Computer Network

Introduction

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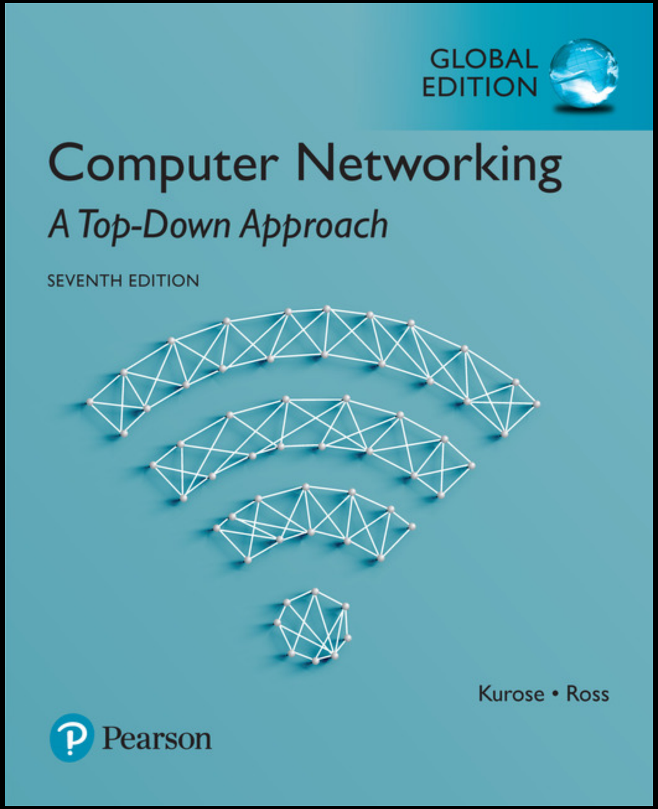
Textbook



Computer Networking

A Top–Down Approach

7th edition

Jim Kurose, Keith Ross

Pearson

April 2016

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Computer Network introduction

Contents

Computer Network introduction

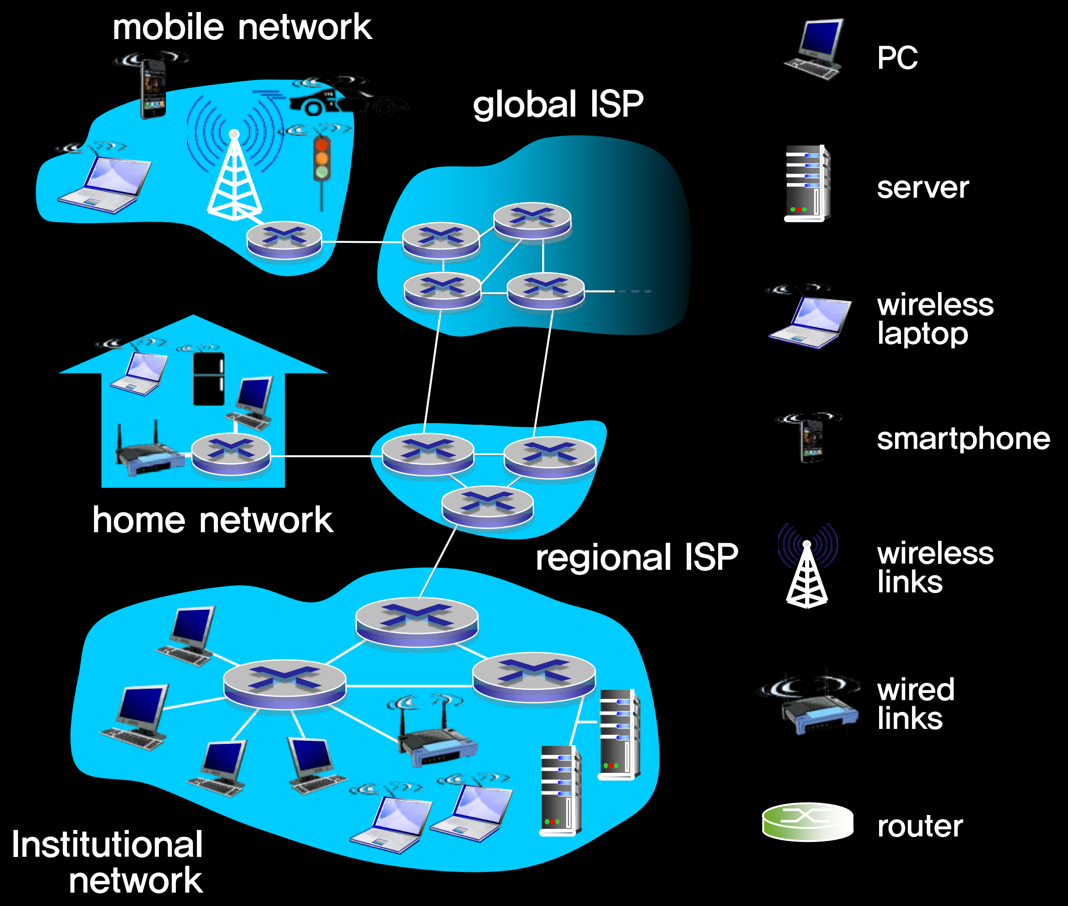
01. What is the Internet?

What is the Internet?

What is the Internet?

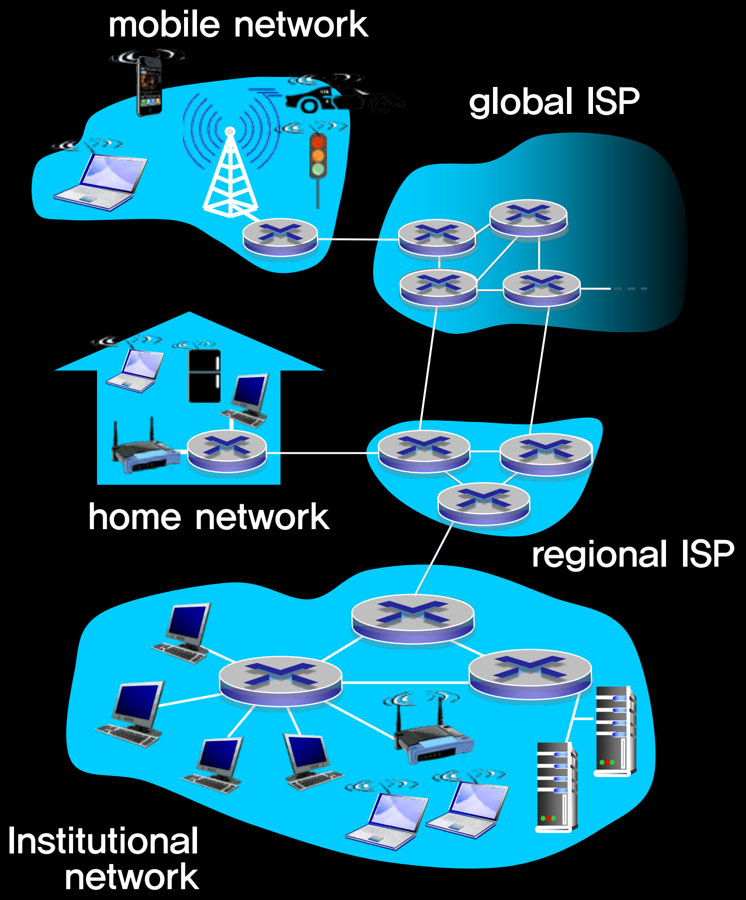
- Internet = Inter– + net (work)
  - "network of networks"

Various types of networks



What is the Internet?

- HW components
  - end hosts
  - links
    - copper, fiber, radio, satellite
  - interconnection devices
    - router, switch, repeater
- SW components
  - operating software
  - application programs
  - protocols



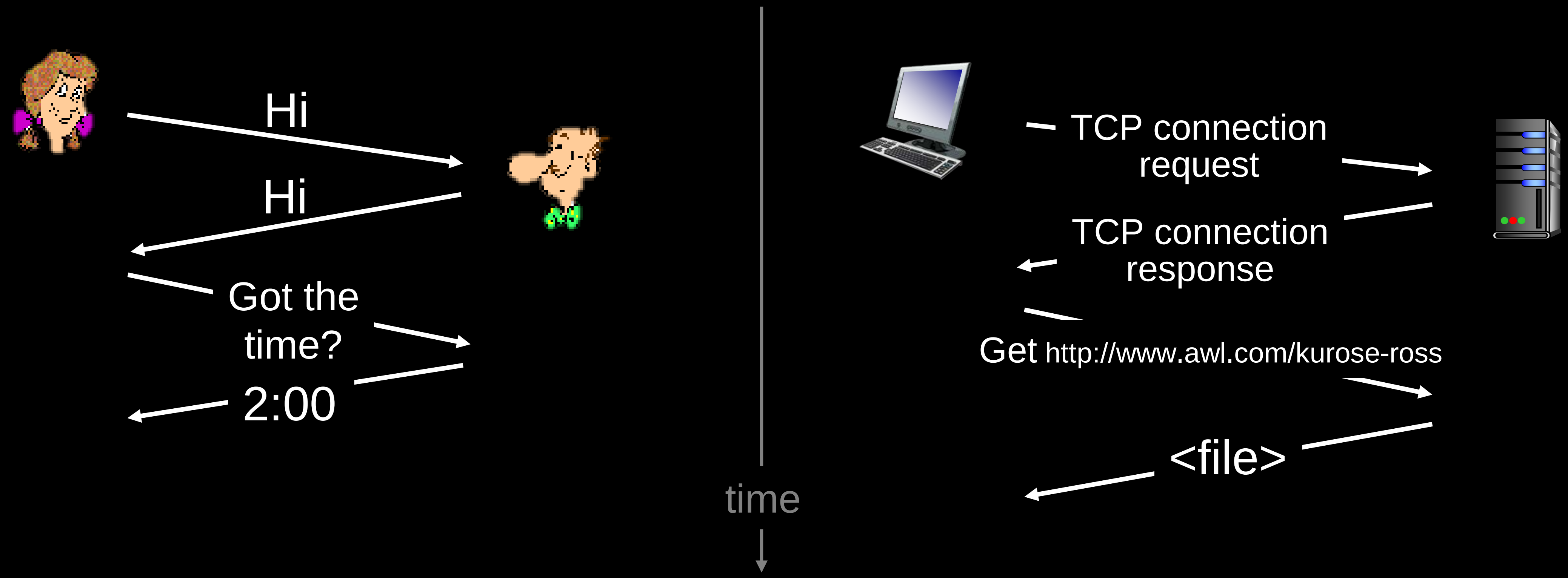
Communication Protocol

- 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/

Communication Protocol

- Human protocol vs. Comm. protocol

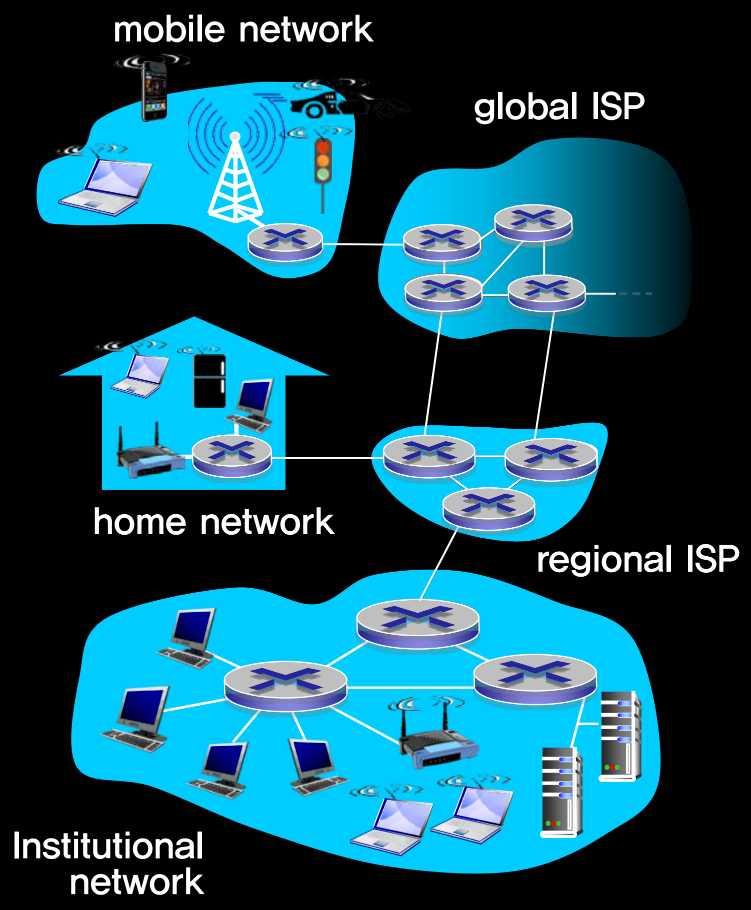


Communication Protocol

- 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

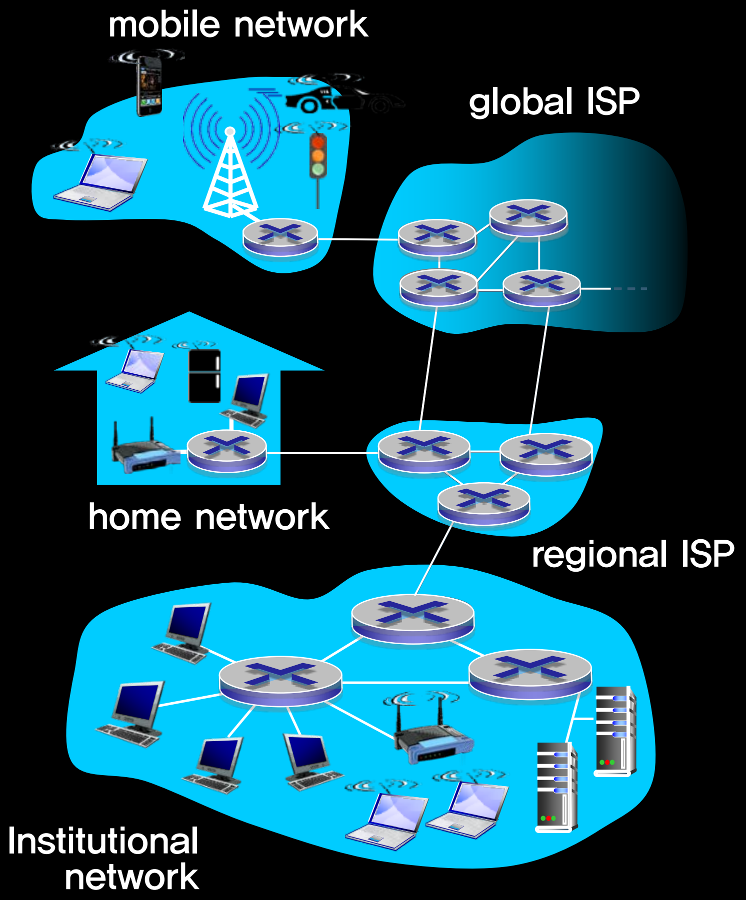
- Network edge
  - hosts： clients and servers
  - servers often in data center
- Network core
  - Interconnected routers or switches



- Network connecting end systems to edge router?

