

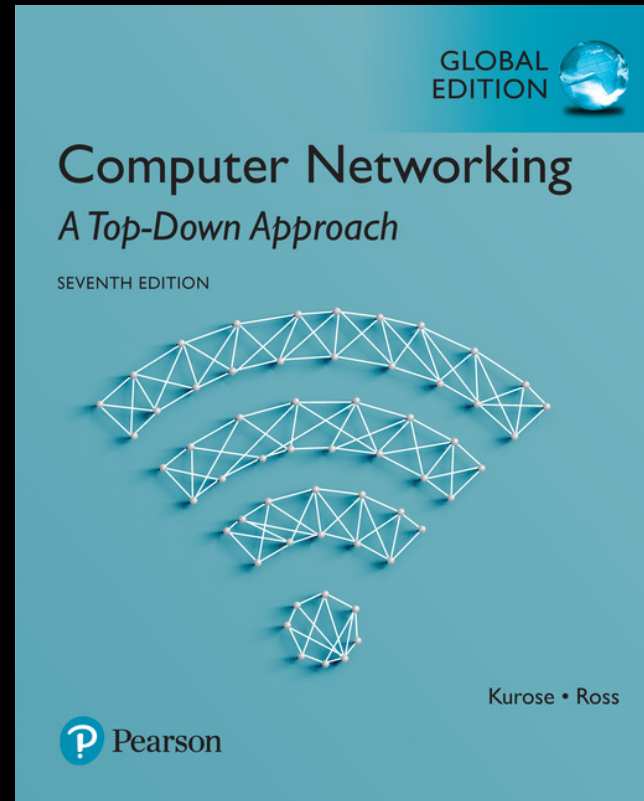
Computer Network

Introduction

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Computer Networking

A Top-Down Approach

7th edition

Jim Kurose, Keith Ross

Pearson

April 2016

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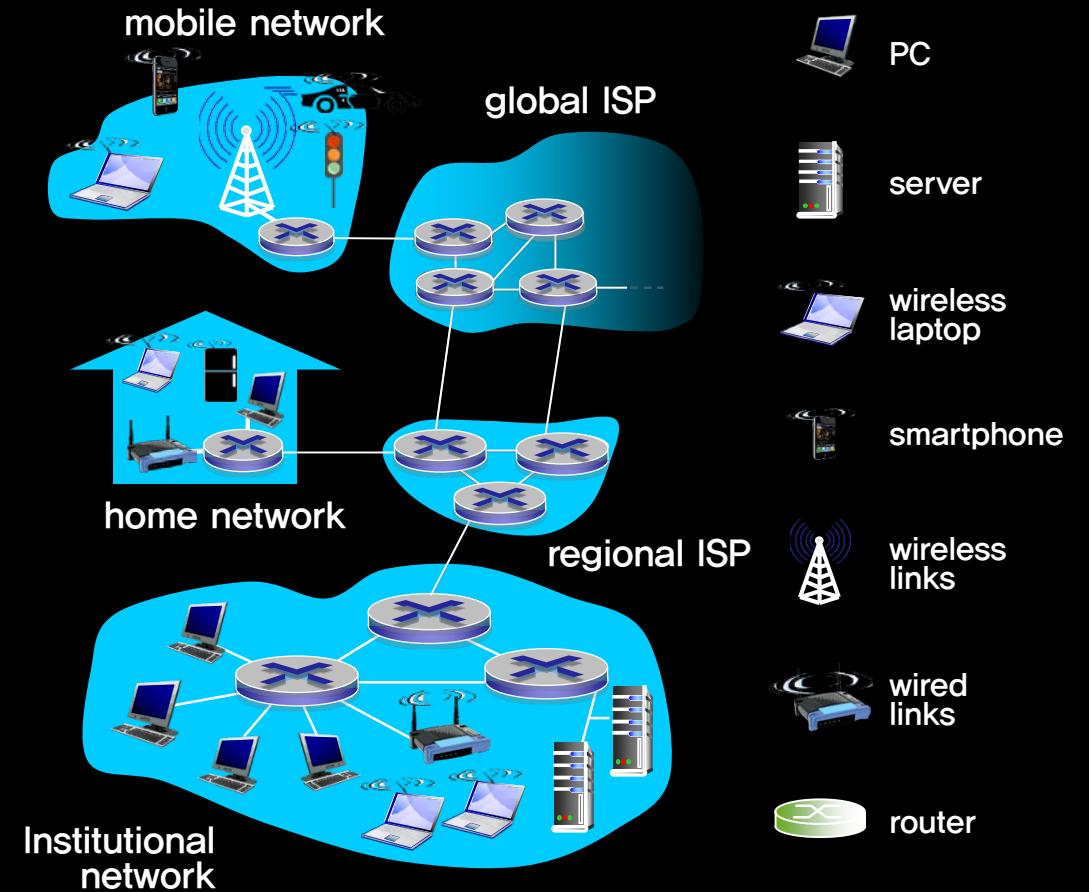
01. What is the Internet?

What is the Internet?



- **Internet** = Inter- + net (work)
 - “network of networks”

■ Various types of networks

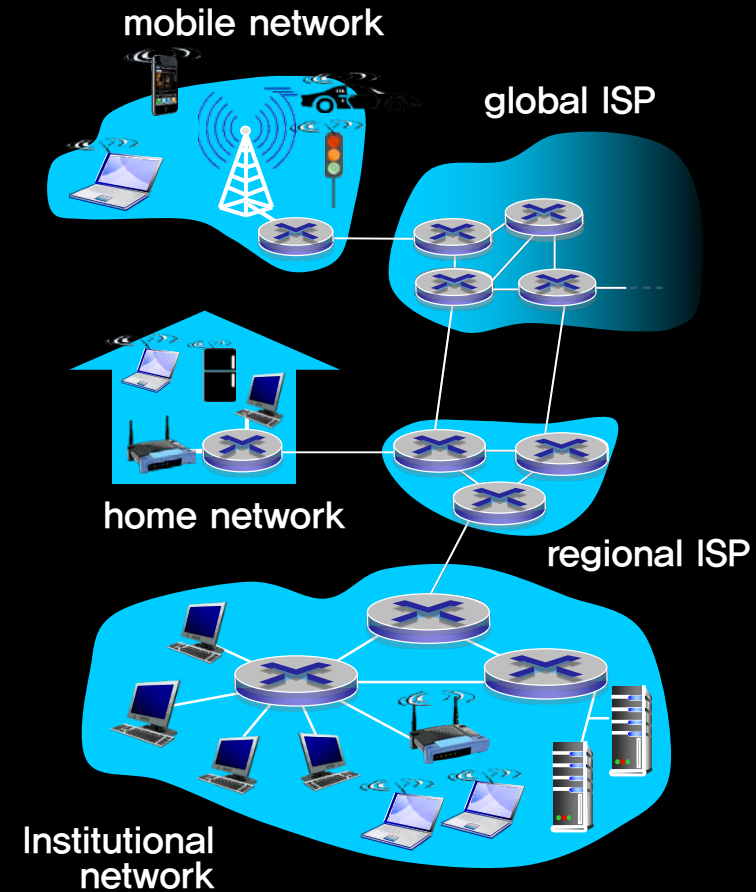


- HW components

- end hosts
- links
 - copper, fiber, radio, satellite
- interconnection devices
 - router, switch, repeater

- SW components

- operating software
- application programs
- protocols



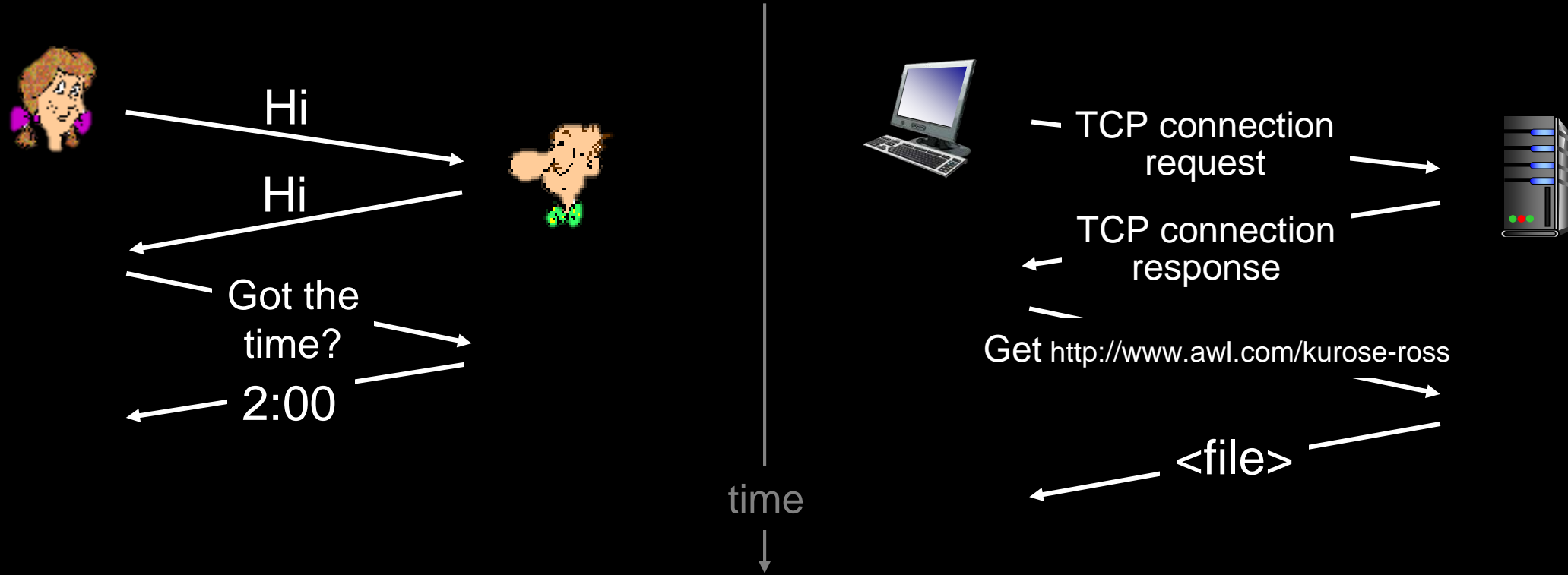
■ Protocols

- a defined set of rules and regulations that determine how data is transmitted in telecommunications and computer networking (from Wikipedia)



출처 - <http://rtrfm.com.au/story/talk-the-talk-why-its-hard-to-learn-a-language/>

Human protocol vs. Comm. protocol

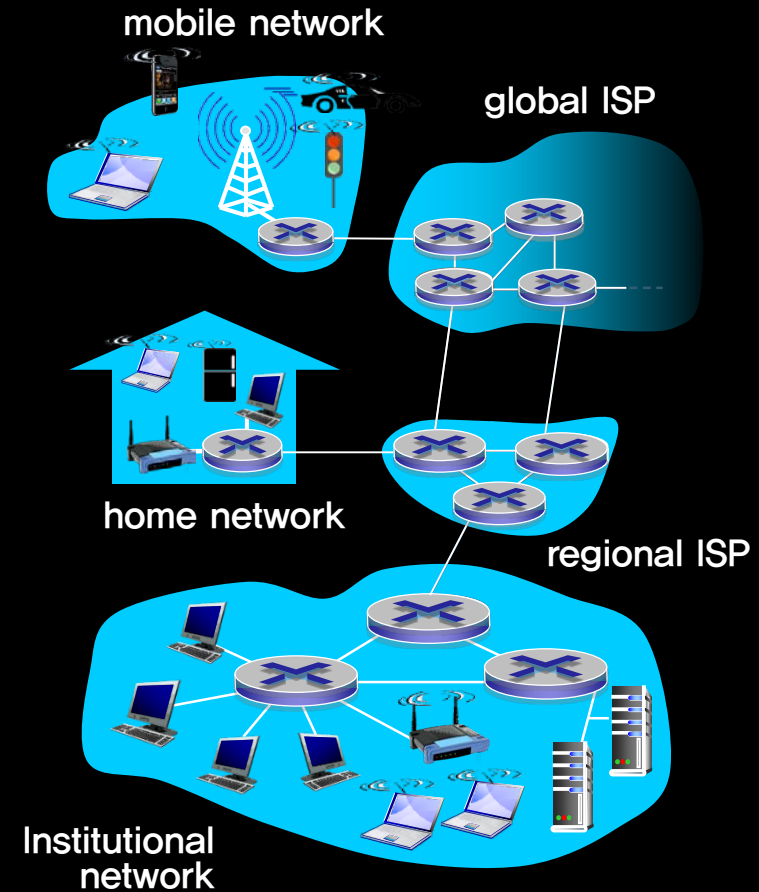


- All communication activity in Internet governed by protocols
- Protocols define
 - message format
 - order of messages sent and received among network entities
 - actions taken on message transmission, receipt



02. Network Edge

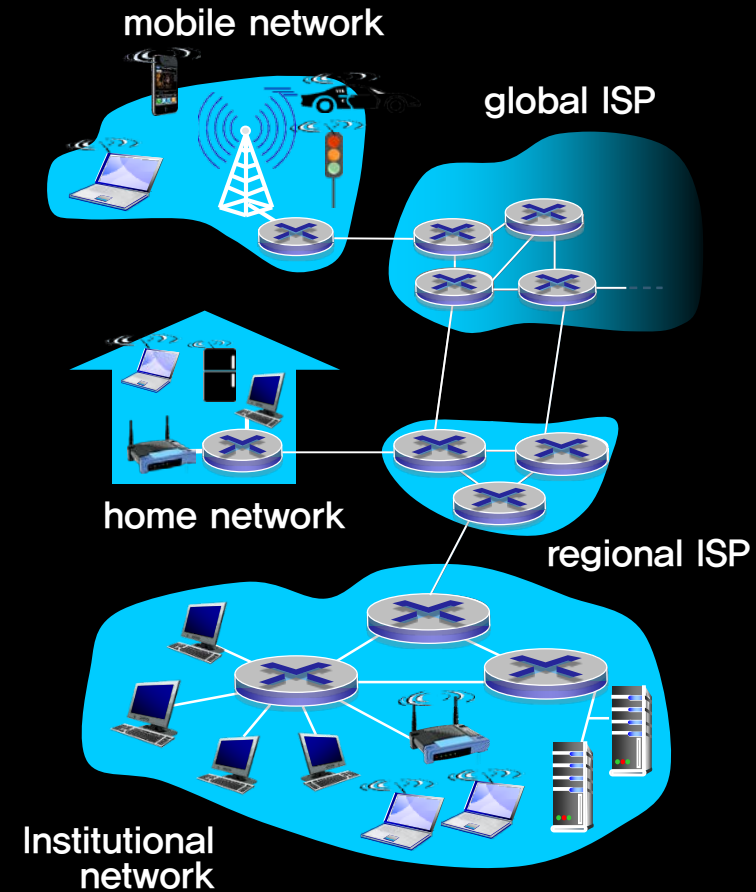
- Network edge
 - hosts: clients and servers
 - servers often in data center
- Network core
 - Interconnected routers or switches



