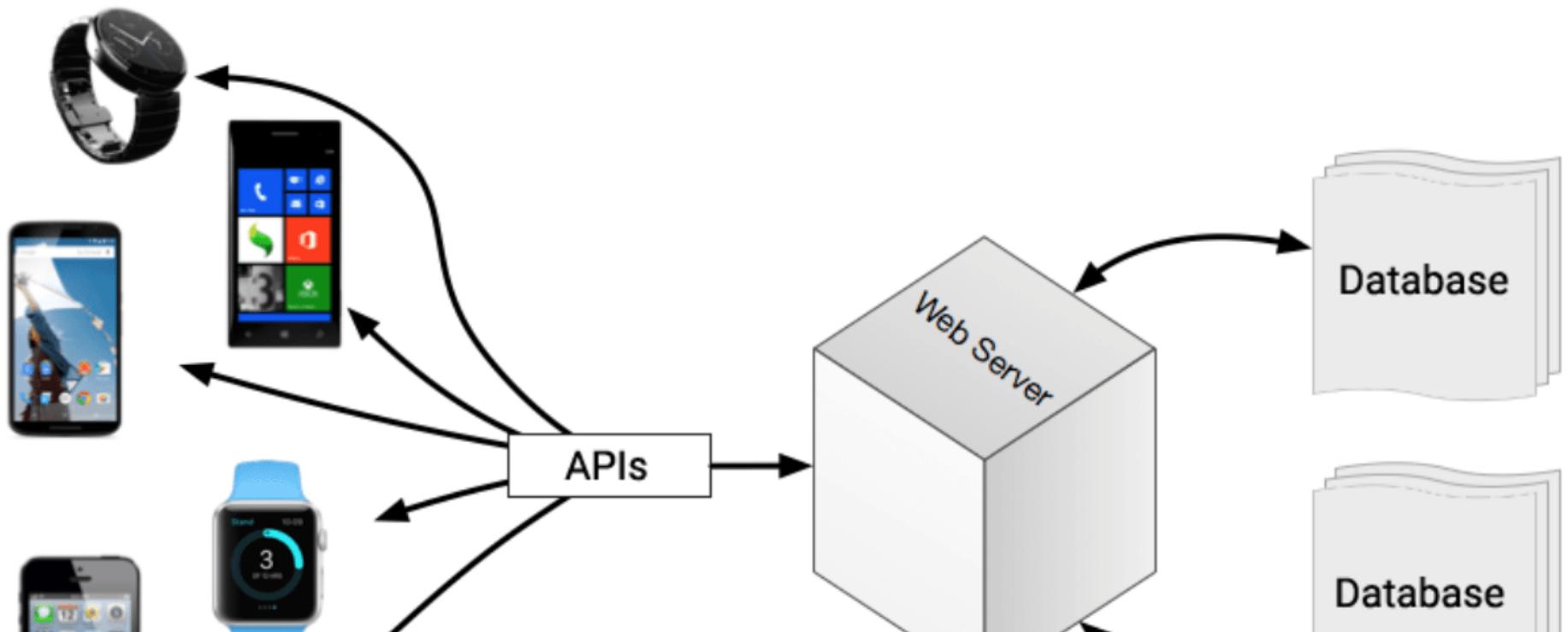
# What's the Internet: a service view

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- ❖ The applications are said to be **distributed applications**, since they involve multiple end systems that exchange data with each other. Importantly, Internet applications run on end systems—they do not run in the packet switches in the network core.
- ❖ End systems attached to the Internet provide an **Application Programming Interface (API)** that specifies how a program running on one end system asks the Internet infrastructure to deliver data to a specific destination program running on another end system.
- ❖ Example: Alice wants to send a letter to Bob using the postal service. drop the envelope into an official postal service mailbox

Thus, the postal service has its own “postal service API,” or set of rules, that Alice must follow to have the postal service deliver her letter to Bob.





**Payment APIs  
Geolocation APIs  
Chat APIs**

...

## 2. 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

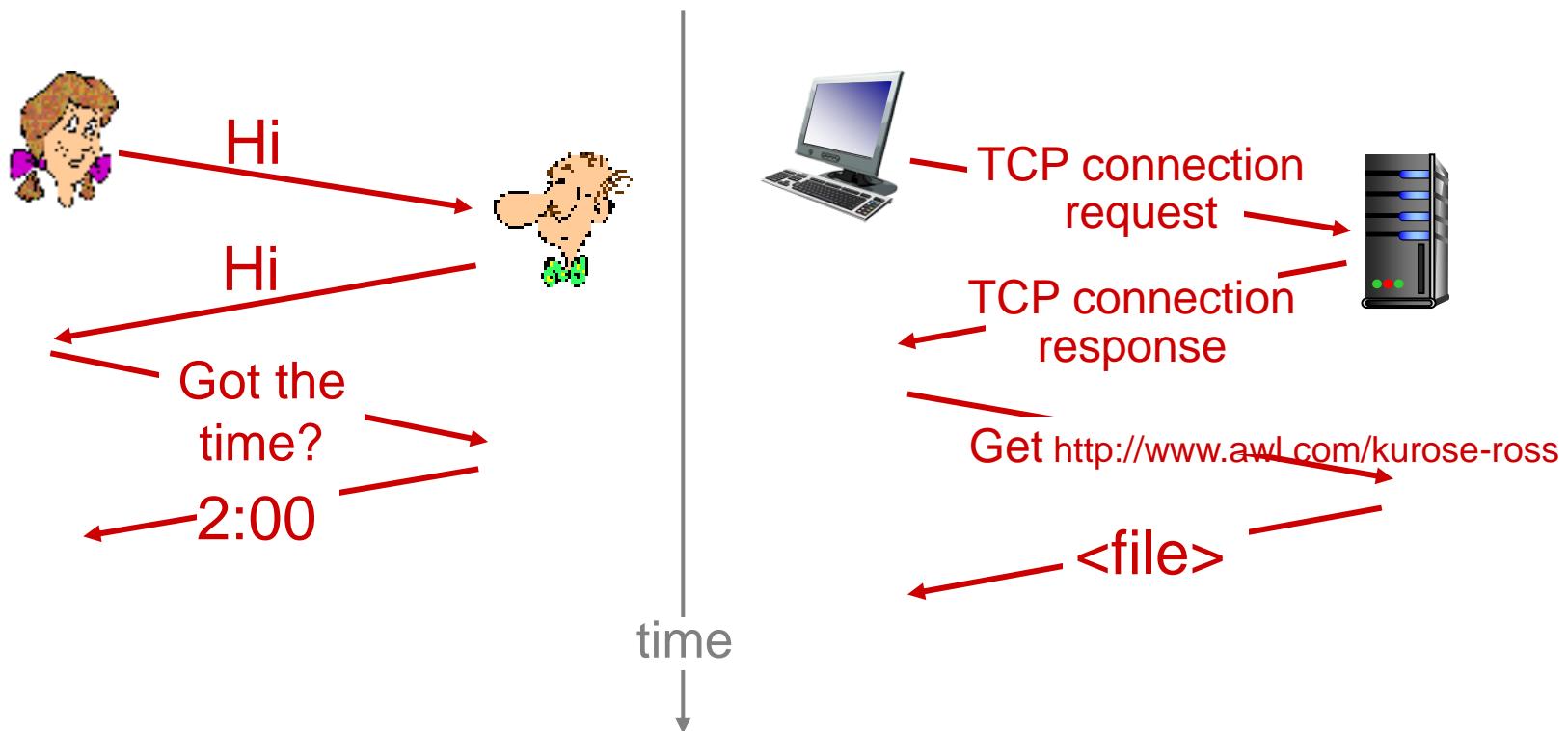
### *network protocols:*

- ❖ 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*

# What's a protocol?

a human protocol and a computer network protocol:



Q: other human protocols?

### 3. Network Edge

Device នៃពេលវេលា Internet

- ❖ We begin in this section at the **edge of a network** and look at the components with which we are most familiar—namely, the **computers, smartphones and other devices that we use on a daily basis**.
- ❖ Furthermore, an increasing number **of non-traditional devices** are being attached to the Internet as end systems
- ❖ IP-enabled phones with GPS capabilities put location-dependent services (maps, information about nearby services or people) at your fingertips. Networked sensors embedded into the physical environment allow monitoring of buildings, bridges, seismic activity, wildlife habitats, river estuaries, and the weather. Biomedical devices can be embedded and networked in a body-area network. With so many diverse devices being networked together, the Internet is indeed becoming an “**Internet of things**” [ITU 2005b].
- ❖ In the next section we’ll move from the network edge to the **network core** and examine **switching and routing** in computer networks.

↓ IoT

# Network Edge

---

- ❖ End systems are also referred to as *hosts* because they host (that is, run) application programs such as a Web browser program, a Web server program, an e-mail client program, or an e-mail server program. Throughout this book we will use the terms hosts and end systems interchangeably; that is, *host = end system*.

ବ୍ୟୁତିପରିକଳନ

ବ୍ୟୁତିପରିକଳନ

- ❖ Hosts are sometimes further divided into two categories: **clients** and **servers**. Informally, clients tend to be desktop and mobile PCs, smart phones, and so on, whereas servers tend to be more powerful machines that store and distribute Web pages, stream video, relay e-mail, and so on.
- ❖ Today, most of the servers from which we receive search results, e-mail, Web pages, and videos reside in large **data centers**. For example, Google has 30–50 data centers, with many having more than one hundred thousand servers.



