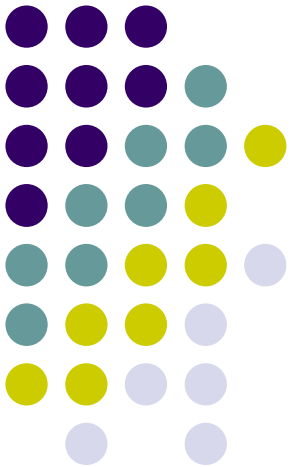
Concept of Computer networks

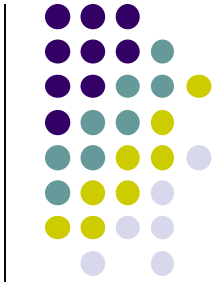


Course Introduction
History of Internet
Concept of computer networks
Network architecture
Packet switching vs. circuit switching

Reading: Chapter 1, Computer Networks, Tanenbaum

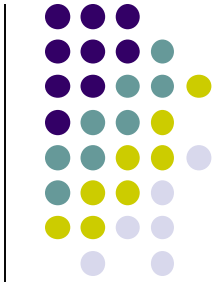
Lecturer: Ngoc Nguyen Tran
Email: ngoctn@soict.hust.edu.vn;
ngoc.trannguyen@hust.edu.vn
Office: B1 - Room 405

Course objectives



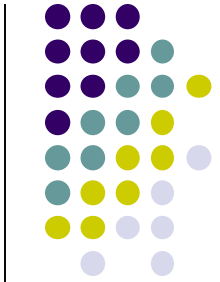
- Understand the Internet technology
  - Some networking mechanisms
  - Some protocols of TCP/IP
- Explain how the Internet works
- Be able to use the Internet efficiently, install new technologies and services

Topics



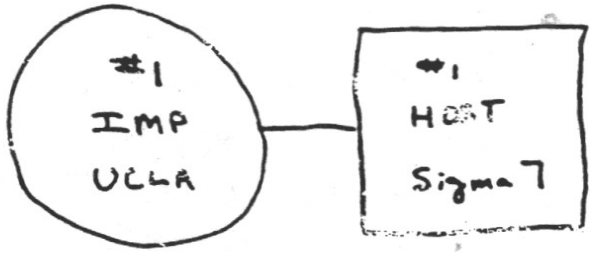
- Introduction to computer networks
- Basic concepts of computer communication model (OSI)
- Details of each layer
  - Physical Layer
  - Data-link Layer
  - Internet/ Network Layer
    - Routing problem
  - Transport Layer
  - Application Layer

Assessment



- Progress (50%)
  - Practical labs (60%)
  - Mid-term examination (40%)
  - Attendance (HUST regulation)
    - No absence: +1 point
    - Missing 3-4 classes: -1 point
    - Missing 5 classes: -2 points
  - Exercise: Students can earn extra points by solving exercises provided by the lecturer
- Final examination (50%)

History of the Internet



- Originated from an experiemental project of ARPA
- Intially having only two nodes (IMP atUCLA and IMP at SRI).

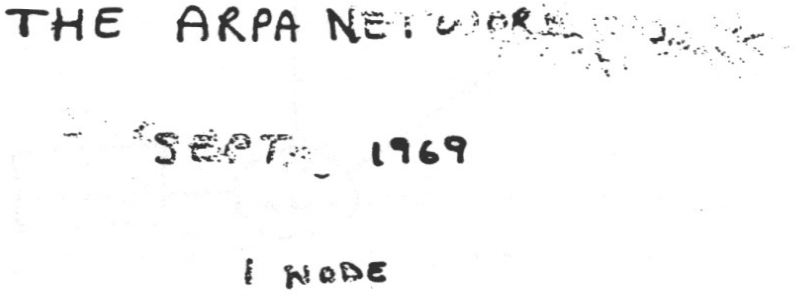
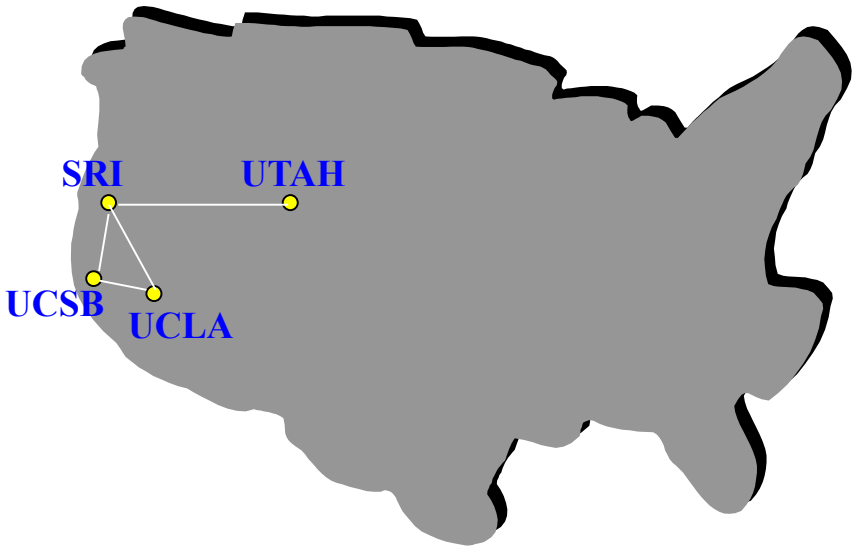


FIGURE 6.1 Drawing of September 1969 (Courtesy of Alex McKenzie)

ARPA: Advanced Research Project Agency
UCLA: University California Los Angeles
SRI: Stanford Research Institute
IMP: Interface Message Processor

Source: http://www.cybergeography.org/atlas/historical.html

In 12/1969, after 3 months



A network with 4 nodes, 56kbps

UCSB:University of California, Santa Barbara
UTAH:University of Utah

source: http://www.cybergeography.org/atlas/historical.html

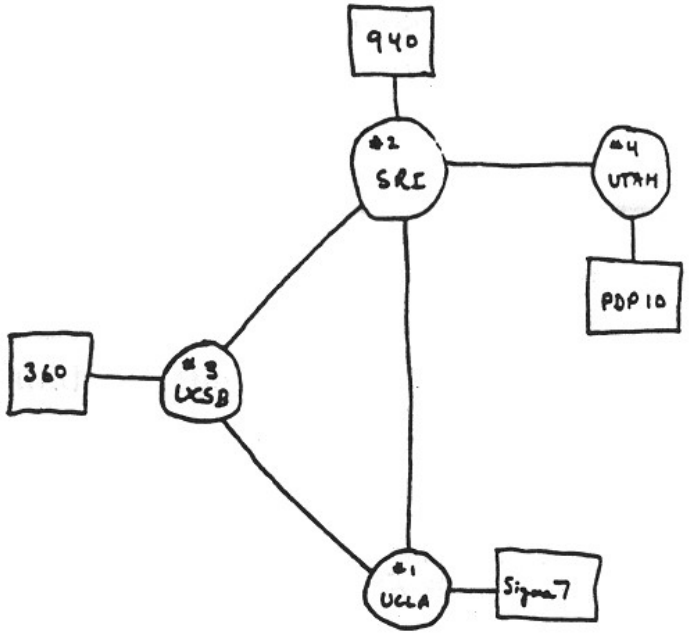
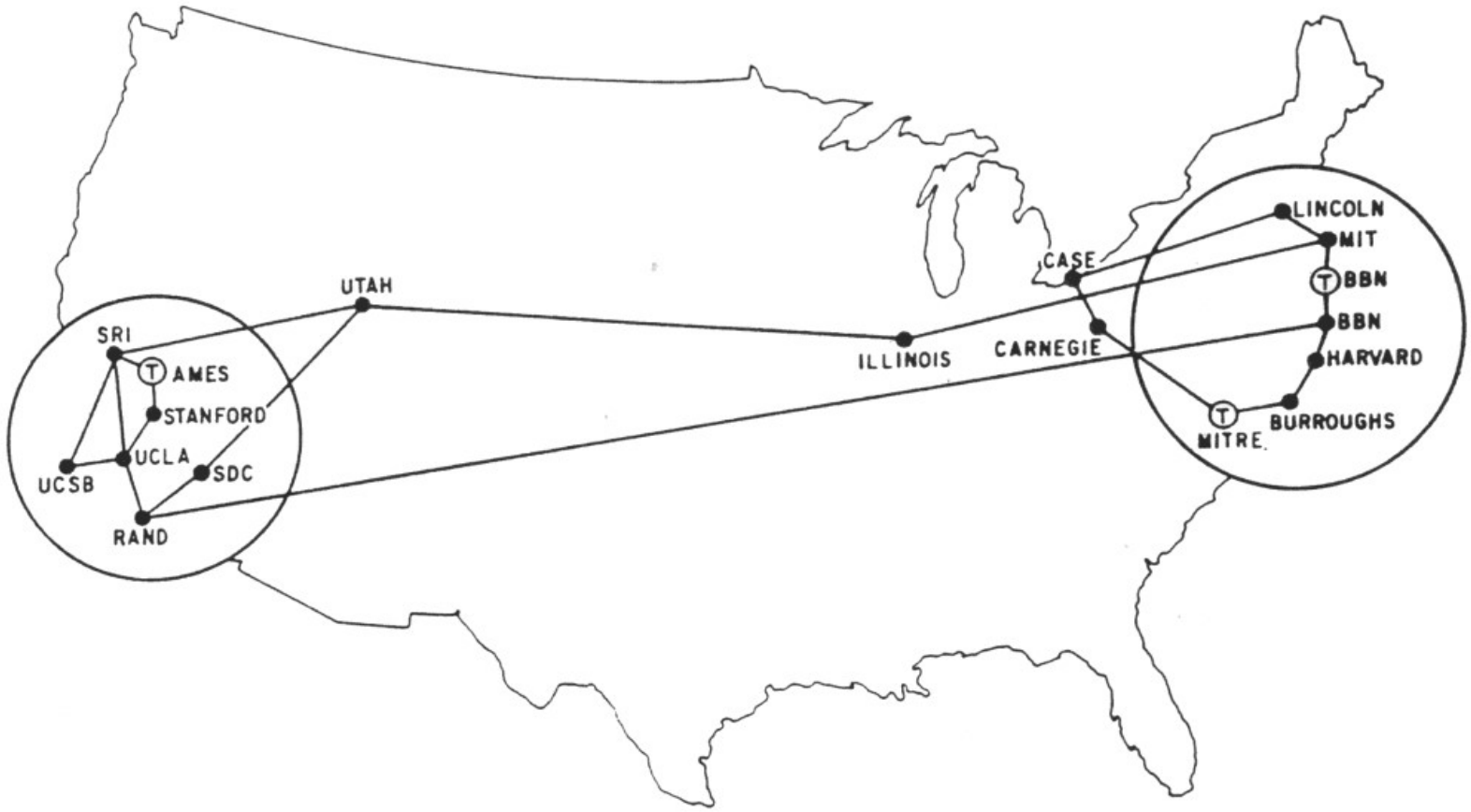


FIGURE 6.2 Drawing of 4 Node Network (Courtesy of Alex McKenzie)

ARPANET, 1971

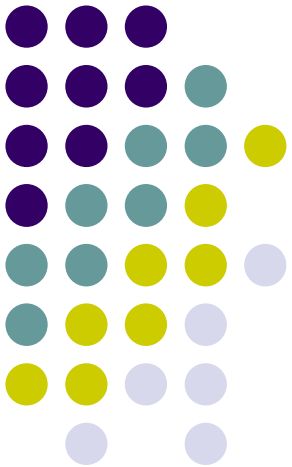


MAP 4 September 1971

Source: http://www.cybergeography.org/atlas/historical.html

One node was added each month

Years 70s: Interconnection, new network architecture and private architectures



Expansion of ARPANET, 1974

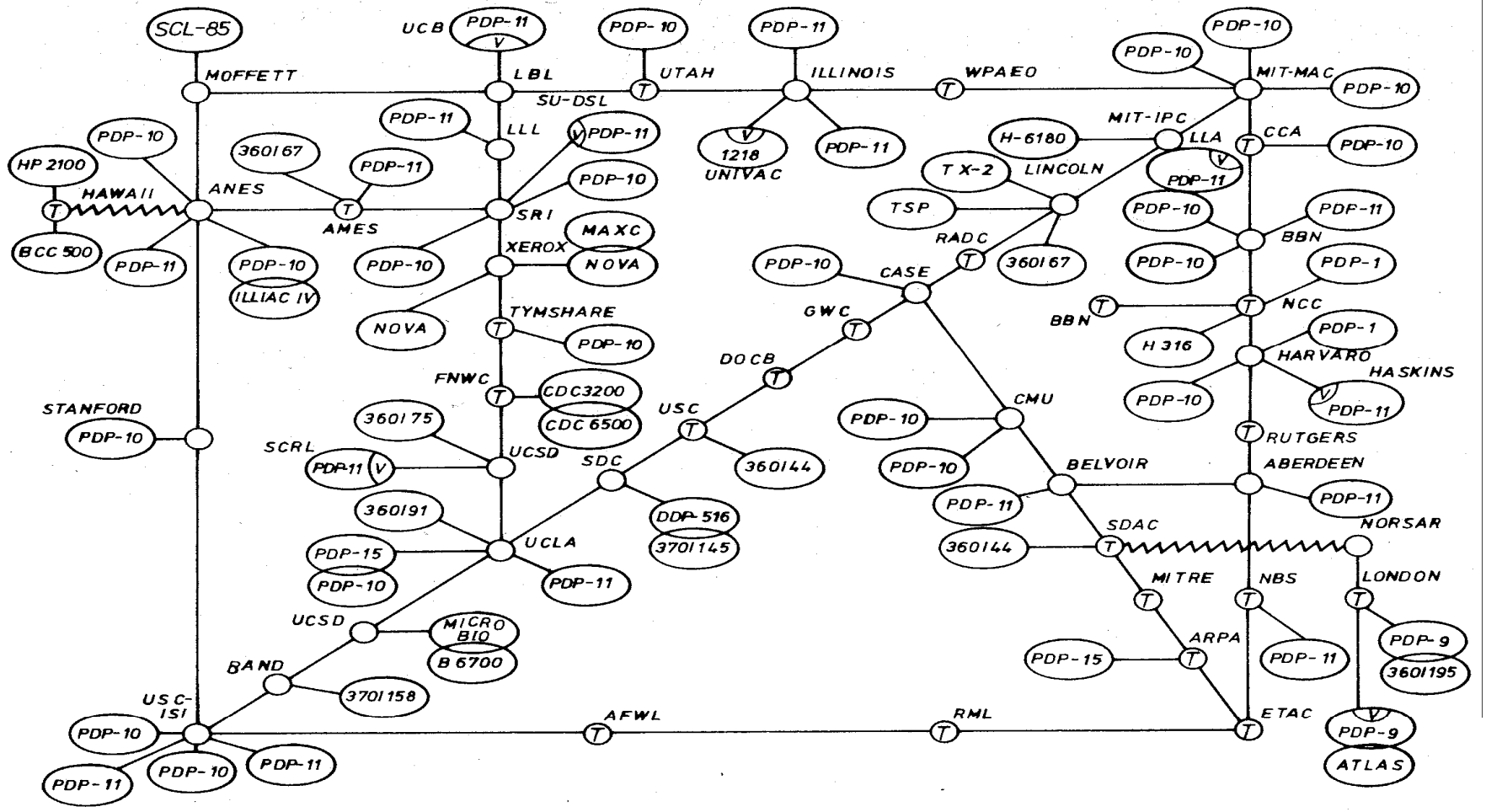
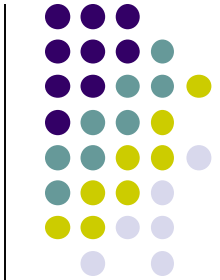


Abb. 4 ARPA NETwork, topologische Karte. Stand Juni 1974.

source:
http://www.cybergeography.org/atlas/historical.html

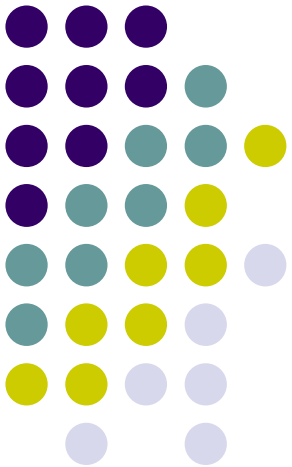
Traffic each day not more than 3.000.000 package

Years 70s



- Since 1970, new networks private architectures appear:
  - ALOHAnet in Hawaii
  - DECnet, IBM SNA, XNA
- 1974: Cerf & Kahn – principles of interconnection of open systems (Turing Awards)
- 1976: Ethernet, Xerox PARC
- End of 1970s: ATM

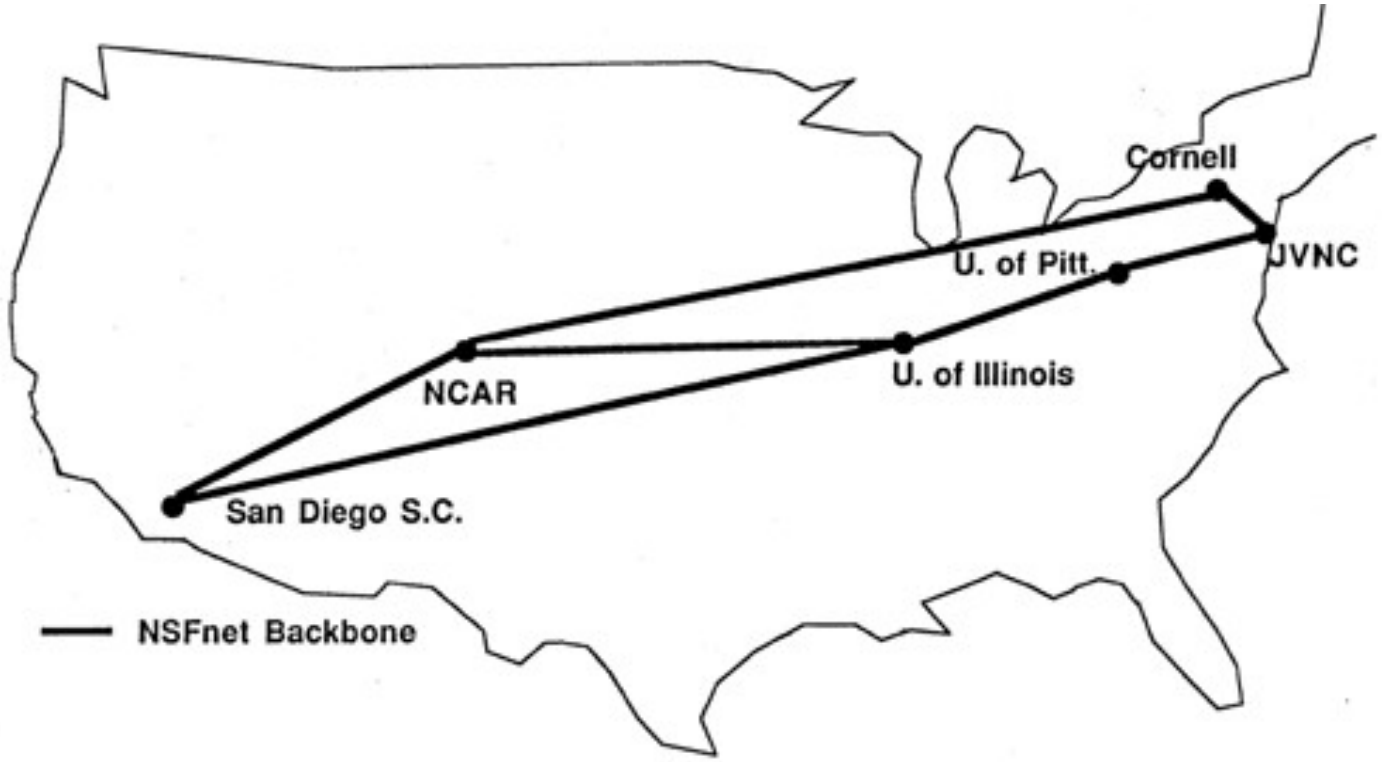
Years 80s: New protocols, more expansion



1981: Beginning of NSFNET

NSF: National Science Foundation

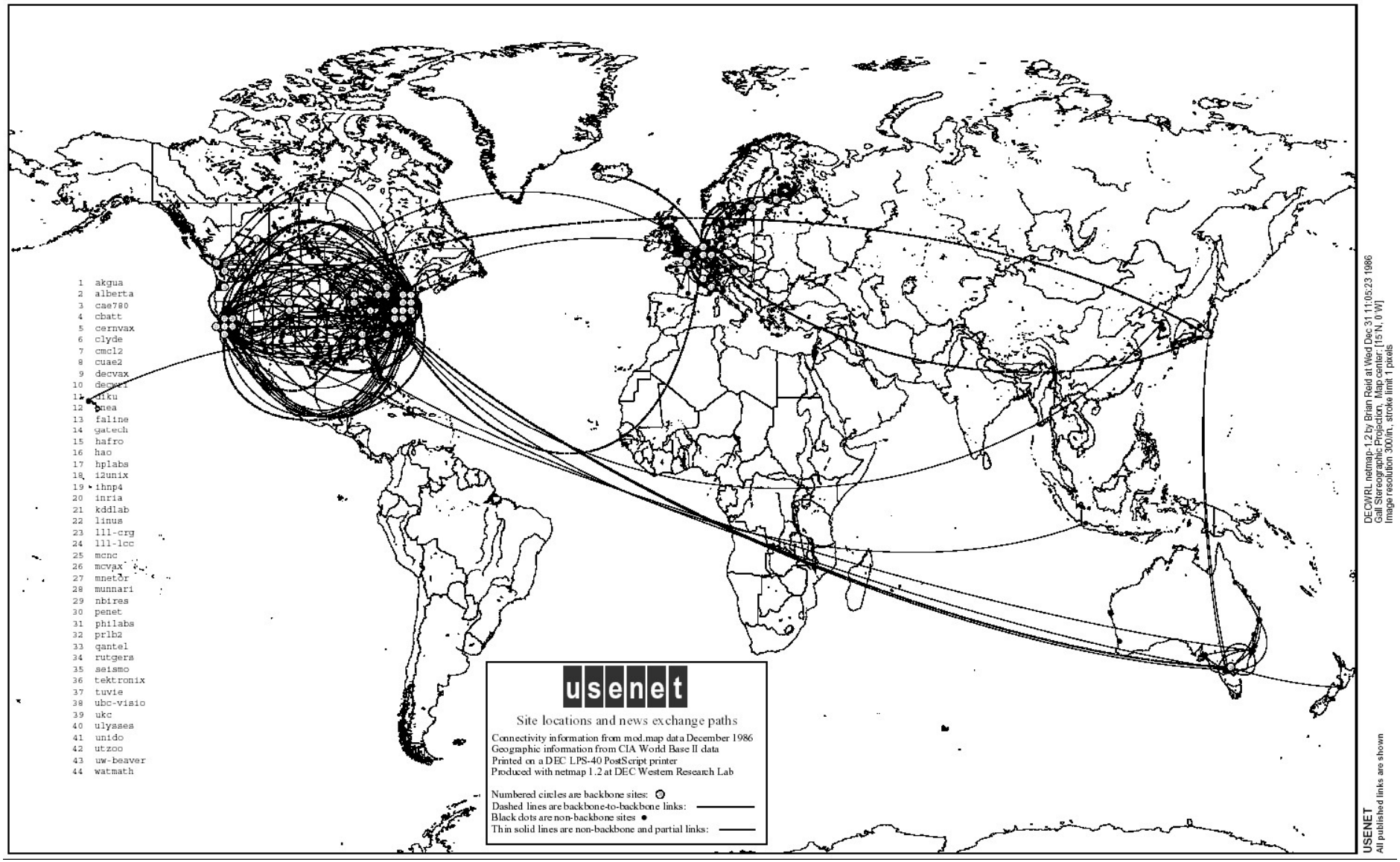
NSF network is separated from ARPANET for academic research uniquely



NSFnet Backbone Network

National Center For Atmospheric Research
March 19, 1986

1986: Connect USENET and NSFNET

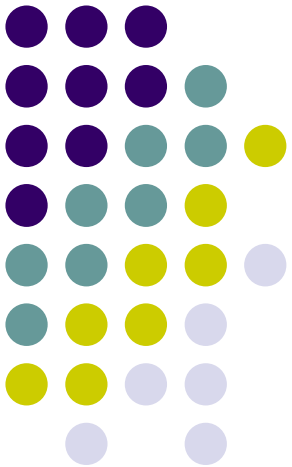


Source: http://www.cybergeography.org/atlas/historical.html

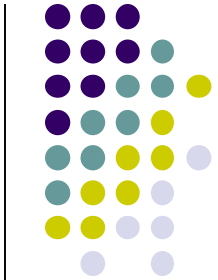
More network to join and more protocol

- More networks join in: MFENET, HEPNET (Dept. Energy), SPAN (NASA), BITnet, CSnet, NSFnet, Minitel …
- TCP/IP is standardized and becomes popular in 1980
- Berkeley integrate TCP/IP in BSD Unix
- Services: FTP, Mail, DNS …

Years 90s: Web and E-commerce over Internet



Years 90s



- Begining of 90s:
  Begining of Web
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, Netscape
- End of 90s:
  Commercialized the Internet

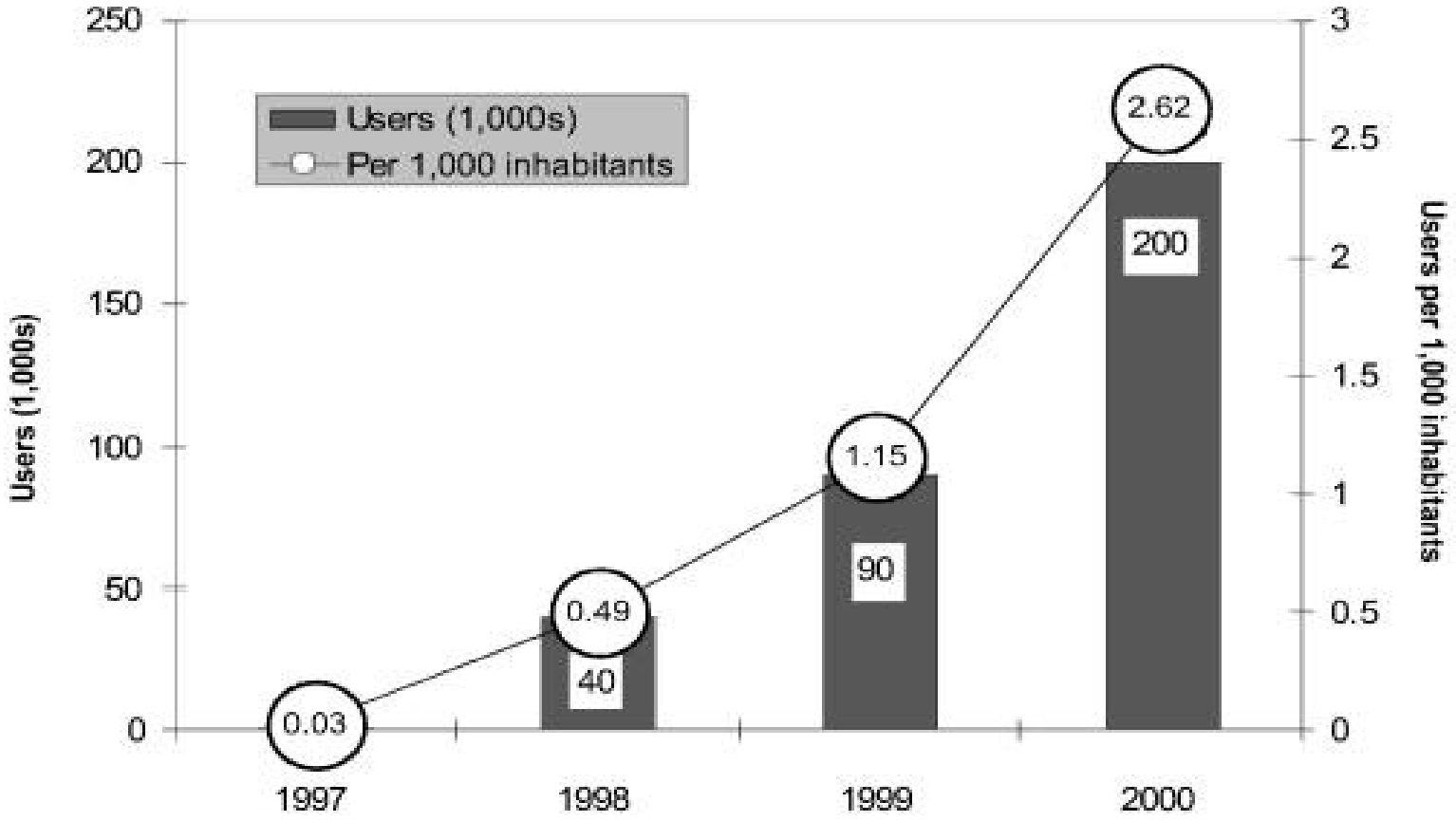
End of 1990's – 2000's:

- Many new Internet applications was introduced:
  - Chat, file sharing P2P…
  - E-commerce, Yahoo, Ebay, Amazon, Google…
- > 50 millions hosts, > 100 millions users.