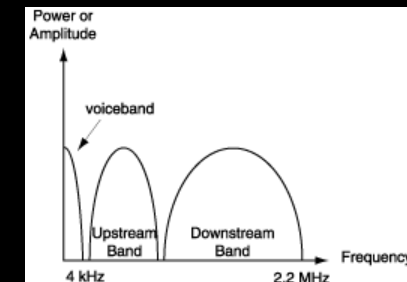
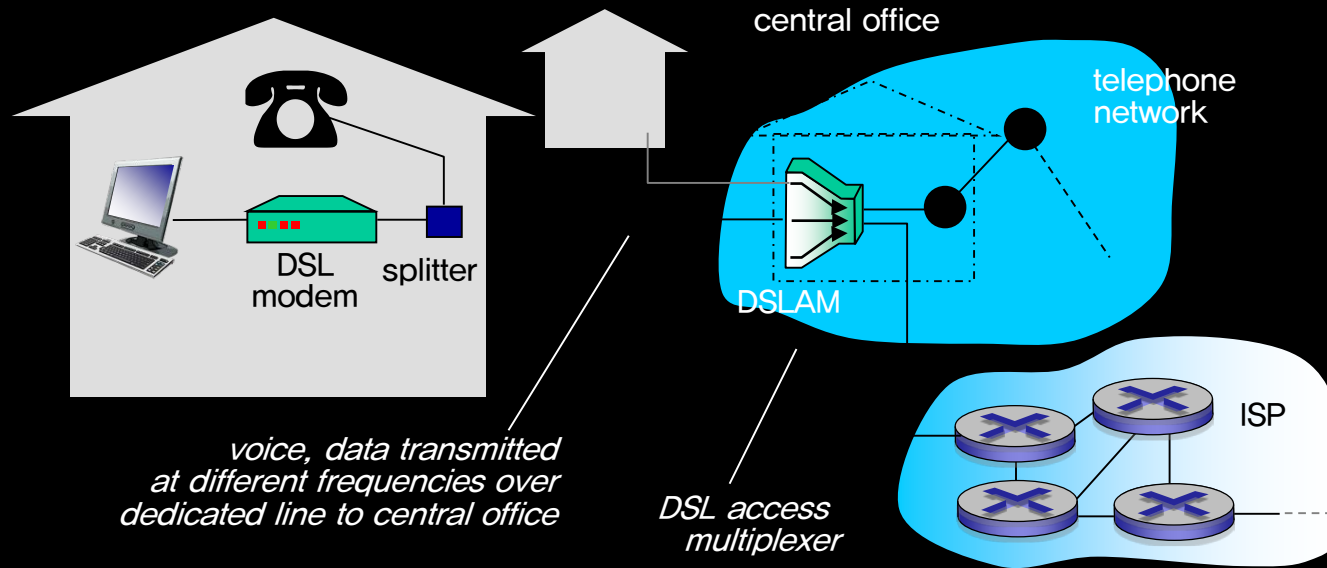
- Network connecting end systems to edge router?

- **Access network**

- residential access nets
- institutional acc. nets
- wireless access nets



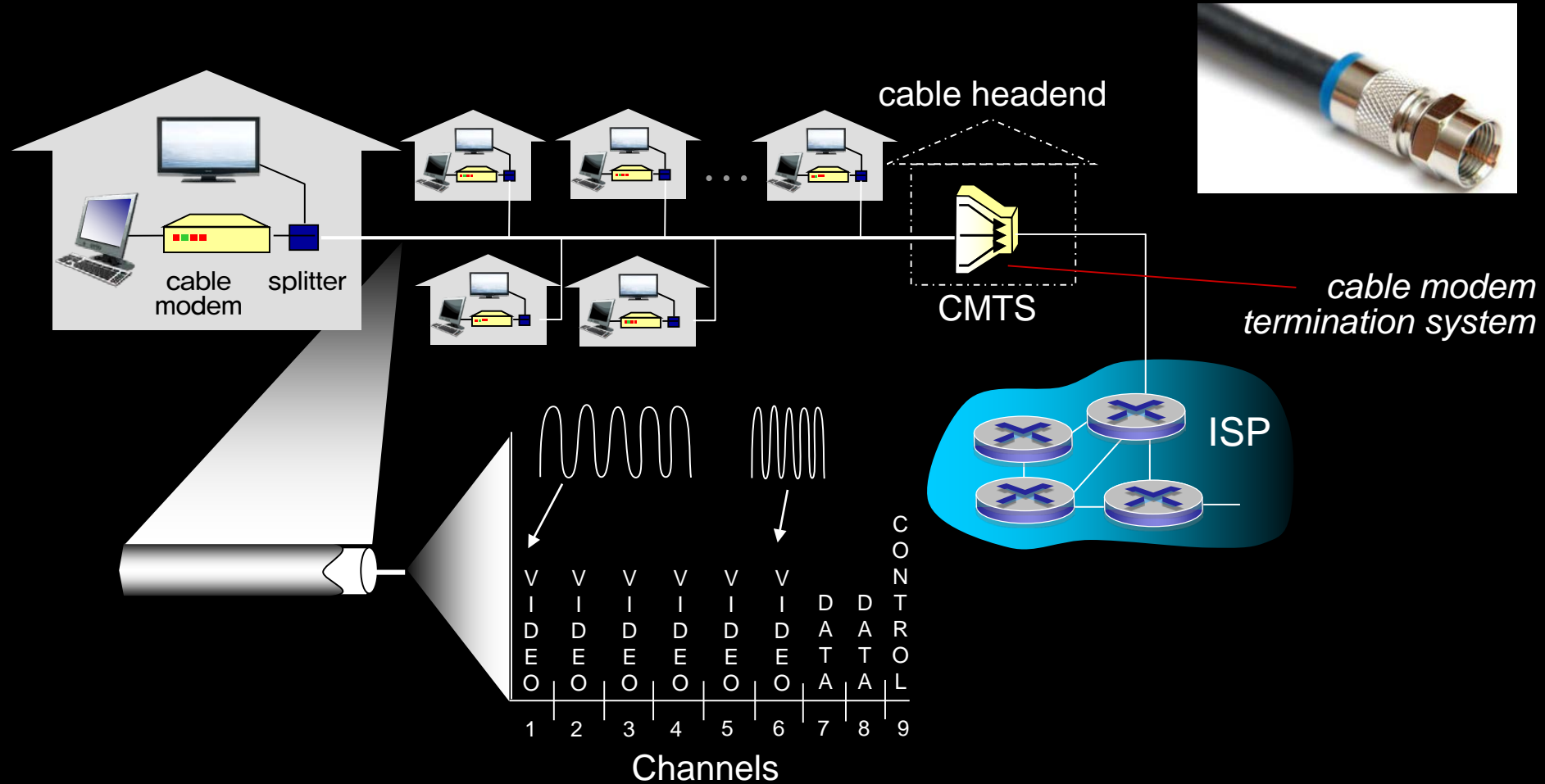
■ Digital subscriber line (DSL)



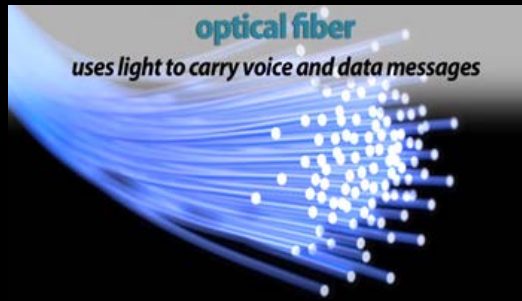
출처 – <http://sunsite.uakom.sk/sunworldonline/swol-02-1998/swol-02-connectivity.html/>

- voice over a phone line to telephone net
- data over a phone line to the Internet

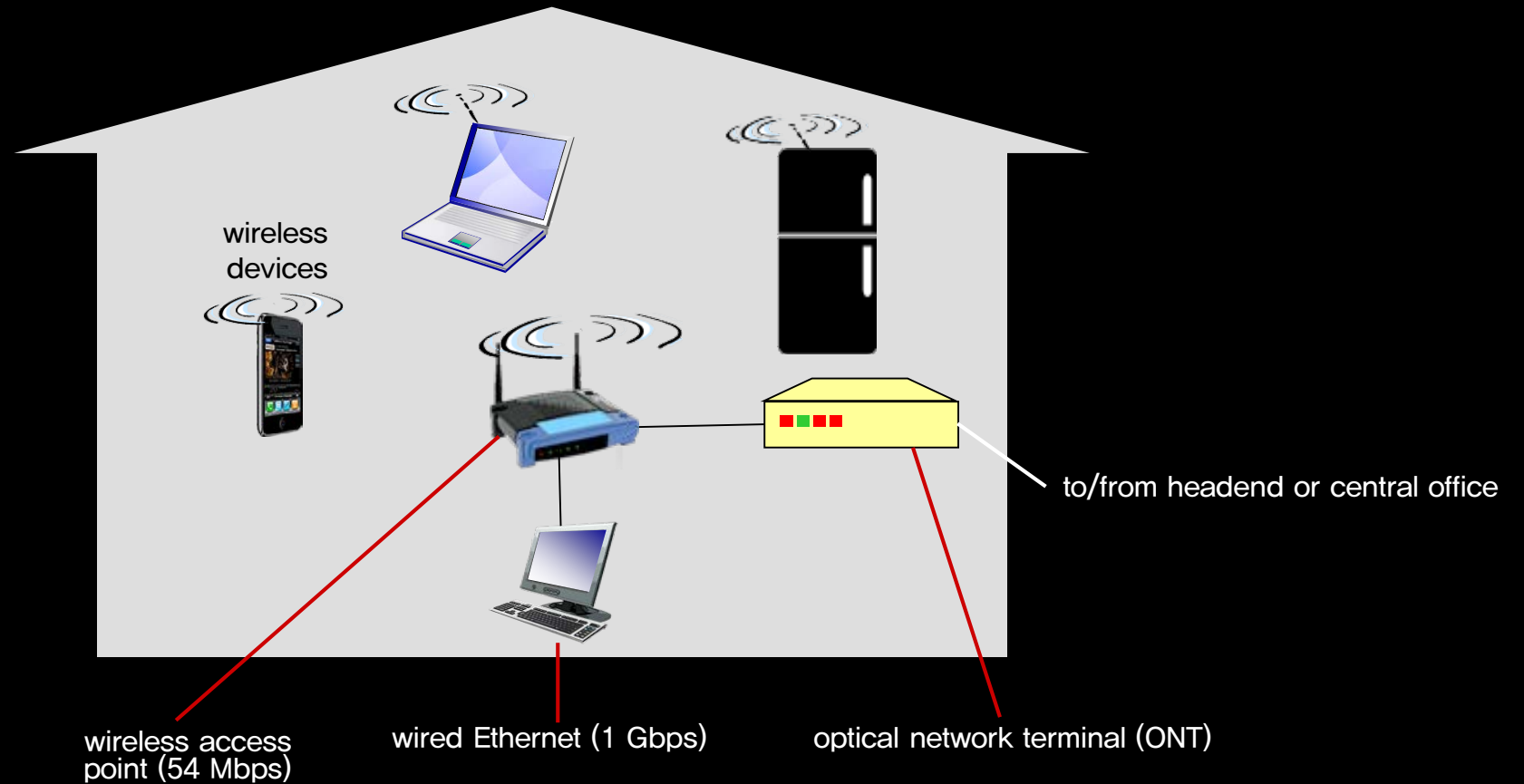
■ Cable network



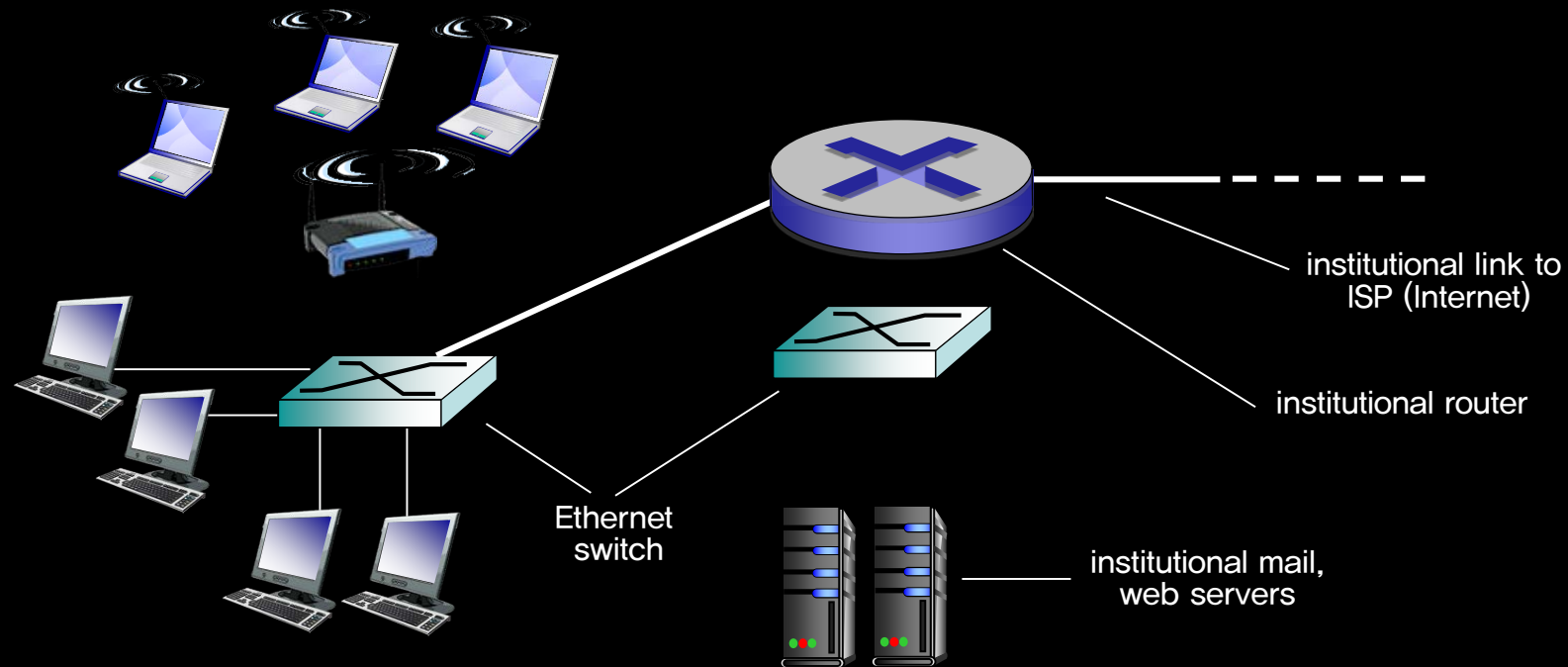
■ Fiber-to-the-Home (FTTH)



출처 - <https://study.com/academy/lesson/what-is-optical-fiber-definition-lesson-quiz.html/>



- Typically used in companies, universities
- 10Mbps, 100Mbps, 1Gbps, 10Gbps transmission rates



