Intro. to Computer Networks

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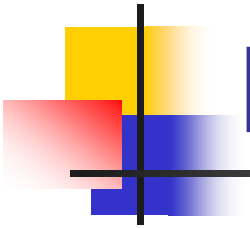
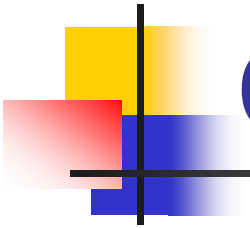
https://ceiba.ntu.edu.tw/1052EE4020_Net2018



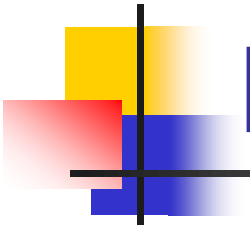
Network Players

- Network users
  - Service and application users
  - Content providers
- Network providers
  - Infrastructure and service etc.
- Network (service) designers
  - Components and protocols



Computer Networks

- Types of networks
  - Technical networks: phone, TV, radio, computer
  - Internet of Things (IoT)/M2M: smart grid, etc.
  - Social networks ??
- Components
  - Hardware: hosts/end-systems, routers/switches, links
  - Software: network protocols
  - Application: e.g., web service, blog, email, VoIP, IPTV, etc.

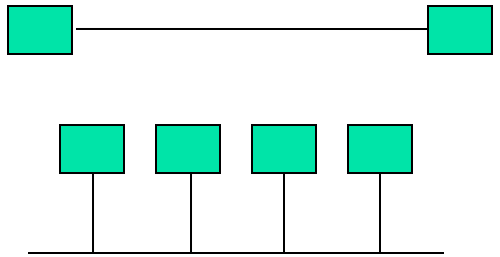


Network Classification

- Coverage
  - Local Area Network (LAN)
    - e.g., Ethernet, WiFi
  - Metropolitan Area Networks (MAN)
    - e.g., CATV, FTTx, ADSL, WiMAX
  - Wide Area Networks (WAN)
    - e.g., Internet, GSM
  - Others:
    - e.g., PAN, DAN
    - e.g., NFC, Bluetooth, Zigbee

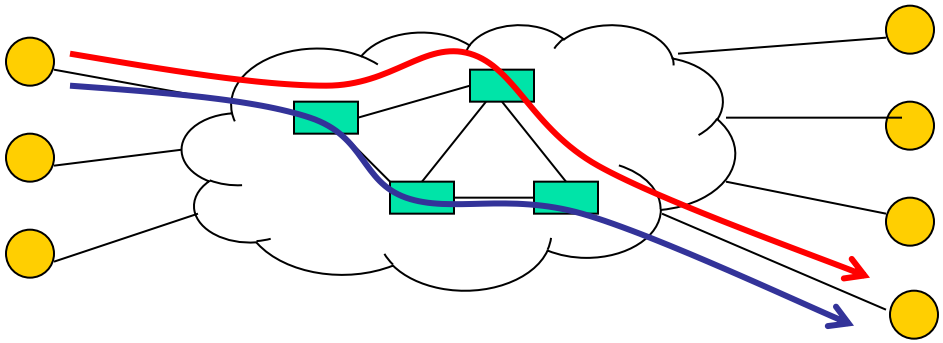
Requirements

- Connectivity
  - Scalability
  - Link, node, cloud
  - Two types of connections
    - Direct link
      - Point to point
      - Multiple access



Requirements (cont.)

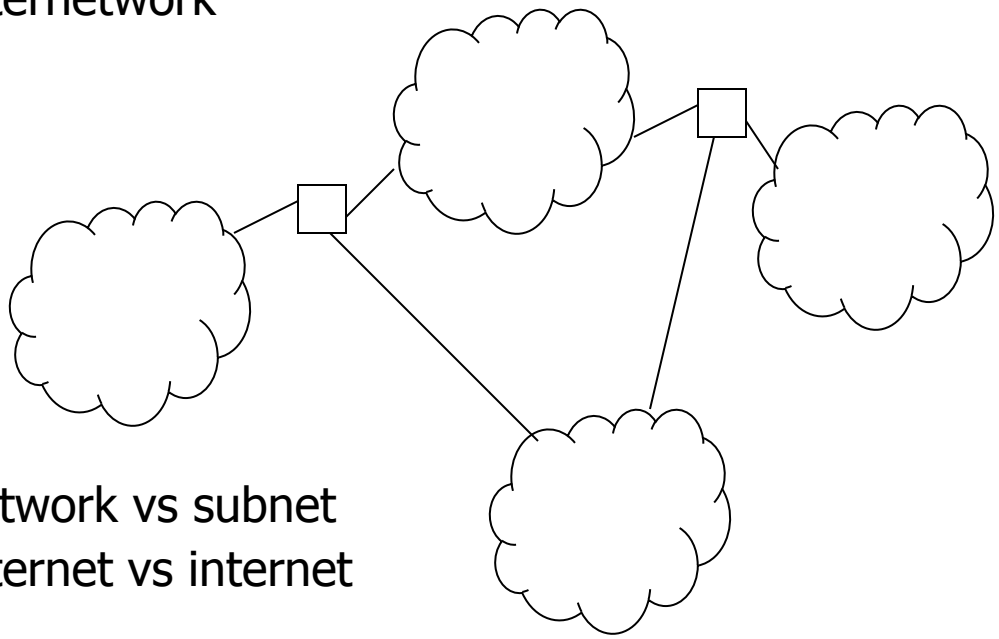
- Connectivity (cont.)
  - Indirect links
    - Switched network



    - Circuit switched network
    - Packet switched networks (store-and-forward, packet)

Requirements (cont.)

- Indirect links
  - Internetwork



  - Network vs subnet
  - Internet vs internet
- Addressing and routing

Requirements (cont.)

- Efficiency: cost-effective resource sharing
  - Multiplexing and de-multiplexing

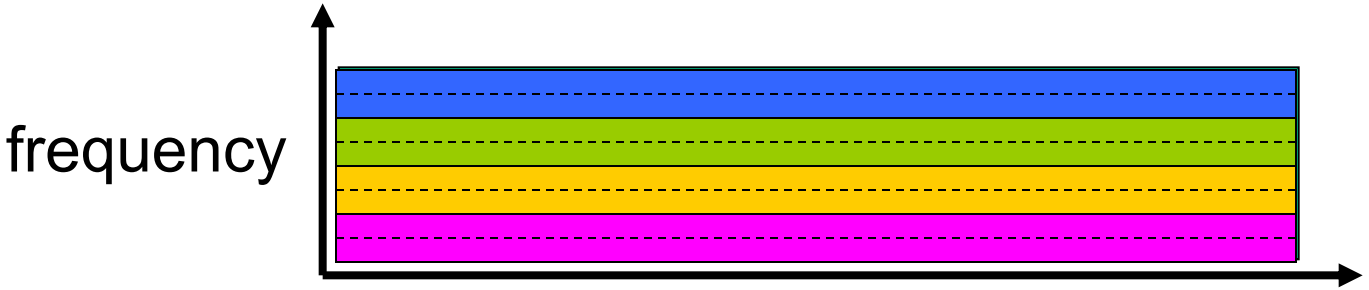
  - Multiplexing approaches
    - Synchronous Time-Division Multiplexing (TDM)
    - Frequency-Division Multiplexing (FDM)
    - Statistical Multiplexing
      - Max. limited block size: fragment and reassembly
      - Fairly allocating link capacity to different flows
      - Congestion control

FDM and TDM

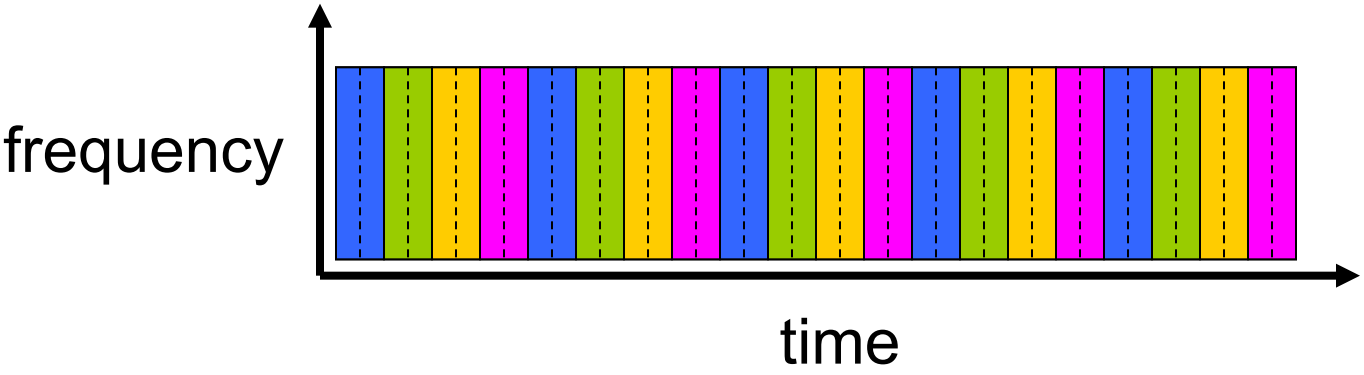
Example:

4 users

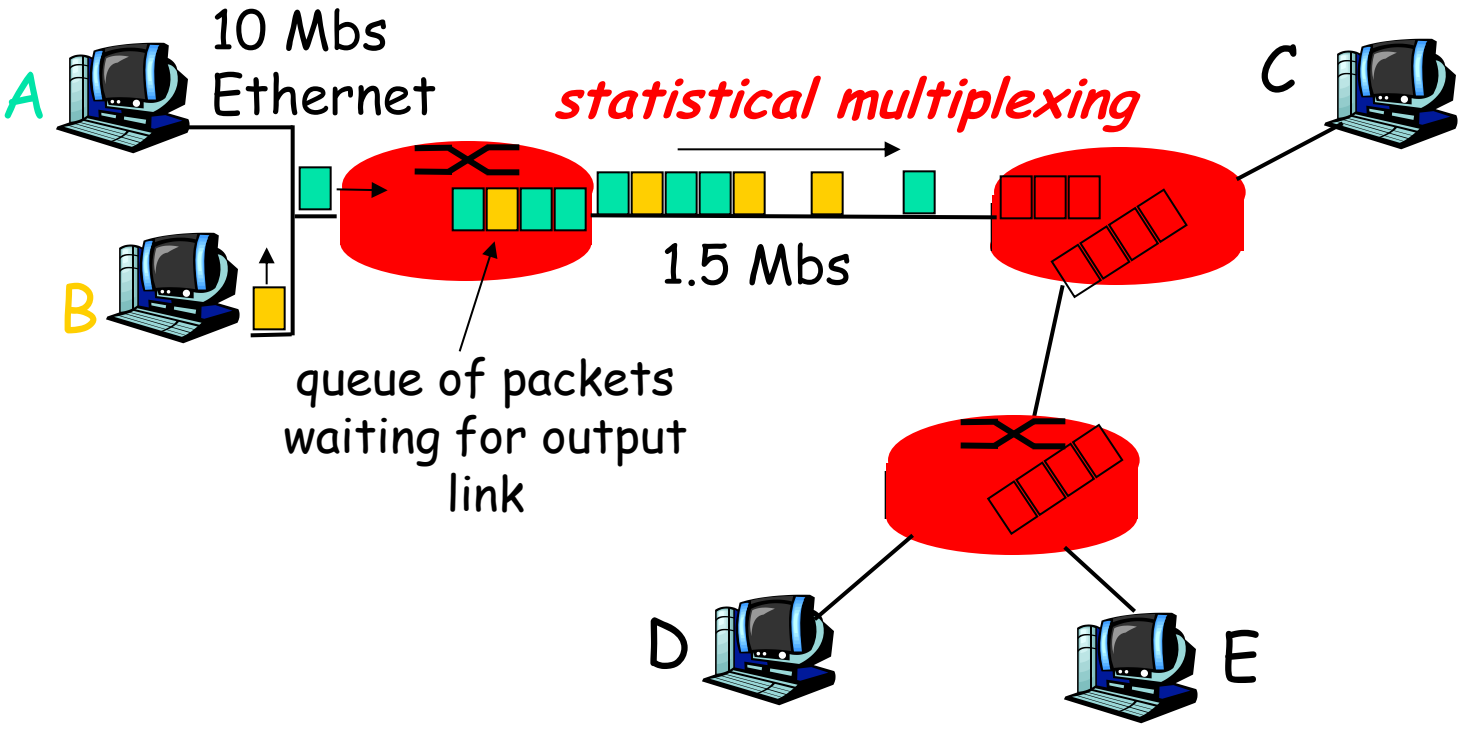
FDM

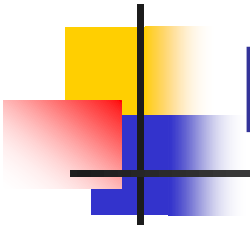


TDM



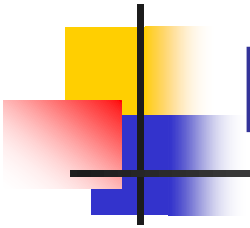
Statistical Multiplexing





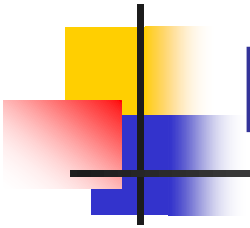
Requirements (cont.)

- Support for common services
  - End-to-end logical channels
    - Identifying common communications pattern
  - Communication model
    - Client/server model: e.g., ftp, WWW
    - Peer-to-peer model: video conference, file sharing
  - Communication service
    - Request/reply
    - Message stream
  - Where?
    - End-to-end or in the network?



Requirements (cont.)

