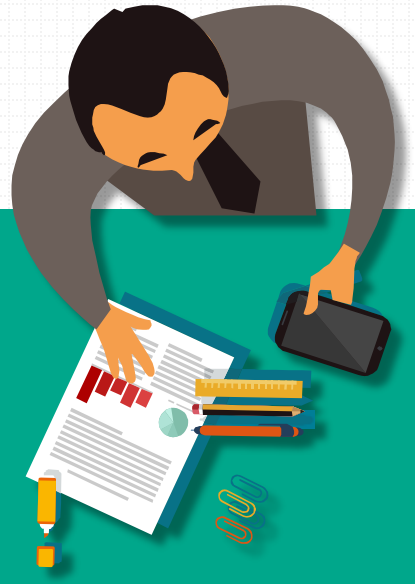
電腦網路
(Computer Network)

異質多網多媒體服務

國立臺北科技大學電子工程系
授課教師：李昭賢 副教授
電子郵件：chlee@ntut.edu.tw
校內分機：2288



學習目標 Outline

- 網際網路(Internet)
- 網路協定(Protocol)
- 網路效能(Performance)

網際網路(Internet)組成

NTUT NESL

網際網路(Internet)組成

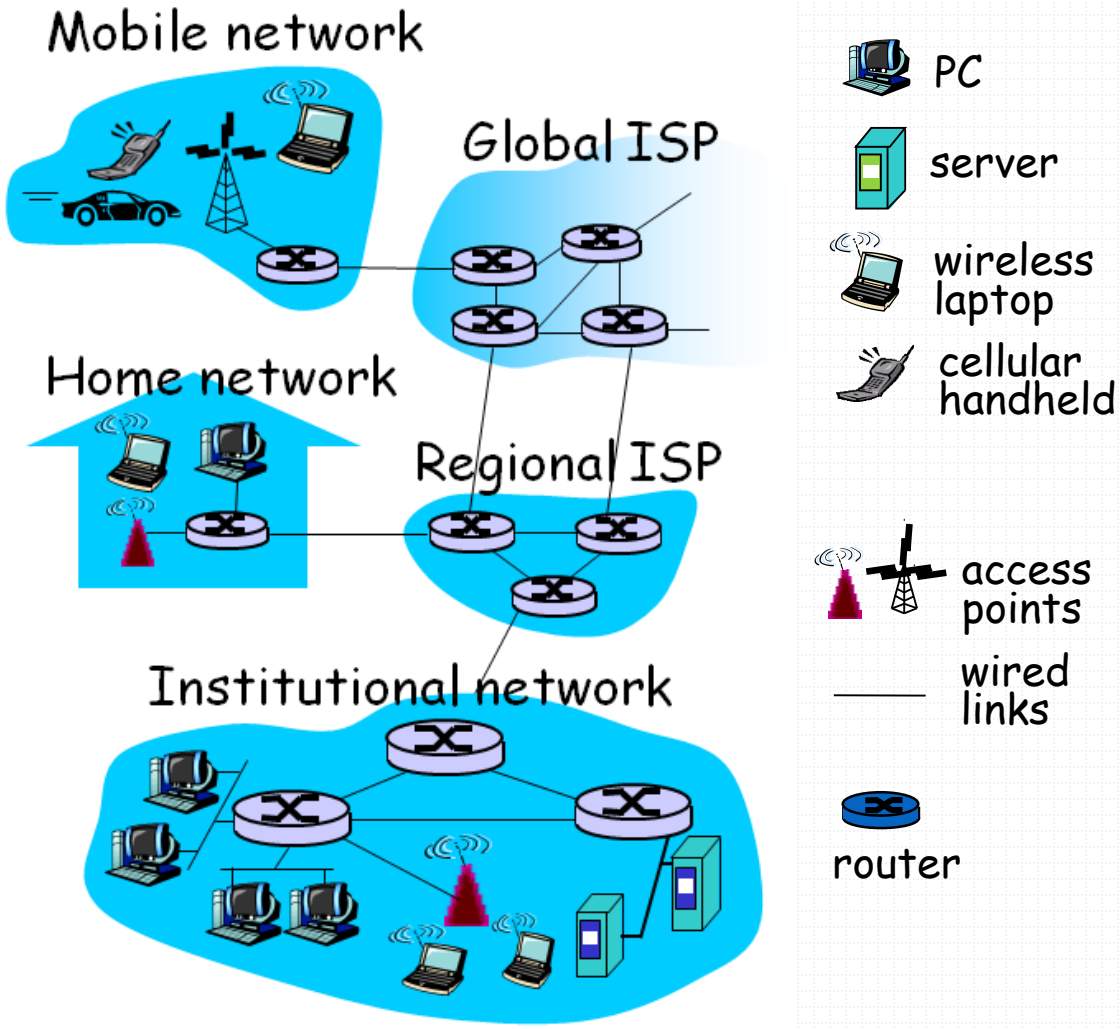
- Internet
  - Network Core
    - Routers
    - Internet Service Providers (ISPs)
  - Network Edge
    - Access Networks
      - Wired/Wireless Communication Links
      - Hubs/Switches/Routers
    - End Devices/Terminals/Nodes or Network Applications

Internet

- Nuts-and-bolts description
  - network of networks
    - loosely hierarchical
    - public Internet v.s. private intranet
  - millions of connected devices
    - Hosts (=end systems): run network applications
      - e.g., PC, Notebook, Smartphones, Tablets, etc.
    - Communication links
      - e.g., fiber, copper, radio, satellite, etc.
    - Hub/Switch/Router: forward packets
- Services description
  - Communication infrastructure enables distributed applications:
    - Web, VoIP, email, games, e-commerce, file sharing
  - Communication services provided to applications
    - reliable data delivery from source to destination
    - “best effort” (unreliable) data delivery

Network Structure

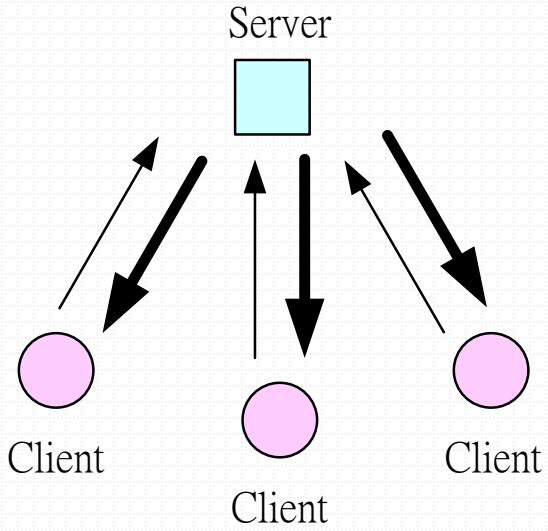
- Network Edge
  - Applications and hosts
  - Access Networks
    - Wired and wireless communication links
- Network Core
  - Interconnected routers
  - Network of networks



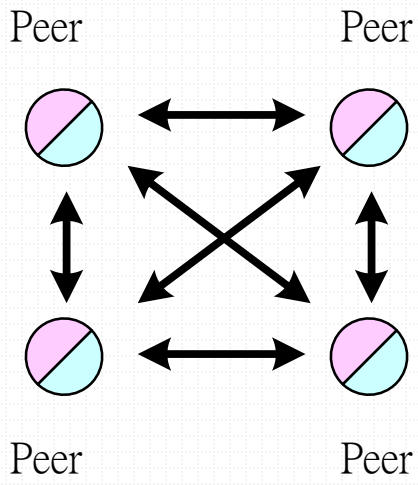
圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Network Edge

- Client/Server Model
  - clients request and receive services from always-on servers.
    - e.g., web browser/server, email client/server, etc.

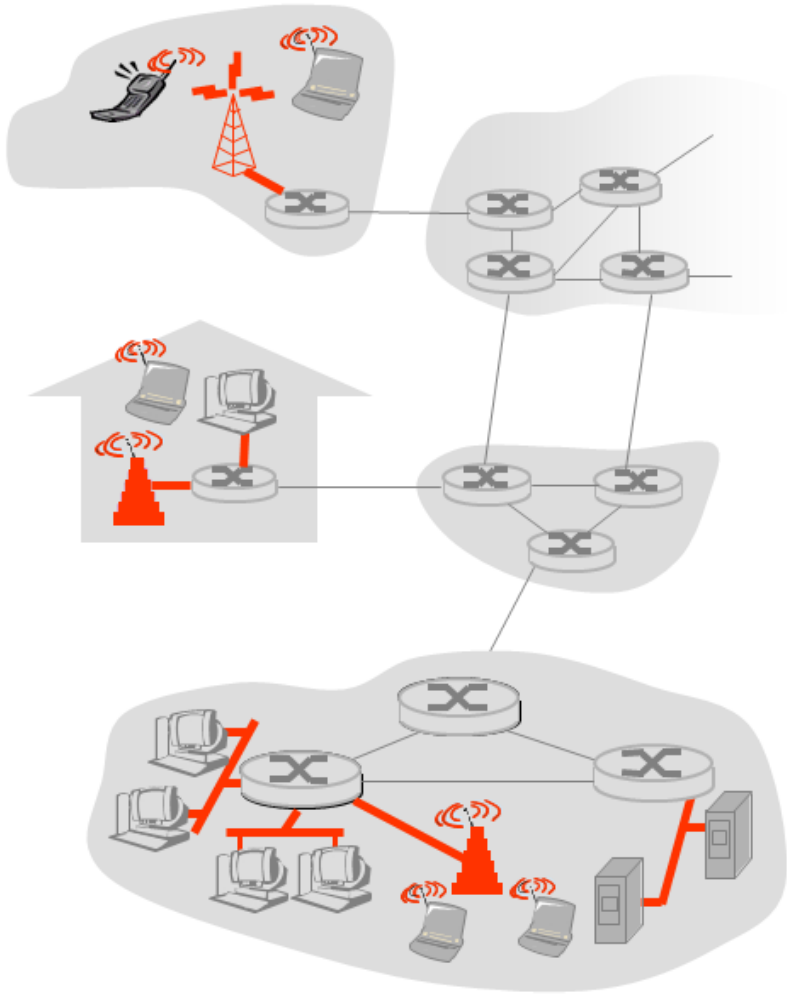


- Peer-to-peer (P2P) Model
  - minimal (or no) use of dedicated servers
  - Peer: perform both client and server functions.
    - e.g., skype, BitTorrent (BT), etc.



Access Network

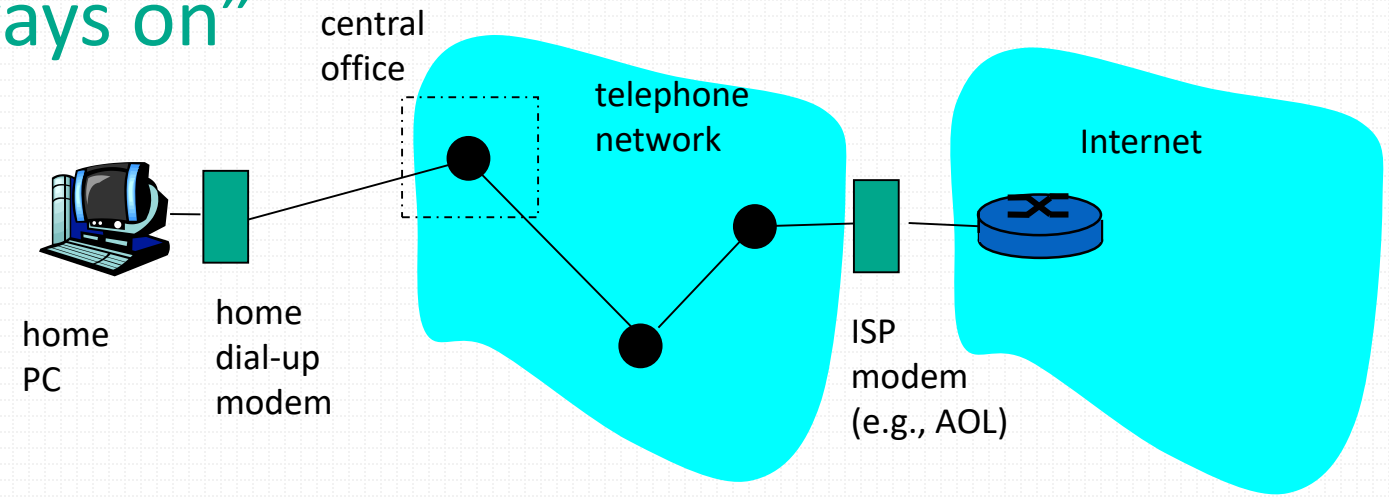
- Link Characteristics
  - Shared or Dedicated
- Environment Conditions
  - Residential access, e.g., home
  - Institutional access, e.g., school, company, etc.
  - Mobile access
- Distance / Range
  - Local Area Network (LAN)
    - Personal Area Network (PAN)
    - Body Area Network (BAN)
  - Metropolitan Area Network (MAN)
  - Wide Area Network (WAN)



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Residential Access – Point-to-point

- Dialup via modem
  - Uses existing telephony infrastructure (analog)
    - Home is connected to central office (CO)
  - Up to 56Kbps direct access to router (often less)
  - Can't surf and phone at same time: can't be "always on"