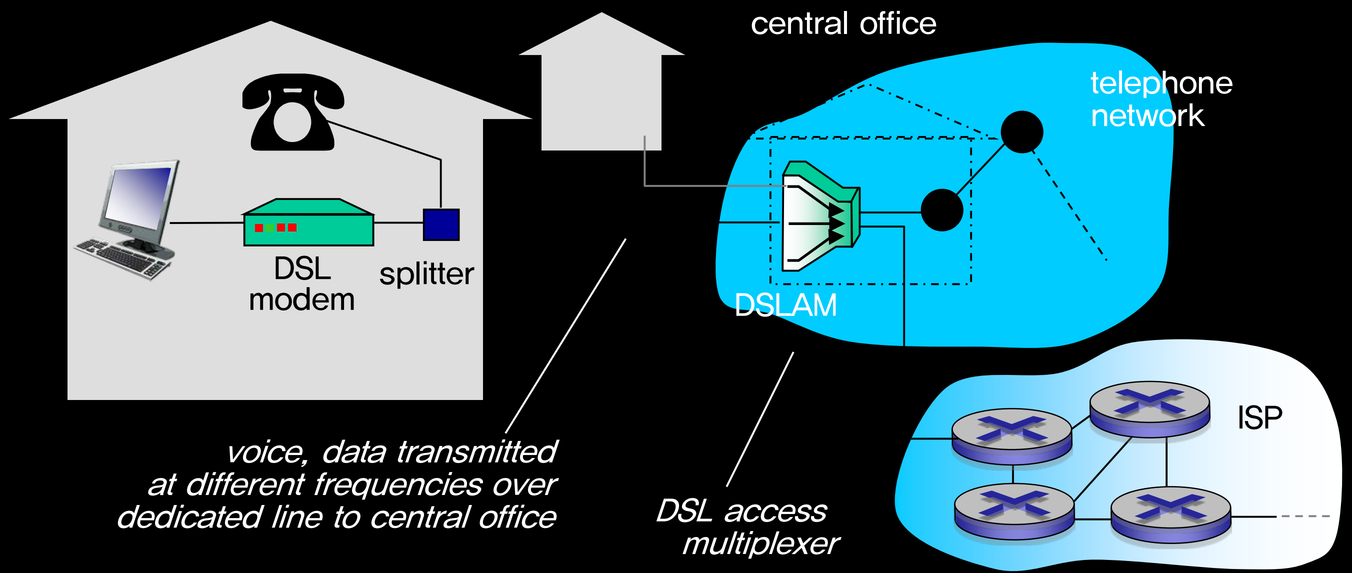
Access network

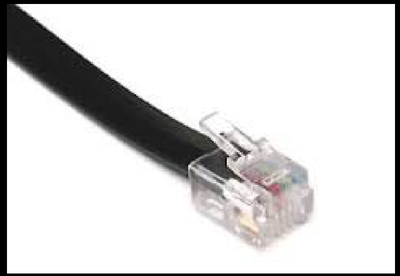
- residential access nets
- institutional acc. nets
- wireless access nets

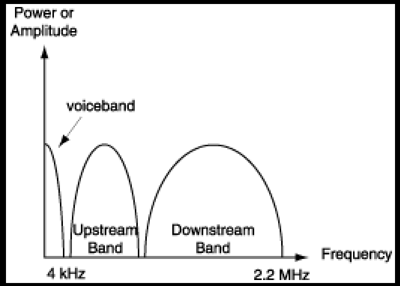


Residential Acc. Nets.: DSL

- Digital subscriber line (DSL)





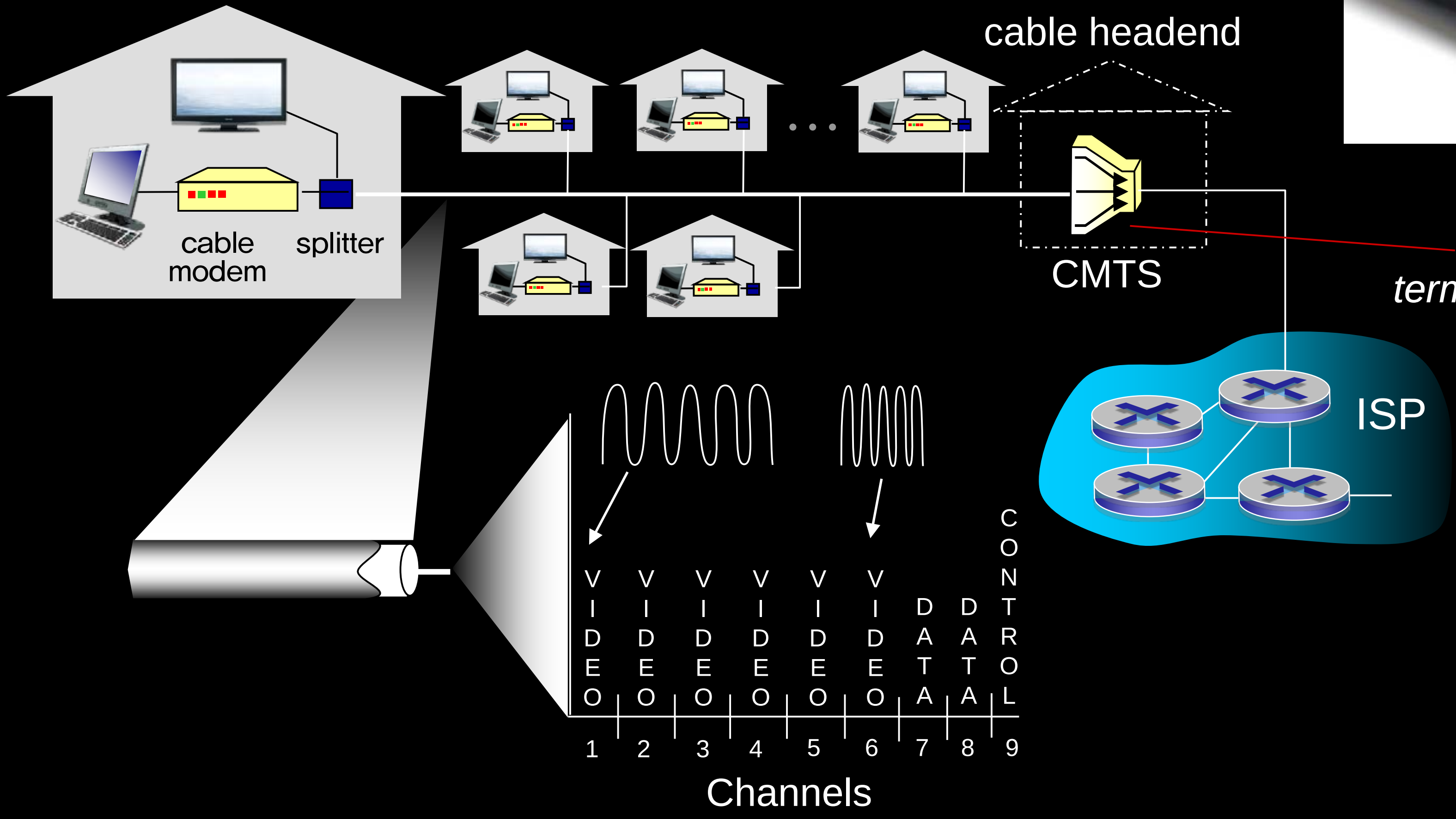


출처 – http://sunsite.uakom.sk/sunworldonline/swol-02-1998/swol-02-connectivity.html/

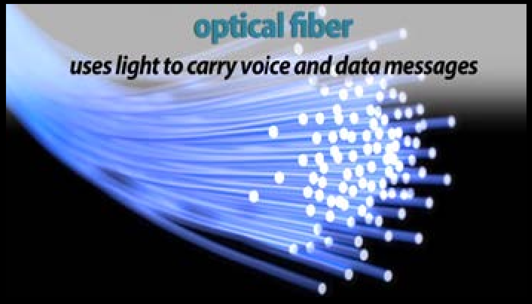
- voice over a phone line to telephone net
- data over a phone line to the Internet

Residential Acc. Nets.: Cable

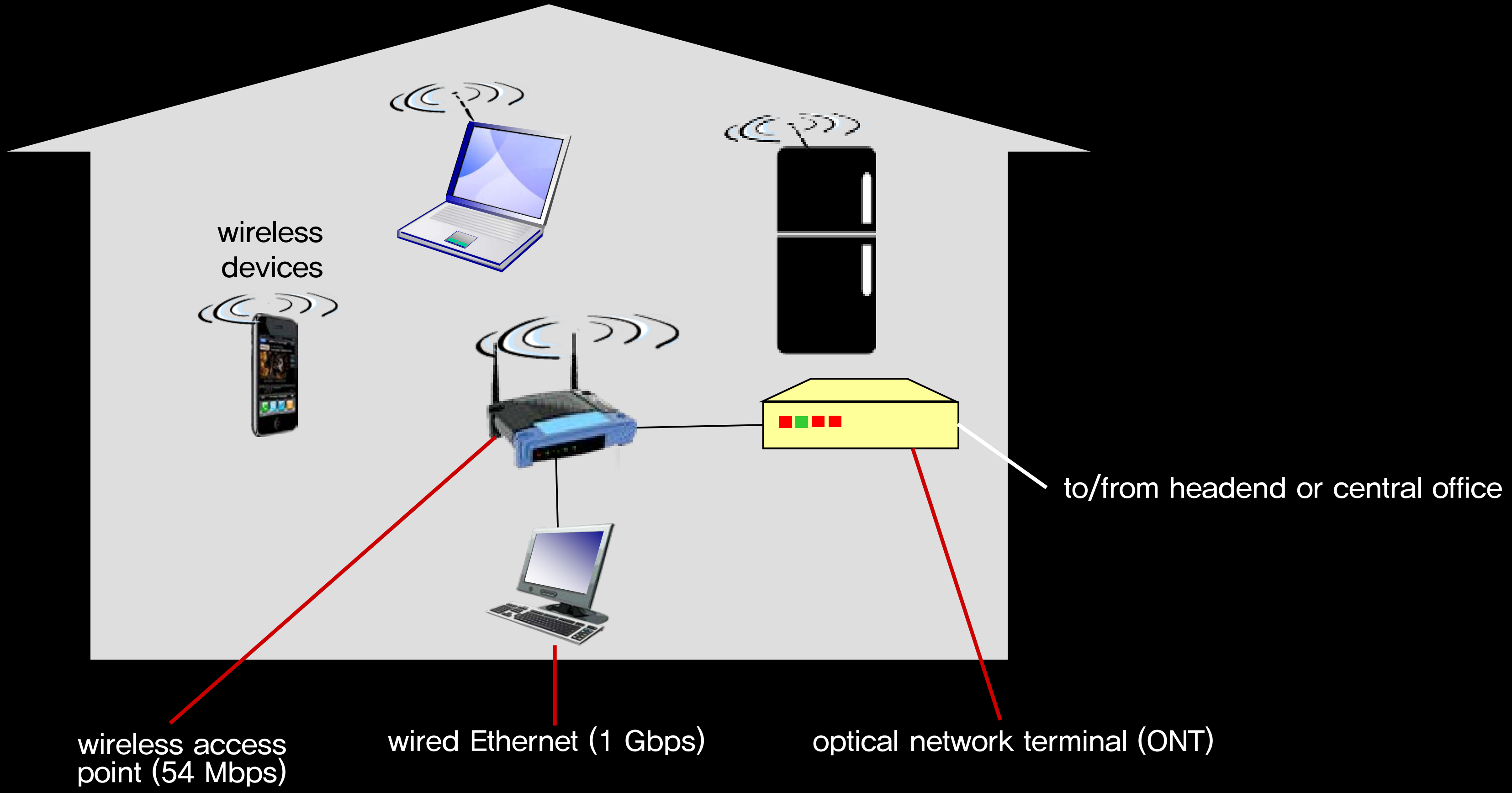
- Cable network



- Fiber–to–the–Home (FTTH)

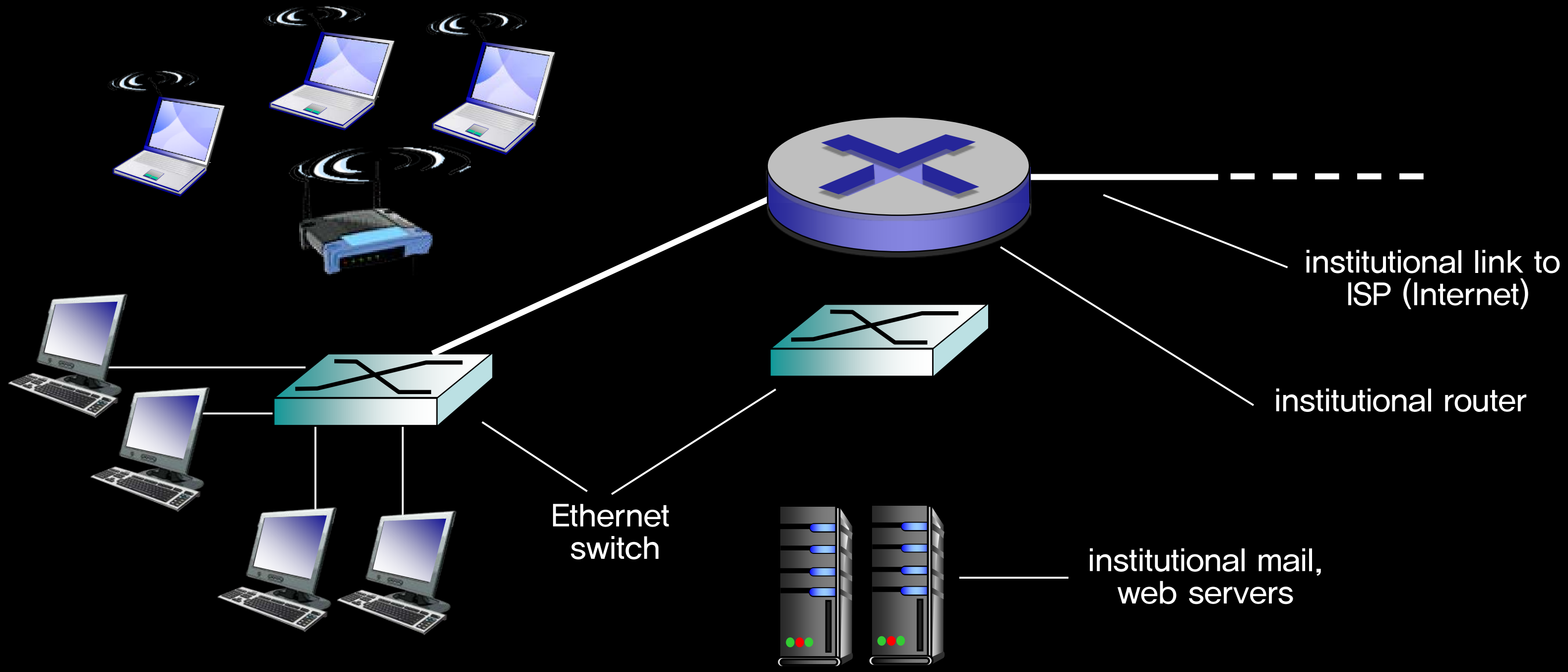


출처 – https://study.com/academy/lesson/what-is-optical-fiber-definition-lesson-quiz.html/