Vietnam at that time

- 1991: In an effort, negotiations for connecting Vietnam to Internet failed.☹ (what a pity!)
- 1996: Again, prepare for Internet infrastructure
  - ISP: Only VNPT
  - 64kbps, 1 international out-link, hundreds special users (dial-up connections)
- 1997: Officially open and connect Vietnam to Internet
  - 1 IXP (Internet Exchange Point): VNPT
  - 4 ISP: VNPT, Netnam (IOT), FPT, SPT
- 2007: "Ten years of Vietnam Internet Development"
  - 20 ISPs, 4 IXPs
  - 19 million of Internet users, 22.04% of population

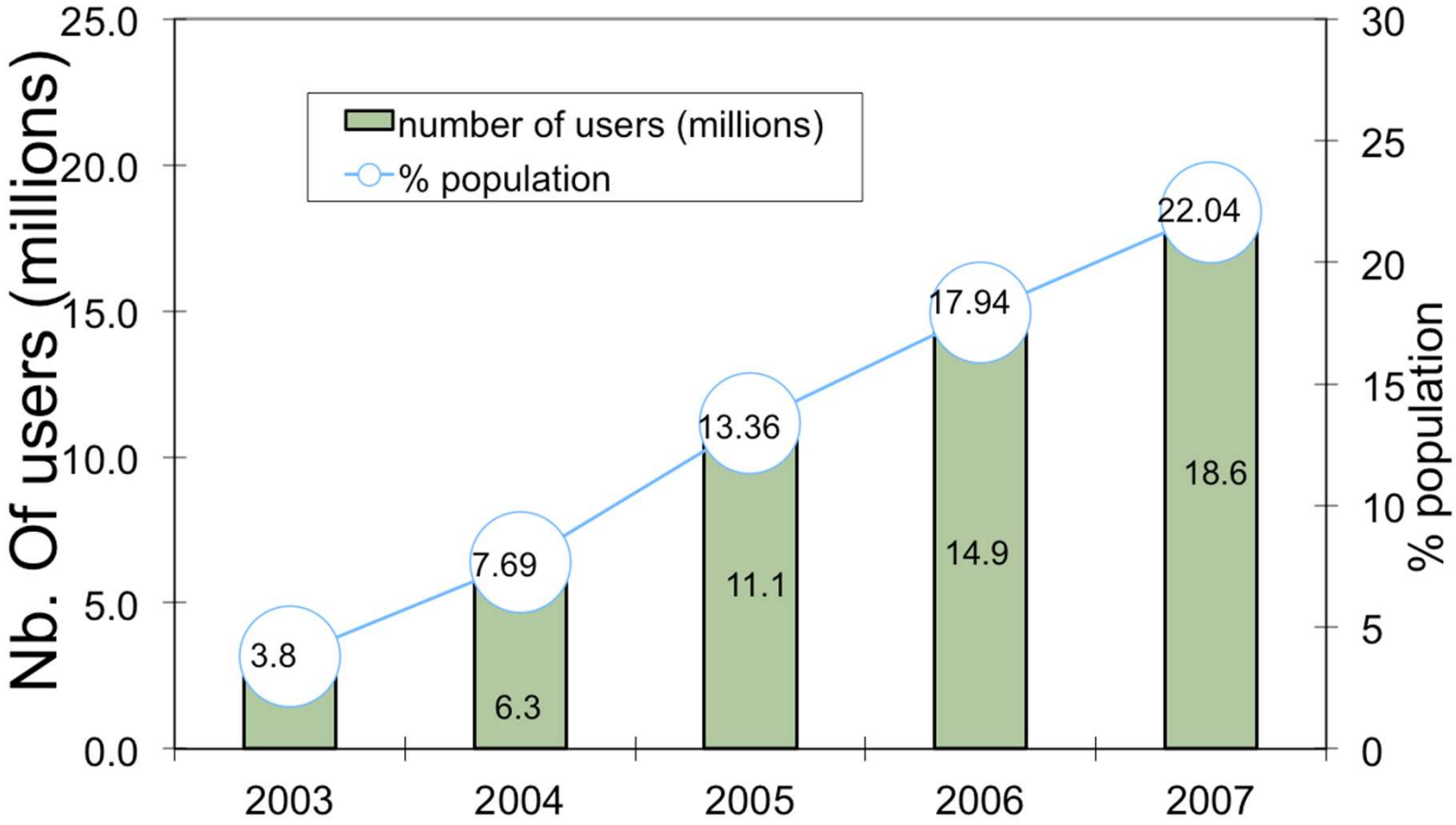
Development of the Internet in Vietnam



The numbers of users are estimated by 2 times the number of subscribers

Source: Vietnam Internet Case Study, http://www.itu.int/asean2001/reports/material/VNM%20CS.pdf

Statistics until 2007



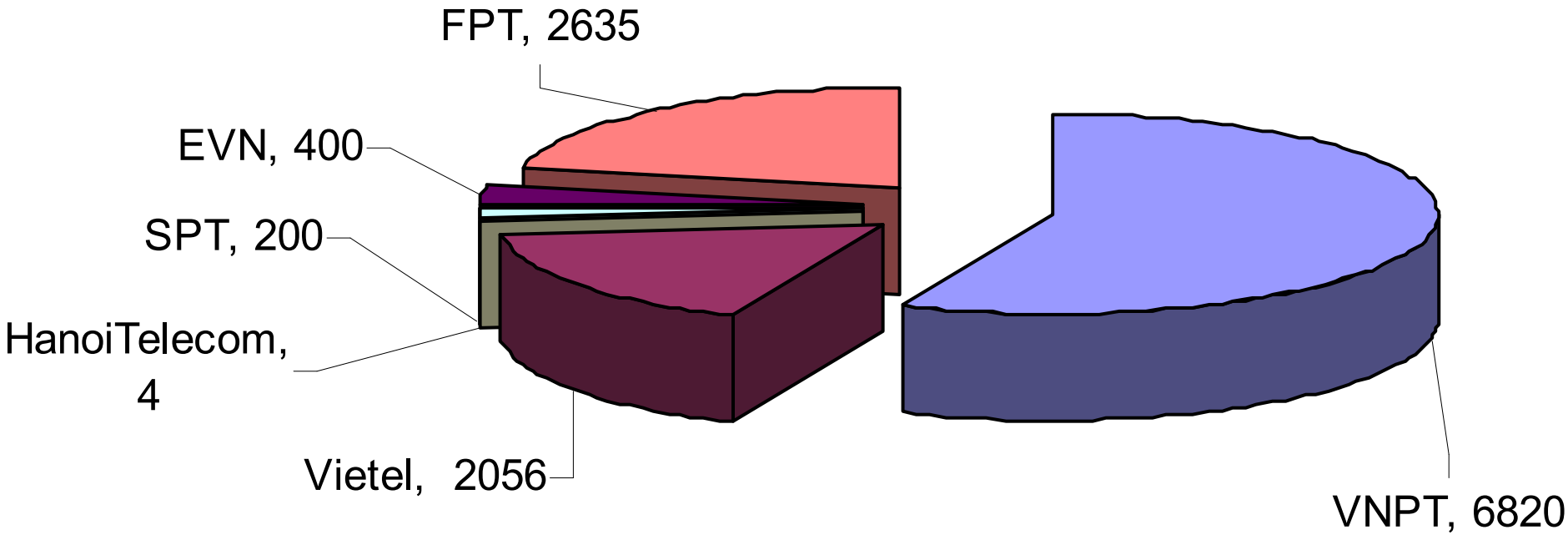
Source: *Vnnic*, http://www.thongkeinternet.vn

Recent statistics

Number of Vietnamese mobile users in 2019

Source: *Vnnic*, http://www.thongkeinternet.vn

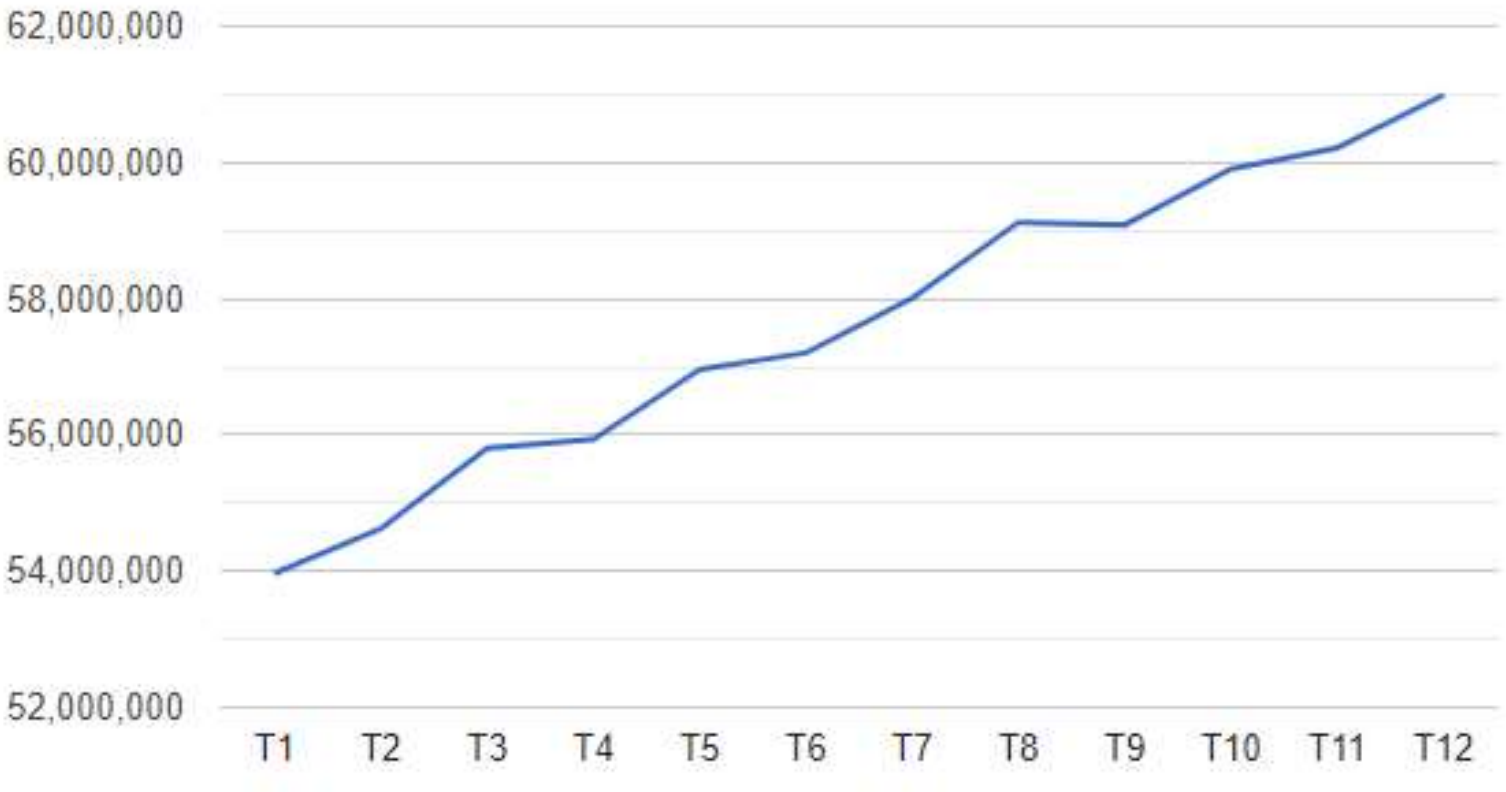
Bandwidth to the world (Mbps), 3rd Quarter 2007



Total: 12115.0 Mbps

Recent statistics

Number of Vietnamese mobile users in 2019



Source: *Vnnic*, http://www.thongkeinternet.vn

Internet subscription, 2019

5 2019 Xem

Tình hình phát triển thuê bao băng rộng cố định tháng 5/2019	
Số thuê bao truy nhập Internet qua hình thức xDSL:	182,853
Số thuê bao truy nhập Internet qua kênh thuê riêng:	22,929
Số thuê bao truy nhập Internet qua hệ thống cáp truyền hình (CATV):	868,039
Số thuê bao truy nhập Internet qua hệ thống cáp quang tới nhà thuê bao (FTTH):	12,606,506
Tổng số thuê bao băng rộng cố định:	13,680,327

Statistics are provided by Department of Telecommunication, Ministry of Information and Communication.
http://vnta.gov.vn/thongke/Trang/dulieuthongke.aspx

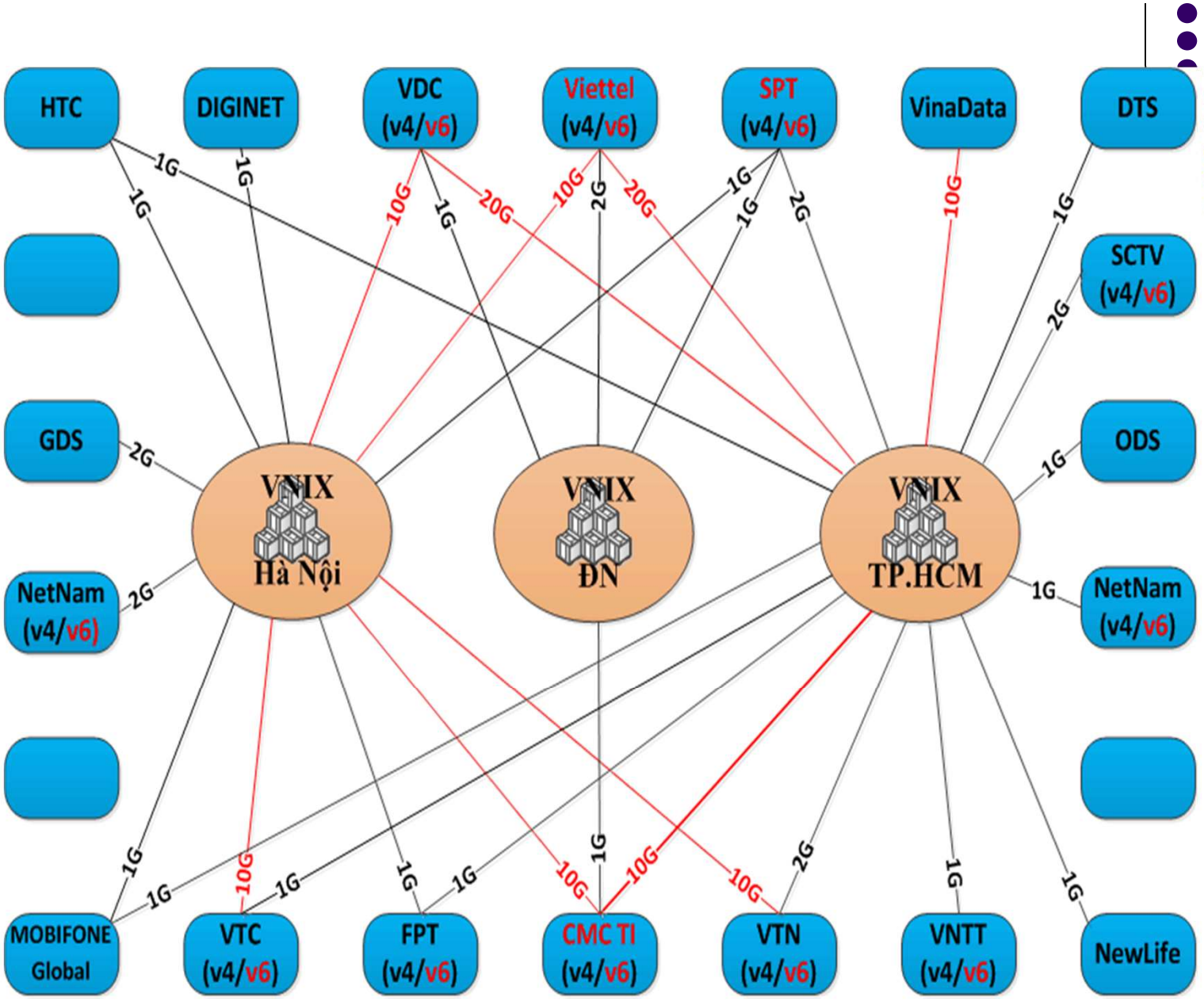
Internet usage on Mobile phone 2019

Tình hình phát triển thuê bao điện thoại di động tháng 5/2019	
▸ Tổng số thuê bao điện thoại di động có phát sinh lưu lượng:	133,877,535
▸ Tổng số thuê bao điện thoại di động đang hoạt động chỉ sử dụng thoại, tin nhắn:	75,216,569
▪ Thuê bao trả trước:	70,448,710
▪ Thuê bao trả sau:	4,767,859
▸ Tổng số thuê bao điện thoại di động đang hoạt động có sử dụng dữ liệu:	58,660,966
▪ Thuê bao trả trước:	54,158,129
▪ Thuê bao trả sau:	4,502,837

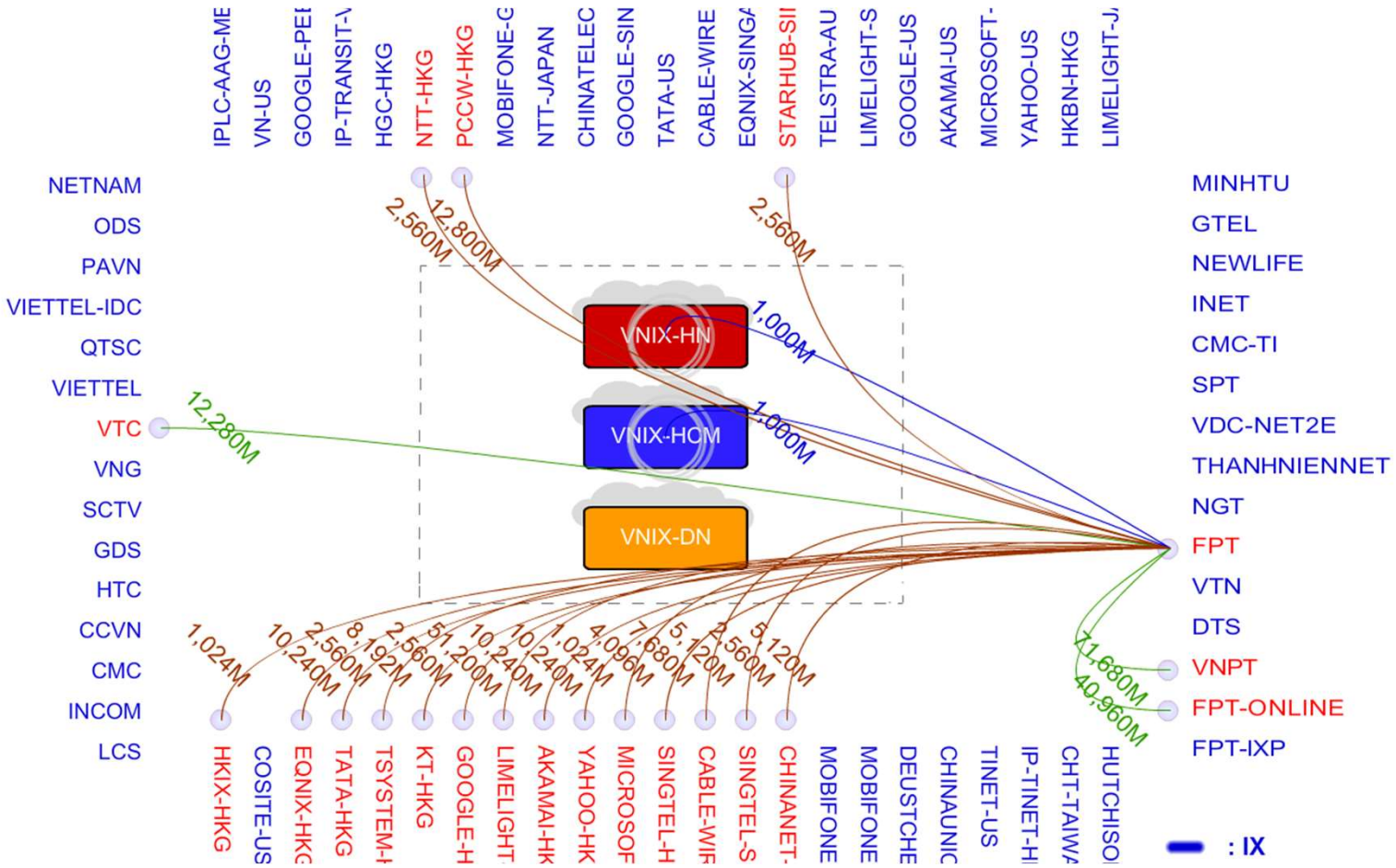
Statistics are provided by Department of Telecommunication, Ministry of Information and Communication.
http://vnta.gov.vn/thongke/Trang/dulieuthongke.aspx

Internet management in Vietnam

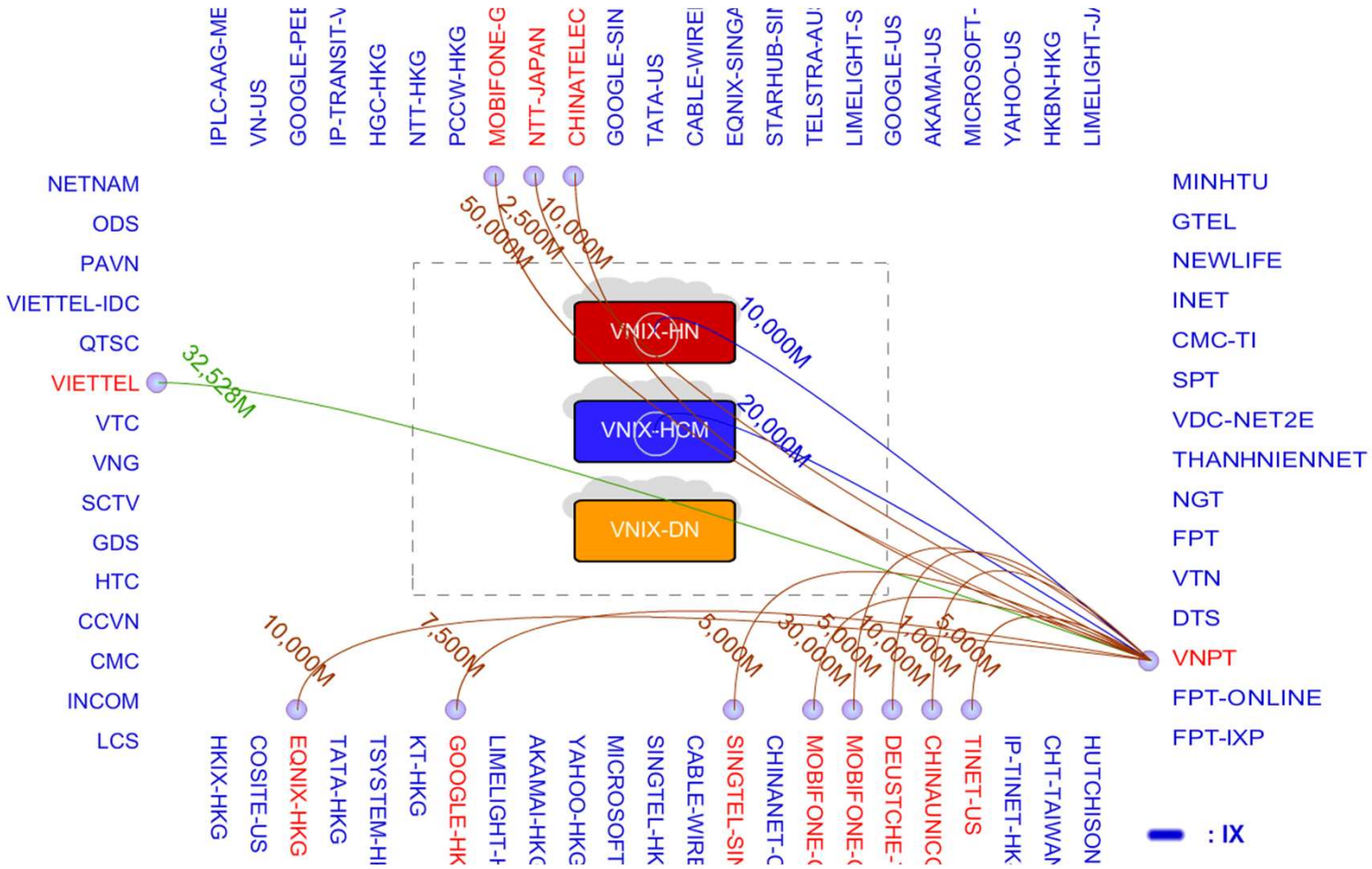
- VNNIC
  - Is responsible for managing the Internet domain name, address in Vietnam;
  - Provides guidelines, statistics about Internet and participates in international activity about Internet.
- **VNIX: V**ietnam **N**ational **I**nternet e**X**change
  - switching system between national ISP.


HTC
DIGINET
VDC (v4/v6)
Viettel (v4/v6)
SPT (v4/v6)
VinaData
DTS
SCTV (v4/v6)
GDS
ODS
NetNam (v4/v6)
NetNam (v4/v6)
VNIX Hà Nội
VNIX ĐN
VNIX TP.HCM
MOBIFONE Global
VTC (v4/v6)
FPT (v4/v6)
CMC TI (v4/v6)
VTN (v4/v6)
VNTT (v4/v6)
NewLife
1G
2G
10G
20G