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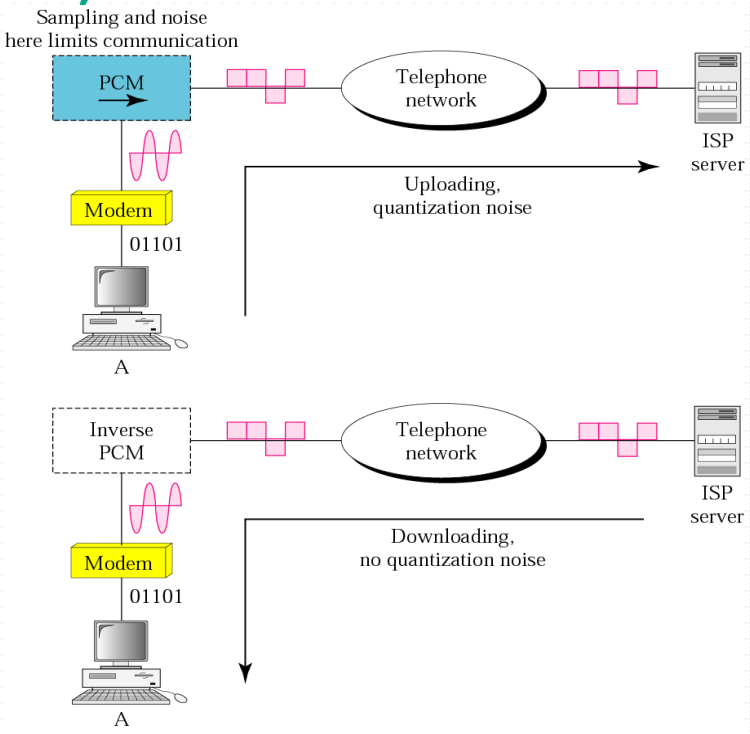
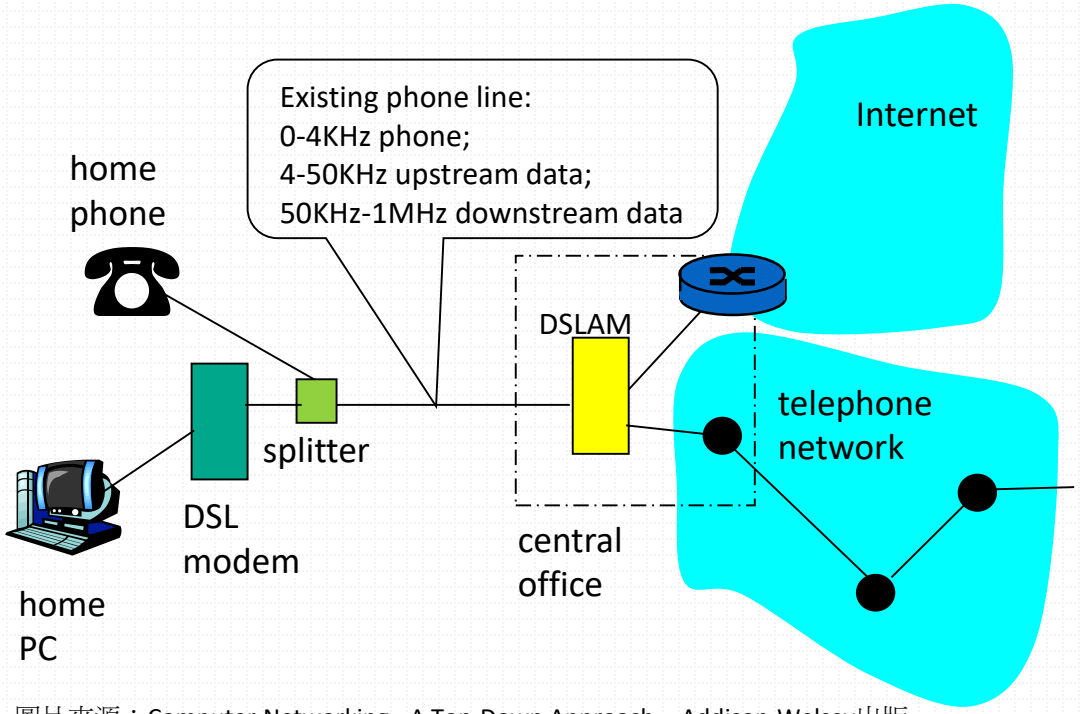
圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版



Residential Access – Point-to-point

- Digital Subscriber Line (DSL)
  - Uses existing telephony infrastructure (digital)
  - Dedicated physical line to telephone central office (CO)



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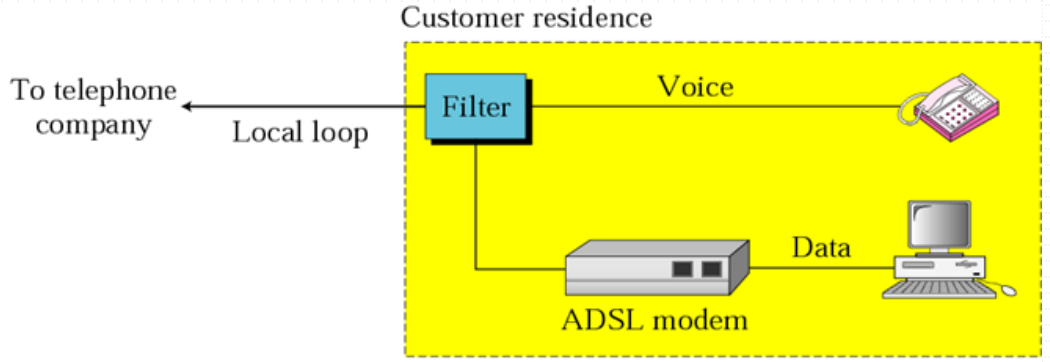
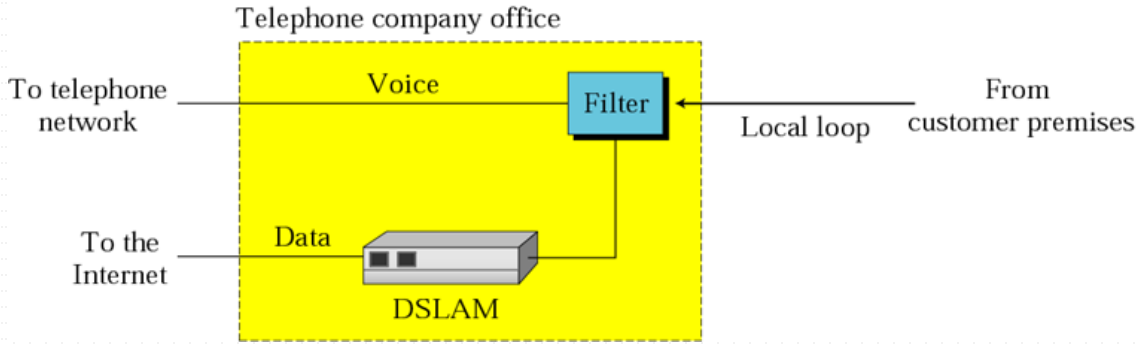
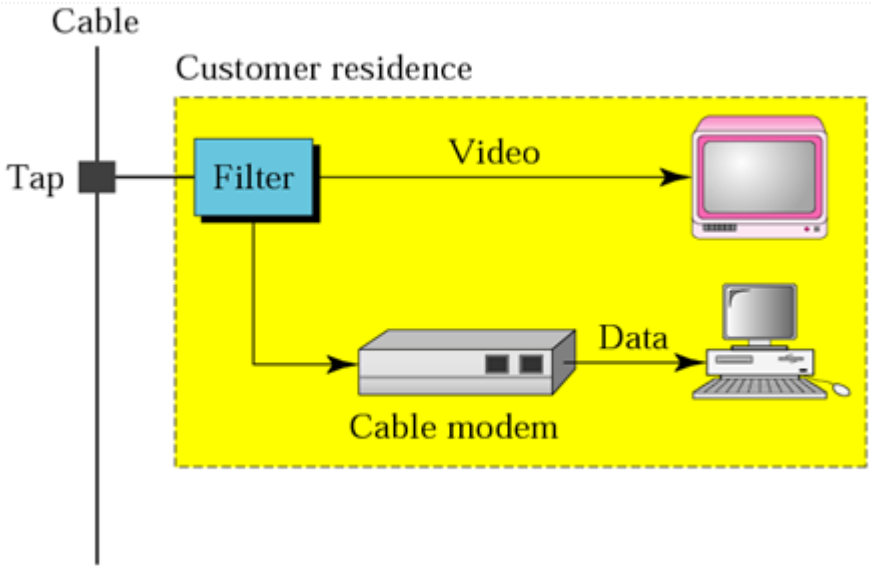




圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版

Residential Access – Cable Modem

- uses cable TV infrastructure instead of telephony infrastructure
  - homes share access to router



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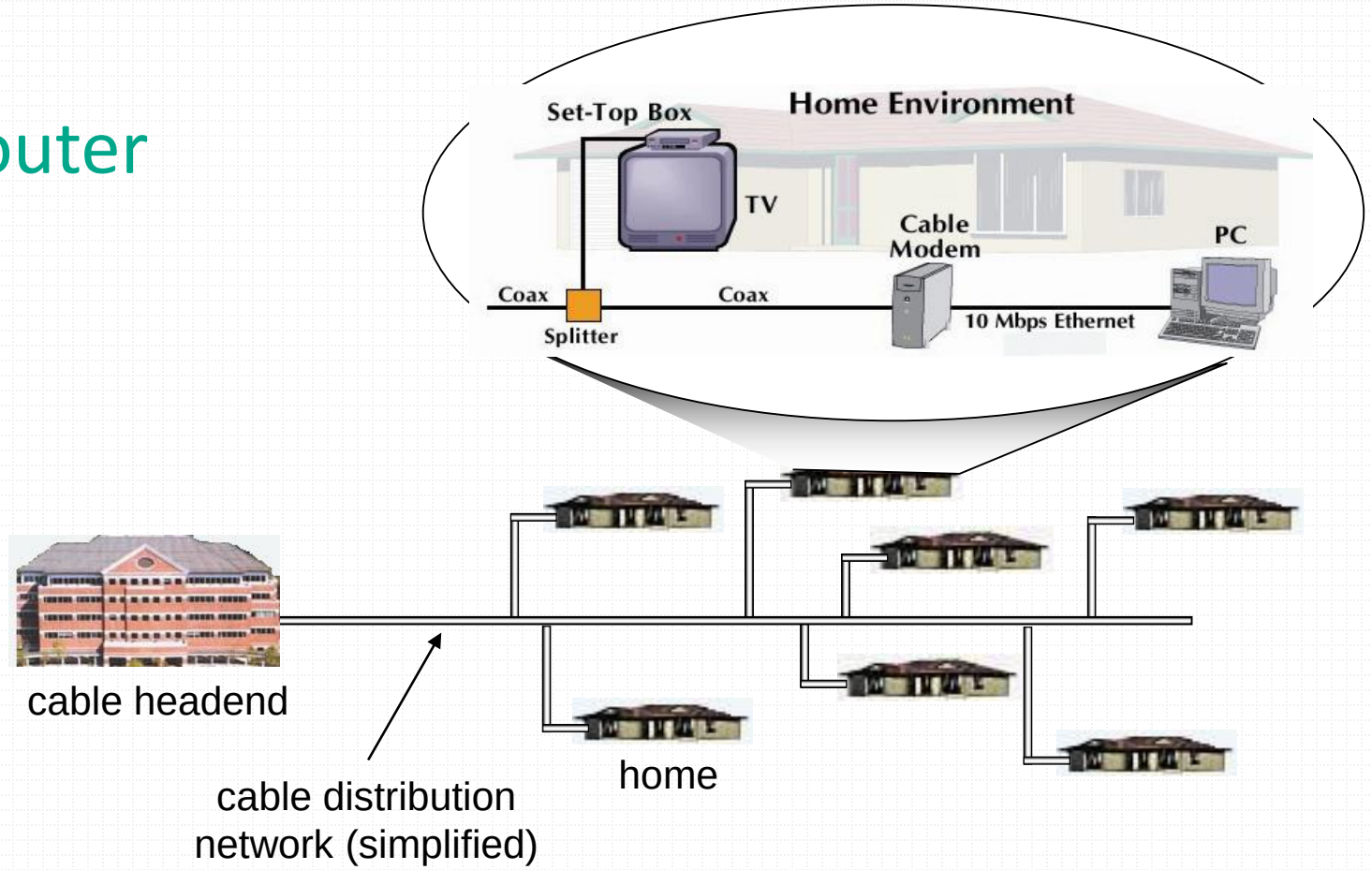
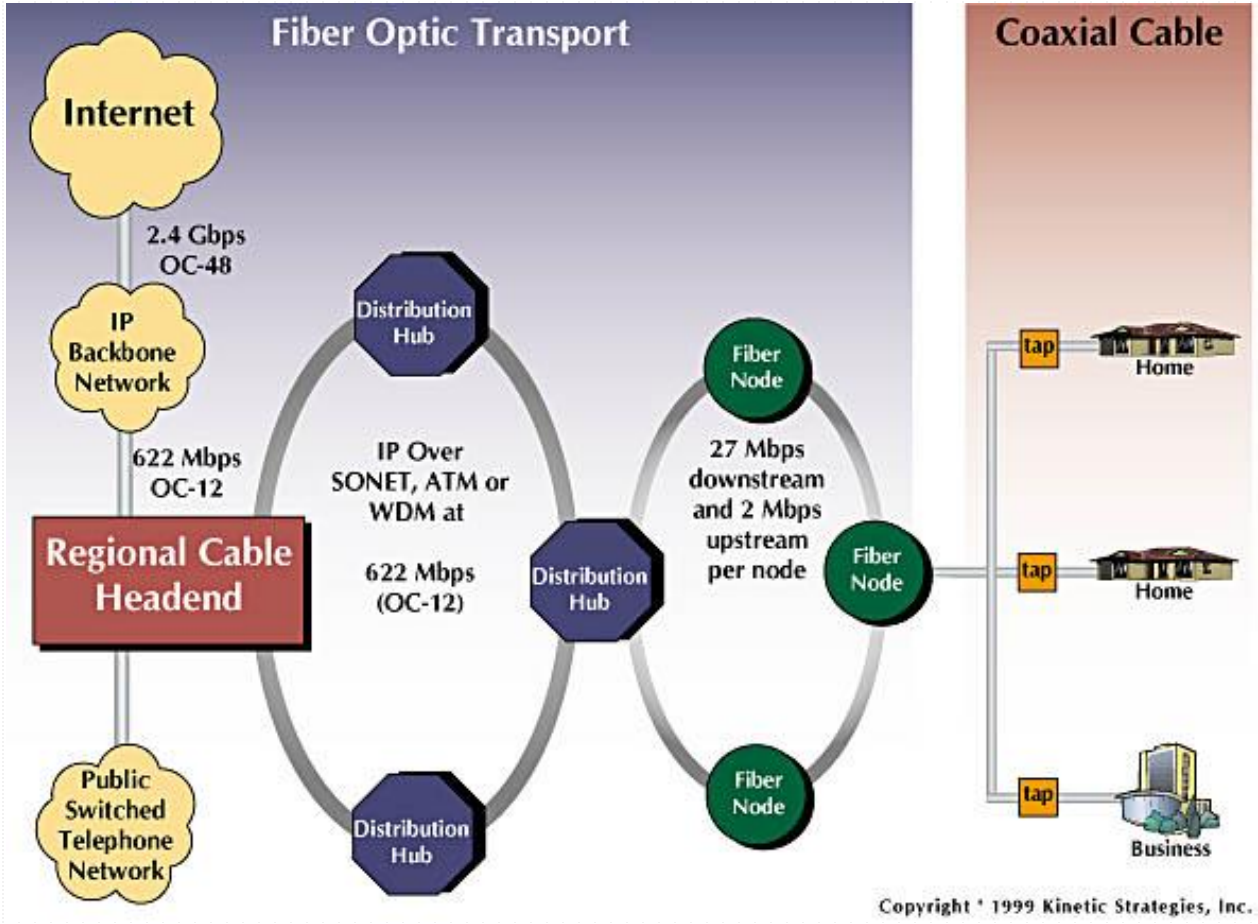


圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Residential Access – Cable Modem

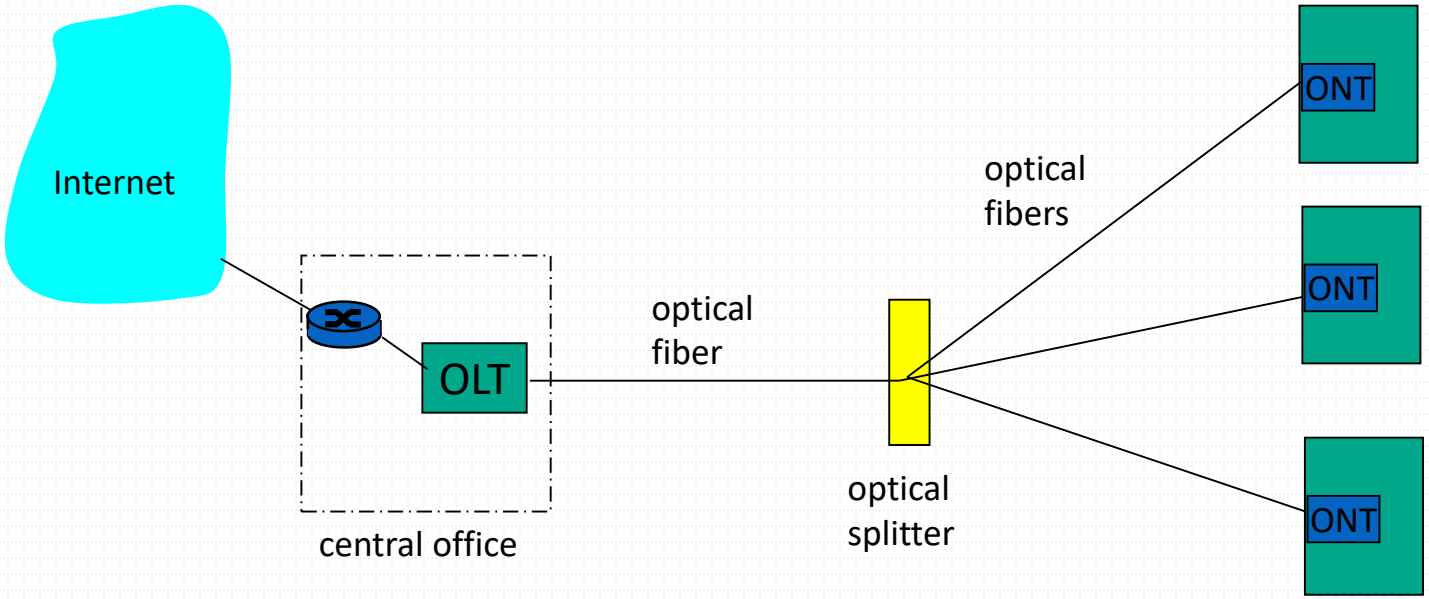
- Hybrid Fiber Coax (HFC)
  - Asymmetric
    - up to 30Mbps downstream, and 2 Mbps upstream



圖片來源：http://www.cabledatacomnews.com/cmic/diagram.html

Residential Access – Fiber to the Home (FTTH)

- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (PAN)



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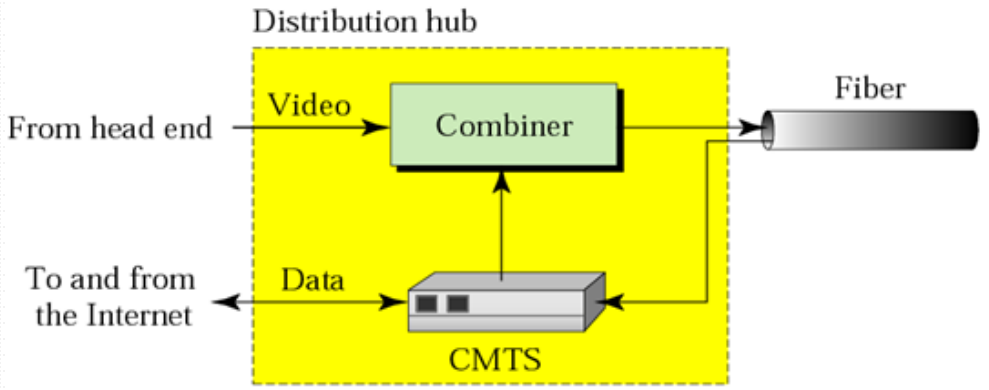


圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版

Residential Access – Digital Home

- Power Line Communication (PLC)
  - Communication protocol that uses electrical wiring to simultaneously carry both data.

- HomePlug 1.0 / AV / AV2 / Green PHY / Access Broadband Power Line (BPL)
  - Technology for enabling devices to communicate with each other, and the Internet, over existing home electrical wiring.

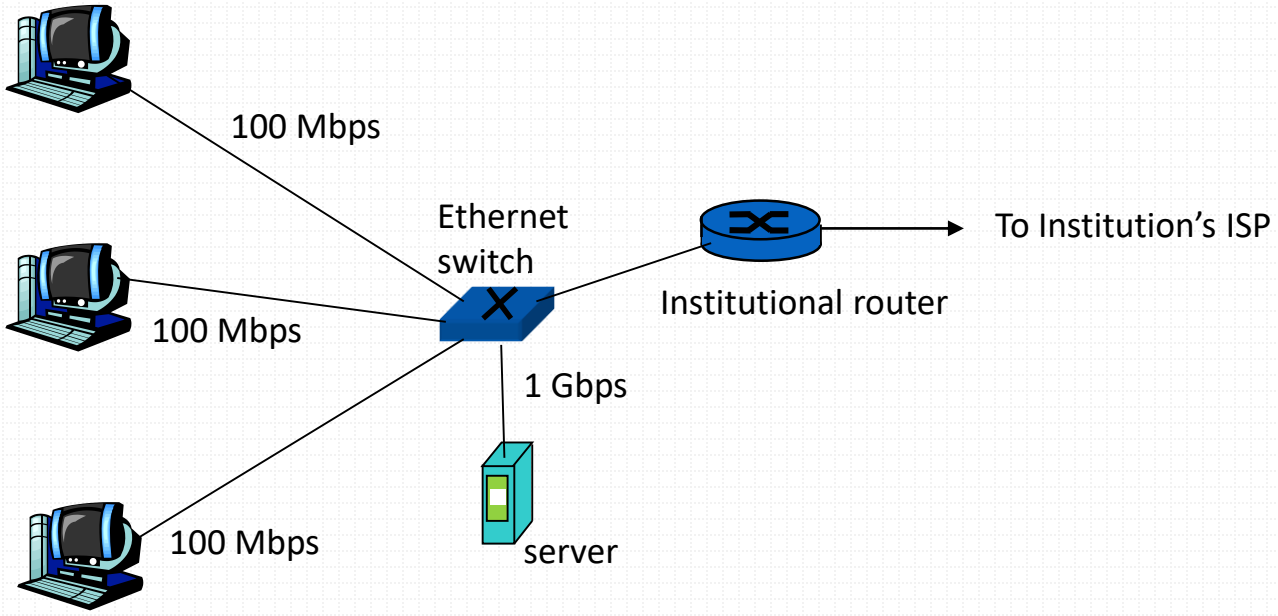
Residential Access – Digital Home

- HomePNA 1.0/2.0/3.0/3.1
  - Technology for home networking over the existing coaxial cables and telephone wiring within homes.

- Home Grid / Gigabit Home Networking (G.hn)
  - Specification for home networking with data rates up to 1 Gbit/s and operation over three types of legacy wires
    - telephone wiring, coaxial cables and power lines

Institution Access – Local Area Network (LAN)

- Ethernet (IEEE 802.3)
  - 10 Mbs, 100Mbps, 1Gbps, 10Gbps, etc.
  - Modern configuration: end systems connect into Ethernet switch



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Mobile Access

- Shared wireless access network connects end system to router
  - base stations (BS) for cellular telephony
  - access points (AP) for wireless LAN
- Wireless LAN (Wi-Fi)
  - 802.11a: max 54 Mbps
  - 802.11b: max 11 Mbps
  - 802.11g: max 54 Mbps
  - 802.11n: max 600 Mbps
  - 802.11ac: max 6.93 Gbps
  - etc.
- Wider Area Wireless Access
  - 3G, 3.5G (HSDPA), 4G (LTE), 5G, etc.
  - WiMAX (IEEE 802.16)
  - etc.
- Vehicular Access
  - Dedicated Short Range Communication (DSRC) / IEEE 802.11p / Wireless Access in Vehicular Environments (WAVE)
    - Specifically designed for automotive use
    - Enhancements to 802.11a
- Others
  - Personal Area Network (PAN)：Bluetooth (IEEE 802.15.1), Zigbee (IEEE 802.15.4), etc.
  - Low Power Wide Area Network (LPWAN)：LoRaWAN, SigFox, etc.

Physical Media – Guided / Wired

- Signals propagate in solid media
  - Twisted Copper Wire
    - Unshielded Twisted Pair (UTP)
      - Category 3: traditional phone wires, 10 Mbps Ethernet
      - Category 5: 100Mbps Ethernet
      - Category 6: 10Gbps Ethernet
  - Coaxial cable
    - Two concentric copper conductors
  - Fiber
    - Glass fiber carrying light pulses

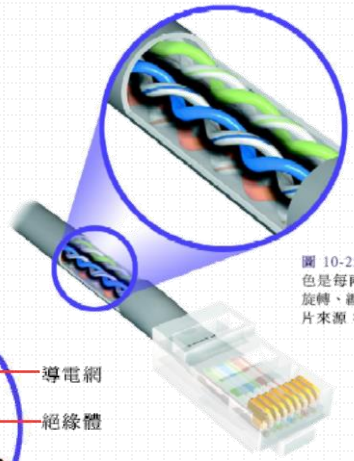


圖 10-25 雙絞線的特色是每兩條芯線相互旋轉、纏繞在一起(圖片來源：旗立資訊)

圖 10-28 同軸電纜的構造圖(圖片來源：旗立資訊)

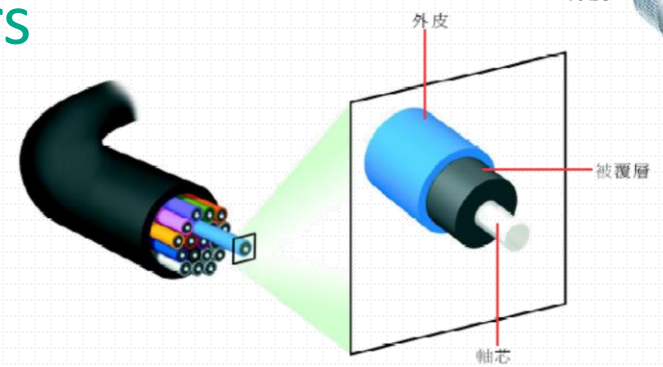


圖 10-27 光纖的構造圖(圖片來源：旗立資訊)