■ Wireless LAN

- 802.11g: 54 Mbps
- 802.11n: 600 Mbps
- 802.11ac: 2.6 Gbps (three 160MHz chs)



to Internet

■ Cellular network

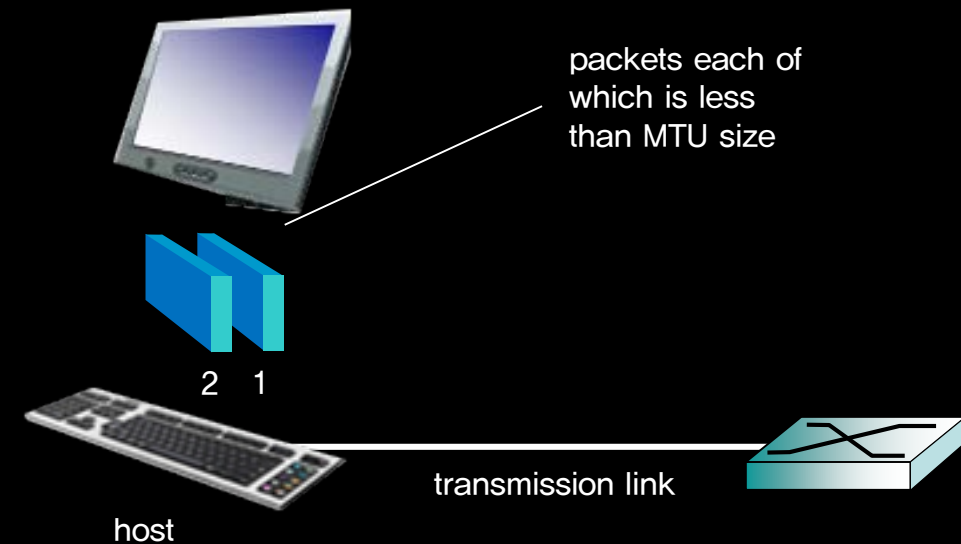
- 3G, 4G LTE, 5G
- 1, 10, 100 Mbps per person



to Internet



- Takes an application message
- Breaks it into smaller chunks, known as *packets*, of length less than MTU
- Transmits packet into access network
 - link transmission rate, a.k.a. link capacity or link bandwidth



Twisted pair

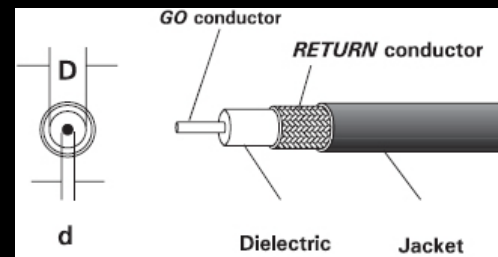
- Two insulated copper wires
- 100 Mbps ~ 10 Gbps



출처 - https://commons.wikimedia.org/wiki/File:USB_Twisted_Pair.svg/

Coaxial cable

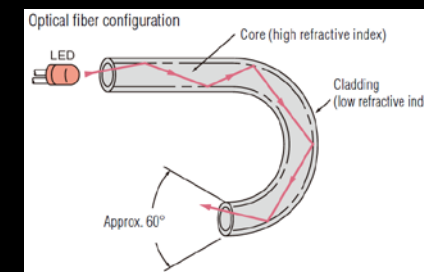
- Two concentric copper conductors
- Broadband
- Multiple channels on cable



출처 - http://www.standard-wire.com/coax_cable_theory_and_application.html/

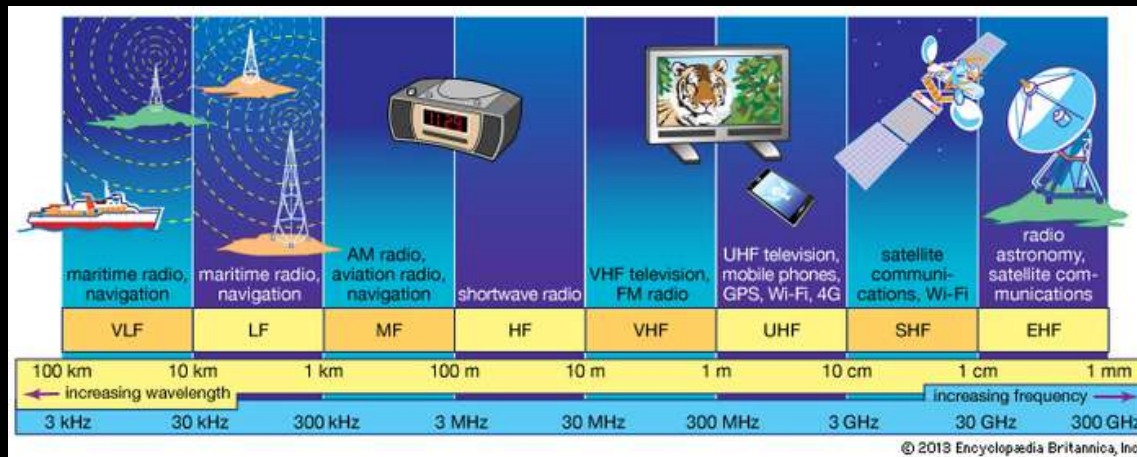
Optical fiber

- High speed, low error
- Less attenuation
- Immune to electromagnetic noise

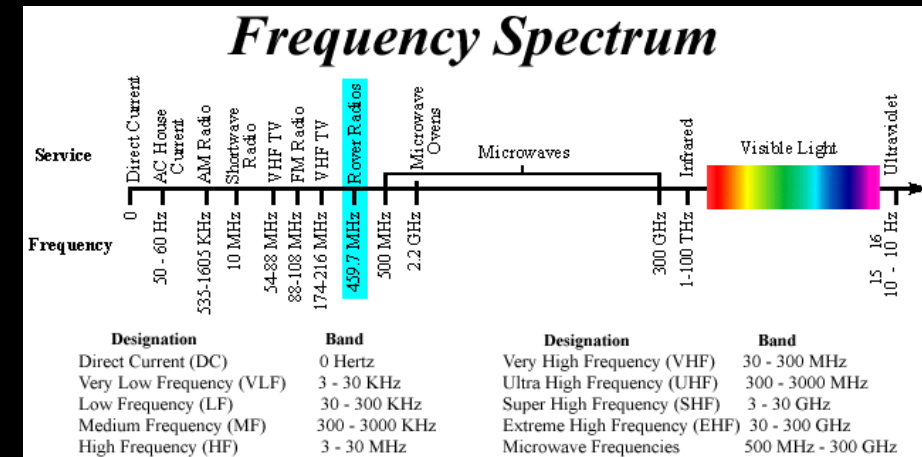


출처 - <https://www.keyence.co.uk/ss/products/sensor/sensorbasics/fiber/info/>

- Bandwidth for each service
 - WiFi: 2.4 GHz, 5 GHz
 - IMT-Advanced (4G LTE): about 2 GHz
 - IMT-2020 (5G): 30 GHz~300 GHz
 - Satellite communication: 1~40 GHz

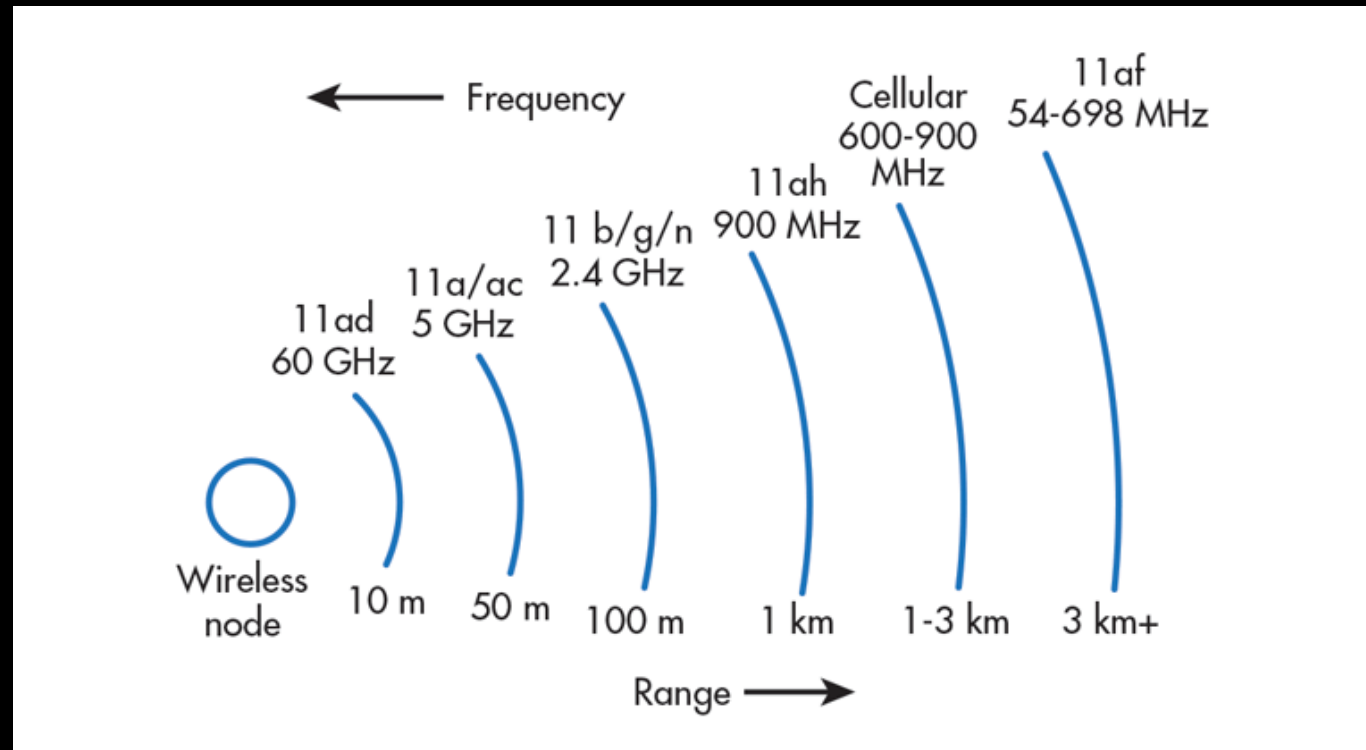


출처 - <https://www.britannica.com/science/radio-frequency-spectrum/>



출처 - <https://mars.nasa.gov/MPF/rovercom/radio.html/>

- The higher the frequency, the stronger the linearity and the faster the attenuation

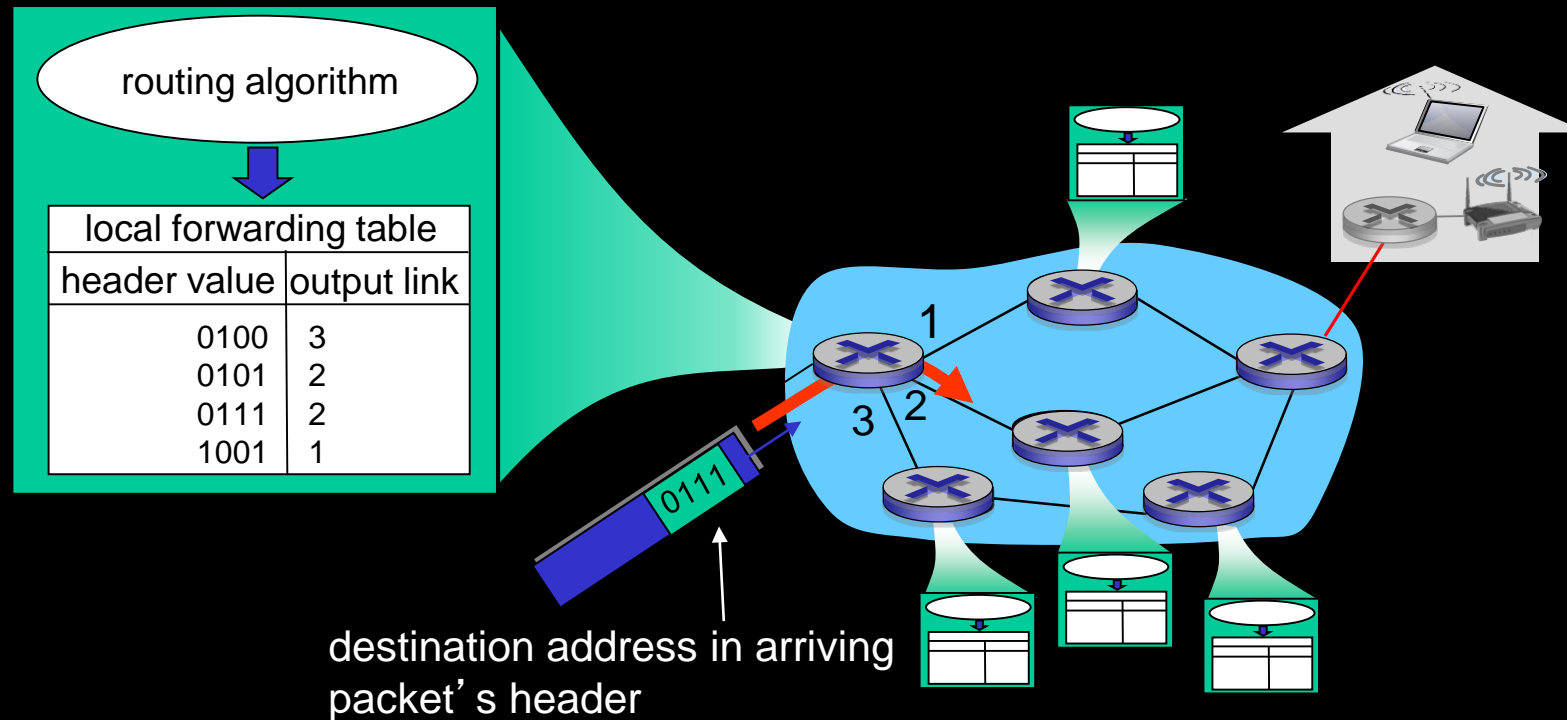


출처 - <http://www.electronicdesign.com/industrial-automation/what-s-difference-between-ieee-80211ah-and-80211af-iot/>



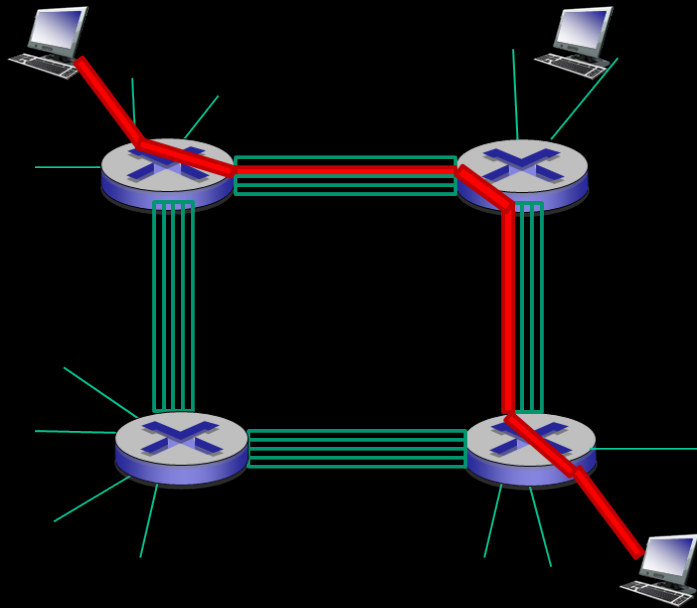
03. Network Core

- Mesh of interconnected routers
- Function
 - packet forwarding from one router (or switch) to the next along the path from source to dest.