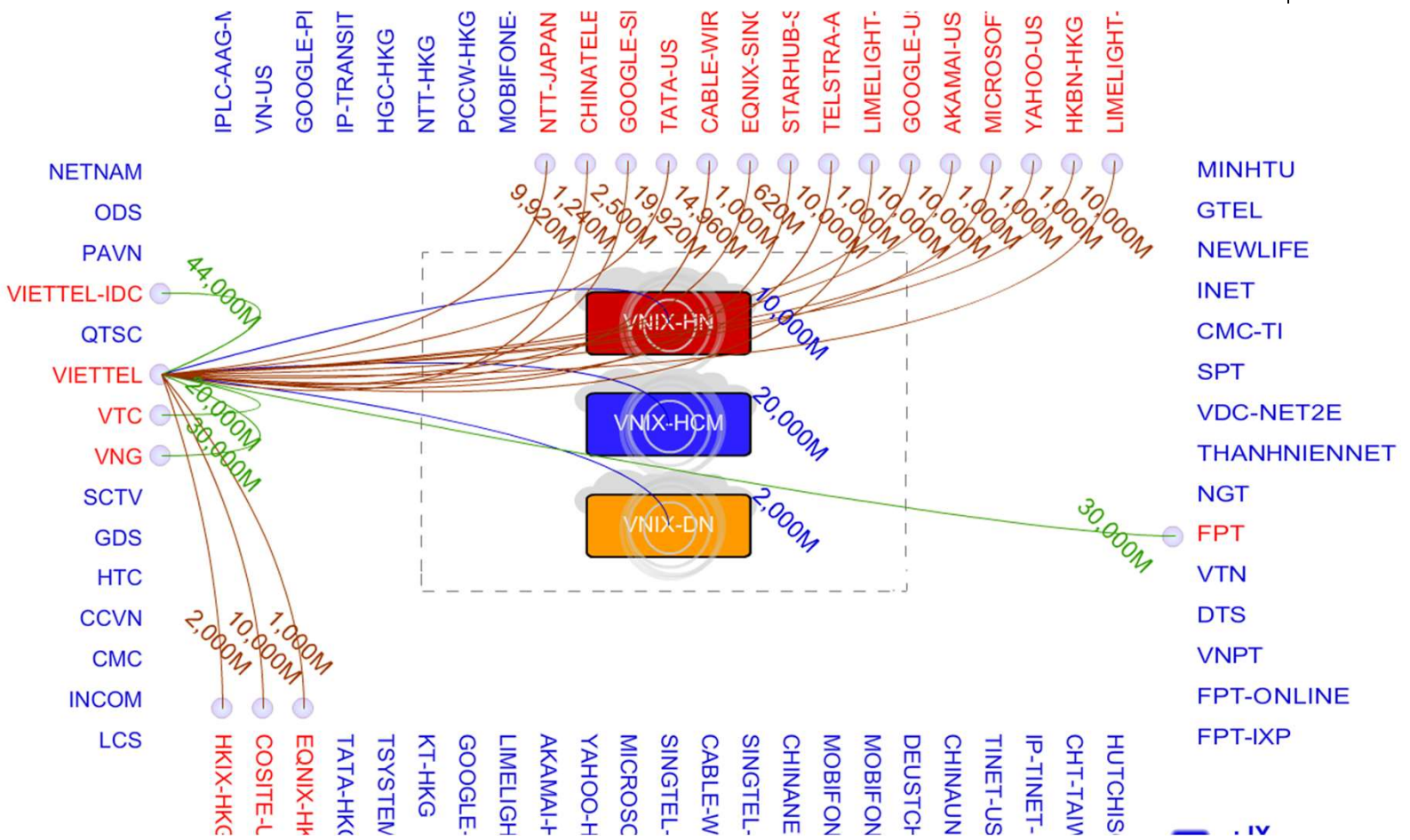
International connections



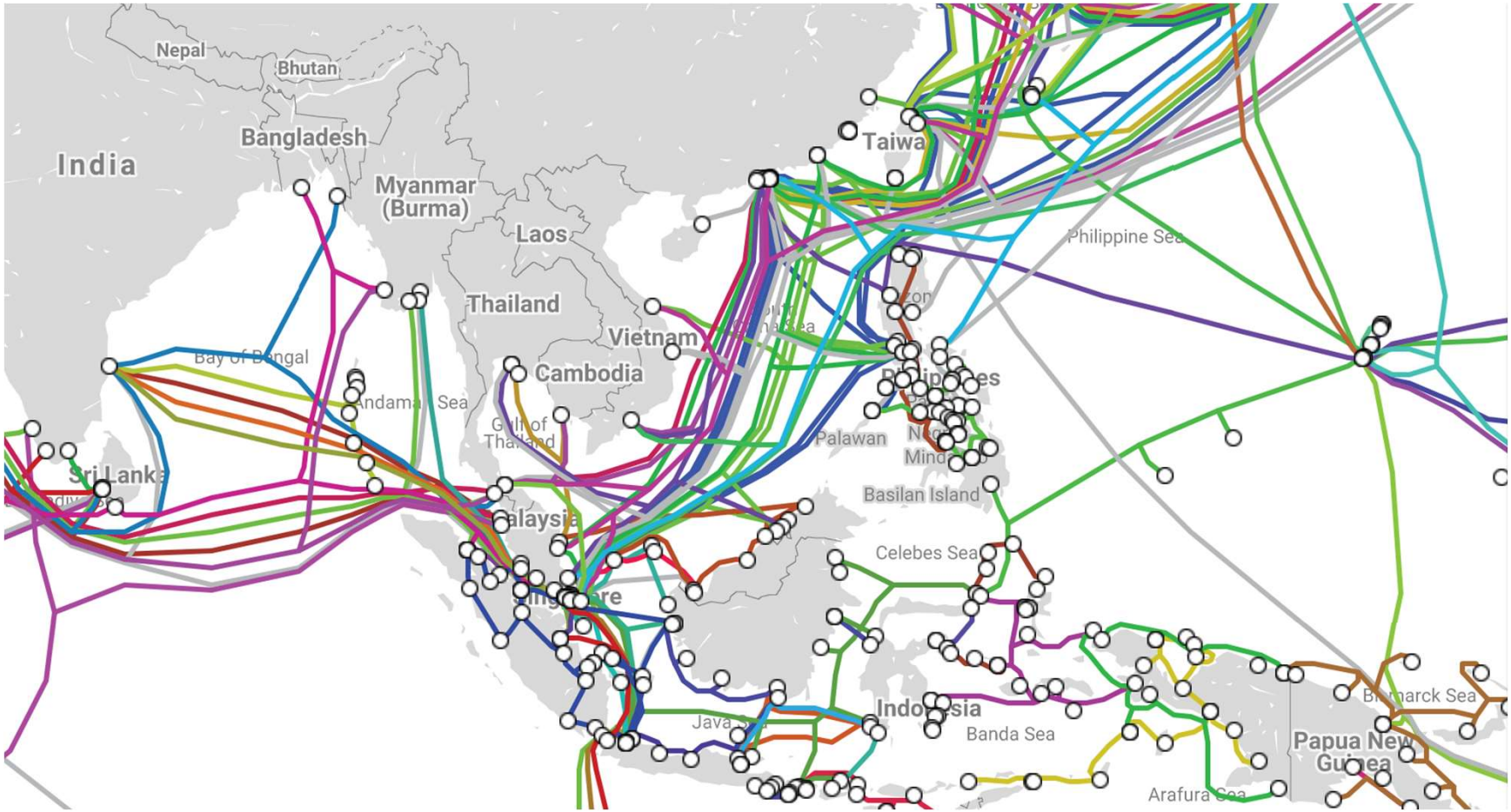
International connections



International connections

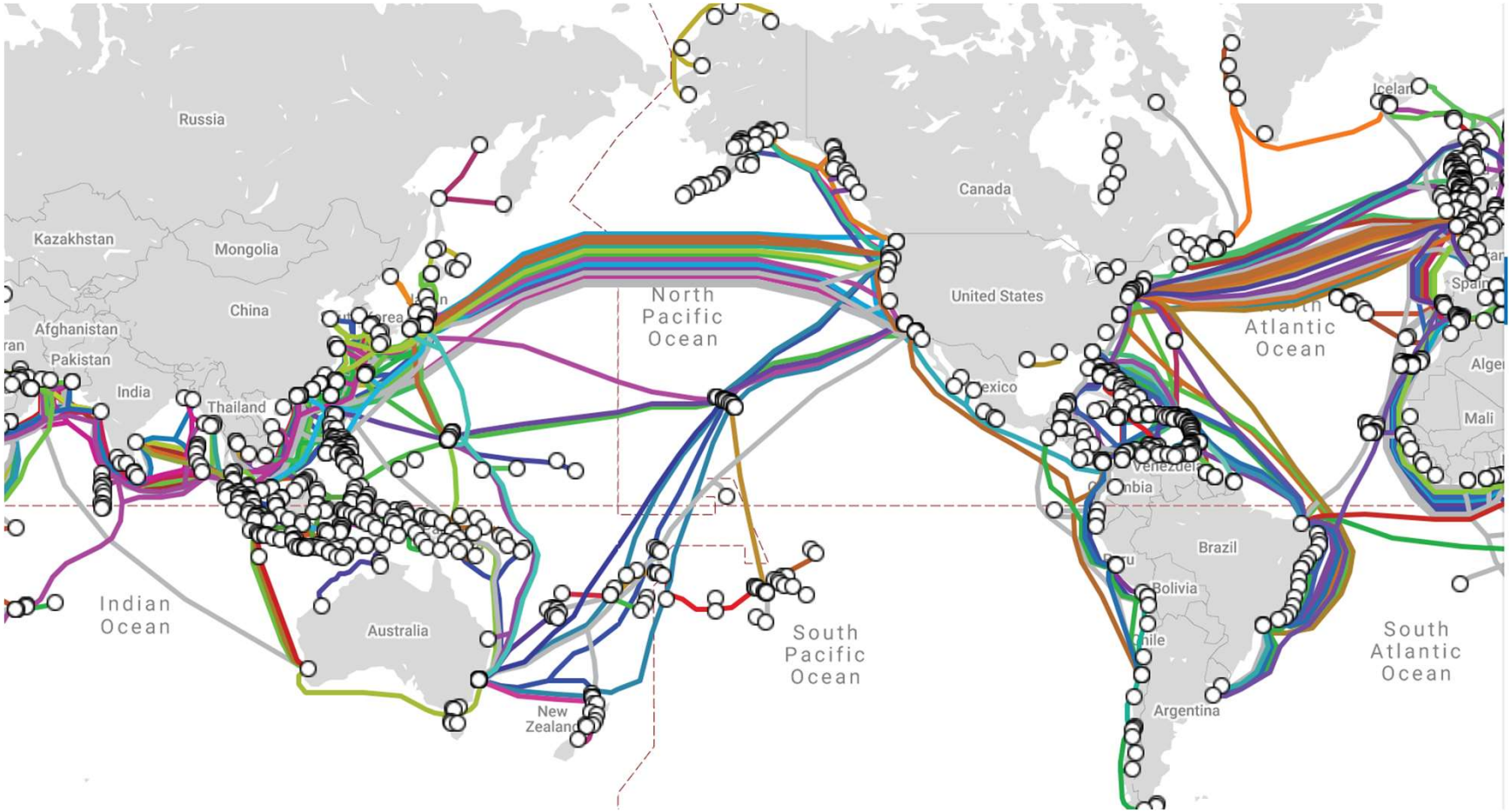


Optical fiber under the ocean



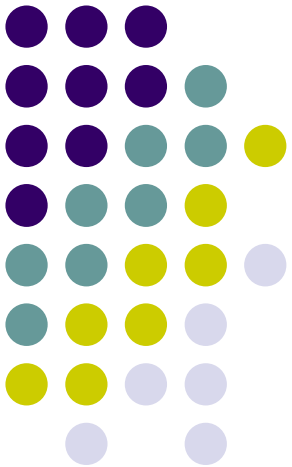
Source: https://www.submarinecablemap.com

Optical fiber under the ocean



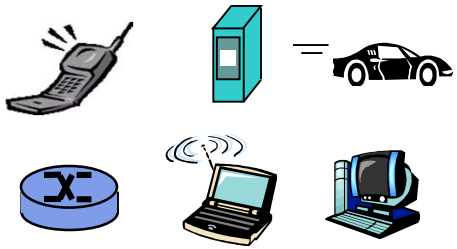
Source: https://www.submarinecablemap.com

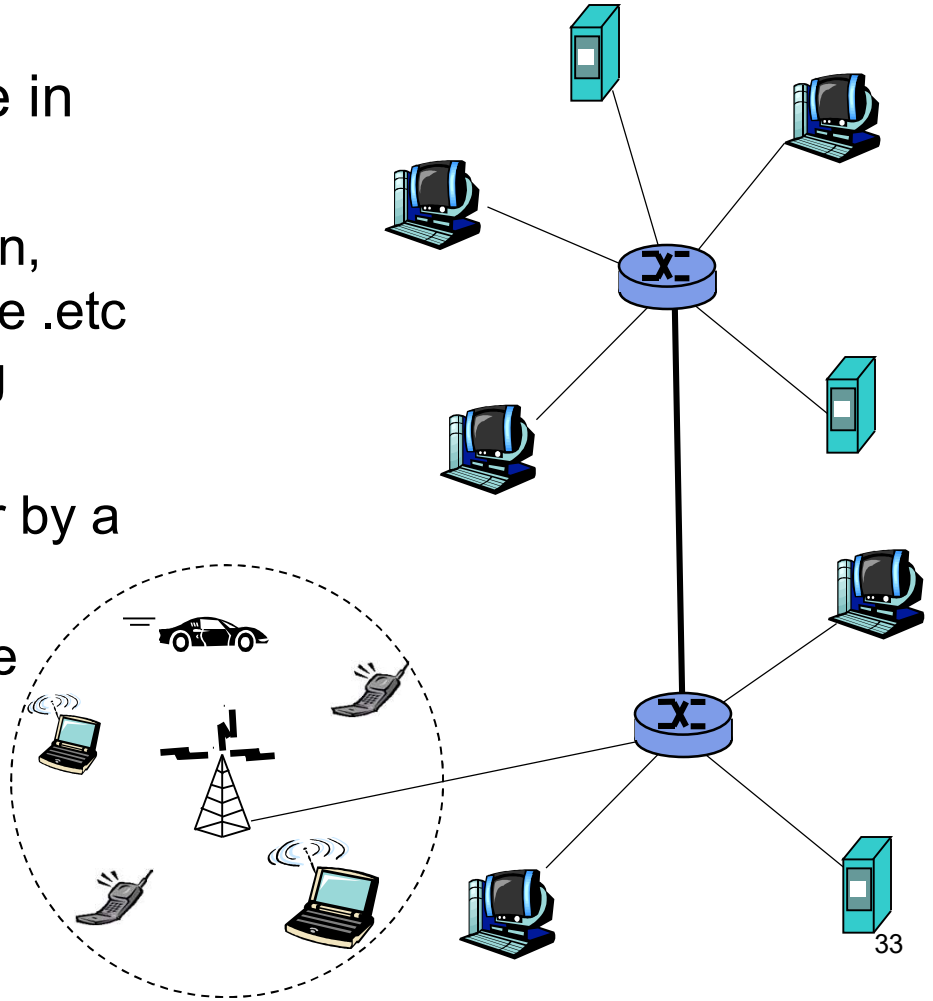
Concepts of computer networks



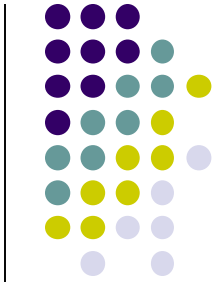
Concepts

- A set of computers/nodes connecting to each other according to an architecture in order to exchange data
  - Computer/node: workstation, server, router, mobile phone .etc with information processing capacity
  - They connect to each other by a media (wired or wireless)
  - Arcording to an archirecture
- Different kind of computers



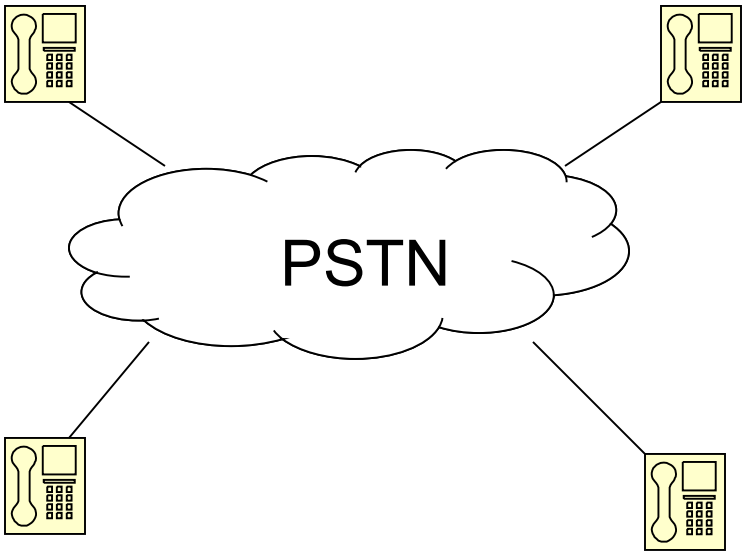


Example of networks

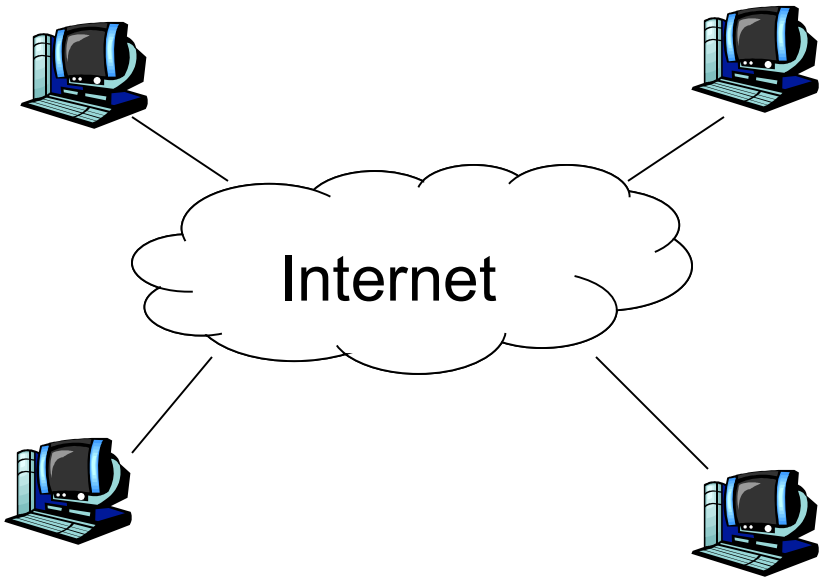


- Computer networks
  - The Internet
  - Ethernet
  - Wireless LANs: 802:11
  - …
- Banking system (ATM networks)
- Traffic light networks
- Train networks (our new train systems in Hanoi and HCM city)
- Power, gas networks (in developed countries)

Centralized or distributed



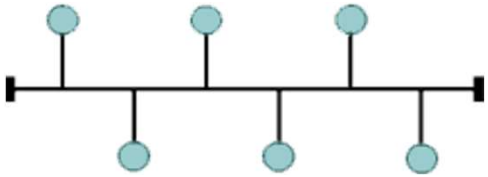
- Centralized: Network does everything

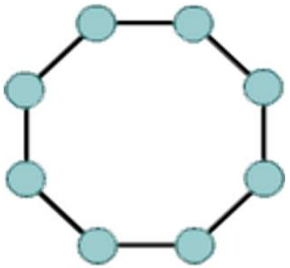


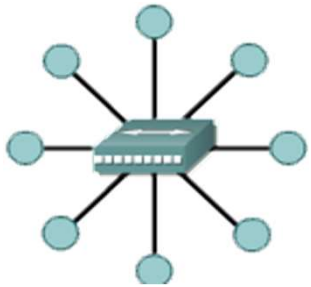
- Computer has stronger power
- Most functions are implemented at host

Network architecture

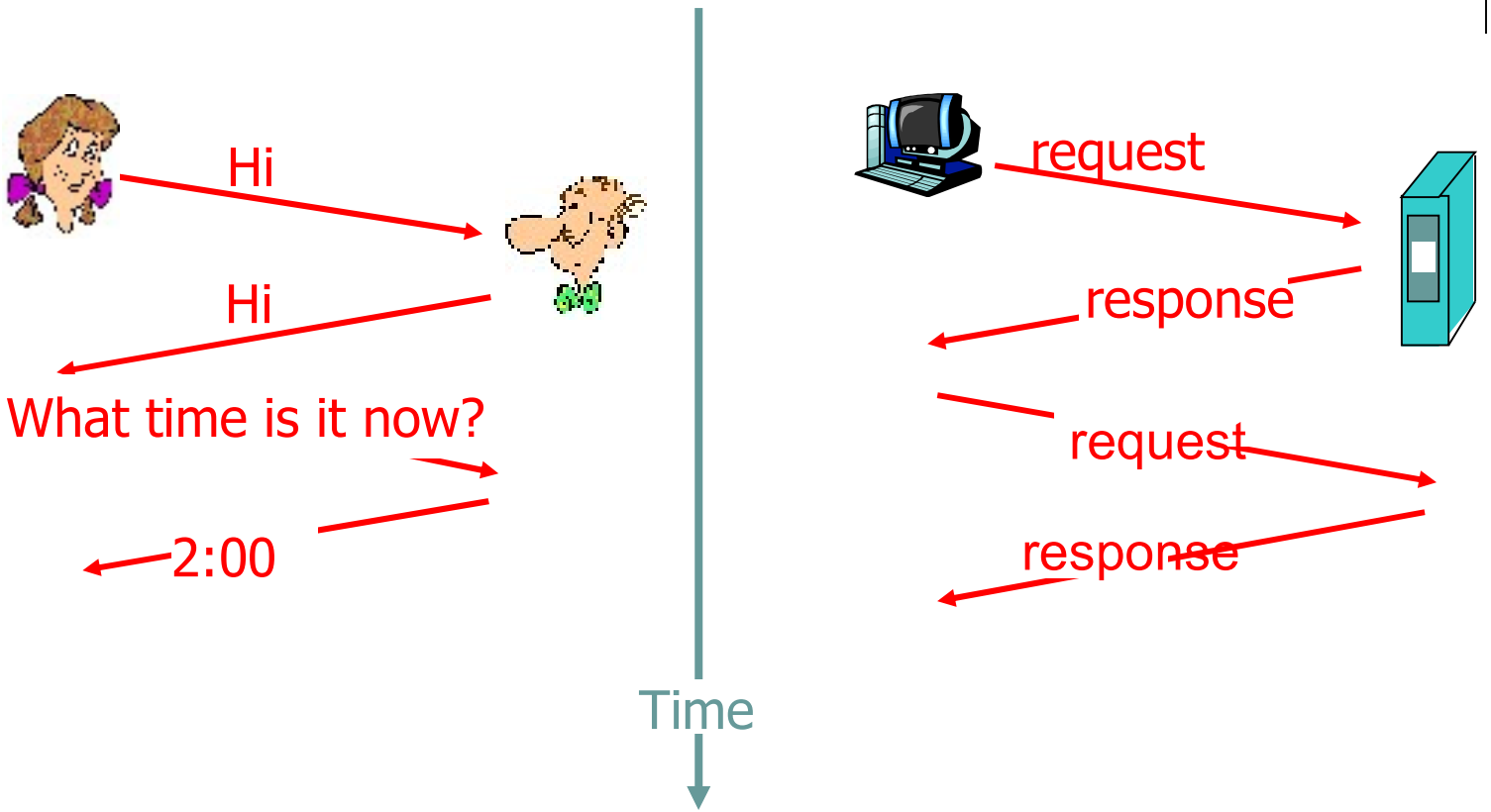
- Network architecture contain 2 aspects:
  - topology: the form that network nodes connects to each other
  - Protocol: language and procedure of communication between nodes.
- Topology
  - Bus, Ring, Star…







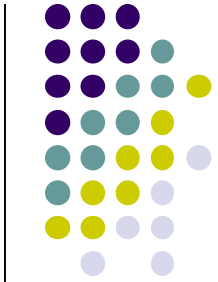
What is a protocol?



Protocol between human being: vocabulary, procedure

Protocol between machines

Network protocol

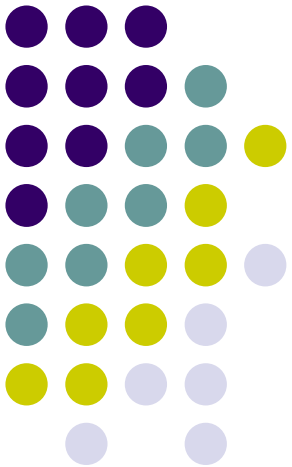


- Protocol: Communication rules
  - An entity/node sends a request
  - An entity/node receives some information or requests an action
  - Requests and information are under the form of messages.
- Protocol defines:
  - Format of messages/ information to be exchanged between nodes.
  - Order of messages sending between entities/nodes
  - Action should be performed when an entity receives a message.
- Example of protocols: TCP, UDP, IP, HTTP, Telnet, SSH, Ethernet, …

Transmission models

Packet switching vs. Circuit switching

Connection oriented vs. Connectionless



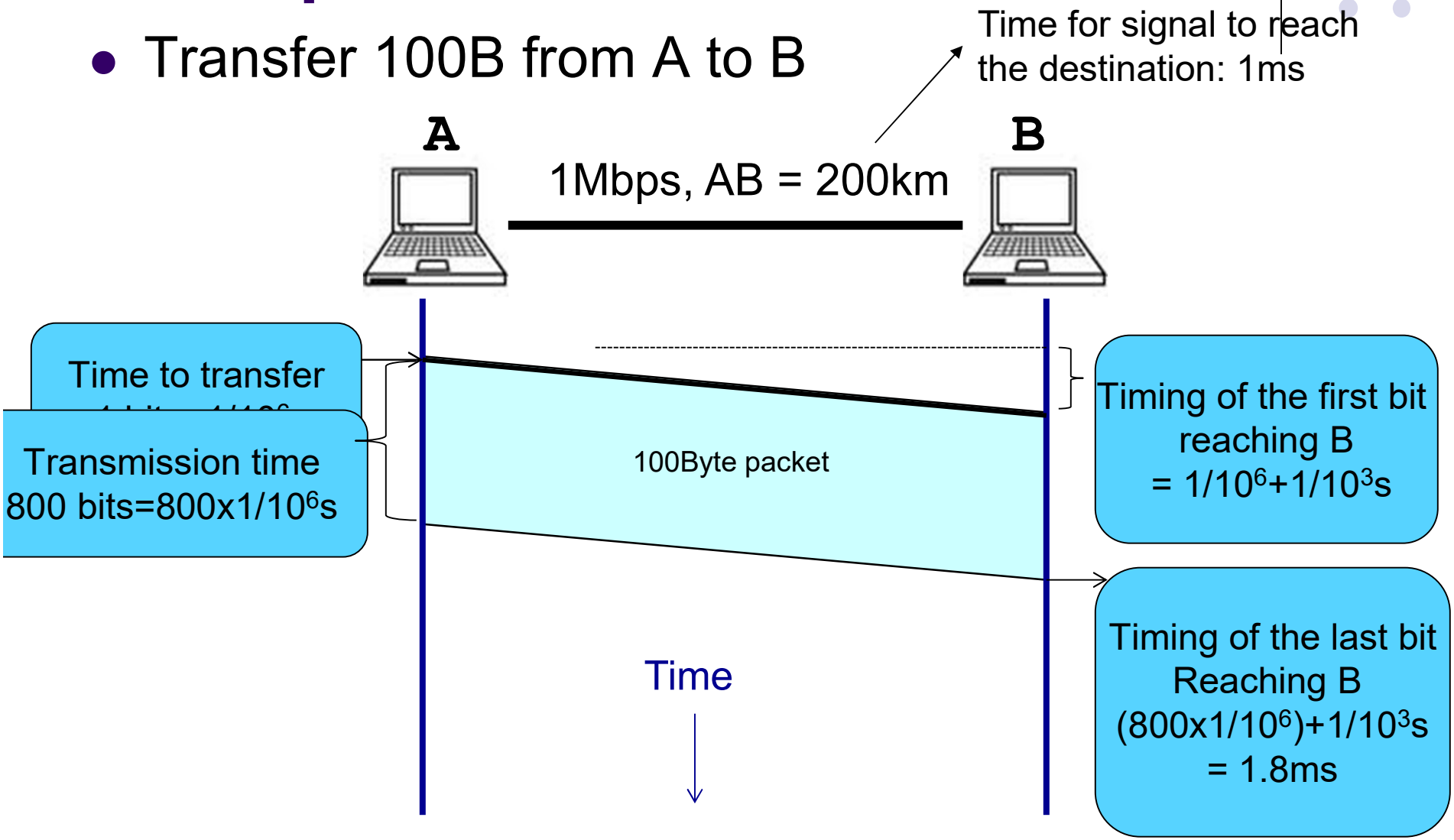
Problem

- Point-point connection between two hosts

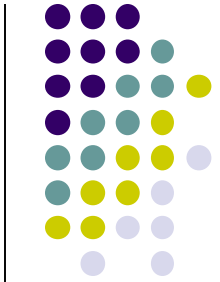
- Connection parameters:
  - Bandwith - R: maximum amount of data transmitted within a time unit (bps – bit per second).
  - Example: optical cable has the bandwidth of 100Mbps.
  - Latency: transmission delay from A to B
    - Propagation delay: Connection length / speed of signal
    - Example: optical cable has the length of 10 km, speed of light (3×10^8m/s) ➔ $10 \times 10^3/(3 \times 10^8) \sim 3.333 \times 10^{-5} = 0.03333$ ms
    - Transmission delay: data size / bandwidth

Point-point connection

- Transfer 100B from A to B

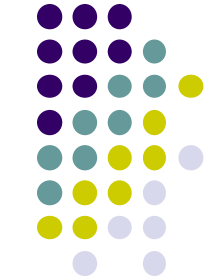


Exercise

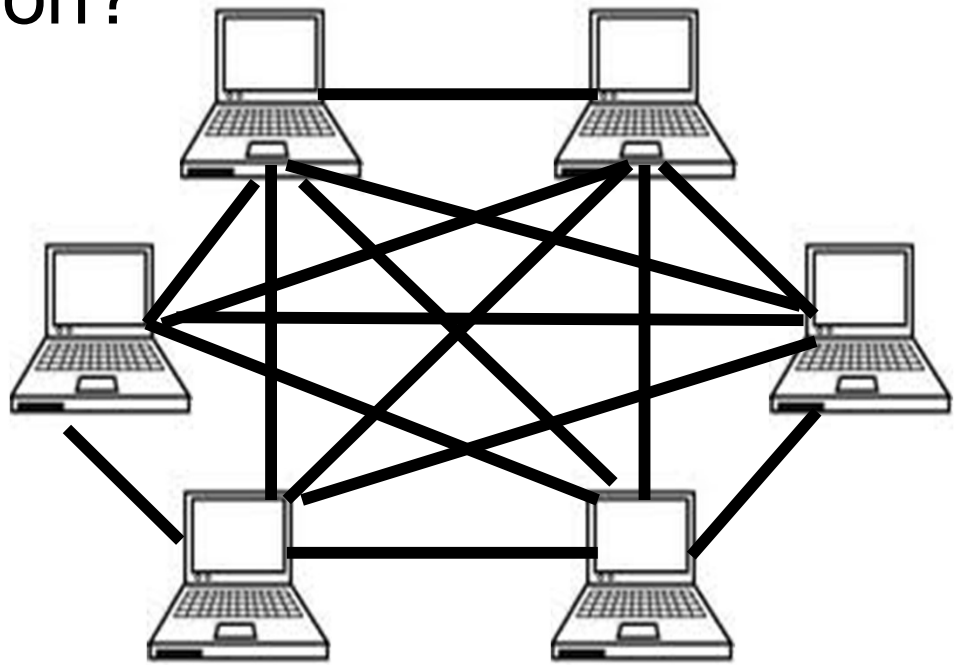


- Each packet with the size of 1000 bytes need to transfer through optical cable with the bandwidth of 100 Mbps. Cable length is 100km. Calculate
  - A) Time for the source to send a packet
  - B) Time for one bit to reach the destination (assume that the propagation speed is 200000 km/s)
  - C) Number of packages can be appeared on the transmission medium
  - D) The practical speed, if each sent bit need to be replied by an ACK bit by the destination

Connection between multiple hosts

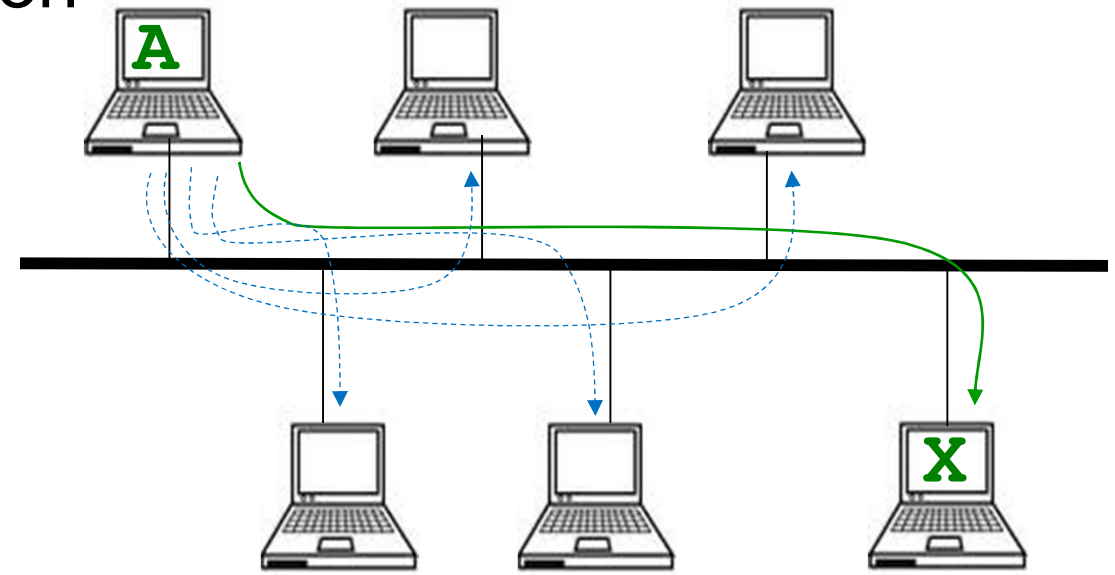


- Point-point between all hosts
- Limitation?