მერაბ გეორგიავარდიშვილი  
უნივერსიტეტი  
ერთეული 24 წელი

## Google data centers

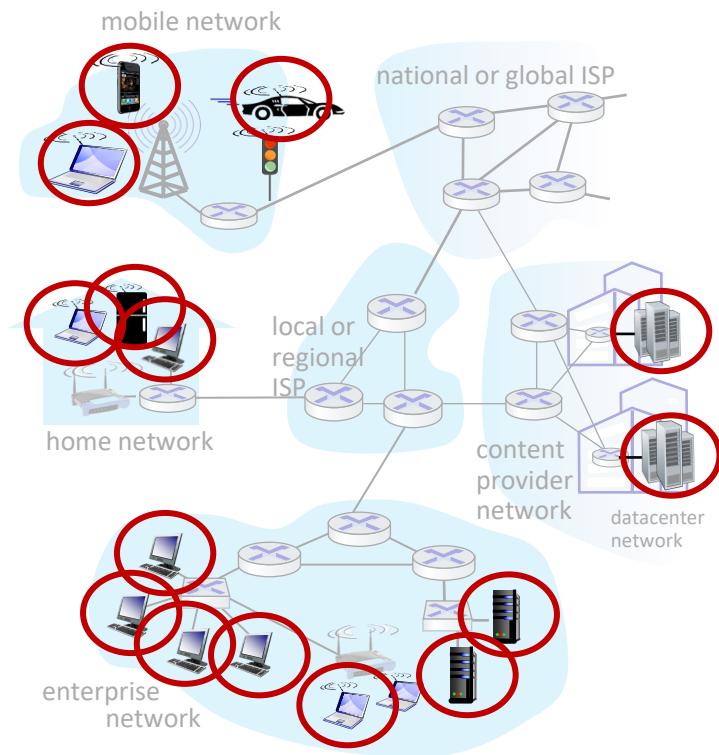


# A closer look at Internet structure

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## Network edge:

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



# A closer look at Internet structure

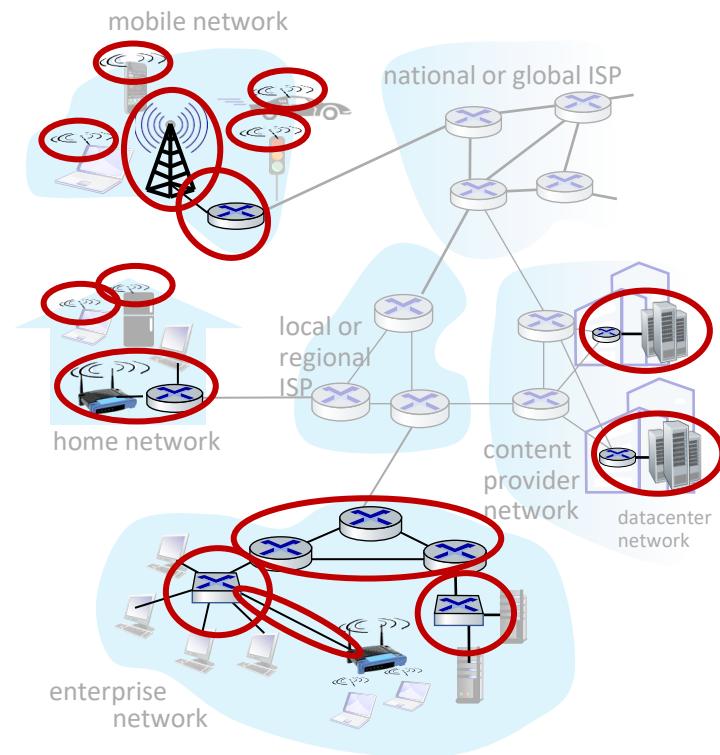
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## Network edge:

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

## Access networks, physical media:

- **wired, wireless communication links**



# A closer look at Internet structure

## Network edge:

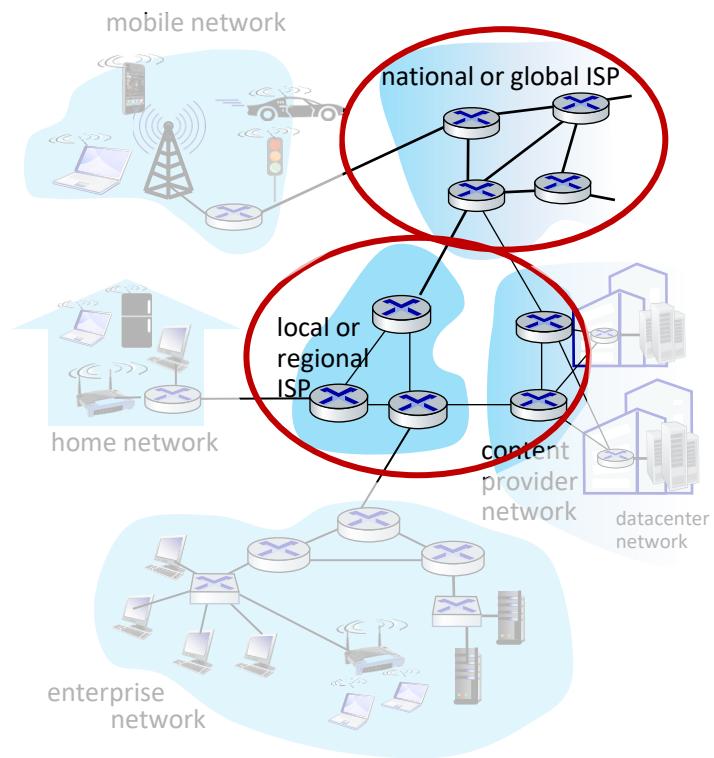
- hosts: clients and servers
- servers often in data centers

## Access networks, physical media:

- wired, wireless communication links

## Network core:

- interconnected routers
- network of networks



# 4. Access networks and physical media

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

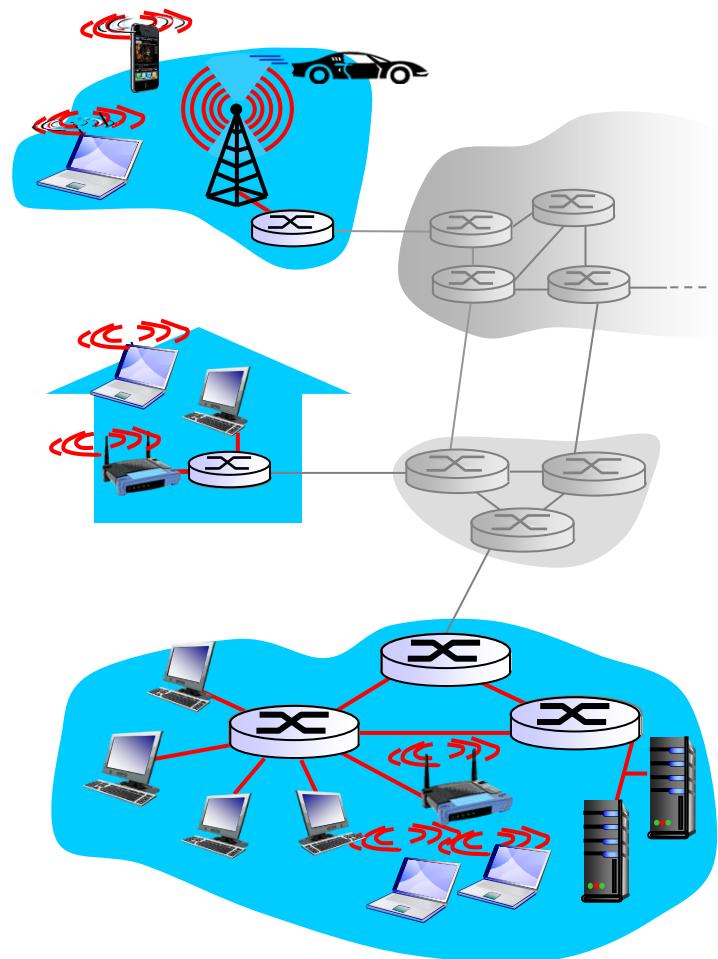
- ❖ residential access nets
- ❖ institutional access networks (school, company)
- ❖ mobile access networks

