Chapter 1
Introduction – part 1

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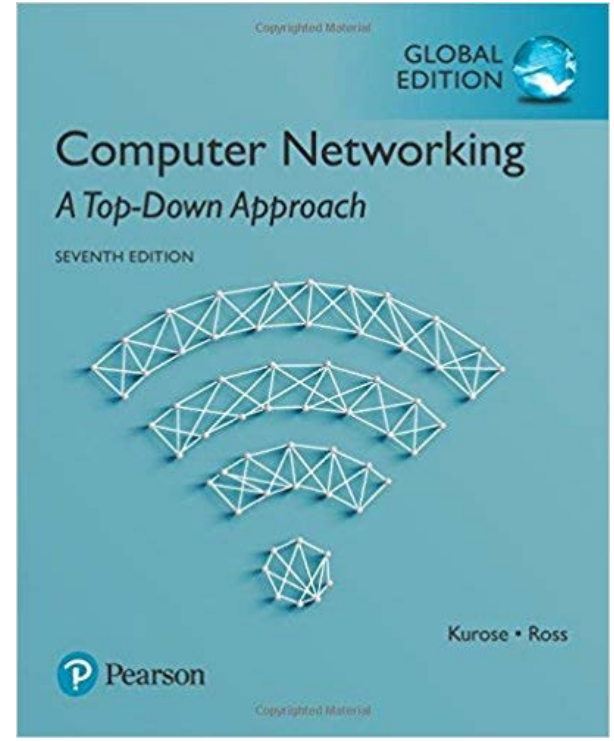


Computer Networking: A Top Down Approach

7th edition
Jim Kurose, Keith Ross
Pearson, 2017

Most of slides from J.F Kurose and K.W. Ross. And, some slides from Prof. Joon Yoo

Chapter 1: introduction

overview:

- what's the **Internet**?
- what's a **protocol**?
- network **edge**; hosts, access net, physical media
- network **core**: packet/circuit switching, Internet structure
- performance: **loss, delay, throughput**
- **protocol layers**, service models

our goal:

- get "feel" and terminology.
- more depth, detail *later* in course
- approach: use **Internet** as example

Chapter 1: roadmap

1.1 what *is* the Network (Internet)?

1.2 network edge

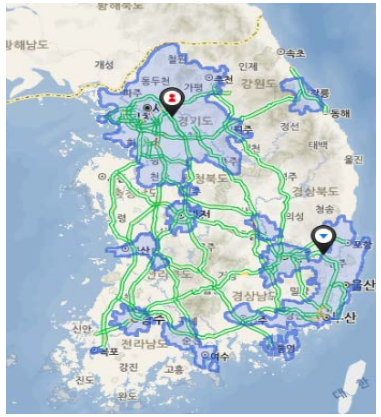
- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

Many types of communication networks

- Communication networks offer one basic service: deliver information
  - smoke signal 
  - messenger 
  - telegraph (전신) 
  - telephone
  - Internet …
- Another example, transportation network: deliver objects
  - horse, train, truck, airplane ...  

Computer Network - definition

- A **computer network**, or simply a **network**,
  - a collection of **computers** and other **hardware components** **interconnected**, either *physically* or *logically* using special hardware and software
  - so that they can **communicate** with each other,
  - allowing them to **share/exchange resource** and **information**

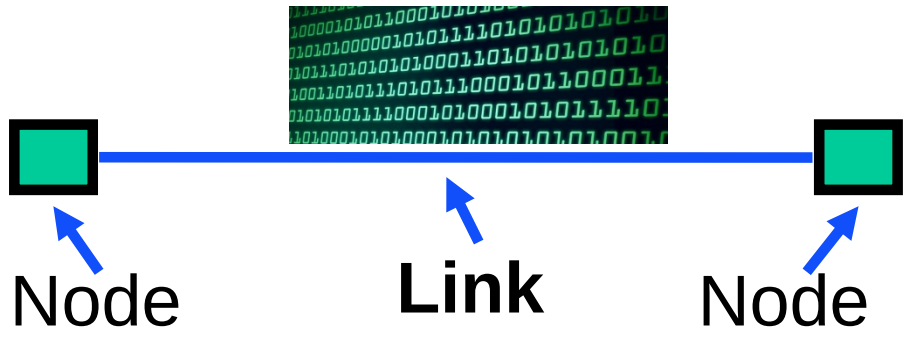
Communicate with each other

Share/exchange Information & resources

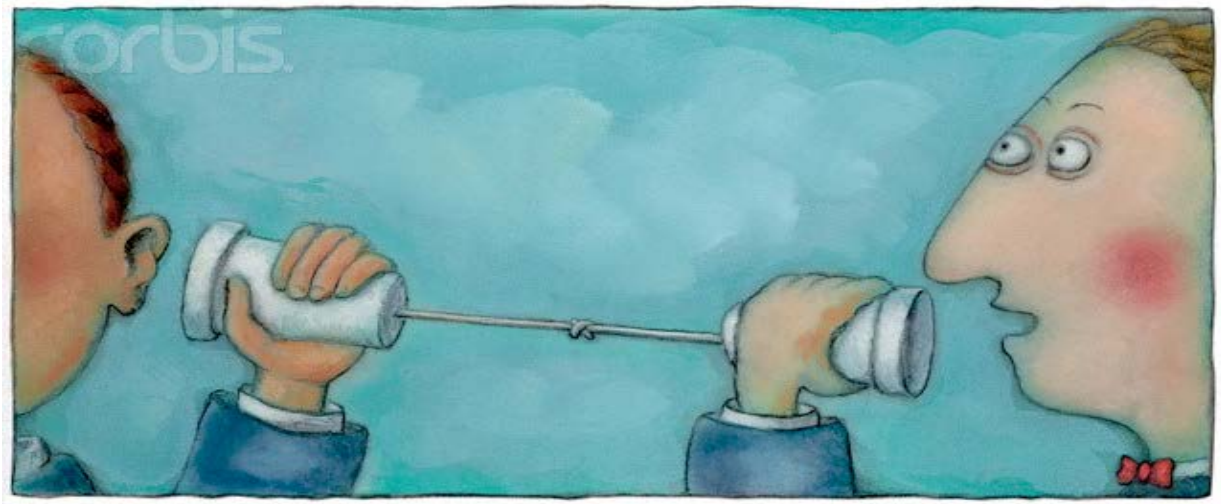
Analogy : Networking in Silicon Valley

Computer Network

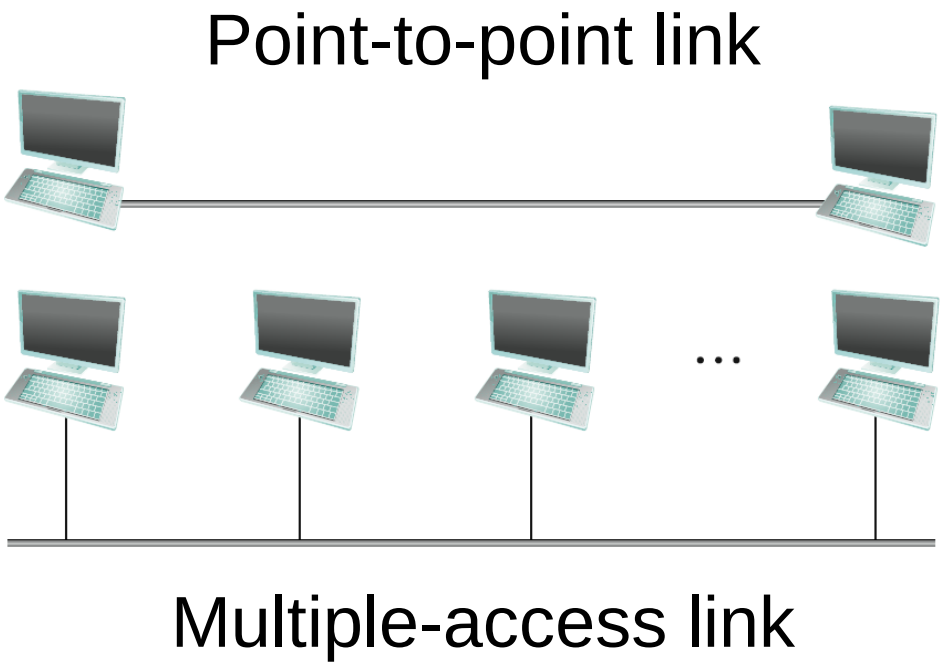
- collection of nodes and links that connect them



  - Link: path followed by bits



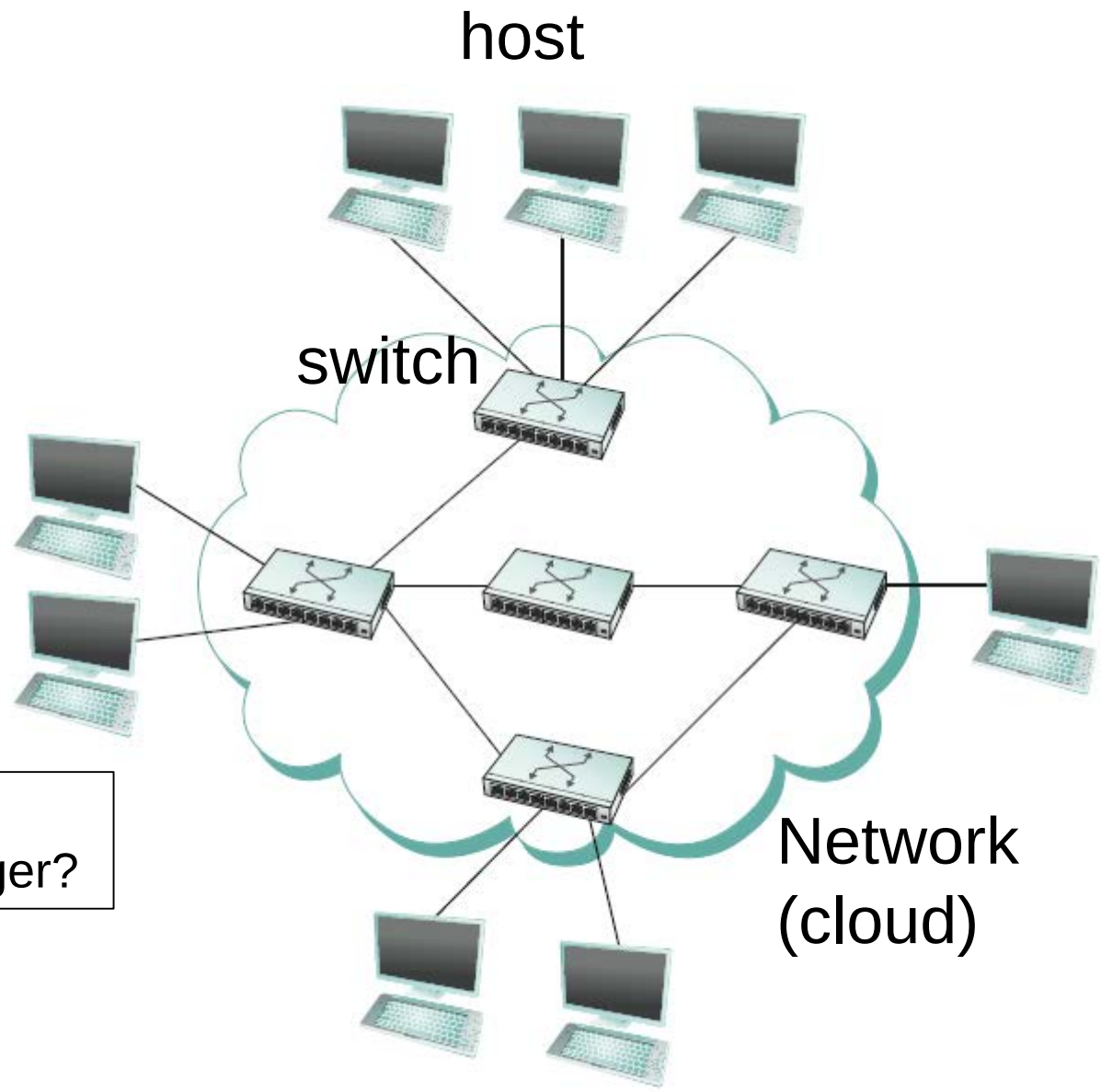
Direct Links



- **Nodes (Hosts)**
  - run application programs
  - send blocks of data (called ***packets***) to each other

Indirect Links

- Switched network
  - ***Switch*** devices
    - store and forward packets

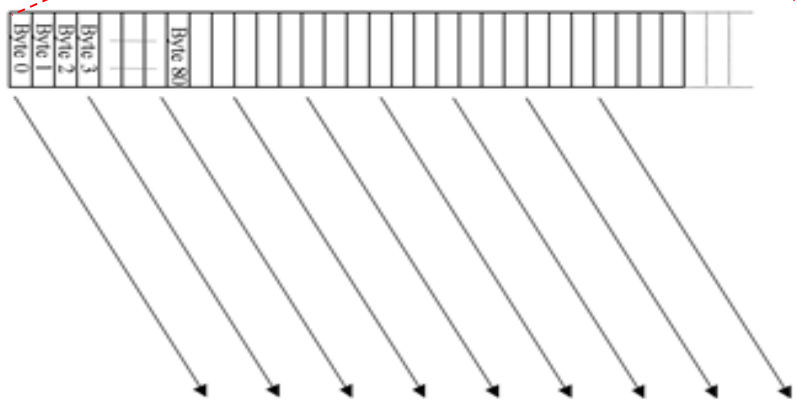


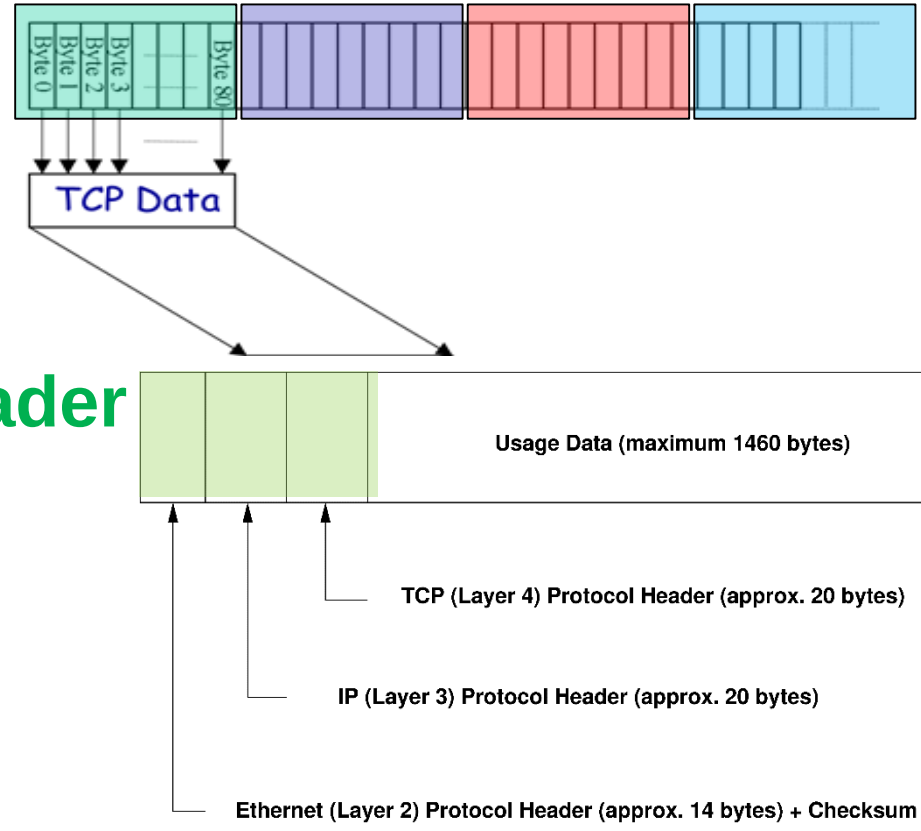
Q1: What are packets?
Q2: What happens if networks become bigger?