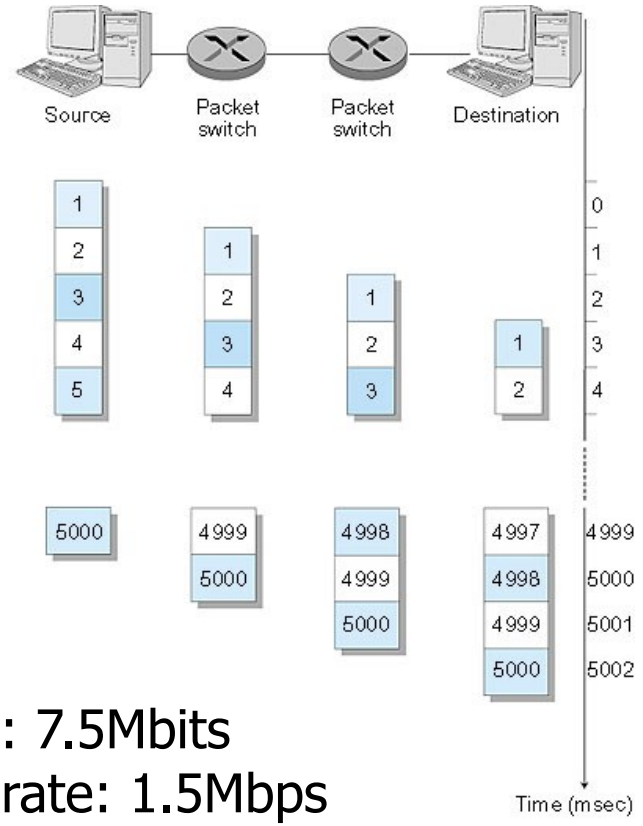
- Support for common services (cont.)
  - Reliability
    - Error-free, in-sequence, no duplication, no loss
    - Three levels of failure
      - Bit level: (0 → 1, 1→ 0)
      - Packet level
      - Node/link level
  - Quality of Service (QoS)
    - Error rate
    - Delay, delay jitter
    - Throughput



Requirements (cont.)

- Performance (cont.)
  - Latency (delay)
    - How long the network takes a message to travel from one end to another (time)
    - One-way latency v.s. round-trip time (RTT)
    - Three components: P+T+Q
      - Propagation delay: Distance/the speed of light
      - Transmission delay: Size/Bandwidth
      - Queuing delay

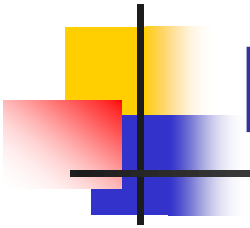
Packet Switching vs. Message Segmenting



Data: 7.5Mbits
Link rate: 1.5Mbps

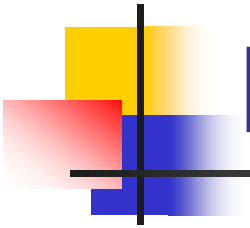
Now break up the message into 5000 packets, 1.5Kbits each

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining:* each link works in parallel
- Delay reduced from 15 sec to 5.002 sec



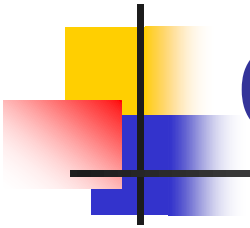
Requirements (cont.)

- Performance
  - Bandwidth
    - The number of bits can be transmitted over the network in a certain period of time (bps)
  - Throughput: measured performance
    - Depend on the path and the number of flows passing through
    - Bottleneck link



Requirements (cont.)

- Manageability
  - In home/small office: plug and play
  - Software Defined Networks (SDN)

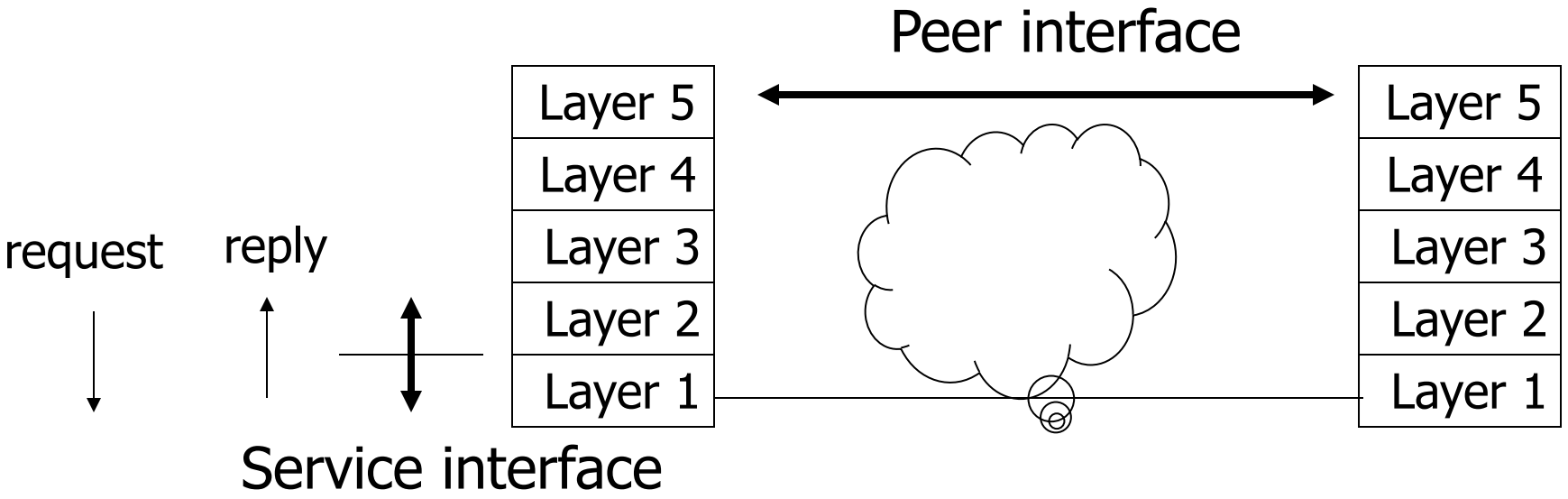


Computer Networks (cont.)

- Network architecture
  - Guide the design and implementation of networks
  - Layered architecture
    - Reference model, layer model, etc.
      - ISO OSI 7-layer model
      - IETF TCP/IP protocol stack/suite

Computer Networks (cont.)

- Network architecture
  - Service interface and peer interface



Computer Networks (cont.)

- Network architecture
  - Encapsulation

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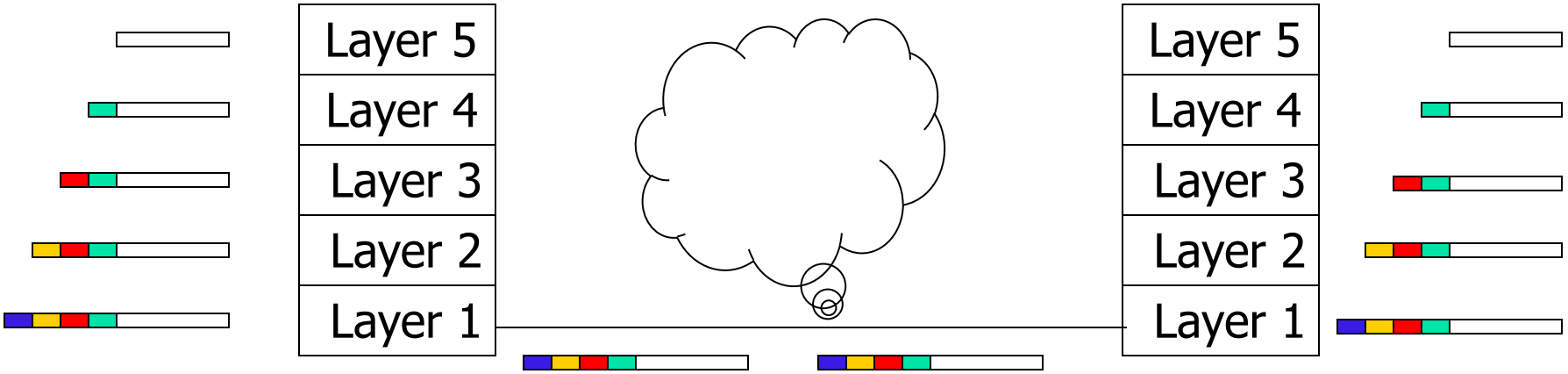
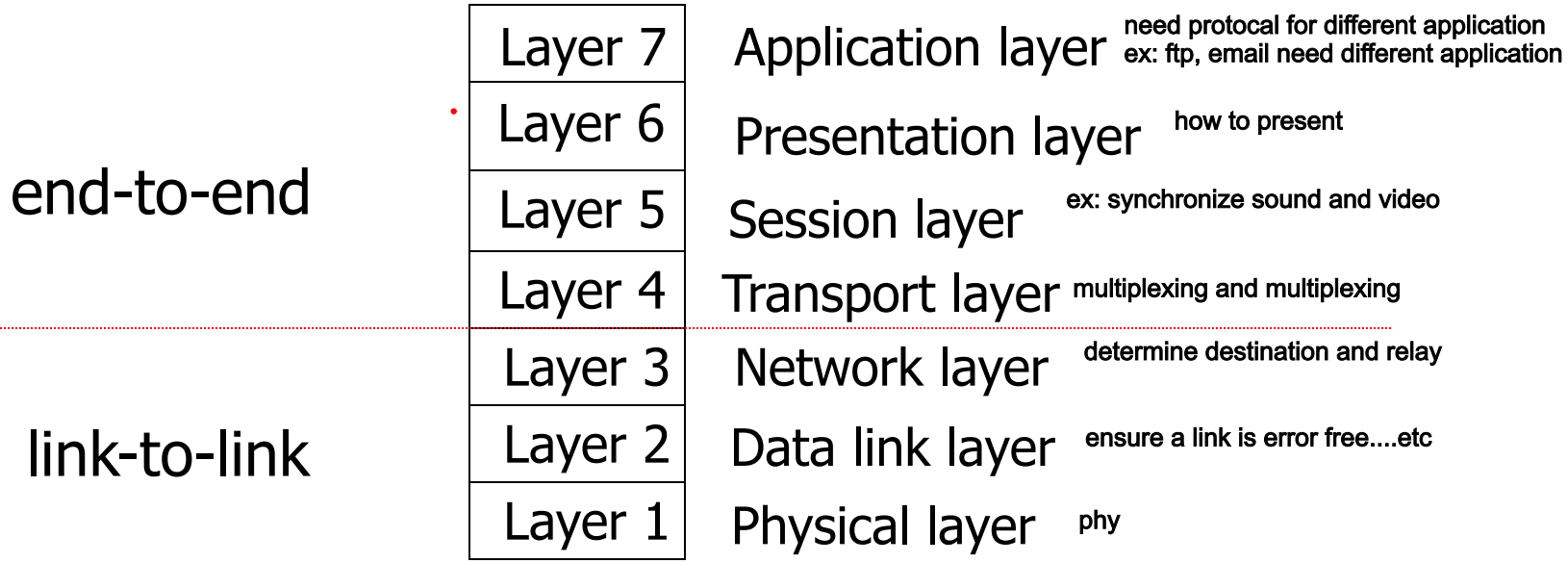


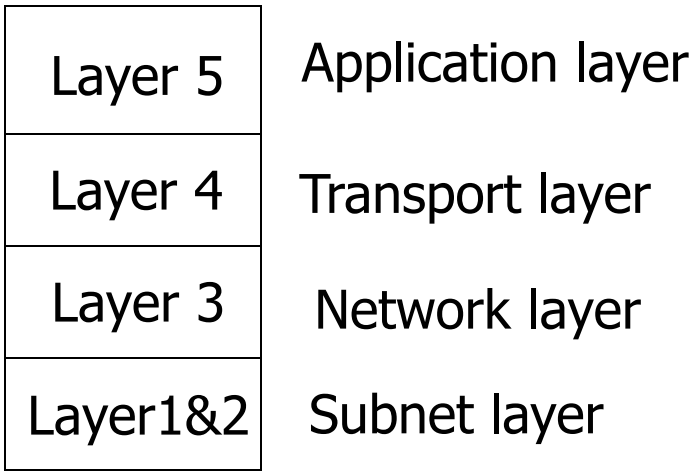
Computer Networks (cont.)

- Network architecture
  - Two reference models
    - ISO OSI 7-layer models



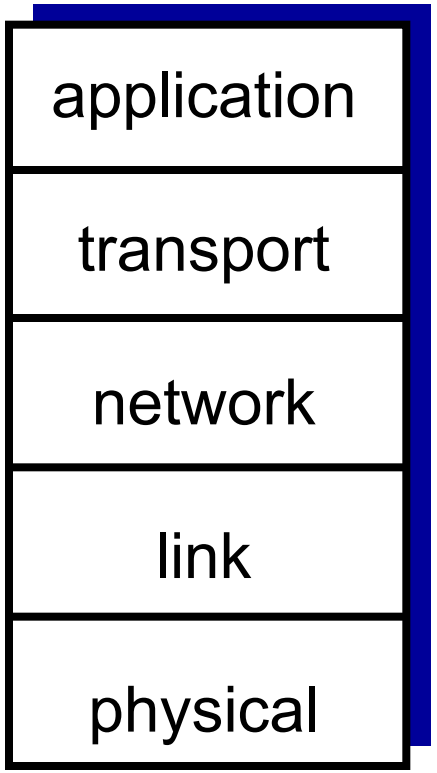
Computer Networks (cont.)