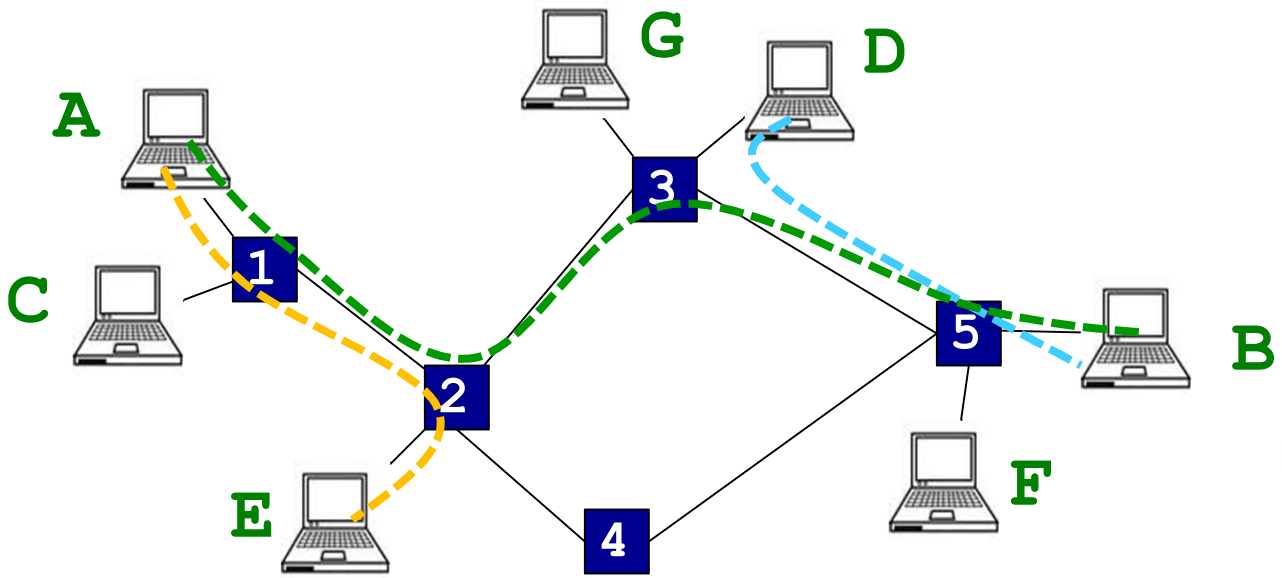
Connections between hosts

- Point – multipoints: share one medium → truyền "quảng bá" (broadcast)
- Limitation?



Connections between hosts

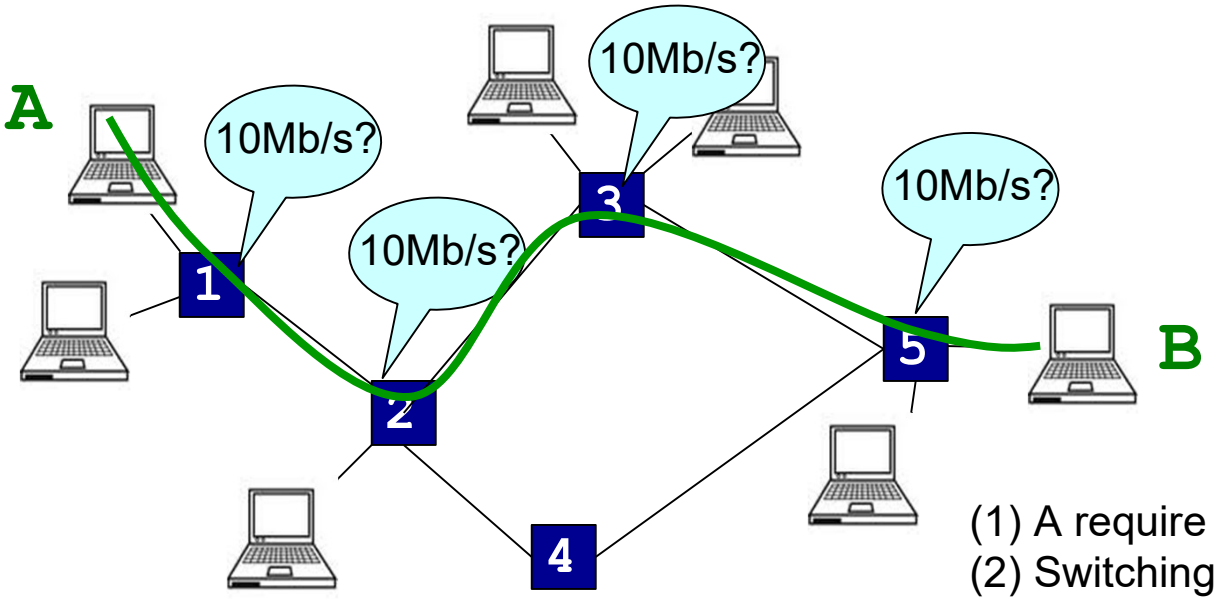
- Solution: switching network
  - Each host connects to be switching device
  - Switching devices connect point-to-point and forward data to the destination
  - Share resources



Question: How to determine the routes?
Answer: Routing

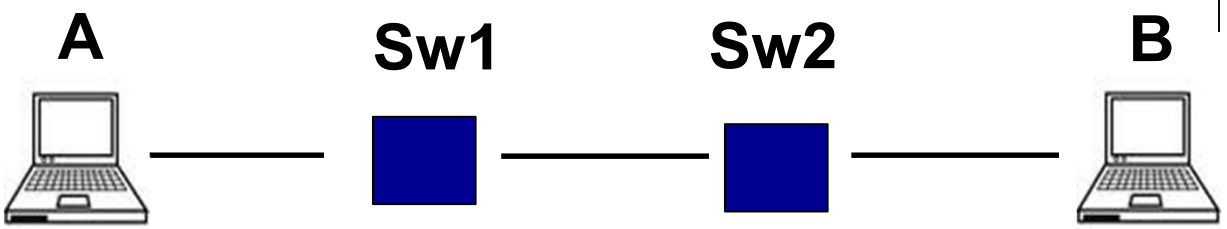
Circuit switching

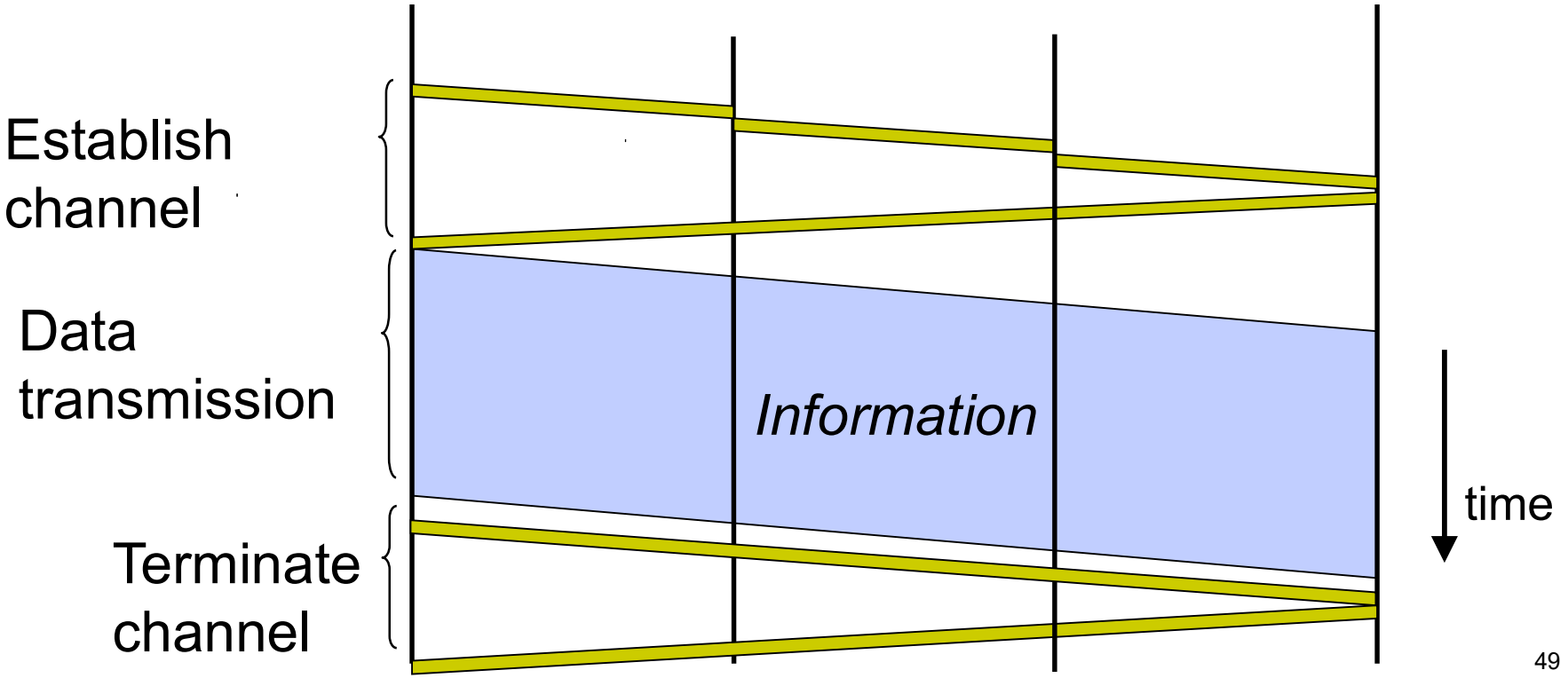
- Circuit switching network: allocate resources for logical private channels between 2 network points



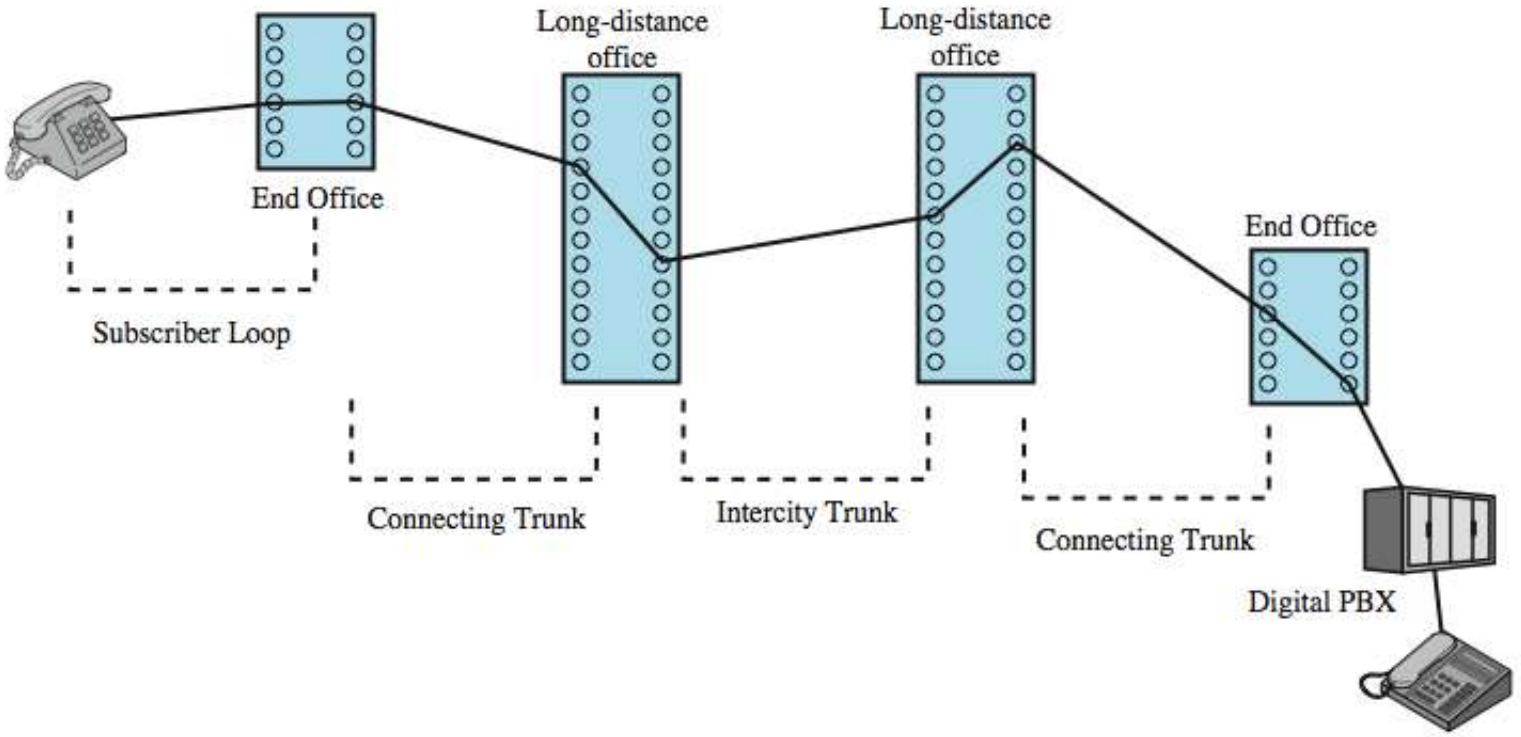
(1) A require to establish a channel
(2) Switching devices establish the channel
(3) A start data transmission
(4) A finish its transmission: send a signal to terminate the channel

Timelines

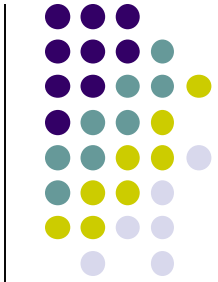

A
Sw1
Sw2
B


Establish channel
Data transmission
Information
Terminate channel
time

Example of circuit switching: Public Switched Telephone Network PSTN

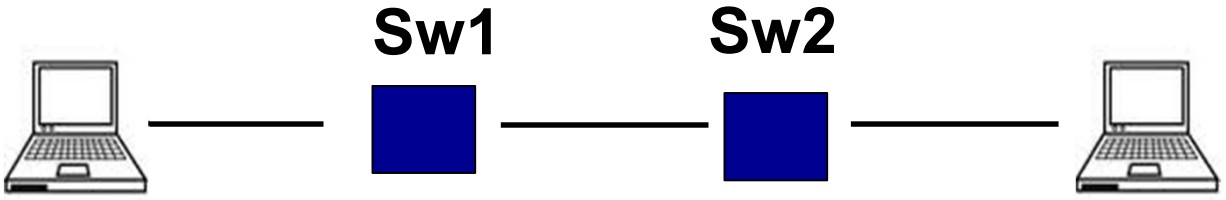


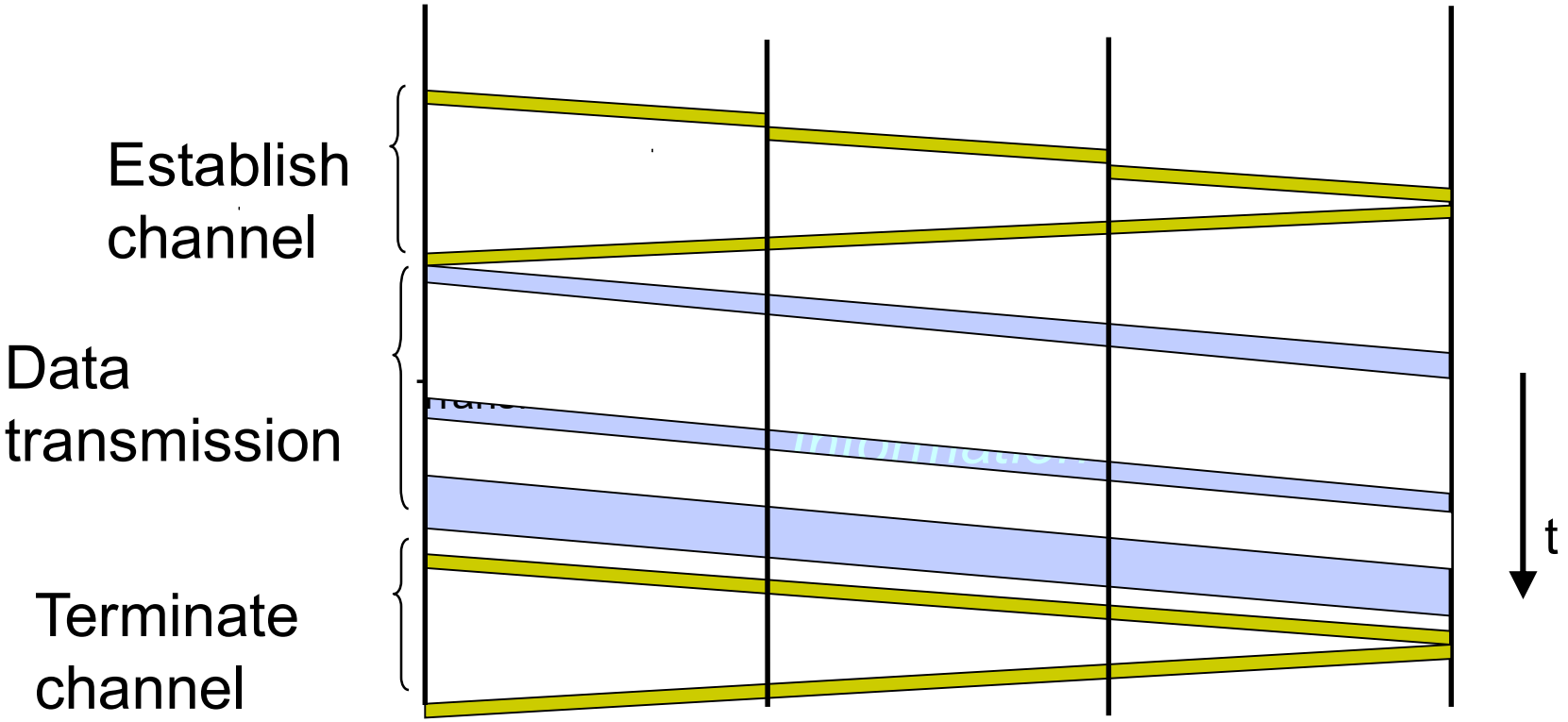
Pros and cons



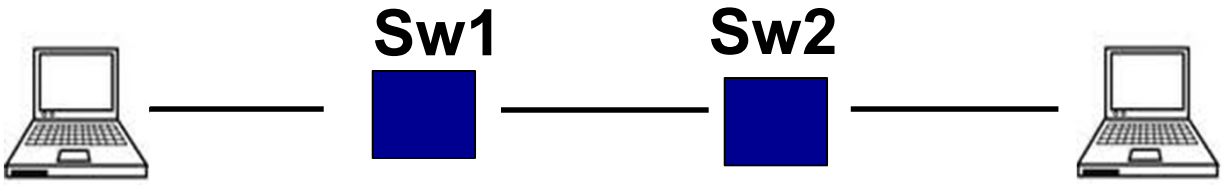
- Pros:
  - Established channel → low latency in switching
  - Reserved resources are private and stable during data transmission → quality of service
- Cons?

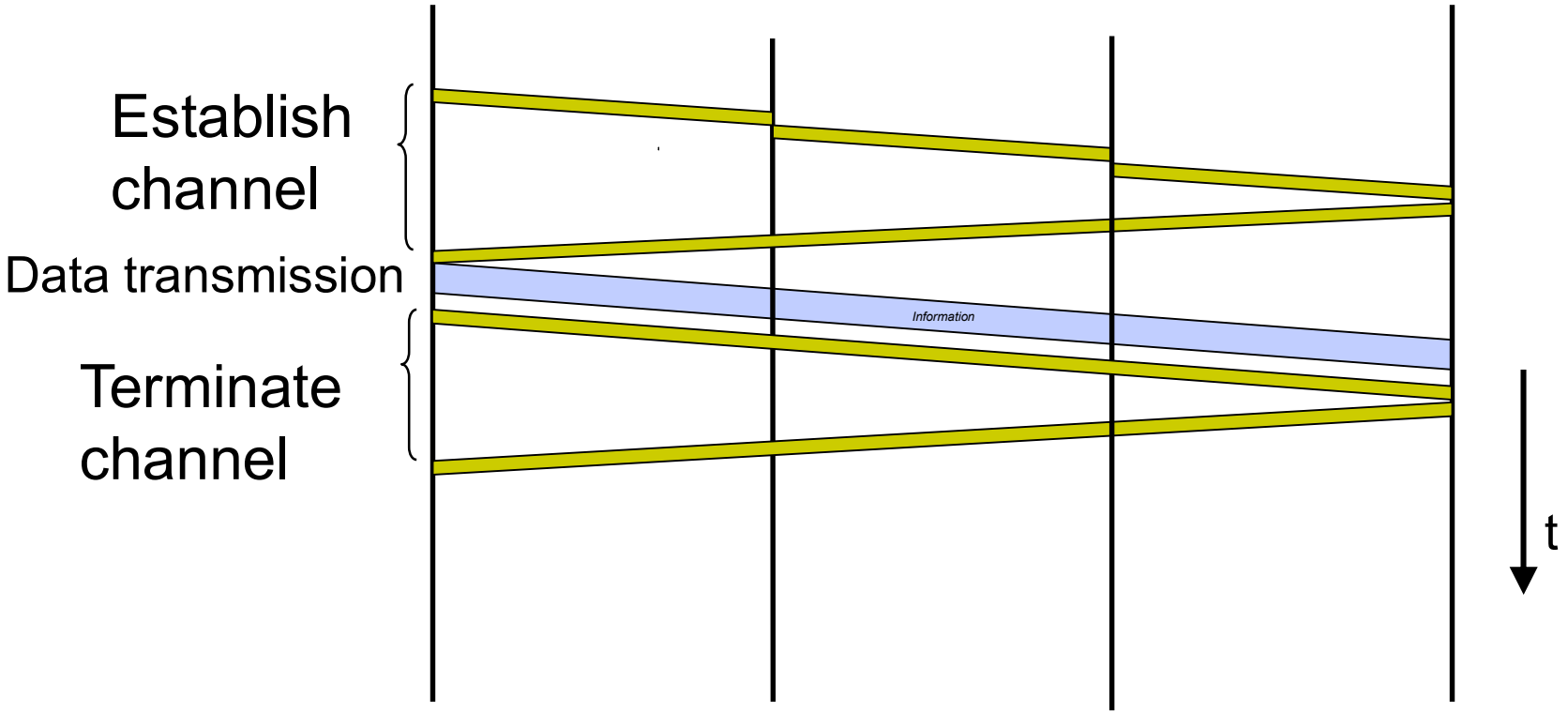
Cons: “blank” channel



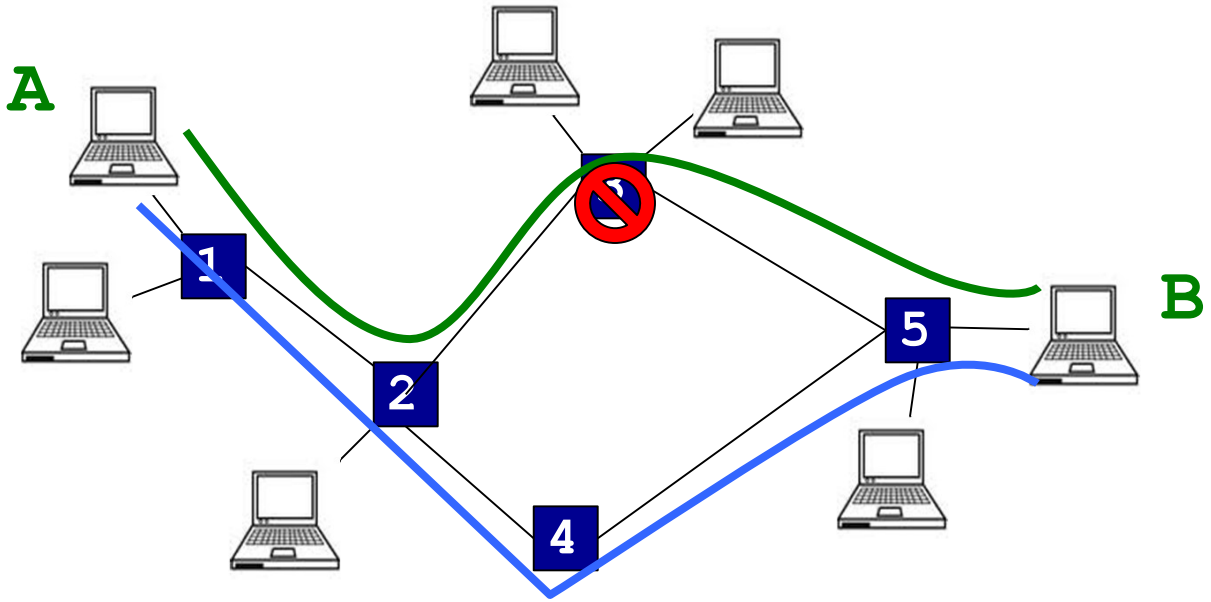


Cons: “small” channel





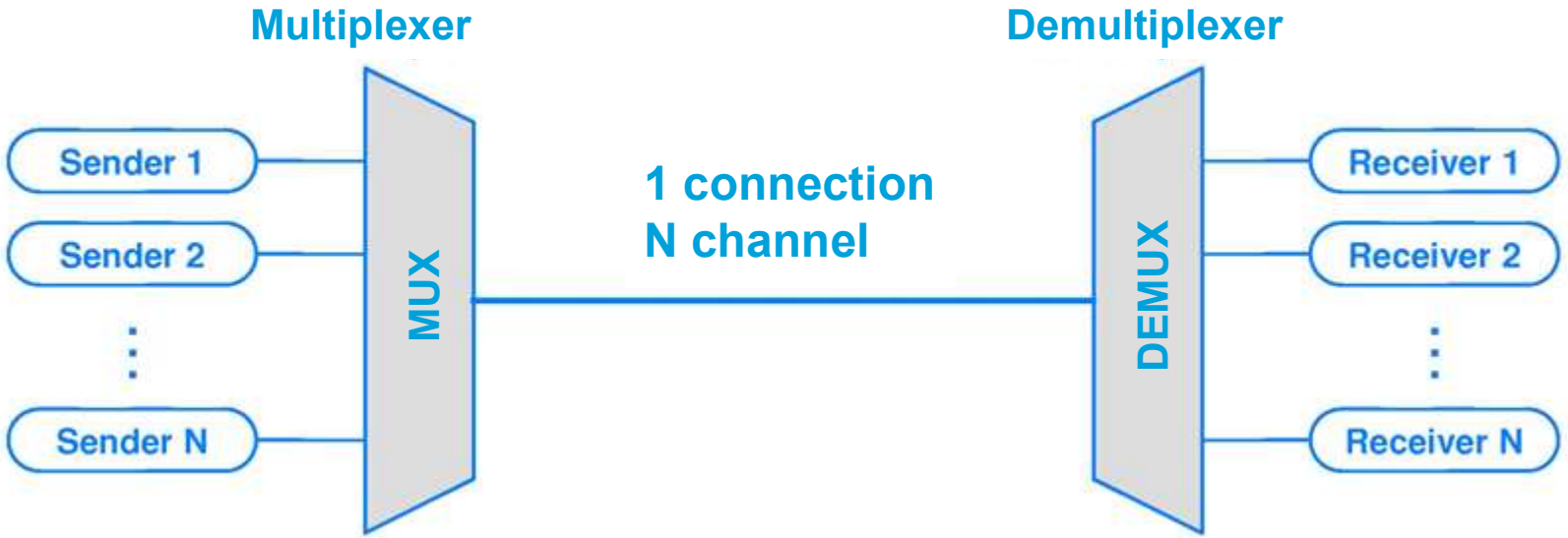
Cons: fault channel



- Have to restart from the channel establishment stage if errors happen

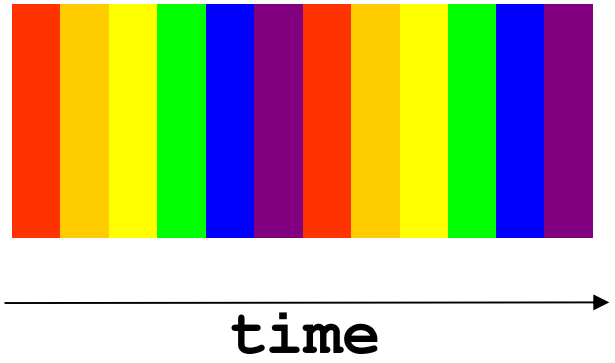
Multiplexing/ Demultiplexing

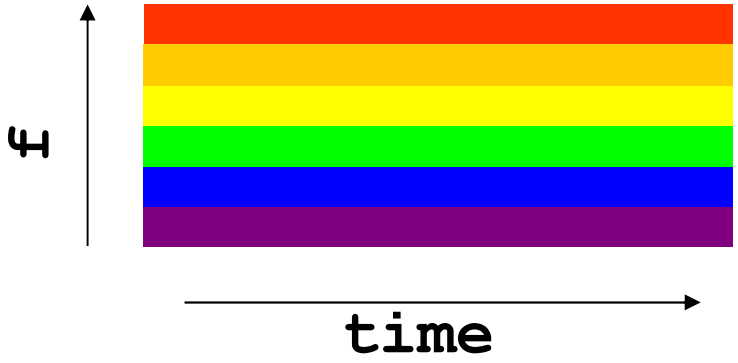
- Goal: many channels in a single physical connection
- Ghép kênh (Multiplexing): send data of multiple channels into a single physical connection
- Phân kênh (Demultiplexing): split data of multiple channels to the right channels and forward to the destinations