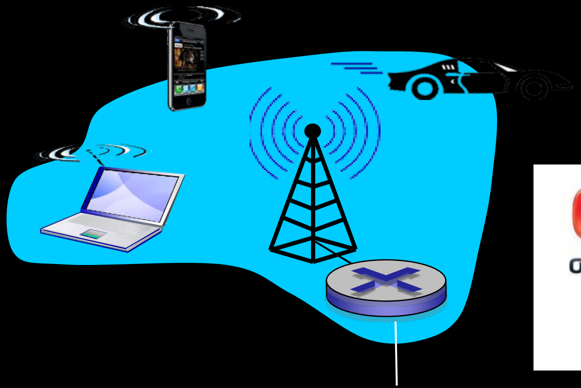
Institutional Acc.: Ethernet

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



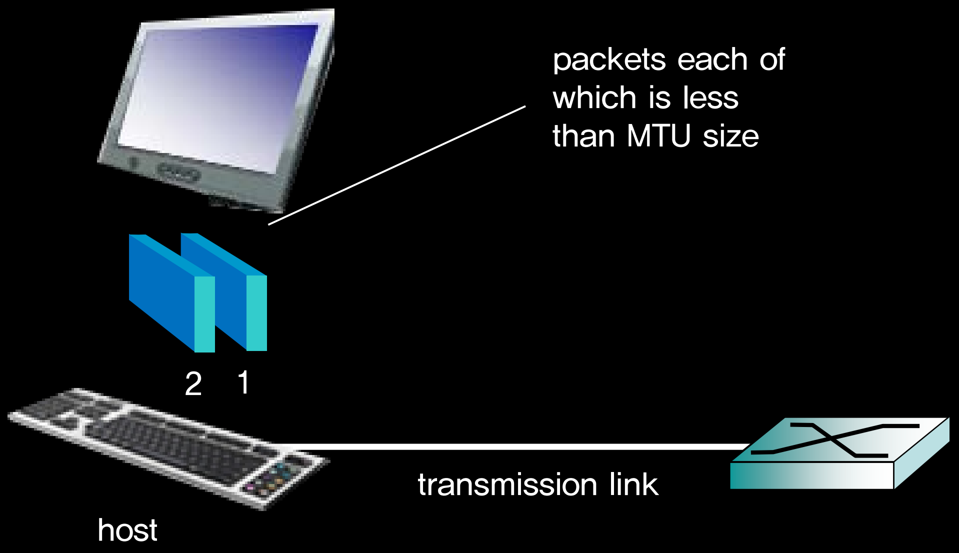
- Wireless LAN
  - 802.11g: 54 Mbps
  - 802.11n: 600 Mbps
  - 802.11ac: 2.6 Gbps (three 160MHz chs)

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



End Host

- 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



Communication Link: Wired

Twisted pair

Coaxial cable

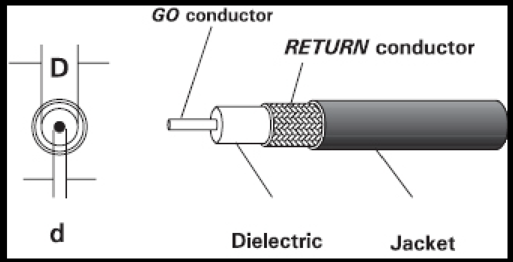
Optical fiber

- Two insulated copper wires
- 100 Mbps ~ 10 Gbps

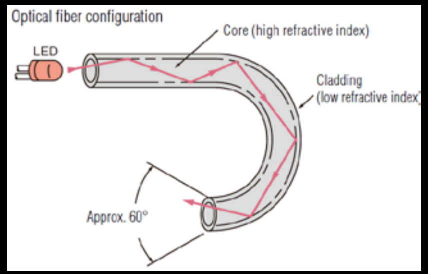
- Two concentric copper conductors
- Broadband
- Multiple channels on cable

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

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

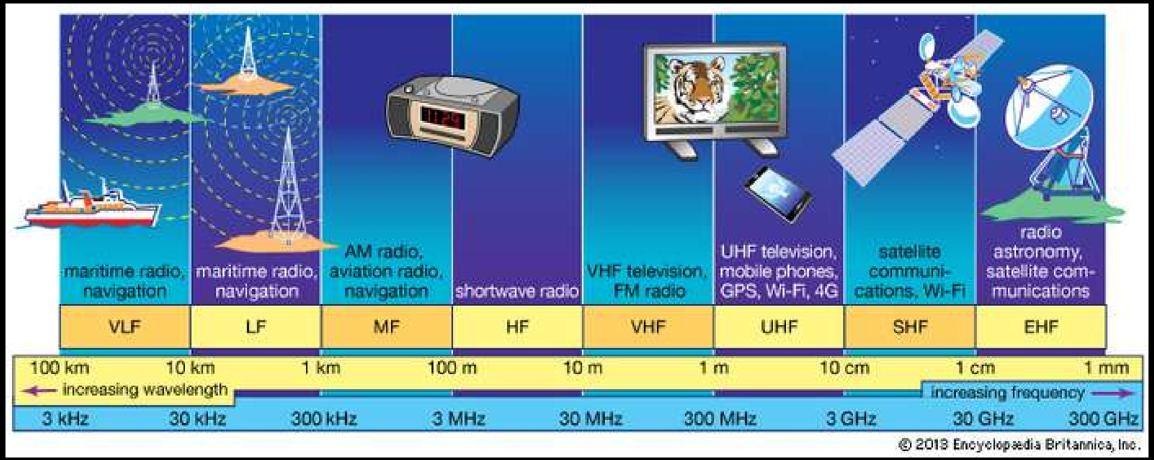


출처 – http://www.standard-wire.com/coax_cable_theory_and_application.html/

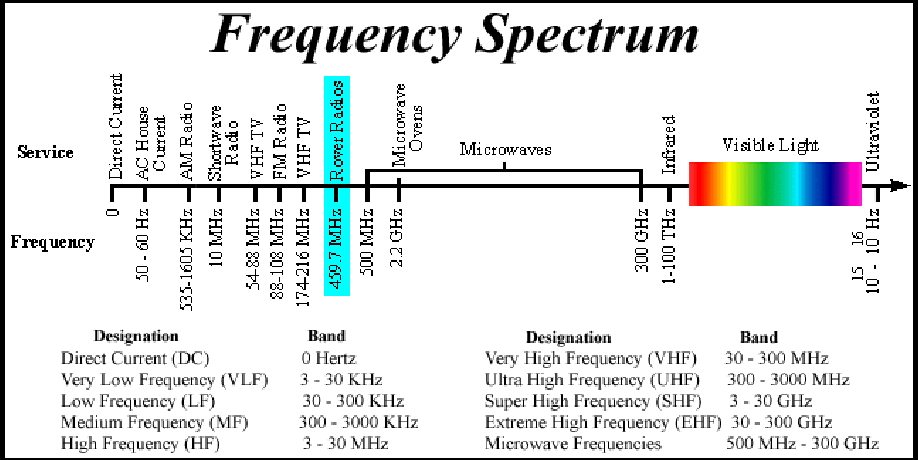


출처 – https://www.keyence.co.uk/ss/products/sensor/sensorbasics/fiber/info//

- 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

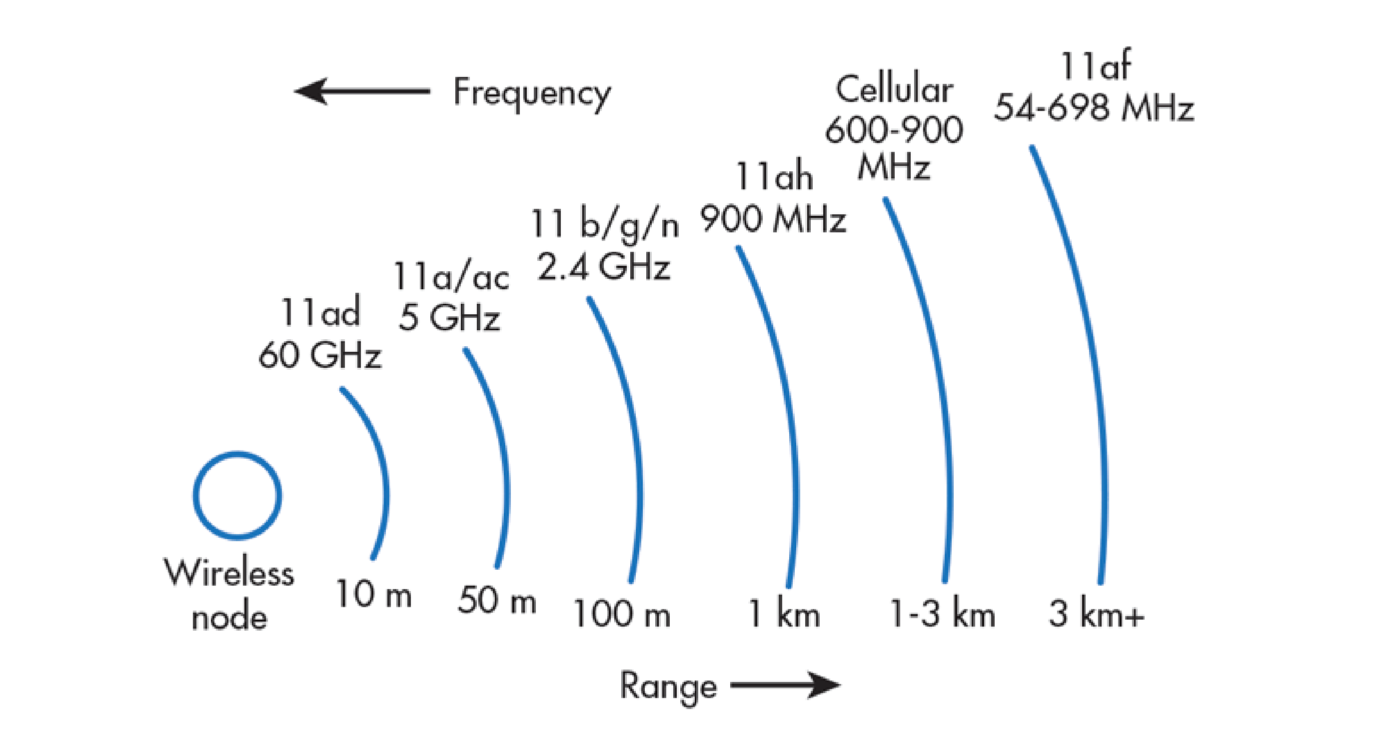


출처 - https://www.britannica.com/science/radio-frequency-spectrum/



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

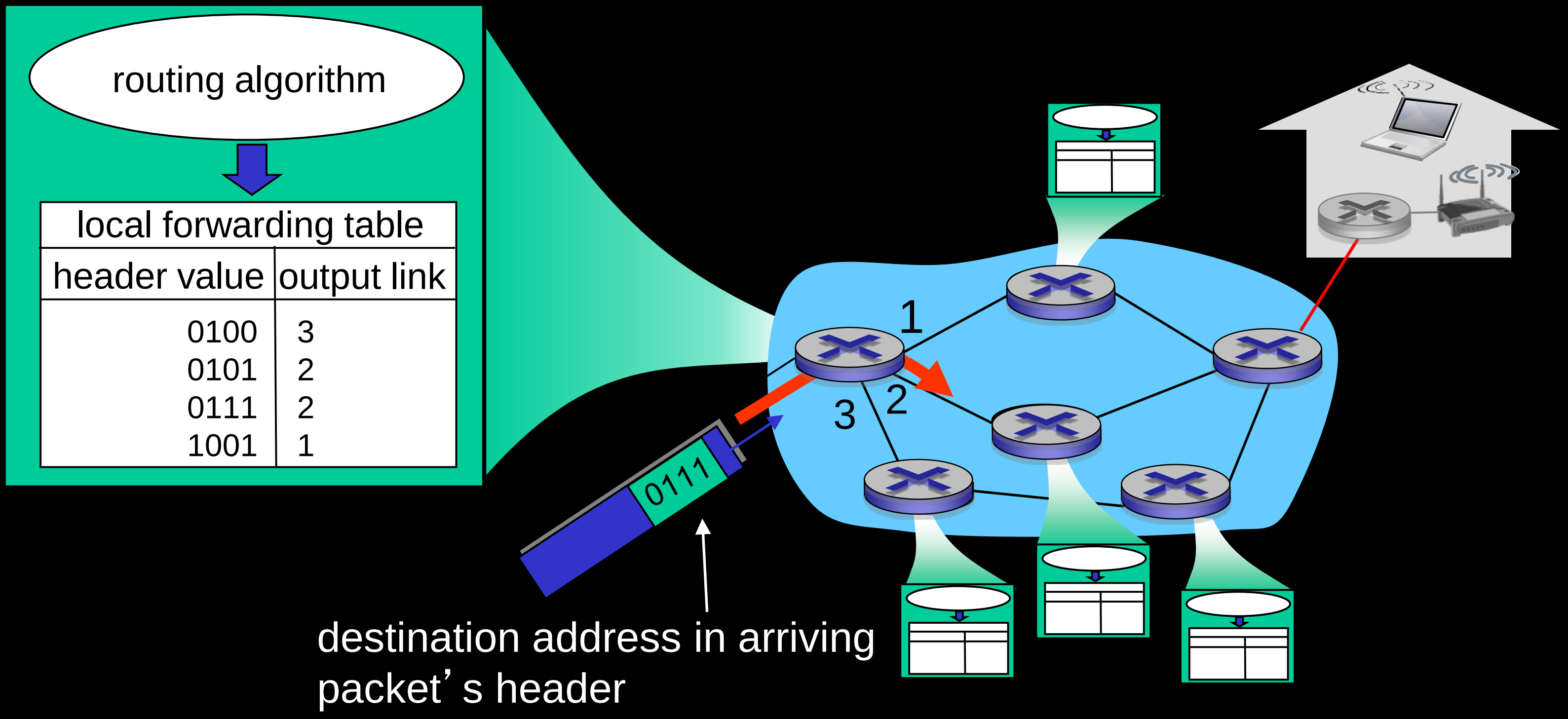
- The higher the frequency, the stronger the linearity and the faster the attenuation