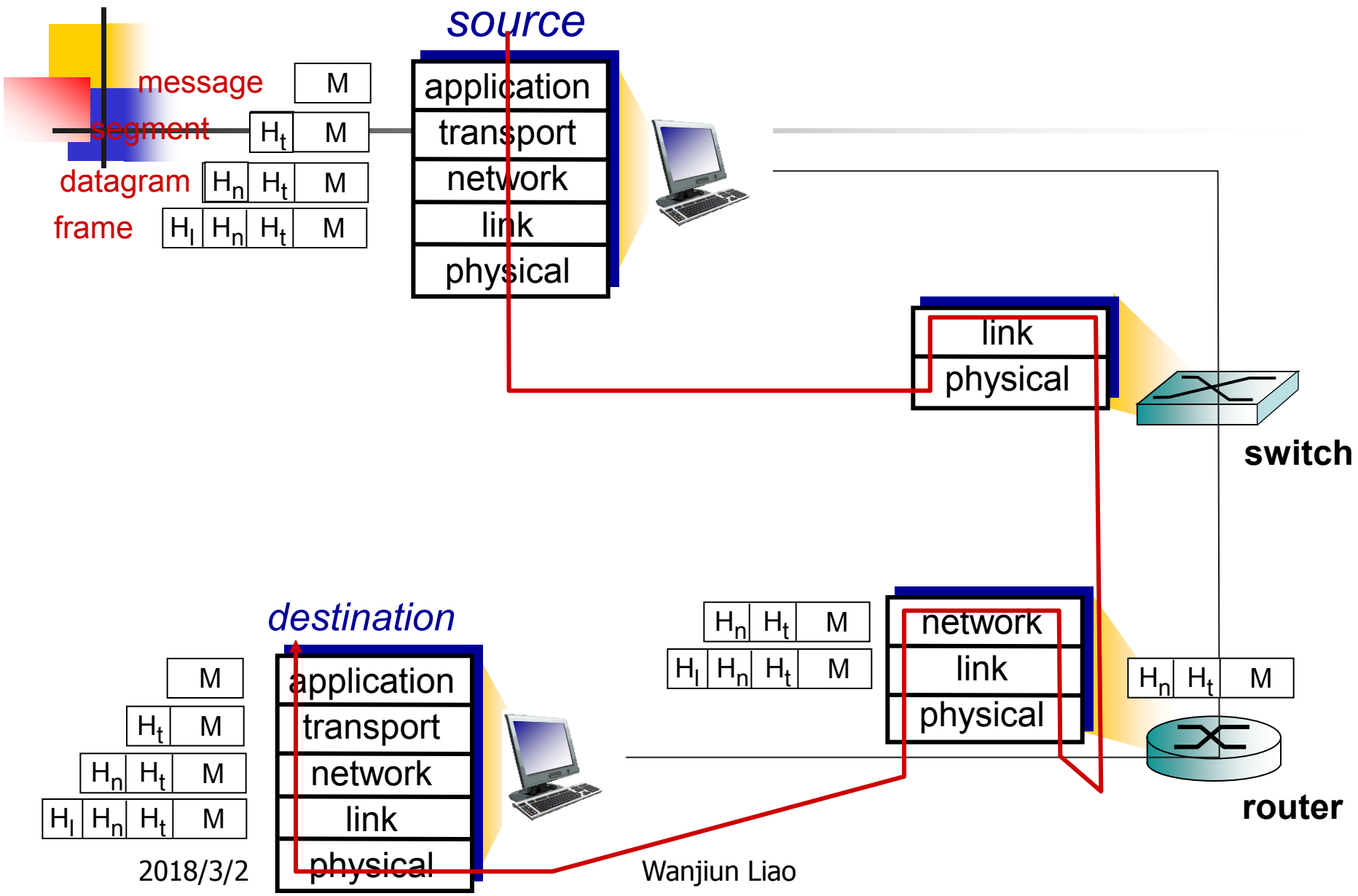
- Network architecture
  - Two reference models
    - IETF TCP/IP protocol stack



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"




source
message
segment
datagram
frame
M
H_t M
H_n H_t M
H_l H_n H_t M
application
transport
network
link
physical
link
physical
switch
destination
M
H_t M
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H_l H_n H_t M
application
transport
network
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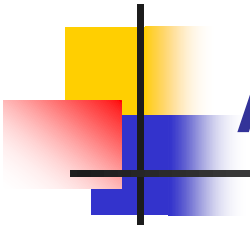
network
link
physical
H_n H_t M
router



Access Networks

- Last mile to home (edge of the network)
  - Wired v.s. wireless
- Three categories
  - Residential access networks
  - Company access networks
  - Mobile access networks

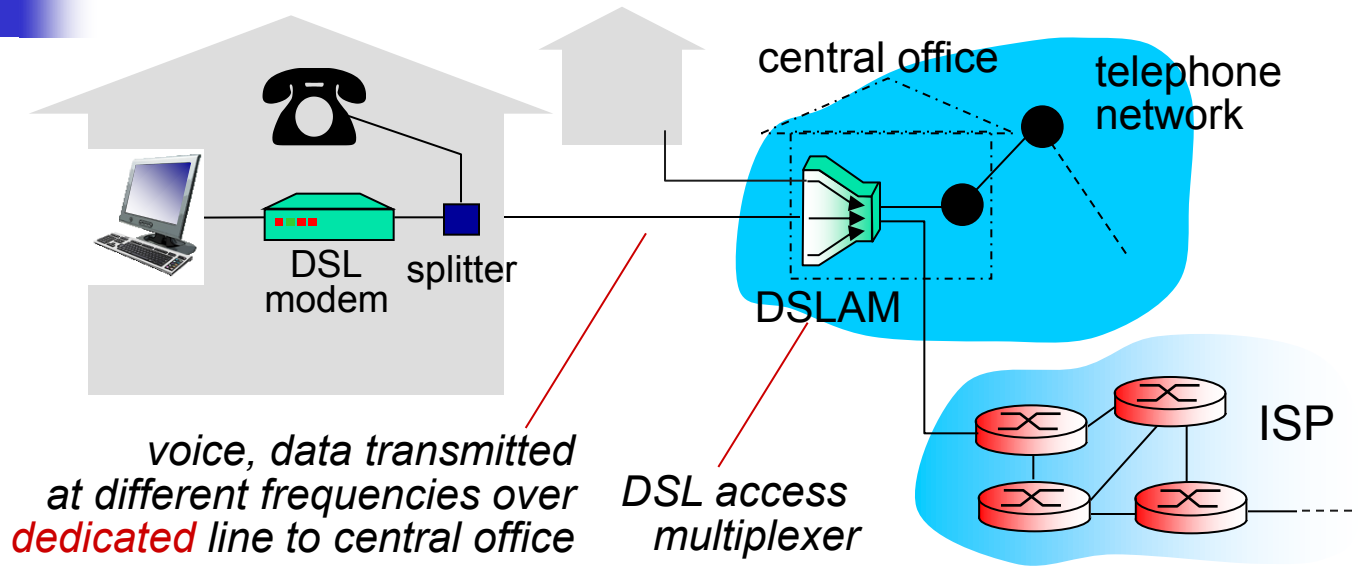
Access Networks (cont.)

- Residential access networks
  - ADSL: Asymmetric ~~Digital~~ discrete Scriber Line
  - HFC: Hybrid Fiber Coax
  - FTTH/FTTC/FTTB: all-fiber solution

Access Networks (cont.)

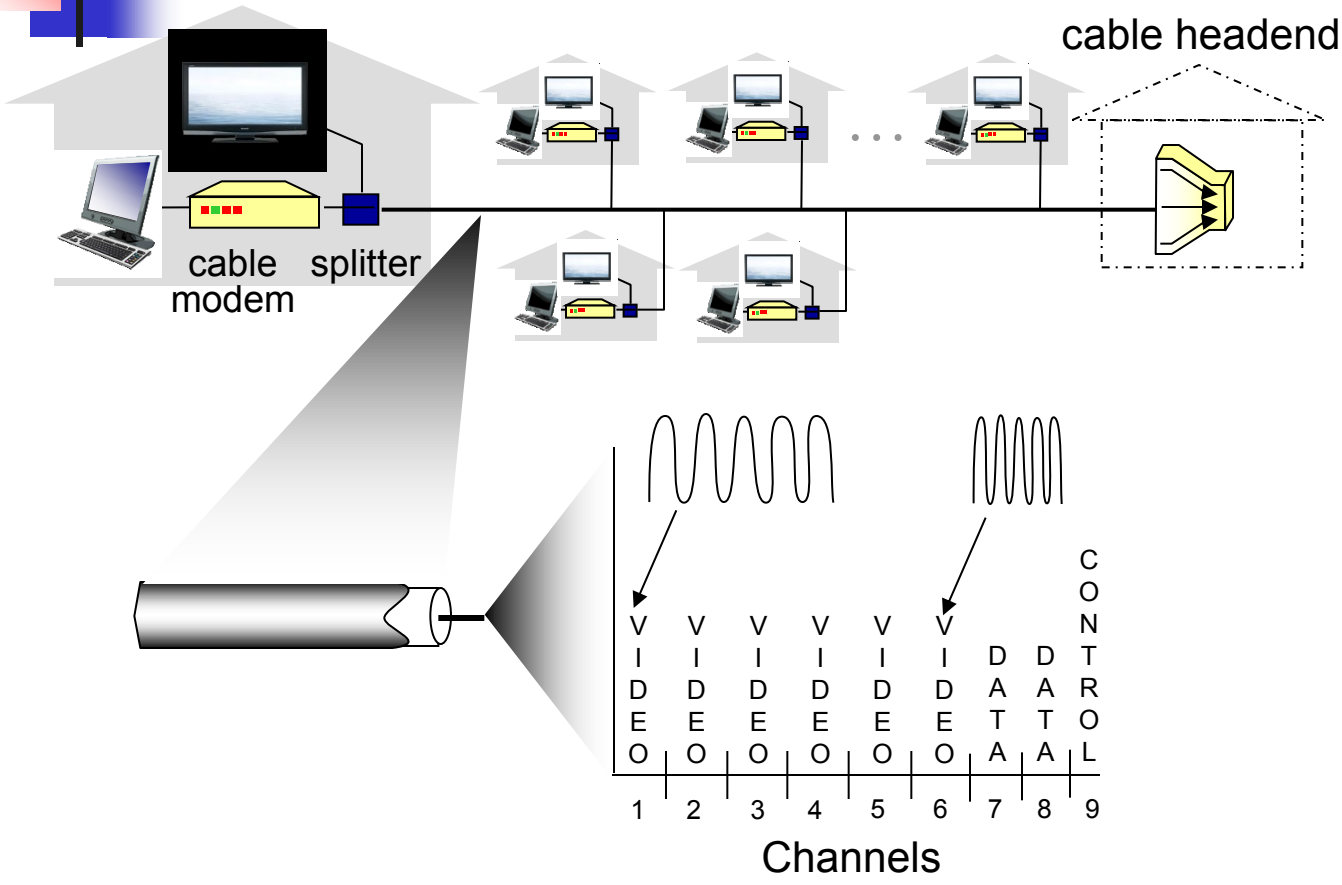
- More on HFC and ADSL
  - HFC
    - Tree and branch, e.g., Fig. 1.17
    - Coaxial cable + fiber optics, shared media
    - Down: 42.8 Mbps; up: 30.7 Mbps
    - Up: 5-45MHz, AS: 50-550MHz, DS: 550-750MHz
  - ADSL
    - xDSL, x=A, S, H, V, etc.
    - Twisted pair, point to point connection
    - Down: 24Mbps, up: 2.5Mbps
    - POTS: 0-4KHz, up: 4-50KHz, down: 50KHz-1MHz

DSL



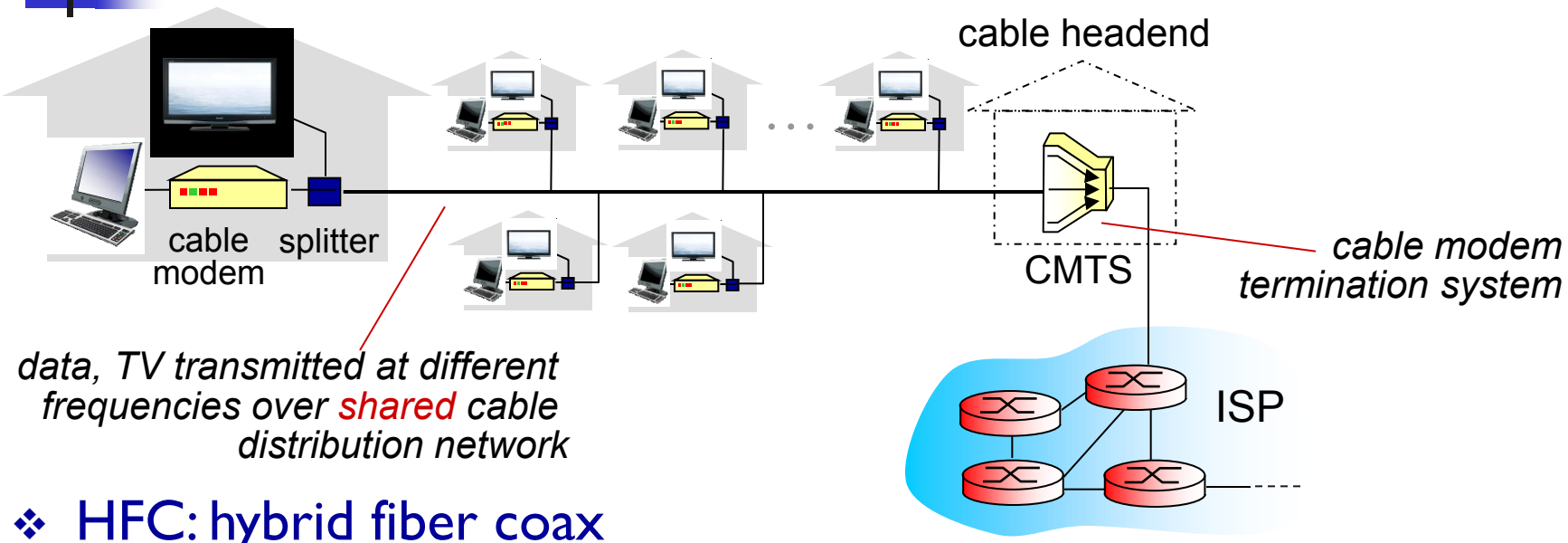
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- < 2.5 Mbps upstream transmission rate (typically < 1 Mbps)
- < 24 Mbps downstream transmission rate (typically < 10 Mbps)