Some techniques for multiplexing

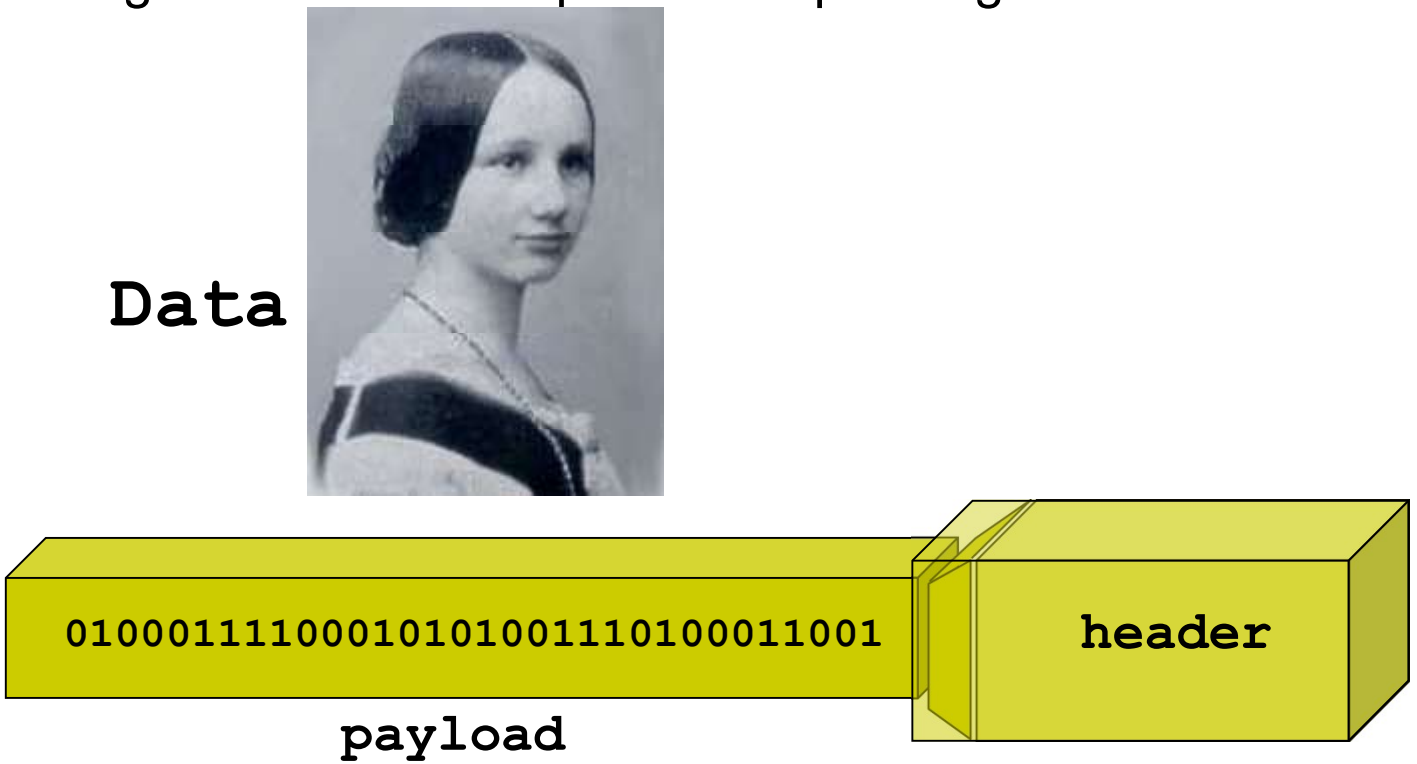
- Time Division Multiplexing: each connection use time-slot resources
- Frequency Division Multiplexing: each connection use a different frequencies



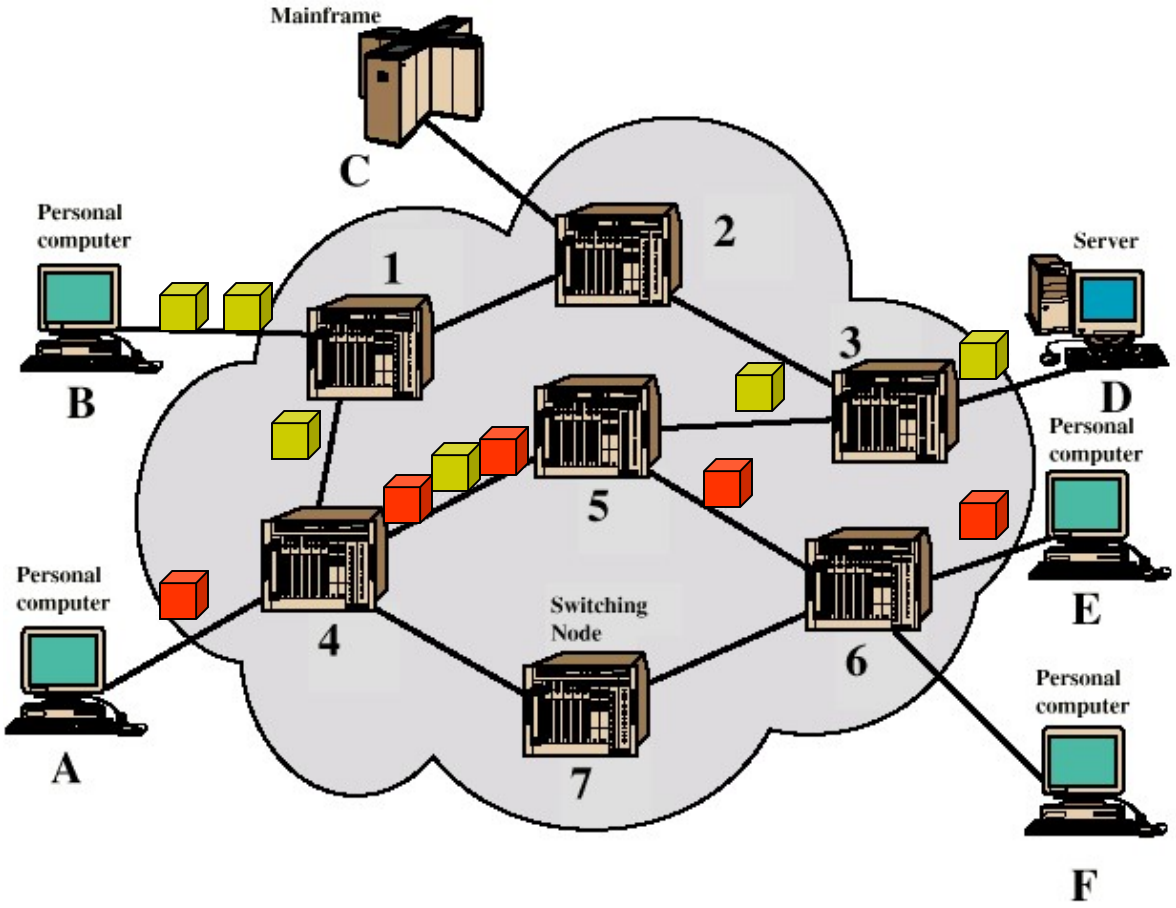


Packet switching

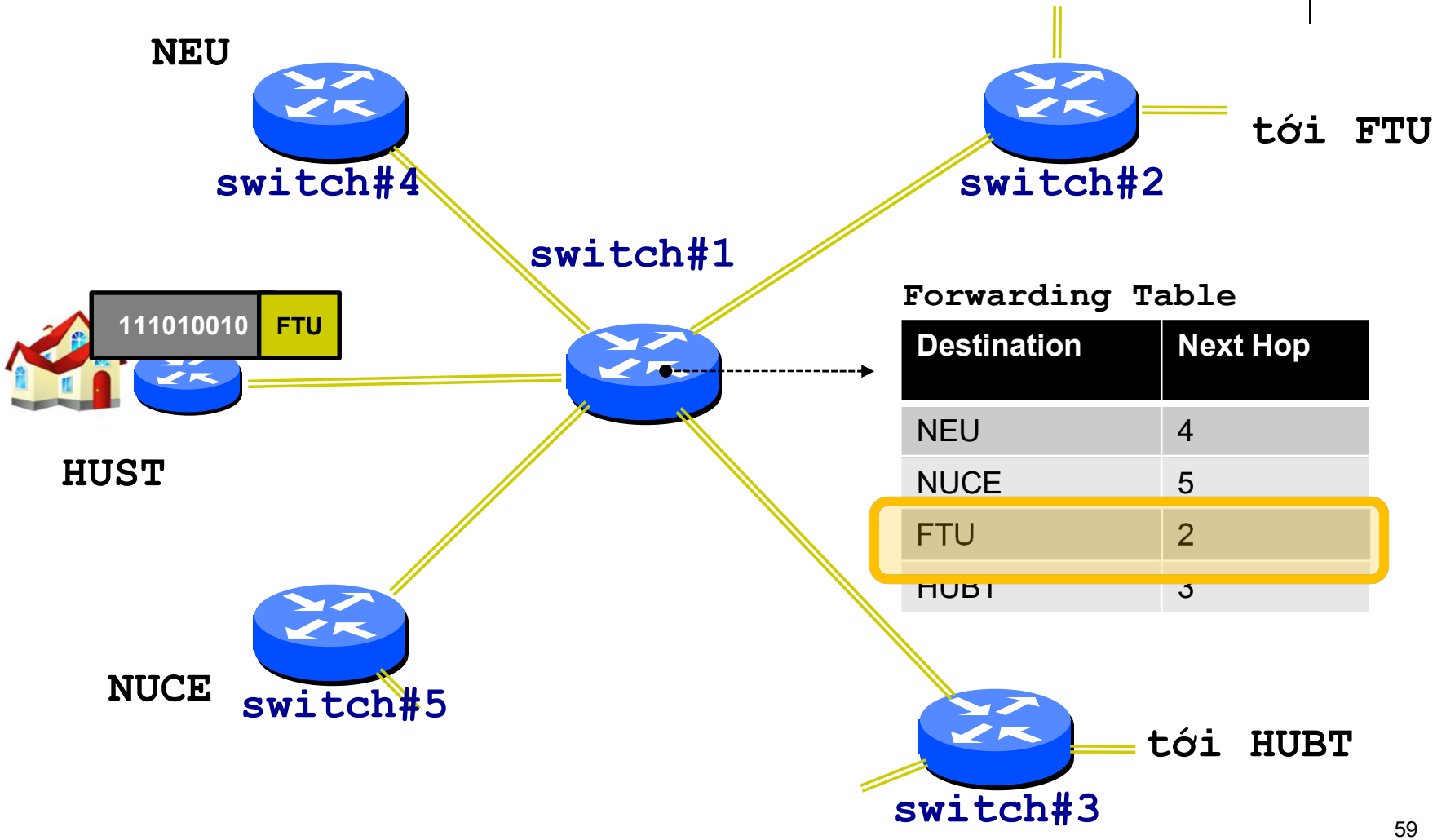
- Data are splitted to packets
  - Header: address, order number
  - Payload data
- Switching devices forward packets depending on header



Example

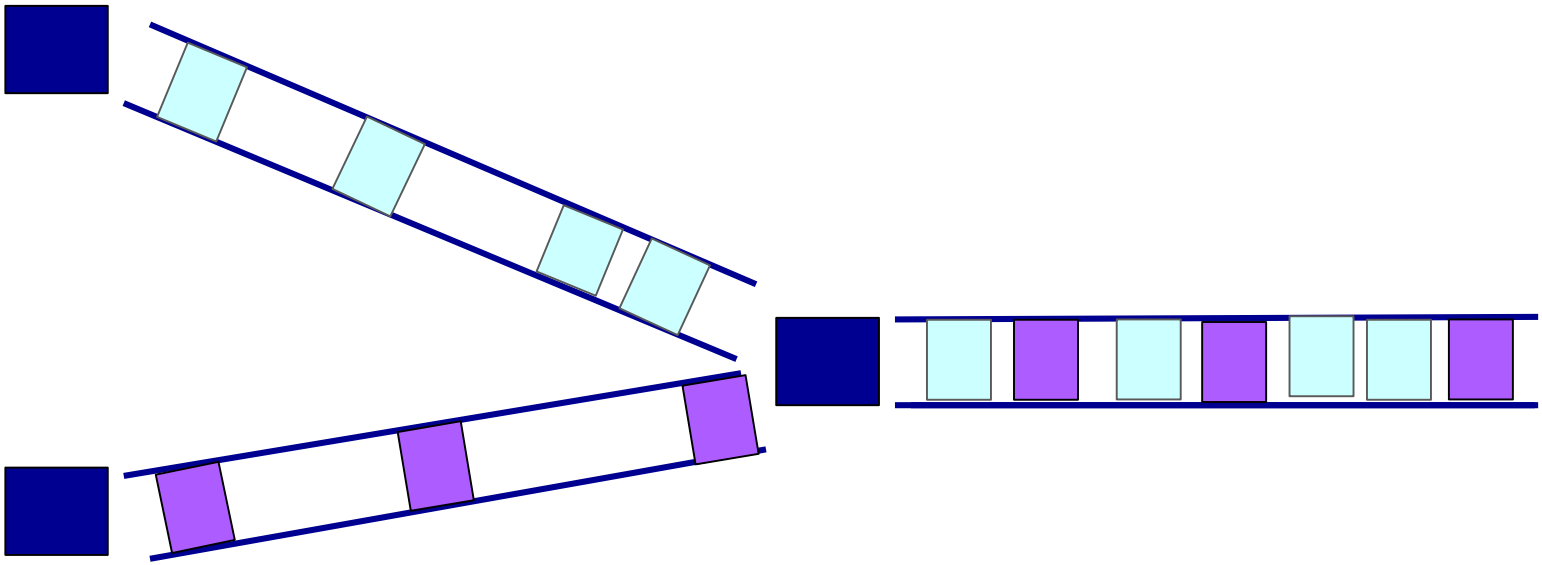

Mainframe
C
Personal computer
B
1
2
Server
D
3
Personal computer
E
5
Personal computer
A
4
Switching Node
6
7
Personal computer
F

Forwarding packets



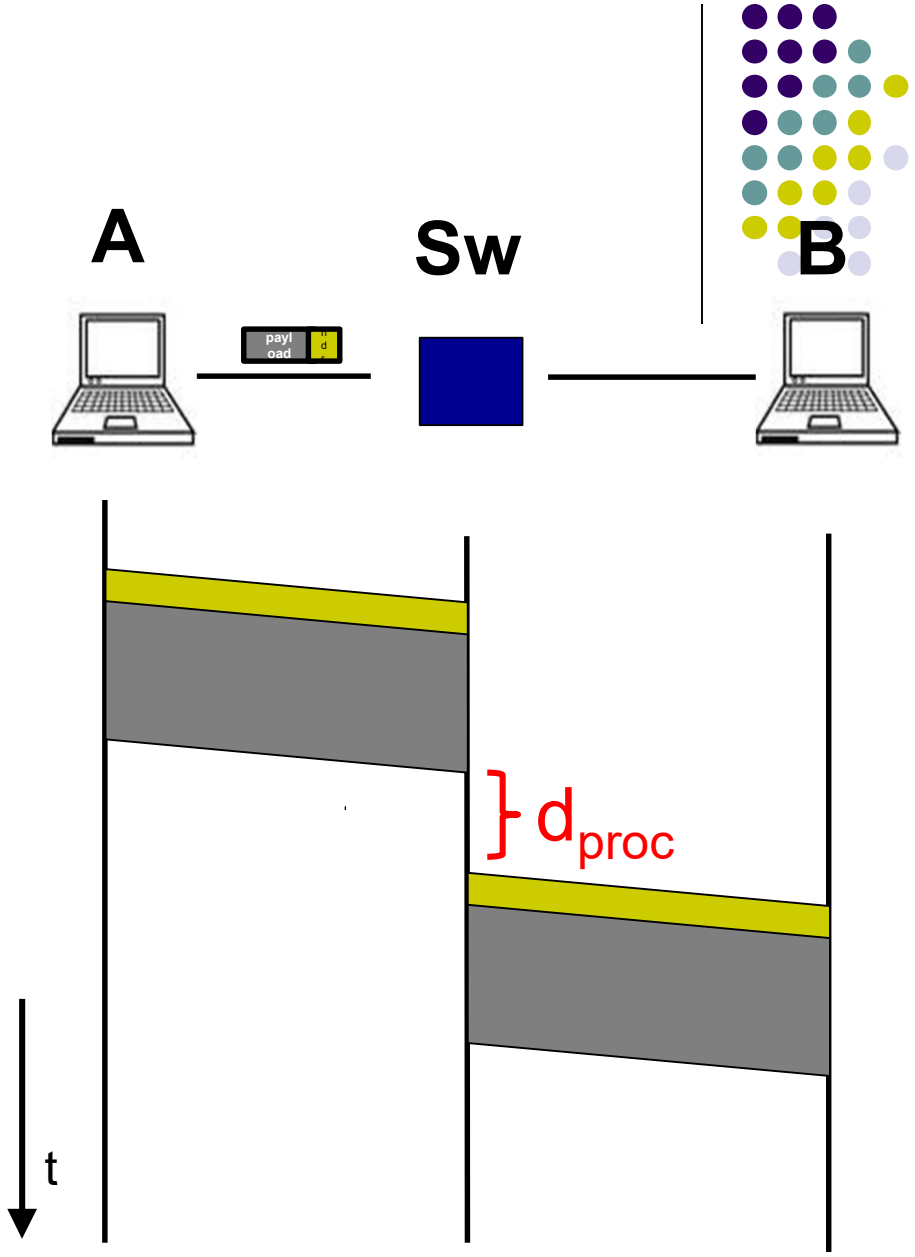
Packet switching

- Each packet can be processed independently
  - Each packet can have different paths to the destination, without the ordering
- Resources are shared for all connections
  - If resources are available, it can be used by any node



Timeline

- Switching devices only forward if receiving a completed packet (store and forward)
- Switching devices need time to process a packet (d_{proc}):
  - Check errors
  - Decide where to send
  - Typicallly much smaller than propagation delay



Circuit vs packet switching

Example:

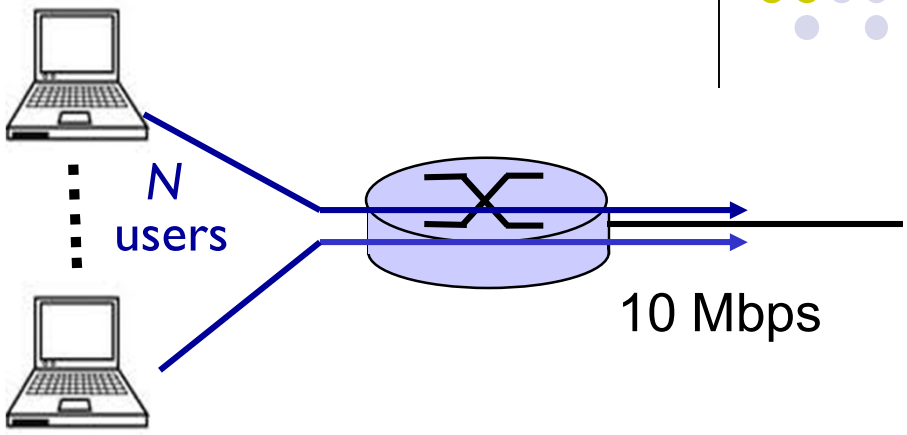
- Bandwidth10 Mb/s
- Each connection of users:
  - Allocate 1 Mb/s
  - Time to use for data transmission: 10% of total time

❖ *Circuit switching:*

- Maximum 10 users can transmit data simultaneously

❖ *Packet switching :*

- Assume there are 30 shared users
- Probability of more than 10 users to send data at the same time? (~0.0001)



- *Binomial distribution:*

$P(x = k) = C_n^k \, p^k \, (1-p)^{n-k}$

- *What happen if there are more users?*

Switching performance

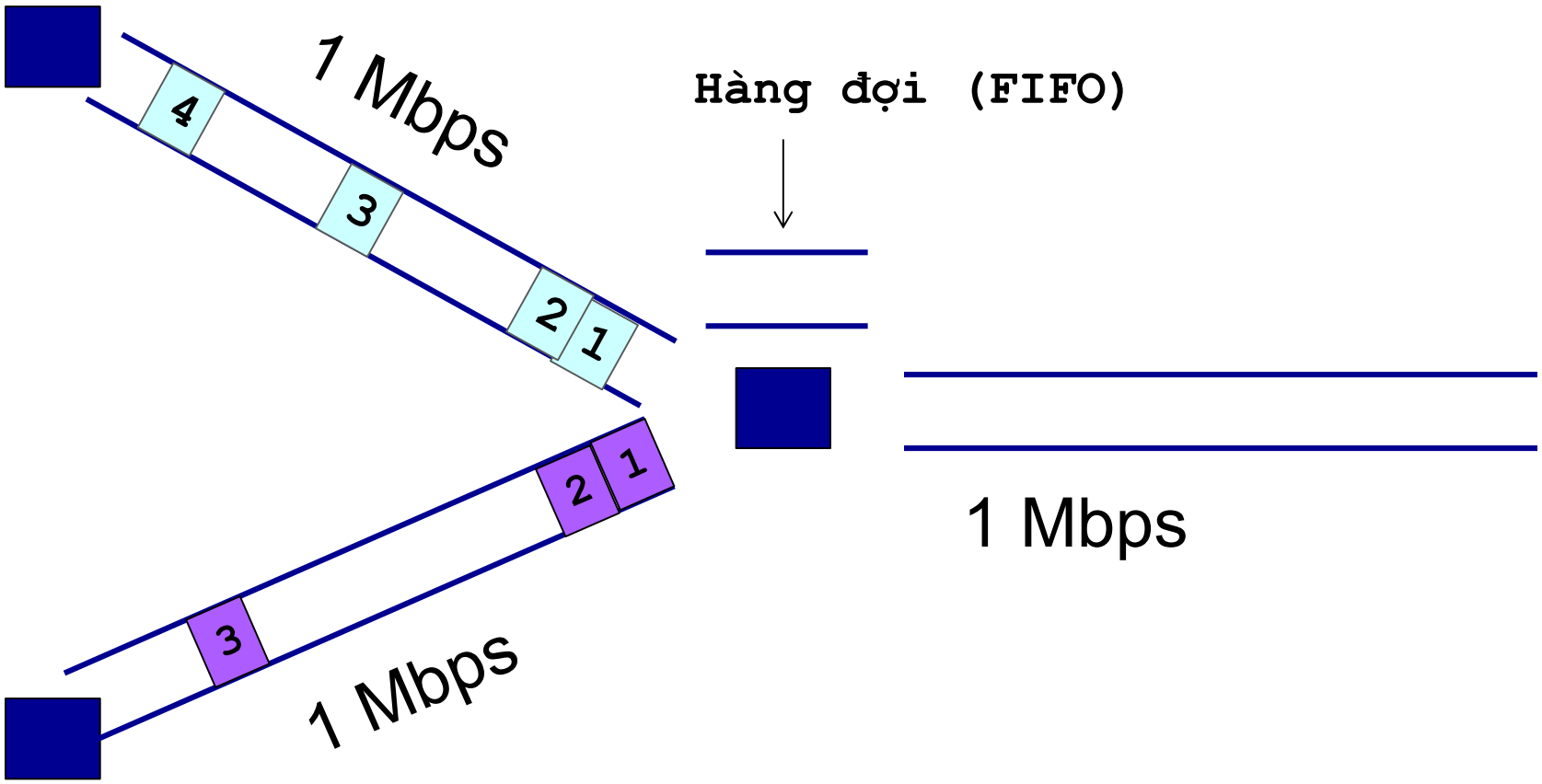
- Circuit switching network : Probability of all 10 users to send data at the same time:

$$P(k = 10) = C_{10}^{10} \times 0.1^{10} \times 0.9^{0} = 10^{-10}$$

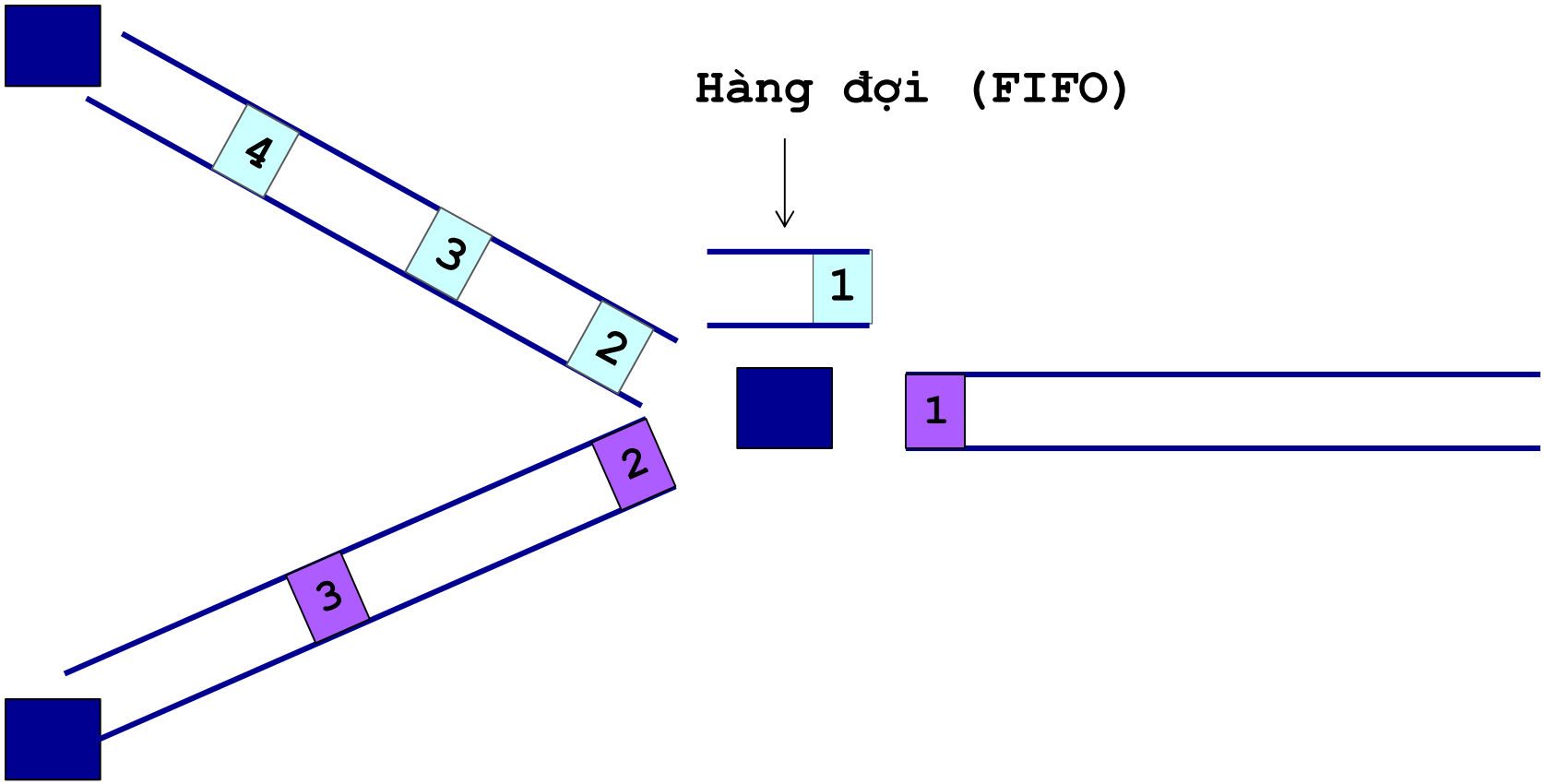
- Packet switching network : Probability of more than 10 users to send data at the same time