Packet ?

data

Byte stream data





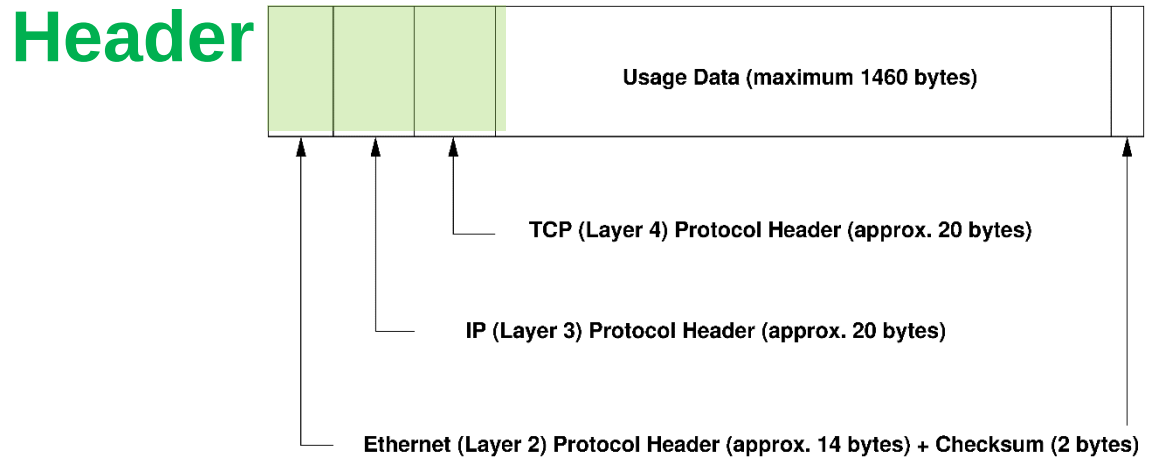
- A unit of data segment (조각) carried by a packet-switched network.

Why packets?

Internet packets are usually 1.5kB

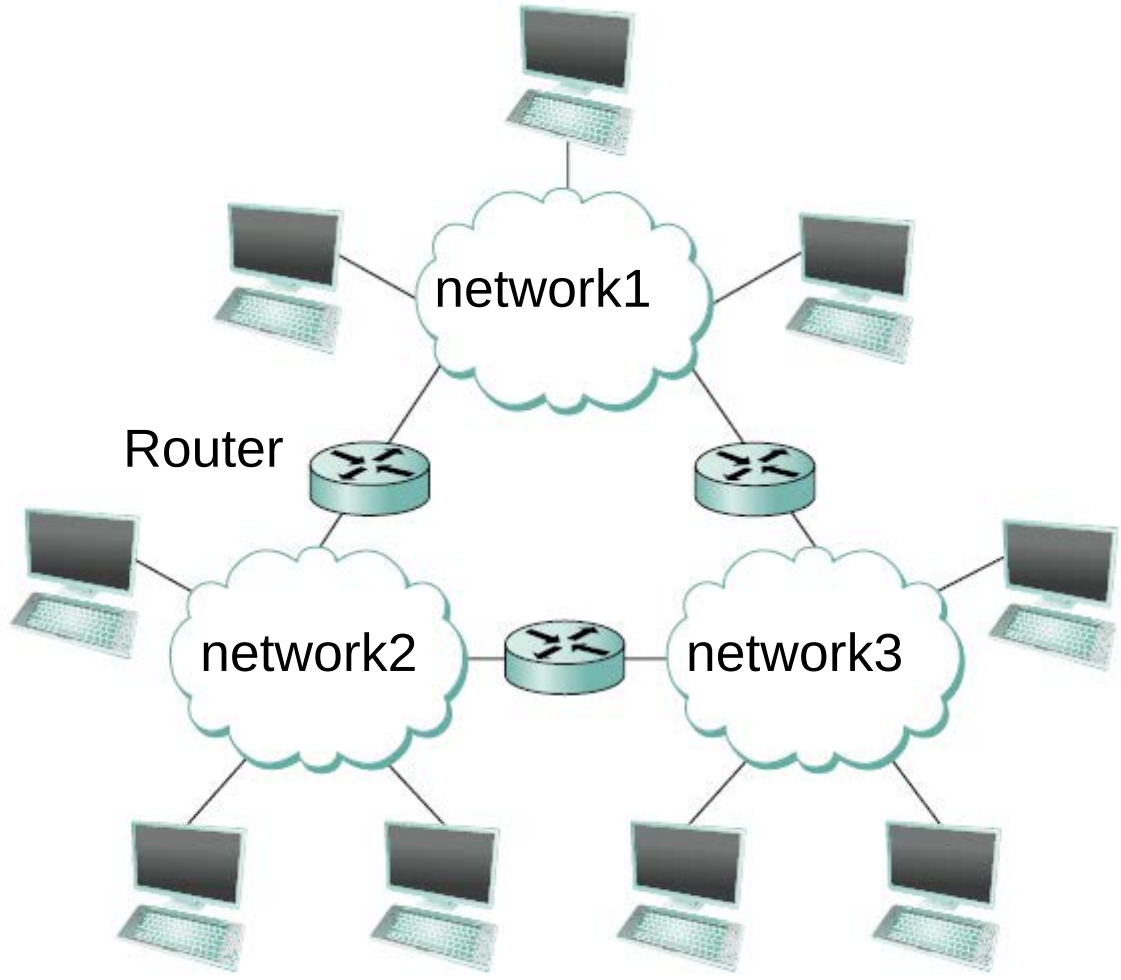
- Case 1: Sending 150MB file at once
- Case 2: Sending 1.5kB x 100,000 packets

- Pros: What happens if there is a 1-bit error in 150MB file?
  - Case 1 vs. Case 2
- Cons: Header overhead?



Internetwork

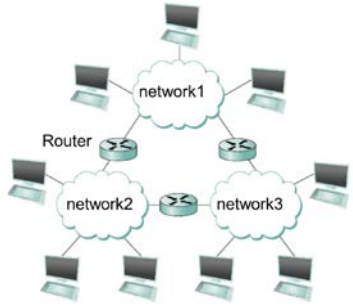
- inter-network (or internet)
  - Network of networks
  - Smaller networks are interconnected by ***routers*** (or gateways)
- Finding path to destination (***Routing***)
  - Identify destination address
  - Switches/routers find path to destination

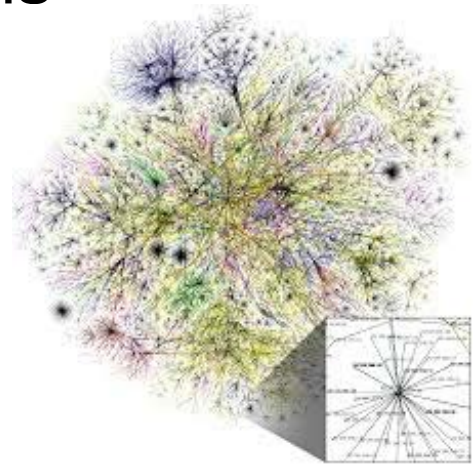


Routers and Routing

- **Router**
  - Connect networks
  - Forward/route packets

- **Routing** (done by routers)
  - Finding path from source to destination
  - Very interesting algorithms
    - Link-state, Dijkstra, …

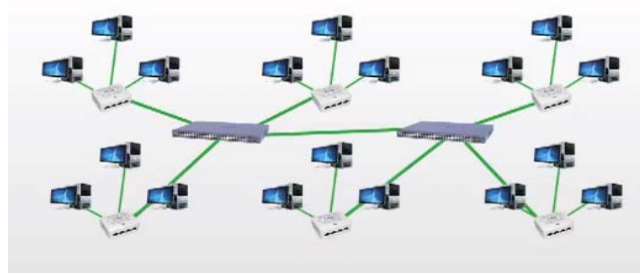




Important Definitions

- **Network**: A group of connected, communicating devices such as computers

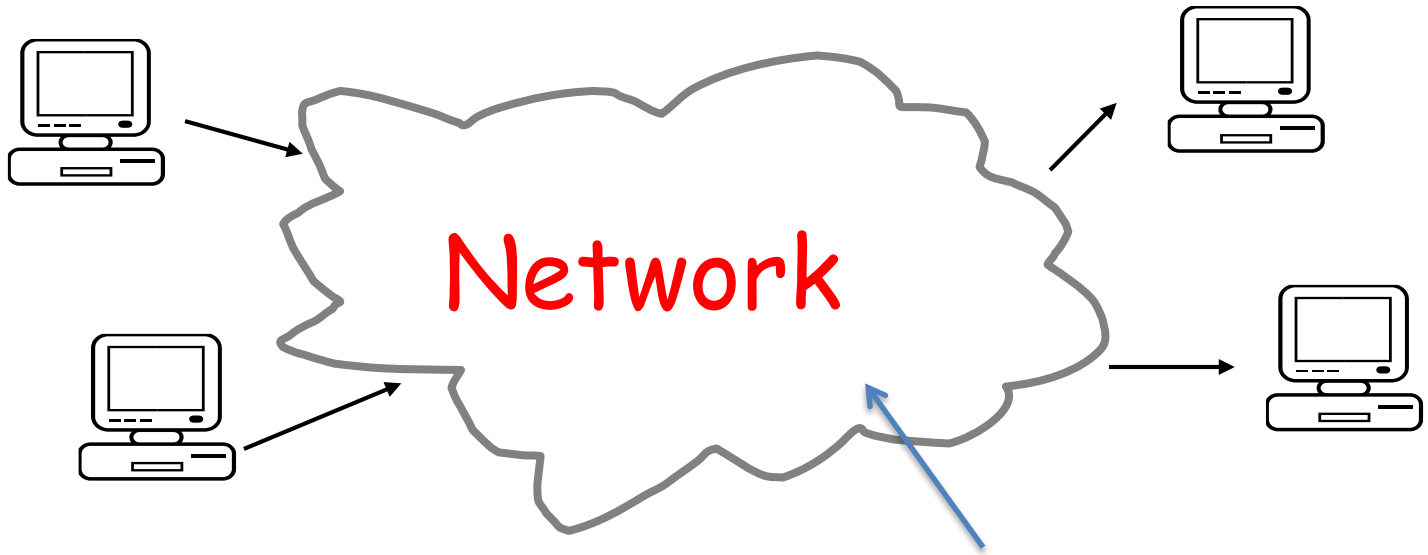
- **internet** (inter+network): It is two or more networks that can communicate with each other. Network of networks.



- **Internet**: It is a type of internet and is composed of hundreds of thousands of interconnected networks

Computer Network

- Network's Goal: **Universal Communication** (any to any)
- "Networking"
  - the processes involved in designing, implementing, managing and other working with networks and network technologies

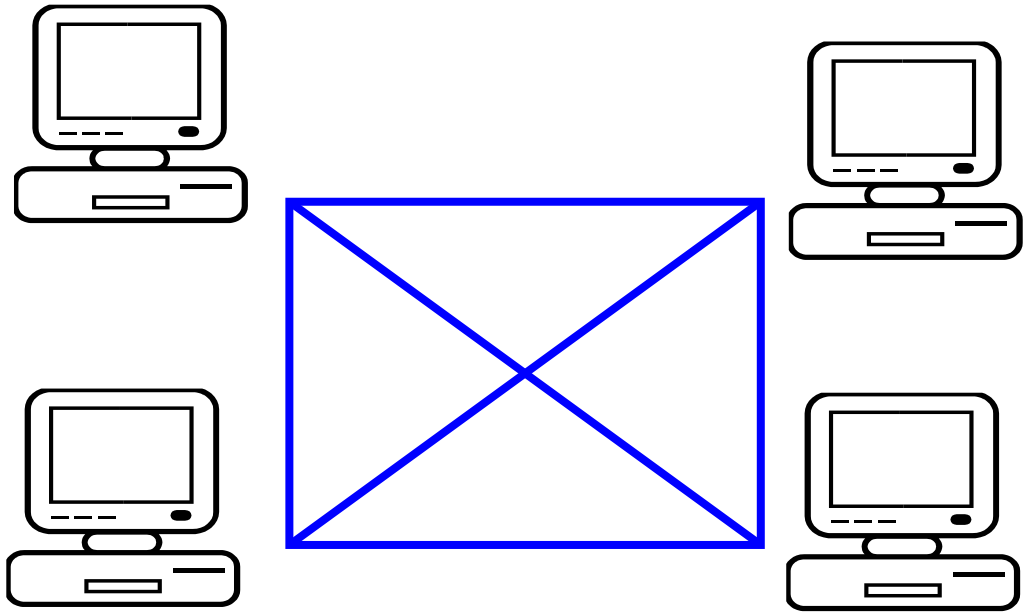


How to design the "cloud" to realize "any-to-any" communication ?