*keep in mind:*

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

សំគាល់ពាក្យ, ការបិទមិនាំង  
ឱ្យរាជ្យក្នុងភាគខាងក្រោម → នឹងមែនមួយចំណែកផ្តល់ជូន

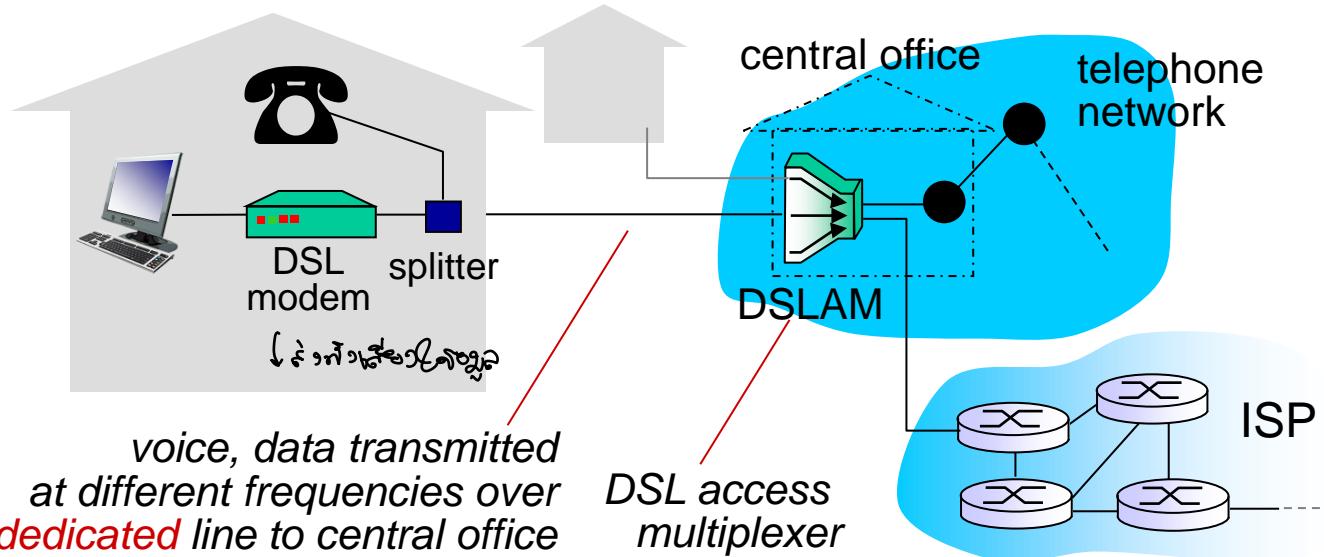
ក្នុងខេត្តឈរឈរ, → Bandwidth ខ្ពស់



# Access networks and physical media

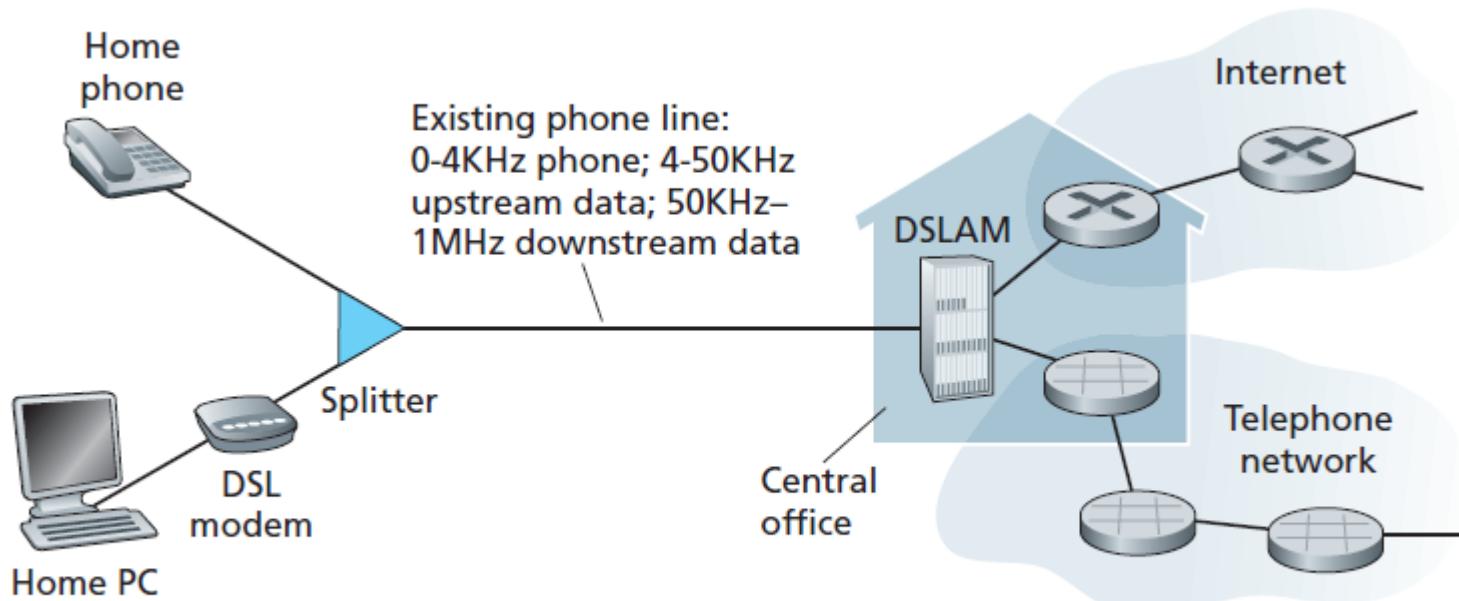
- ❖ **Access Network**
  - ❖ **Home Access:** DSL, Cable, FTTH, Dial-Up, and Satellite
  - ❖ **Access in the Enterprise (and the Home):** Ethernet and WiFi
  - ❖ **Wide-Area Wireless Access:** 3G and LTE
- ❖ **Physical Media**
  - Physical media fall into two categories:
    - guided media**
    - unguided media**

# 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
- ❖ 3.5-16 Mbps upstream transmission rate
- ❖ 24- 52 Mbps downstream transmission rate

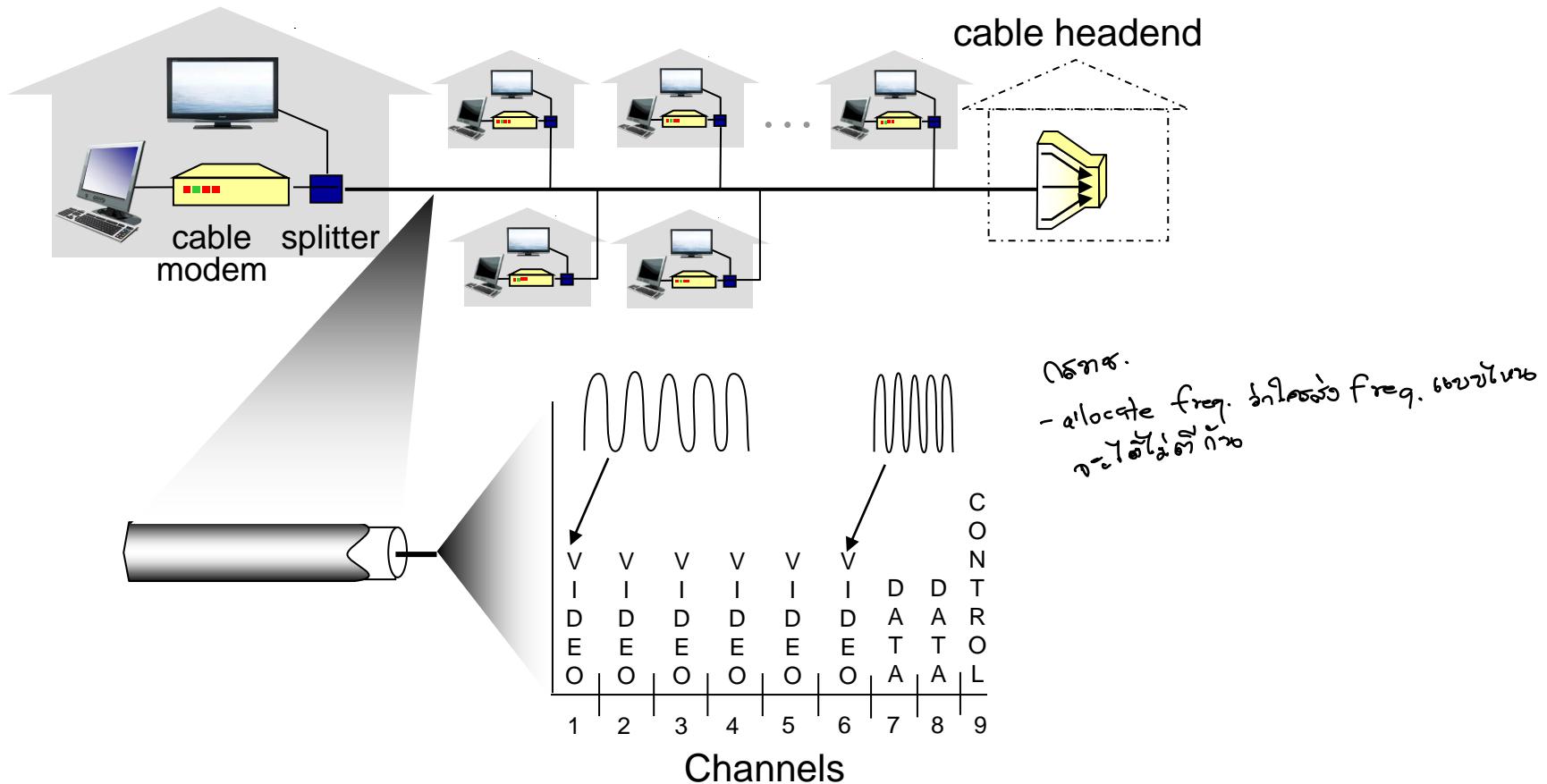
# Access net: digital subscriber line (DSL)



**Figure 1.5** ♦ DSL Internet access

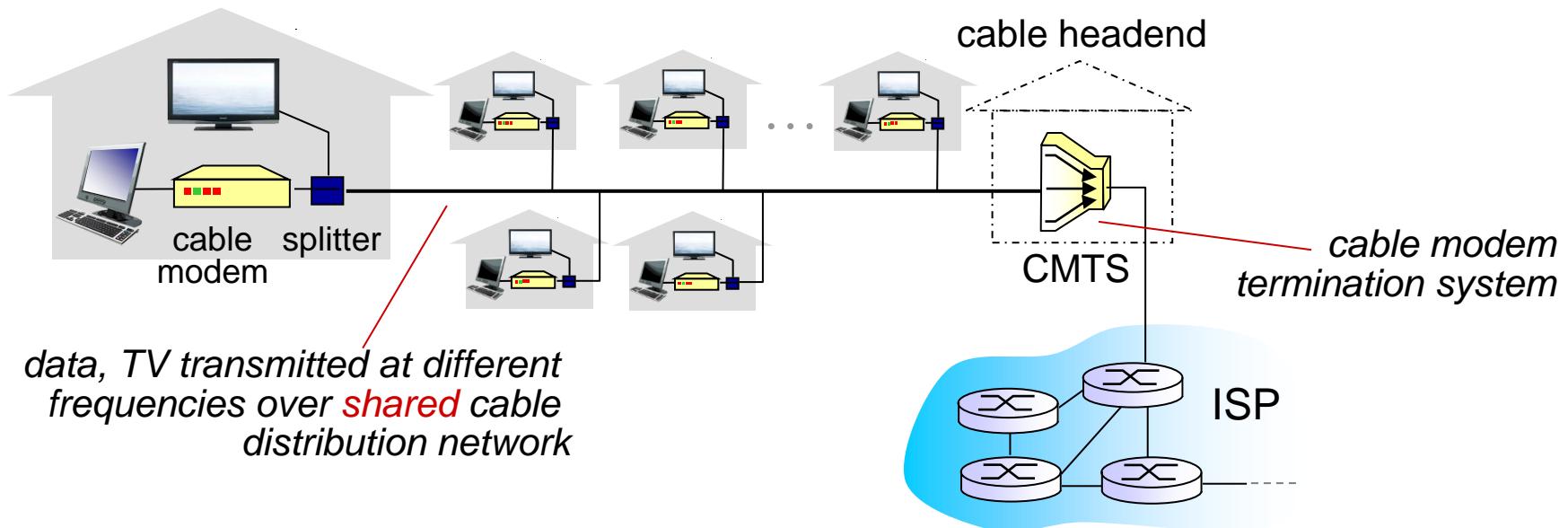
DSLAM separates the data and phone signals and sends the data into the Internet