$$P(k = 10) = C_{30}^{10} \times 0.1^{10} \times 0.9^{20} =$$

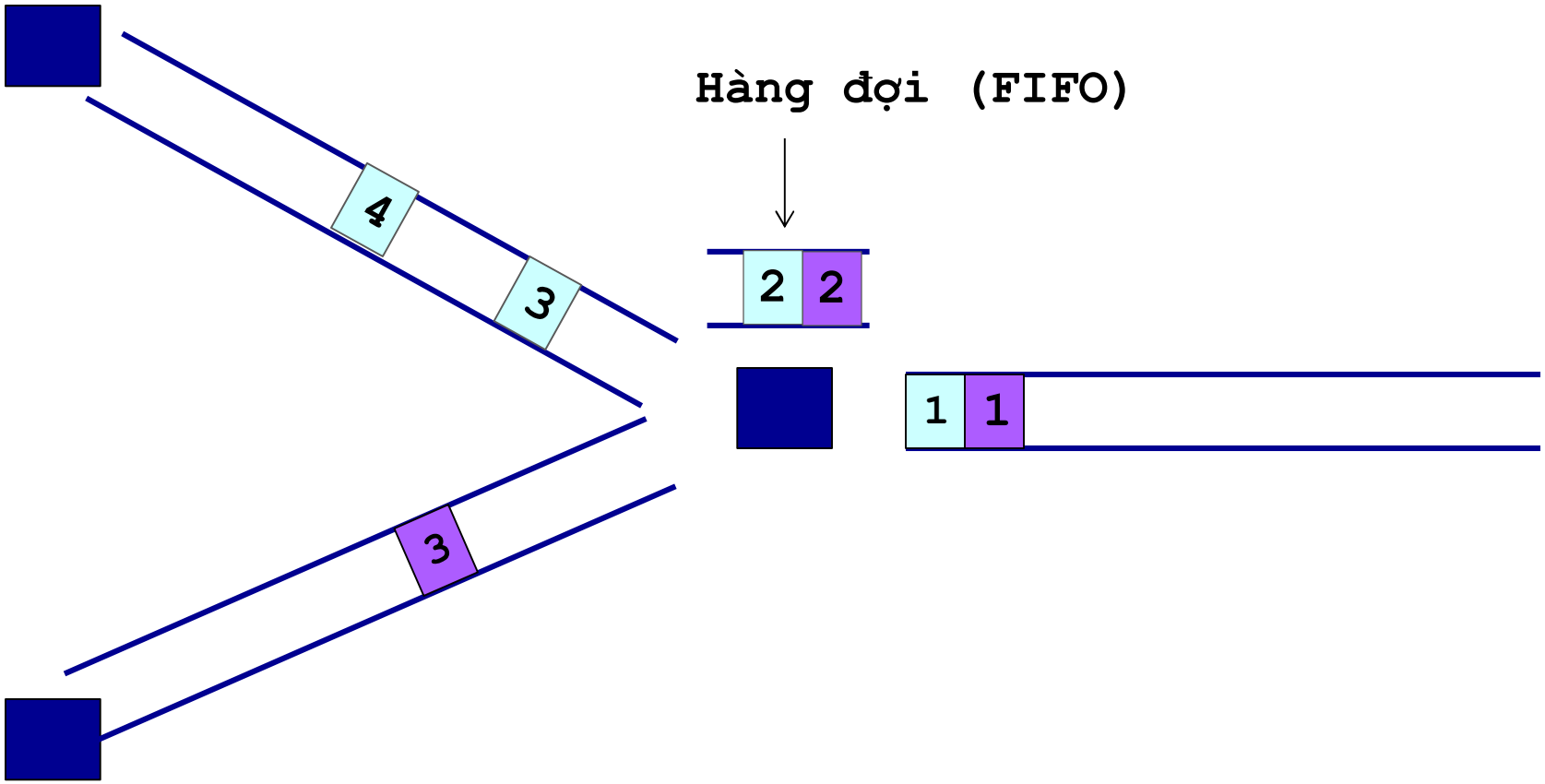
Queue



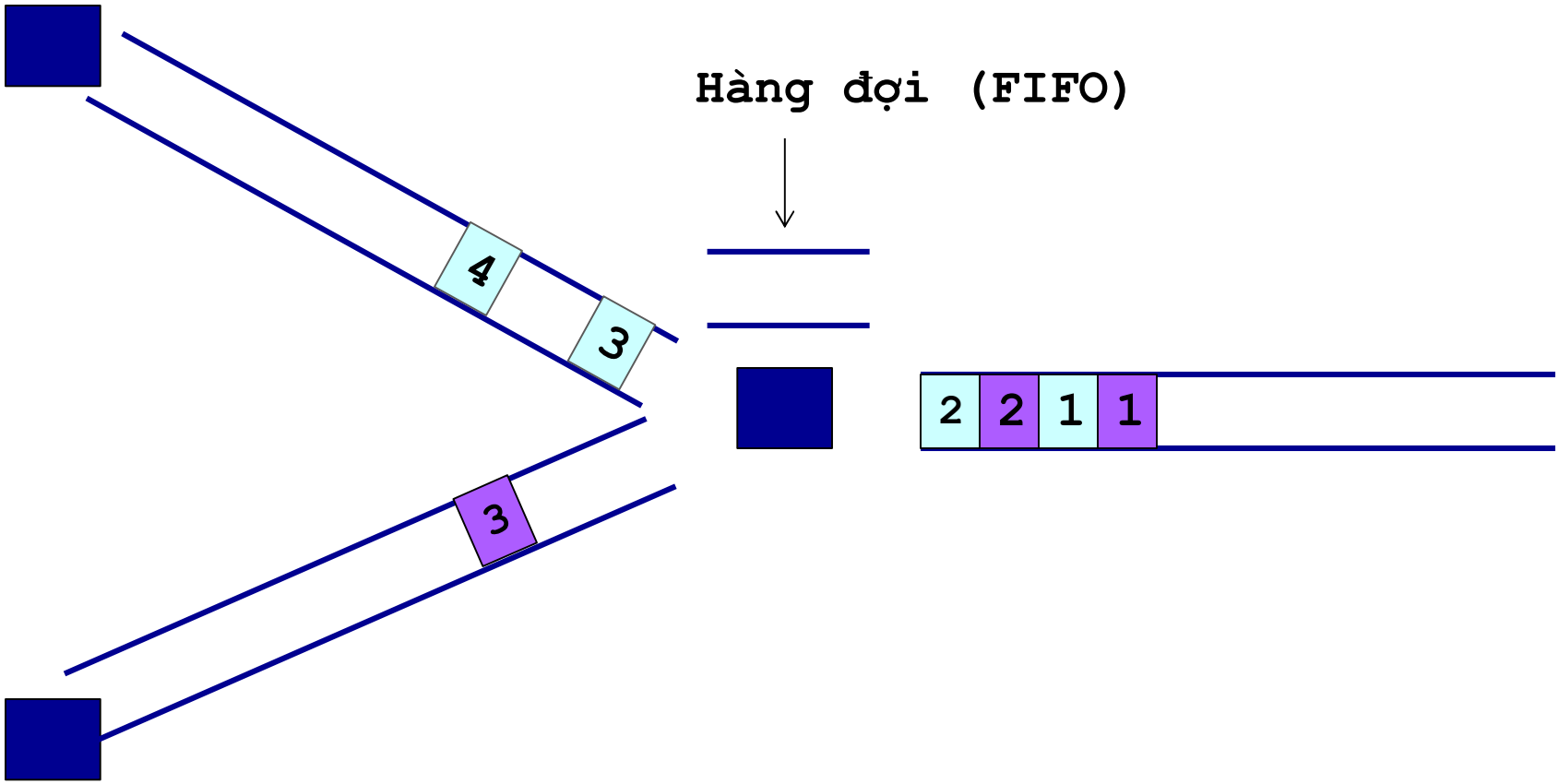
Queue



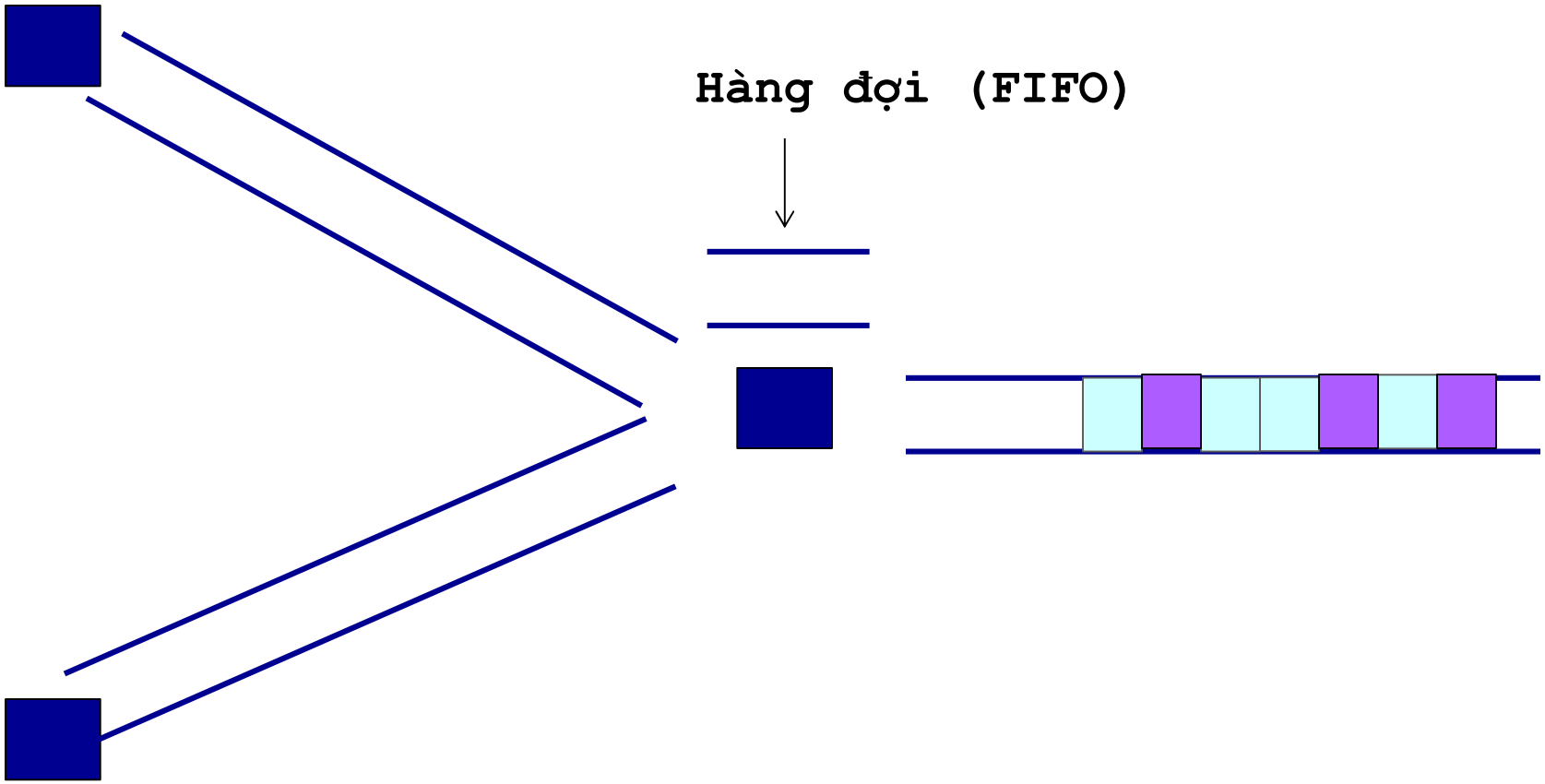
Hàng đợi



Queue

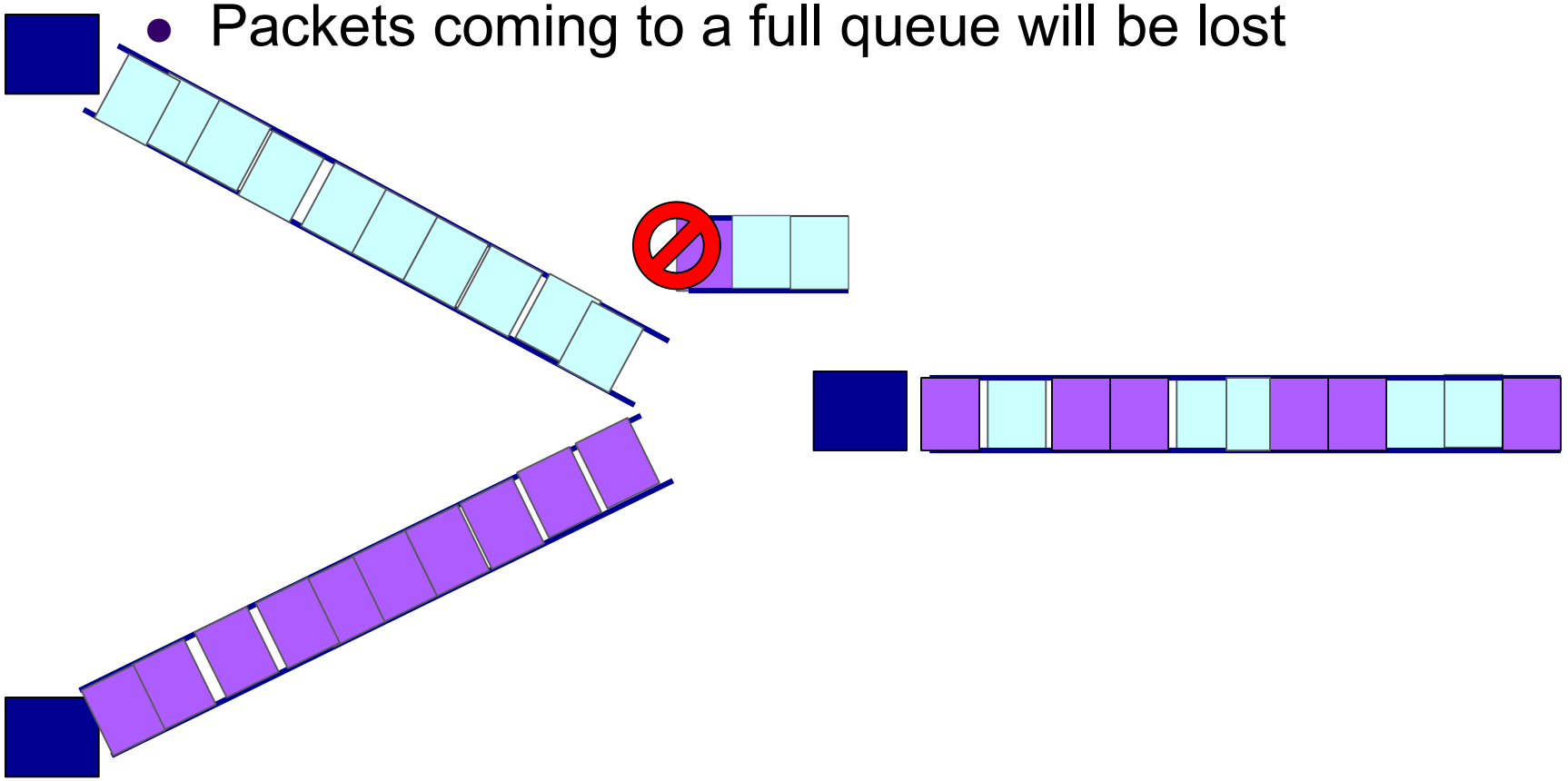


Queue



Packet loss

- Queue has its own limit
- Packets coming to a full queue will be lost

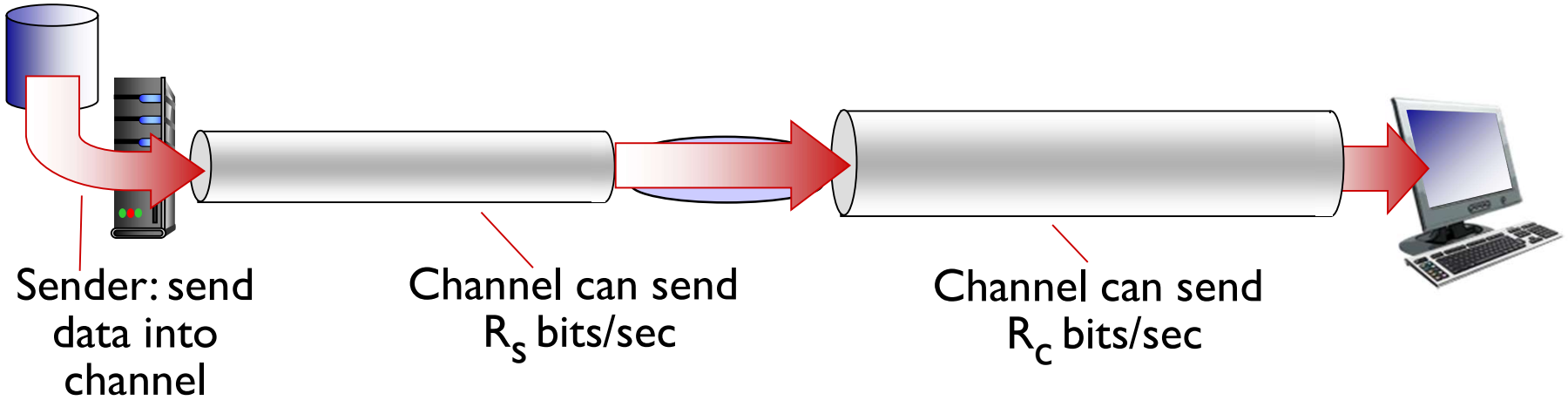


3. Một số thông số cơ bản trong mạng

- Bandwidth
- Throughput
- MTU (Maximum Transmission Unit)
- Latency
  - Delay on end nodes
  - Delay on intermediate nodes
  - Transmission delay
  - Propagation delay
- Package loss

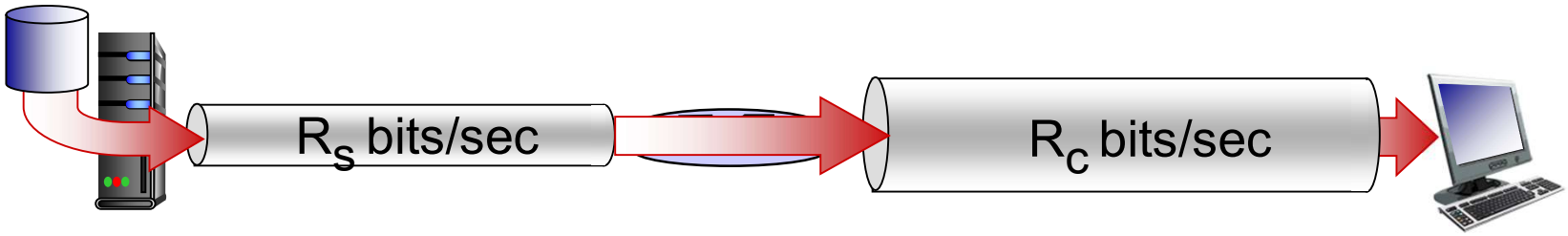
Thông lượng (throughput)

- *Throughput:* Speed (bits/sec) of data transmission at a time
  - *Instant:* throughput at a time
  - *Average:* average throughput during a period of time

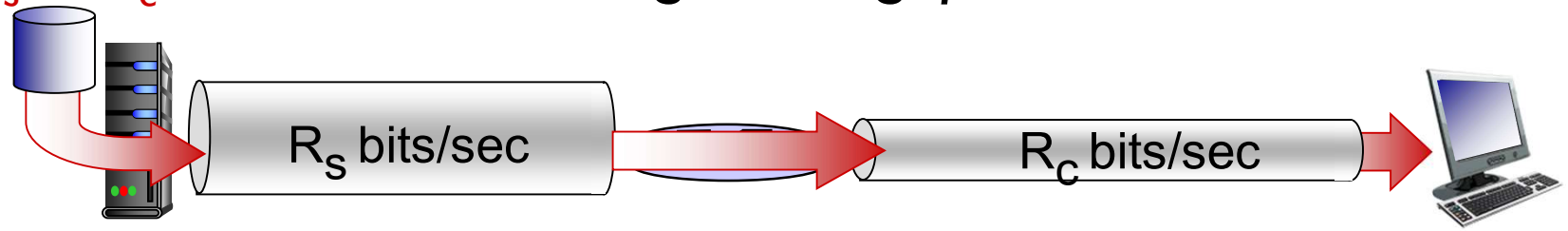


Throughput (cont.)

- $R_s < R_c$ *What is the average throughput?*



- $R_s > R_c$ *What is the average throughput?*

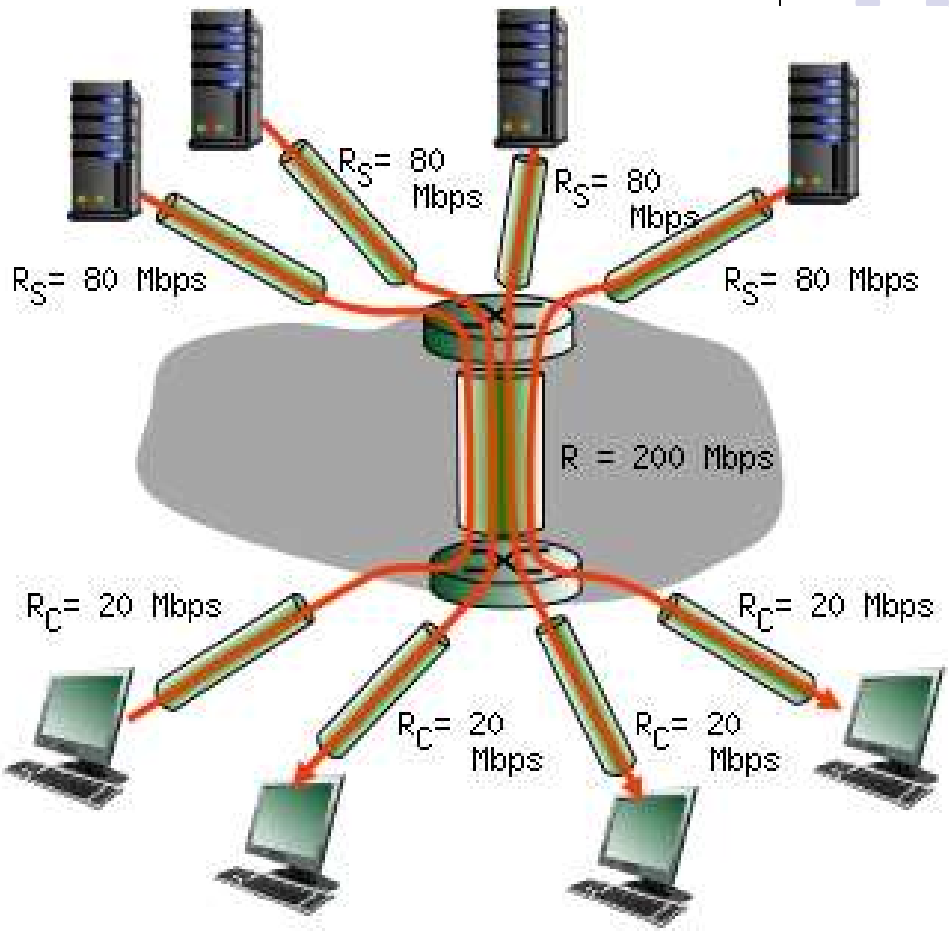


Nút thắt cổ chai (bottleneck)

The point limits the bandwidth of the transmission connection

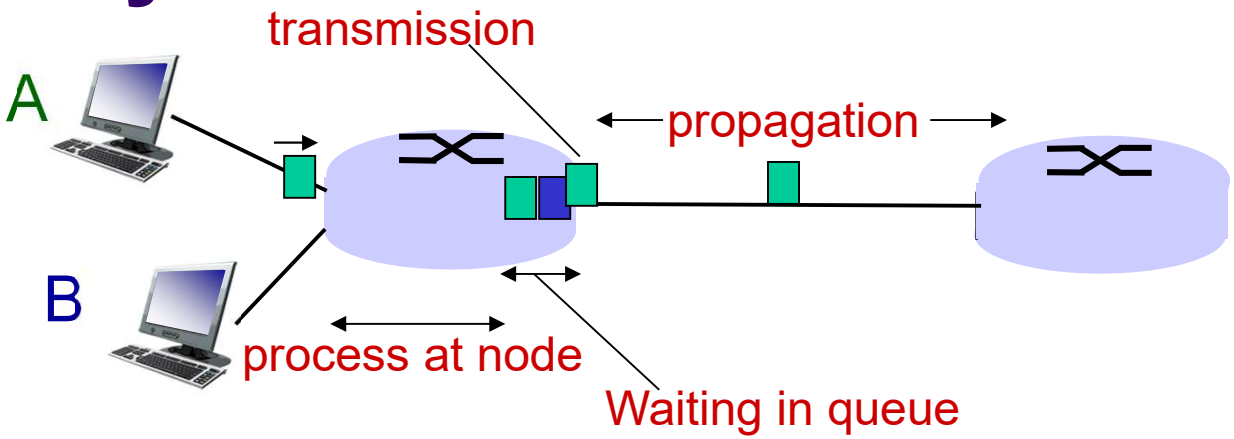
Bottleneck

- How to determine the bottlenecks?



Latency

Delay on end nodes
Delay on intermediate nodes
Transmission delay
Propagation delay



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

d_{trans}: transmission delay:

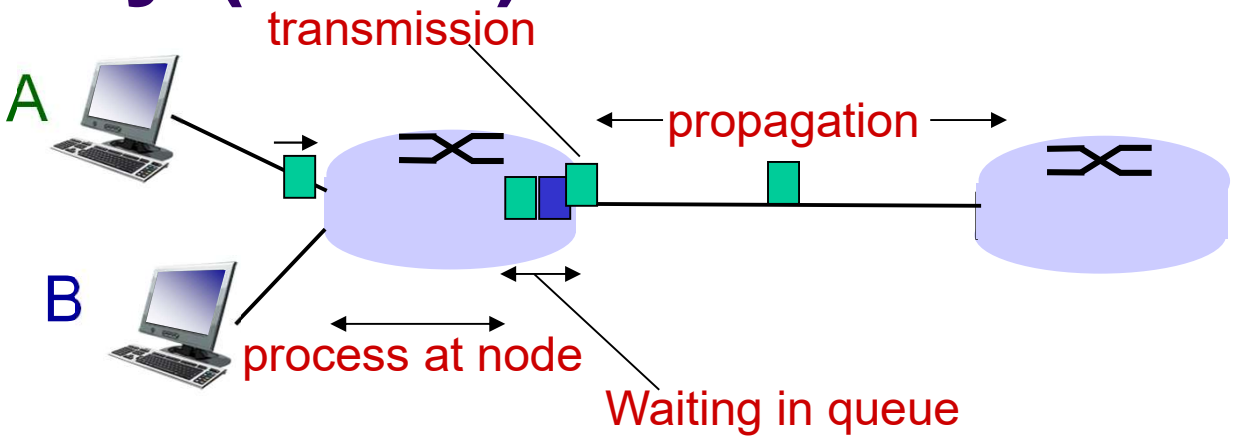
- *L*: size of data (bits)
- *R*: bandwidth*(bps)*
- $d_{trans} = L/R$

d_{prop}: propagation delay

- *d*: connection length
- *s*: speed of propagation (~2×10^8 m/sec)
- $d_{prop} = d/s$

Latency (cont.)