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

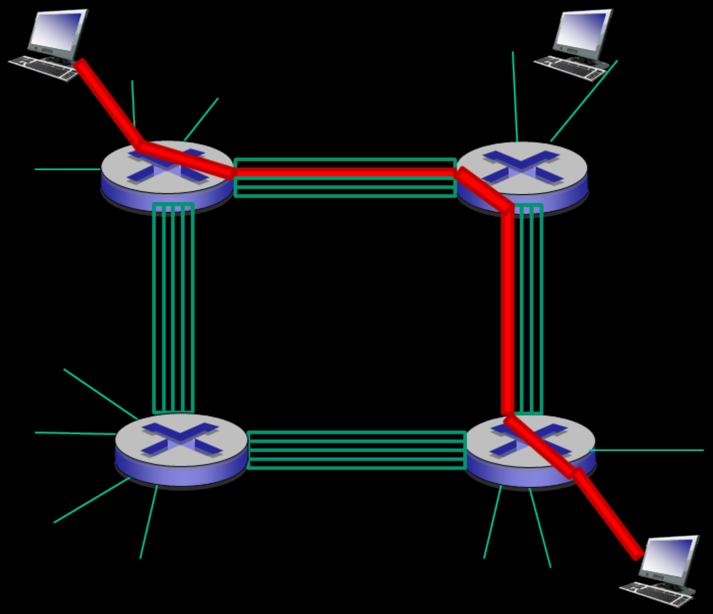
03. Network Core

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

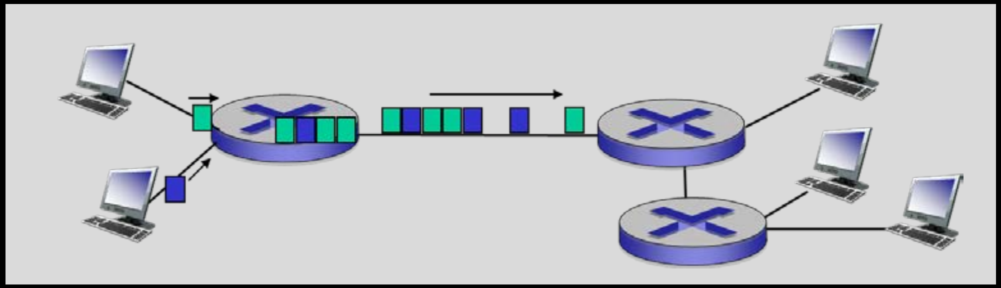


Switching Mechanisms

- Circuit Switching
  - End–end resources reserved for "call" between src. & dest.
  - Entire data flew along the path like water

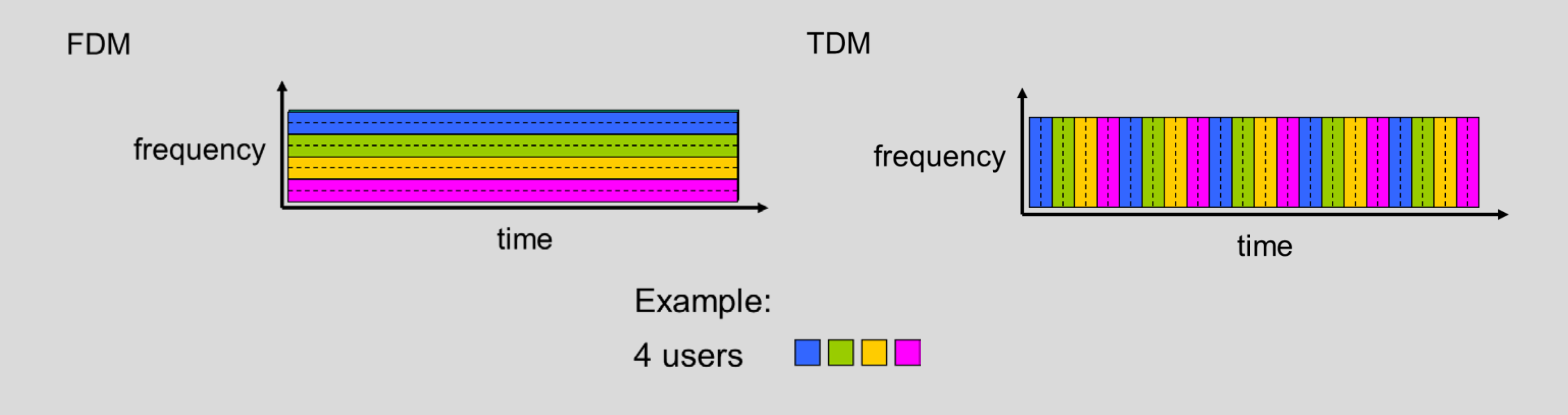


- Packet Switching
  - Entire data broken into small packets
  - Each packet has its destination address
  - Each packet handled independently



Circuit Switching: Detail

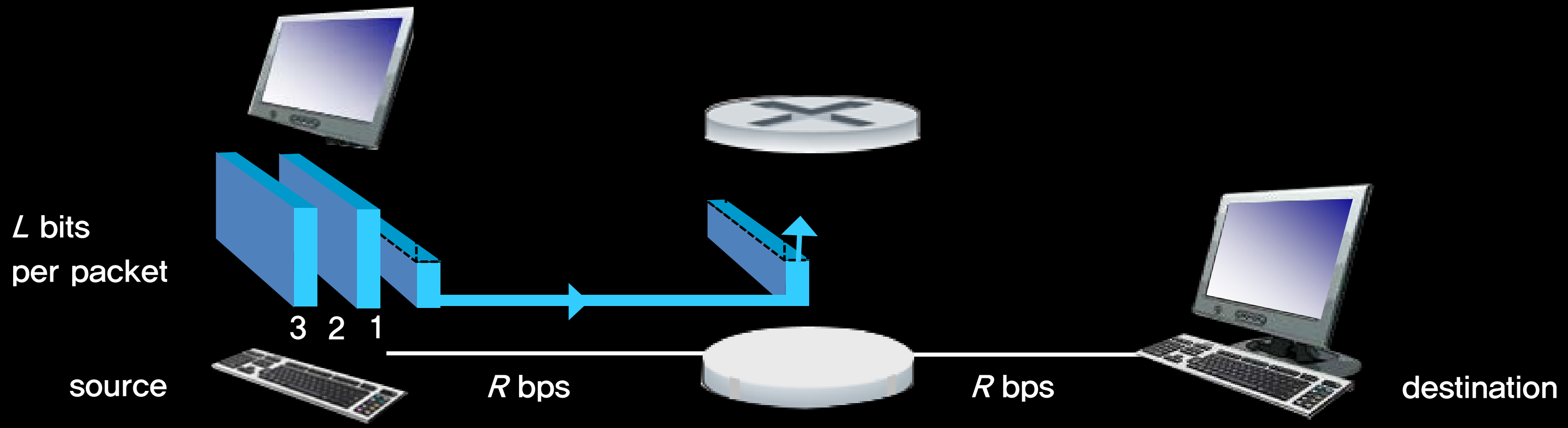
- Resources dedicated to each call
  - circuit segment idle if not used by the call (no sharing)
- Commonly used in traditional telephone networks
- Channel allocation methods: FDM, TDM



- 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 ≈ 2L/R

numerical example:

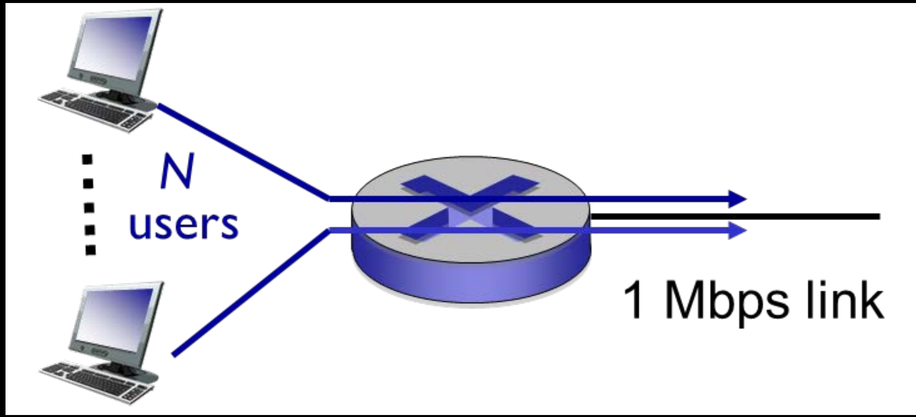
- L = 7.5 Mbits
- R = 1.5 Mbps
- One-hop transmission delay = 5s
- End-end delay ≈ 10s



Switching: Comparison

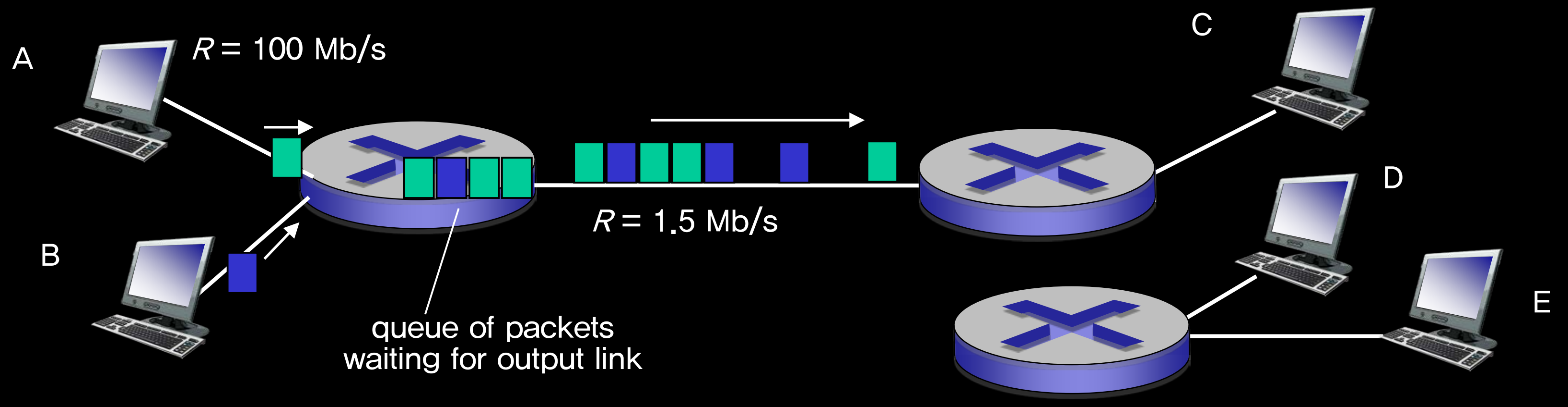
- Packet switching allows more users to use network!
- Example
  - 1 Mbps link
  - each user:
    - 100 kbps when "active"
    - only 10% of time active
  - circuit switching
    - 10 users
  - packet switching
    - with 35 users, probability of 10 users being active at the same time is about .0004

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



Switching: Comparison

- 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

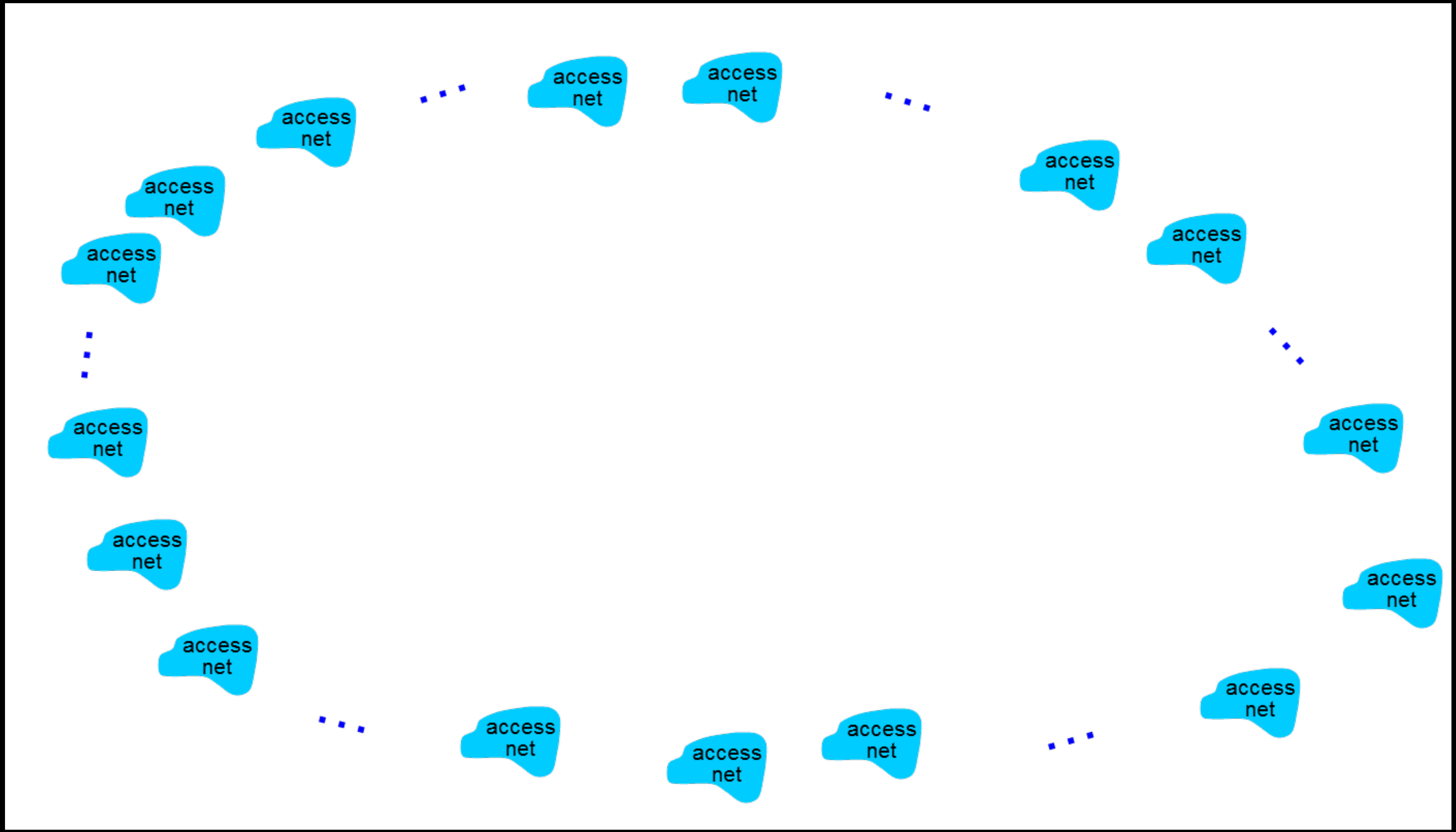
- Who's in charge of the Internet?

Nobody! Or Everybody!