Any-to-Any Connectivity

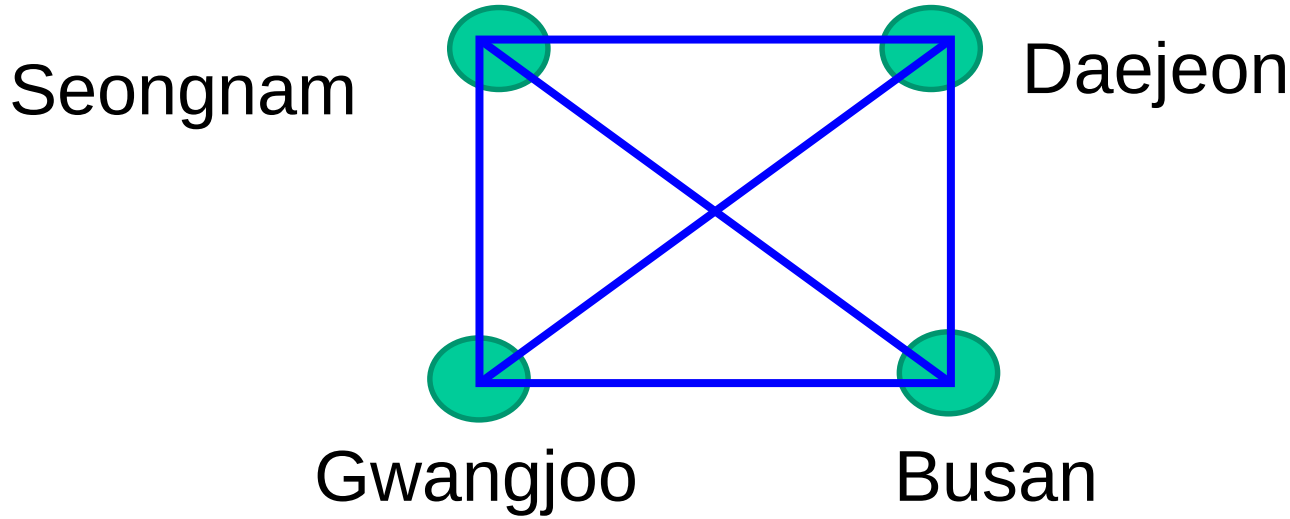
- If there are N devices, how many links are required ?
- A mesh requires (N-1)*(N-2)➔O(N^2) links ??

→ too costly



Analogy (비유)

- Transportation (교통) network
  - Goal: any-to-any connectivity
    - Need to get to a place wherever you want to go
    - E.g. from Seongnam to Busan, Daejeon
  - For N cities; need transportation roads (links) of O(N^2) ?

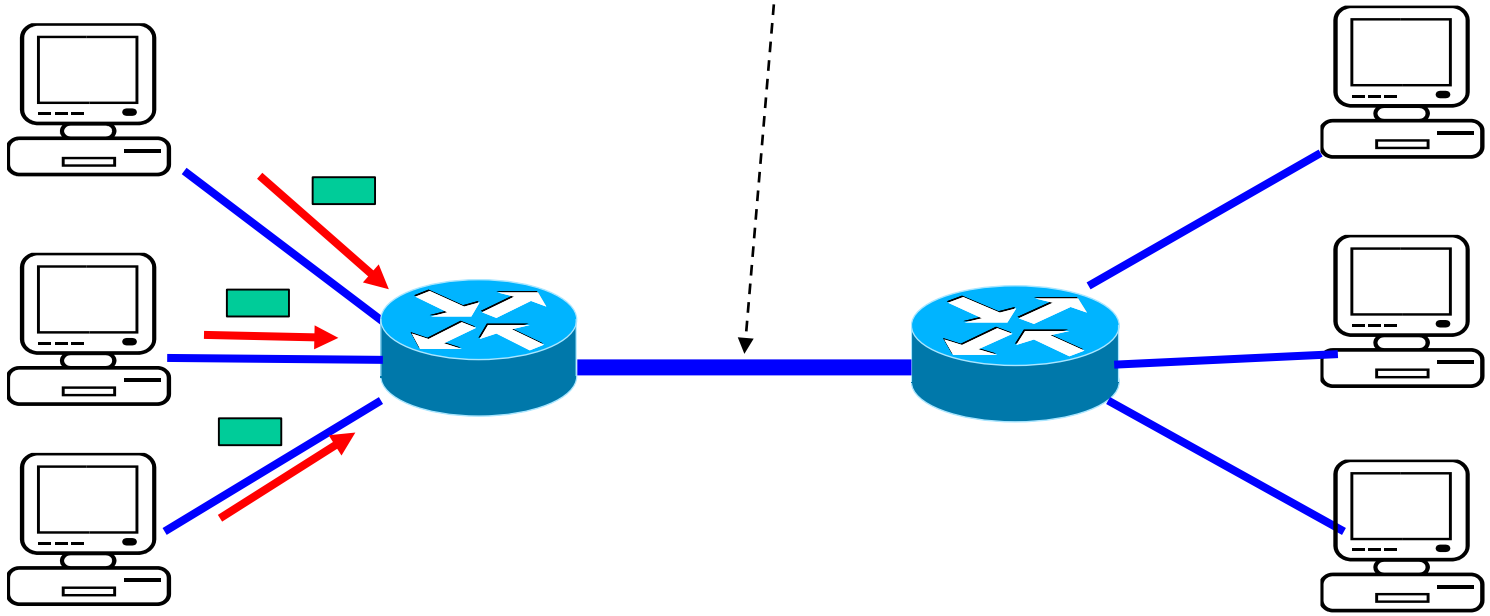


No!

- Transportation network has a hierarchical architecture and shares infrastructures
  - National-wide Expressway, (state) highway roads, local roads, …

Any-to-Any Connectivity: **Share** the **Infrastructure**

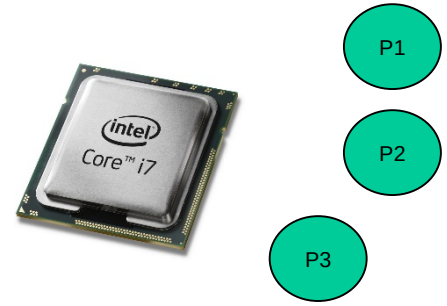
- Intermediate nodes called **switches** or **routers** allow the hosts to share the infrastructure



How to share ?

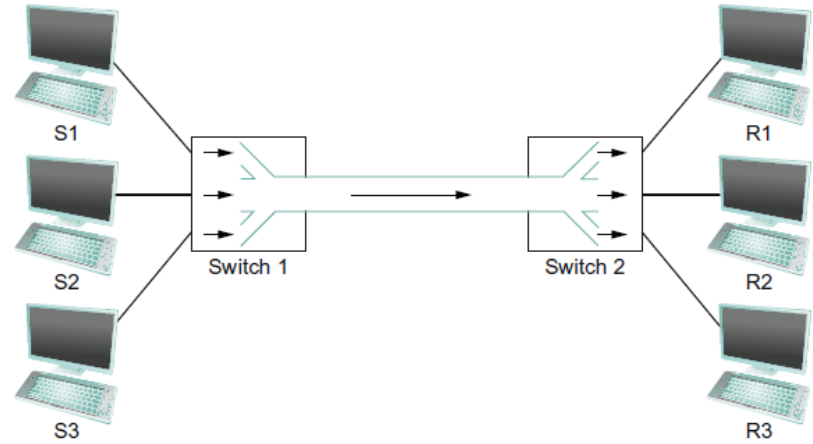
→ Multiplexing

Multiplexing



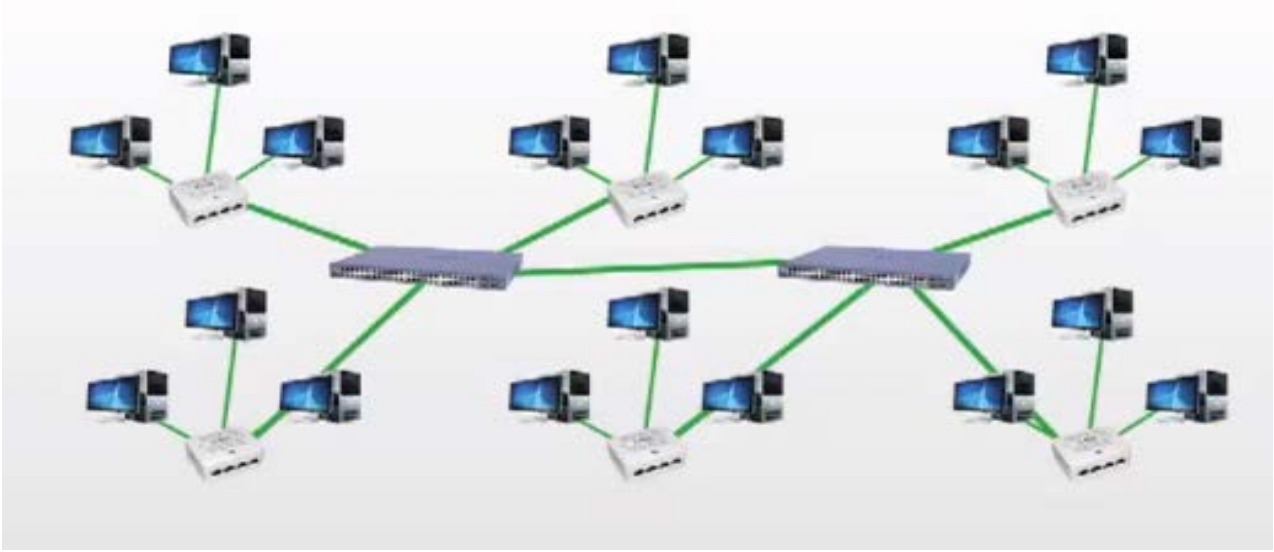
- Recall Operating Systems
  - Timesharing computer system
  - The CPU resource is shared (**multiplexed**) among multiple jobs (processes)