Delay on end nodes
Delay on intermediate nodes
Transmission delay
Propagation delay



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

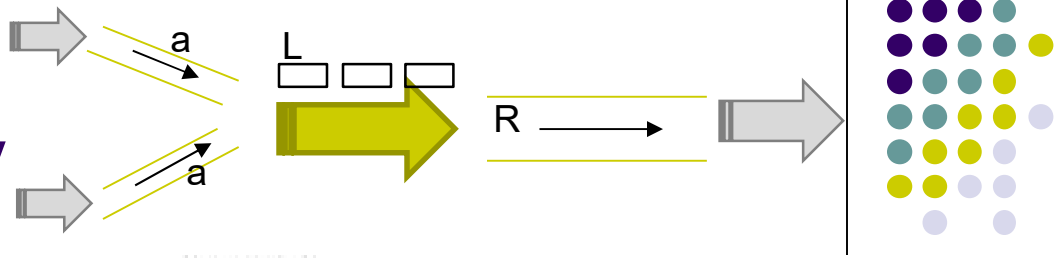
d_{proc}: processing delay

- Checking errors
- Determine the output connection
- Normally < μsec

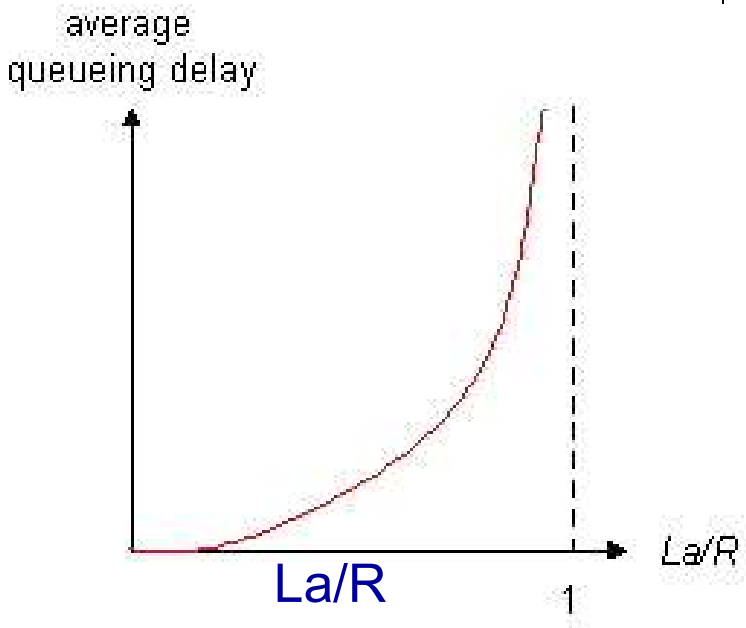
d_{queue}: queuing delay

- Depend on queuing data

Queuing delay



- *R*: bandwidth(bps)
- *L*: size of packet (bits)
- a: coming speed of packet



- *La/R* ~ 0: small delay
- *La/R* → 1: high delay
- *La/R* > 1: extreme high delay (loss)

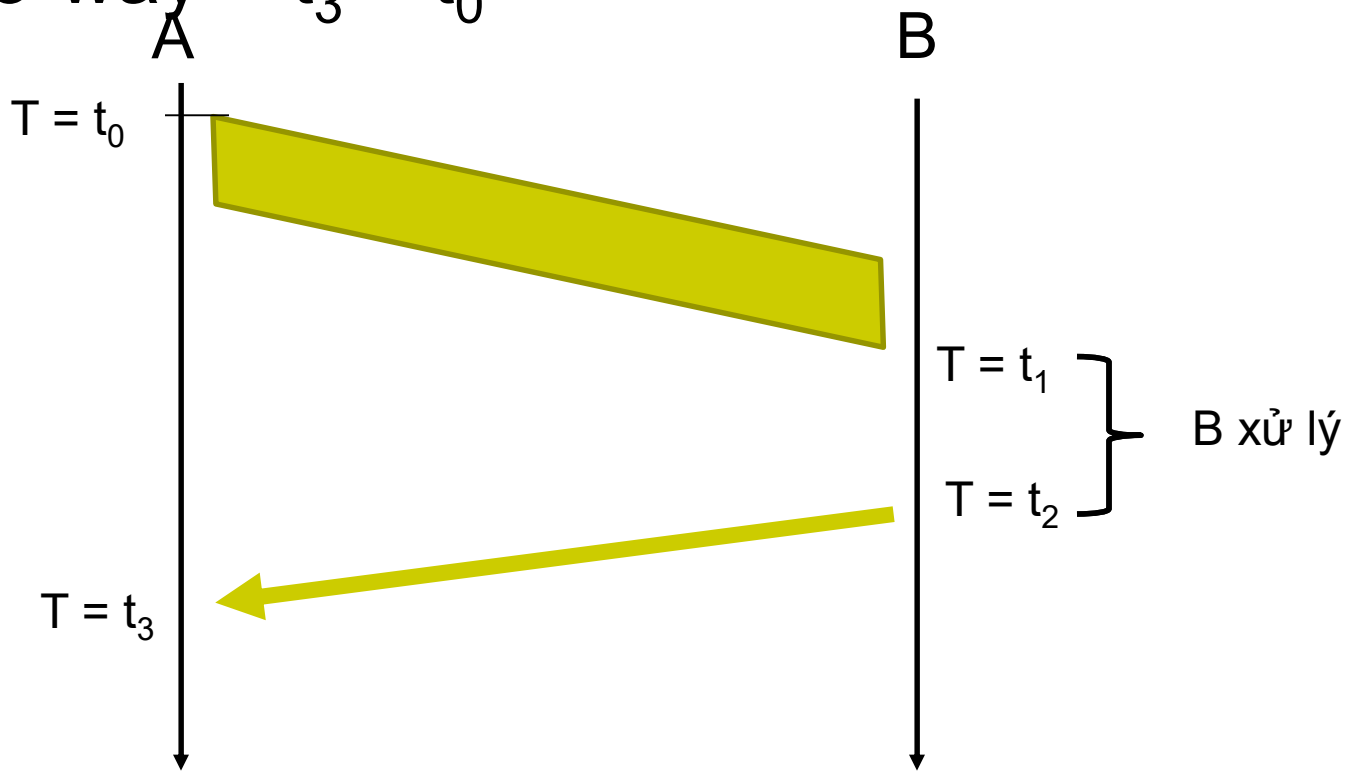
➔ The problem of speed coordination on end-to-end connection

La/R ~ 0

La/R -> 1

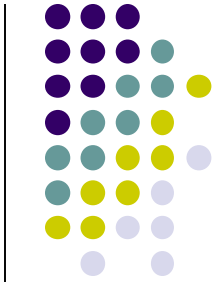
Round Trip Time

- RTT: Two-way = $t_3 - t_0$



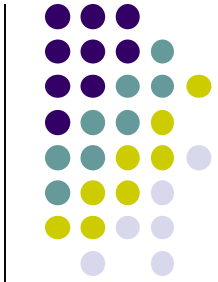
- One-way : $t_1 - t_0$

MTU



- Maximum Transmission Unit: maximum size of a packet can be sent on the connection
- Example: Ethernet has MTU of 1526 byte
- Why?
- Reason 1: reduce error rate
  - BER = error bits / total sent bits → constant
  - Ex: BER = 10^{-3} → send 1000 bits will yield 1 error bit
  - If L = 1000 bit → probability of a packet having error(s)?
  - If L = 100 bit → probability of a packet having error(s)?
- Reason 2: reduce the probability (or data size) of sending lost packets
  - Queue size: N byte
  - If L = 1000 byte: full queue → lost packet → resend it → send 1000 bytes
  - If L = 1000 byte: full queue → ?
- Conclusion: reducing MTU will reduce the size of re-sending data

But MTU cannot be too small



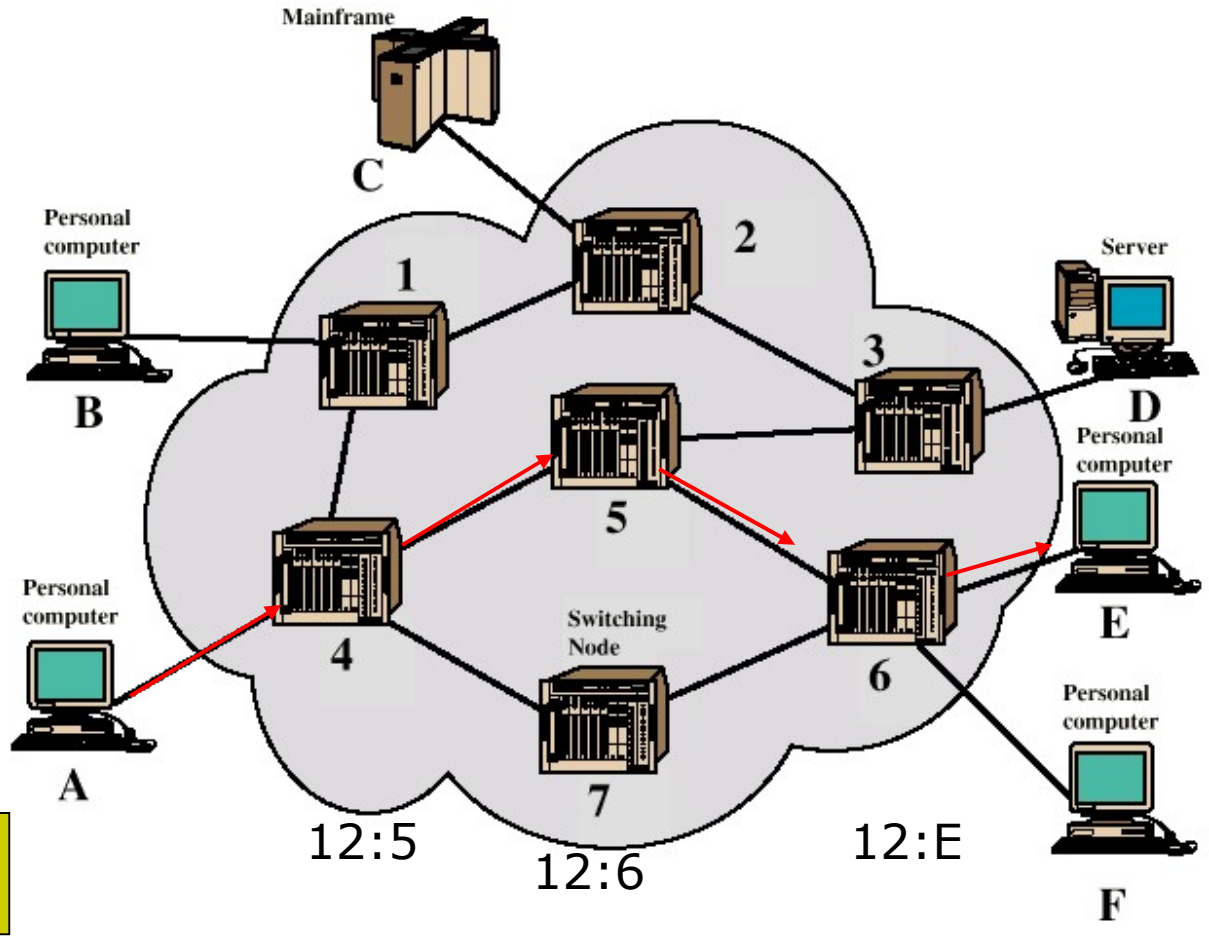
- Too small MTU will reduce performance of data transmission
- Explanation :
  - Packet: header + payload
  - Header: Constant
  - Performance:

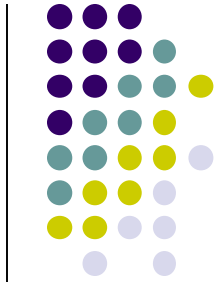
$$H = \frac{payload}{header + payload}$$

Virtual circuit switching

- Packets are forwarded using a fixed route → virtual circuit
- Different parts of the circuit (links) can still be shared between different connections
- Packets arrive to destination in order.
- Fast packet switching

Data	12



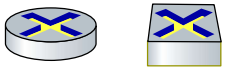


INTERNET

The Internet: a "nuts and bolts" view

Billions of connected computing *devices*:

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



Packet switches: forward packets (chunks of data)

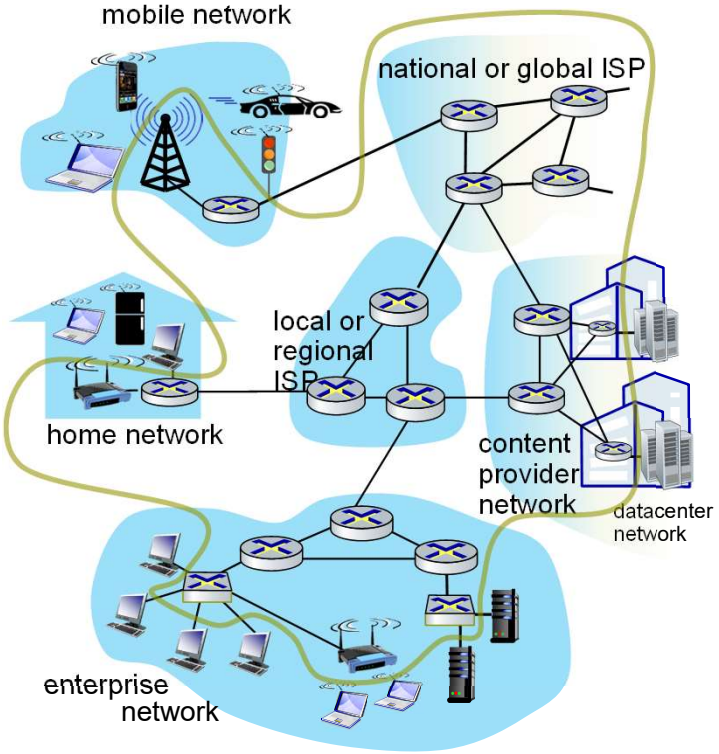
- *routers*, *switches*

Communication links

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

Networks

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



“Fun” Internet-connected devices

Amazon Echo

Internet refrigerator

IP picture frame

Pacemaker & Monitor

Tweet-a-watt: monitor energy use

bikes

cars

scooters

Security Camera

Slingbox: remote control cable TV

Web-enabled toaster + weather forecaster

AR devices

Internet phones

Gaming devices

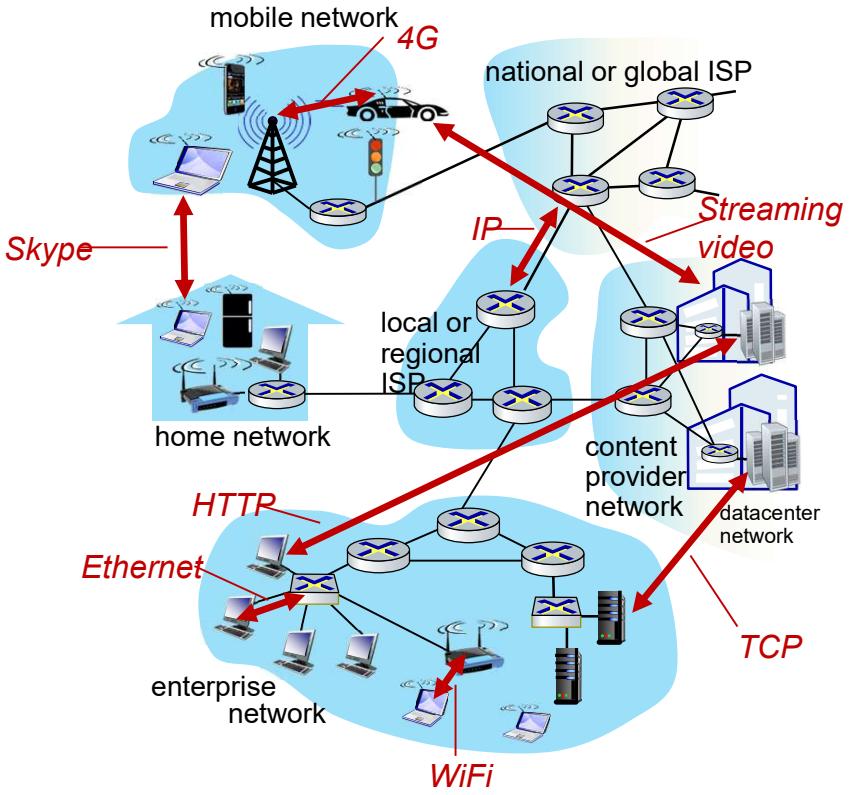
sensorized, bed mattress

Fitbit

Others?

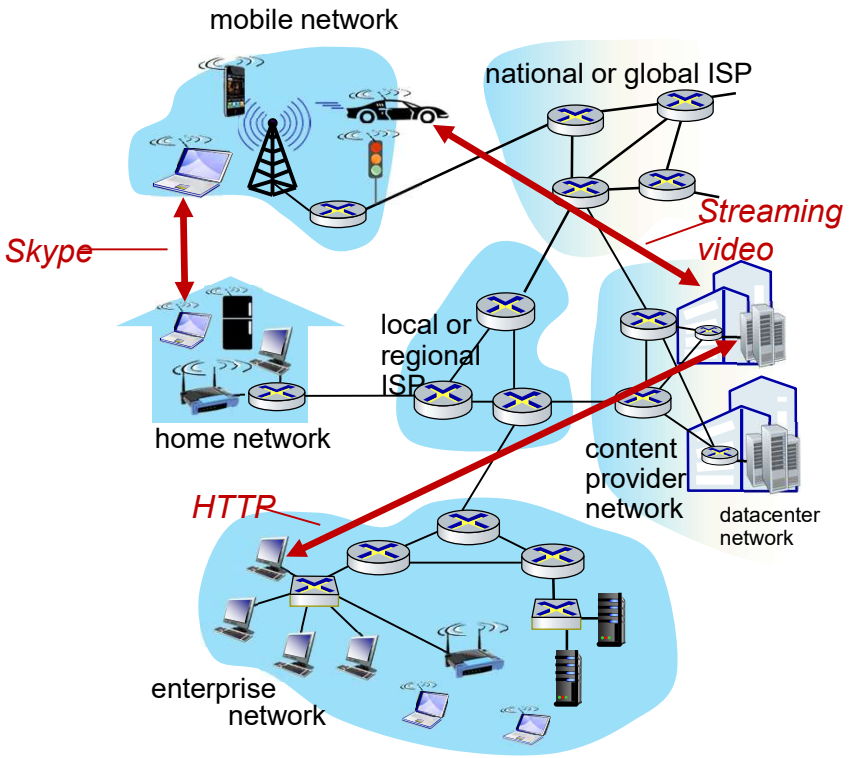
The Internet: a "nuts and bolts" view

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



The Internet: a "services" view

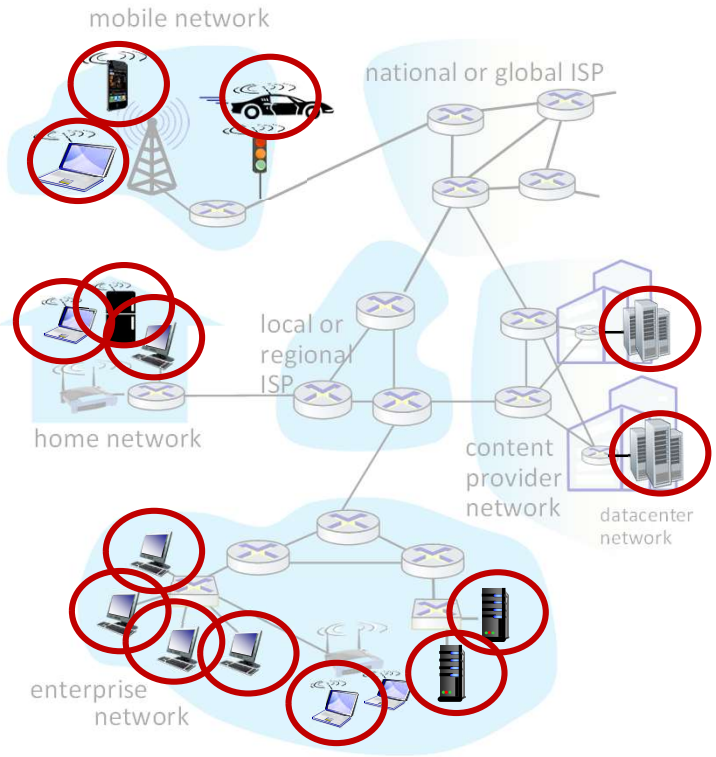
- *Infrastructure* that provides services to applications:
  - Web, streaming video, multimedia teleconferencing, email, games, e-commerce, social media, inter-connected appliances, …
- provides *programming interface* to distributed applications:
  - "hooks" allowing sending/receiving apps to "connect"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



A closer look at Internet structure

Network edge:

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



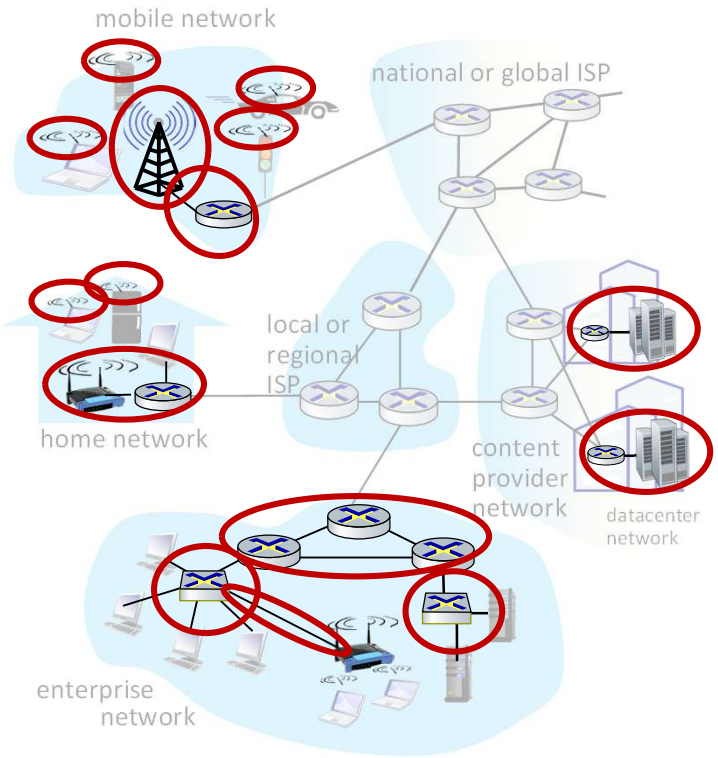
A closer look at Internet structure

Network edge:

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

Access networks, physical media:

- wired, wireless communication links



A closer look at Internet structure

Network edge:

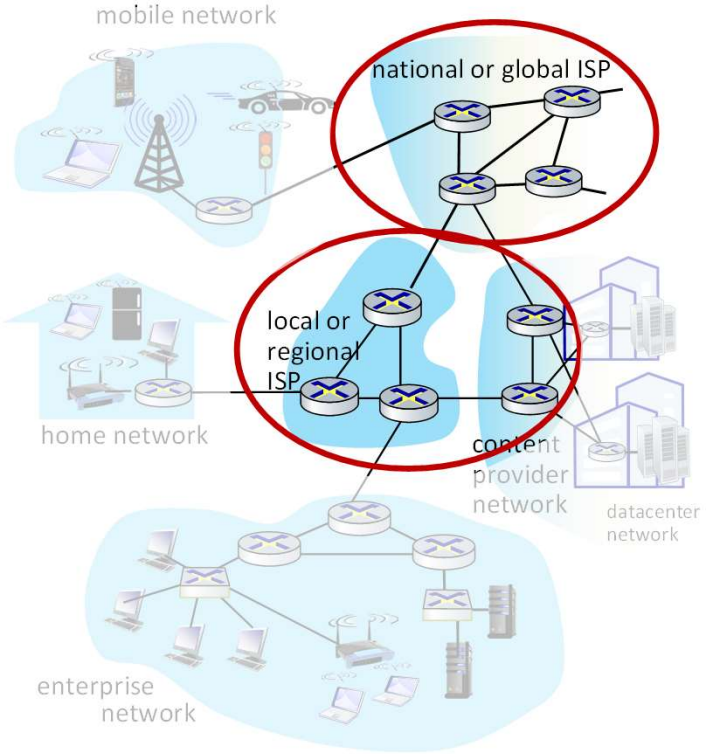
- hosts: clients and servers
- servers often in data centers

Access networks, physical media:

- wired, wireless communication links

Network core:

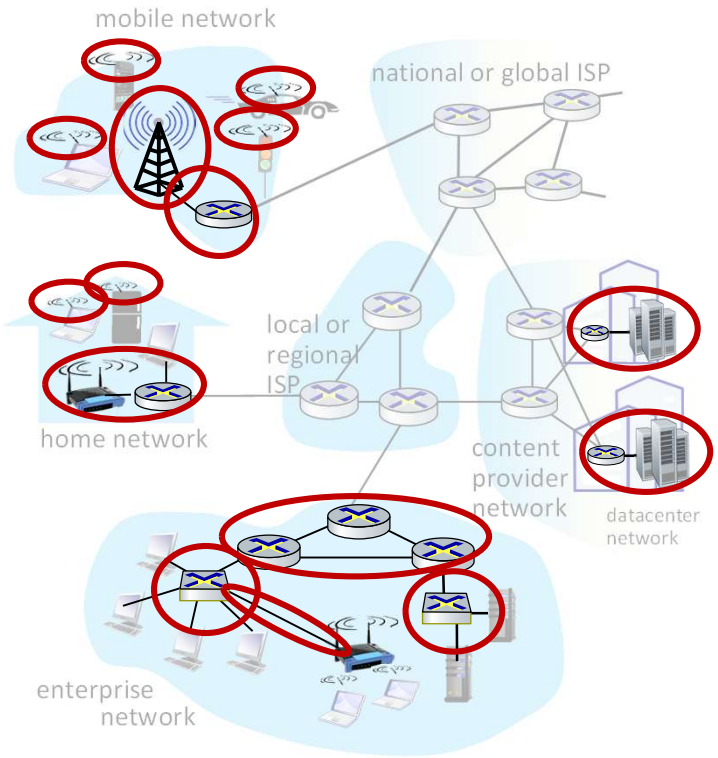
- interconnected routers
- network of networks



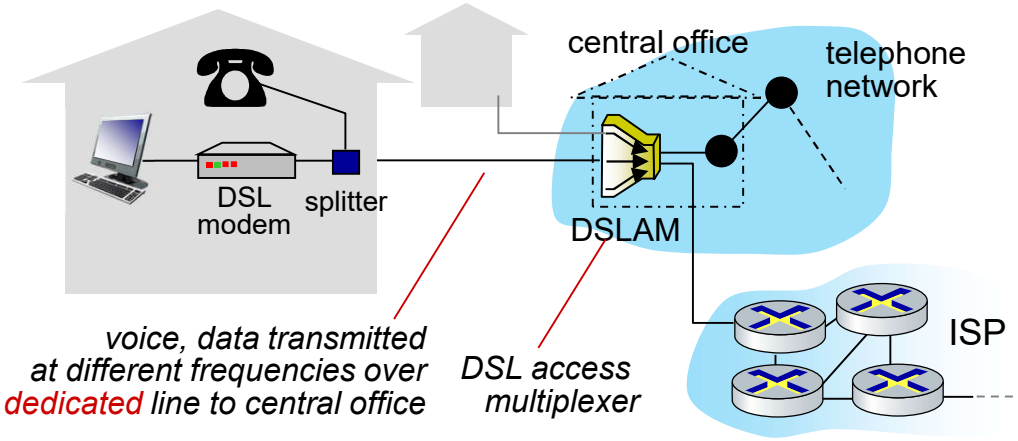
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks (WiFi, 4G/5G)

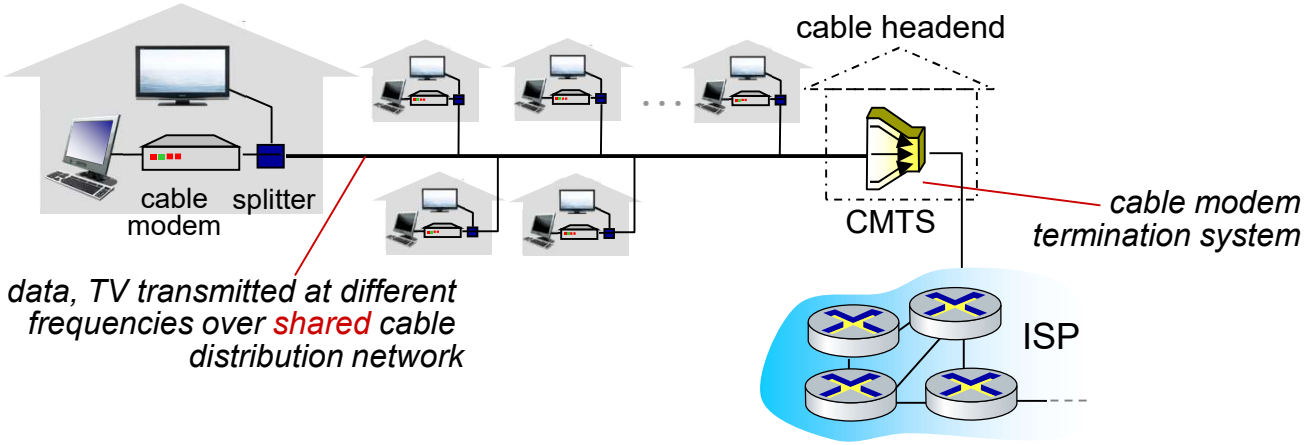


Access networks: digital subscriber line (DSL)



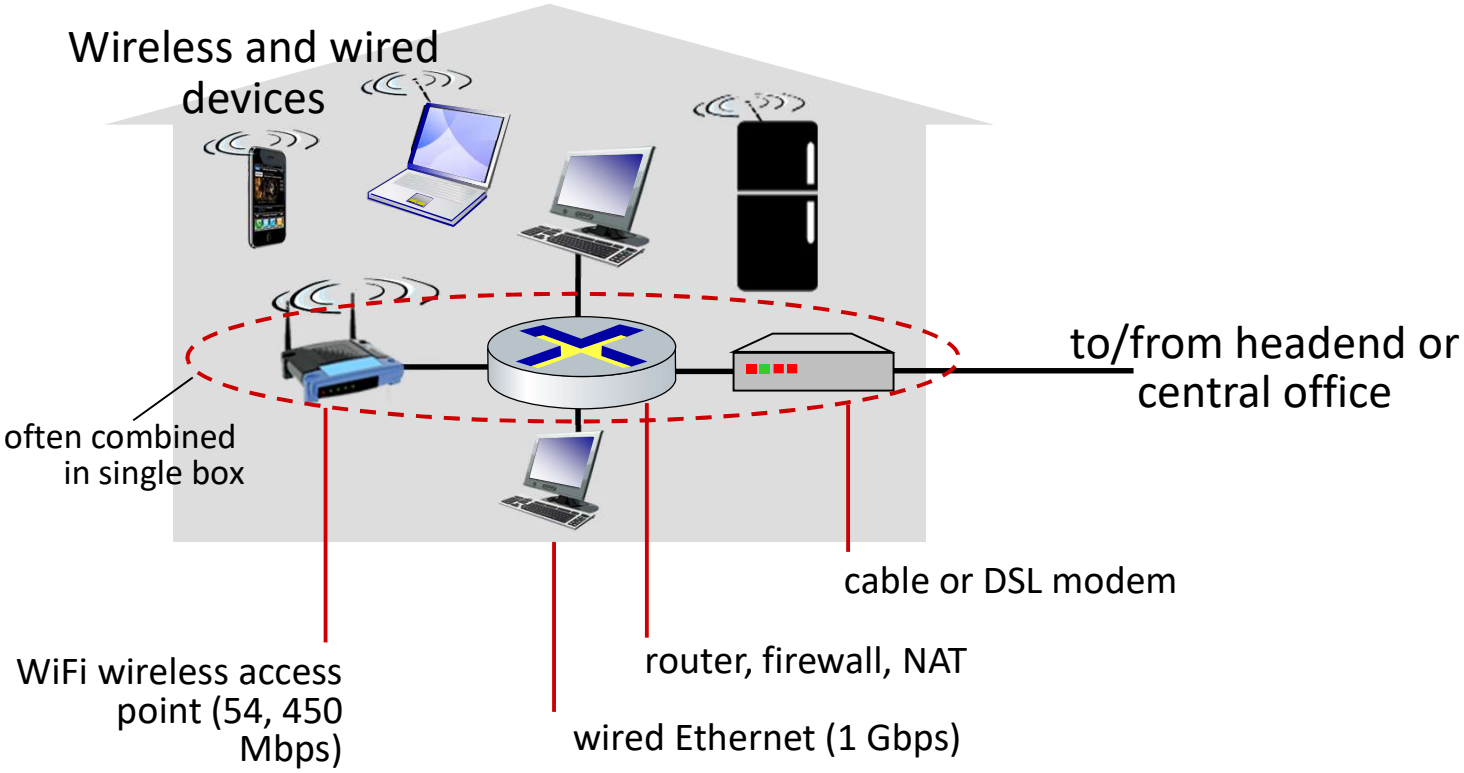
- use *existing* telephone line to central office DSLAM
  - data over DSL phone line goes to Internet
  - voice over DSL phone line goes to telephone net
- 24-52 Mbps dedicated downstream transmission rate
- 3.5-16 Mbps dedicated upstream transmission rate