# Access net: cable network



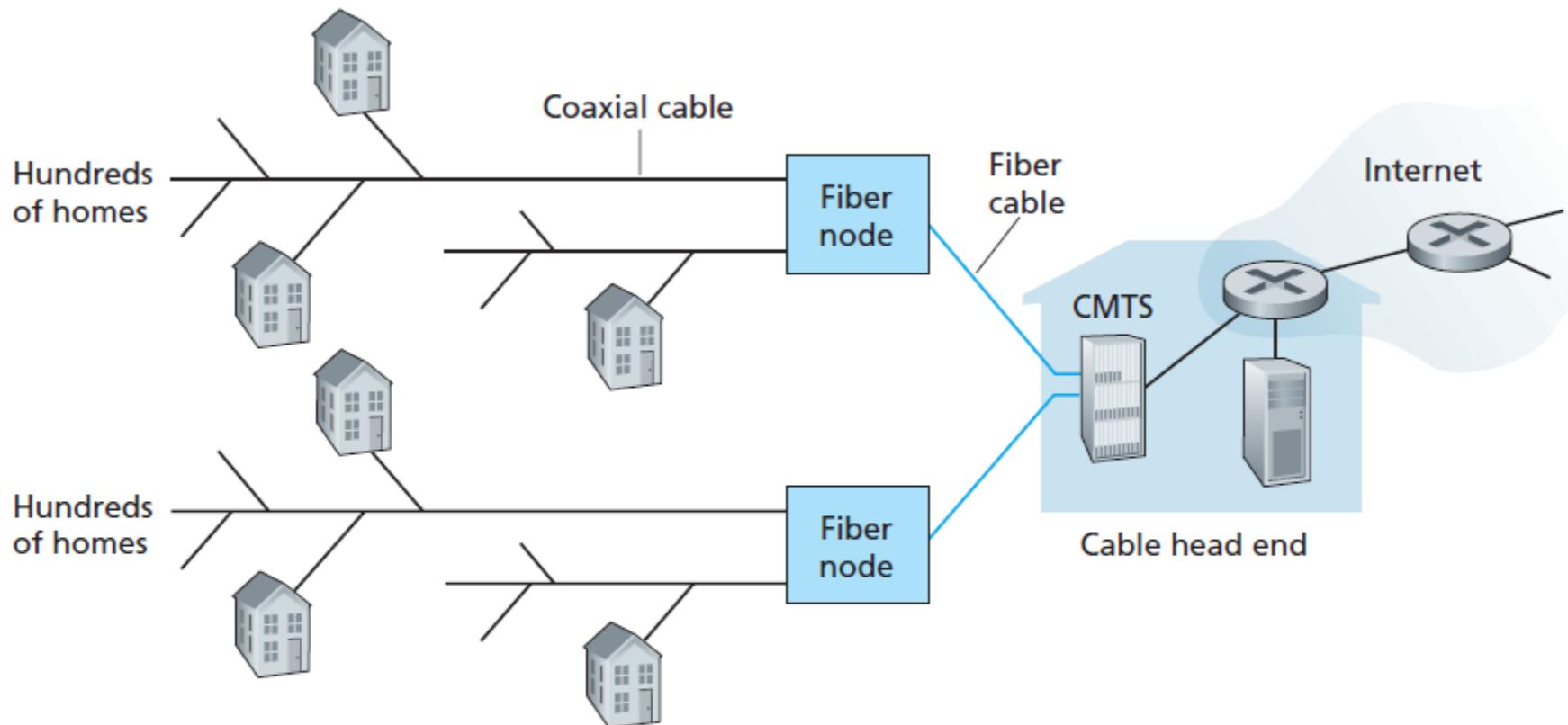
**frequency division multiplexing:** different channels transmitted in different frequency bands

# Access net: cable network



- ❖ **HFC: hybrid fiber coax**
  - asymmetric: up to 40 Mbps -1.2Gbps downstream transmission rate, 30-100 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

# Access net: cable network HFC



**Figure 1.6** ♦ A hybrid fiber-coaxial access network

# FTTH (Fiber to the home) Internet access

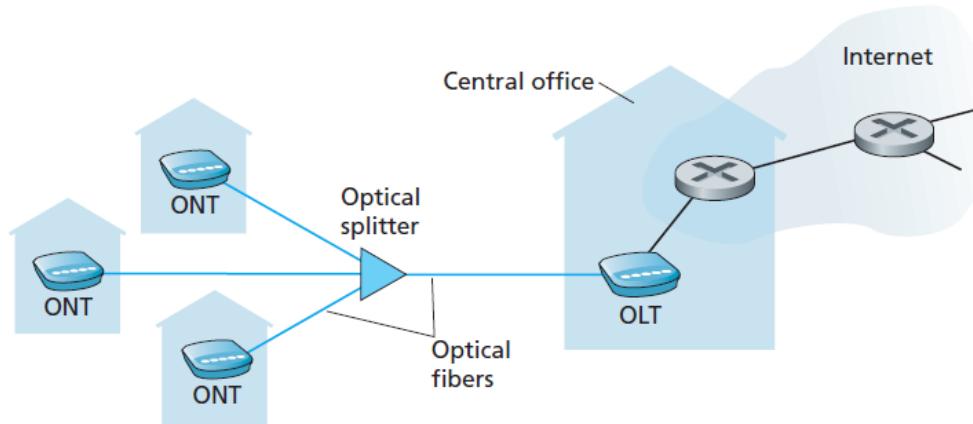


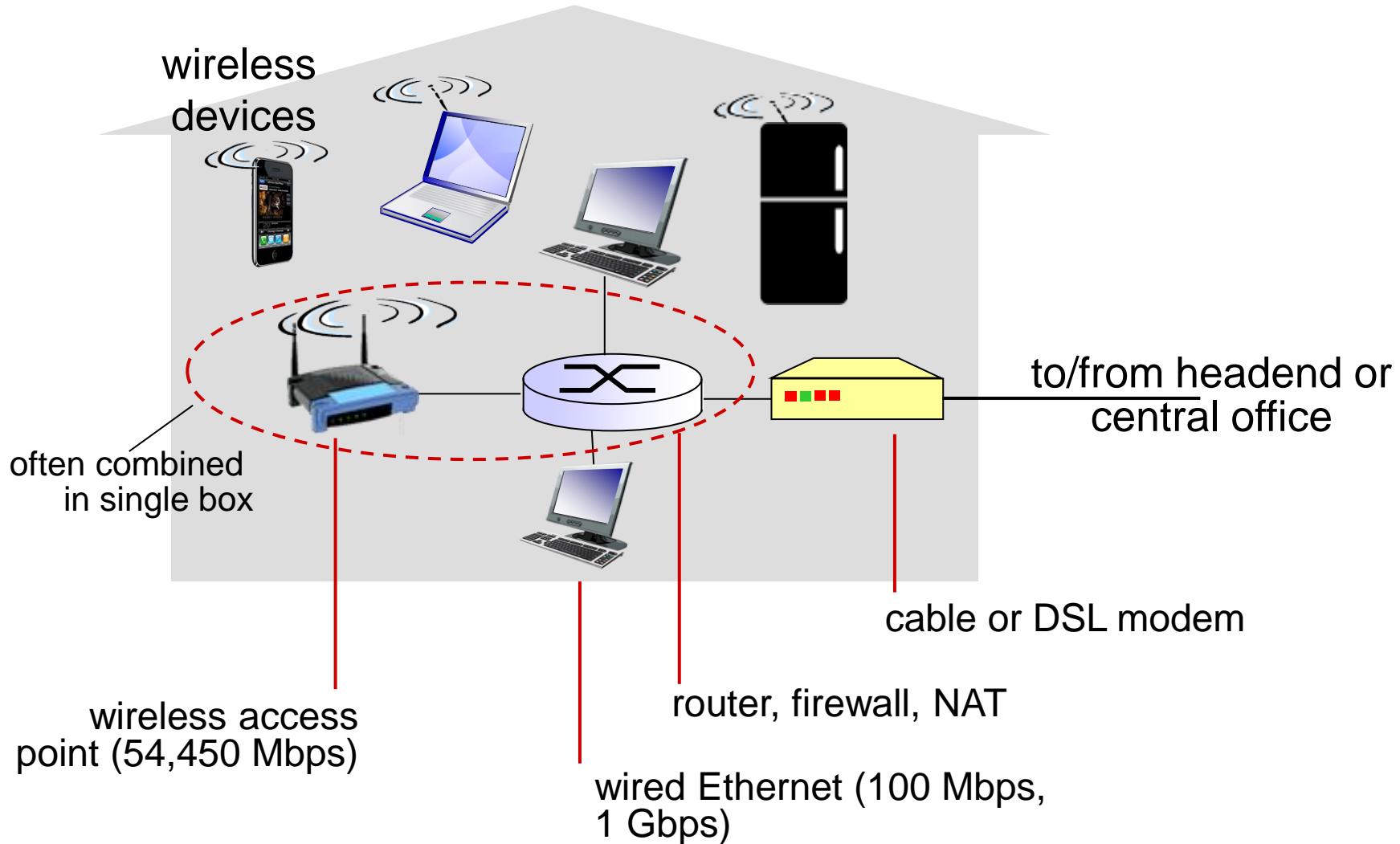
Figure 1.7 ♦ FTTH Internet access

Two other access network technologies are also used to provide Internet access to the home. In locations where DSL, cable, and FTTH are not available (e.g., in some rural settings),

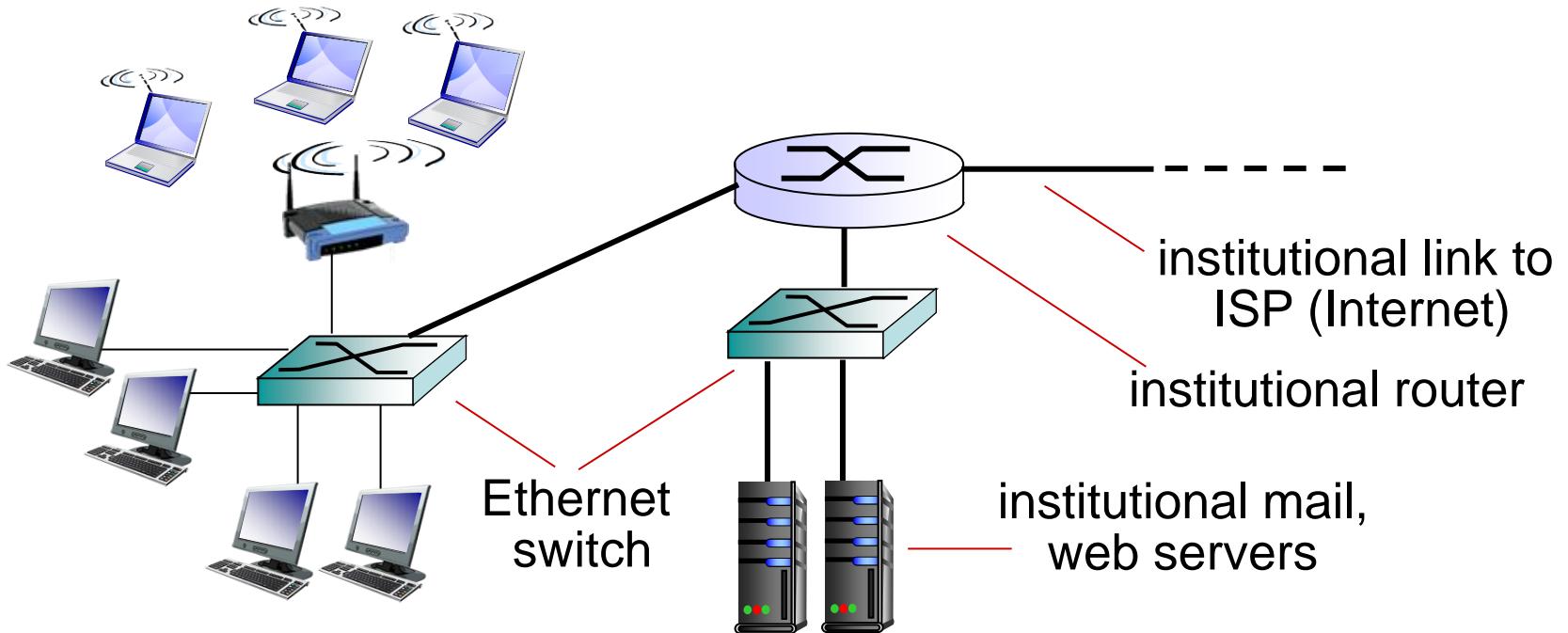
a **satellite link** can be used to connect a residence to the Internet at speeds of more than 1 Mbps; StarBand and HughesNet are two such satellite access providers.