- The data from S1, S2, S3 are **multiplexed** onto a single link

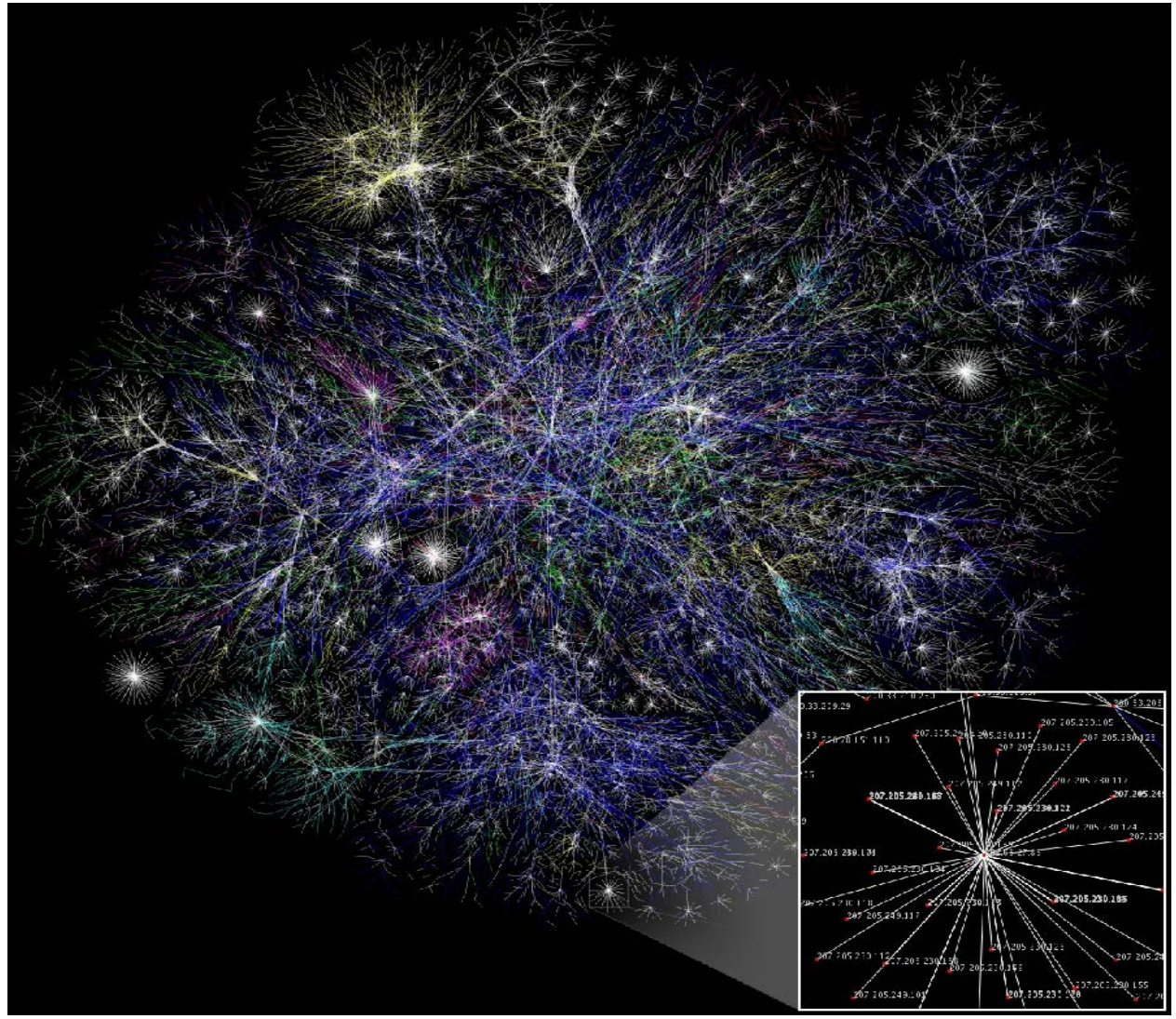


- TDM (Time Division **Multiplexing**)
  - Divide resource into time

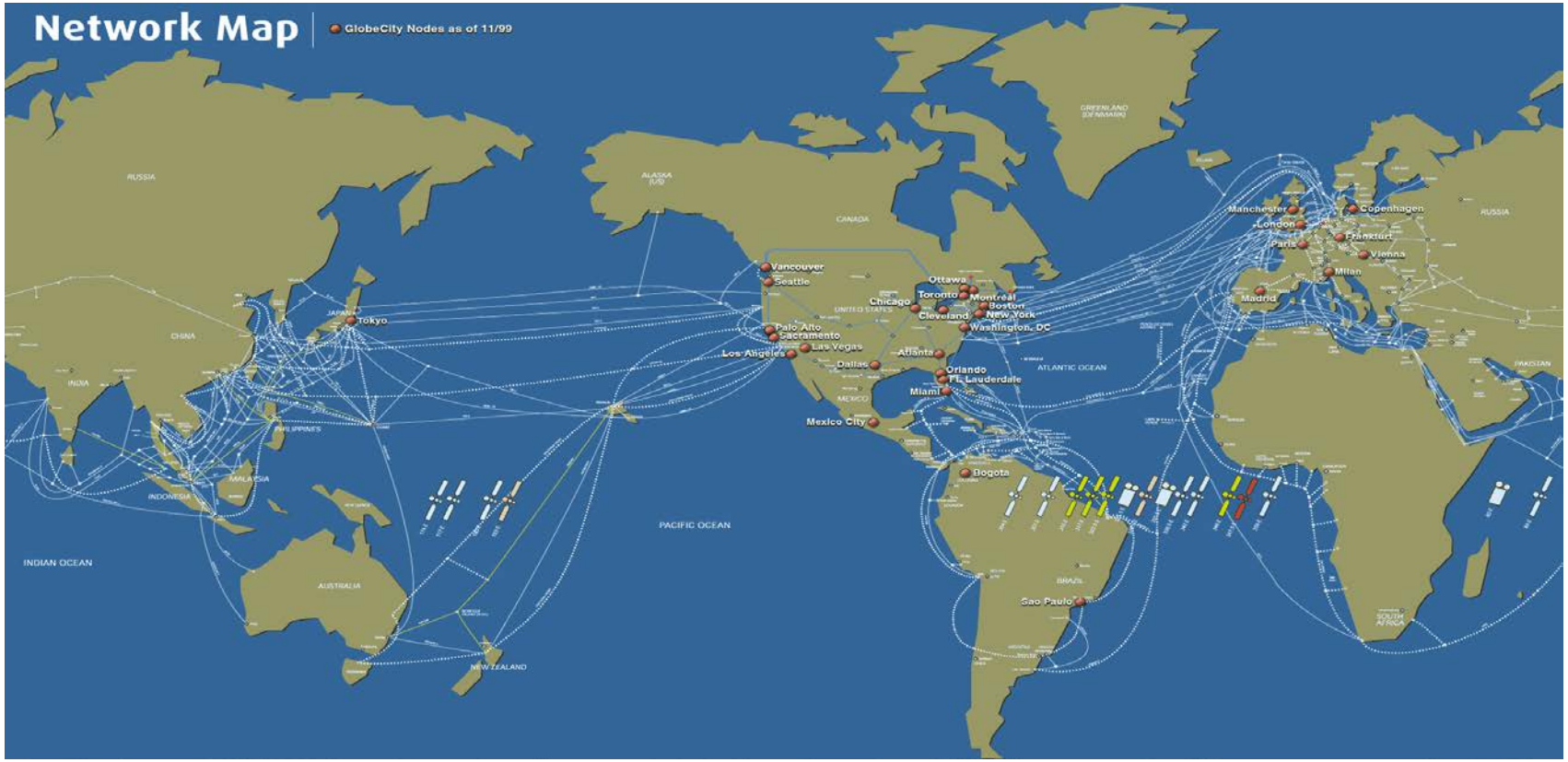
The Big Picture of Internet Architecture



Internet



Internet Backbone



What's the Internet: Nuts-and-Bolts view

PC

server

wireless laptop

smartphone

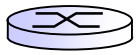
- billions of connected computing devices:
  - ***hosts*** = *end systems* (=단말)
  - running *network apps*
  - *End systems* are connected by…

wireless links

wired links

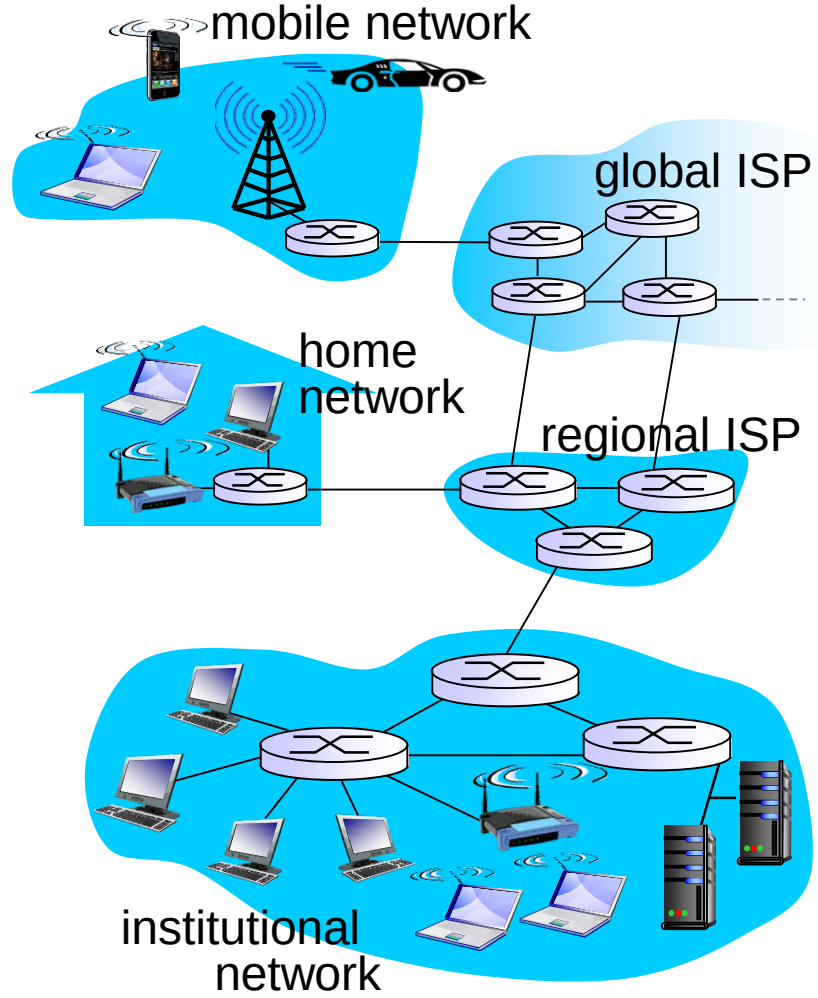
선으로된 link는 없지만 무선 link를 통해 전달

- *Communication **links***
  - fiber, copper(구리), radio, satellite
  - transmission rate (bit/s): *bandwidth*



router

- *Routers:* connects networks, forward **packets** (chunks of data)



radio link

“Fun” Internet-connected devices

IP picture frame
http://www.ceiva.com/

Web-enabled toaster +
weather forecaster

Tweet-a-watt:
monitor energy use

Internet
refrigerator

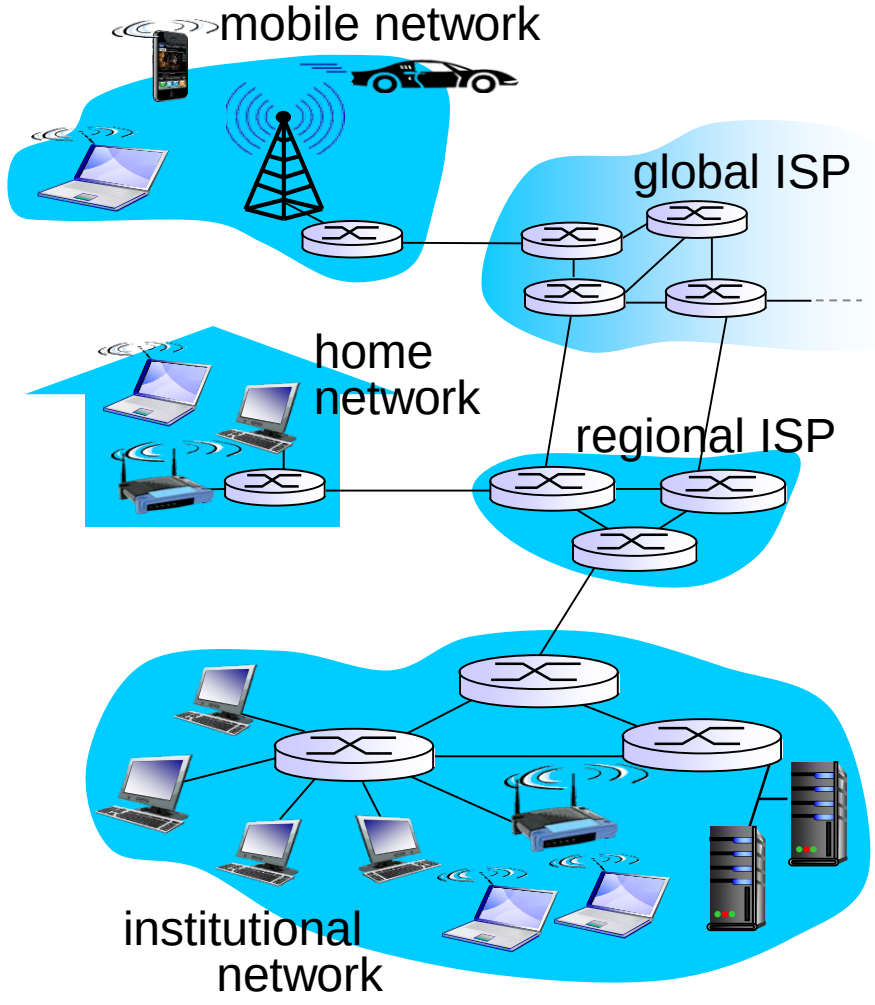
Slingbox: watch,
control cable TV remotely

sensorized,
bed
mattress

Internet phones

What's the Internet: "nuts and bolts" view

- *Internet:* "network of networks"
- *protocols* control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, Skype, 802.11
- *Internet standards*
  - RFC Standards are developed by IETF
    - IETF: Internet Engineering Task Force
    - RFC: Request for comments



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

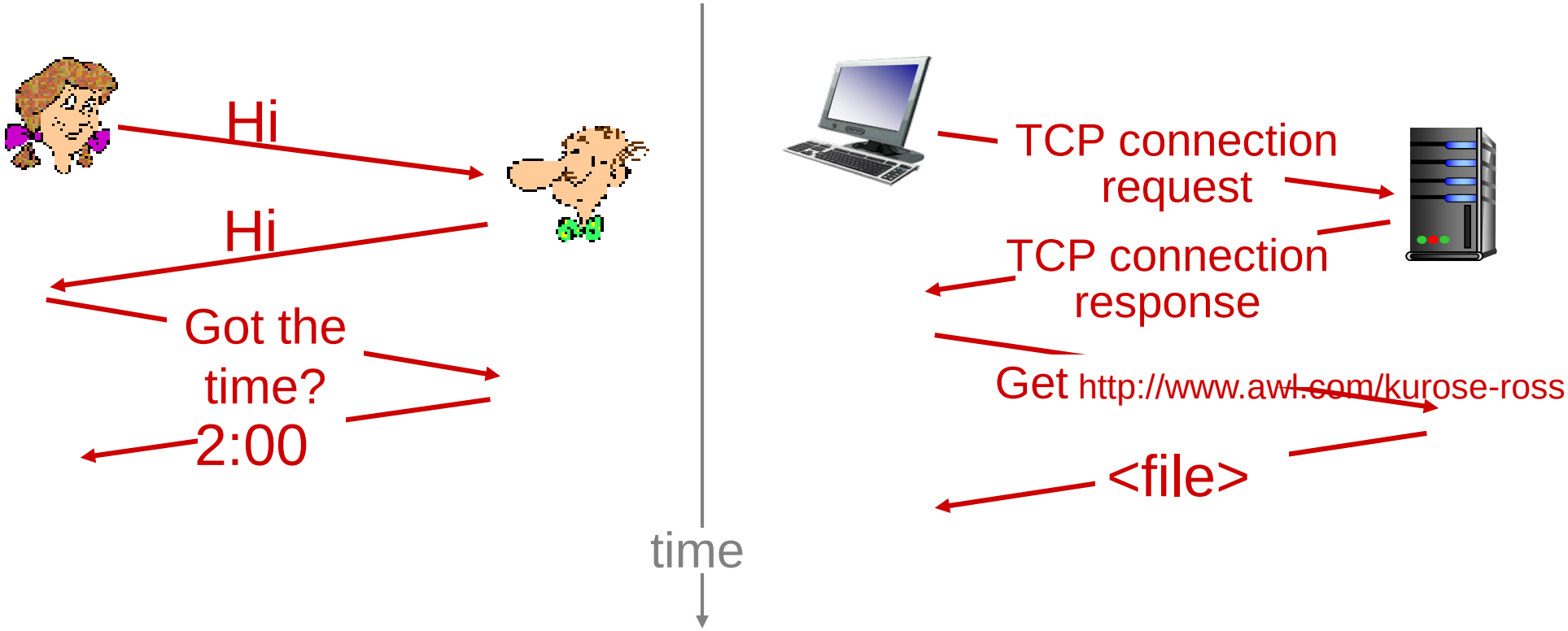
network protocols:

- 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:



Chapter 1: roadmap

1.1 what *is* the Internet?