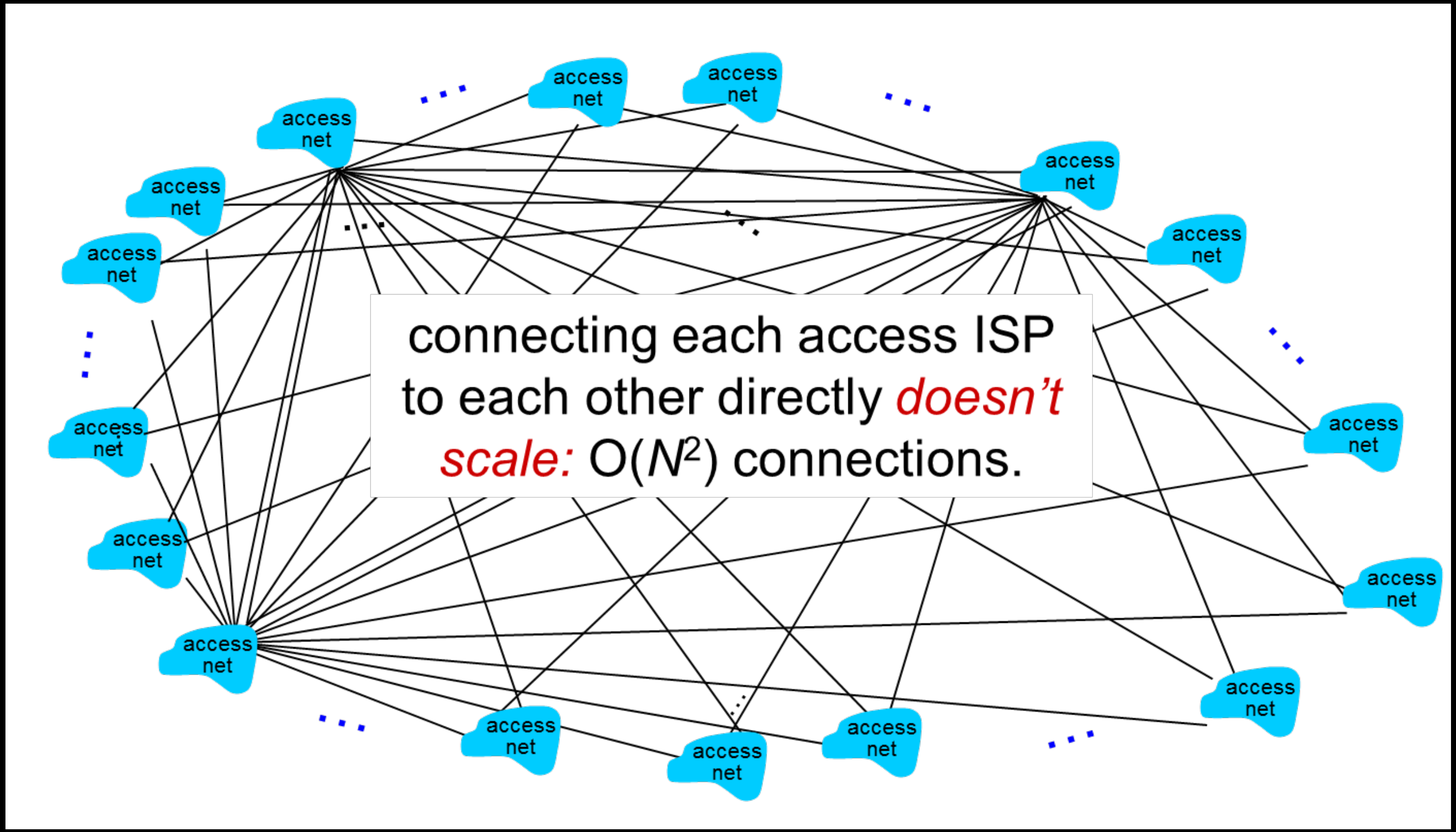
  - independently operated networks

- 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

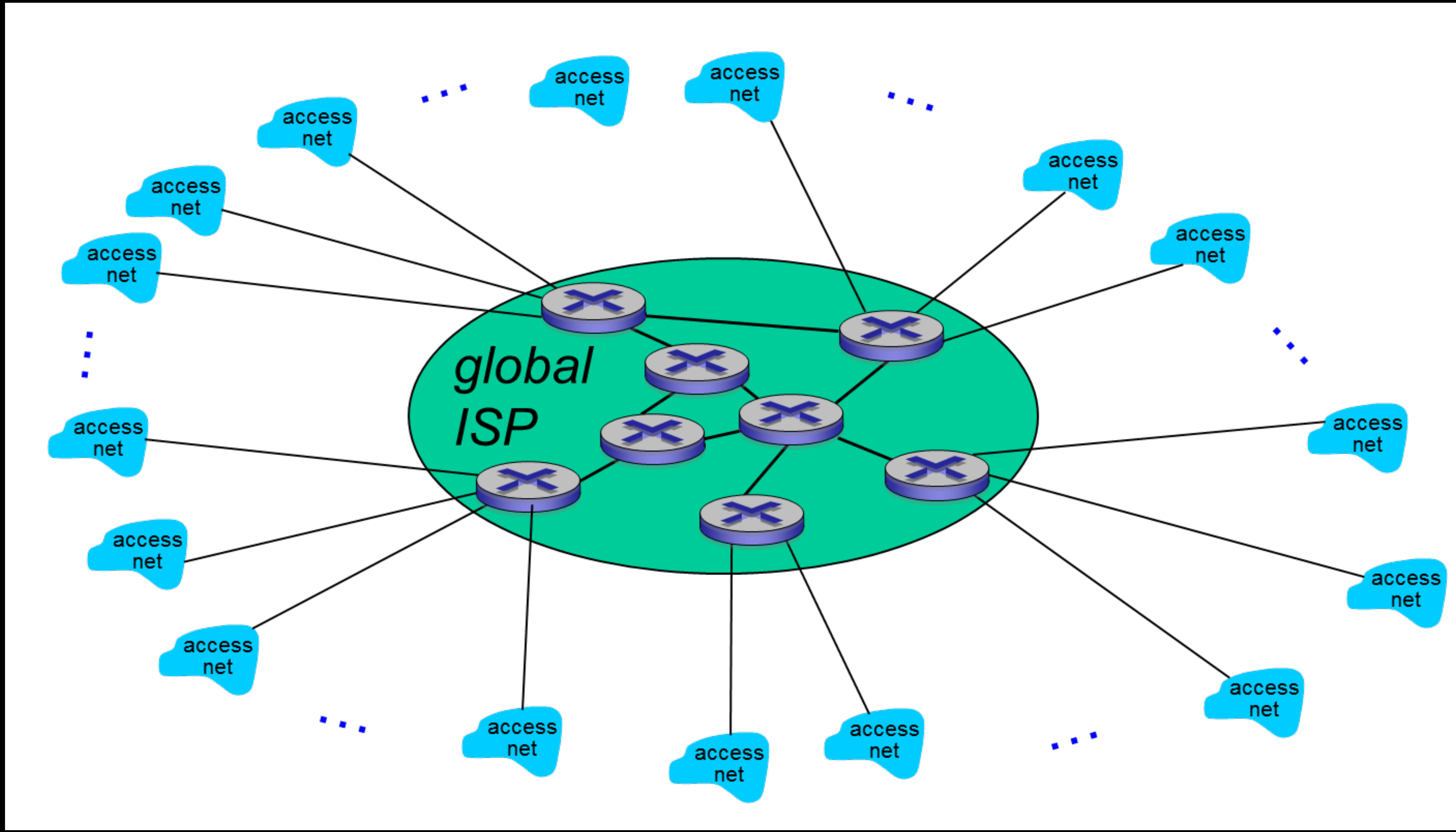
- Question: given millions of access ISPs, how to connect them together?



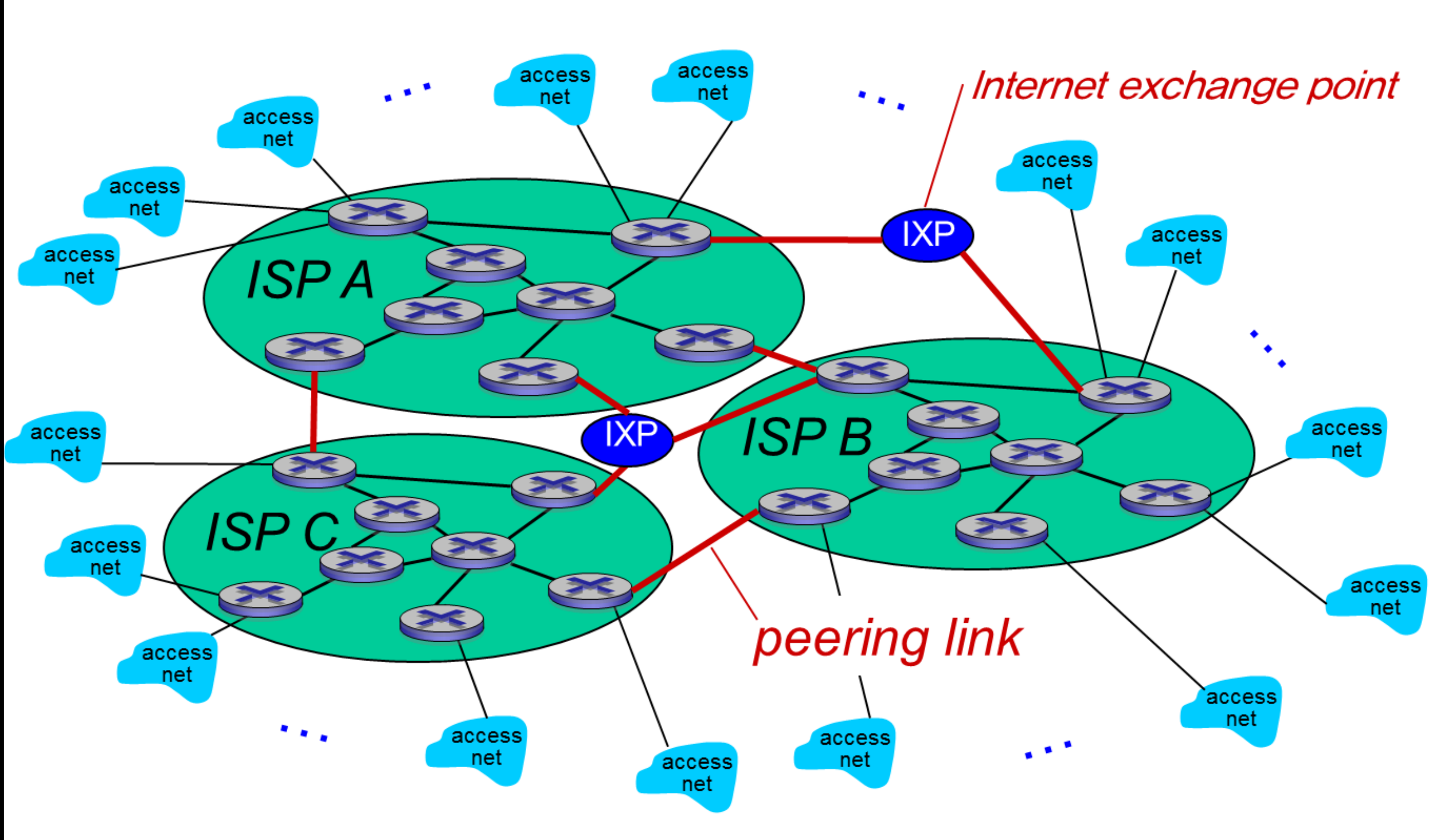
- Naïve method: connect each access ISP to every other access ISP



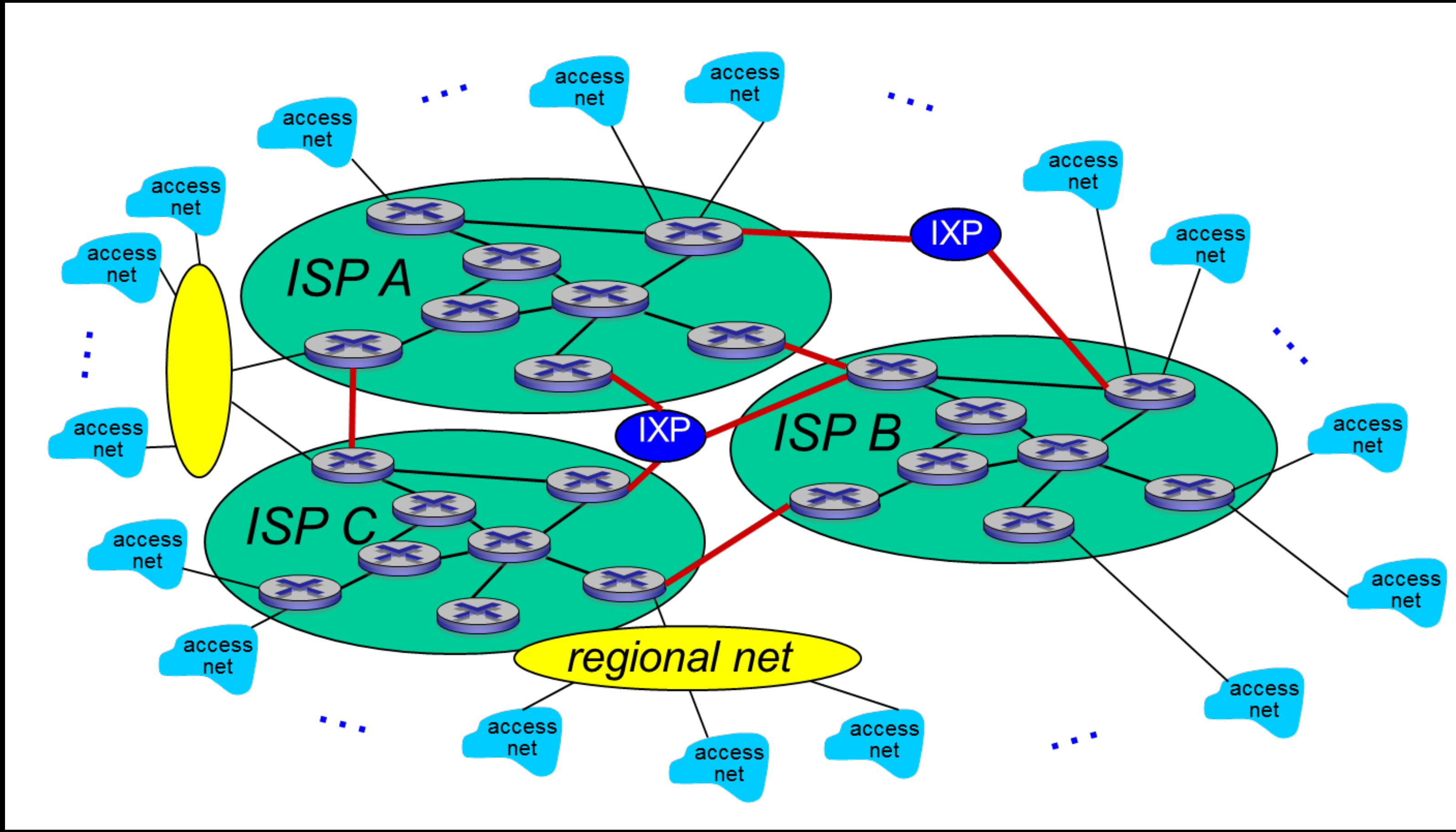
- Scalable method: connect each access ISP to one global transit ISP