Physical Media – Unguided / Wireless

- Signals propagate freely

TABLE 1: STANDARD DEFINITIONS OF RADIO SPECTRUM SEGMENTS

Name	Frequency range	Applications
Low frequency (LF)	30 to 300 kHz	Navigation, time standards
Medium frequency (MF)	300 kHz to 3 MHz	Marine/aircraft navigation, AM broadcast
High frequency (HF)	3 to 30 MHz	AM broadcasting, mobile radio, amateur radio, shortwave broadcasting.
Very high frequency (VHF)	30 to 300 MHz	Land mobile, FM/TV broadcast, amateur radio
Ultra high frequency (UHF)	300 MHz to 3 GHz	Cellular phones, mobile radio, wireless LAN, PAN
Super high frequency (SHF), millimeter-wave range	3 to 30 GHz	Satellite, radar, backhaul, TV, WLAN, 5G cellular
Extremely high frequency (EHF)	30 to 300 GHz	Satellite, radar, backhaul, experimental, 5G cellular
Terahertz , tremendously high fequency (THF) or far infrared (FIR)	300 GHz to IR	R & D, experimental

TABLE 2: MICROWAVE LETTER BAND DESIGNATIONS

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay, Wi-Fi, DSRC
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul, 5G cellular
Q	30 to 50 GHz	Microwave backhaul, 5G cellular
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

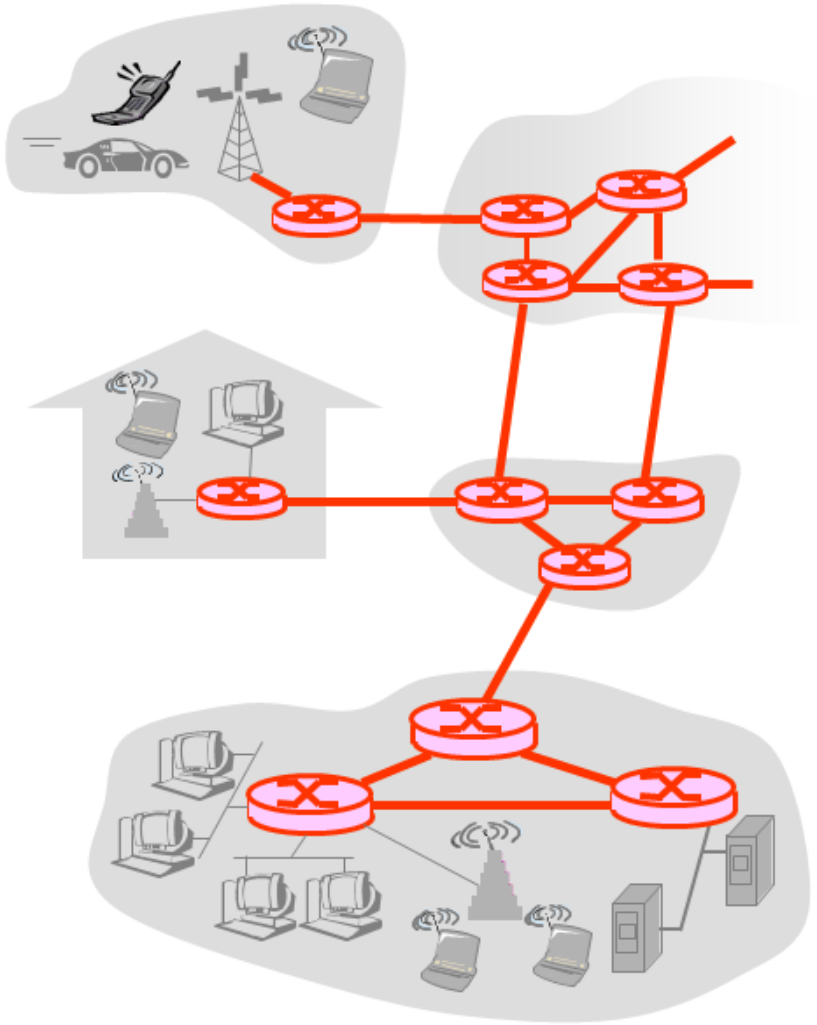
WIRELESS TECHNOLOGIES AT A GLANCE

Technology	Frequency	Data rate	Range	Power	Cost
2G/3G	Cellular bands	10 Mb/s	Several km	High	High
802.15.4	2.4 GHz	250 kb/s	100 m	Low	Low
Bluetooth	2.4 GHz	1, 2.1, 3 Mb/s	100 m	Low	Low
LoRa	< 1 GHz	<50 kb/s	2-5 km	Low	Medium
LTE Cat 0/1	Cellular bands	1-10 Mb/s	Several km	Medium	High
NB-IoT	Cellular bands	0.1-1 Mb/s	Several km	Medium	High
SIGFOX	<1 GHz	Very low	Several km	Low	Medium
Weightless	<1 GHz	0.1-24 Mb/s	Several km	Low	Low
Wi-Fi (11f/h)	2.4, 5, <1 GHz	0.1-1 Mb/s	Several km	Medium	Low
WirelessHART	2.4 GHz	250 kb/s	100 m	Medium	Medium
ZigBee	2.4 GHz	250 kb/s	100 m	Low	Medium
Z-Wave	908.42 MHz	40 kb/s	30 m	Low	Medium

圖片來源： http://www.spectrumeffect.com/the-wireless-spectrum-conundrum.html
圖片來源：http://www.electronicdesign.com/iot/12-wireless-options-iotm2m-diversity-or-dilemma

Network Core

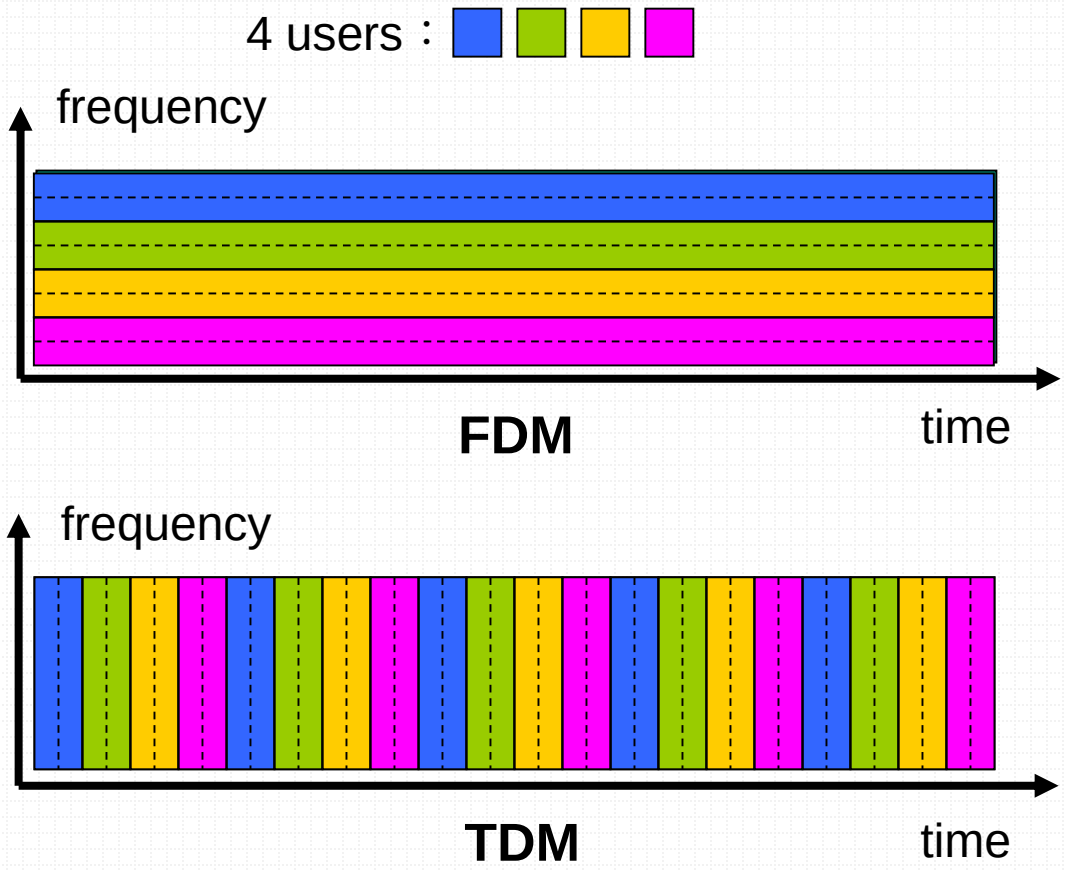
- Mesh of interconnected routers
- How is data transferred through networks?
  - circuit switching
    - dedicated circuit per call
  - packet-switching
    - data sent through networks in discrete “chunks”



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

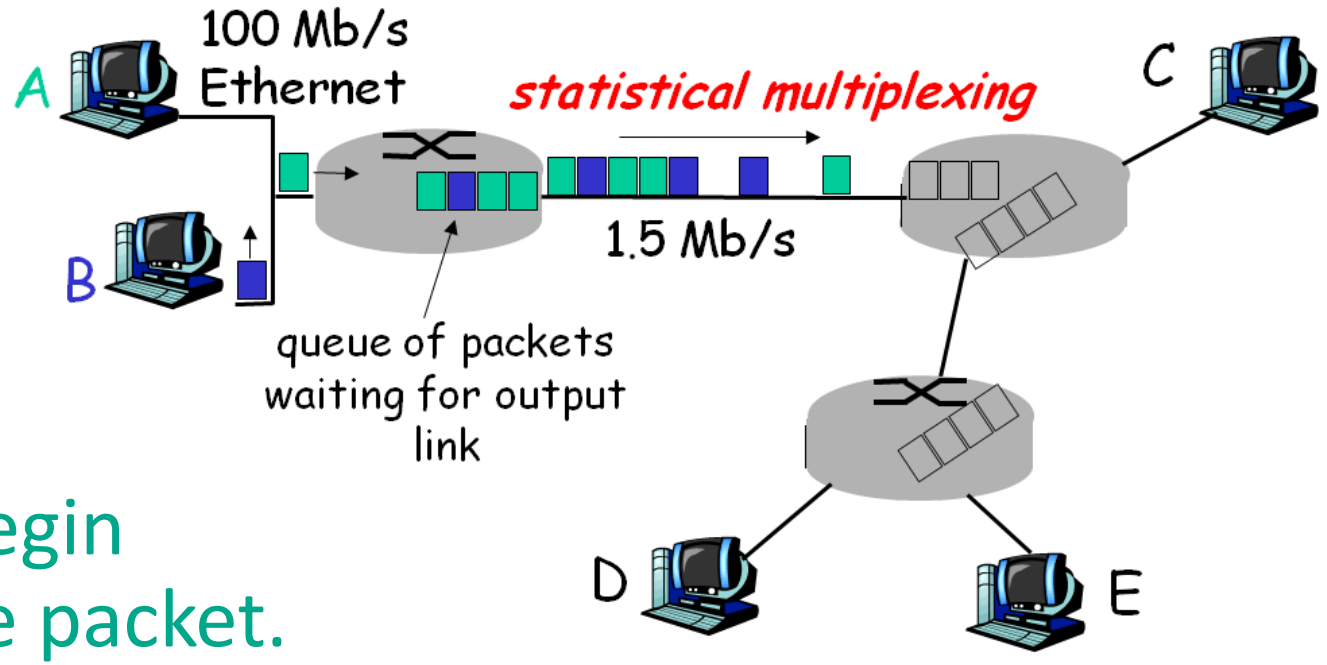
Circuit Switching

- End-end resources reserved for “call”, e.g., Telephone
  - Circuit-like (guaranteed) performance
  - Dedicated resources
  - Call setup required
- Dividing link bandwidth into “pieces”
  - Frequency-division multiplexing (FDM)
  - Time-division multiplexing (TDM)



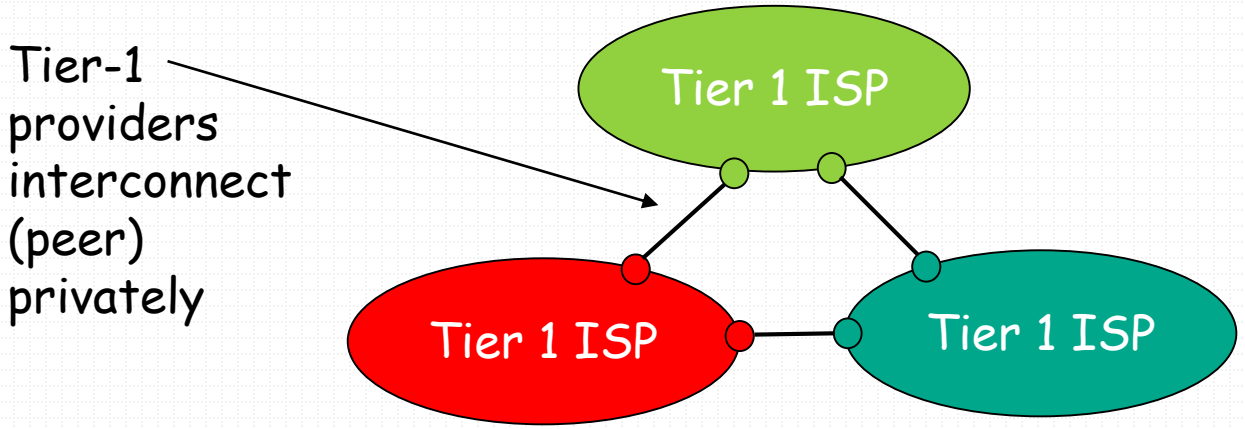
Packet Switching

- Packet
  - The source breaks messages into small chunks of data.
  - Each packet uses full transmission rate of this link.
- Store-and-forward transmission
  - Packets move one hop at a time.
  - The switch must receive the entire packet before it can begin to transmit the first bit of the packet.