1.2 network edge

- end systems, access networks, links

1.3 network core

- packet switching, circuit switching, network structure

1.4 delay, loss, throughput in networks

1.5 protocol layers, service models

Network Applications

- Reliable byte stream communication between applications
  - How do we provide communication? – Network Layering

Example: E-commerce

Application-layer communication

Apps. rely on underlying layers for their reliable communication

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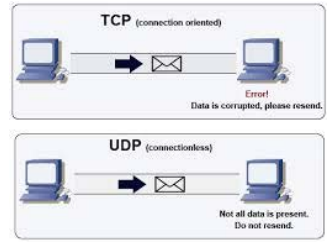
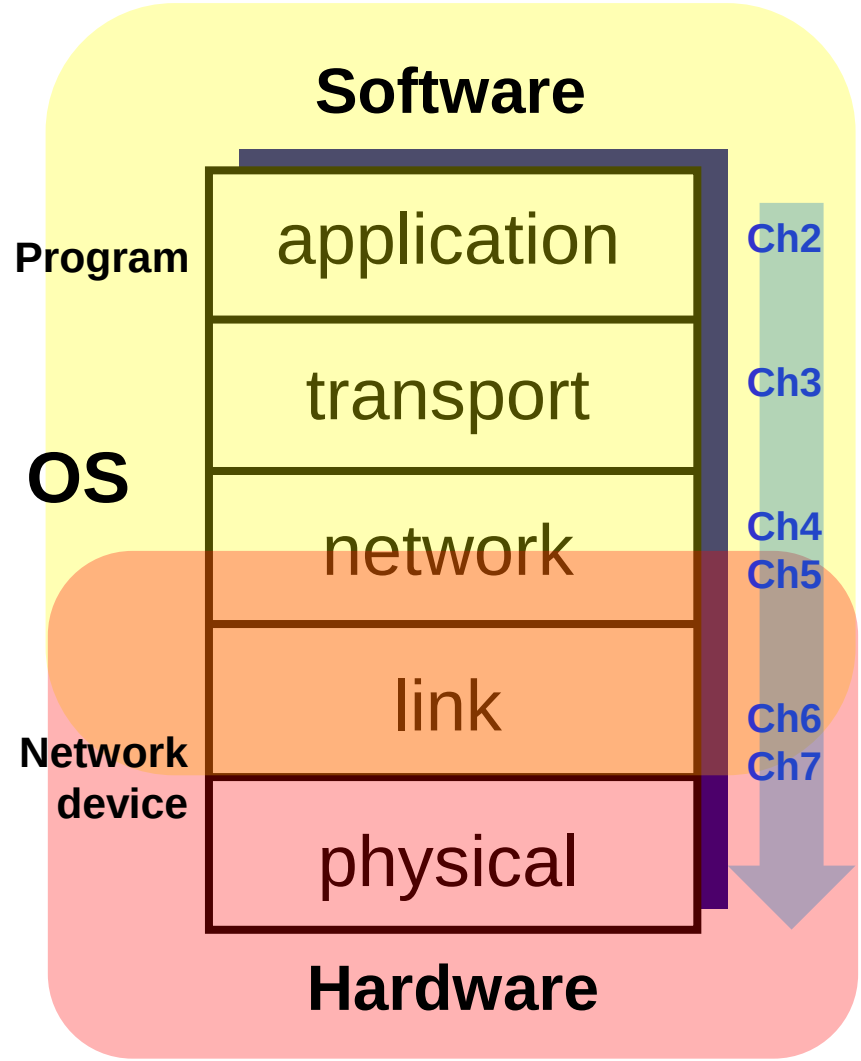
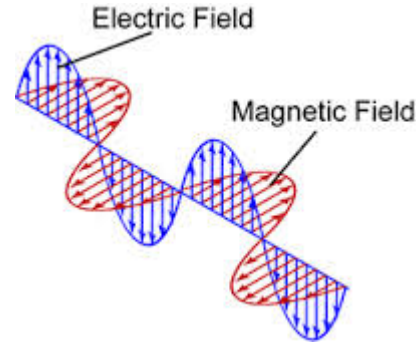
Internet protocol stack

- *application:* supporting various network applications
  - HTTP, SMTP, FTP, DNS
- *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)
- *physical:* bits "on the wire"

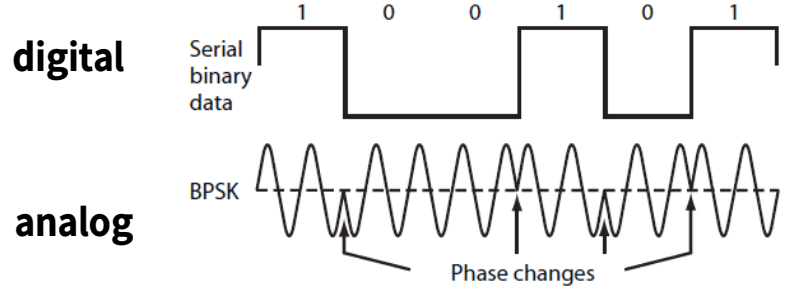




Physical Layer (PHY)



- Computer: Digital data (0101…)
- Link (Ethernet, Wi-Fi, LTE, …): Analog signals – electromagnetic waves
- Digital → Analog: **Modulation**
  - Data rate (Mbps)…



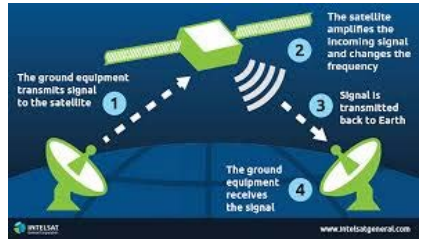
- Analog → Digital : **Demodulation**
  - **MODEM**: Modulation + Demodulation

Physical media

전파하다

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media (wired):
  - signals propagate in solid media: copper, fiber, coax (동축)
- unguided media (wireless):
  - signals propagate freely, e.g., radio

위성 통신은 신호가 왔다갔다 해서 지연이 길. 저궤도 위성은 사용할만 하다.



twisted pair (TP): LAN cable

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

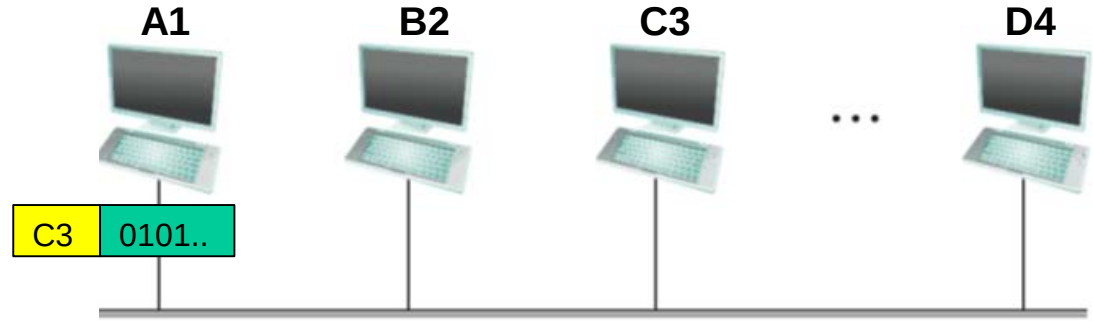
radio (무선) link types:

- WLAN (e.g., WiFi)
  - 54 Mbps ~ 3Gbps
- wide-area (e.g., cellular)
  - 3G cellular: ~ few Mbps
  - 4G LTE: ~ 1000 Mbps
- satellite (e.g., TV broadcast)
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay

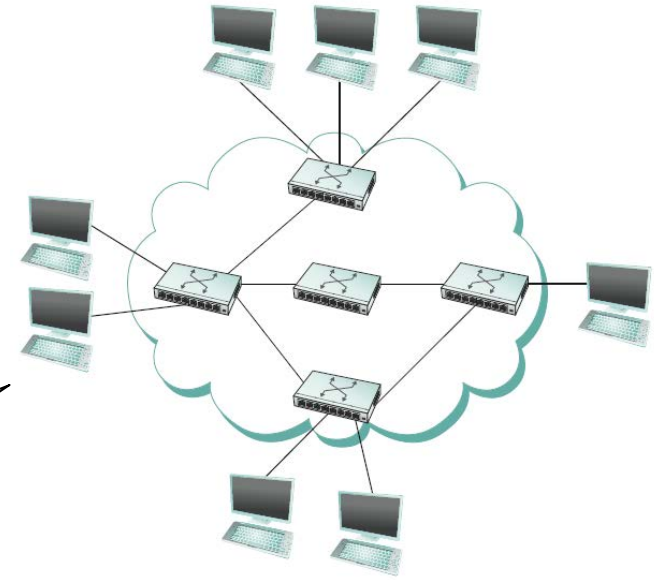
Link Layer (LL or MAC)

(Physical, LAN)

- **MAC address** (48-bit)
  - Address for device-to-device communication
  - E.g., “A1:23:41:C6:45”
- Data transfer between *neighboring* network devices
- Switching, Error correction, Multiple Access, …



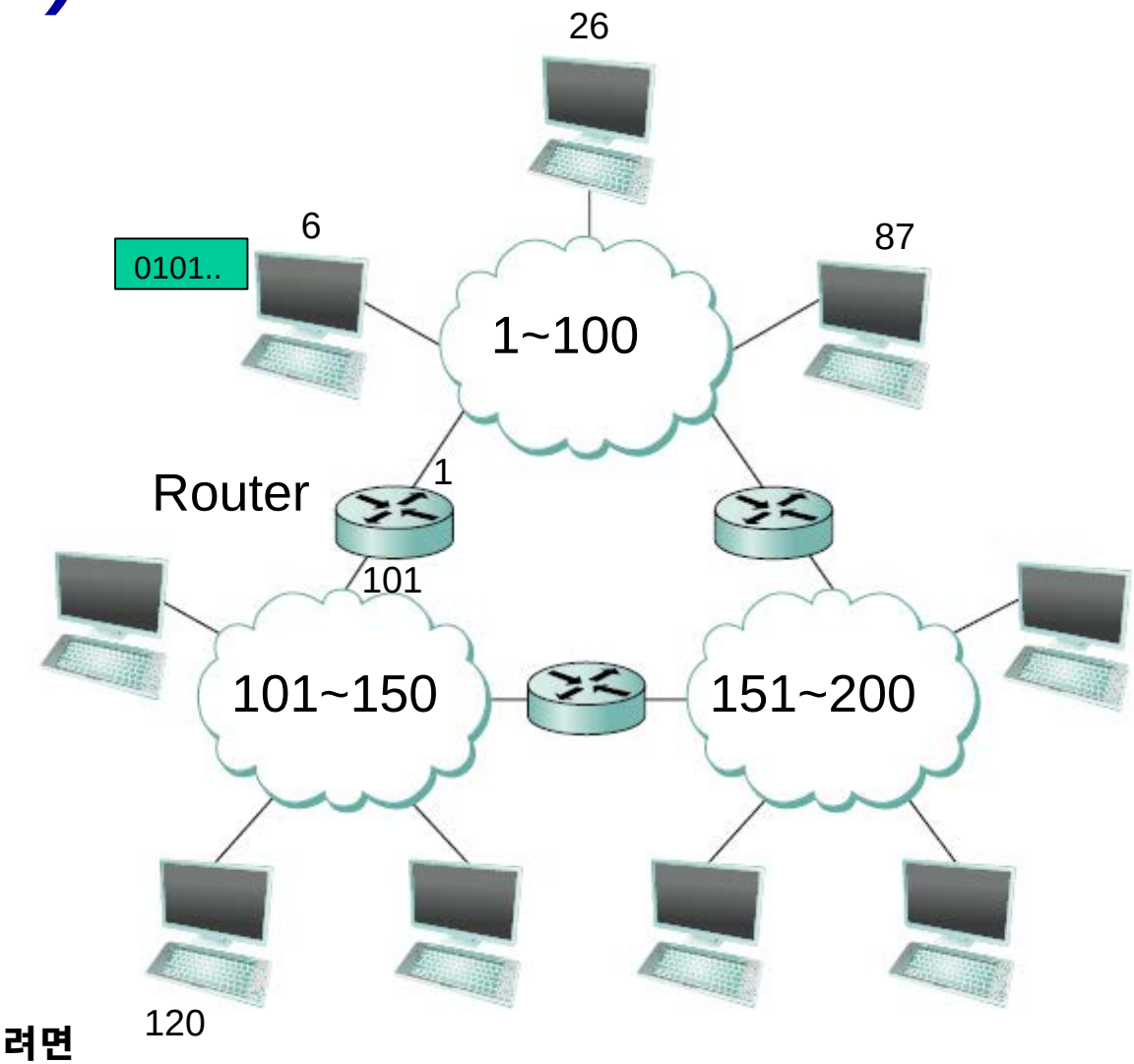
이 이웃 사이에 보내고자 하는 데이터를
보내기 위해선 mac address가 필요



Broadcast
(*opp.* Unicast?)

Network Layer (IP)

- **IP address** (32-bit)
  - Global address
  - E.g., “169.34.11.56”
- **Routing**
  - Done by router
  - Finding path for packet to destination
- Questions
  - Did “120” receive the packet or not?
  - How can we check?

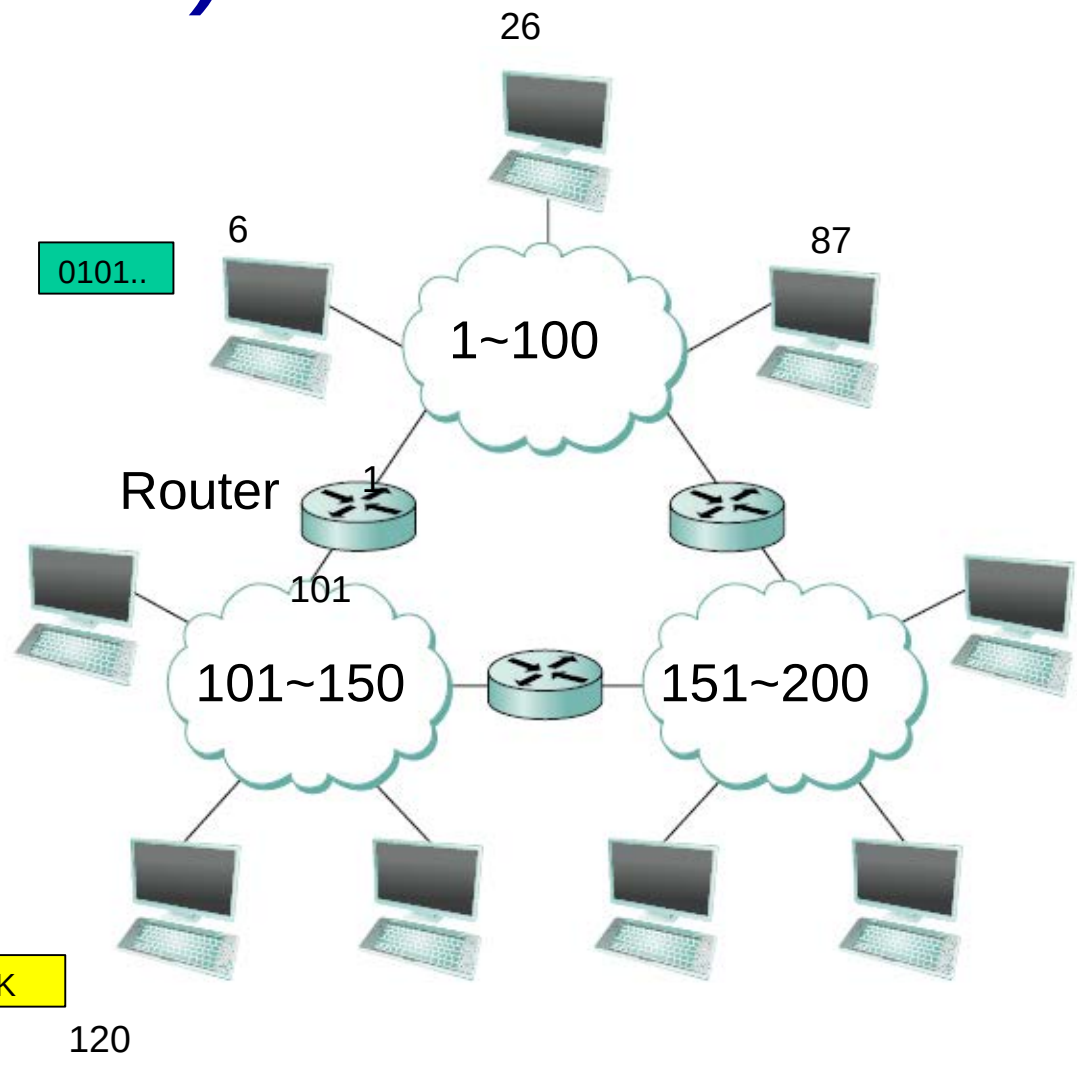


6번이 데이터를 보내고자 할 때 제대로 도착했는지 확인하려면
데이터 잘 받았다고 알려줌, 만약에 데이터 전송이 느리고 잘 받았다고 한 시점이 빠르면..