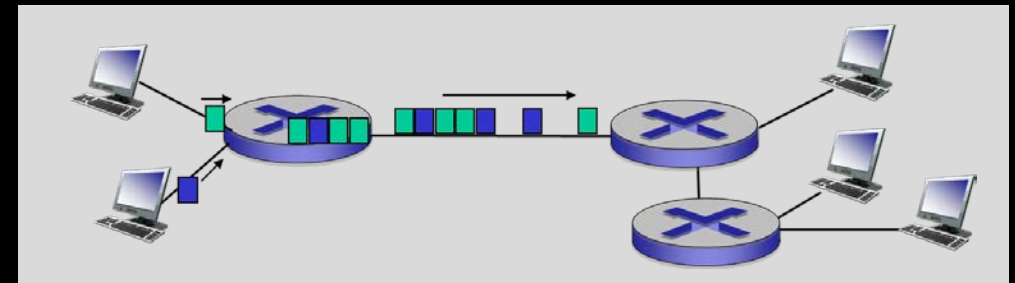
■ Circuit Switching

- End–end resources reserved for “call” between src. & dest.
- Entire data flow along the path like water

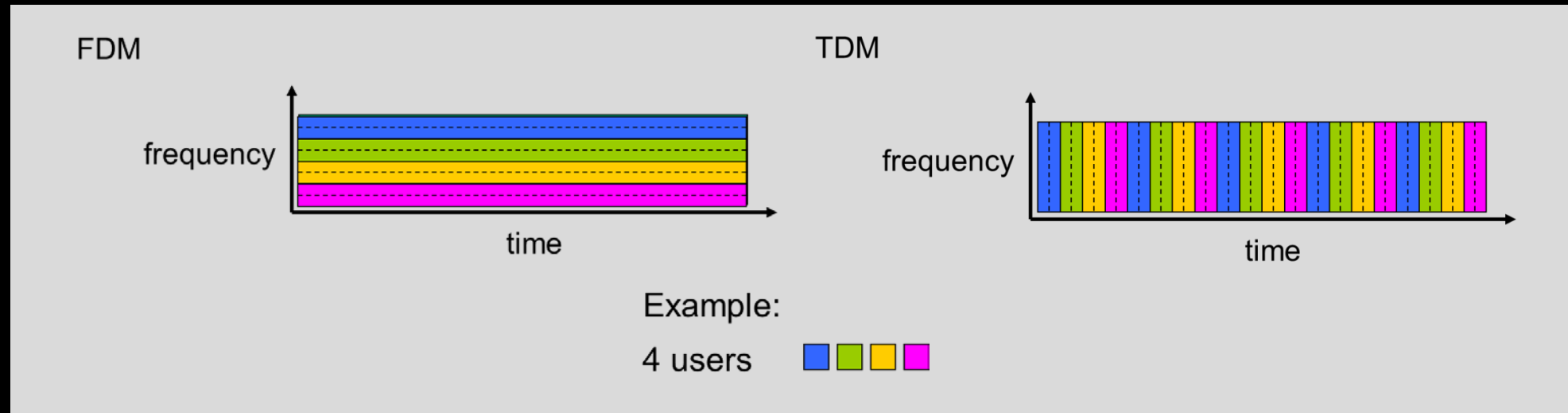


■ Packet Switching

- Entire data broken into small packets
- Each packet has its destination address
- Each packet handled independently



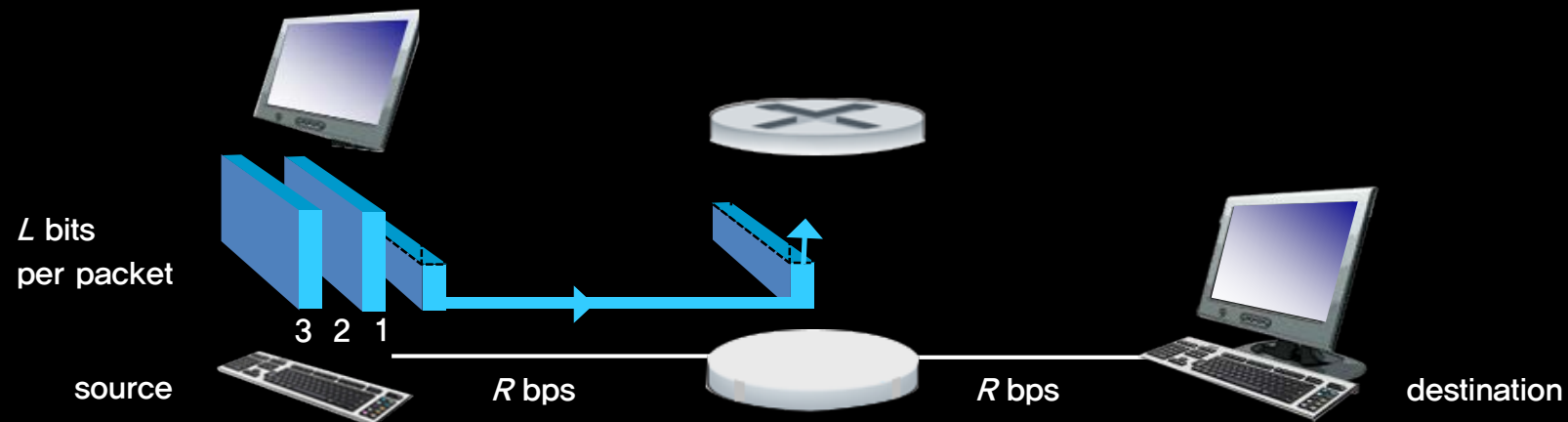
- Resources dedicated to each call
 - circuit segment idle if not used by the call (no sharing)
- Commonly used in traditional telephone networks
- Channel allocation methods: FDM, TDM



- Packet transmitted at full link capacity
- Takes L/R seconds to transmit L -bit packet into link at R bps
- *Store-and-forward*: entire packet must arrive at router before forwarded to the next
- End-end delay $\approx 2L/R$

numerical example:

- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- One-hop transmission delay = 5s
- End-end delay ≈ 10 s



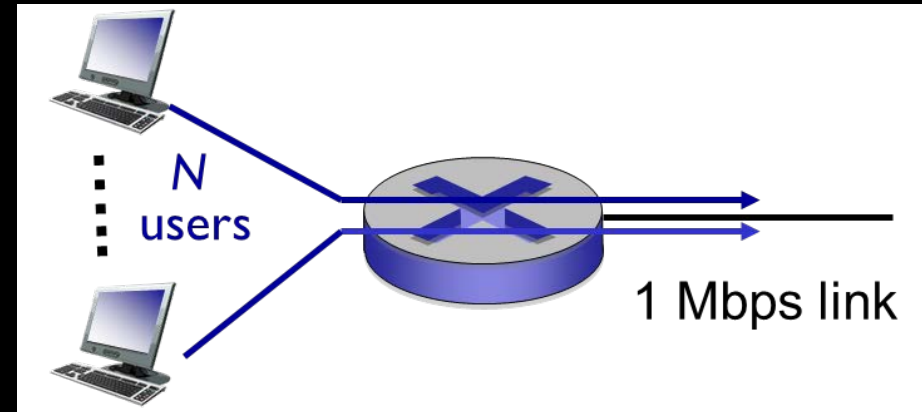
- **Packet switching allows more users to use network!**

- **Example**

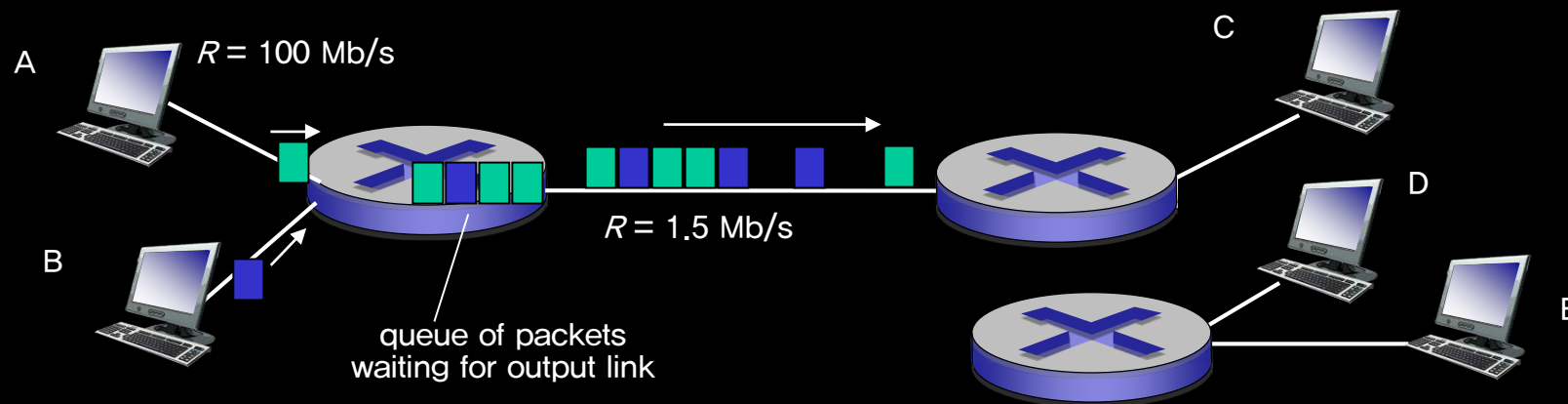
- 1 Mbps link
- each user:
 - 100 kbps when “active”
 - only 10% of time active
- circuit switching
 - 10 users
- packet switching

- with 35 users, probability of 10 users being active at the same time is about .0004

$$1 - \sum_{k=0}^{10} \binom{35}{k} \left(\frac{1}{10}\right)^k \left(\frac{9}{10}\right)^{35-k} = 0.0004243$$



- **Circuit switching guarantees the quality of service for each call!**
- On the other hand, packet switching may suffer from queuing and loss
 - if arrival rate exceeds transmission rate of link
 - packet queued before being transmitted
 - can be dropped (lost) if memory fills up





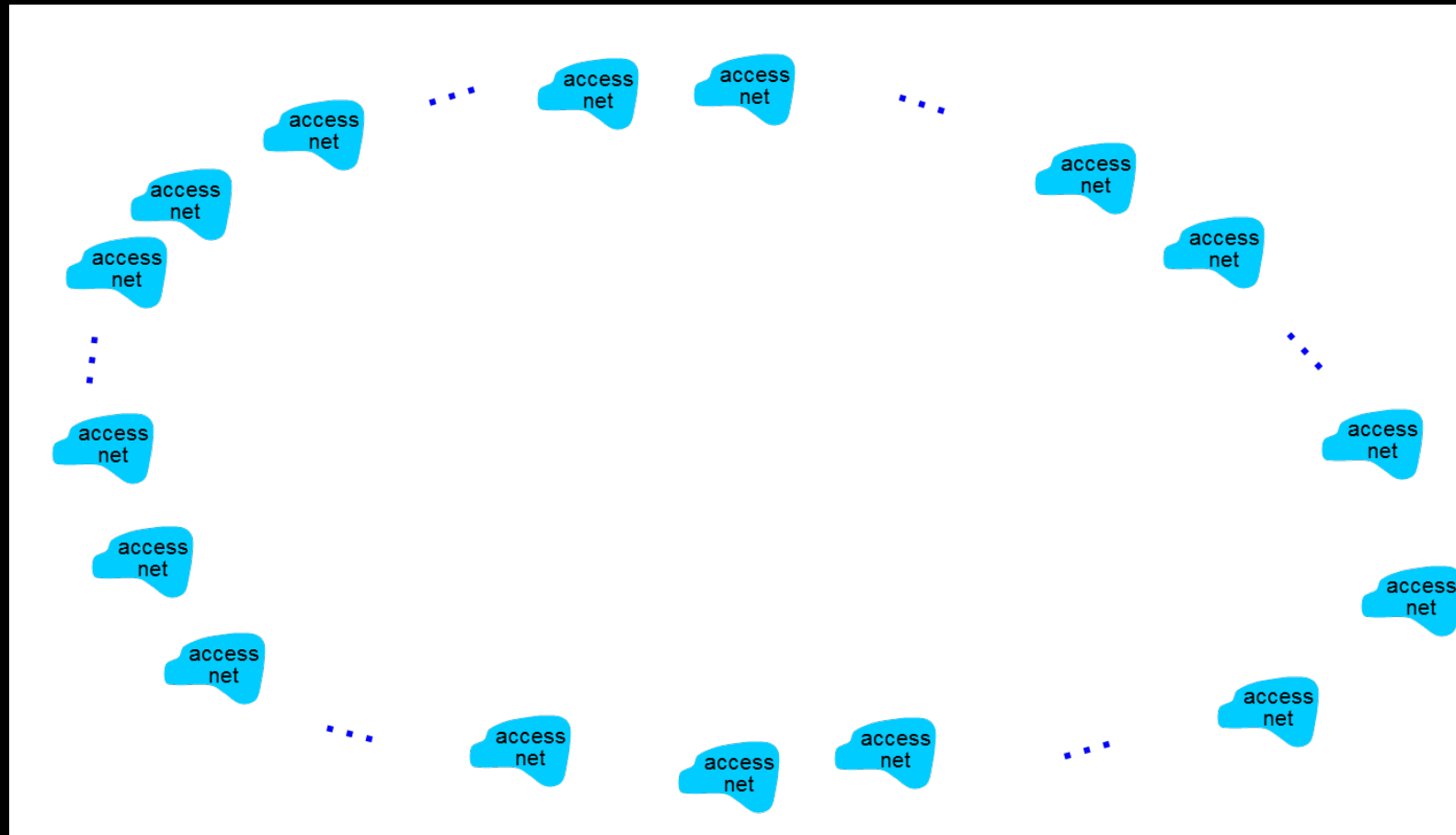
04. Internet Structure

- Who's in charge of the Internet?