Internet Service Provider (ISP)

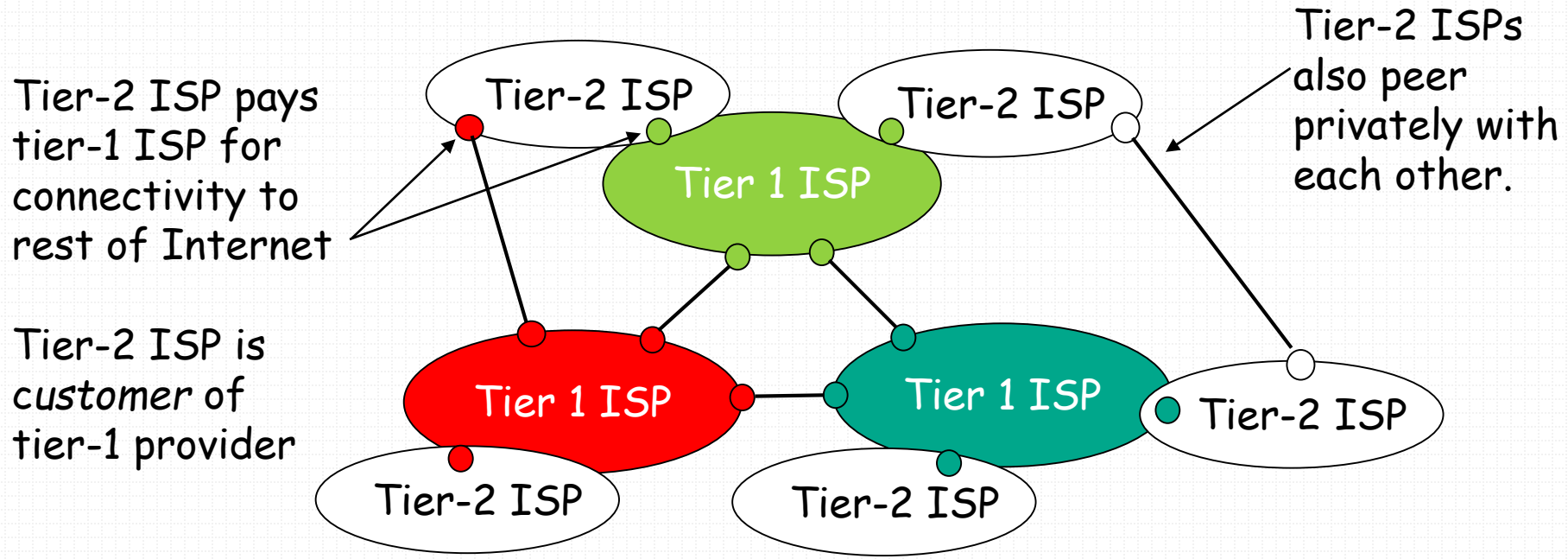
- Roughly hierarchical
- "Tier-1" ISPs at center
  - e.g., Verizon, Sprint, AT&T,
  - International coverage
  - Internet backbone



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Internet Service Provider (ISP)

- "Tier-2" ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs
  - Regional or national coverage



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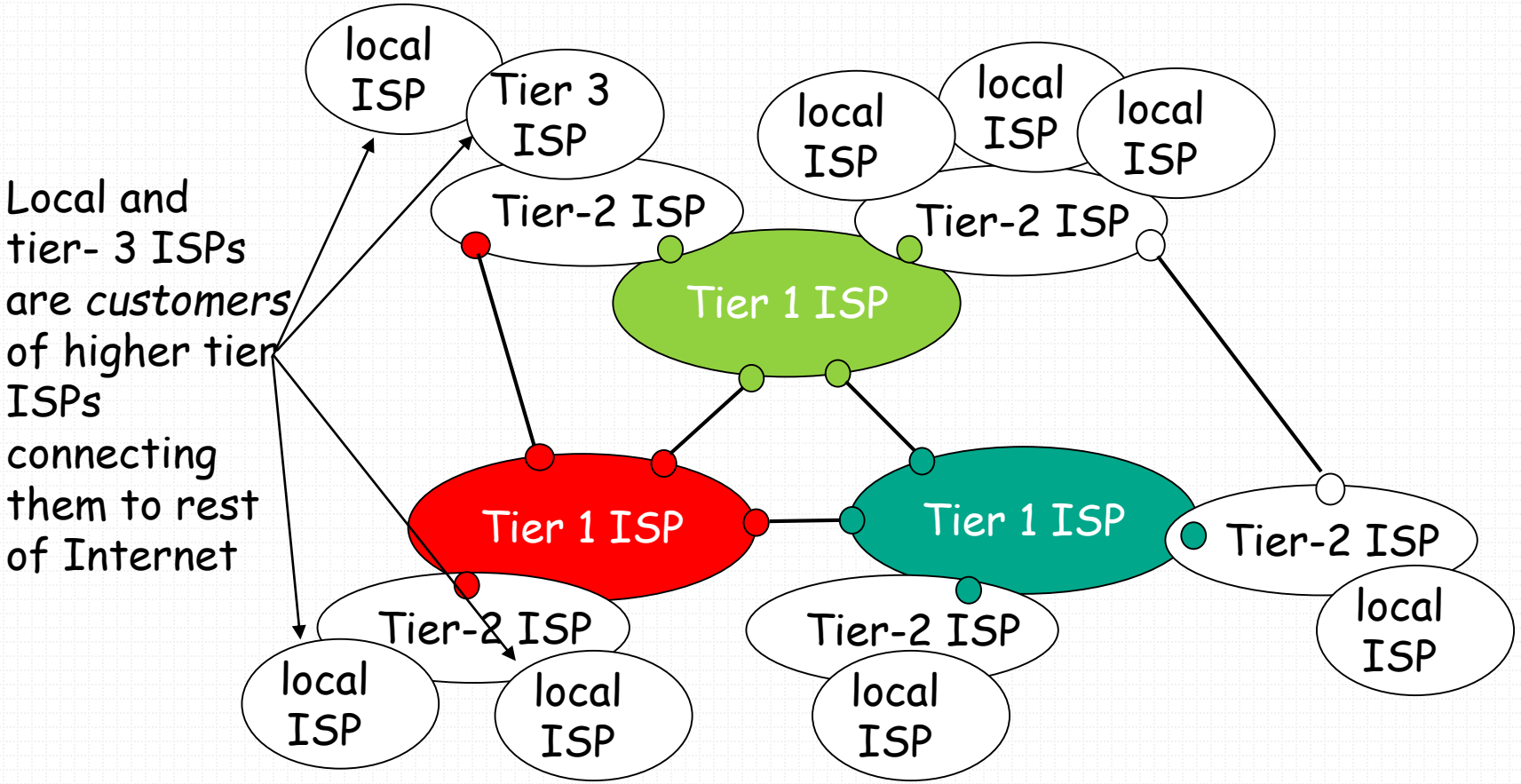
Internet Service Provider (ISP)

- "Tier-3" ISPs and local ISPs



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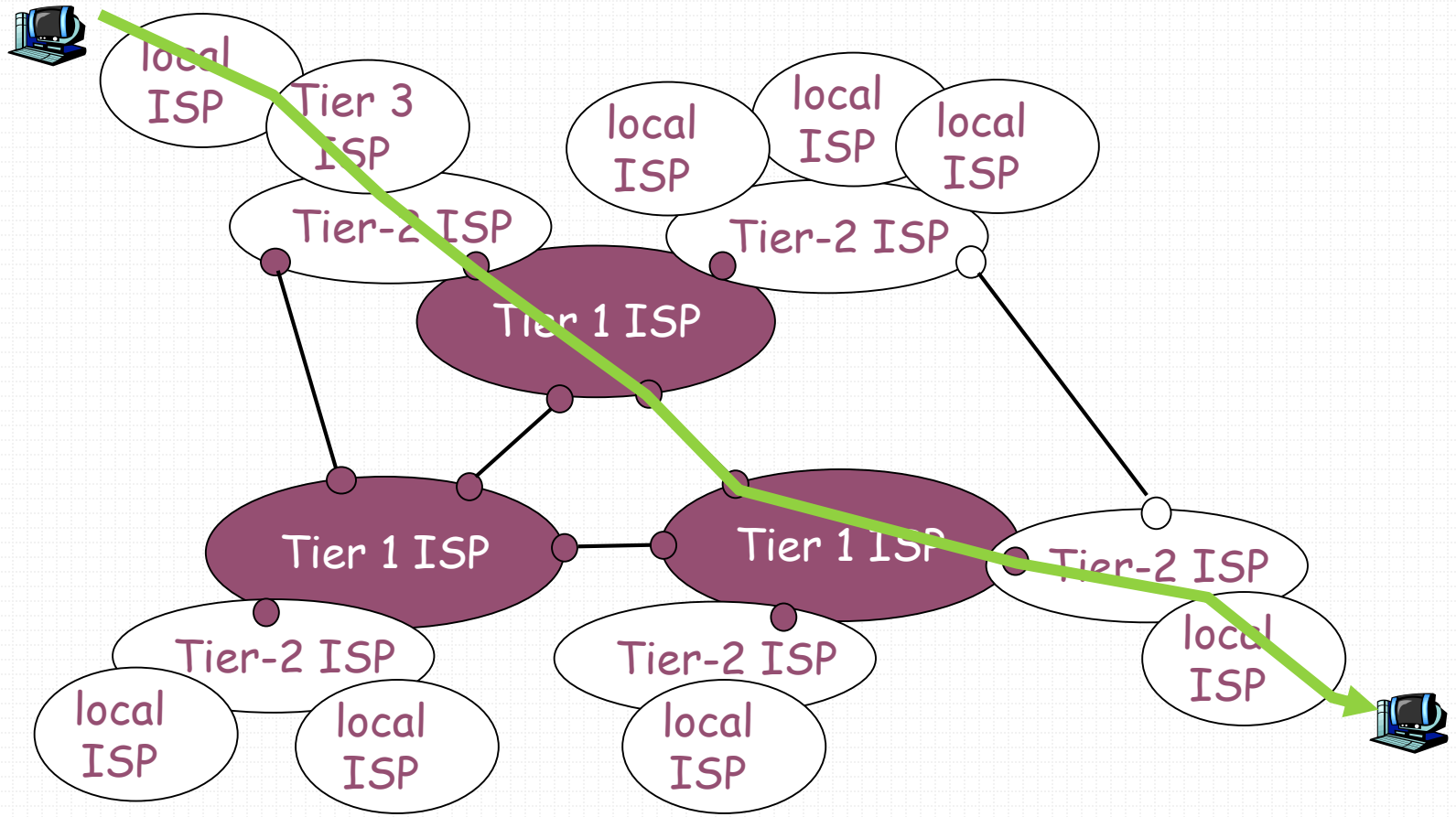
Internet Service Provider (ISP)

- A packet passes through many networks!



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網路協定堆疊(Protocol Stack)