HFC



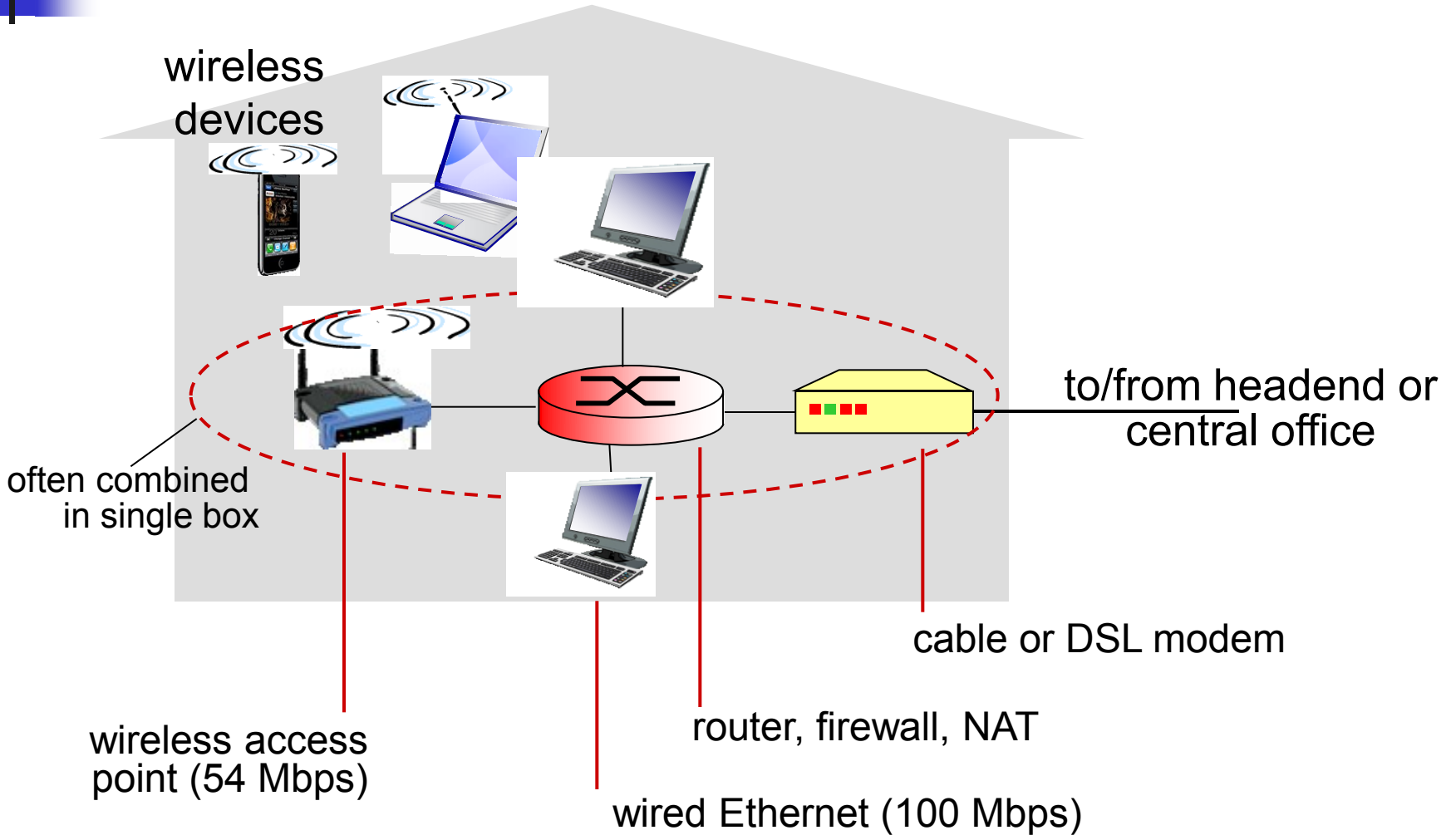
frequency division multiplexing: different channels transmitted in different frequency bands

HFC



- 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

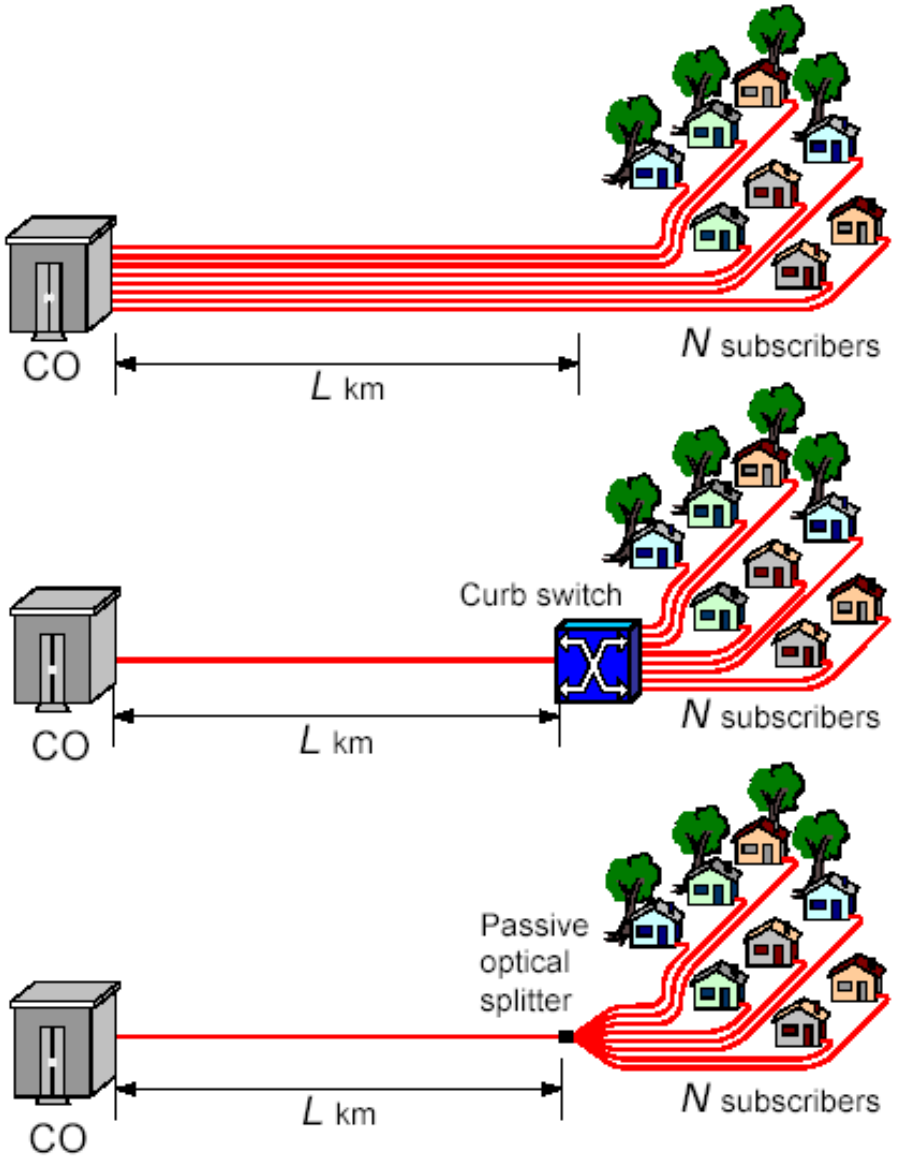
Home Network

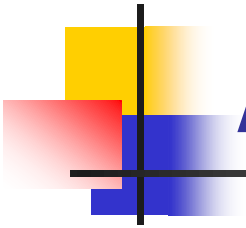


FTTH

AON

PON

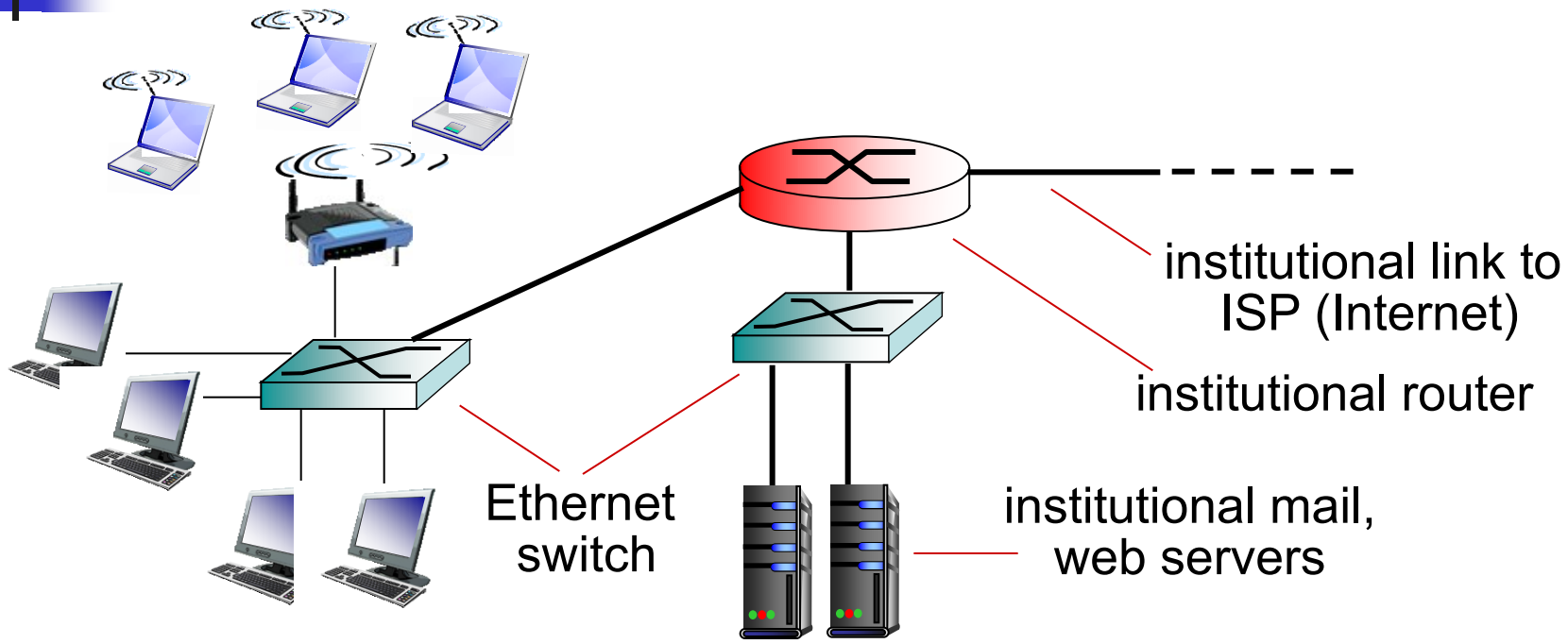

CO
L km
N subscribers
Curb switch
CO
L km
N subscribers
Passive
optical
splitter
CO
L km
N subscribers



Access Networks (cont.)

- Company access networks
  - Ethernet
    - 10, 100, 1000 Mbps, shared media
  - Wireless LAN
    - IEEE 802.11a/b/g: up to 54Mbps
    - ETSI HiperLAN/2
- Mobile access networks
  - Cellular system
    - GSM/AMPS → HSCSD/GPRS/EDGE → 3G/4G
  - Wireless Local Loop
    - MMDS/LMDS: 36Gbps up and 1Mbps down by a sector

Ethernet



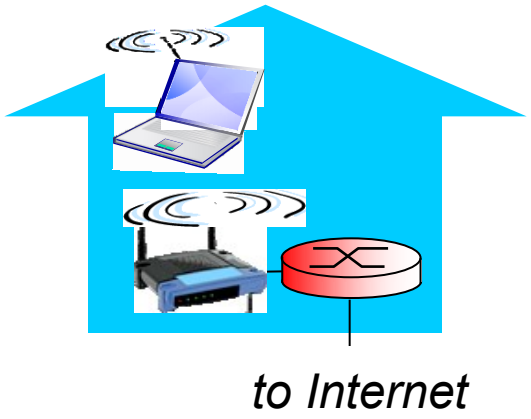
- typically used in companies, universities, etc
- 10 Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates
- today, end systems typically connect into Ethernet switch

Wireless Access Networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"

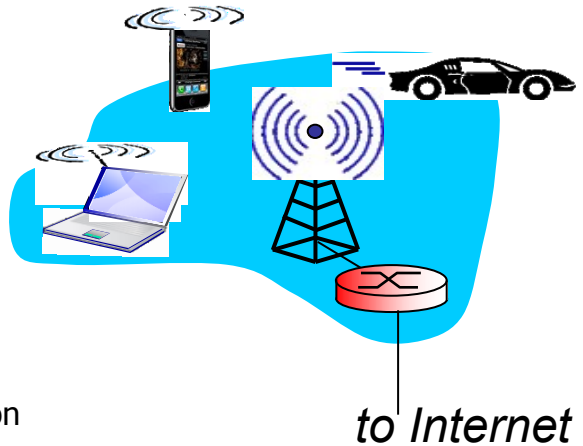
wireless LANs:

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

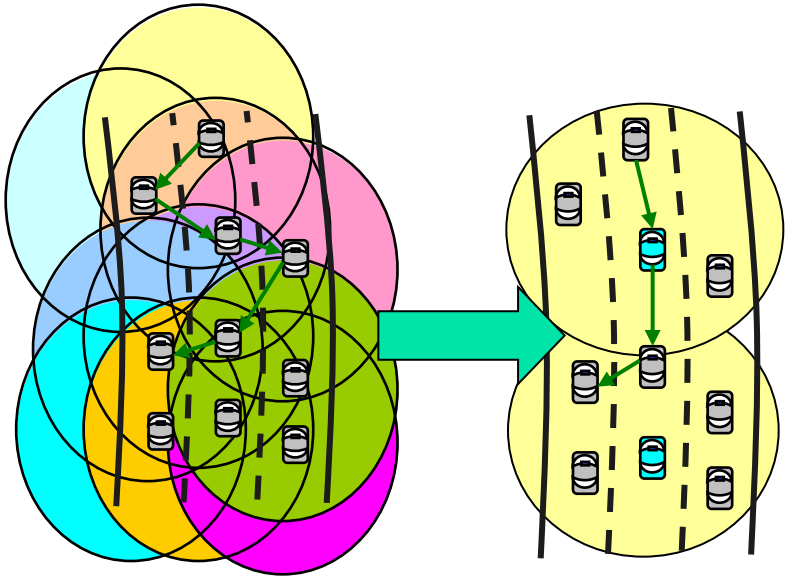


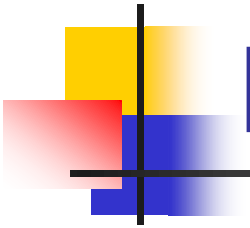
wide-area wireless access

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



ITS and Telematics



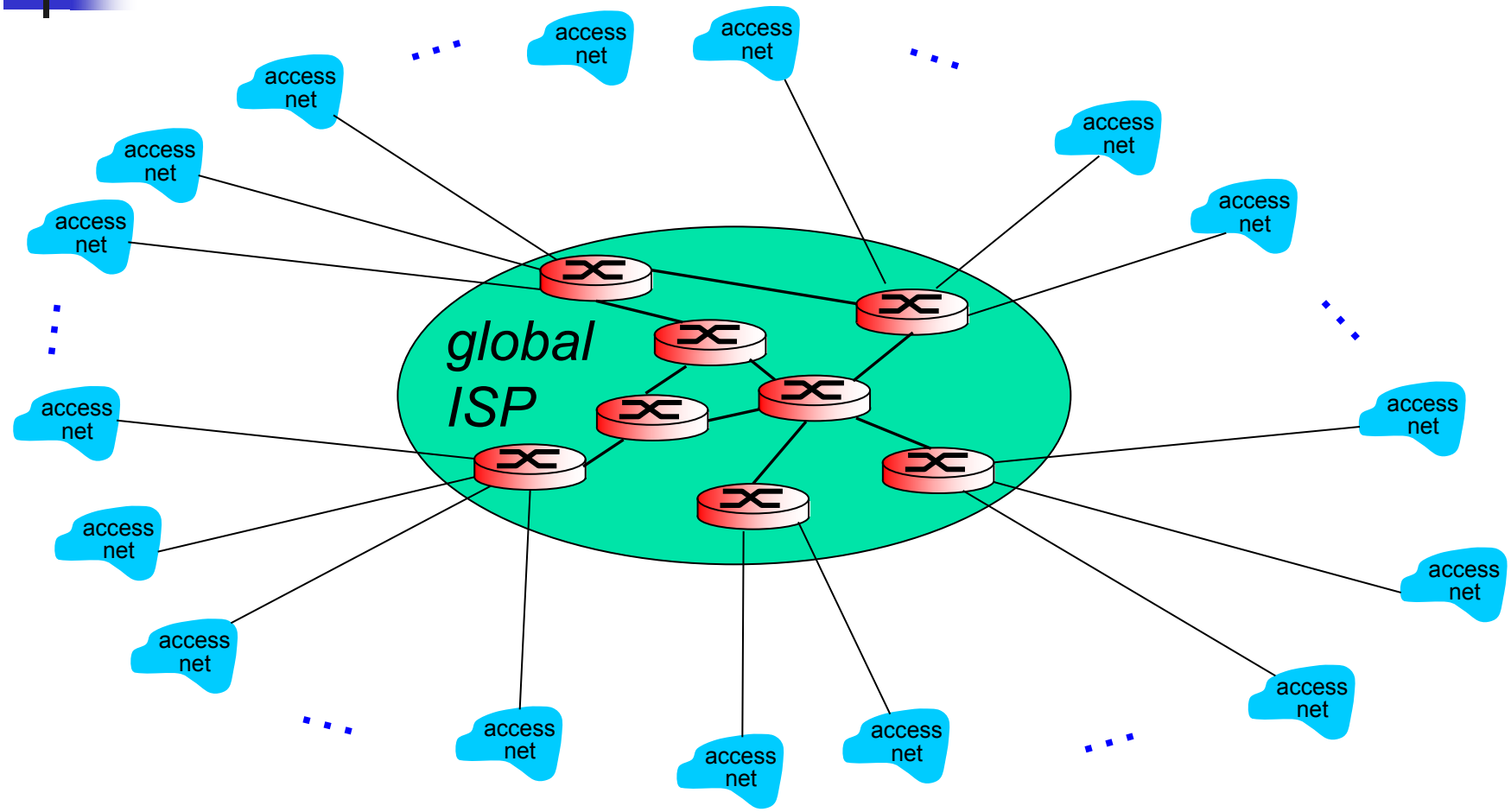


Network of Networks

- Tier-1, tier-2, .., access ISP
- Tier-1: Internet backbone
  - MCI/UUNet, Verizon, Spring, Cable&Wireless, AT&T
  - International coverage
- Point of Presence (PoP)
- Network Access Point (NAP)
- Peering and Transit service