Access networks: cable-based access



- HFC: hybrid fiber coax
  - asymmetric: up to 40 Mbps – 1.2 Gbps downstream transmission rate, 30-100 Mbps upstream transmission rate
- network of cable, fiber attaches homes to ISP router
  - homes *share access network* to cable headend

Access networks: home networks



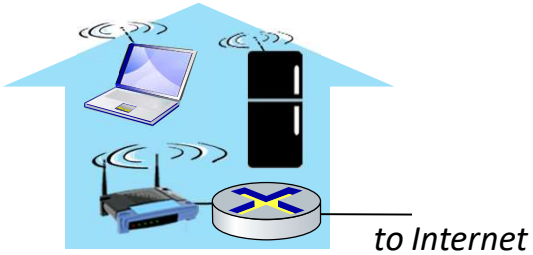
Wireless access networks

Shared *wireless* access network connects end system to router

- via base station aka “access point”

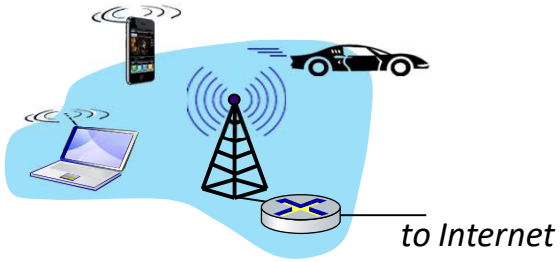
Wireless local area networks (WLANs)

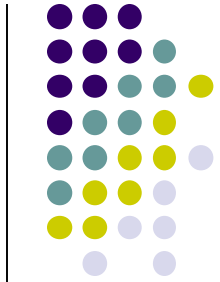
- typically within or around building (~30 m)
- 802.11b/g/n (WiFi): 11, 54, 450 Mbps transmission rate



Wide-area cellular access networks

- provided by mobile, cellular network operator (10’s km)
- 10’s Mbps
- 4G cellular networks (5G coming)

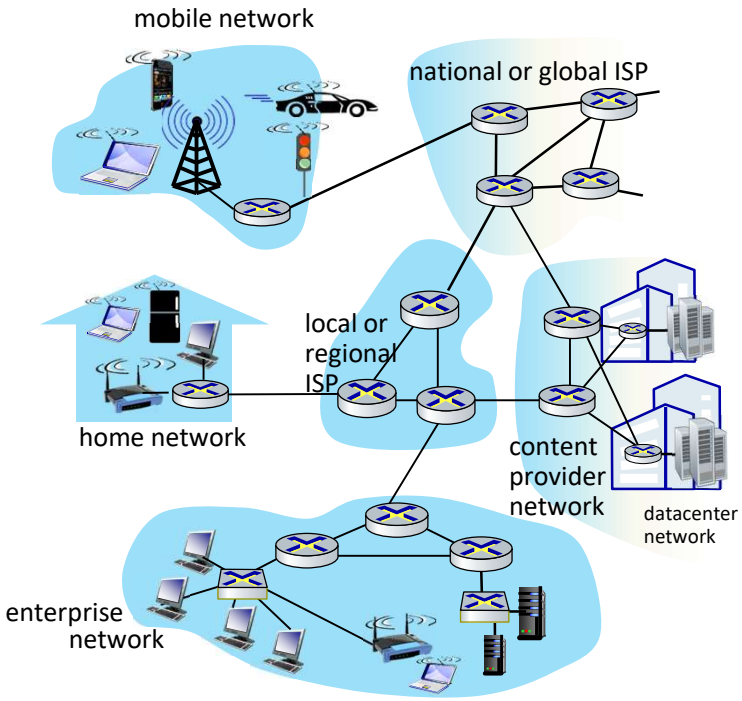




INTERNET STRUCTURE

Internet structure: a "network of networks"

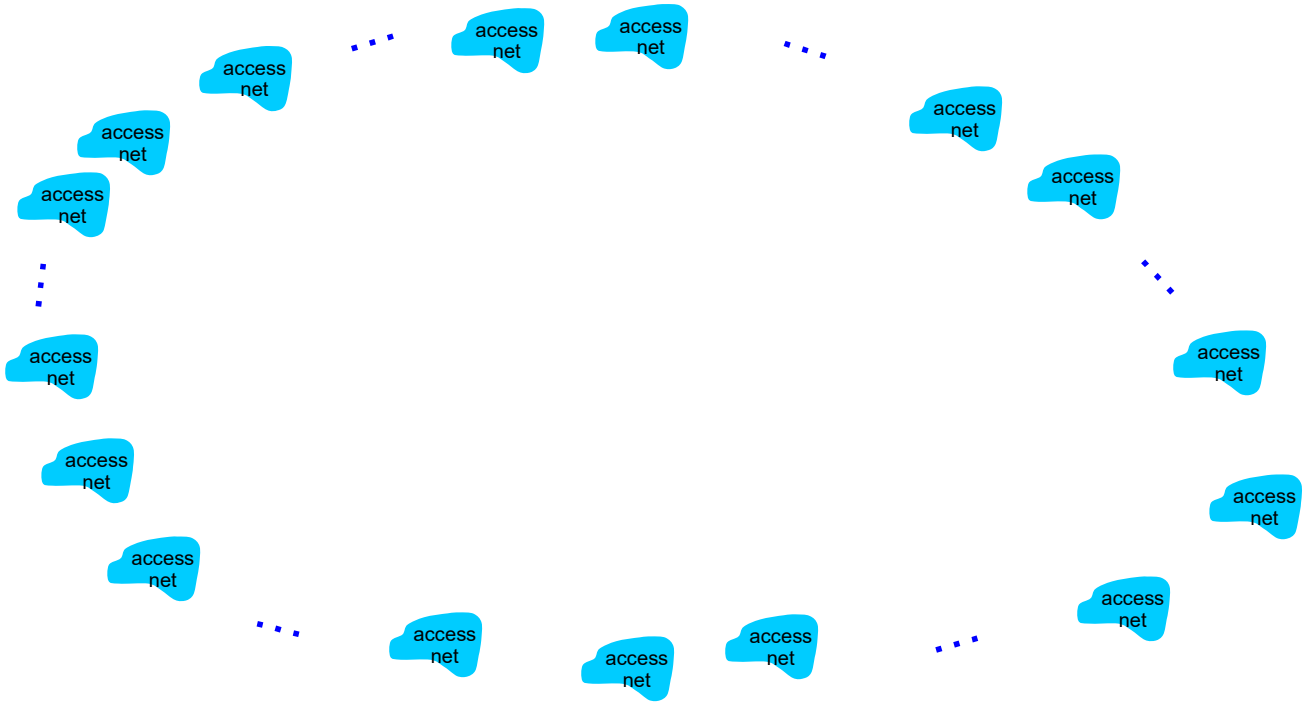
- hosts connect to Internet via access Internet Service Providers (ISPs)
- access ISPs in turn must be interconnected
  - so that *any* two hosts *(anywhere!)* can send packets to each other
- resulting network of networks is very complex
  - evolution driven by economics, national policies



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

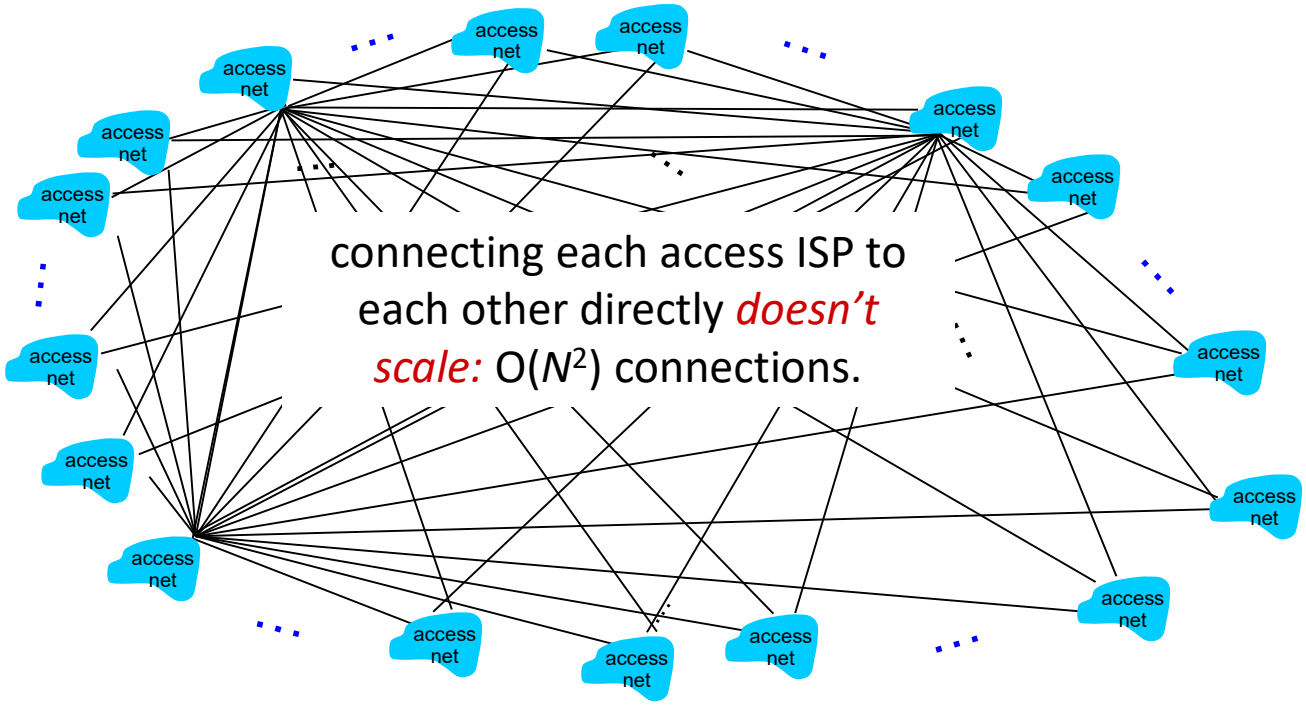
Internet structure: a “network of networks”

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



Internet structure: a "network of networks"

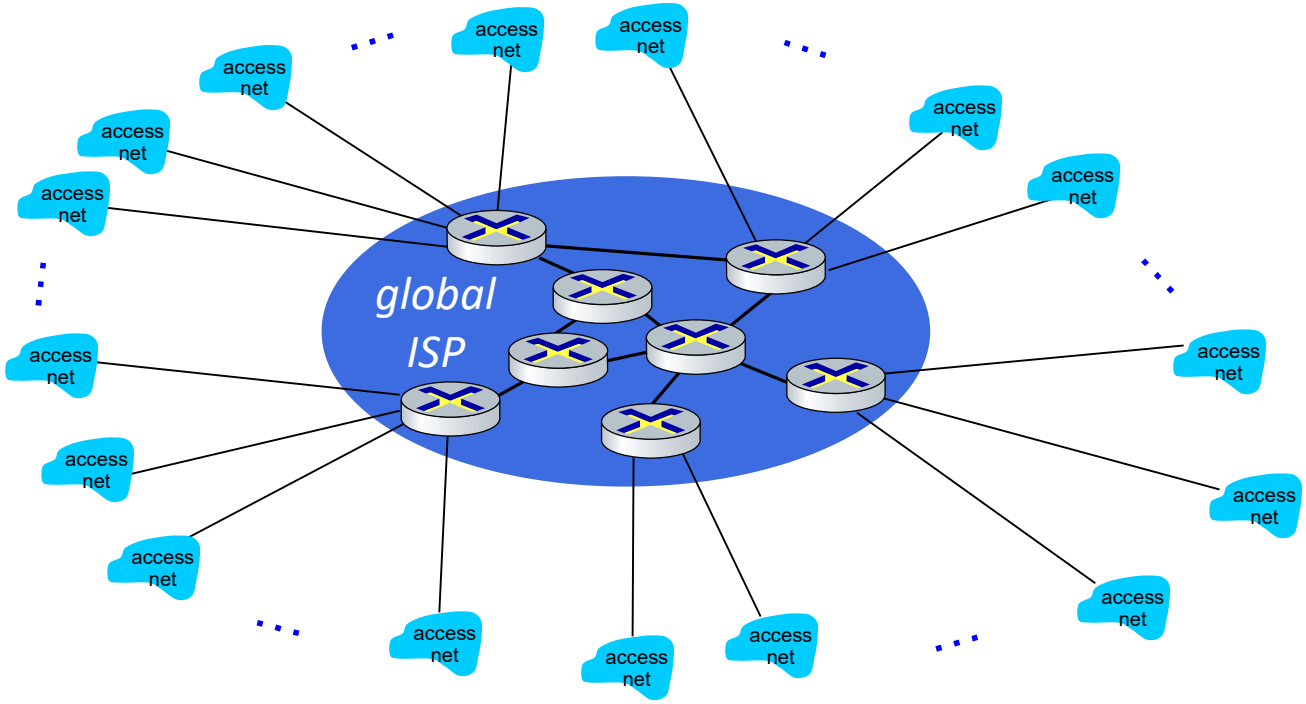
Question: given *millions* of access ISPs, how to connect them together?



Internet structure: a “network of networks”

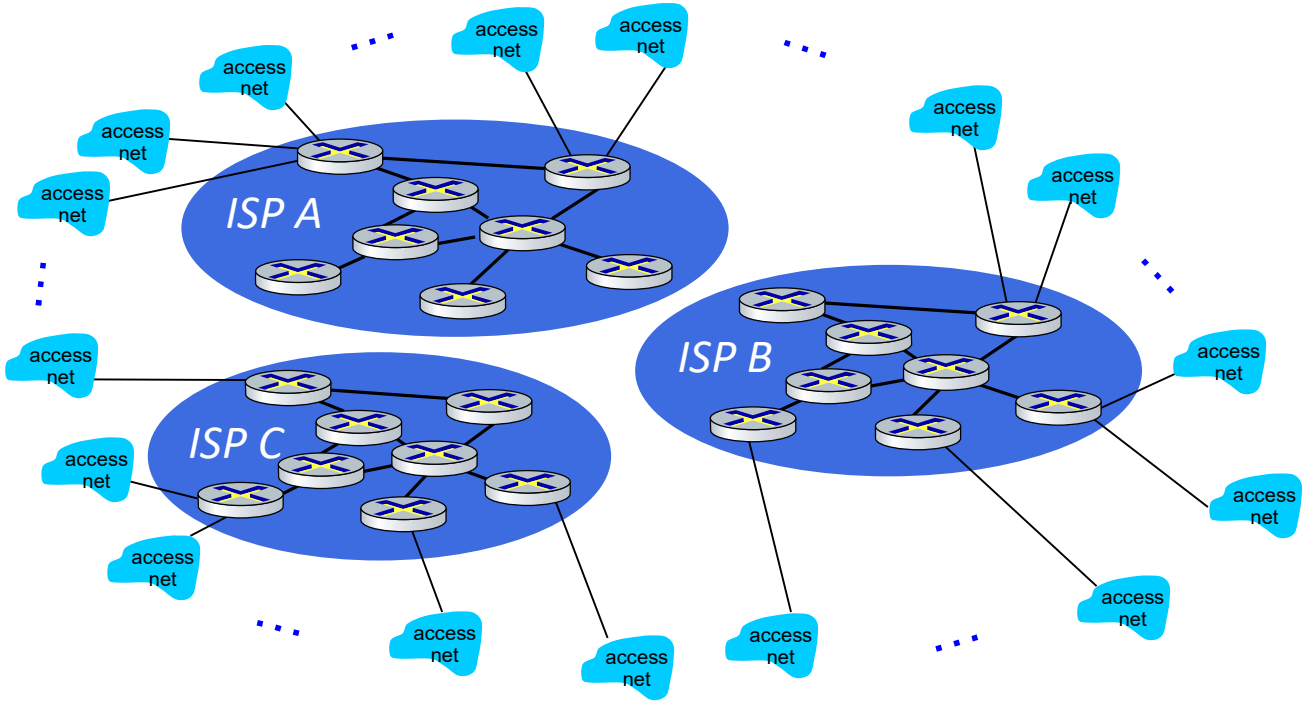
Option: connect each access ISP to one global transit ISP?

Customer and provider ISPs have economic agreement.



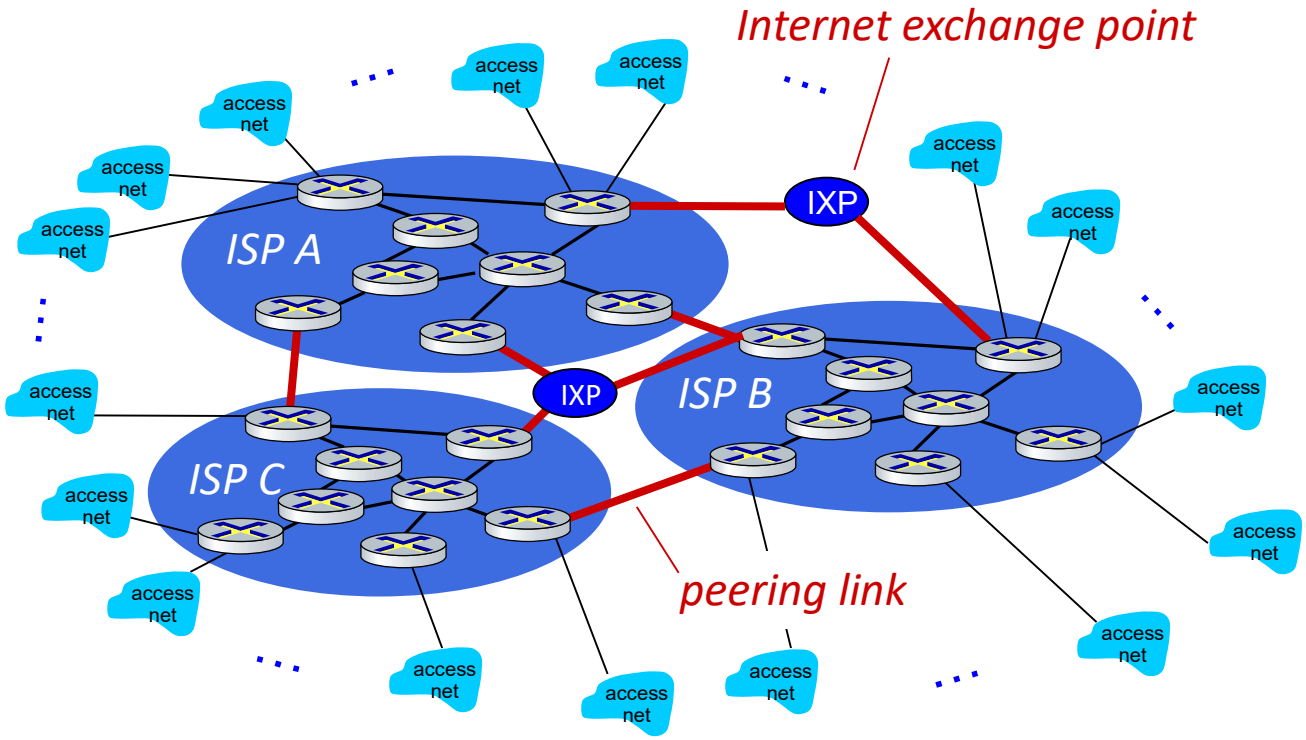
Internet structure: a “network of networks”

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



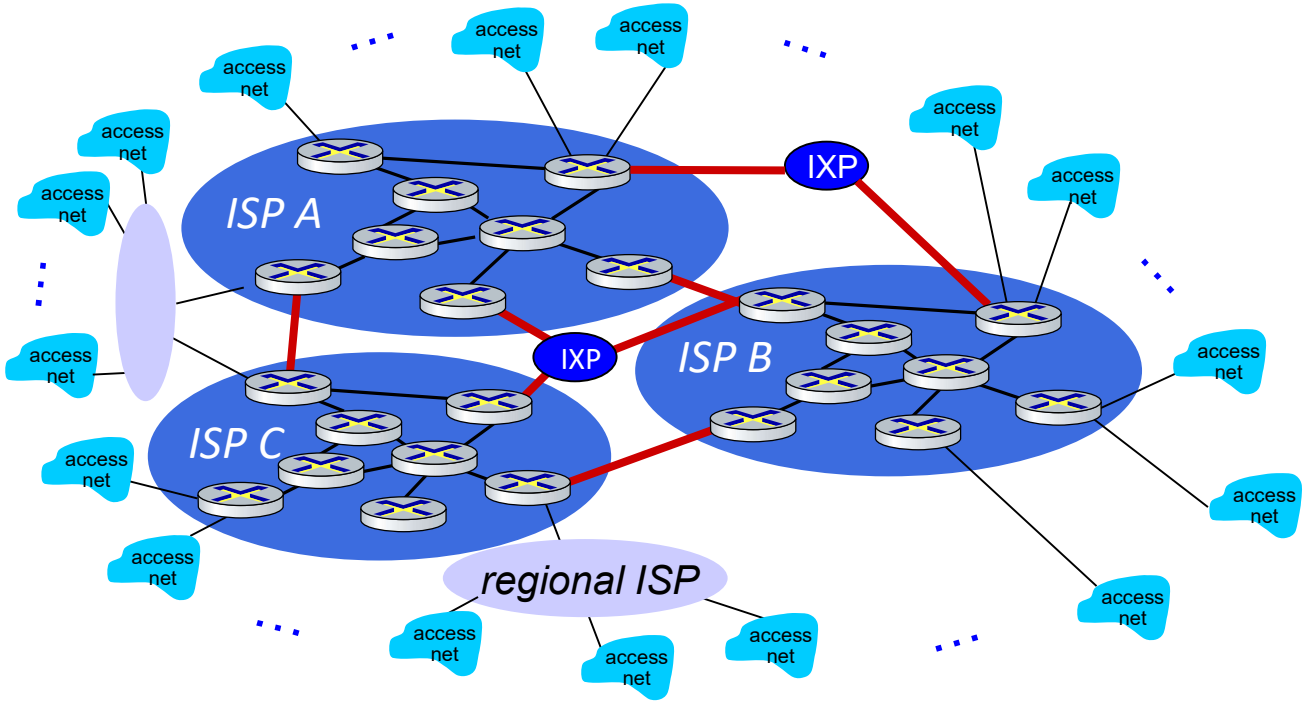
Internet structure: a “network of networks”

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



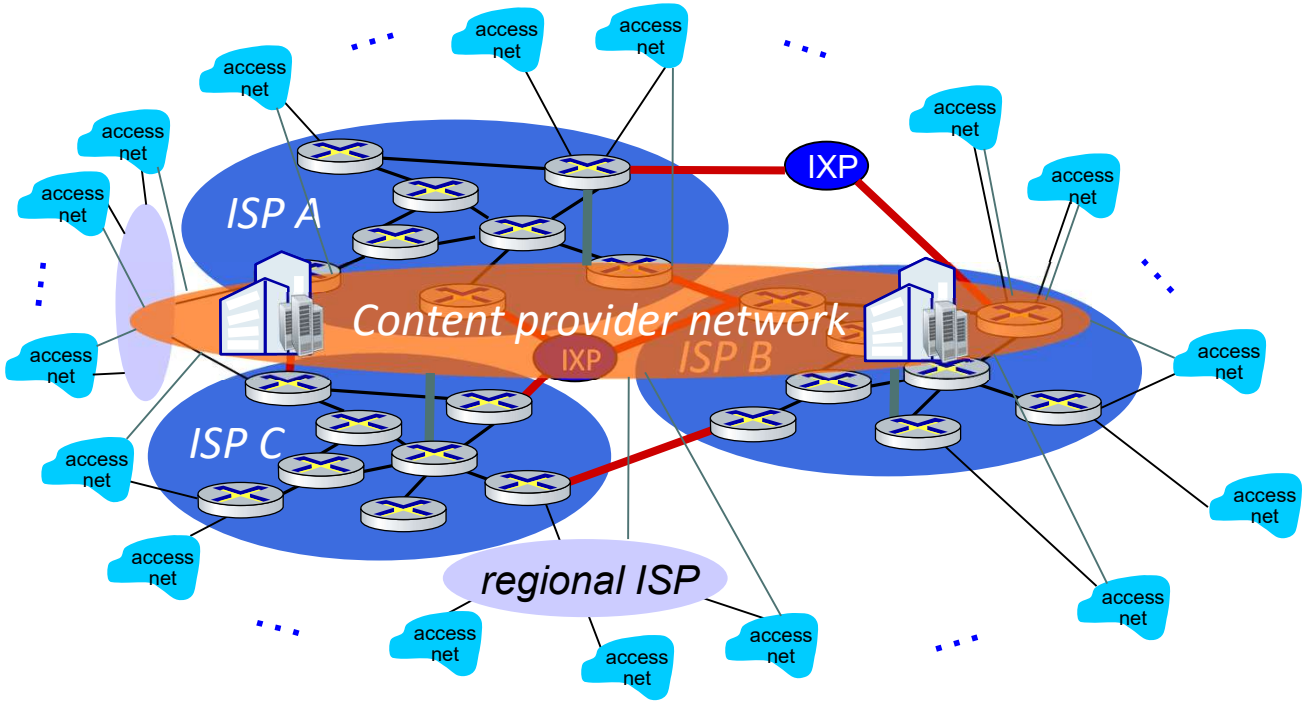
Internet structure: a “network of networks”

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

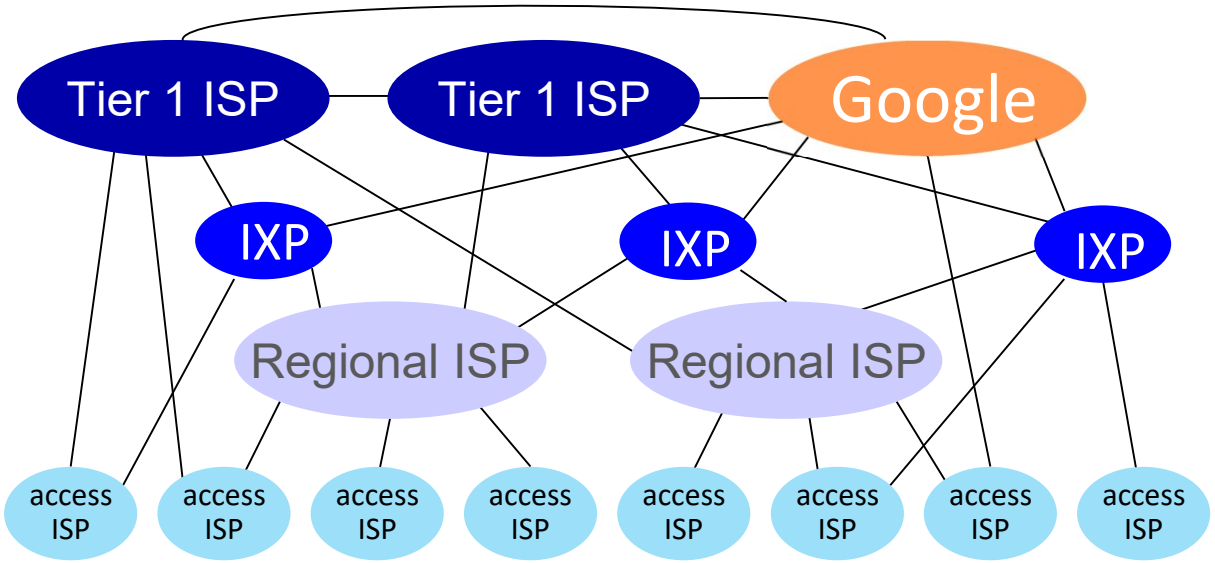


Internet structure: a “network of networks”

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



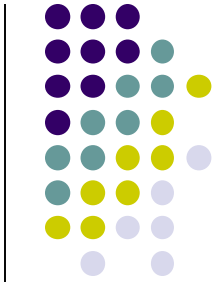
Internet structure: a "network of networks"



At "center": small # of well-connected large networks

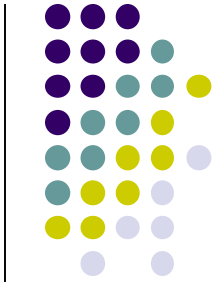
- "tier-1" commercial ISPs (e.g., Level 3, Sprint, AT&T, NTT), national & international coverage
- content provider networks (e.g., Google, Facebook): private network that connects its data centers to Internet, often bypassing tier-1, regional ISPs

Summary



- Introduction to the course
- History of the Internet
- Concept of Computer Networks
- Architecture
  - Topology
  - Protocol
- Circuit switching vs. packet switching
  - Pros & cons

Next week…



- Layering architecture
- OSI reference model
- IP, MAC address, port number
- DNS service.