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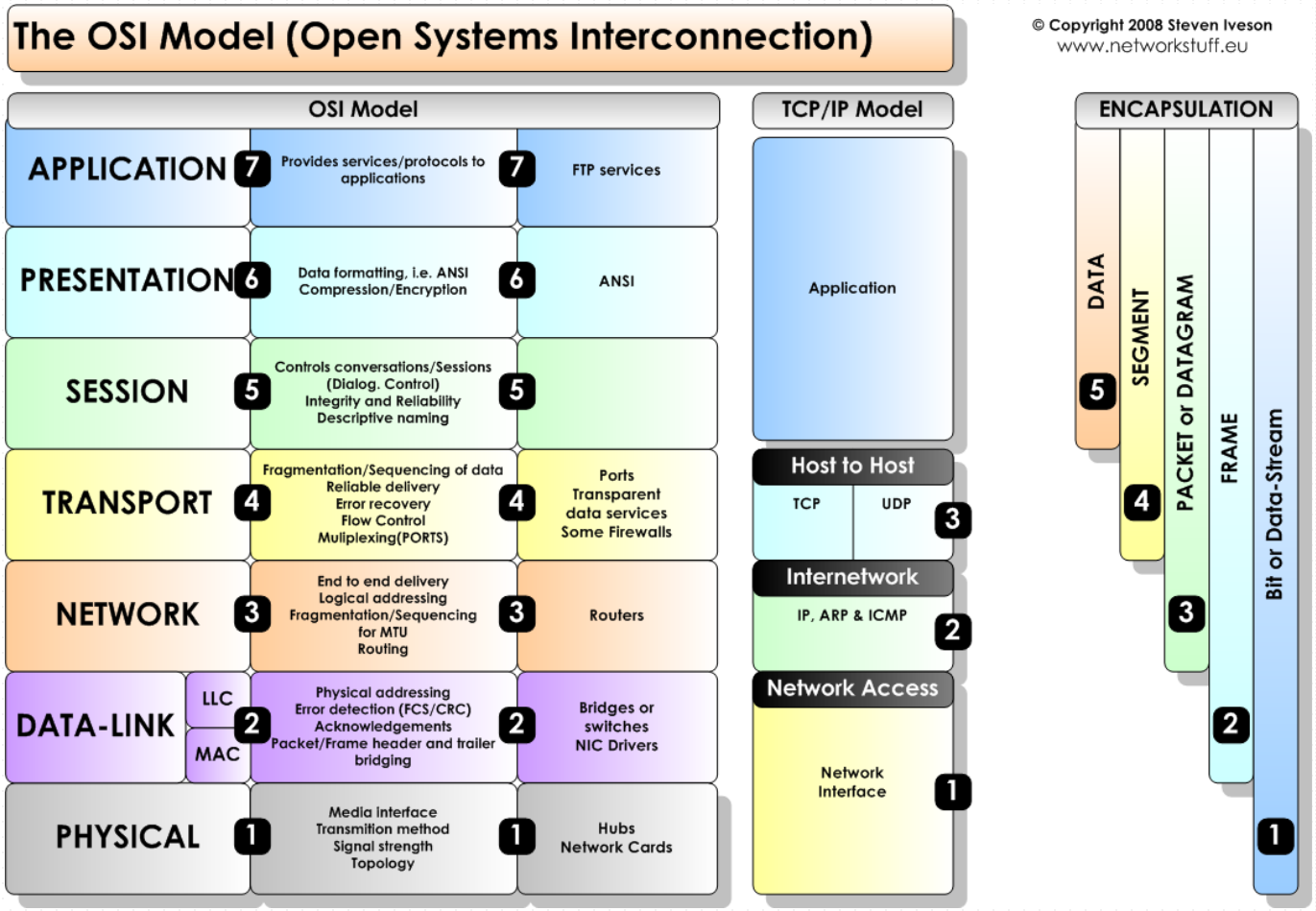
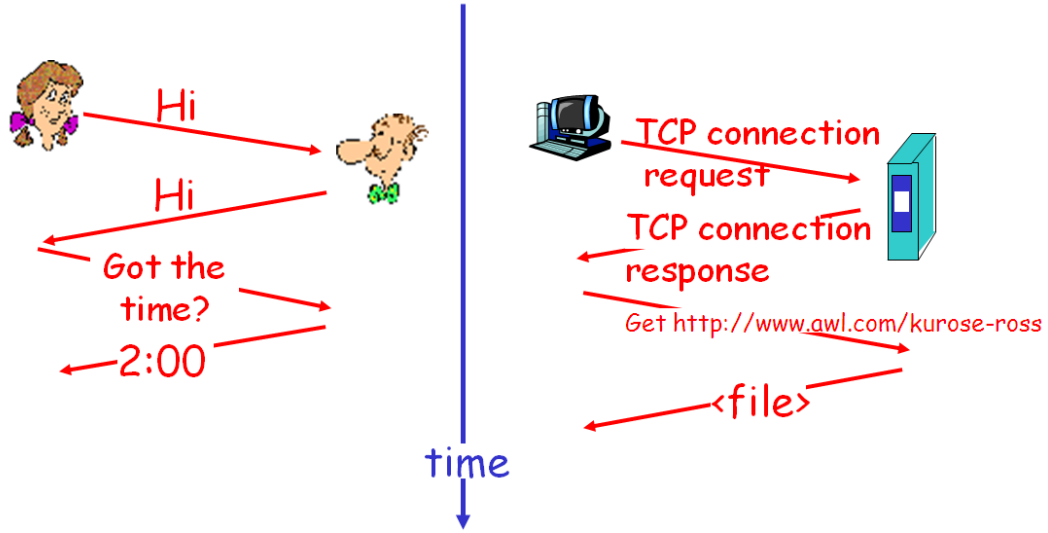
網路協定堆疊(Protocol Stack)



圖片來源：http://programmerhelp404.blogspot.tw/2014/01/iso-osi-layer-model-tcpip-model.html

Protocol & Protocol Layers

- Protocols define format, order of messages sent and received among network entities, and actions taken on message transmission.



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

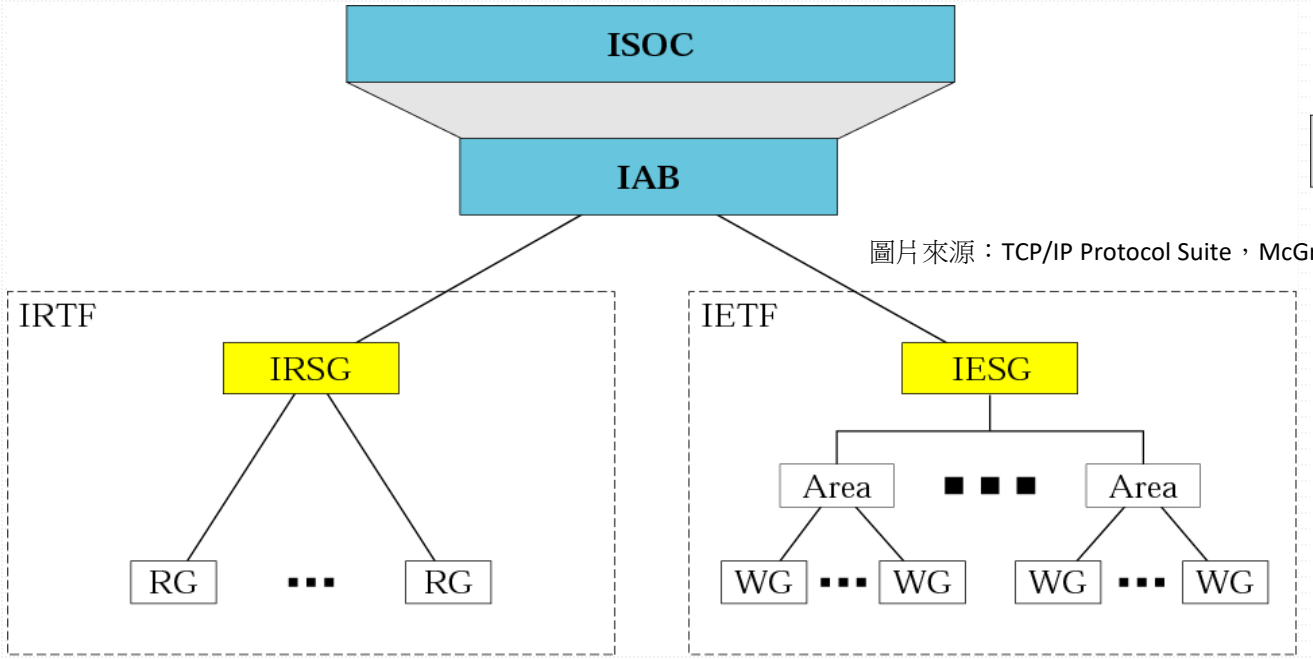
- Networks are complex!
  - Hosts
  - Routers
  - Links of various media
  - Applications
  - etc.
- Protocol Layer
  - Each layer implements a service
    - via its own internal-layer actions
    - relying on services provided by layer below

Protocol & Protocol Layers

- Explicit structure allows identification, relationship of complex system's pieces
- Modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
- Harmful?
  - Some wireless/mobile researches show that cross-layer methods are required.

Internet Administration

- Internet Society (ISOC)
- Internet Architecture Board (IAB)
- Internet Engineering Task Force (IETF)
- Internet Research Task Force (IRTF)



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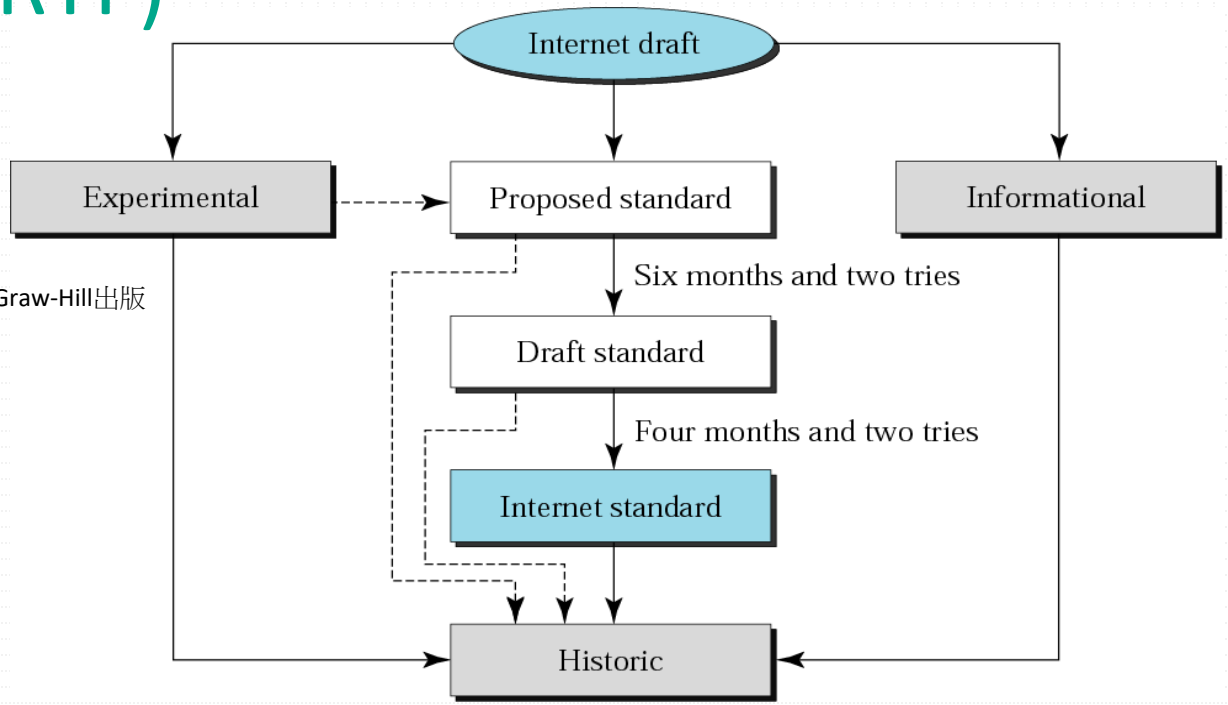


TCP/IP Model

5. Application

- supporting network applications
- message
- e.g., FTP, SMTP, HTTP, etc.

4. Transport

- process-process data transfer
- segment
- e.g., TCP, UDP, SCTP, etc.

3. Network

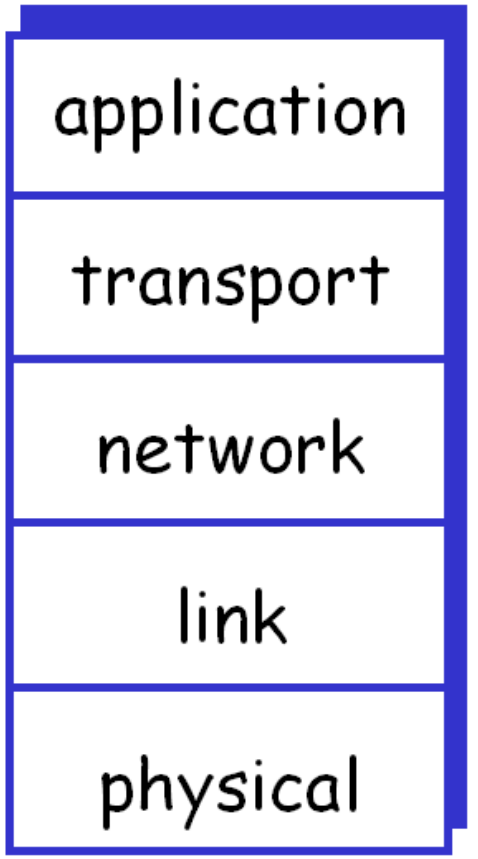
- routing from source to destination
- datagram
- e.g., IPv4 and IPv6

2. Link

- data transfer between neighboring hosts
- frame
- e.g., Ethernet, etc.

1. Physical

- bits “on the wire”



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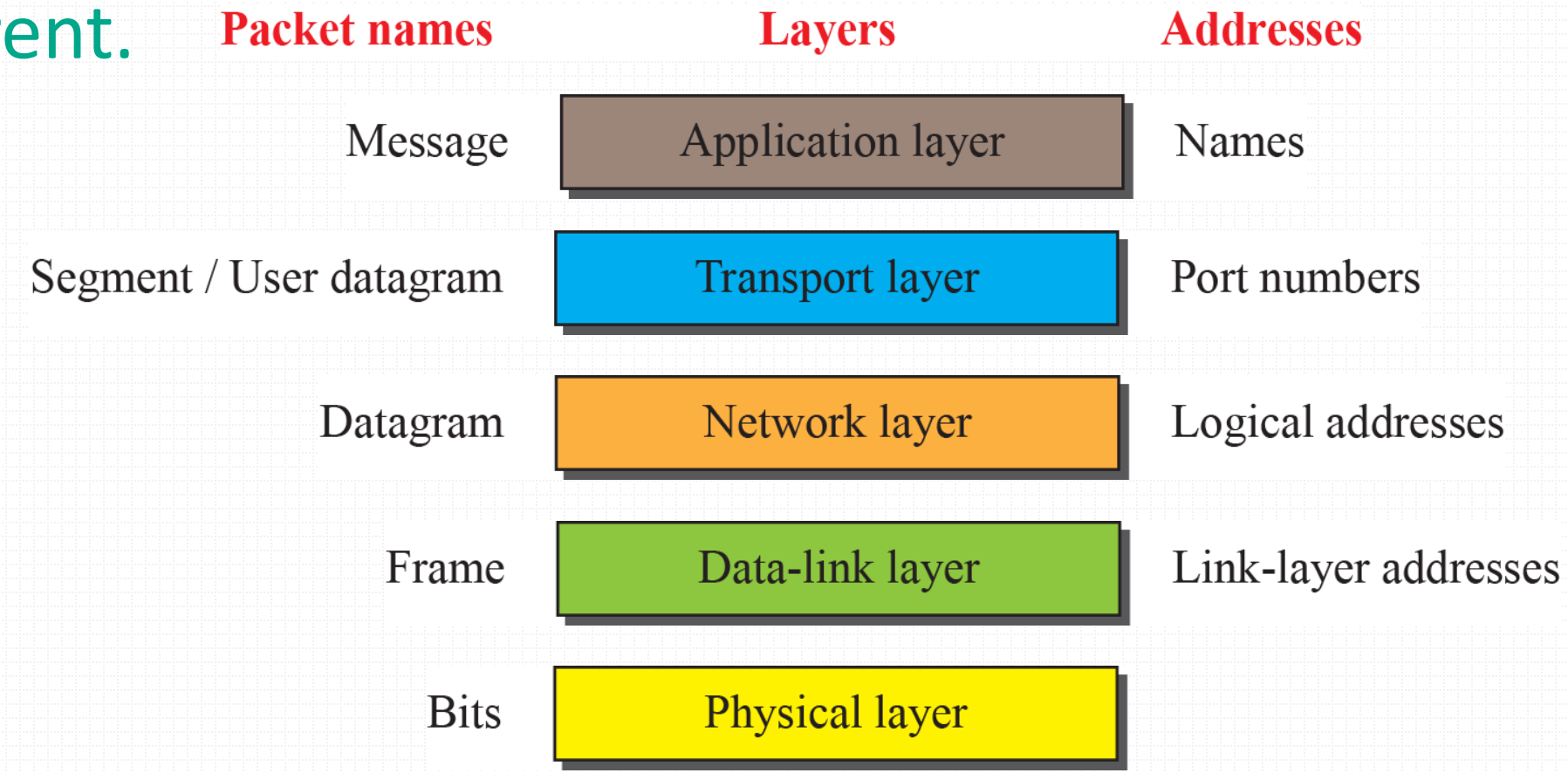
TCP/IP Model

- The address name and packet name in each layer are different.