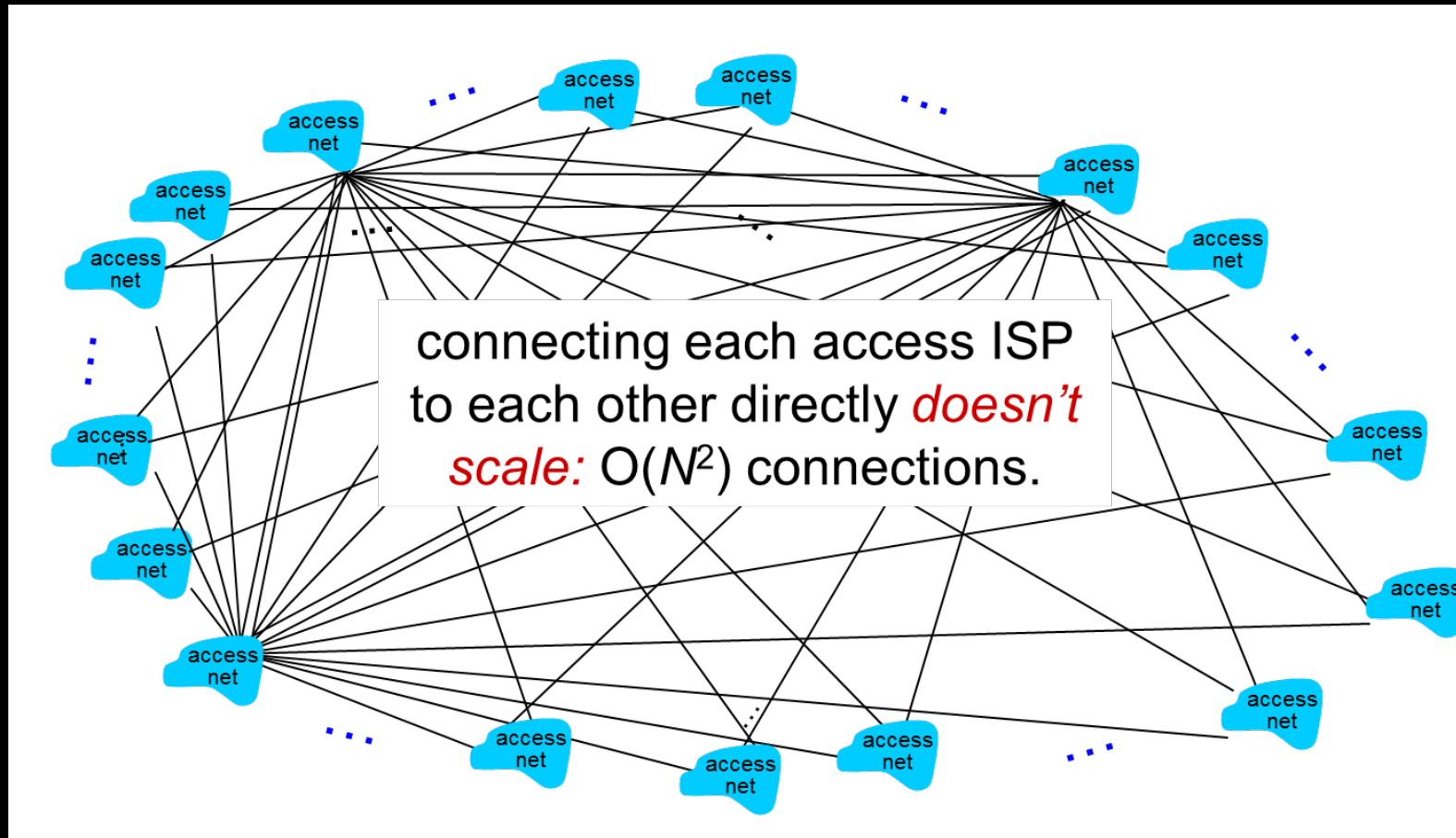
Nobody! Or Everybody!

- independently operated 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 be communicated
- Resulting network of networks is very complex
 - evolution driven by economics and national policy

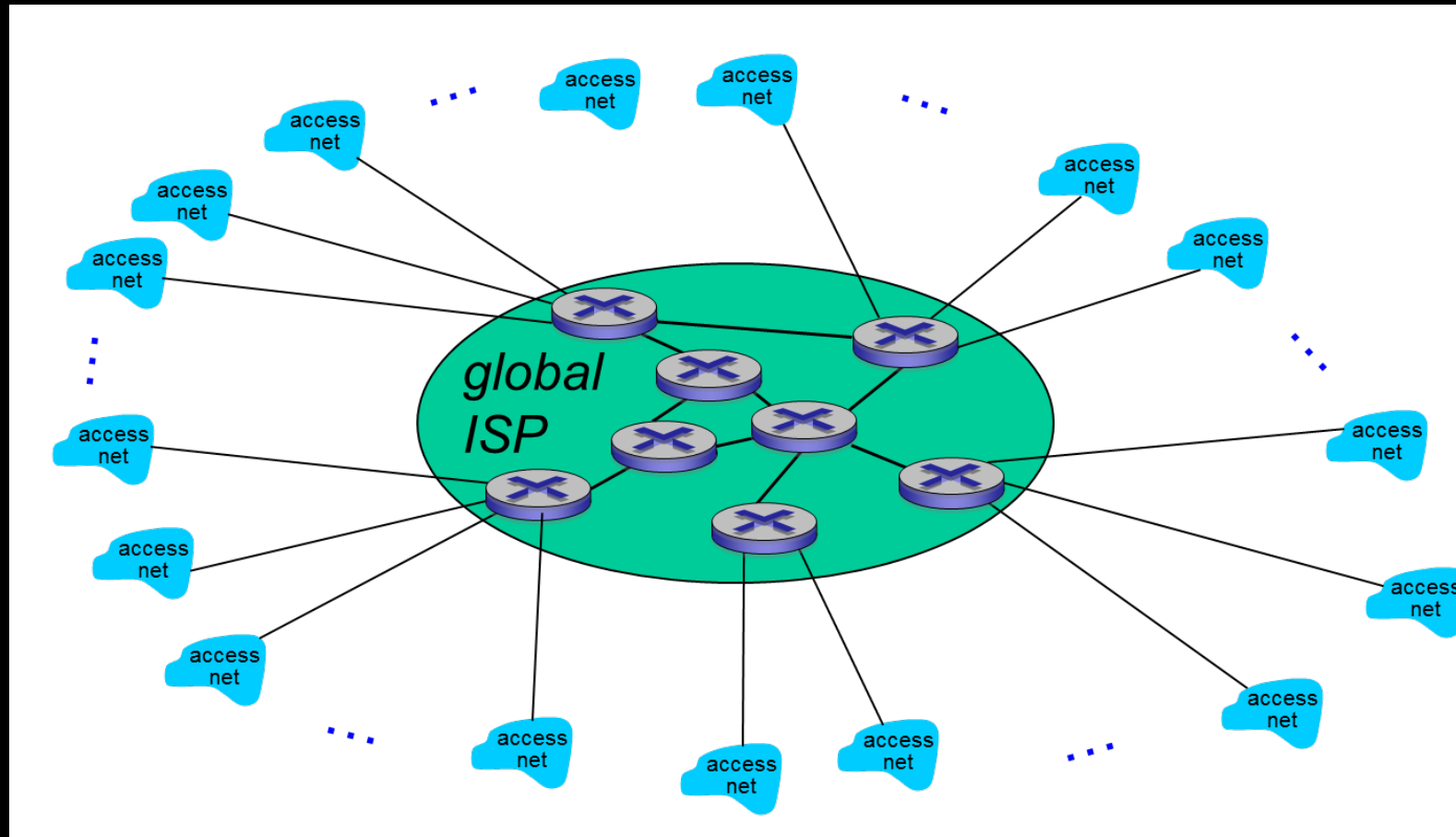
- Question: given millions of access ISPs, how to connect them together?



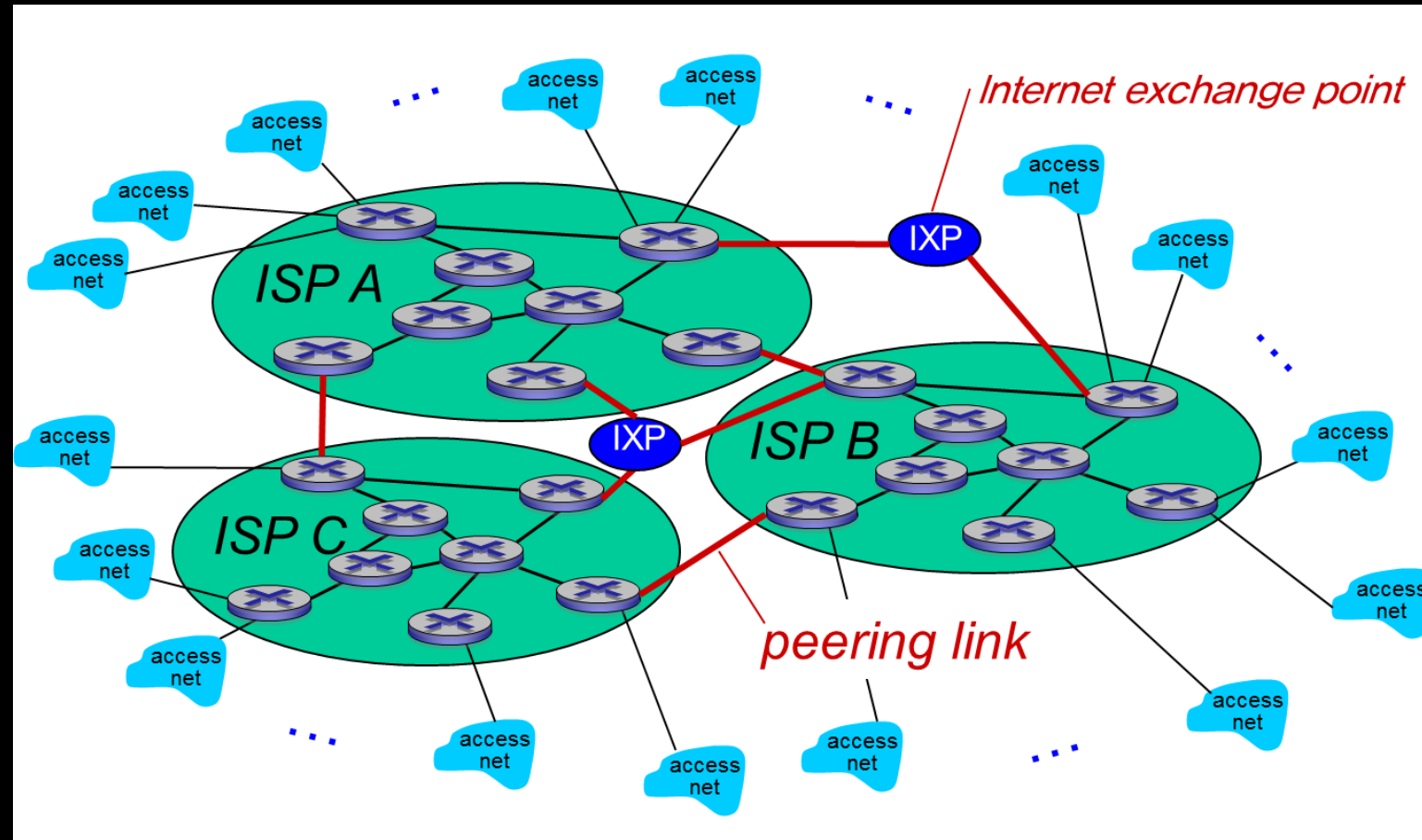
- Naïve method: connect each access ISP to every other access ISP



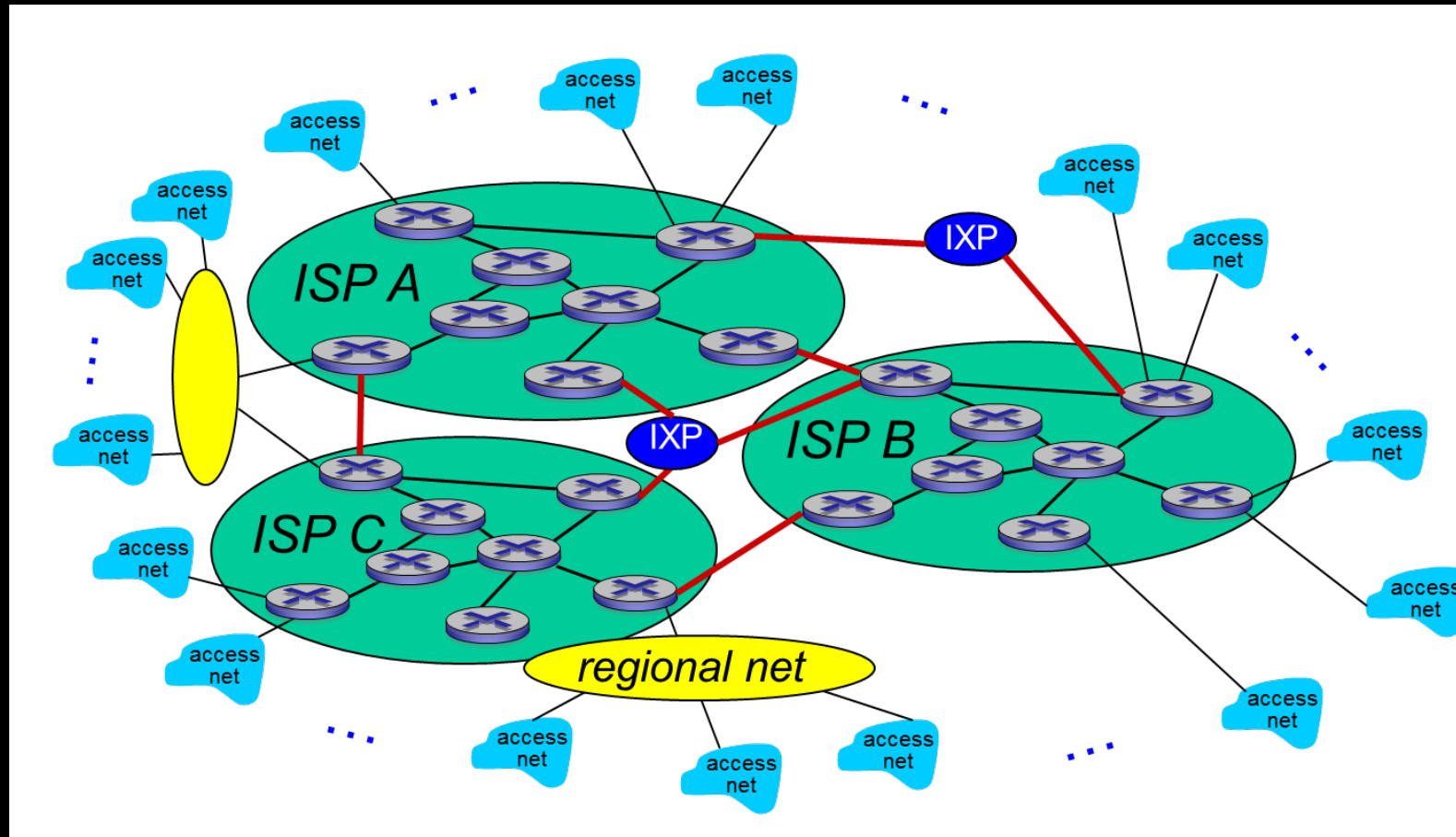
- Scalable method: connect each access ISP to one global transit ISP