Transport Layer (TCP)

- TCP **Reliability**
  - Data/ACK
  - No ACK? - Retransmission

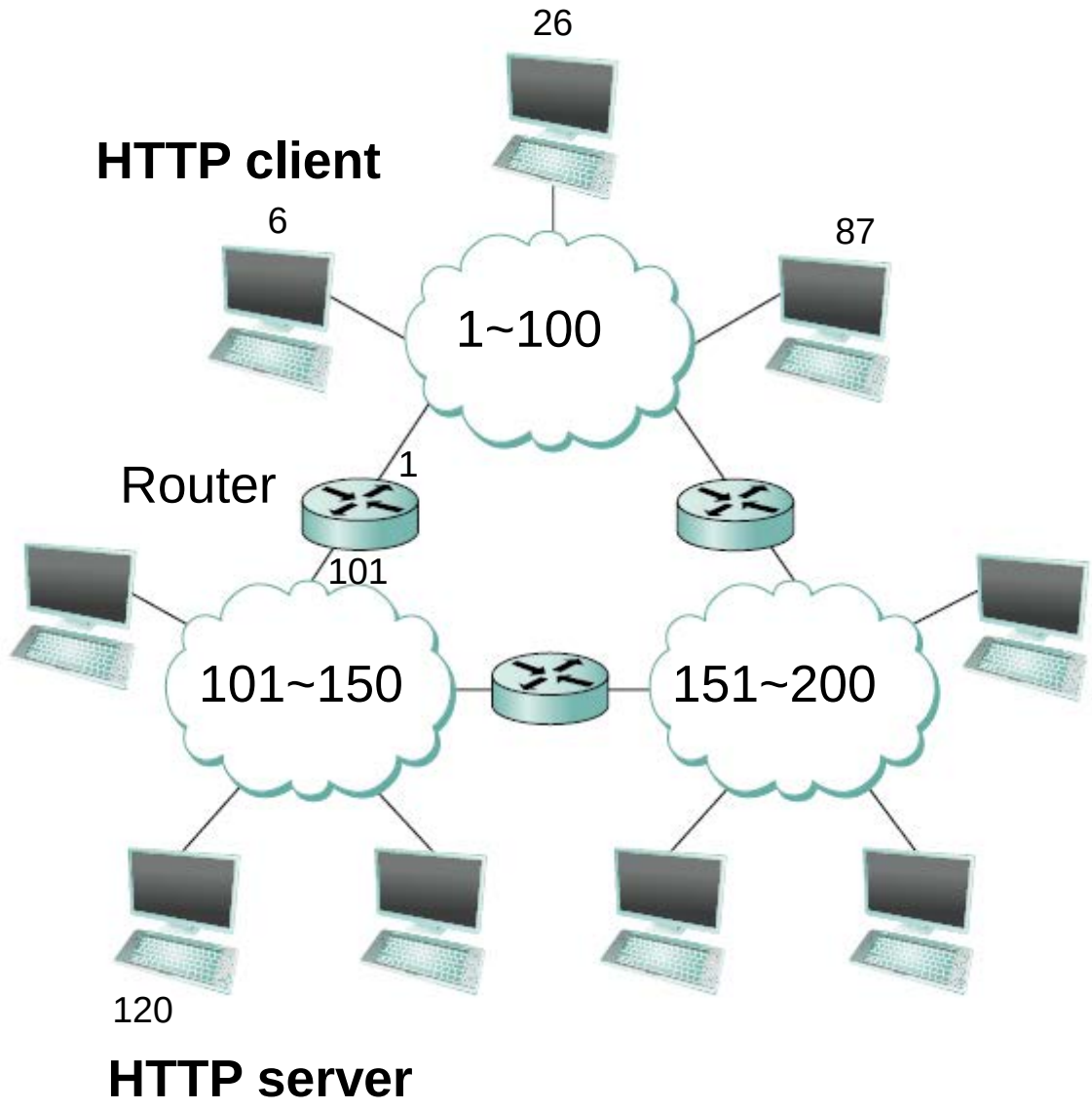
- TCP **Congestion control**
  - If too many end hosts transmit then router buffer overflow (congestion) may happen
  - Prevent too many end hosts transmitting at the same time



TCP reliability, TCP congestion control 매우 중요함
네트워크가 널널하면 최대한 빨리 보냄. traffic이 많으면 양보하면서 사용. 인터넷 사용할때마다 회선을 잡아주는건 지금은 인터넷 사용하는 사람이 많아서 안됨. utilization x

Application Layer

- Various networking applications have different needs
  - **HTTP**: request for Web page from Web server
  - **POP3**: retrieve E-mail from Mail server
  - **DNS**: translate domain name into IP address
- Various Application Layer Protocols



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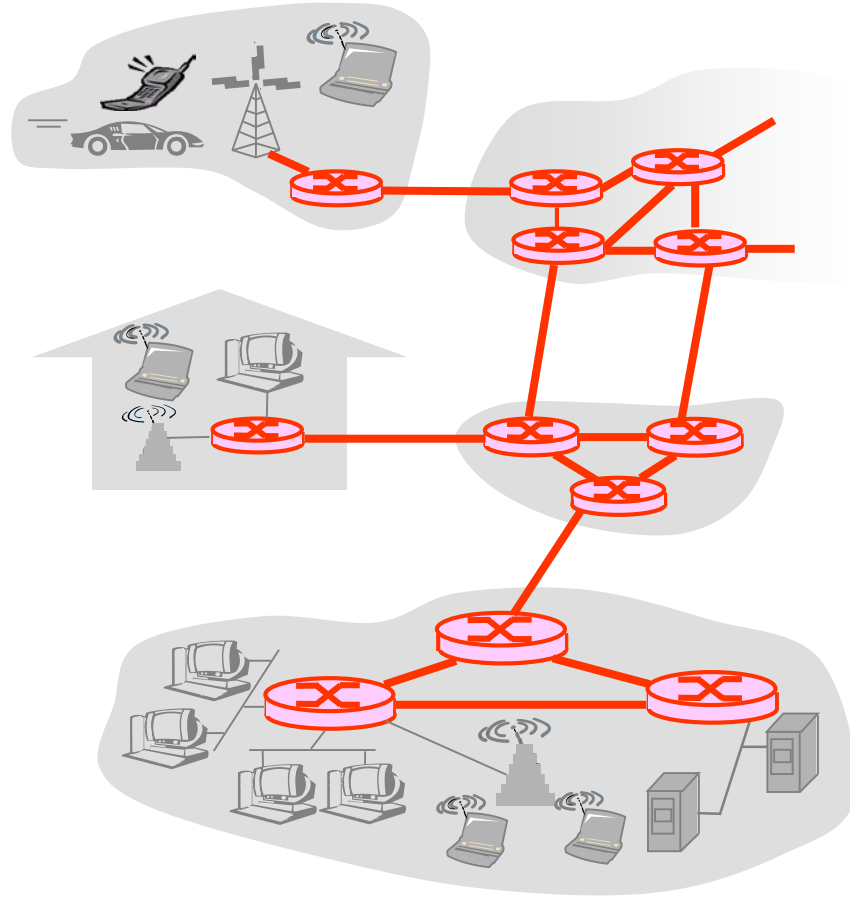
The Network Core

- mesh of interconnected routers
  - "Share the infrastructure" (recall)

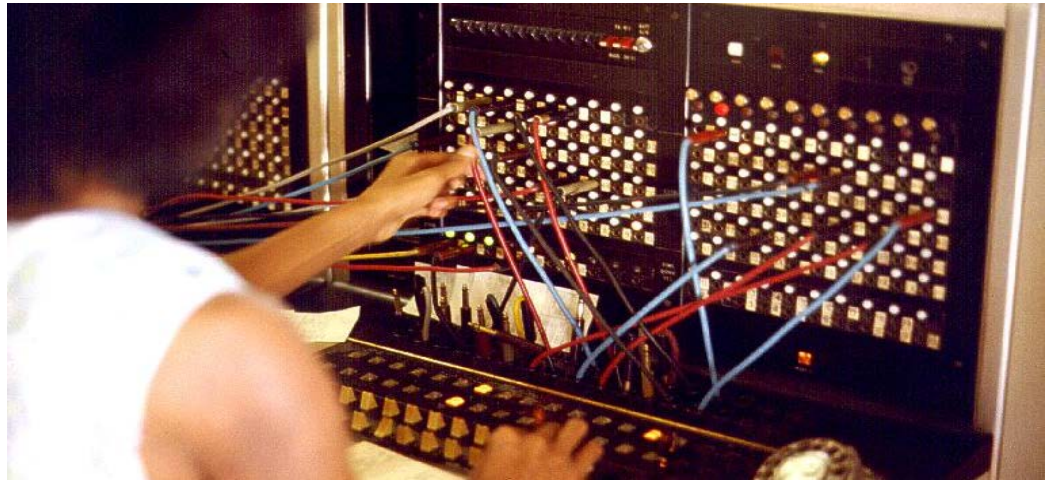
- fundamental question:
  - **How is data transferred through network?**



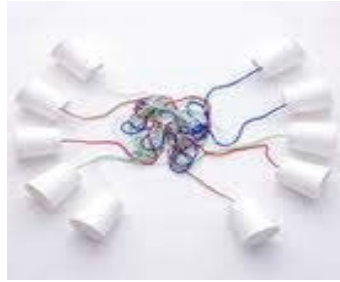
Two ways to share

- Circuit switching (회선교환) – Telephone line
- Packet switching (패킷교환) – Internet line