**Dial-up access** over traditional phone lines is based on the same model as DSL

# Access net: home network



# Enterprise access networks (Ethernet)



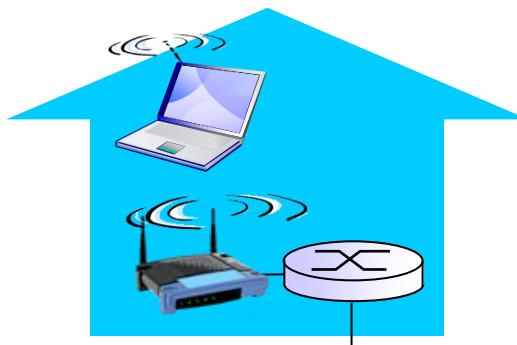
- ❖ typically used in companies, universities, etc
- ❖ mix of wired, wireless link technologies, connecting a mix of switches and routers (we'll cover differences shortly)
  - ❖ 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
  - ❖ WiFi: wireless access points at 11, 54, 450 Mbps

# Wireless access networks

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

## wireless LANs:

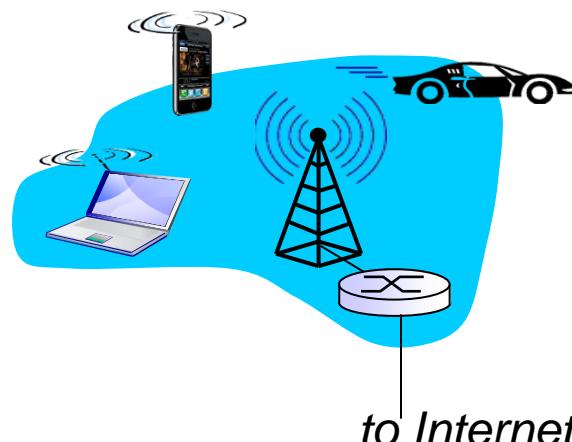
- within building (100 ft)
- 802.11b/g (WiFi): 11, 54, 450 Mbps transmission rate



*to Internet*

## wide-area wireless access

- provided by telco (cellular) operator, 10's km
- 10 Mbps
- 4G, 5G Cellular networks

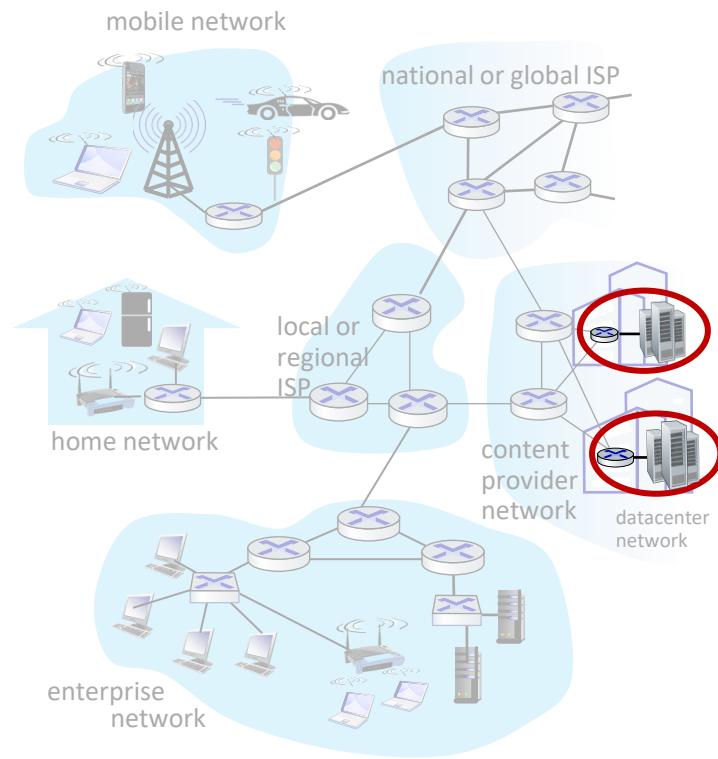


# Access networks: data center networks

- high-bandwidth links (10s to 100s Gbps) connect hundreds to thousands of servers together, and to Internet



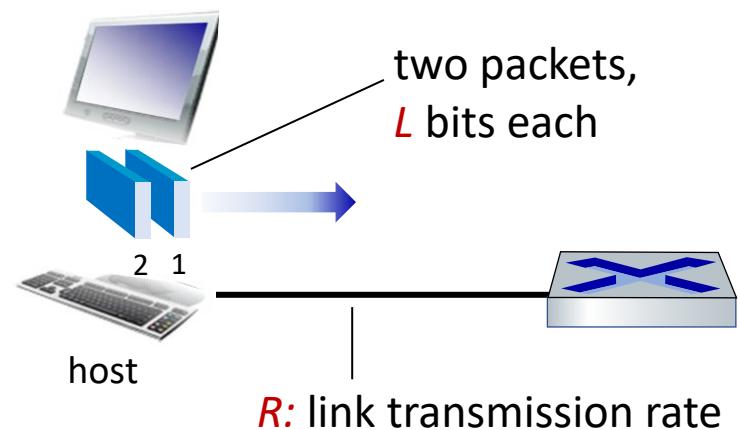
Courtesy: Massachusetts Green High Performance Computing Center ([mghpcc.org](http://mghpcc.org))



# 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*



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

# Physical media

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

## *twisted pair (TP)*

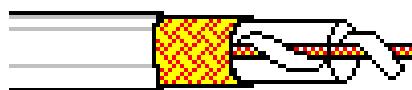
- ❖ two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps



# Physical media: coax, fiber

## *coaxial cable:*

- ❖ two concentric copper conductors
- ❖ bidirectional
- ❖ broadband:
  - multiple channels on cable
  - HFC
  - 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 (e.g., 10' s-100' s Gbps transmission rate)
- ❖ low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise



# Physical media: radio

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

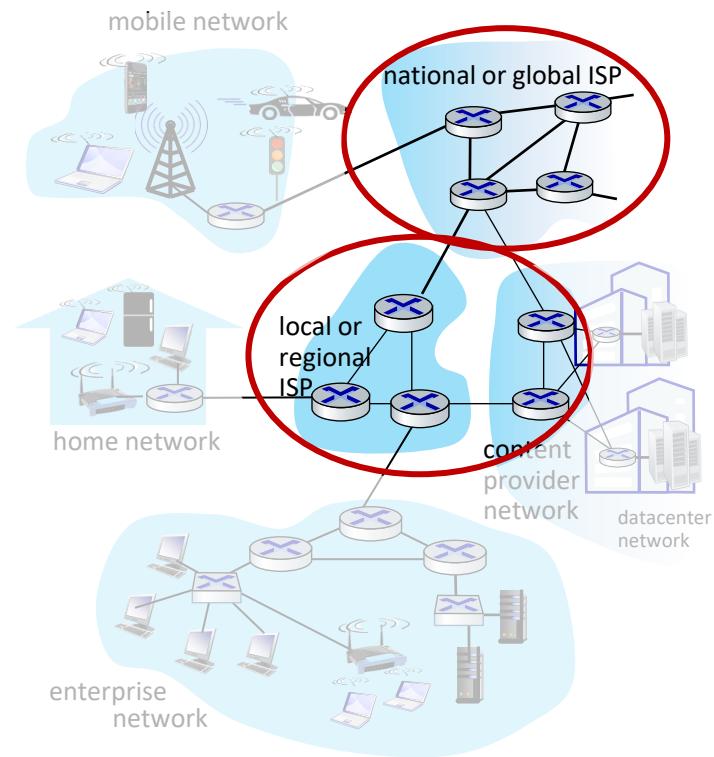
## *radio link types:*

- ❖ terrestrial microwave
  - point-to-point; 45 Mbps channels
- ❖ Wireless LAN (WiFi)
  - 10-100's Mbps; 10's of meters
- ❖ wide-area (e.g., 4G/5G cellular)
  - 10's Mbps (4G) over ~10 Km
- Bluetooth: cable replacement
  - short distances, limited rates
- ❖ satellite
  - up to < 100 Mbps (Starlink) downlink
  - 270 msec end-end delay
  - geosynchronous versus low altitude