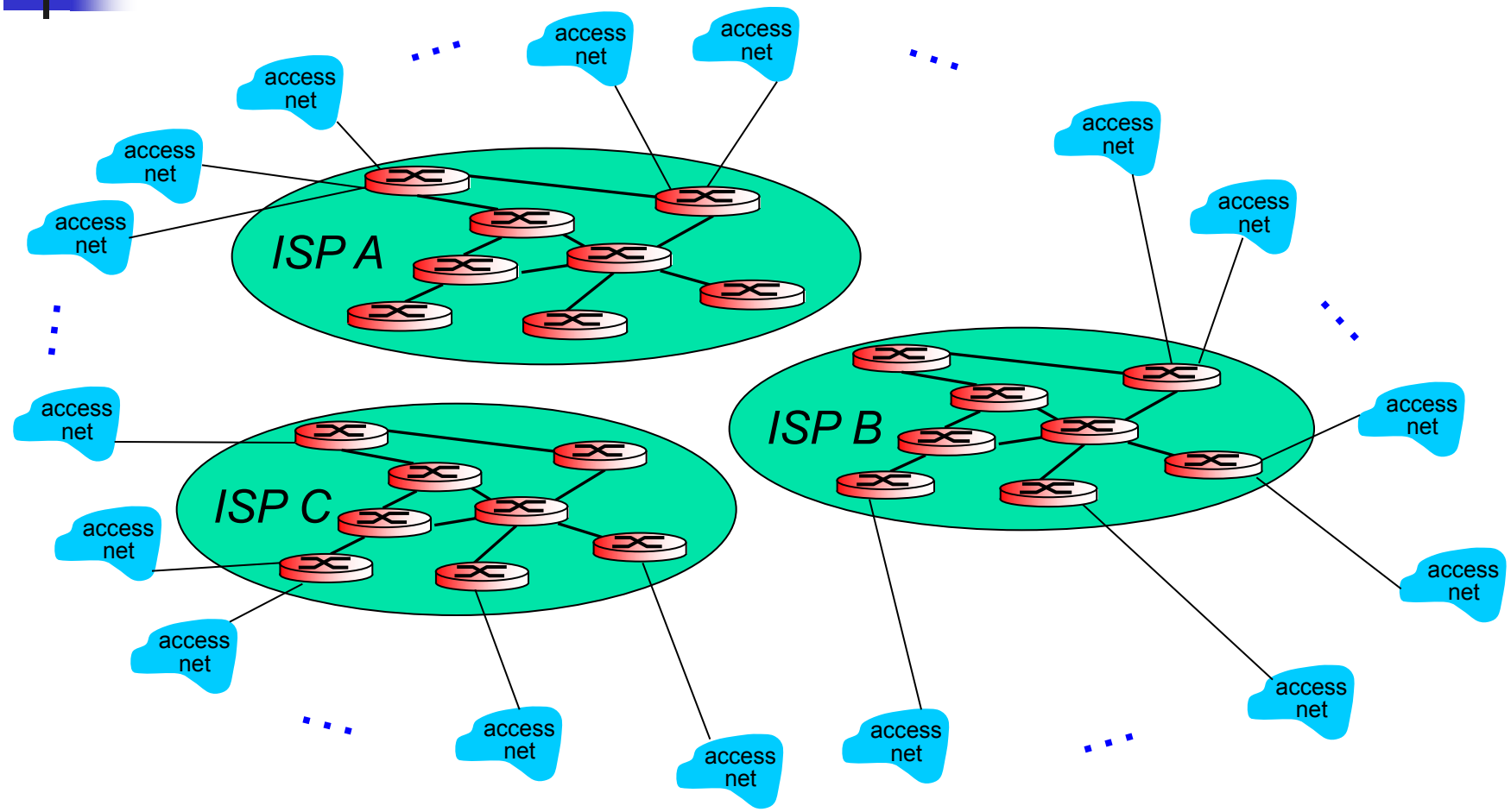
Internet structure: network of networks

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



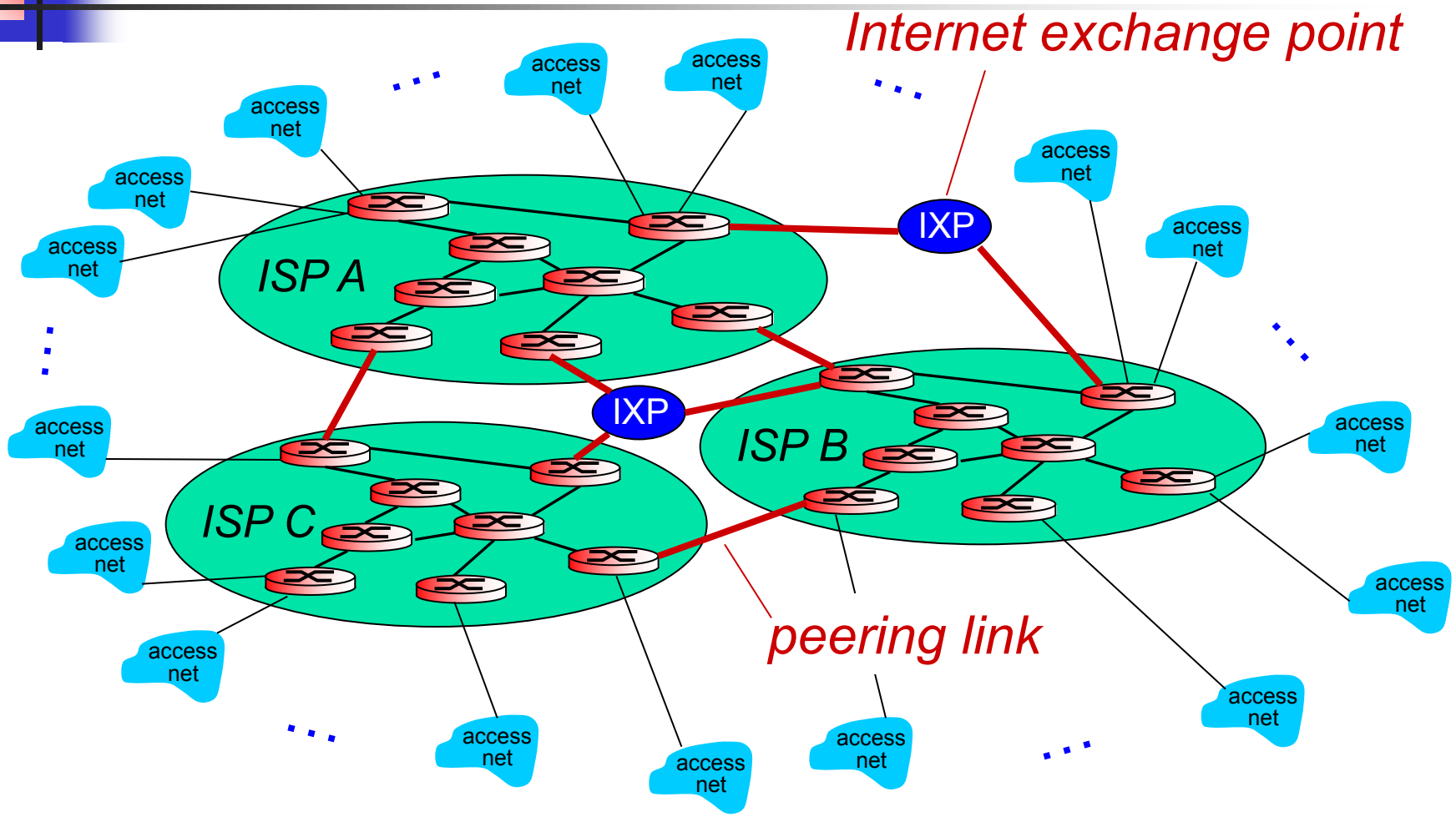
Internet structure: network of networks

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



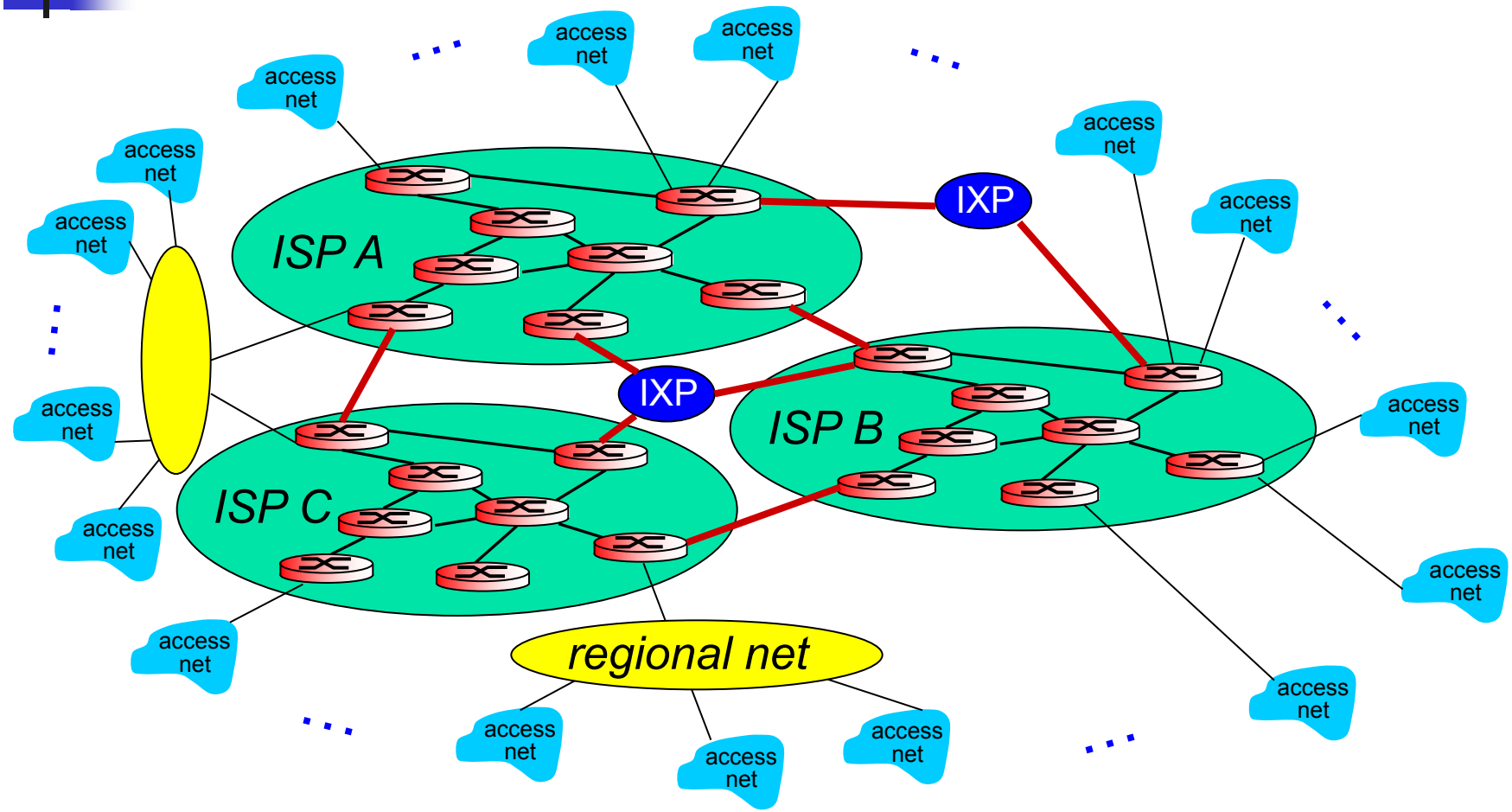
Internet structure: network of networks

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



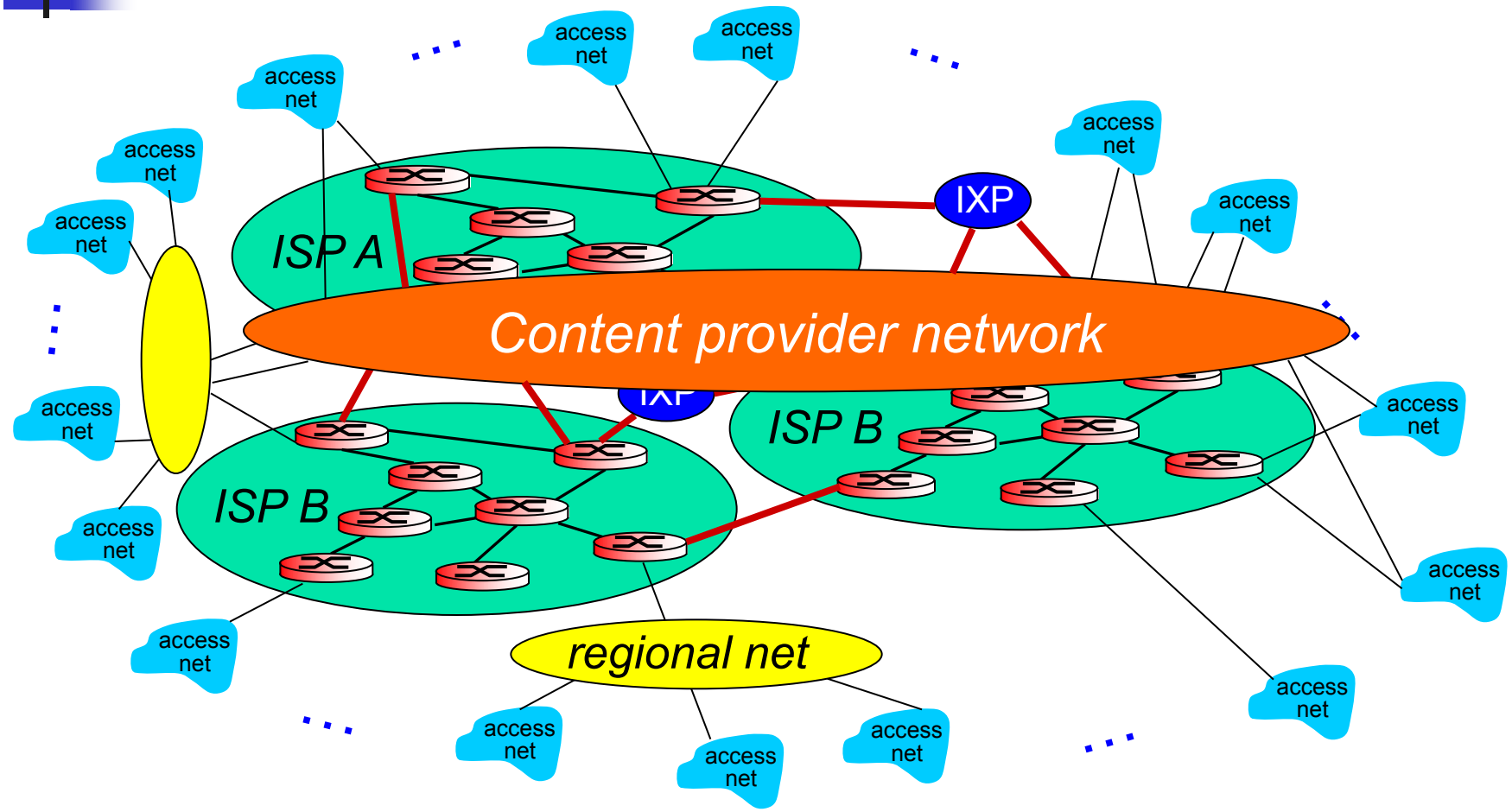
Internet structure: network of networks

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

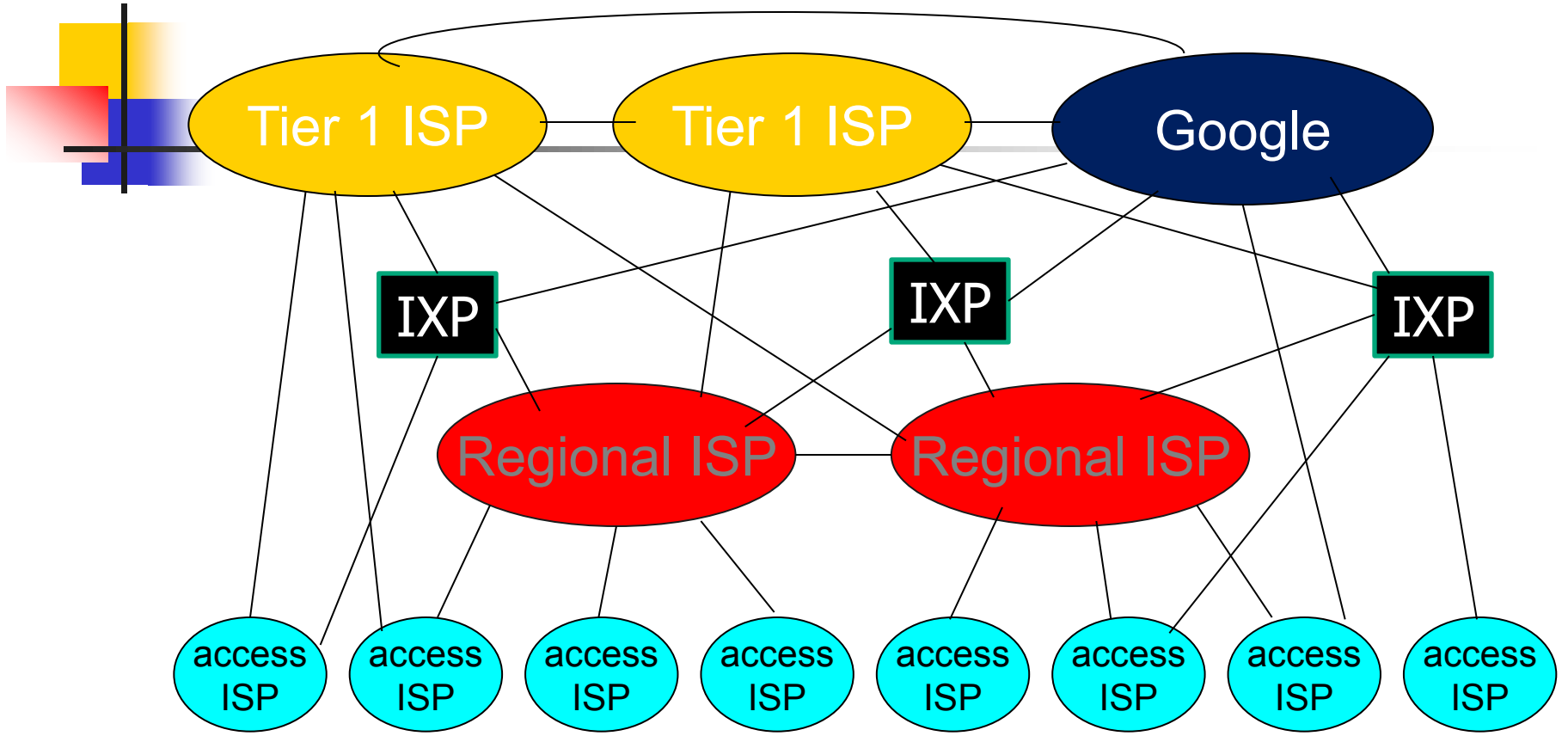


Internet structure: network of networks

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

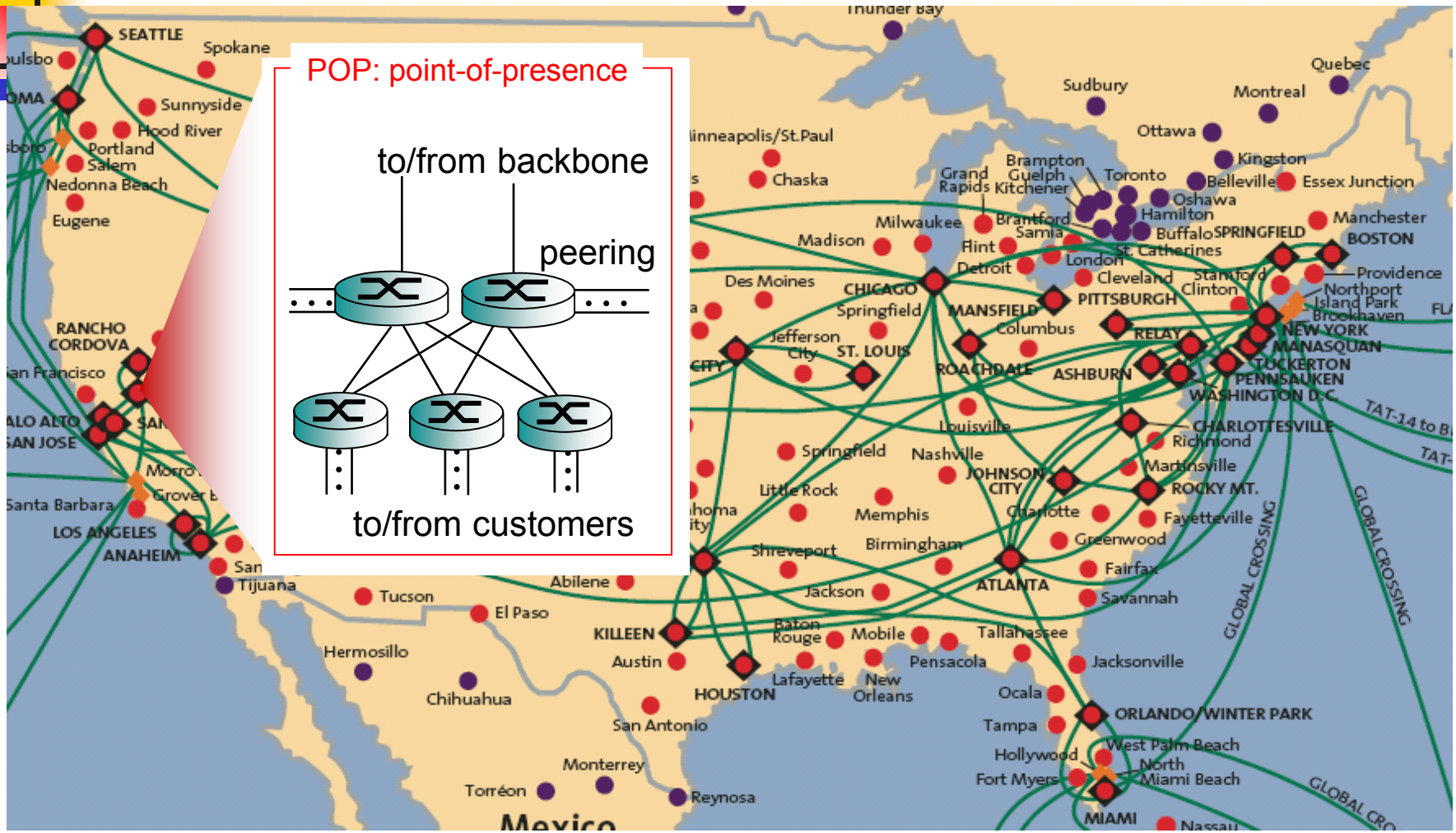


Internet structure: network of networks

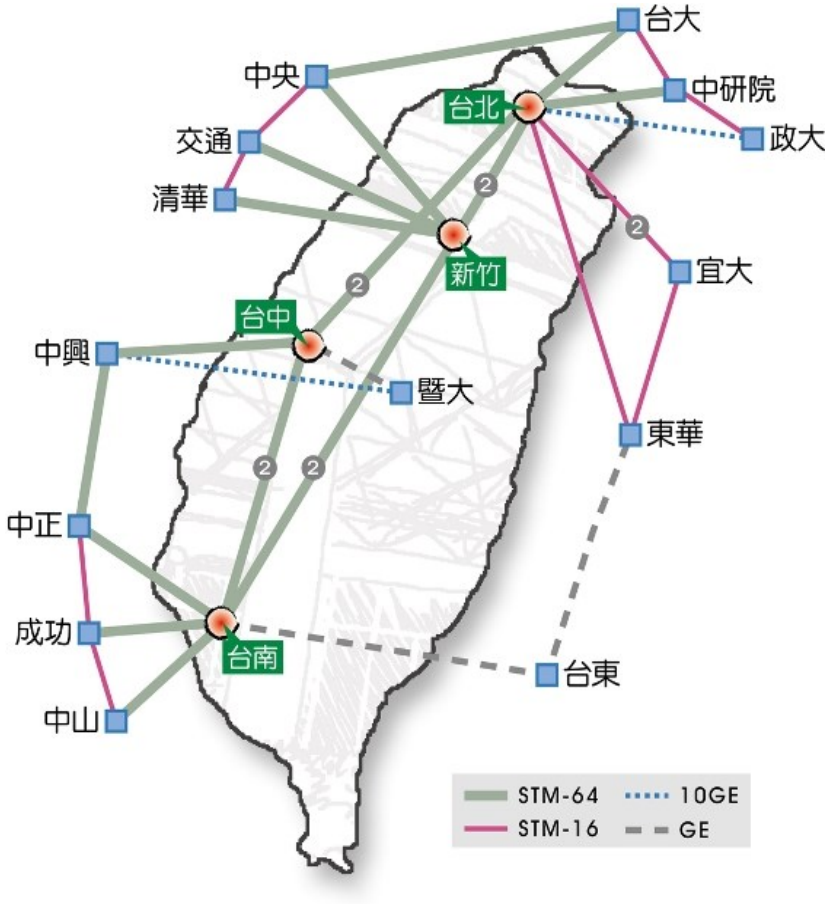


- at center: small # of well-connected large networks
  - "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