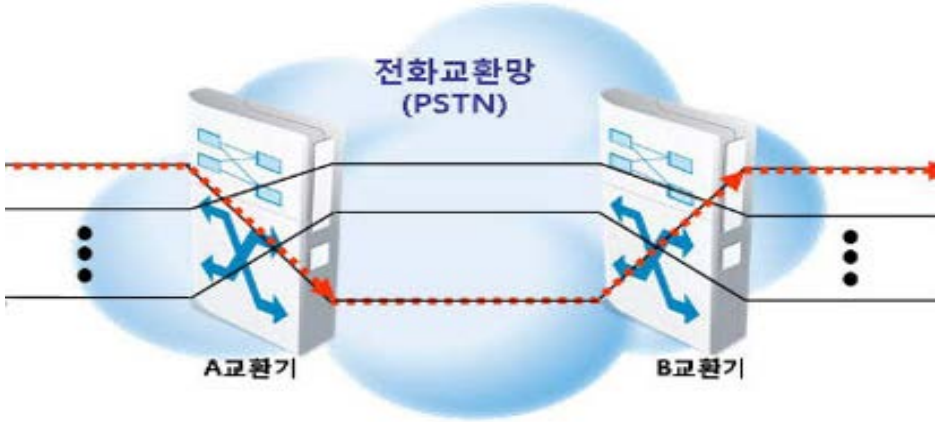
Example



Early Telephone network

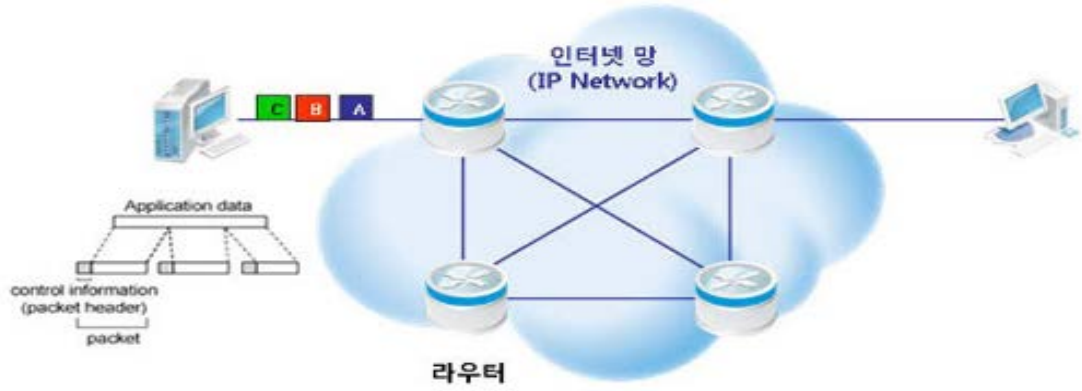


Example



Telephone

versus



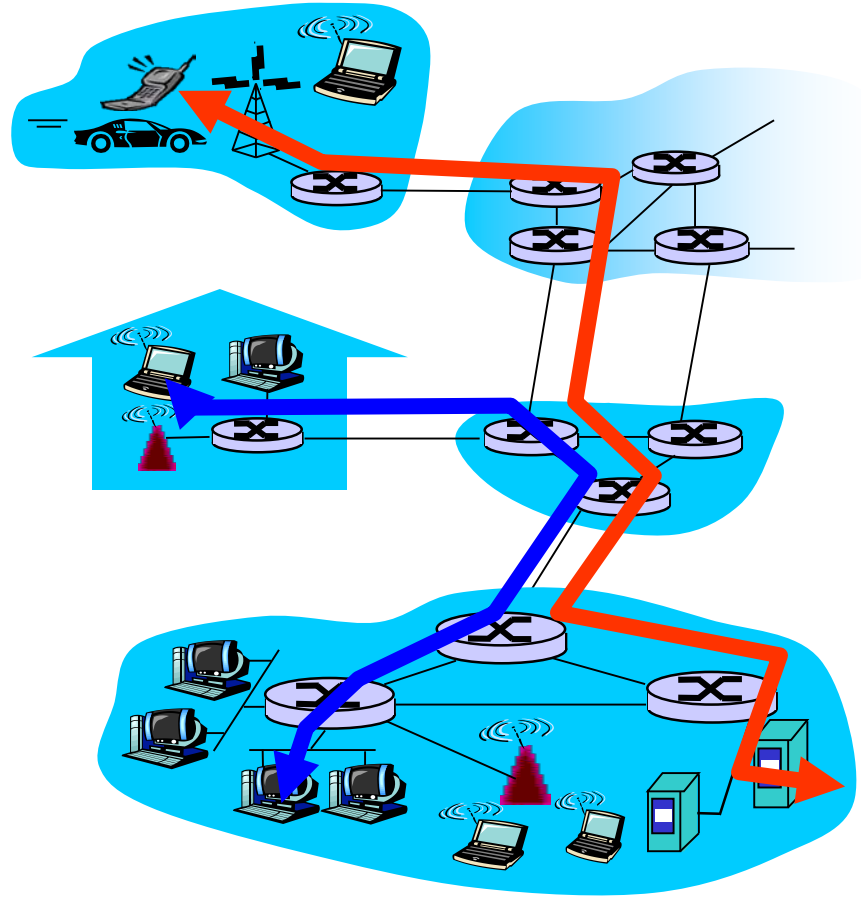
VoIP

Network Core: Circuit Switching

End-end resources **reserved** for "a call"

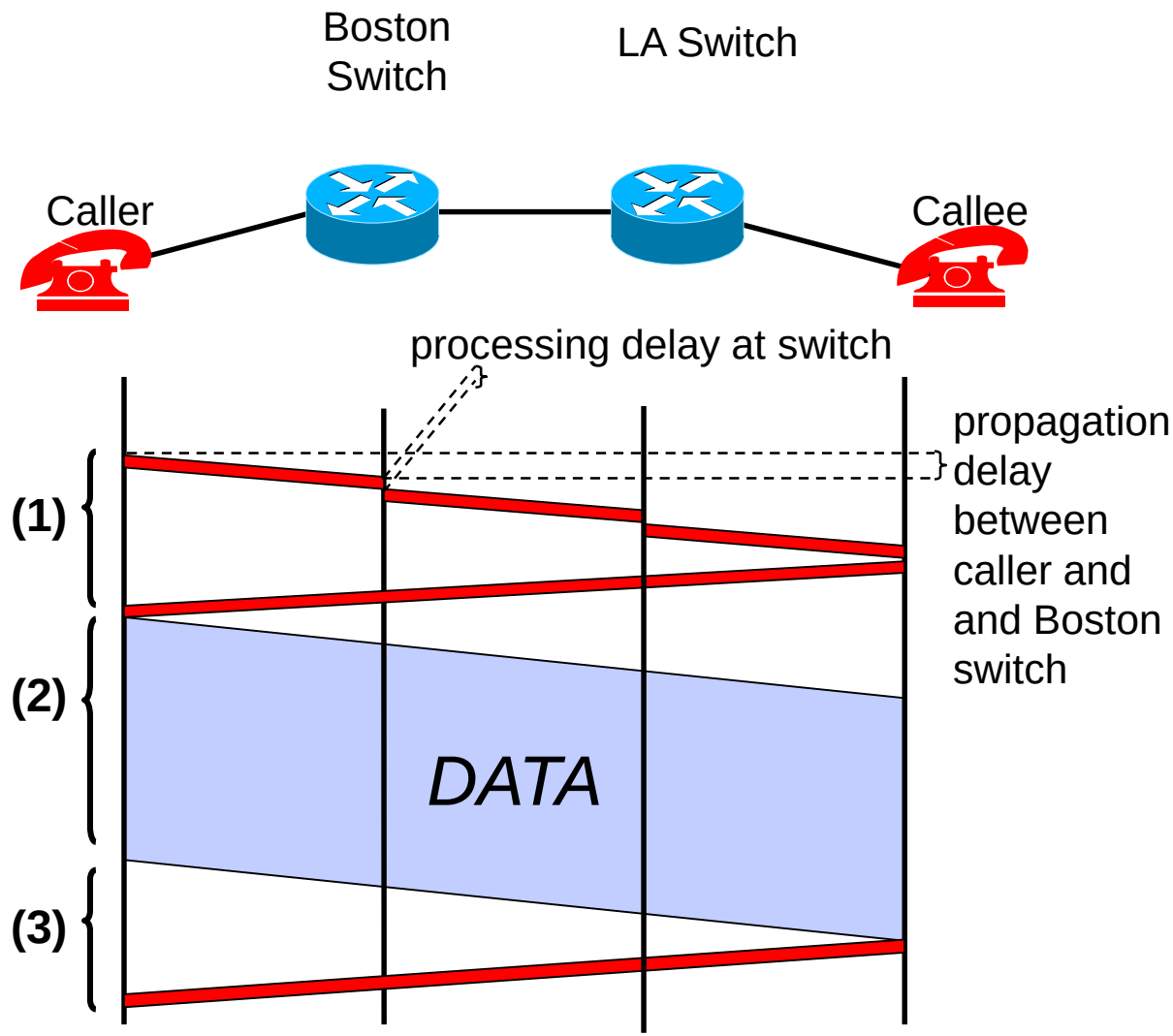
전용의

- a dedicated end-to-end connection
- call setup required
  - Before communication, the network must first reserve one circuit
- Also, disconnect phase required



Telephone Network – Circuit Switching

- the method used by the telephone network
- A call has three phases:
  1. Establish circuit from end-to-end (“dialing”),
  2. Communicate,
  3. Close circuit (“tear down”).
- If circuit not available: “busy signal” (통화중)



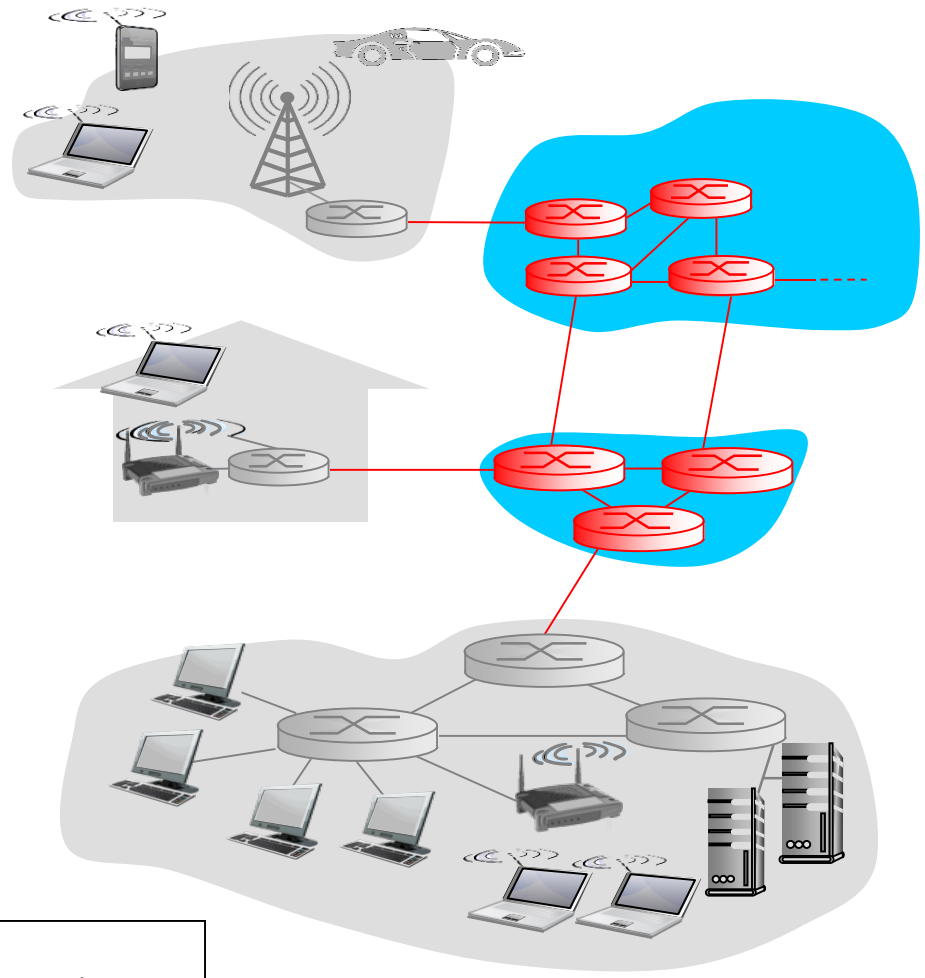
Pros. & Cons. of Circuit switching

- Advantage
  - Circuit is dedicated to the call : no interference, no sharing → guaranteed service
- Disadvantage
  - **Inefficient** – the equipment may be unused for a lot of the call, if no data is being sent, the dedicated line still remains open
  - Takes a relatively long time to set up the circuit
  - It was primarily developed for voice traffic rather than data traffic

Network Core: Packet Switching

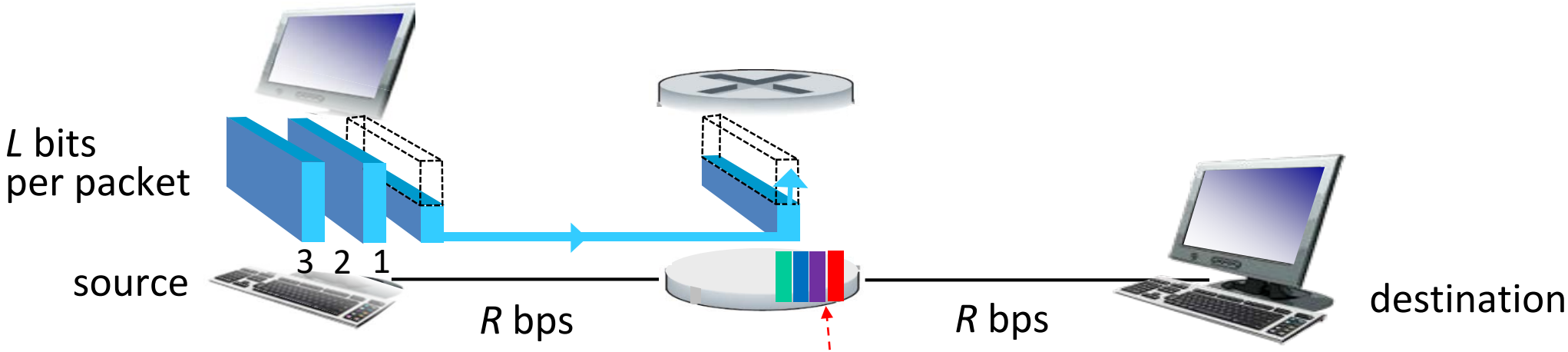
Each end-end data stream divided into ***packets***

- the message gets broken into small data packets
  - E.g., the maximum length of a TCP packet is 1500KByte
- each packet travels around the network seeking out the most efficient route to the destination
  - A link is shared by multiple users
  - No Dedicated allocation, No reservation for the path (links) from source to destination



- *Packet arrives at router:*
  - *(i) If output link is available then send to next router*
  - *(ii) If output link is busy then wait (in router buffer)*

Packet-switching: store-and-forward



- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
  - Need *Buffering*
- takes *L*/*R* seconds to transmit (push out) *L*-bit packet into link at *R* bps
- end-end delay = 2*L*/*R* (assuming zero propagation delay)

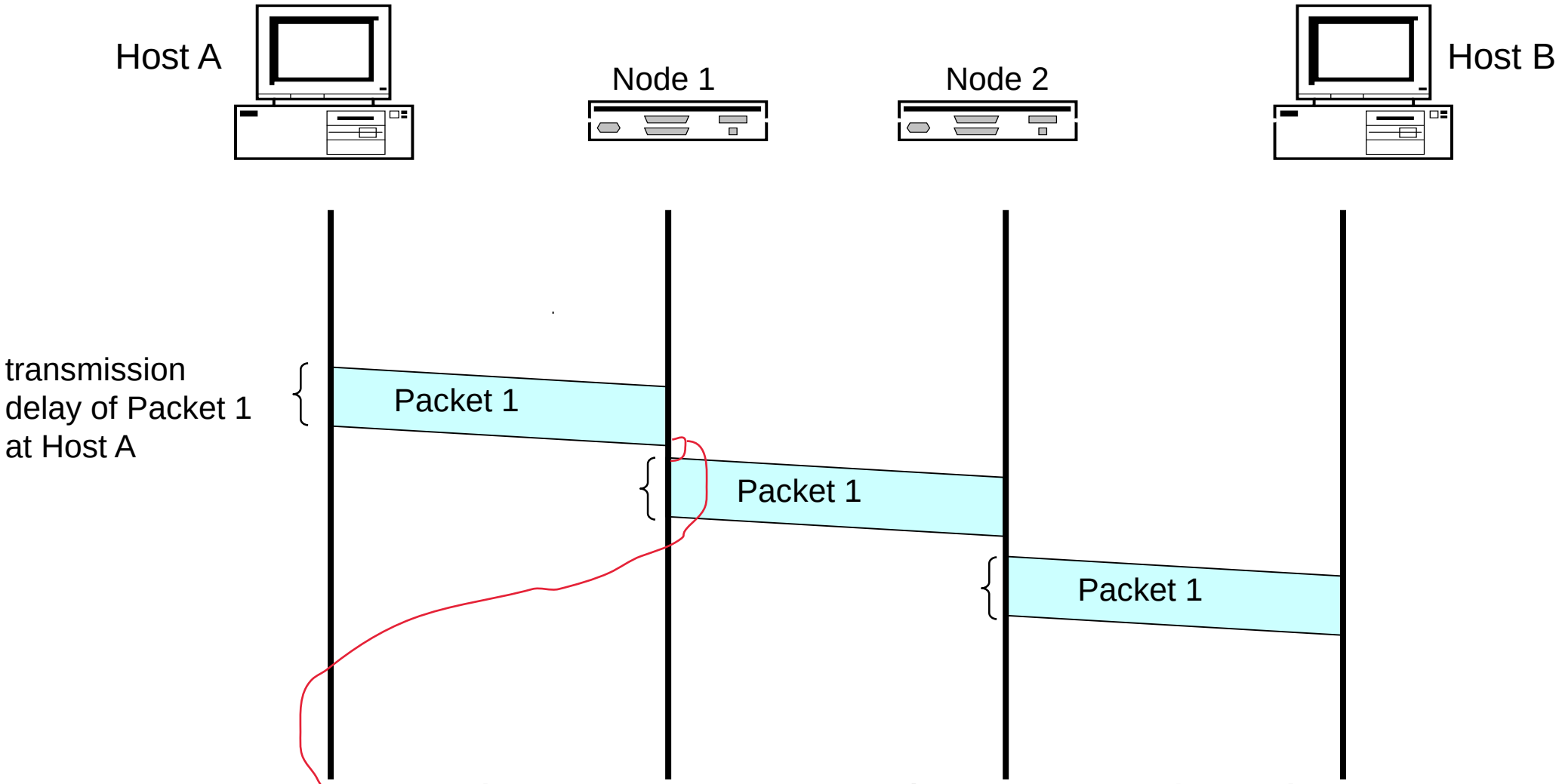
2개의 링크이기 때문에

one-hop numerical example:

- *L* = 7.5 Mbits
- *R* = 1.5 Mbps
- one-hop transmission delay = 5 sec

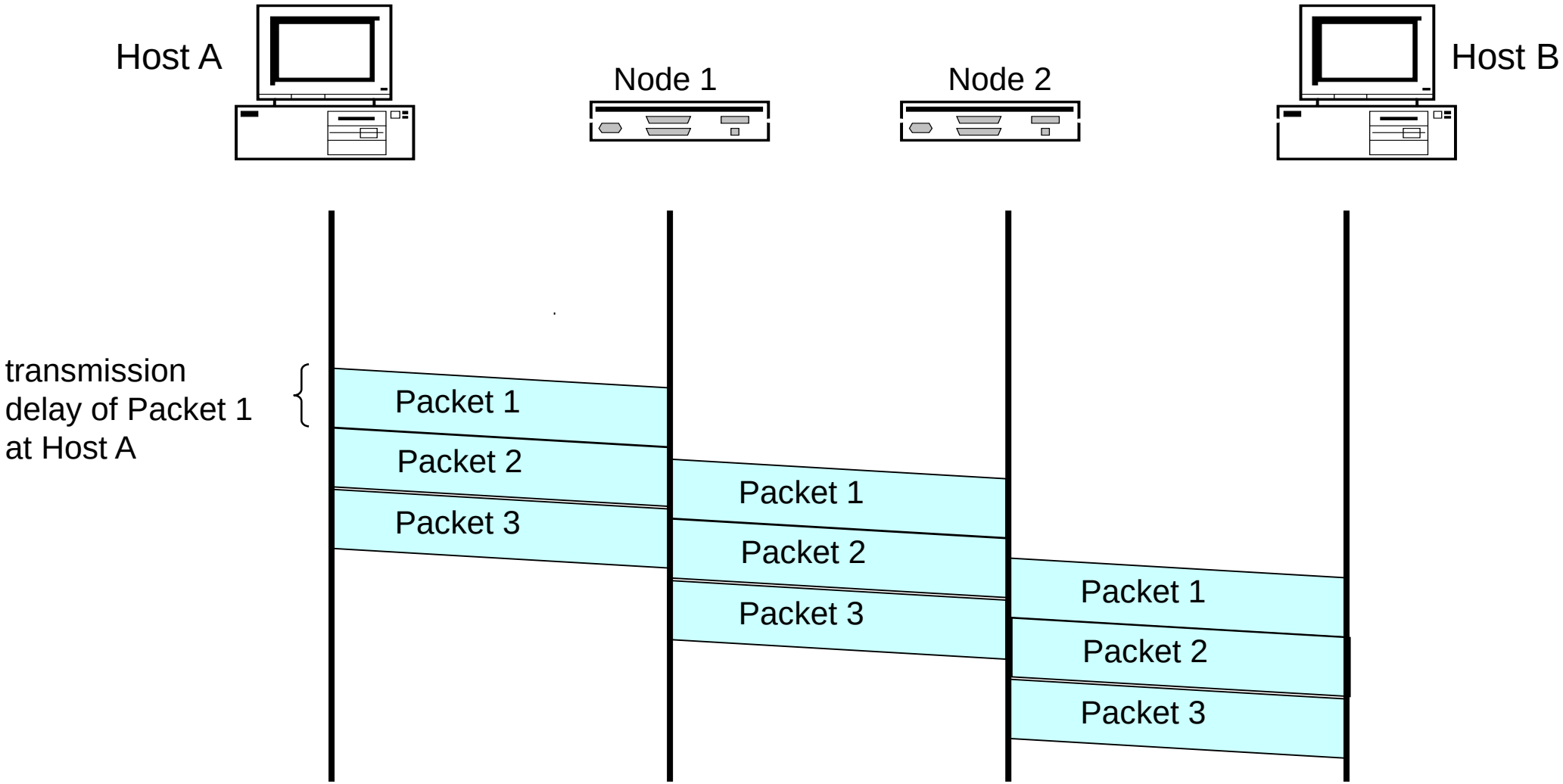
more on delay shortly …

Timing Diagram of Packet Switching

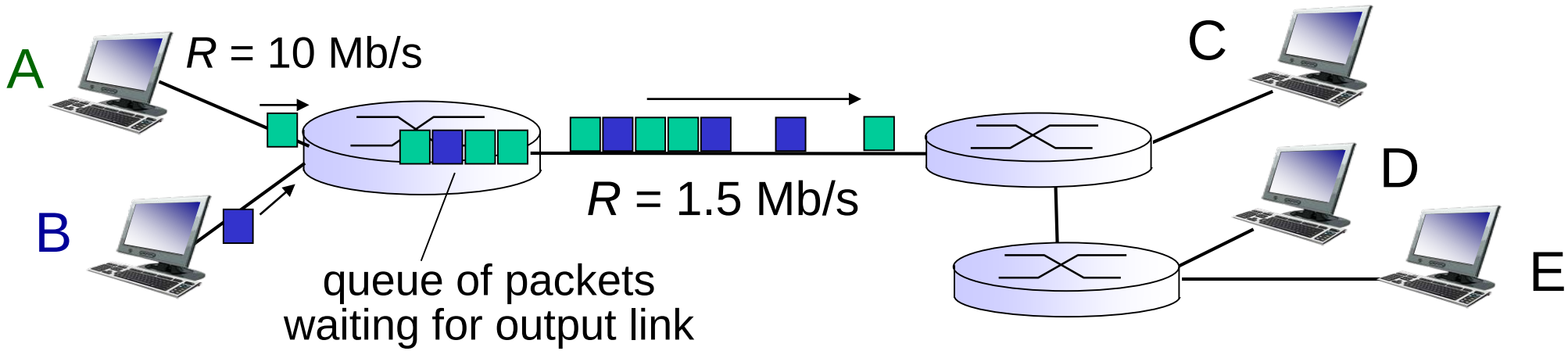


router에서 발생하는 지연은 ip 주소를 보고 어떤 link로 보낼지 선택해야돼서 packet1이 보낸 뒤 또 시간위 걸리고 또 보낸다.

Timing Diagram of Packet Switching



Packet Switching: queueing delay, loss



queuing and loss:

- If arrival rate (in bits) to link exceeds transmission rate of link for a period of time:
  - packets will queue, wait to be transmitted on link
  - packets can be dropped (lost) if memory (buffer) fills up

메모리 사이즈만큼 queueing 할 수 있다. 메모리 이상으로 오면 loss(날라감)이 된다.

Two key network-core functions

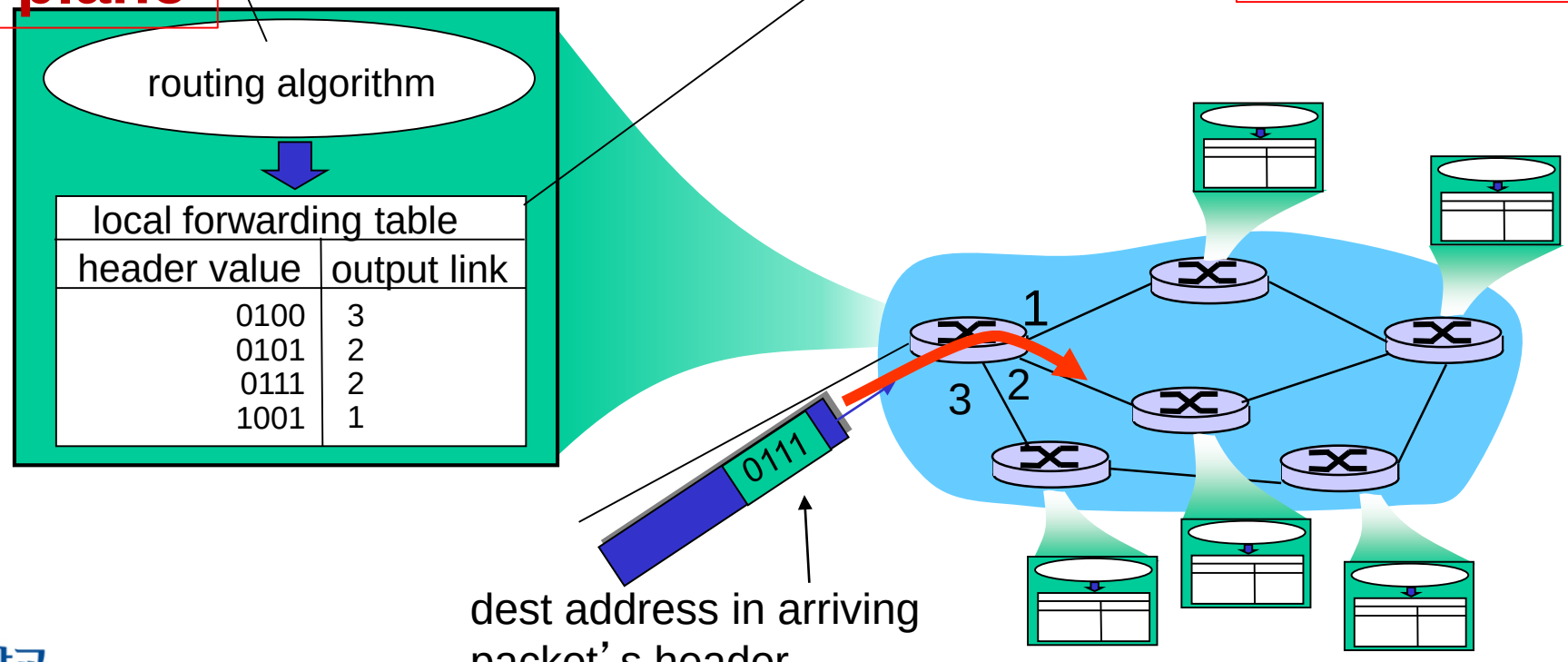
routing: determines source-destination route taken by packets

- *routing algorithms*

forwarding: move packets from router's input to appropriate router output

control plane

data plane



How Do packets make their way through packet-switched networks?

- Each packet contains
  the address of the packet's destination in its header

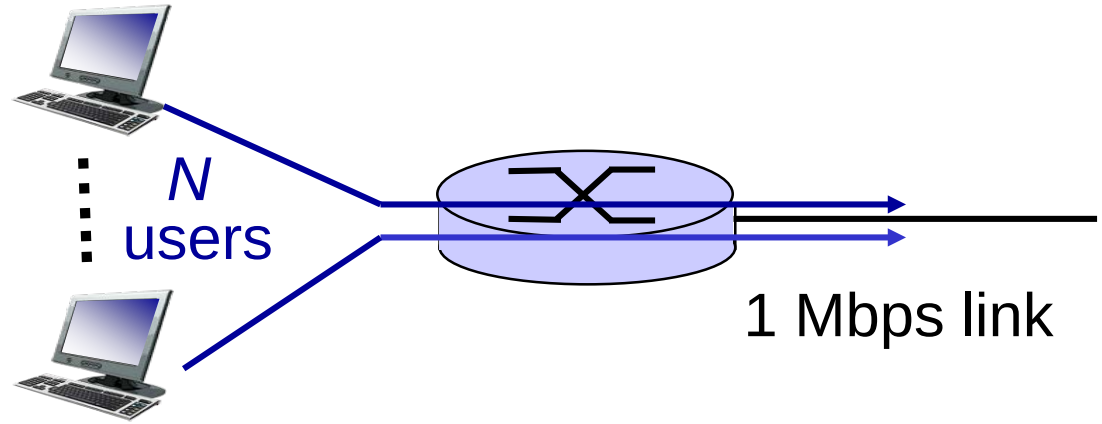
  - C.f. Is the header required in circuit-switching ?
    - A: No, not needed in circuit-switching
- through End-to-end routing!
  - (similar to a way of finding a path when you drive a car)
  - We will learn in Chapter 4

Packet switching versus circuit switching

packet switching allows more users to use network!

example:

- 1 Mb/s link
- each user:
  - 100 kb/s when “active”
  - active 10% of time (90% idle)



- *circuit-switching:*
  - 10 simultaneous users
- *packet switching:*
  - with 35 users, probability > 10 active at same time is less than .0004 *

*Read textbook p. 58-59!

Packet switching versus circuit switching

is packet switching a "slam dunk winner?"

- great for bursty data
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss
  - protocols needed for reliable data transfer, congestion control
- *Current Trend?*
  - Packet switching!
  - Even for telephone networks
    - Voice over IP (VoIP) – e.g., Skype, Kakao voicetalk
    - Voice over LTE (VoLTE) – HD voice calls