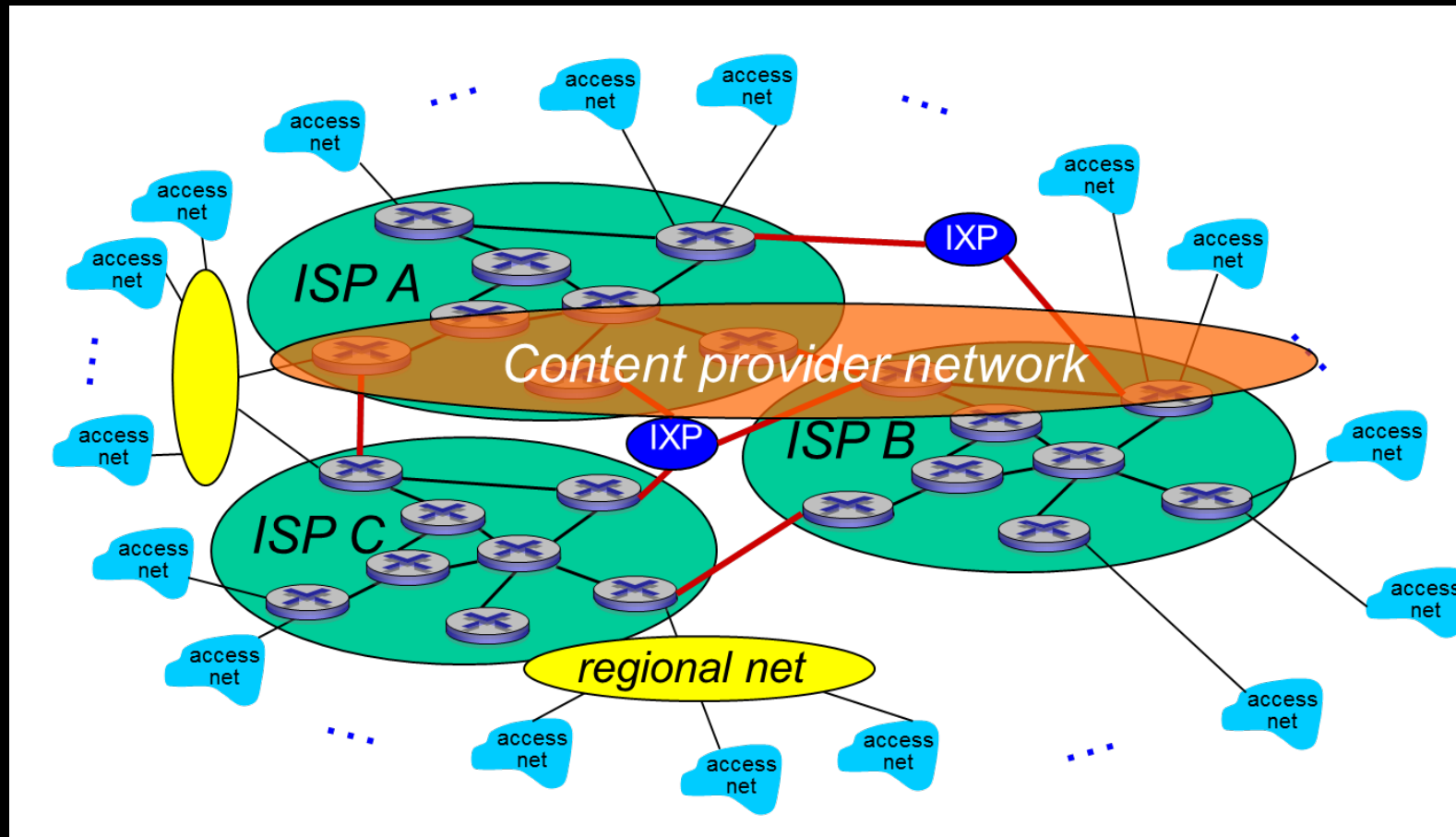
- Competing ISPs appear... which must be interconnected



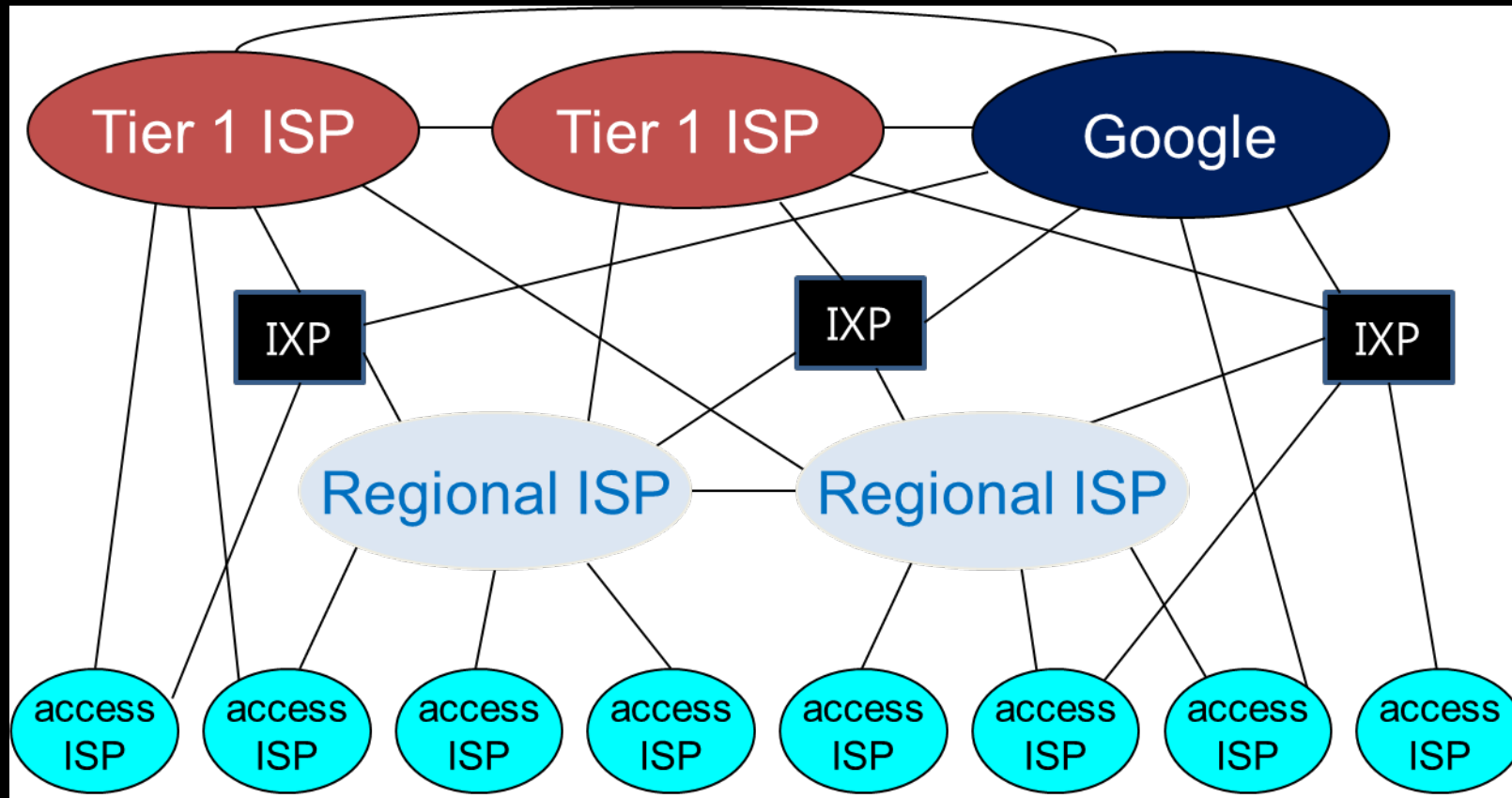
- Regional networks arise to connect access networks to ISPs



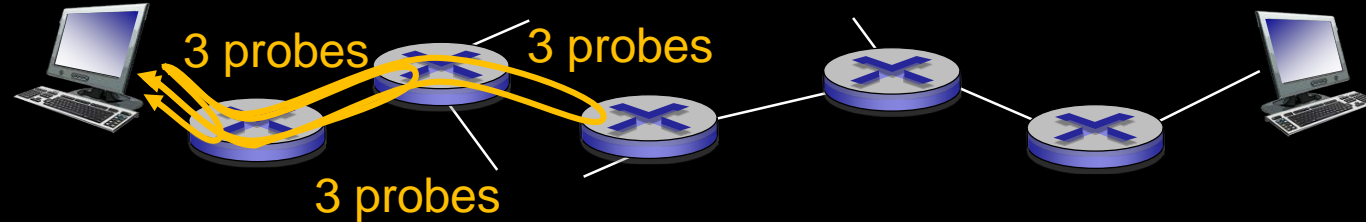
- Content provider (e.g., Google, Microsoft, Akamai) run their own network to bring services and content close to end users



- Seen vertically as:



- Nobody in charge of the entire structure...
- Can we see the entire structure?
- **Traceroute**
 - sends three packets that will reach router i on path towards destination
 - router i will return packets to sender
 - shows interval between transmission and reply




```
C:\Windows\system32\cmd.exe

C:\Users\ >tracert cisco.com

Tracing route to cisco.com [72.163.4.161]
over a maximum of 30 hops:

  0  <1 ms    <1 ms    <1 ms    192.168.1.1
  1  49 ms     37 ms     32 ms     194.146.109.226
  2  40 ms     29 ms     53 ms     cpe-188-129-0-253.dynamic.amis.hr [188.129.0.253]
  3  41 ms     45 ms     37 ms     ljubljana9-ge-2-5.amis.net [212.18.39.113]
  4  50 ms     47 ms     81 ms     mx-lj1-te-1-2-0.amis.net [212.18.44.137]
  5  103 ms    72 ms     60 ms     mx-vil-te-0-0-0.amis.net [212.18.44.142]
  6  53 ms     53 ms     61 ms     xe-0-0-0-300.vie20.ip4.tinet.net [77.67.75.93]
  7  169 ms    145 ms    150 ms     xe-10-3-2.was14.ip4.tinet.net [141.136.110.217]
  8  330 ms    225 ms    303 ms     te-7-2.car4.Washington1.Level3.net [4.68.110.97]
  9  217 ms    *         209 ms     vlan60.csw1.Washington1.Level3.net [4.69.149.62]
 10  205 ms    208 ms    200 ms     ae-61-61.ebr1.Washington1.Level3.net [4.69.134.129]
 11  209 ms    185 ms    204 ms     ae-2-2.ebr3.Atlanta2.Level3.net [4.69.132.85]
 12  204 ms    204 ms    202 ms     ae-7-7.ebr3.Dallas1.Level3.net [4.69.134.21]
 13  282 ms    197 ms    210 ms     ae-63-63.csw1.Dallas1.Level3.net [4.69.151.133]
 14  200 ms    219 ms    230 ms     ae-1-60.edge9.Dallas1.Level3.net [4.69.145.16]
 15  210 ms    197 ms    213 ms     CISCO-SYSTE.edge9.Dallas1.Level3.net [4.30.74.46]
 16  *         *         *         Request timed out.
 17  322 ms    310 ms    329 ms     rcdn9-cd2-dmzdcc-gw2-por1.cisco.com [72.163.0.182]
 18  319 ms    310 ms    315 ms     rcdn9-14a-dcz05n-gw1-ten5-5.cisco.com [72.163.0.238]
 19  324 ms    299 ms    309 ms     www1.cisco.com [72.163.4.161]

Trace complete.

C:\Users\ >
```



05. Performance Metrics

Delay

Packet delivering time from source to destination

Packet Loss

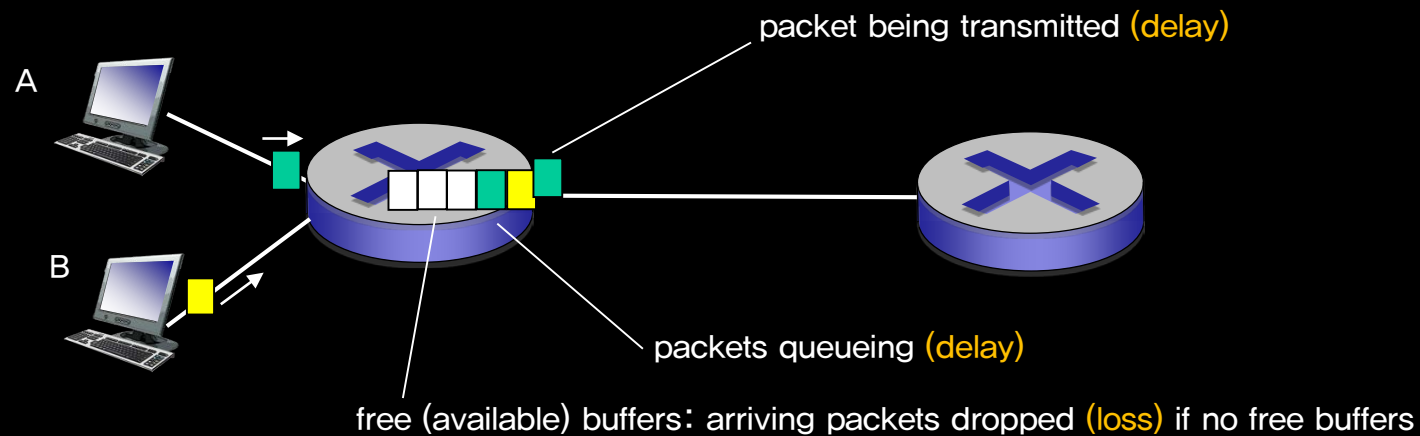
Ratio of lost packets to total sent packets

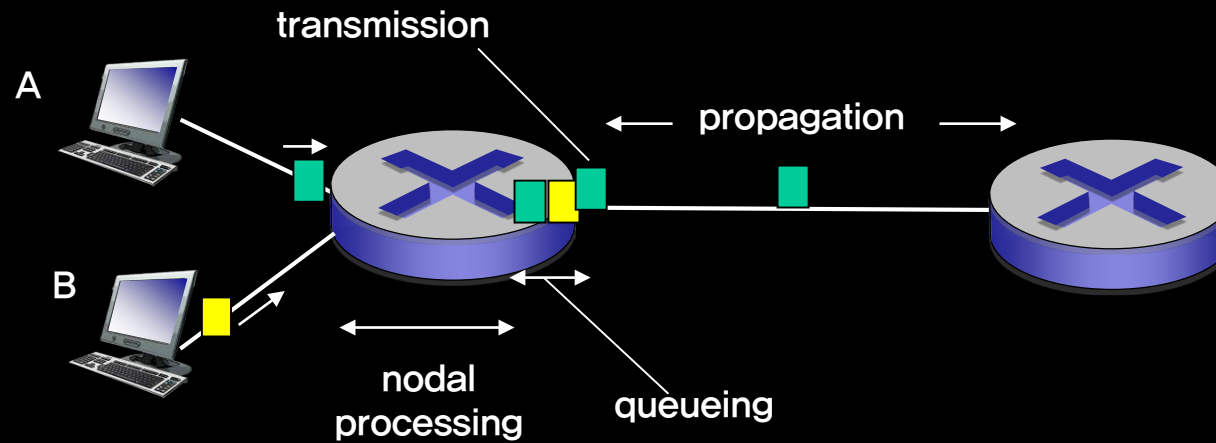
* PDR (Packet Delivery Ratio):
Ratio of packets successfully delivered to the total number of packets

Throughput

The amount of traffic delivered per unit time

if packet arrival rate to link (temporarily) exceeds output link capacity ...