Tier-1 ISP: e.g., Sprint

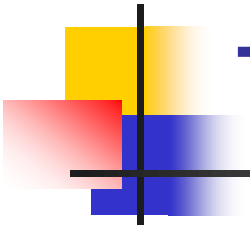


TWAREN: Local Map



NTU: GigaPoP
Leased int'l link: 750Mbps
Peering:
  Hinet: 3Gbps
  台固&和信: 1Gbps

TWAREN: International MAP



Transmission media

- Physical layer: to transmit raw bits from transmitters to receivers
  - Transmission form: electromagnetic wave/optical pulse
  - Data rate, transmission impairment, cost, needs
- Two types of transmission media
  - Guided media (wireline)
    - Physically wired
    - e.g., twisted pair, coaxial cable, fiber optics, etc.
  - Unguided media (wireless)
    - Transmission and reception via antenna
    - e.g., radio spectrum: terrestrial v.s. satellite

Transmission terms (1)

- Transmitter
- Medium
  - Guided medium
    - e.g., copper, fiber, coax, power line
  - Unguided medium
    - e.g., air, water, vacuum, light (LED)
- Receiver

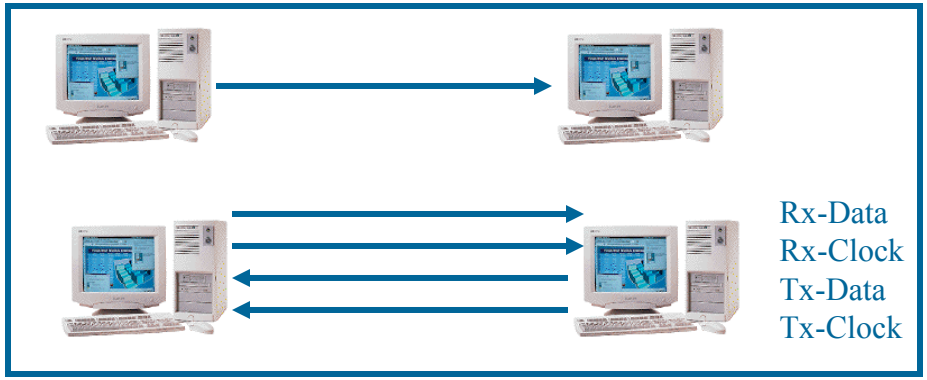
Transmission terms (2)

- Point-to-point
  - Only 2 devices share link

- Multi-point
  - More than two devices share the link

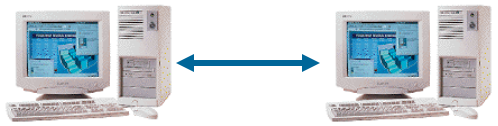
Transmission terms (3)

- Simplex
  - One direction
    - e.g. Television



- Half duplex
  - Either direction, but only one way at a time
    - e.g. police radio

- Full duplex
  - Both directions at the same time
    - e.g. telephone



Transmission media (cont.)

- Twisted pair
  - Low cost, easy to work with, low data rate, short range
  - Used for telephone, LAN wiring

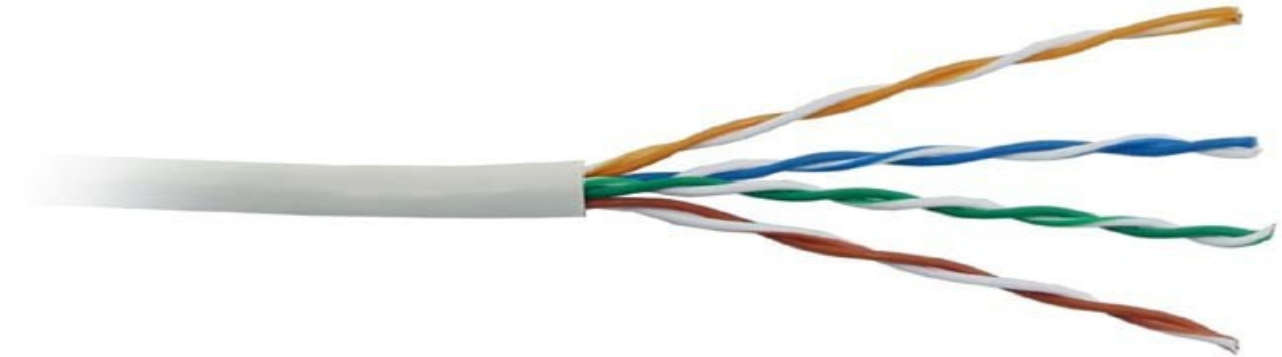
—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction

(a) Twisted pair

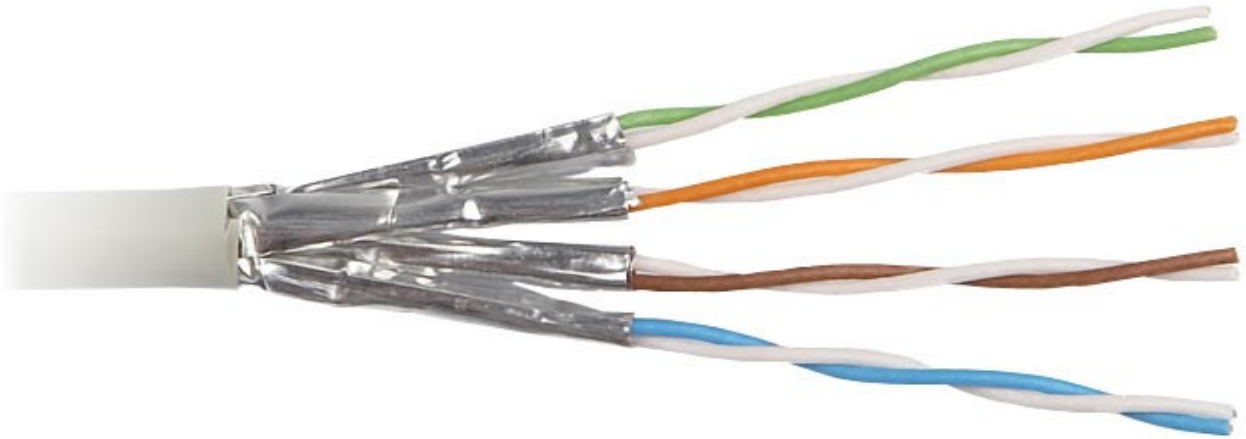
- A pair constitutes a single comm. Link

Twisted Pair

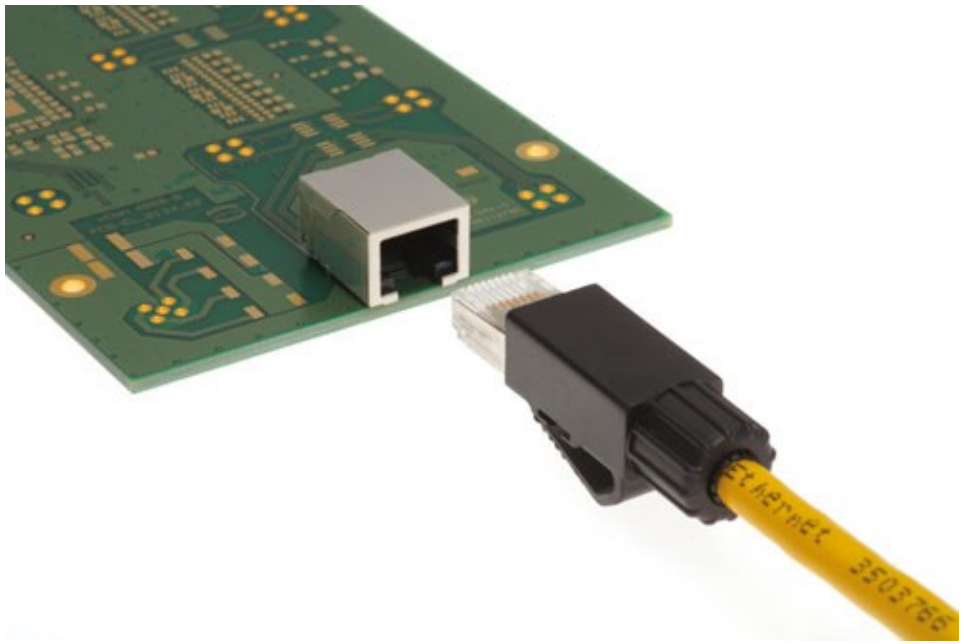
UTP



STP

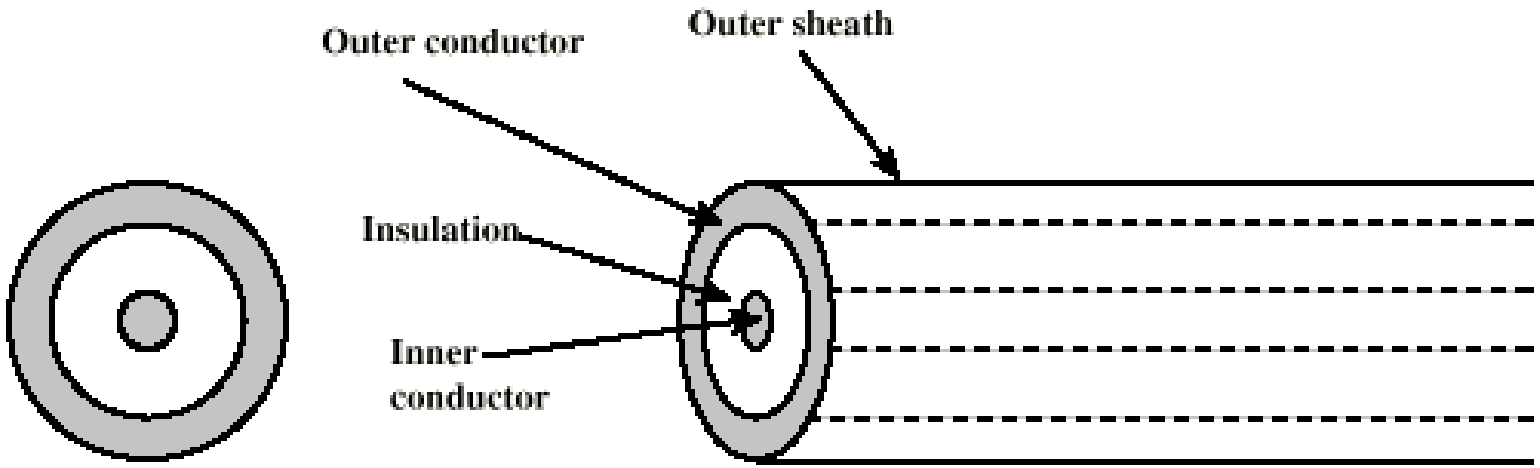


Twisted Pair and RJ-45



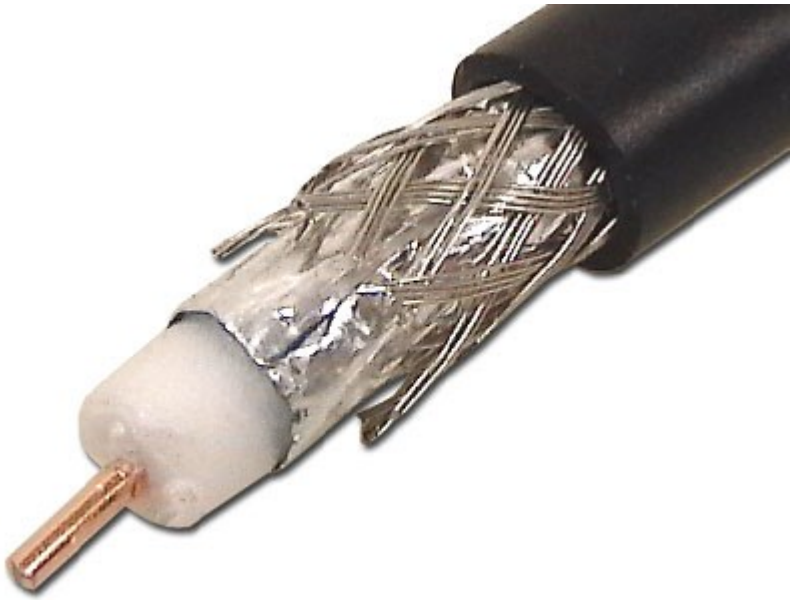
Transmission media (cont.)