- Competing ISPs appear… which must be interconnected

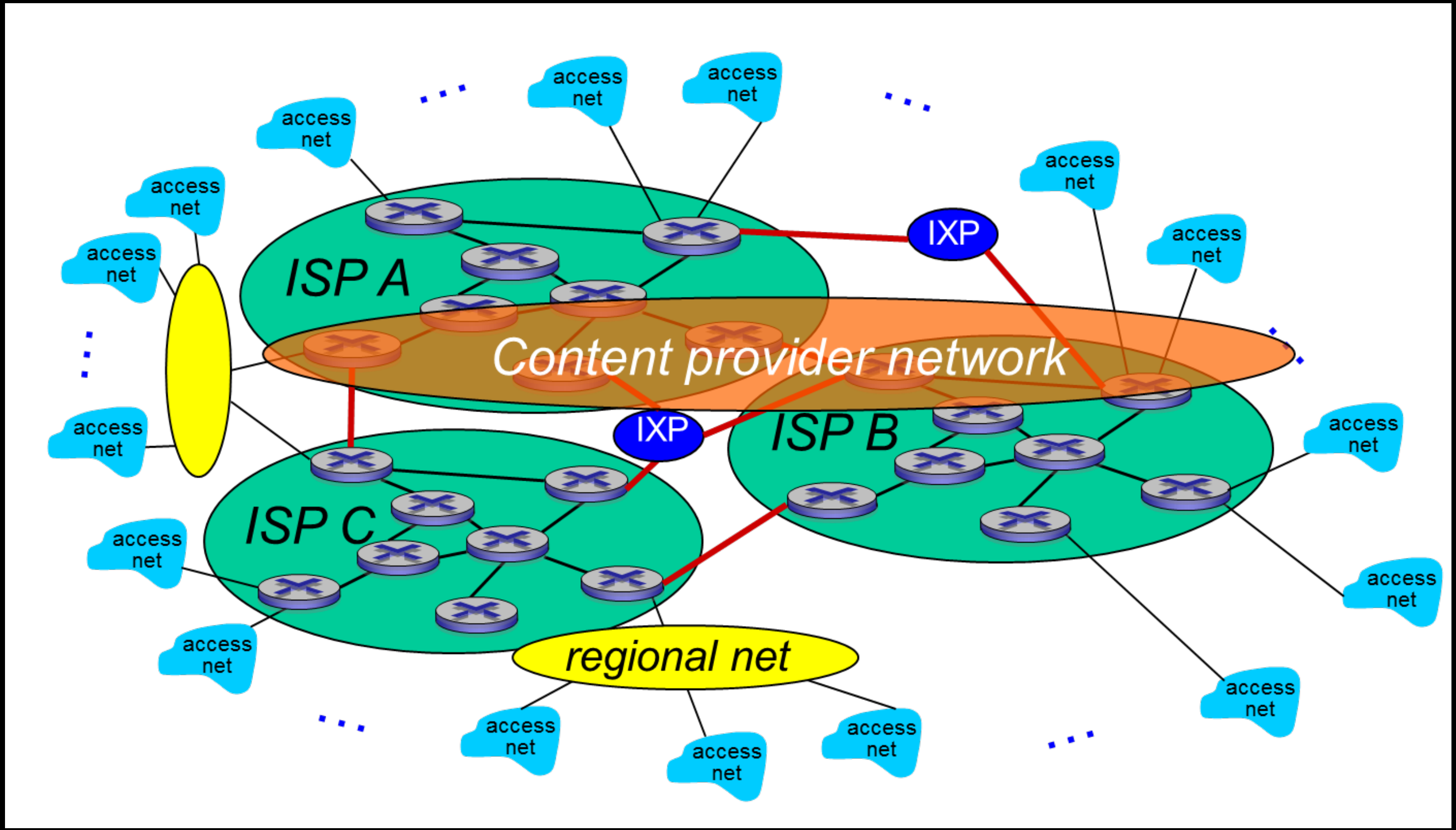


- Regional networks arise to connect access networks to ISPs

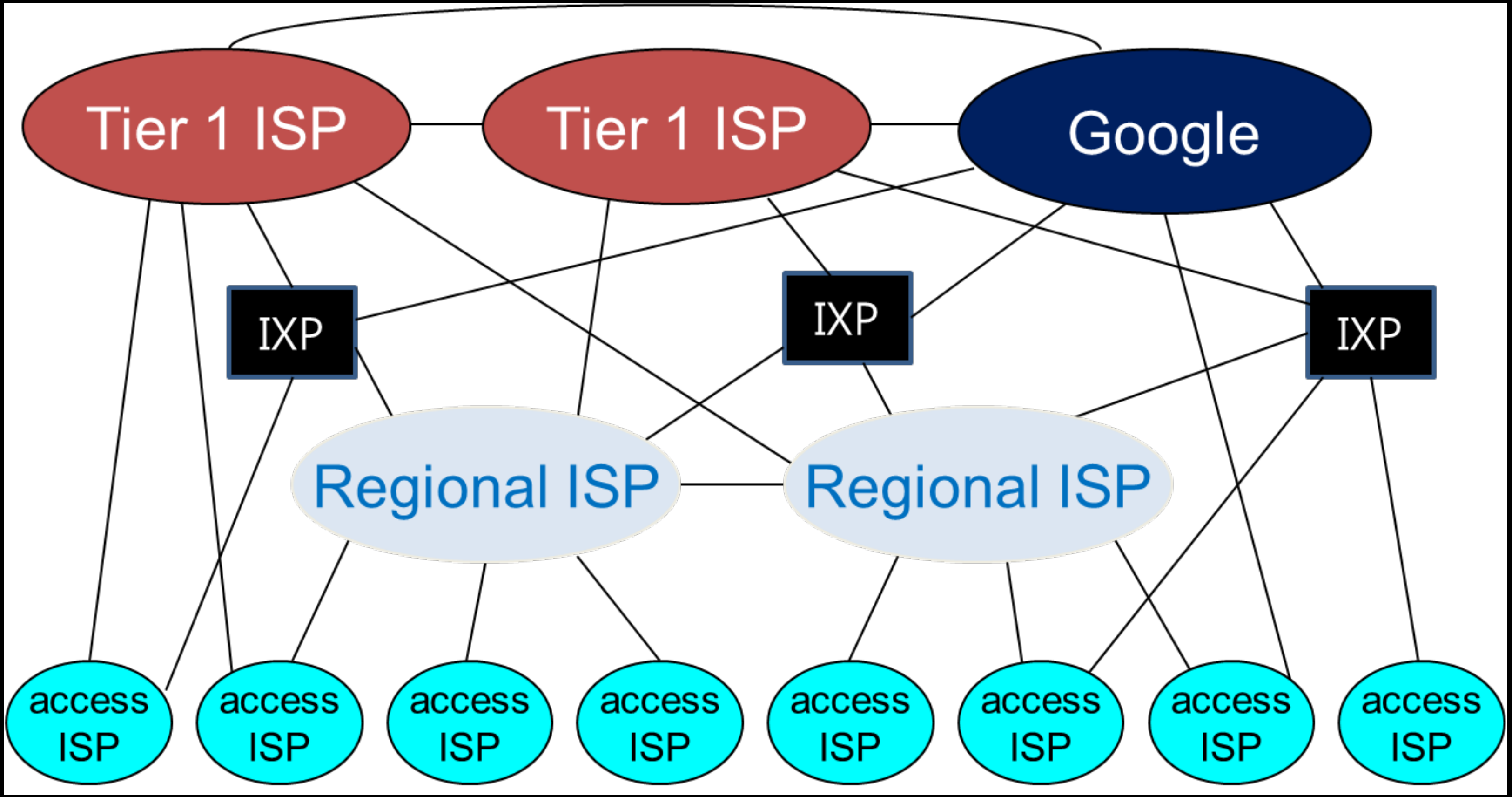


Internet Structure

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

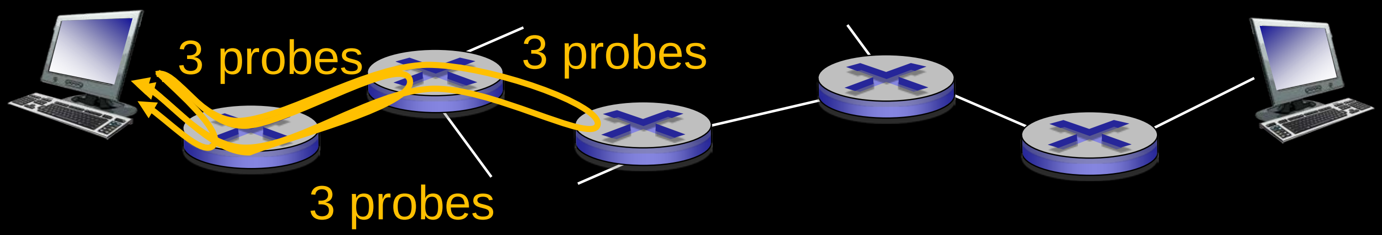


- Seen vertically as:



Traceroute

- 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



Traceroute

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:

  1    <1 ms    <1 ms    <1 ms  192.168.1.1
  2    49 ms    37 ms    32 ms  194.146.109.226
  3    40 ms    29 ms    53 ms  cpe-188-129-0-253.dynamic.amis.hr [188.129.0.253]
  4    41 ms    45 ms    37 ms  ljubljana9-ge-2-5.amis.net [212.18.39.113]
  5    50 ms    47 ms    81 ms  mx-lj1-te-1-2-0.amis.net [212.18.44.137]
  6   103 ms    72 ms    60 ms  mx-vi1-te-0-0-0.amis.net [212.18.44.142]
  7    53 ms    53 ms    61 ms  xe-0-0-0-300.vie20.ip4.tinet.net [77.67.75.93]
  8   169 ms   145 ms   150 ms  xe-10-3-2.was14.ip4.tinet.net [141.136.110.217]
  9   330 ms   225 ms   303 ms  te-7-2.car4.Washington1.Level3.net [4.68.110.97]
 10   217 ms     *      209 ms  vlan60.csw1.Washington1.Level3.net [4.69.149.62]
 11   205 ms   208 ms   200 ms  ae-61-61.ebr1.Washington1.Level3.net [4.69.134.129]
 12   209 ms   185 ms   204 ms  ae-2-2.ebr3.Atlanta2.Level3.net [4.69.132.85]
 13   204 ms   204 ms   202 ms  ae-7-7.ebr3.Dallas1.Level3.net [4.69.134.21]
 14   282 ms   197 ms   210 ms  ae-63-63.csw1.Dallas1.Level3.net [4.69.151.133]
 15   200 ms   219 ms   230 ms  ae-1-60.edge9.Dallas1.Level3.net [4.69.145.16]
 16   210 ms   197 ms   213 ms  CISCO-SYSTE.edge9.Dallas1.Level3.net [4.30.74.46]
 17     *        *        *     Request timed out.
 18   322 ms   310 ms   329 ms  rcdn9-cd2-dmzdcc-gw2-por1.cisco.com [72.163.0.182]
 19   319 ms   310 ms   315 ms  rcdn9-14a-dcz05n-gw1-ten5-5.cisco.com [72.163.0.238]
 20   324 ms   299 ms   309 ms  www1.cisco.com [72.163.4.161]

Trace complete.