# 5. The network core

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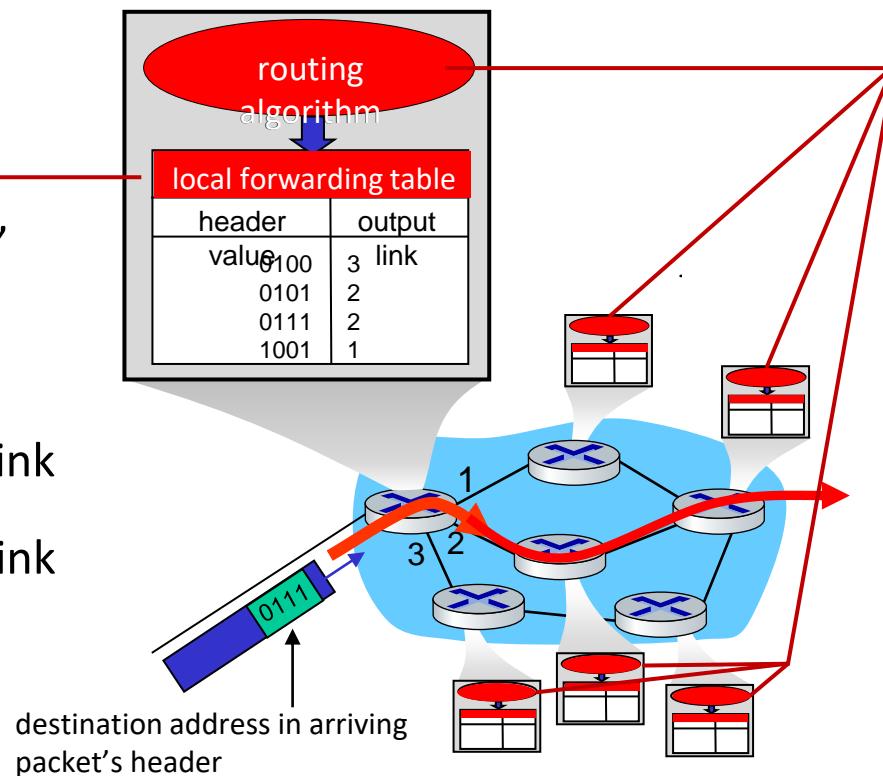
- mesh of interconnected routers
- **packet-switching**: hosts break application-layer messages into *packets*
  - network **forwards** packets from one router to the next, across links on path from **source to destination**



# Two key network-core functions

## *Forwarding:*

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



## *Routing:*

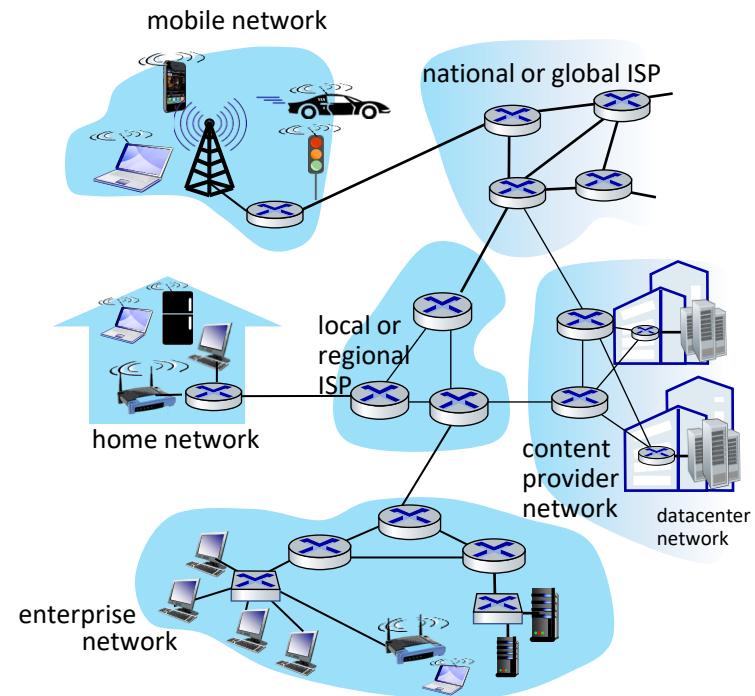
- *global* action: determine source-destination paths taken by packets
- routing algorithms



# 6. 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**

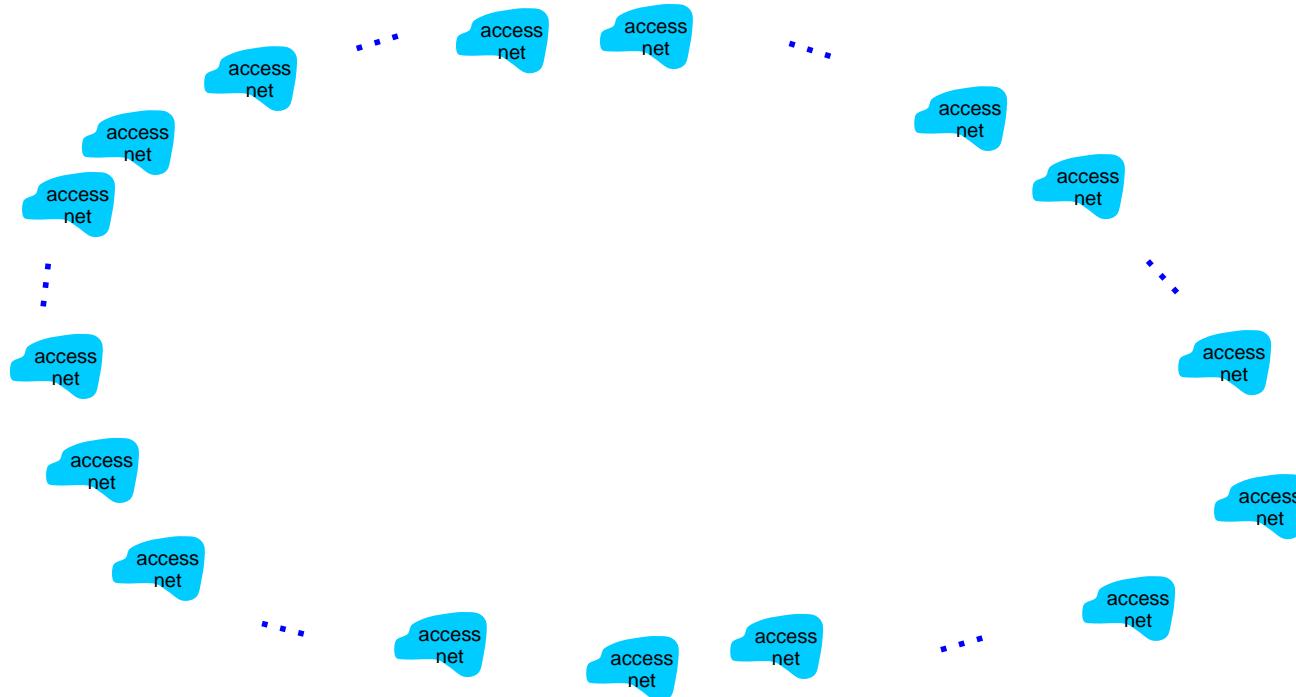


*Let's take a stepwise approach to describe current Internet structure*

# Internet structure: a “network of networks”

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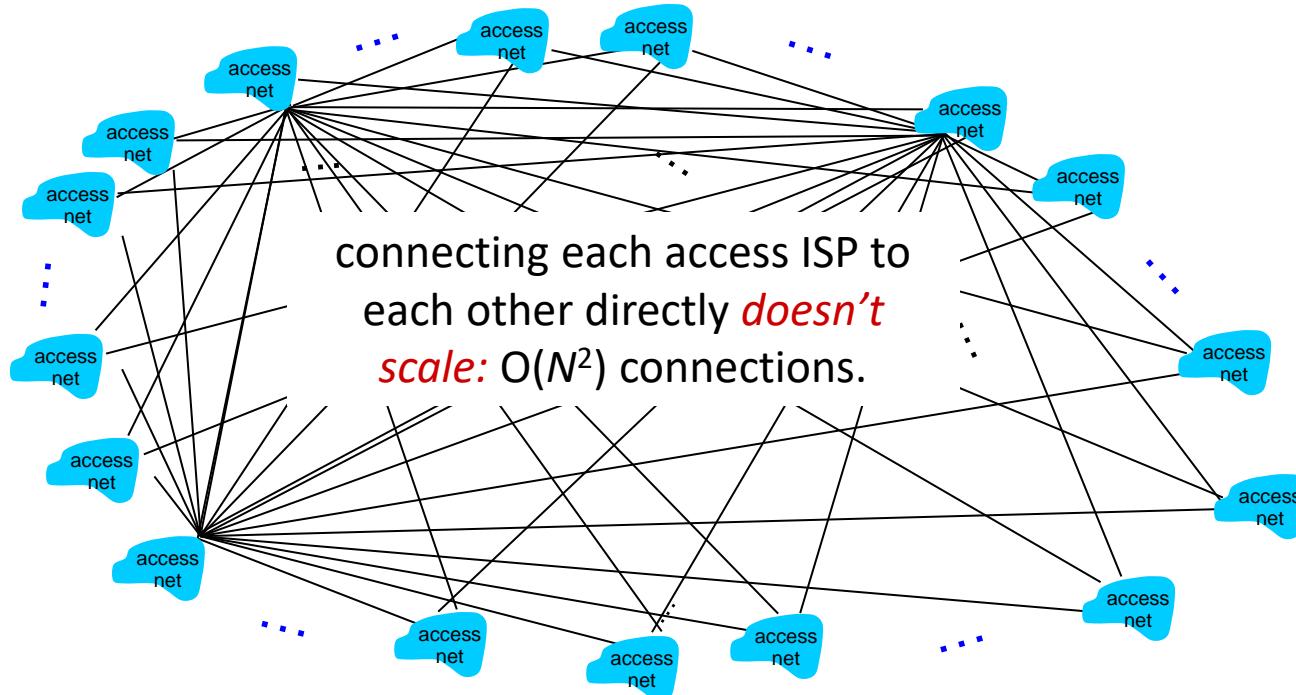
**Question:** given *millions* of access ISPs, how to connect them together?