- Coaxial cable



—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

Coaxial Cable

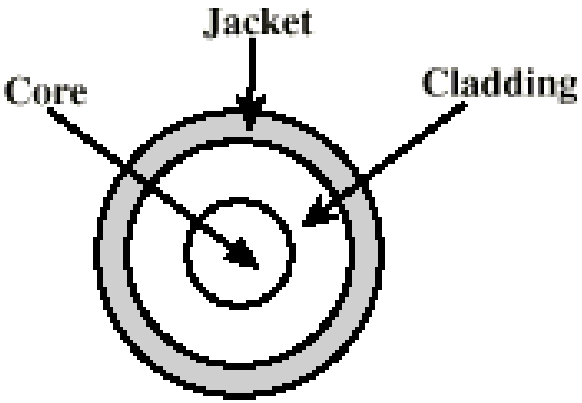


Transmission media (cont.)

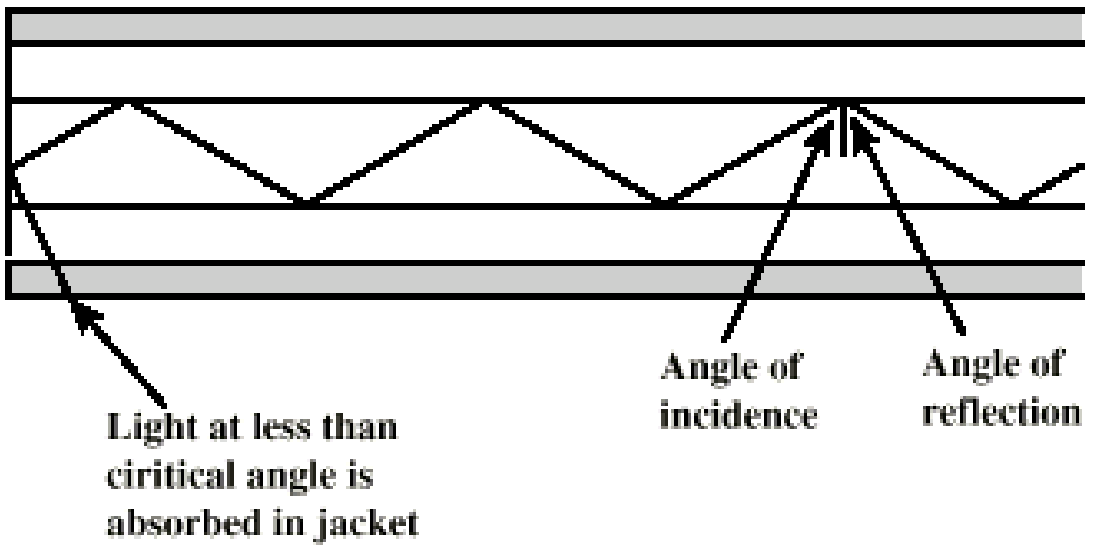
- Coaxial cable
  - Baseband coaxial
    - Thinner (50-ohm)
    - Mostly for LAN
  - Broadband coaxial
    - Thicker (75-ohm)
    - Mostly for CATV
  - Note that broadband coax usually cover a large area and need analogy amplifiers to strength the signals periodically

Transmission media (cont.)

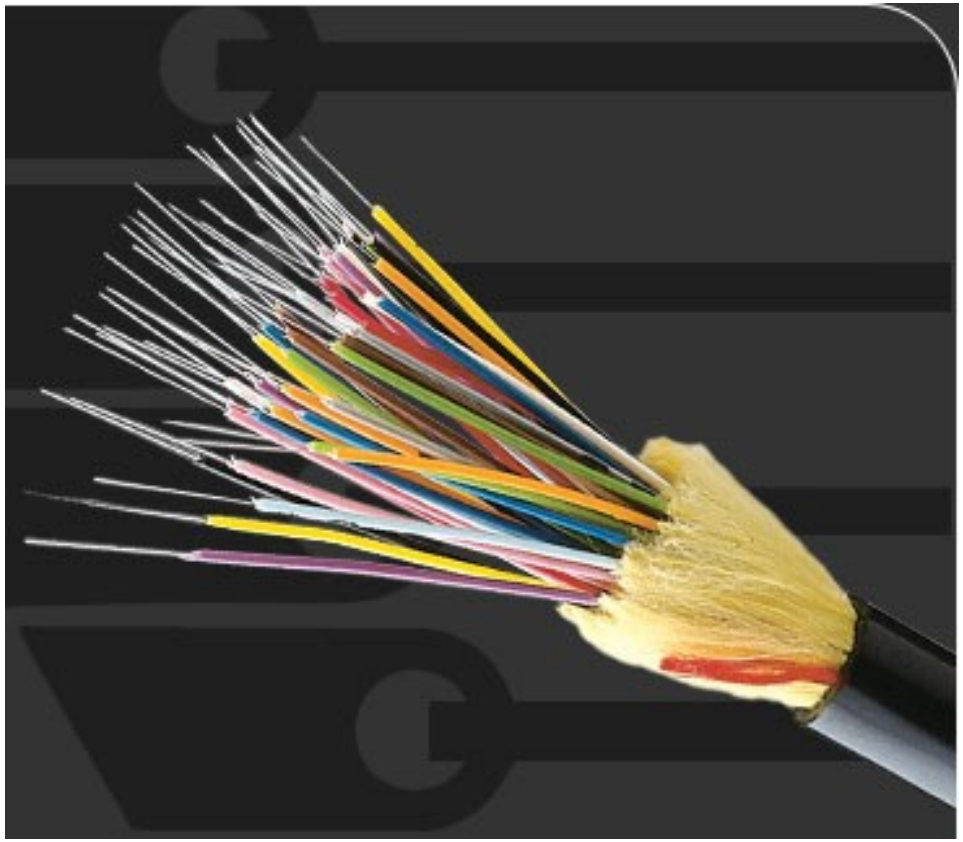
- Fiber optics



—Glass or plastic core
—Laser or light emitting diode
—Specially designed jacket
—Small size and weight



Fiber Optics and its connectors



Transmission media (cont.)

- Fiber optics
  - Advantages
    - Greater capacities (over longer distance)
      - x Gbps over tens of km
    - Smaller size and lighter weight
    - Lower attenuation
    - Electromagnetic isolation
      - Not vulnerable to interference, impulse noise, and cross talk
      - Harder to tap
    - Greater repeater spacing

Transmission media (cont.)

- Terrestrial and satellite radio channels
  - No physically media to install
  - Potentially carry signals for long distances
  - Terrestrial
    - Zigbee
    - WLAN
    - Cellular
  - Satellite
    - Microwave relay station and ground stations
    - Geostationary (earth-orbit) v.s. low attitude
      - GEO v.s. LEO

Classification of Satellites

- GEO: Geostationary Earth Orbit
- MEO: Medium Earth Orbit
- LEO: Low Earth Orbit

	Altitude (km)	RTT (ms)
GEO	36,000	588
MEO	10,390	250
LEO	1,375	70

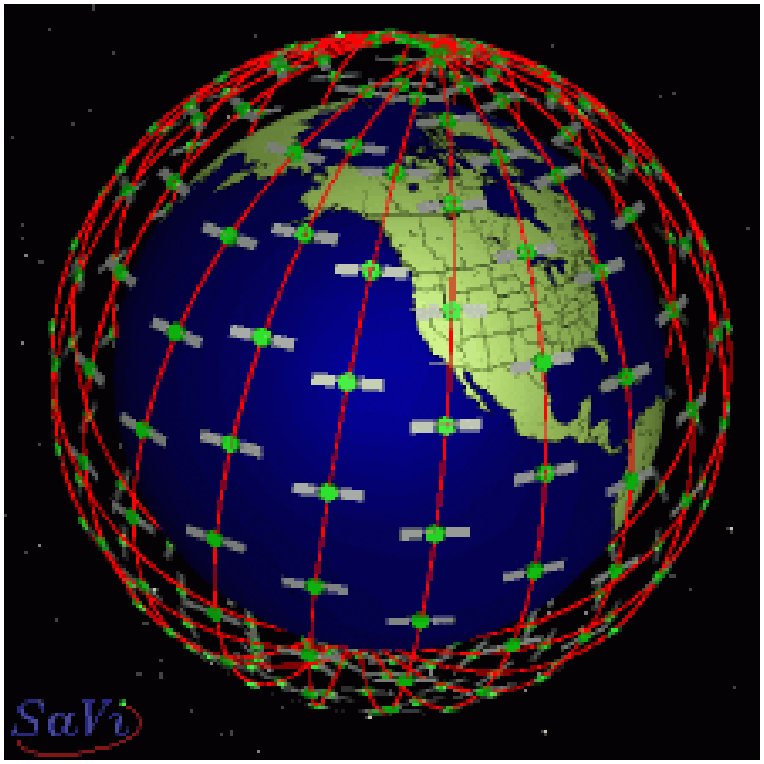
LEO Systems

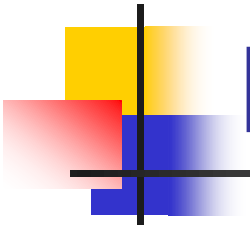
System Type	Little LEO	Big LEO	Broadband LEO
Example	Orbcomm, VITA	Iridium, Globalstar, ICO	Teledesic
Terrestrial Counterpart	Paging	Cellular	Fiber
Frequency	< 1 GHz	1 – 3 GHz	30/20 GHz

Teledesic

- Each Satellite:
  - Frequency: Ka-band (28.6-29.1Ghz up & 18.8-19.3 down)
  - Bandwidth: 64 Mbps / 2 Mbps (down/up)
- 12 planes, each with 24 satellites
- Total 288 satellites

Constellation of the Teledesic System





Network Security

- What? How? And Why?
  - how bad guys can attack computer networks?
  - how we can defend networks against attacks?
  - how to design architectures that are immune to attacks?
- Internet not originally designed with (much) security in mind!

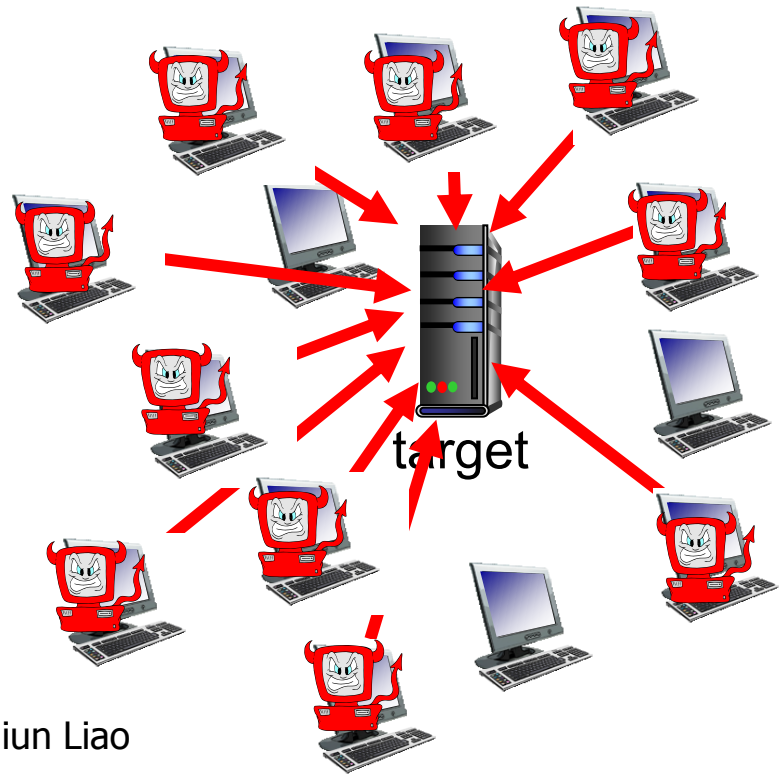
Bad guys put malware into hosts via Internet

- malware can get in host from:
  - *virus:* self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - *worm:* self-replicating infection by passively receiving object that gets itself executed
- spyware malware can record keystrokes, web sites visited, upload info to collection site
- infected host can be enrolled in botnet, used for spam. DDoS attacks

Bad guys attack server, network infrastructure

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

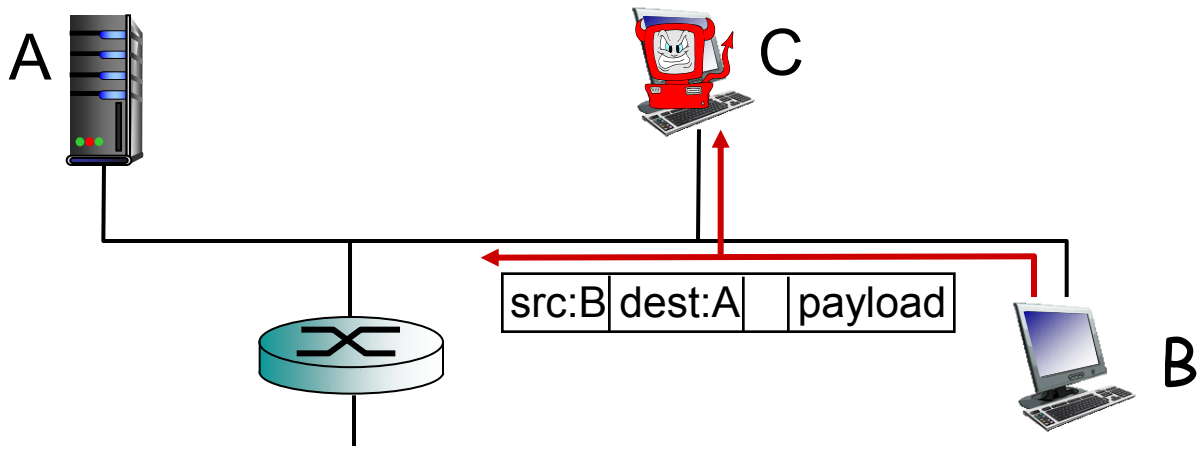
1. select target
2. break into hosts around the network (see botnet)
3. send packets to target from compromised hosts



Bad guys can sniff packets

packet "sniffing":

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



e.g., wireshark

Bad guys can use fake addresses

- *IP spoofing:* send packet with false source address