C:\Users\     >
```

05. Performance Metrics

Evaluation Metrics

Delay

Packet delivering time from source to destination

Packet Loss

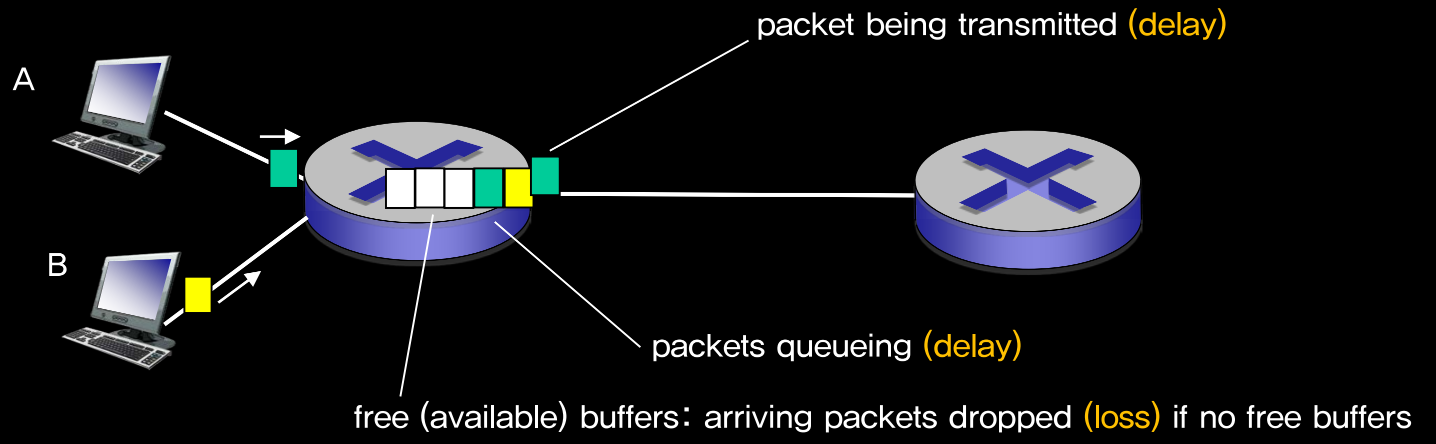
Ratio of lost packets to total sent packets

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

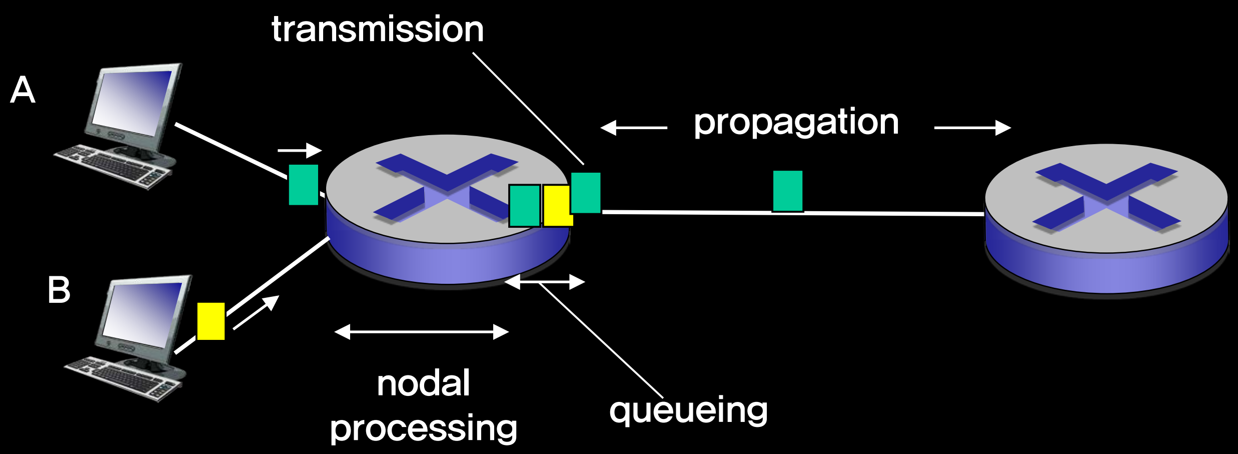
Throughput

The amount of traffic delivered per unit time

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



Four Sources of Delay



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

Four Sources of Delay

Queue-ing

- time waiting at output buffer for transmission
- congestion dependent

Transmi-ssion

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

Process-ing

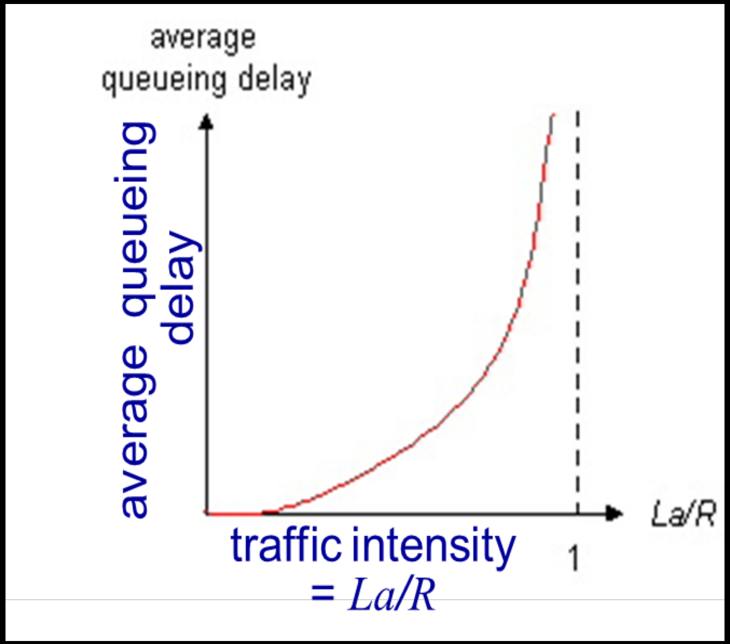
- bit error checking
- decision of output link
- typically 〈 msec

Propaga-tion

- d: length of physical link
- s: signal speed (~$2x10^8$ m/s)
- $d_{prop} = d/s$

More on Queueing Delay

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

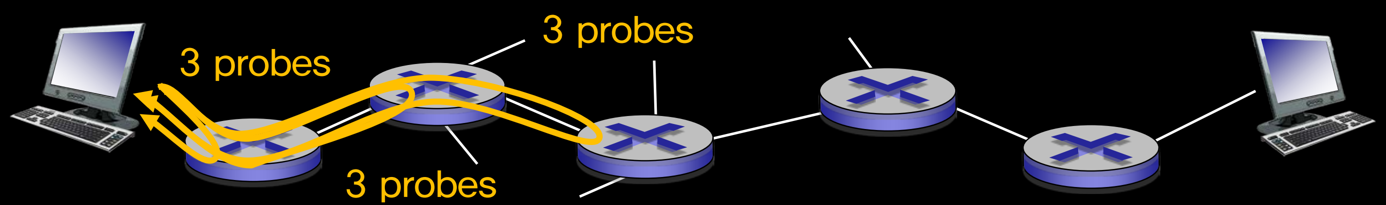


- La/R~0: small queueing delay
- La/R->1: large queueing delay
- La/R~1: increase to the infinite!

La/R ~ 0

La/R -> 1

Traceroute (revisited)



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

3 delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

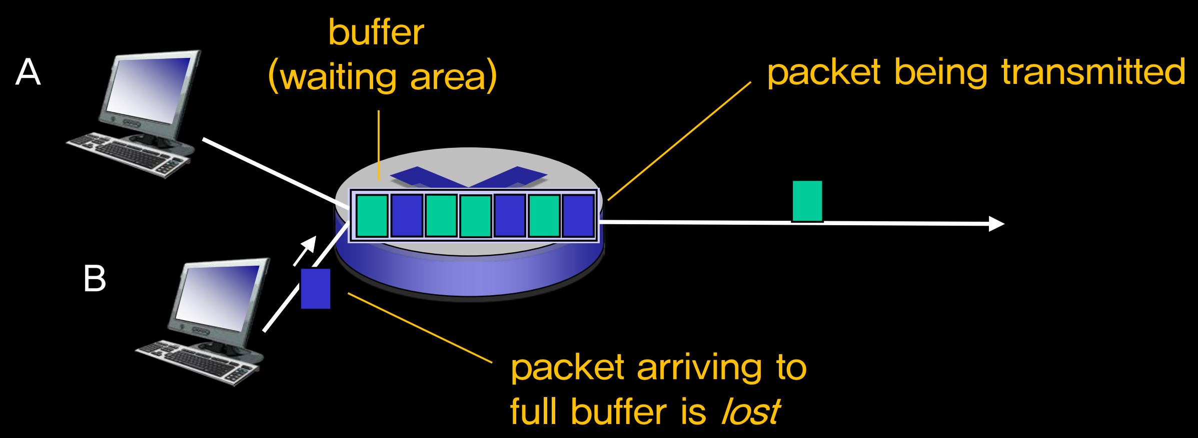
- 1 cs-gw (128.119.240.254) 1 ms 1 ms 2 ms
- 2 border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145) 1 ms 1 ms 2 ms
- 3 cht-vbns.gw.umass.edu (128.119.3.130) 6 ms 5 ms 5 ms
- 4 jn1-at1-0-0-19.wor.vbns.net (204.147.132.129) 16 ms 11 ms 13 ms
- 5 jn1-so7-0-0-0.wae.vbns.net (204.147.136.136) 21 ms 18 ms 18 ms
- 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

trans-oceanic link

* means no response (probe lost, router not replying)

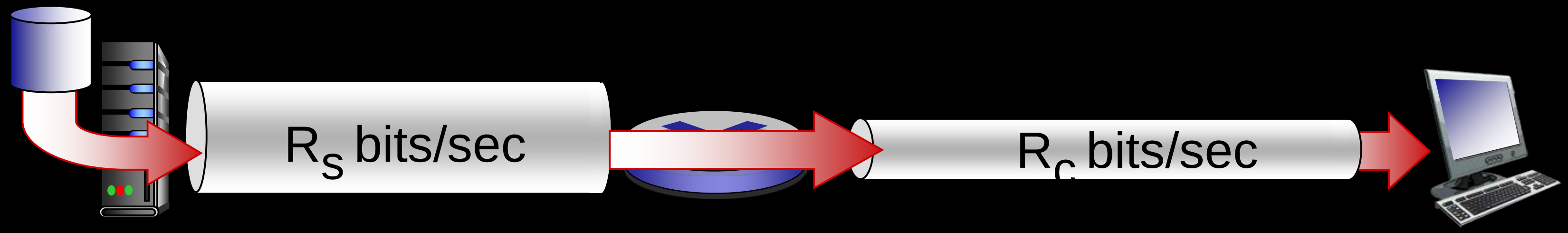
Packet Loss

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



Throughput

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



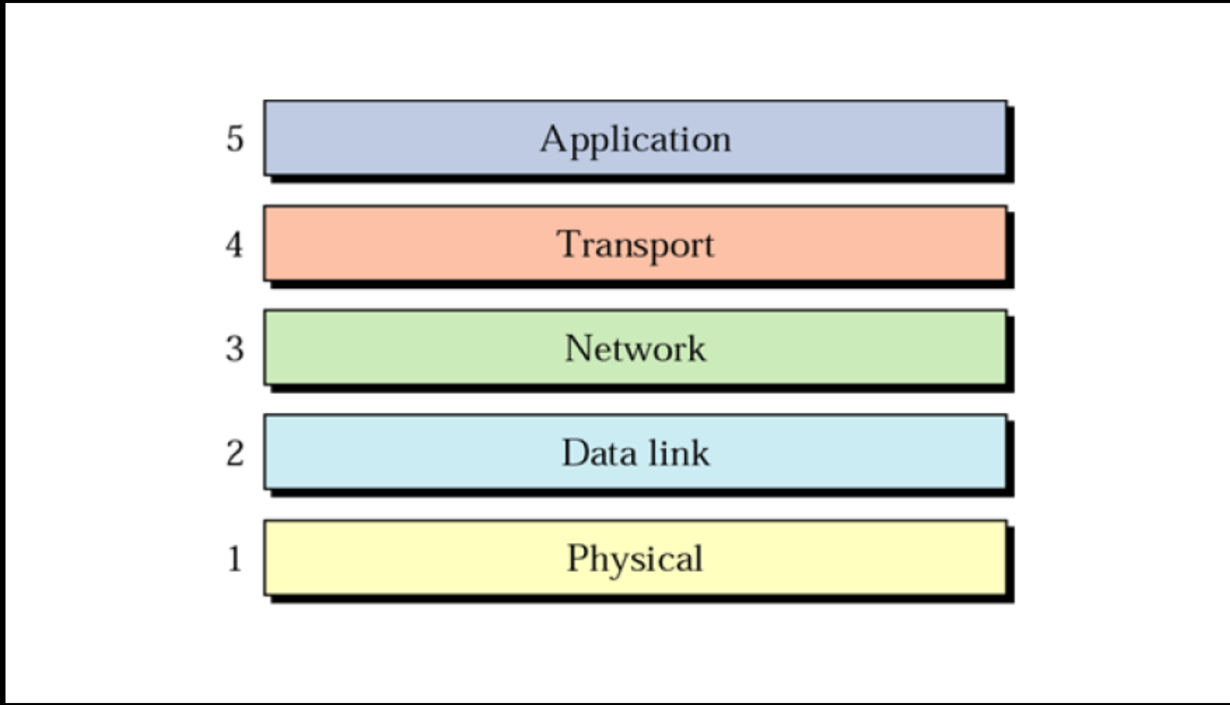
bottleneck link

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

06. Protocol Stack

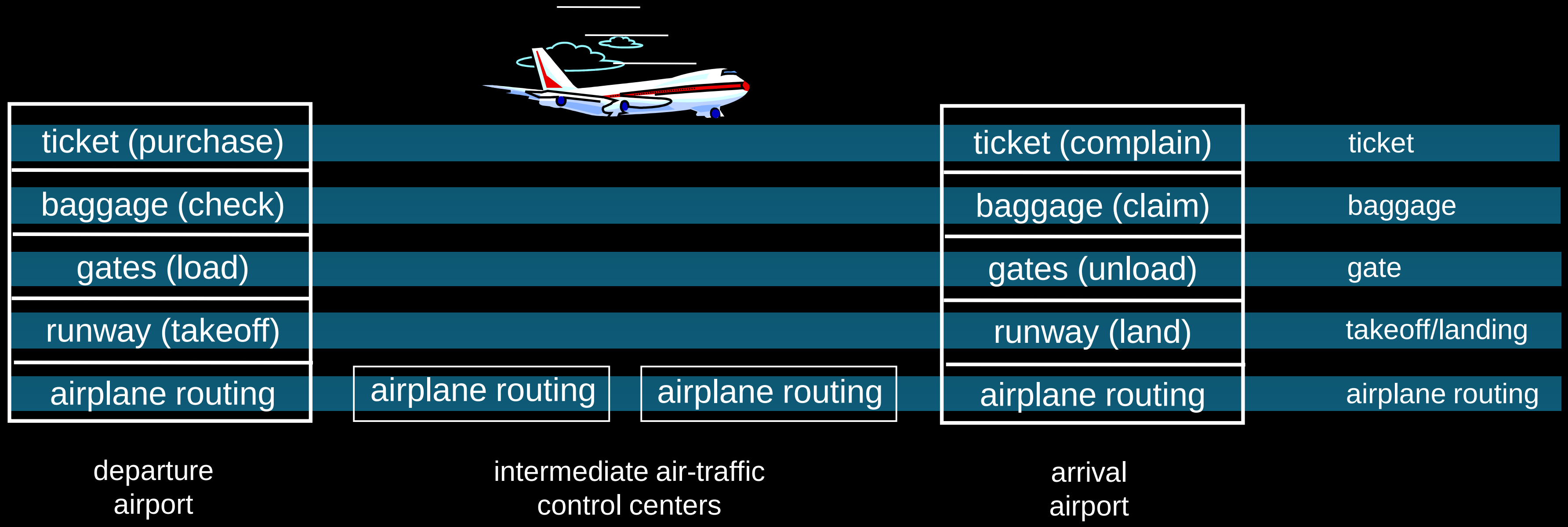
Protocol Stack

- A communication protocol stack is composed of several layers



출처 – http://www.cse.yorku.ca/course_archive/2012-13/F/2041/slides/networks.html/

Layering of Airline Travel