# Internet structure: a “network of networks”

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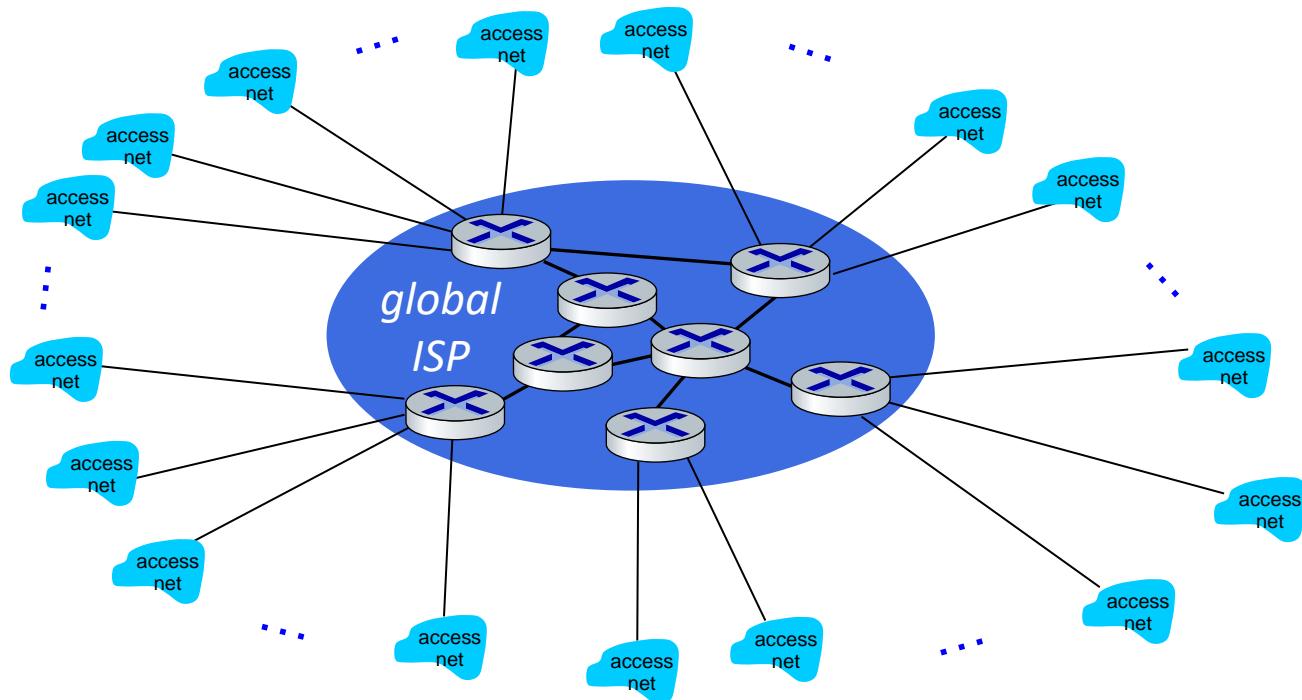


# Internet structure: a “network of networks”

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

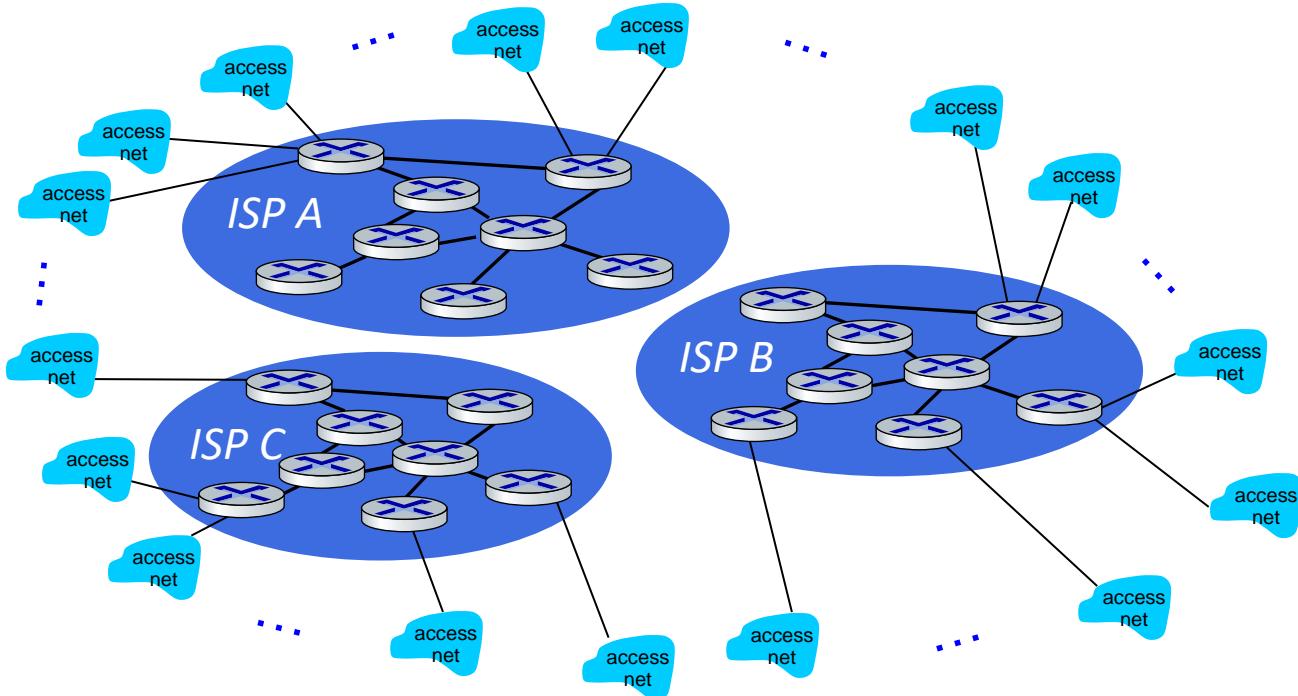
*Customer and provider ISPs have economic agreement.*



# Internet structure: a “network of networks”

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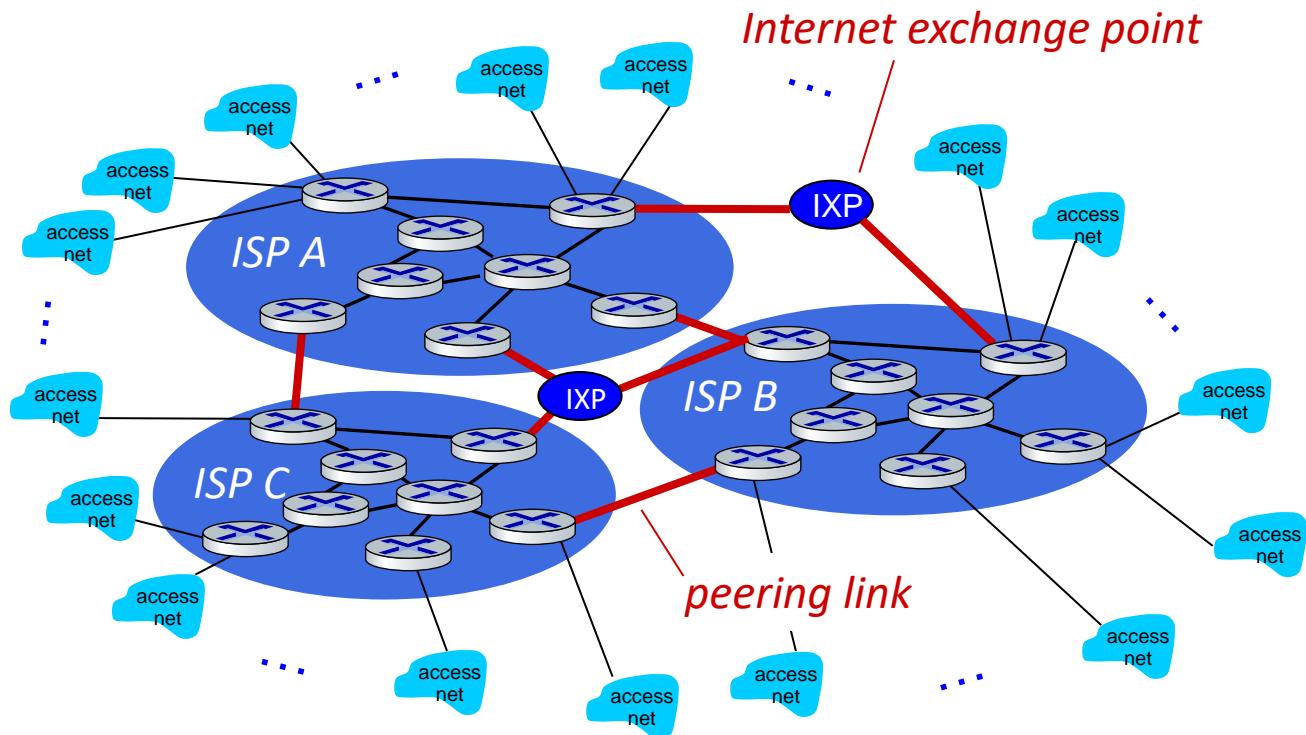
But if one global ISP is viable business, there will be competitors ....



# Internet structure: a “network of networks”

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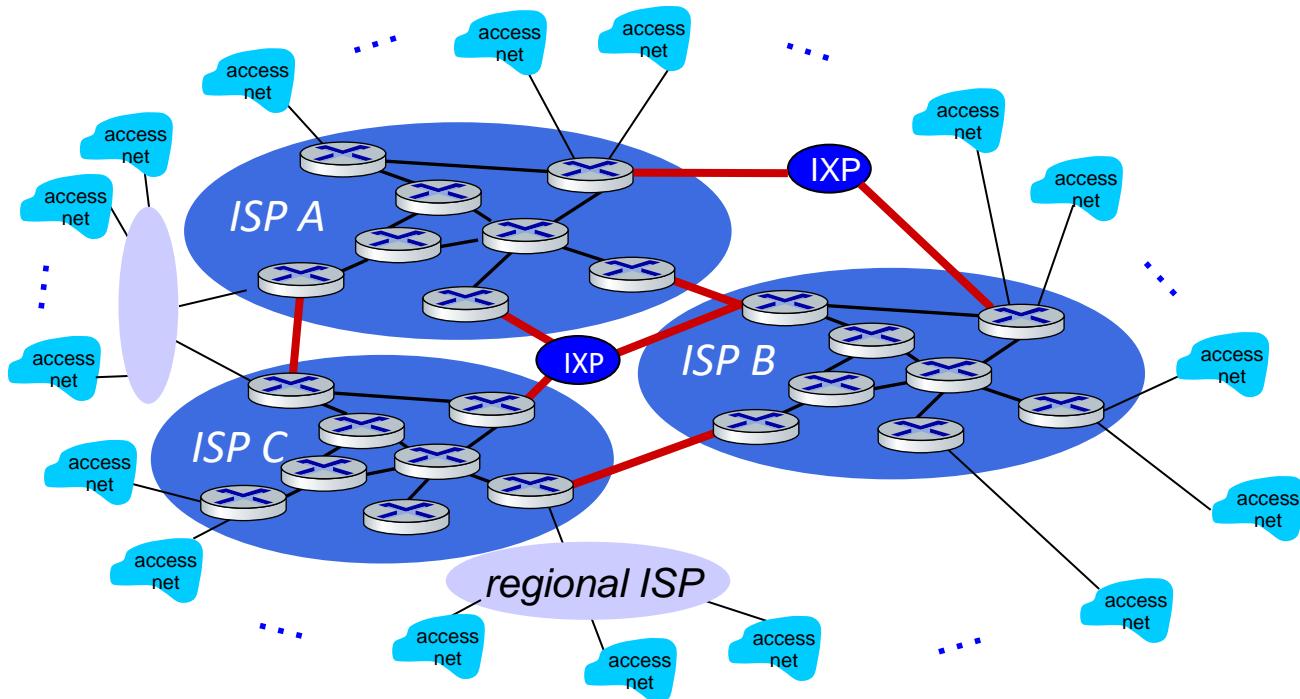
But if one global ISP is viable business, there will be competitors .... who will want to be connected