$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- time waiting at output buffer for transmission
- **congestion dependent**

**Queue-
ing**

**Transmi-
ssion**

- L : packet length (bits)
- R : link bandwidth (bps)
- $d_{trans} = L/R$

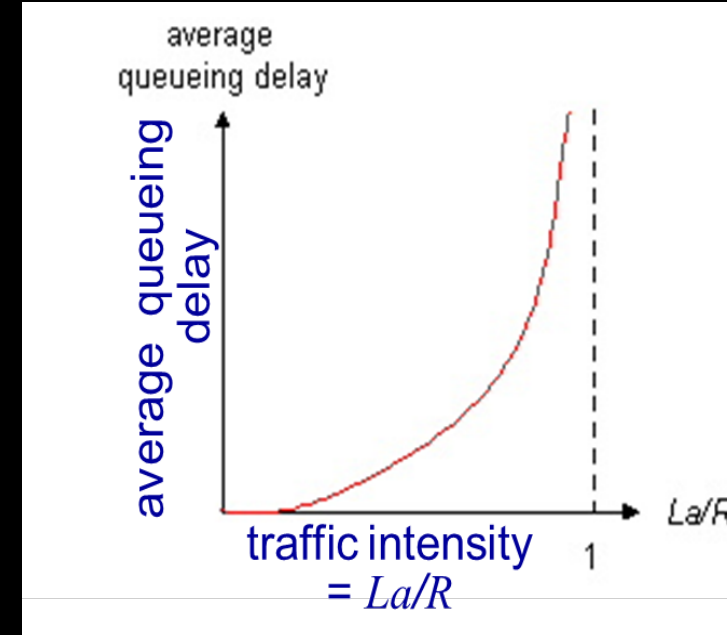
- bit error checking
- decision of output link
- typically \lt msec

**Process-
ing**

**Propaga-
tion**

- d : length of physical link
- s : signal speed ($\sim 2 \times 10^8$ m/s)
- $d_{prop} = d/s$

- R : link bandwidth (bps)
- L : packet length (bits)
- a : avg. packet arrival rate



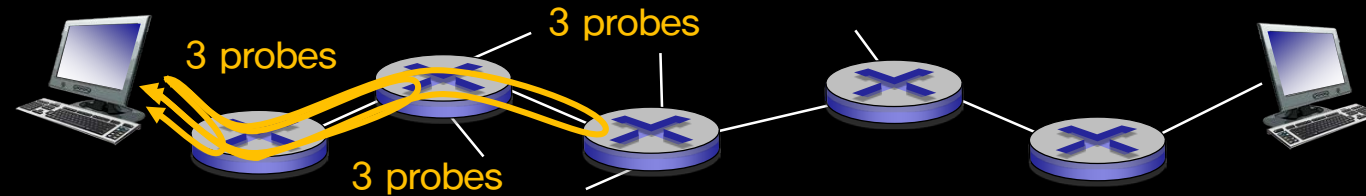
- $La/R \sim 0$: small queueing delay
- $La/R \rightarrow 1$: large queueing delay
- $La/R \sim 1$: increase to the infinite!



$La/R \sim 0$



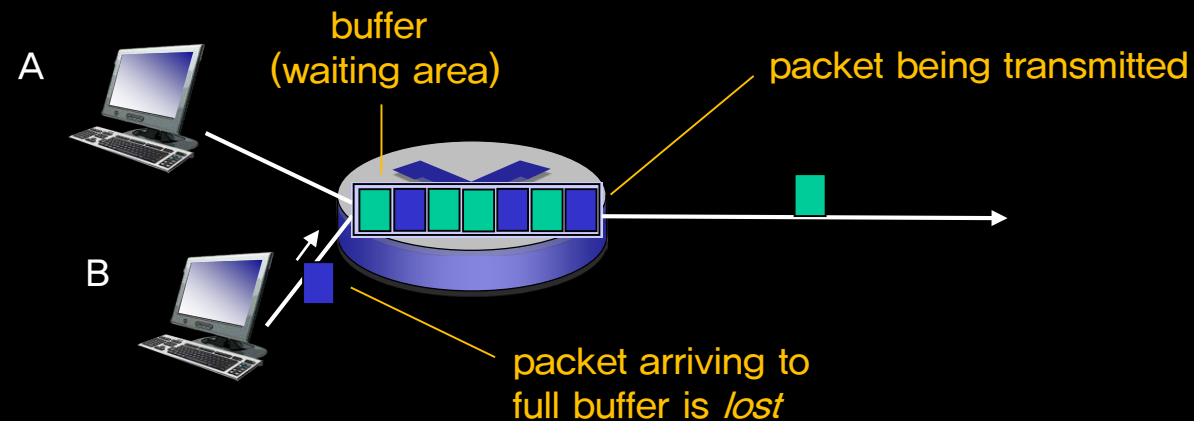
$La/R \rightarrow 1$



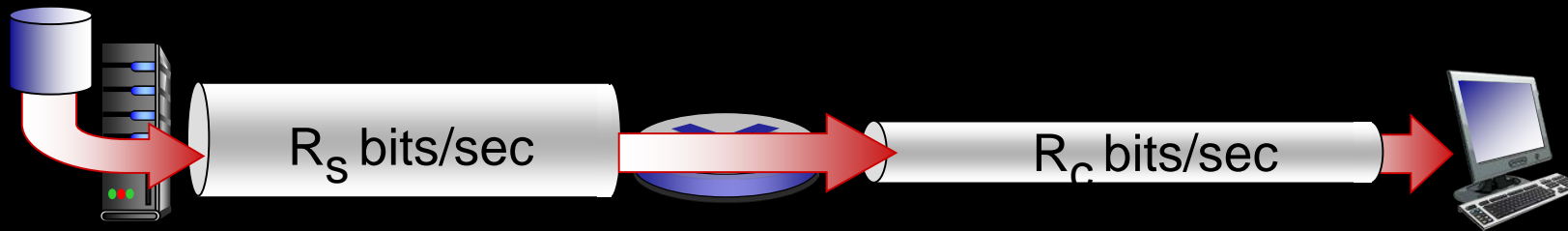
traceroute: gaia.cs.umass.edu to www.eurecom.fr

- 1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
 - 2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
 - 3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
 - 4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
 - 5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
 - 6 abilene-vbns.abilene.ucaid.edu (198.32.11.9) 22 ms 18 ms 22 ms
 - 7 nycm-wash.abilene.ucaid.edu (198.32.8.46) 22 ms 22 ms 22 ms
 - 8 62.40.103.253 (62.40.103.253) 104 ms 109 ms 106 ms
 - de2-1.de1.de.geant.net (62.40.96.129) 109 ms 102 ms 104 ms
 - ...
 - 15 eurecom-valbonne.r3t2.ft.net (193.48.50.54) 135 ms 128 ms 133 ms
 - 16 194.214.211.25 (194.214.211.25) 126 ms 128 ms 126 ms
 - 17 * * *
 - 18 * * *
 - 19 fantasia.eurecom.fr (193.55.113.142) 132 ms 128 ms 136 ms
- 3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu
- trans-oceanic link
- * means no response (probe lost, router not replying)

- Packet arriving to full queue dropped
- Lost packet may be retransmitted by previous node, by source end system, or not at all



- Rate at which bits transferred b.w s–d
 - *instantaneous*: rate at given point in time
 - *average*: rate over longer period of time



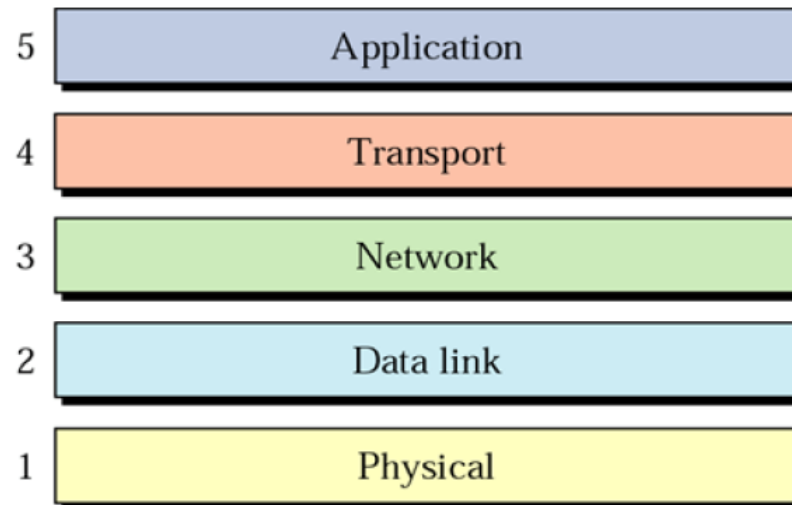
bottleneck link

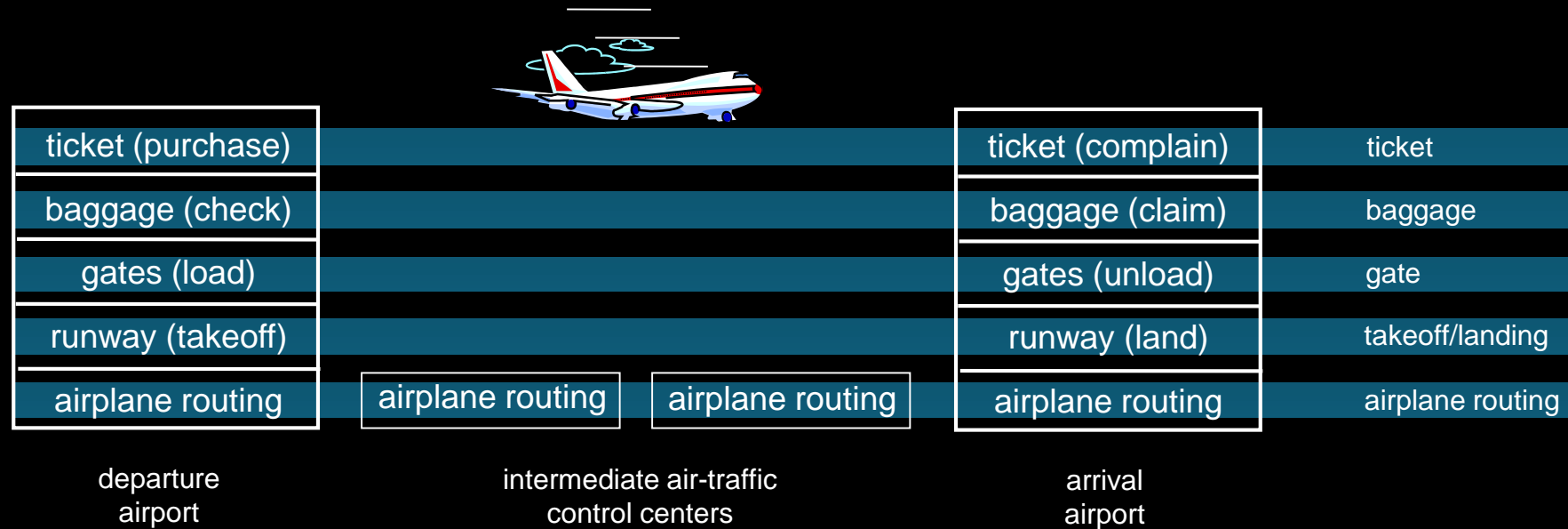
link on end–end path that constrains end–end throughput



06. Protocol Stack

- A communication protocol stack is composed of several layers

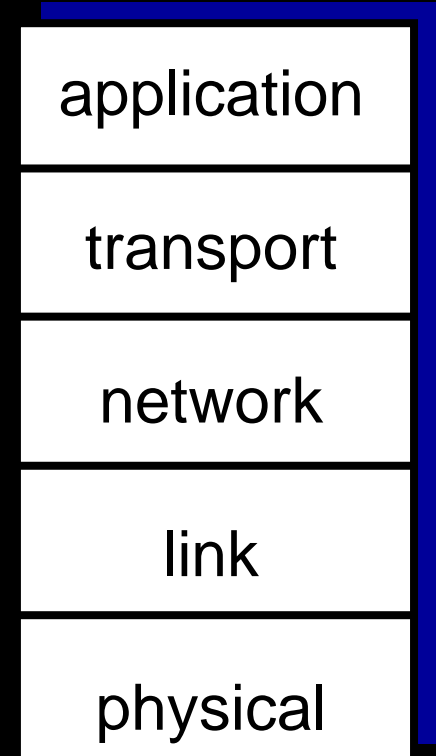




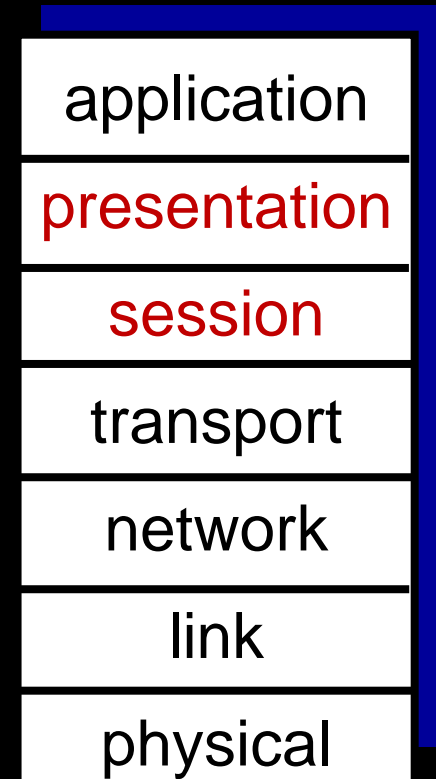
- **layers**: each layer implements a service
 - via its own internal-layer actions
 - relying on services provided by layer below

- Modularization eases development, maintenance, and 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
- Layering considered harmful?

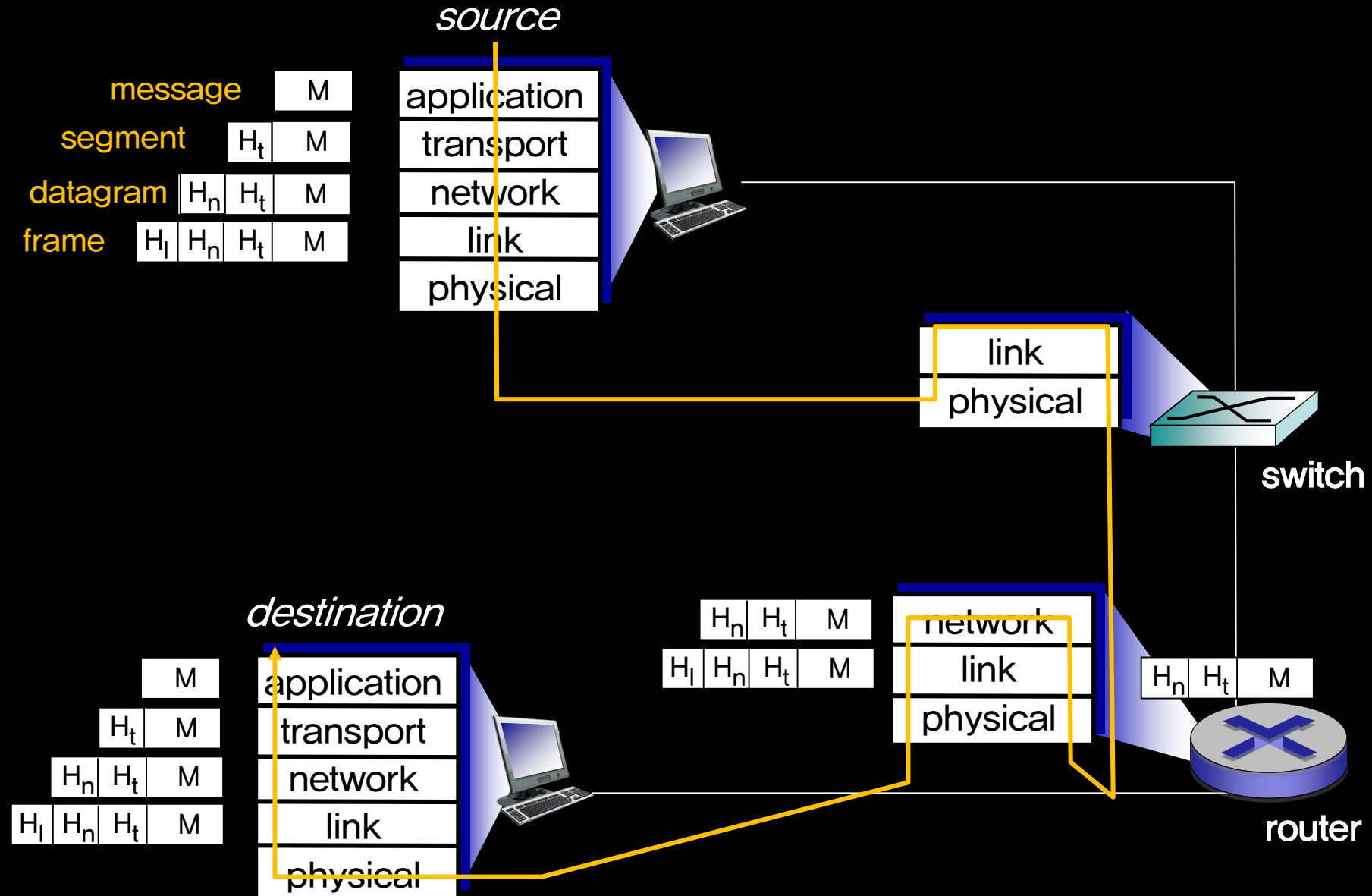
- **application**: supporting network applications
 - FTP, SMTP, HTTP
- **transport**: process–process data transfer
 - TCP, UDP
- **network**: routing of datagrams from source to destination
 - IP, routing protocols
- **link**: data transfer between neighboring network elements
 - Ethernet, 802.11 (WiFi), PPP
- **physical**: bits “on the wire”