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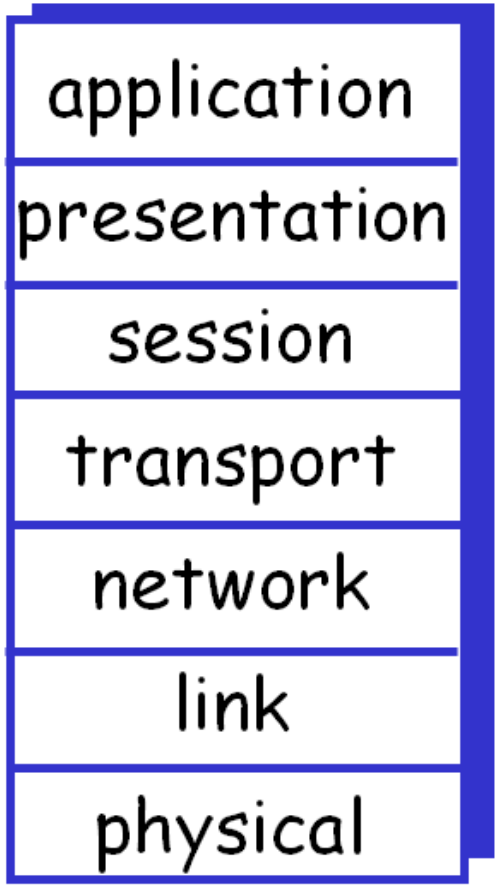
ISO/OSI Reference Model

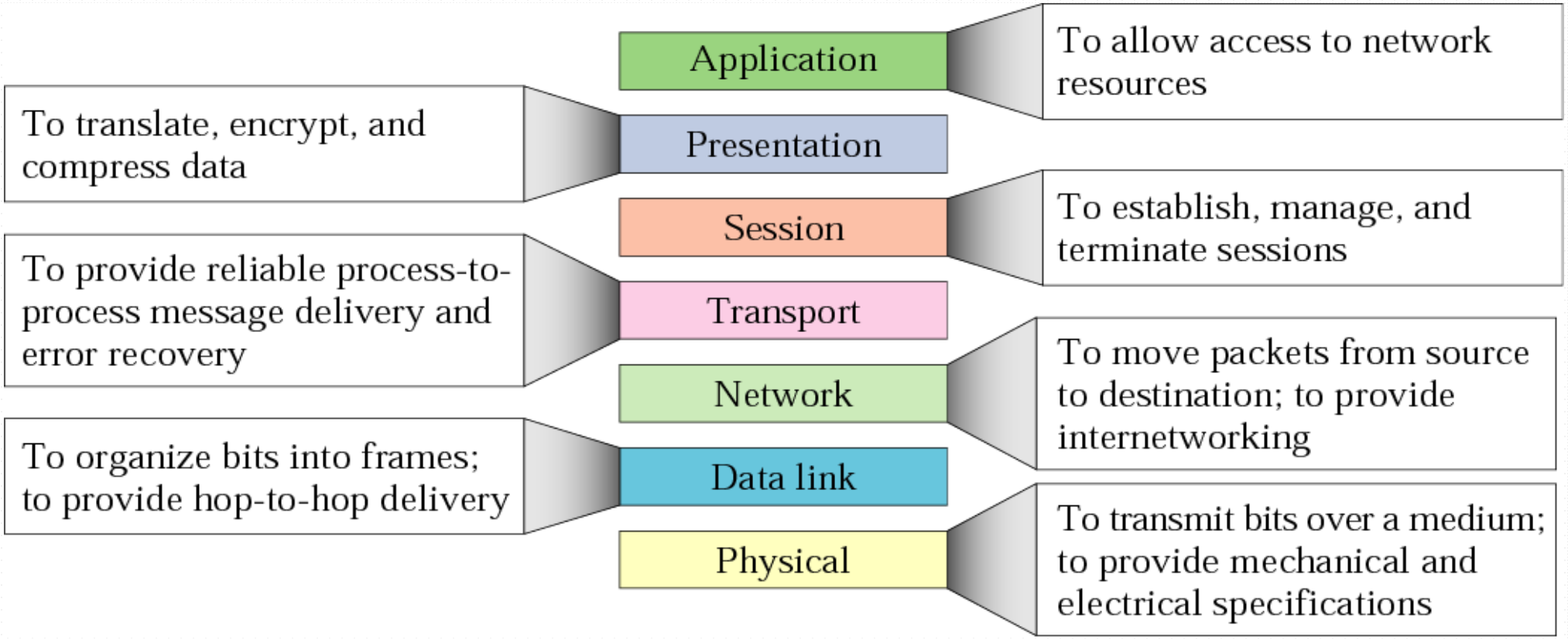
7. Application
6. Presentation
   - allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
5. Session
   - synchronization, checkpointing, recovery of data exchange
4. Transport
3. Network
2. Link
1. Physical



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

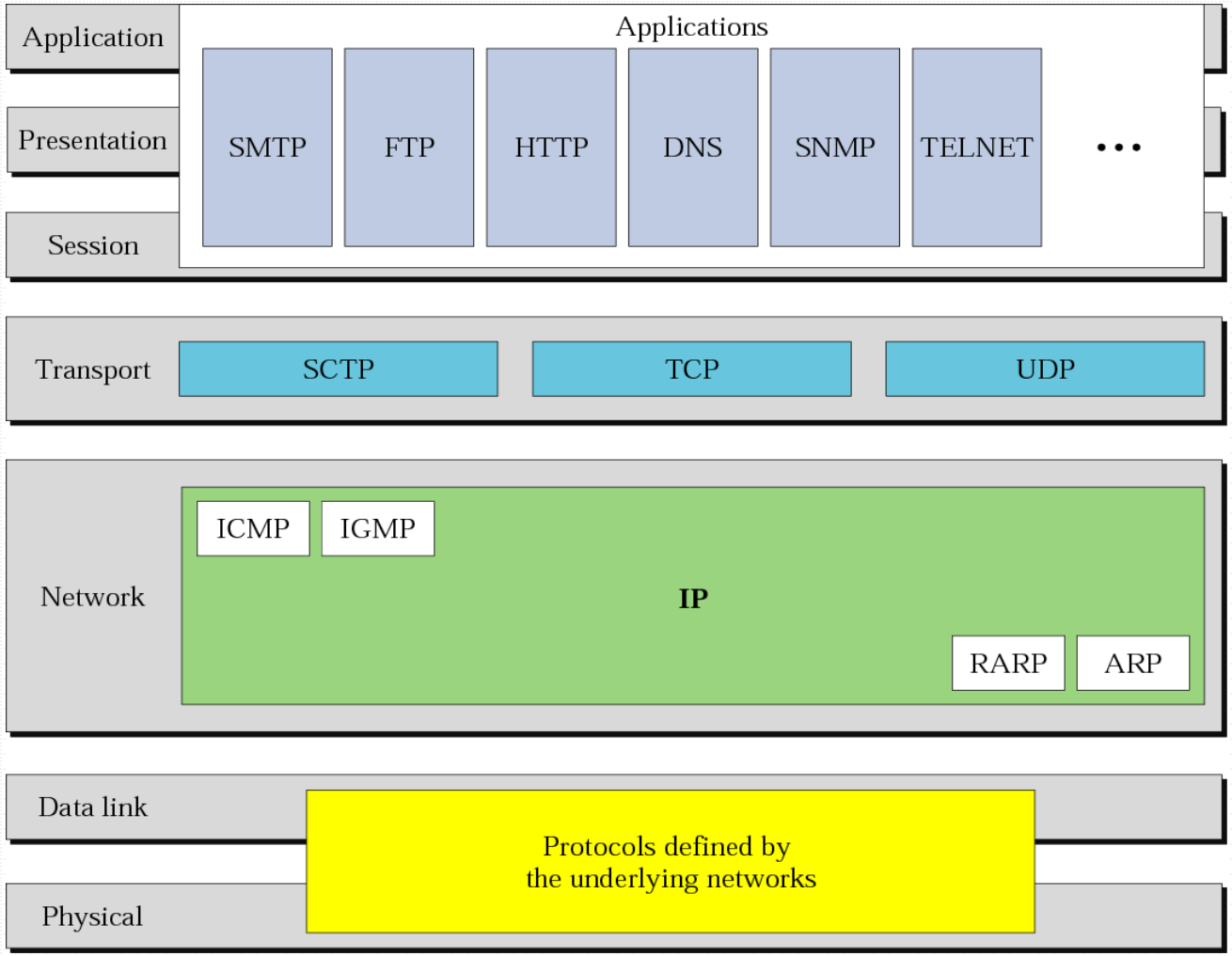
ISO/OSI Reference Model

- It is more suitable for the theoretical analysis.



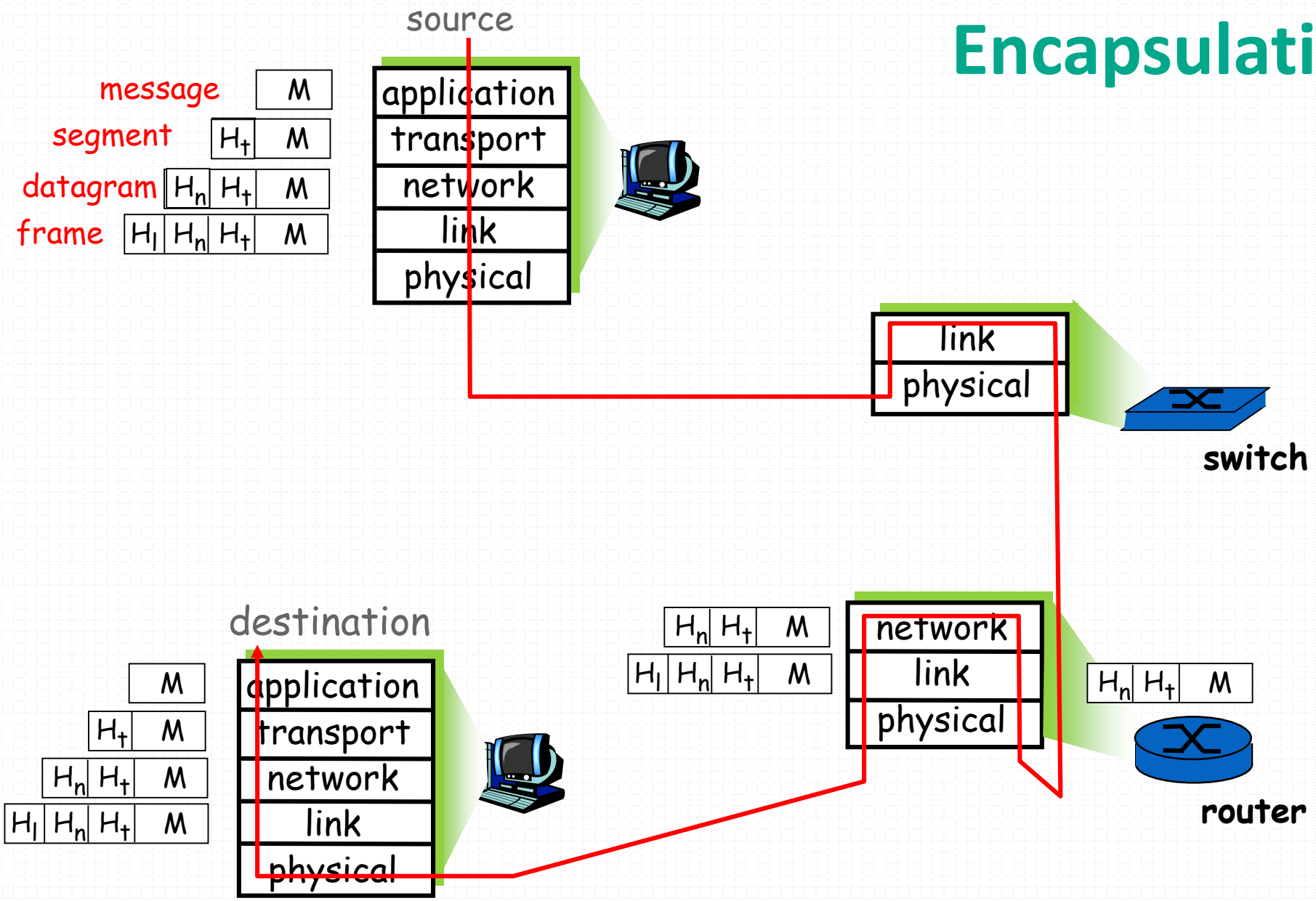
圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版