# Internet structure: a “network of networks”

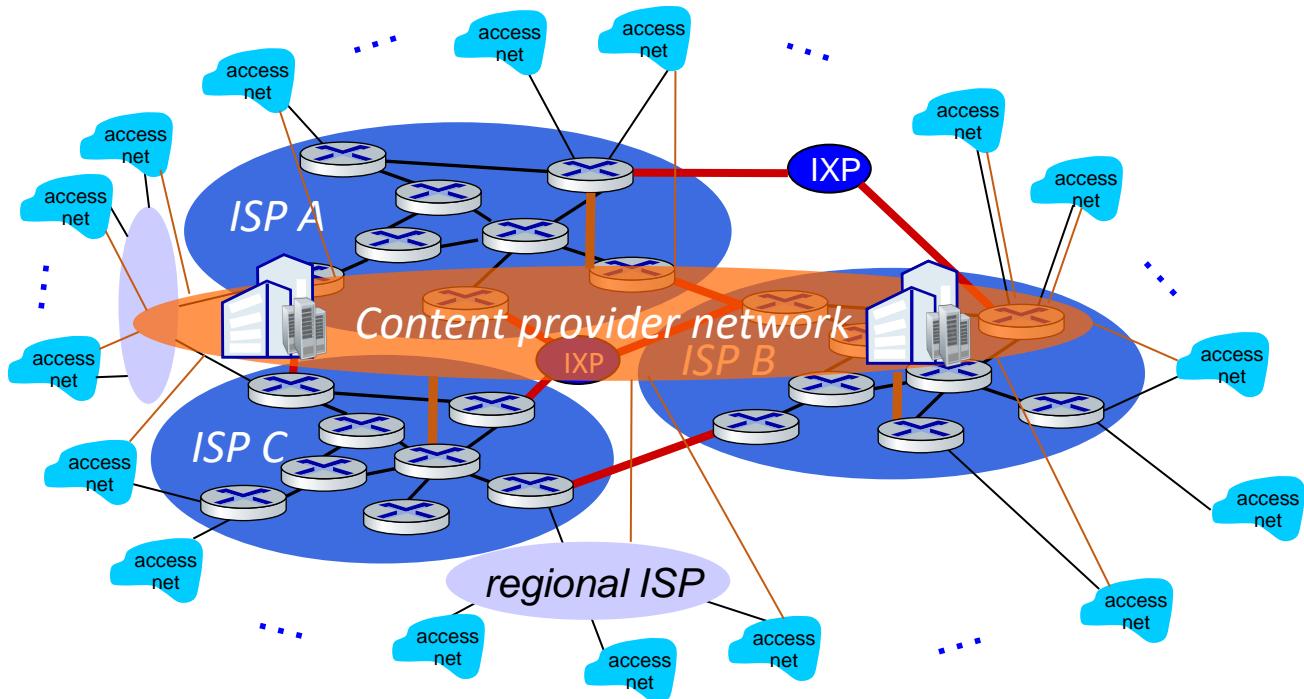
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... and regional networks may arise to connect access nets to ISPs



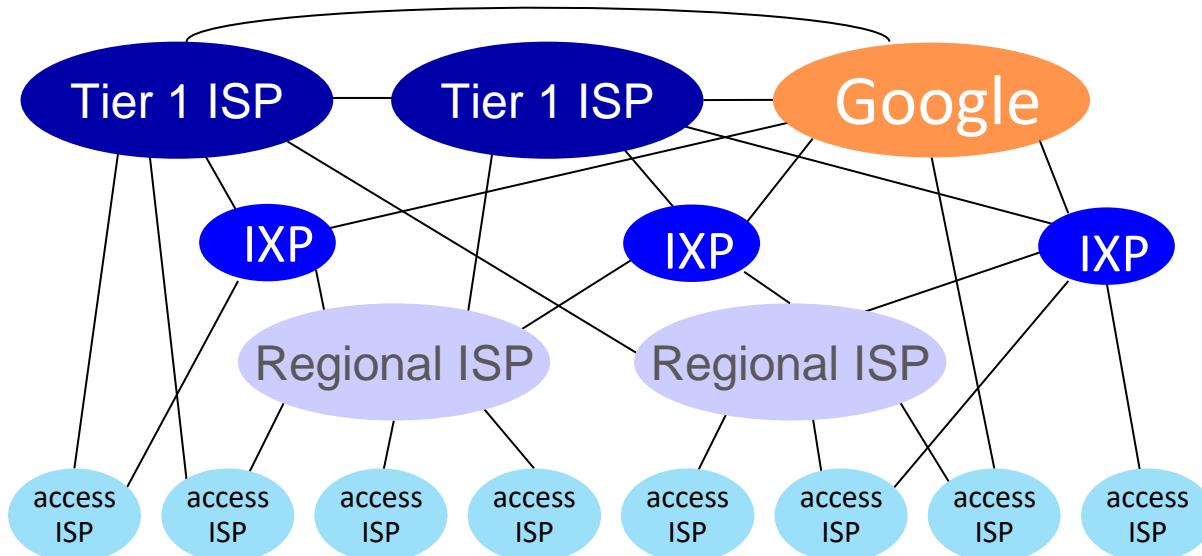
# Internet structure: a “network of networks”

... 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

# 7. Network security

Internet  
zero trust ; ໂັດເຈັດຕື່ອົດ

- Internet not originally designed with (much) security in mind
  - original vision: “a group of mutually trusting users attached to a transparent network” 😊
  - Internet protocol designers playing “catch-up”
  - security considerations in all layers!
- We now need to think about:
  - how bad guys can attack computer networks
  - how we can defend networks against attacks
  - how to design architectures that are immune to attacks

# Network security

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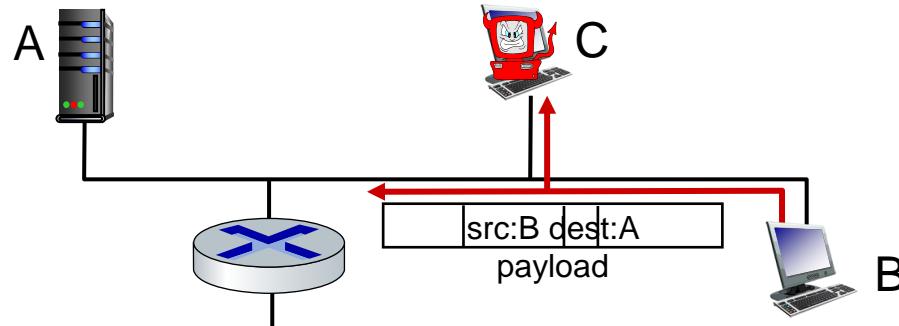
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# Bad guys: packet interception

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**packet “sniffing”:** ຄ່າວັນສູລະຫ້າງທາງ

- broadcast media (shared Ethernet, wireless)
- promiscuous network interface reads/records all packets (e.g., including passwords!) passing by

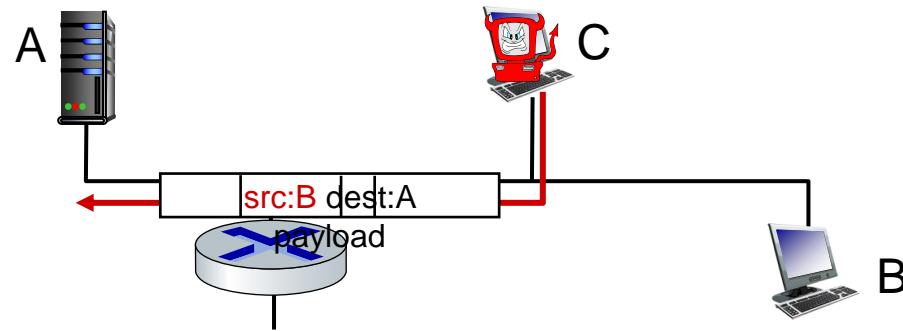


Wireshark software used for packet-sniffer

# Bad guys: fake identity

*IP spoofing:* injection of packet with false source address

អំពីសេវានៃការប្រាក់

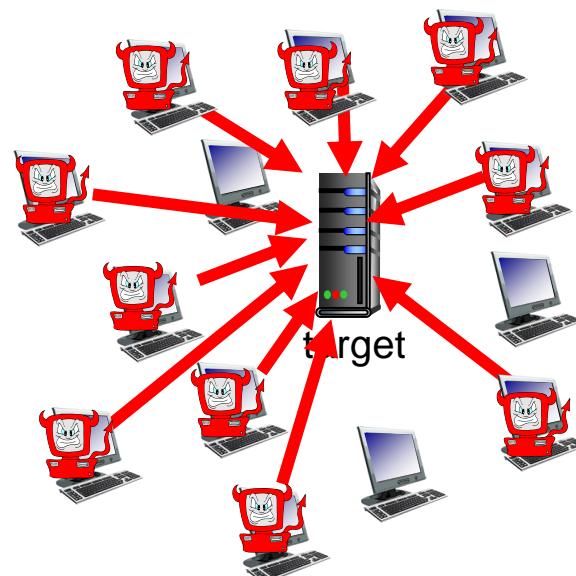


# Bad guys: denial of service

---

*Denial of Service (DoS):* attackers make resources (server, bandwidth) unavailable to legitimate traffic by overwhelming resource with bogus traffic

1. select target
2. break into hosts  
around the network  
(see botnet)
3. send packets to target  
from compromised  
hosts



# Lines of defense:

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- **authentication:** proving you are who you say you are
  - cellular networks provides hardware identity via SIM card; no such hardware assist in traditional Internet
- **confidentiality:** via encryption
- **integrity checks:** digital signatures prevent/detect tampering
- **access restrictions:** password-protected VPNs
- **firewalls:** specialized “middleboxes” in access and core networks:
  - off-by-default: filter incoming packets to restrict senders, receivers, applications
  - detecting/reacting to DOS attacks



# Any Questions