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

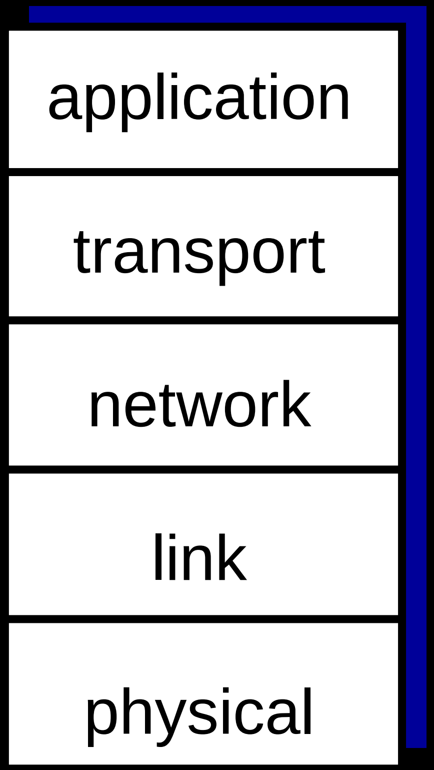
Why Layering?

- 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?

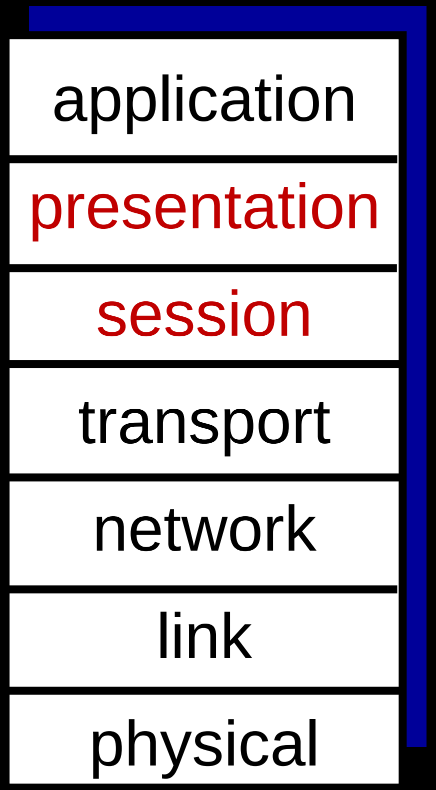
Internet Protocol Stack

- 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, 802.11 (WiFi), PPP
- physical: bits “on the wire”

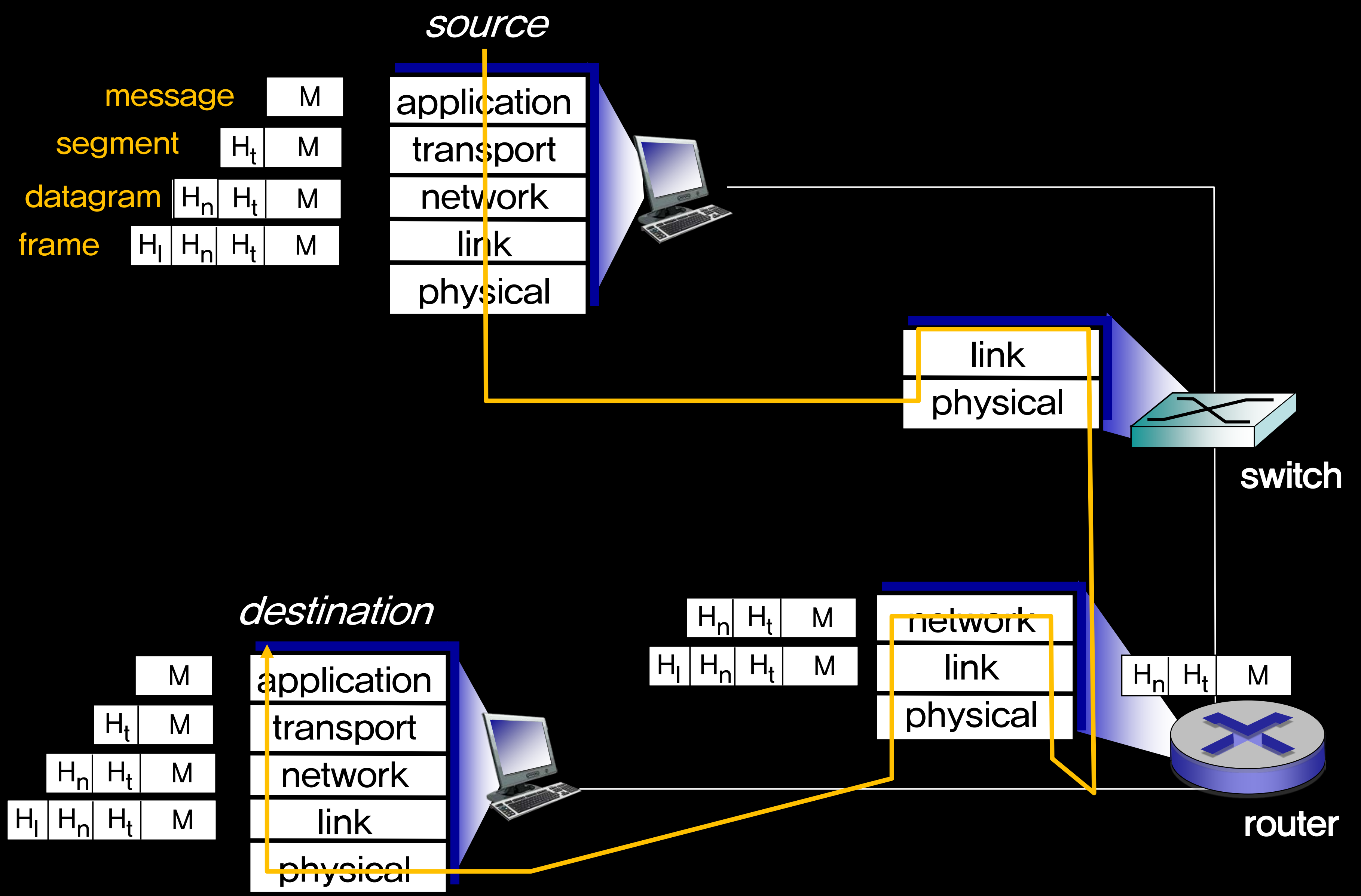


Internet Protocol Stack

- 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

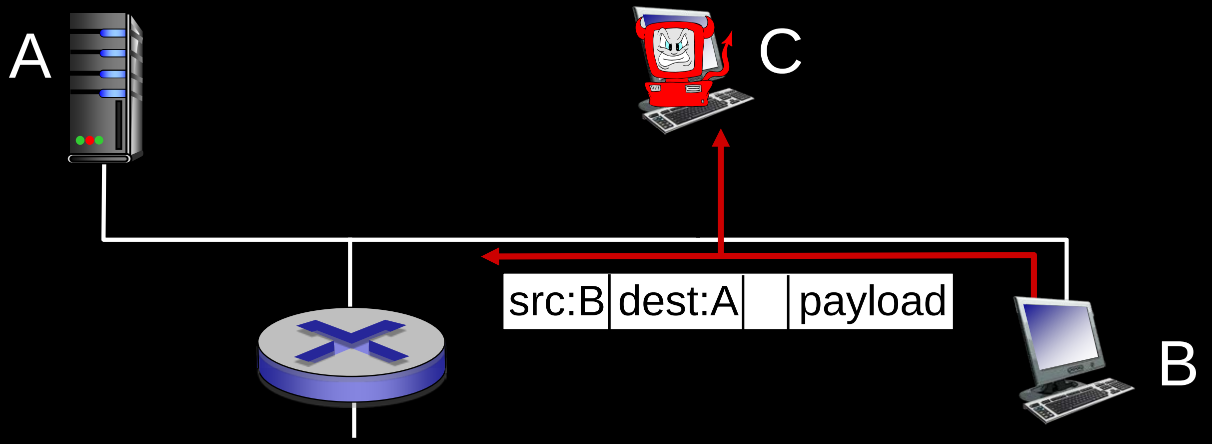
- Malware can get in host from:
  - virus: self-replicating infection by receiving/executing object (e.g., e-mail attachment)
  - worm: self-replicating infection by passively receiving object that gets itself executed

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

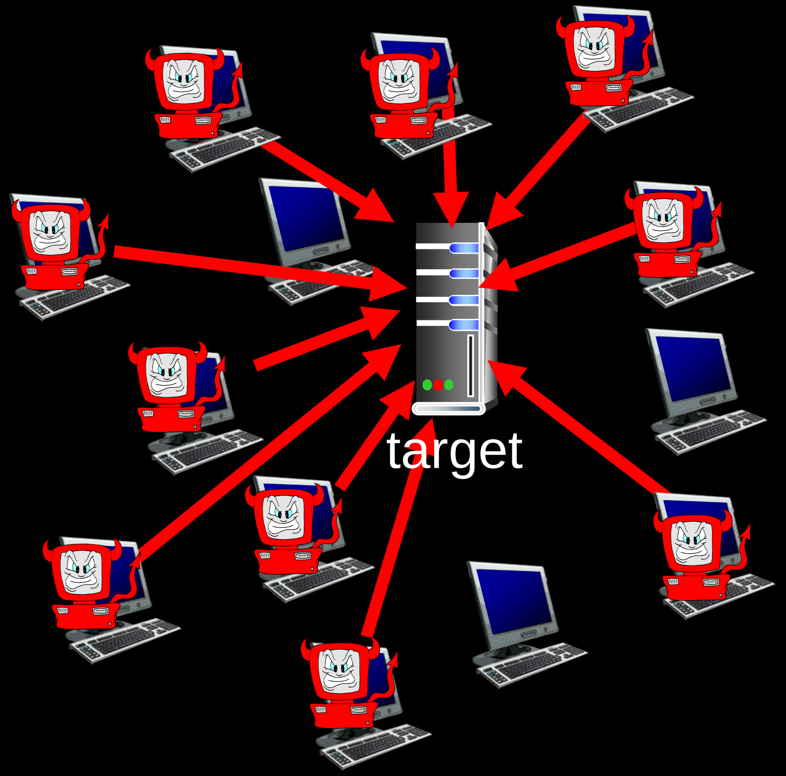
출저 – https://epatientfinder.com/worried-ransomware-need-backup-plan-literally/

Packet Sniffing

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

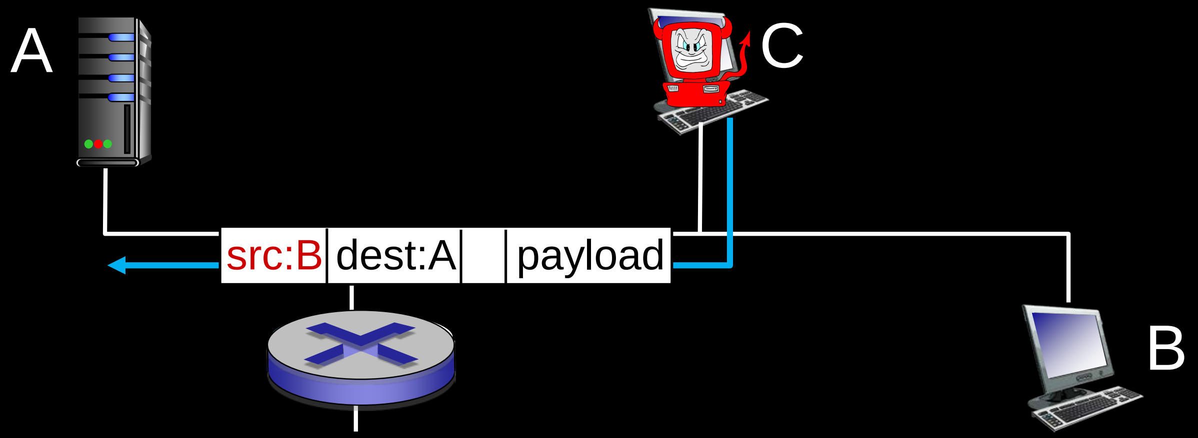


- Attackers make resources (server, bandwidth) unavailable by sending the huge amount of bogus traffic through botnets



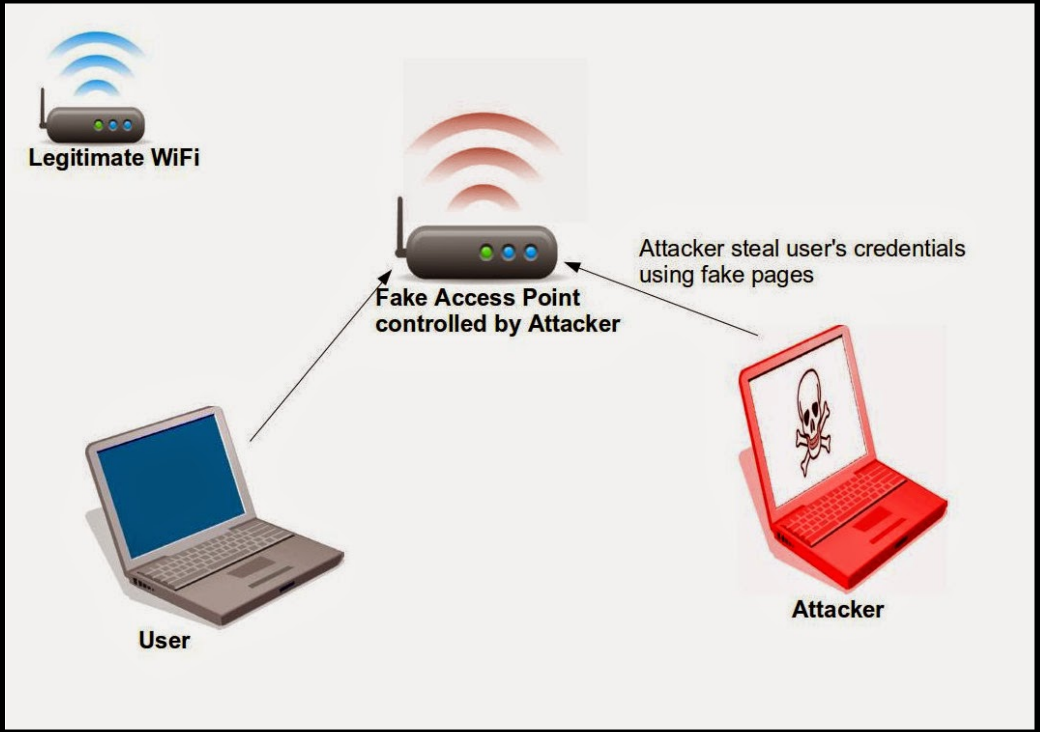
Fake Addresses

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



Fake WiFi Access Point

- Steal user's credentials using fake AP



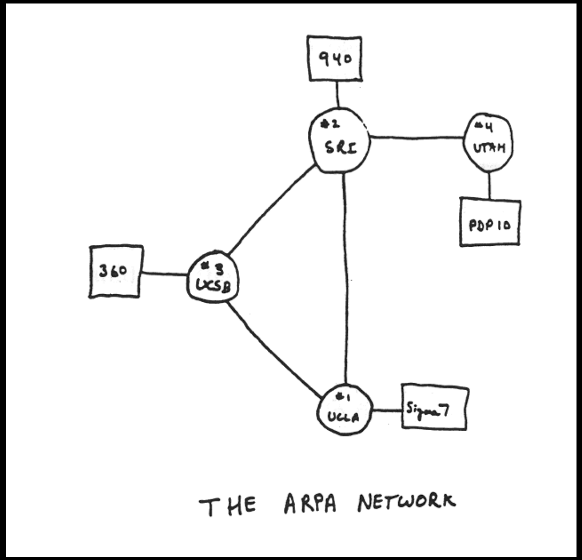
출저 – https://developertz.wordpress.com/2017/03/14/evil-twin-and-fake-wireless-access-point-hacks-what-they-are-how-to-defend//

08. History of the Internet

Internet History (1961~1972)

- 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



Internet History (1972~1980)

- Internetworking, new and proprietary nets
  - 1974
    - Cerf and Kahn – architecture for interconnecting networks

출저 – 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

Internet History (1980~1990)

- 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

출저 – http://fortune.com/2011/04/06/bill-joy-better-batteries-key-to-green-power-adoption/

Internet History (1990~2000)

- 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

출저 – http://techland.time.com/2012/09/05/10-questions-for-sir-tim-berners-lee/

Internet History (Present)

- 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

Summary (1/2)

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

Summary (2/2)

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