- **presentation**: allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- **session**: synchronization, connection management, recovery of data exchange
- Internet stack “missing” these layers!
 - these services, if needed, must be implemented in application



Encapsulation





07. Network Security

- **Field of network security**

- 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**

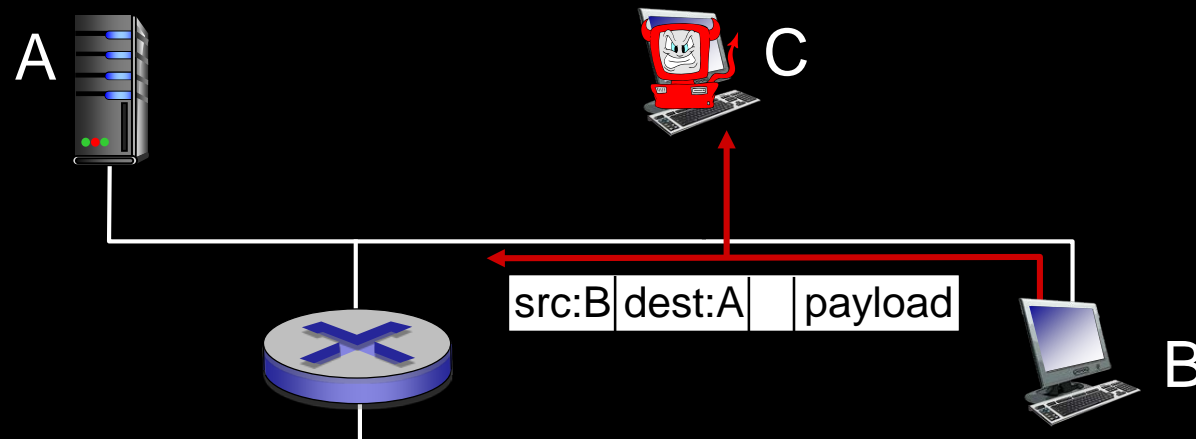
- original vision: “a group of mutually trusting users attached to a transparent network” 😊
- Internet protocol designers playing “catch-up”
- security considerations in all layers!

- 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
- Malware can
 - record keystrokes, web sites visited, upload info to collection site (**spyware**)
 - require ransom or destroy system (**ransomware**)

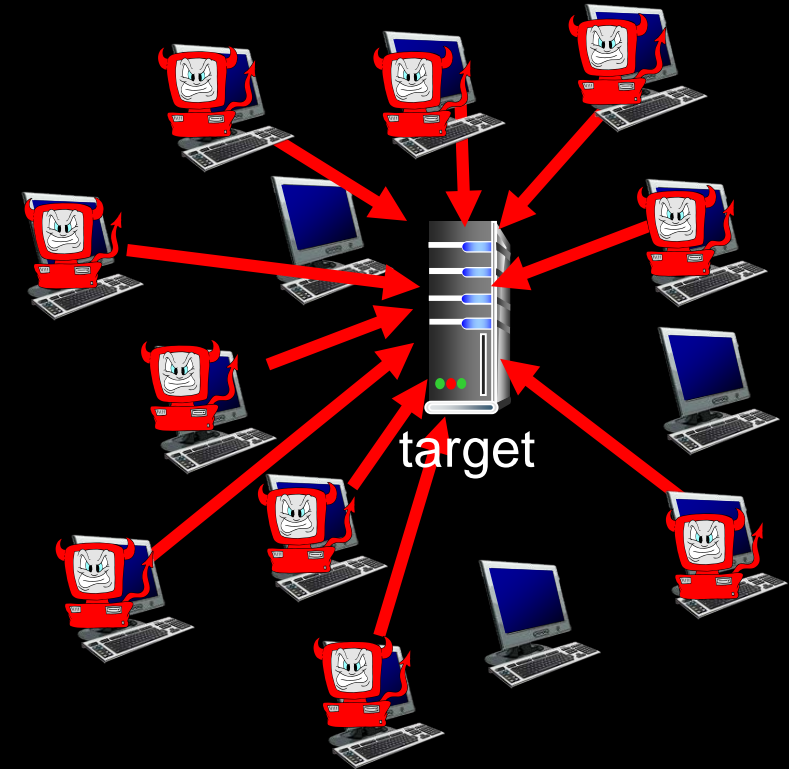


출처 - <https://epatientfinder.com/worried-ransomware-need-backup-plan-literally/>

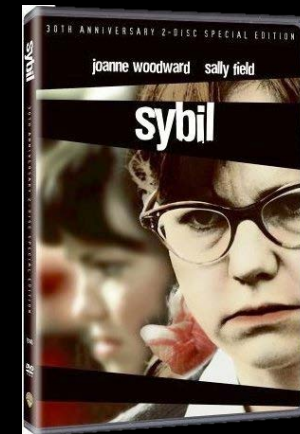
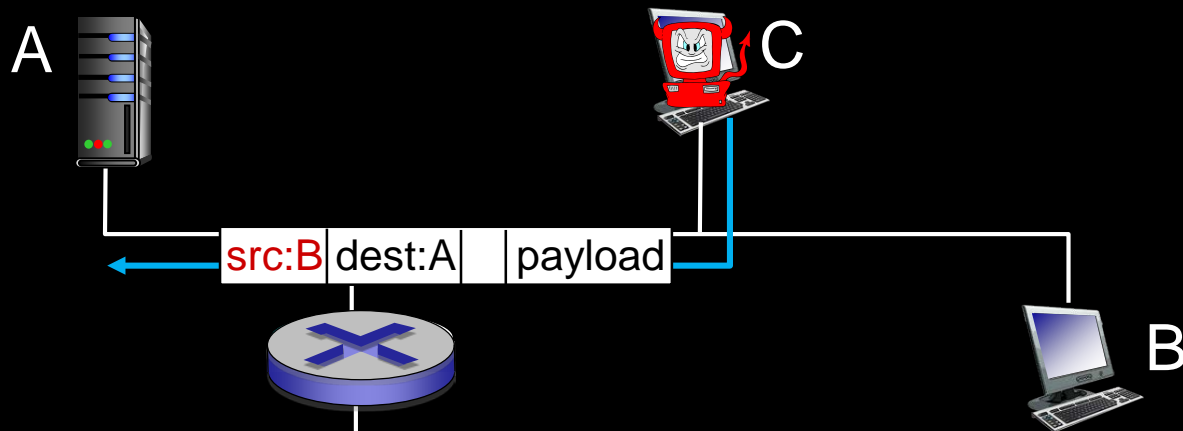
- Broadcast media (shared Ethernet, wireless)
- Promiscuous network interface reads/records all packets (e.g., including passwords!) passing by



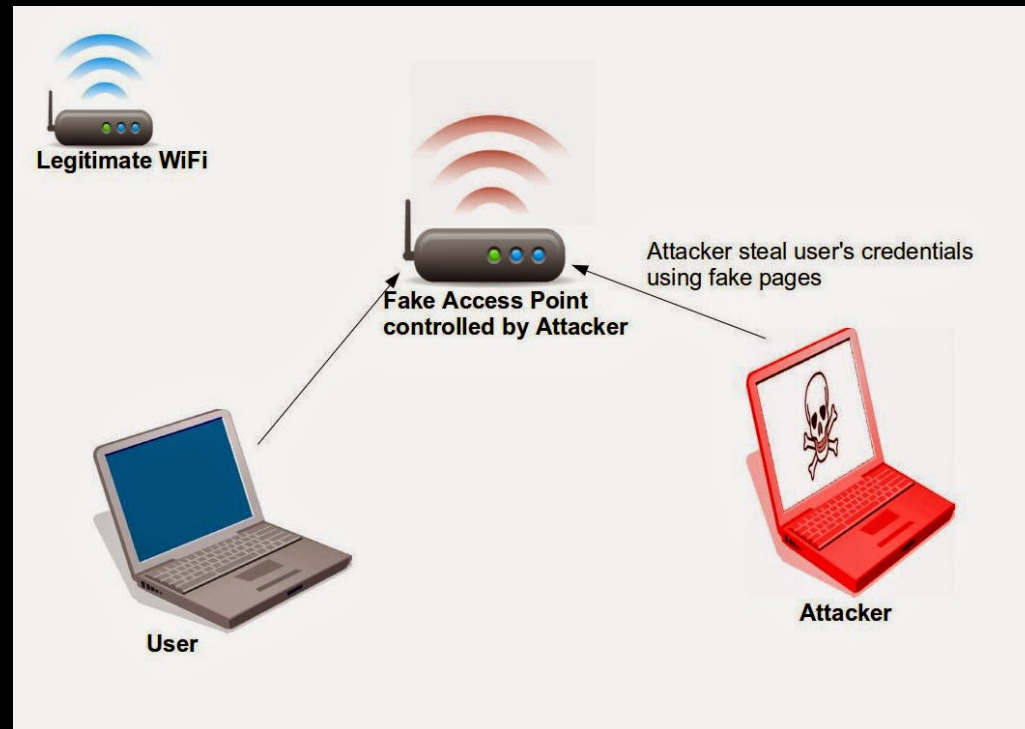
- Attackers make resources (server, bandwidth) unavailable by sending the huge amount of bogus traffic through botnets



- Send packets with fake source address
- a.k.a. “Sybil” attack



- Steal user's credentials using fake AP



출처 - <https://developertz.wordpress.com/2017/03/14/evil-twin-and-fake-wireless-access-point-hacks-what-they-are-how-to-defend/>



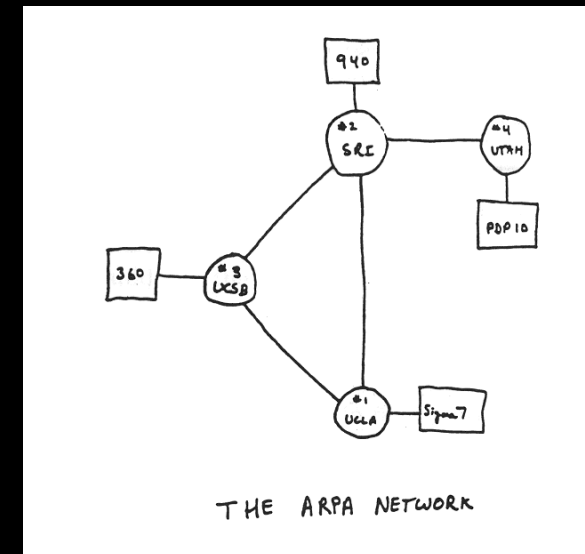
08. History of the Internet

■ Early packet-switching principles

- 1961
 - Kleinrock – queueing theory shows effectiveness of packet-switching
- 1967
 - ARPAnet conceived by Advanced Research Projects Agency
- 1969
 - first ARPAnet node operational
- 1972
 - ARPAnet public demo
 - NCP (Network Control Protocol) first host-host protocol
 - first e-mail program
 - ARPAnet has 15 nodes



*Leonard
Kleinrock*



■ Internetworking, new and proprietary nets

- 1974
 - Cerf and Kahn – architecture for interconnecting networks



출처 - <http://www.amongtech.com/unsung-heroes-internet-pioneers-youve-never-heard/>

- 1976
 - Ethernet at Xerox PARC
- 1979
 - ARPAnet has 200 nodes

Cerf and Kahn's internetworking principles:

- minimalism, autonomy – no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

■ New protocols, a proliferation of networks

- 1983
 - deployment of TCP/IP
- 1982
 - smtp e-mail protocol defined
- 1983
 - DNS defined for name-to-IP-address translation
- 1985
 - ftp protocol defined
- 1988
 - TCP congestion control



Bill Joy

출처 - <http://fortune.com/2011/04/06/bill-joy-better-batteries-key-to-green-power-adoption/>

■ Commercialization, the Web, new apps

- 1991
 - NSF lifts restrictions on commercial use of NSFnet (decommissioned, 1995)
- Early 1990's: Web
 - HTML, HTTP: Tim Berners-Lee
 - 1994: Mosaic, later Netscape
 - Commercialization of the Web
- Late 1990's–2000's
 - more killer apps: instant messaging, P2P file sharing
 - network security to forefront
 - est. 50 million host, 100 million+ users



Tim Berners-Lee

출처 - <http://techland.time.com/2012/09/05/10-questions-for-sir-tim-berners-lee/>

- 5B devices attached to Internet (2016)
 - smartphones and tablets
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
 - Facebook: ~ one billion users
- Service providers (Google, Microsoft) create their own networks
 - bypass Internet, providing “instantaneous” access to search, video content, email, etc.
- e-commerce, universities, enterprises running their services in “cloud” (e.g., Amazon EC2)



Summary

01

Internet overview

- Internet: “network of networks”
- Internet is composed of network edge, access network, core network, and protocol

02

What's a protocol?

- rules and regulations to transfer data in computer networks
- message format, order of messages, actions

03

Network edge, core, access network

- access network: a network connect edge and core
- core network techniques: packet switching vs. circuit switching

04

Internet structure

- independently operated networks
- hierarchical structure of access ISPs, regional ISPs, global ISPs, and so on

05

Network performance

- Delay (transmission, queueing, processing, propagation)
- Packet loss, packet delivery rate
- Throughput

06

Protocol stack

- Layering: advantages of modularization
- Internet protocol stack
- ISO/OSI reference model

07

Network security

- Internet not originally designed with (much) security in mind
- Internet protocol designers playing “catch-up”

08

History of the Internet

- Firstly developed as ARPAnet
- Internetworking architecture = autonomy + minimalism
- TCP/IP, World Wide Web