Comparison between two models



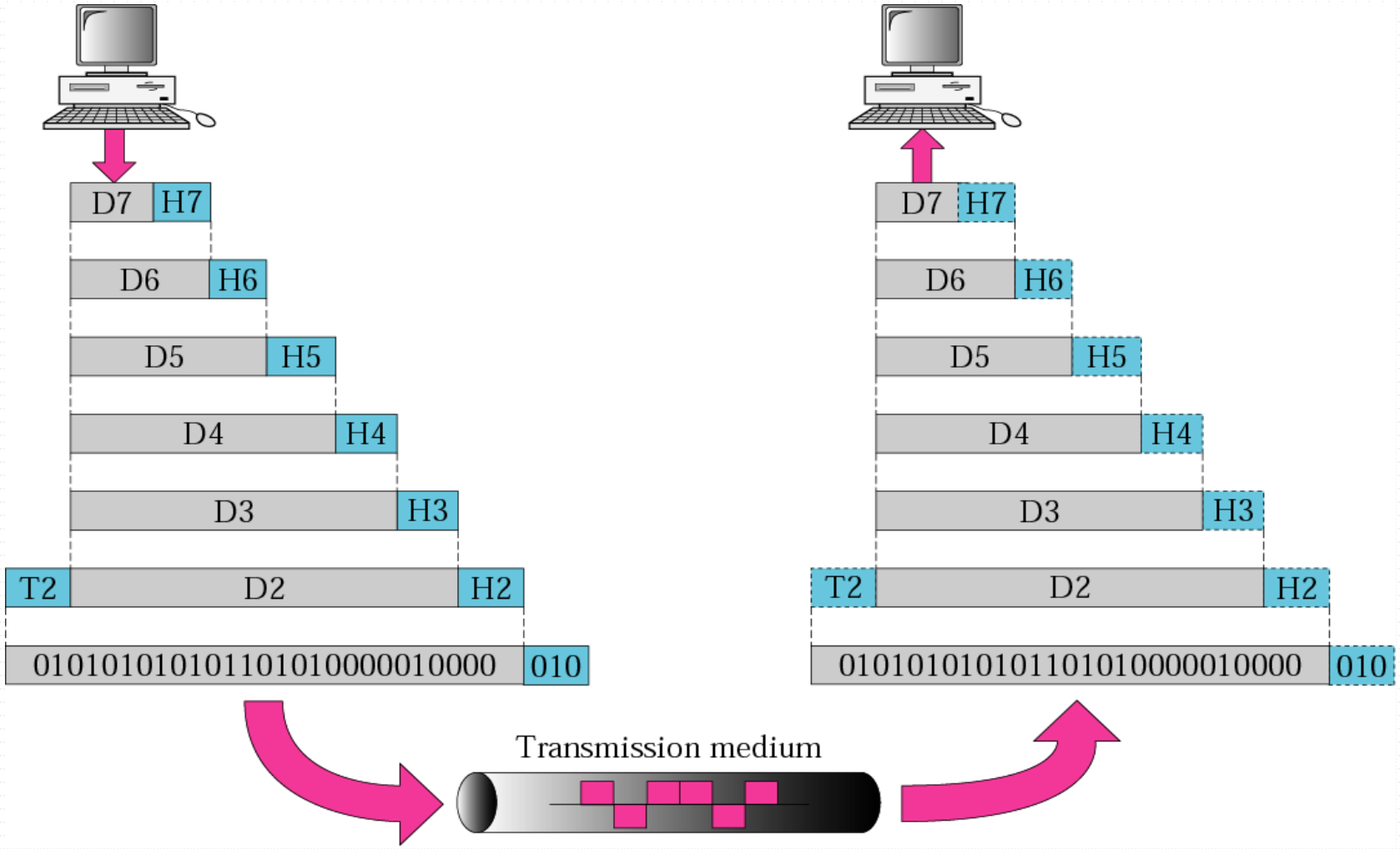
圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版

Encapsulation



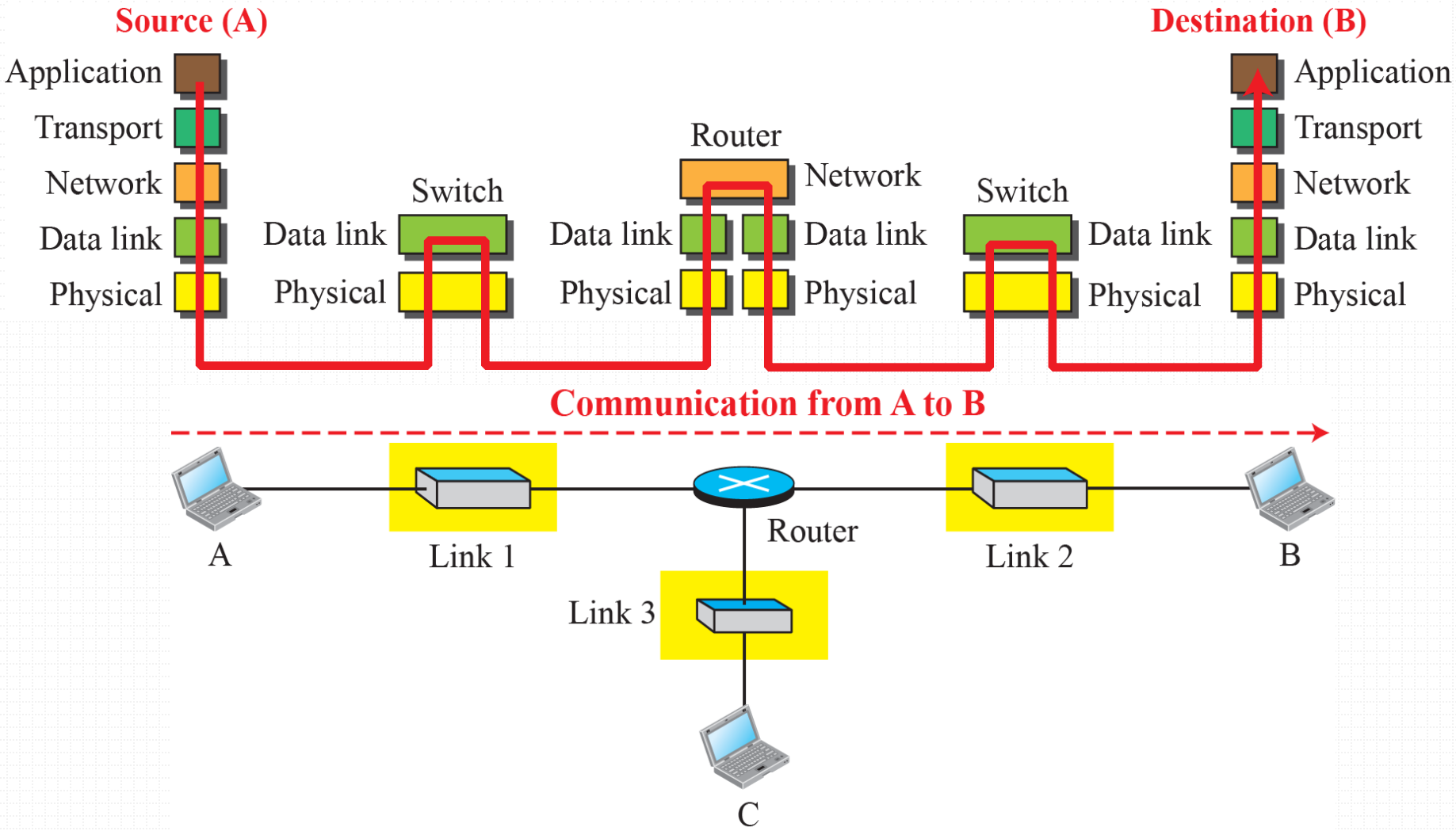
圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

Encapsulation



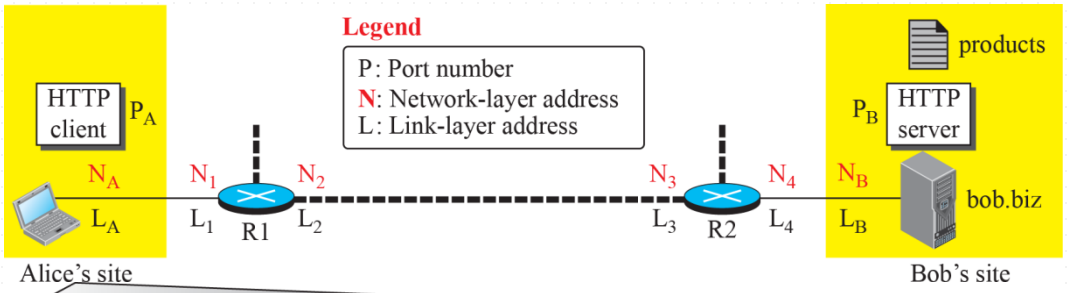
圖片來源：TCP/IP Protocol Suite，McGraw-Hill出版

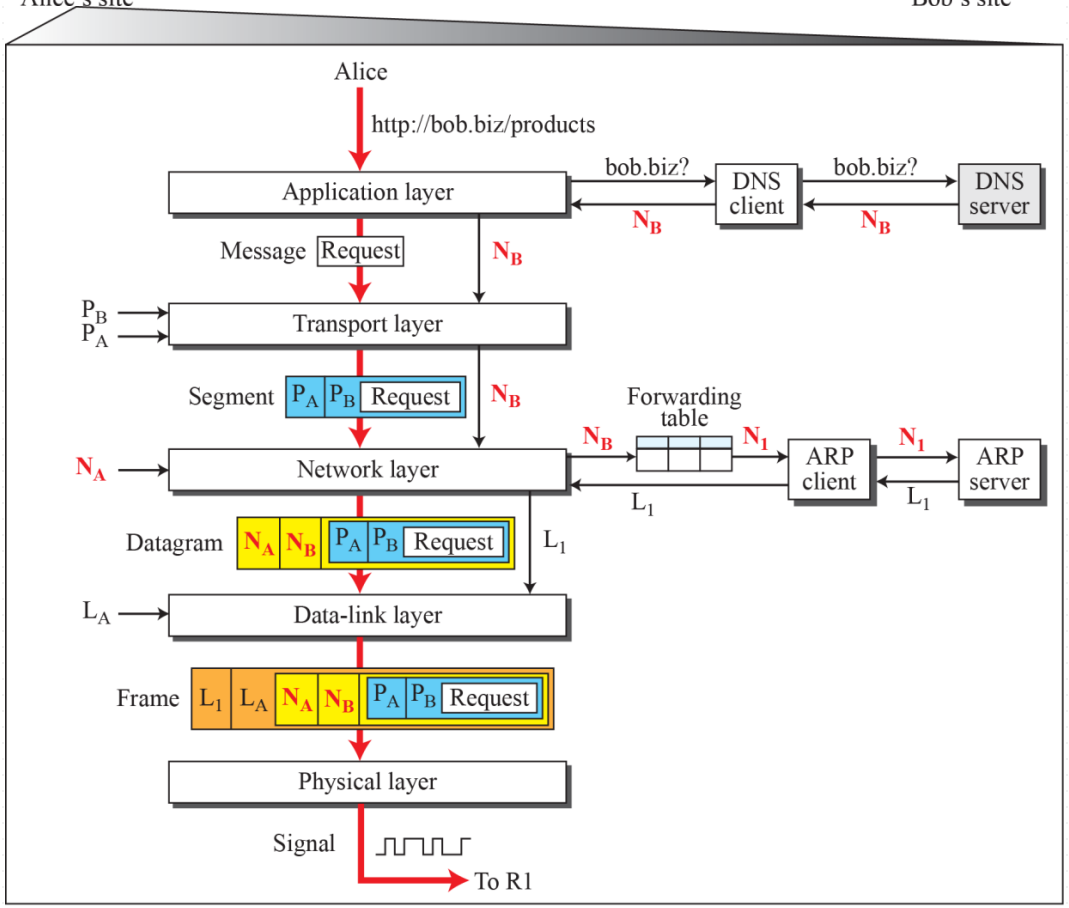
Communication through the Internet



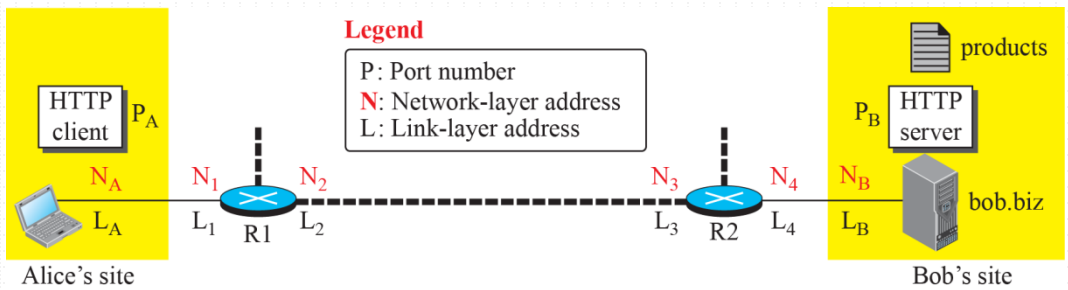
圖片來源：Computer Networks - A Top Down Approach，McGraw-Hill出版

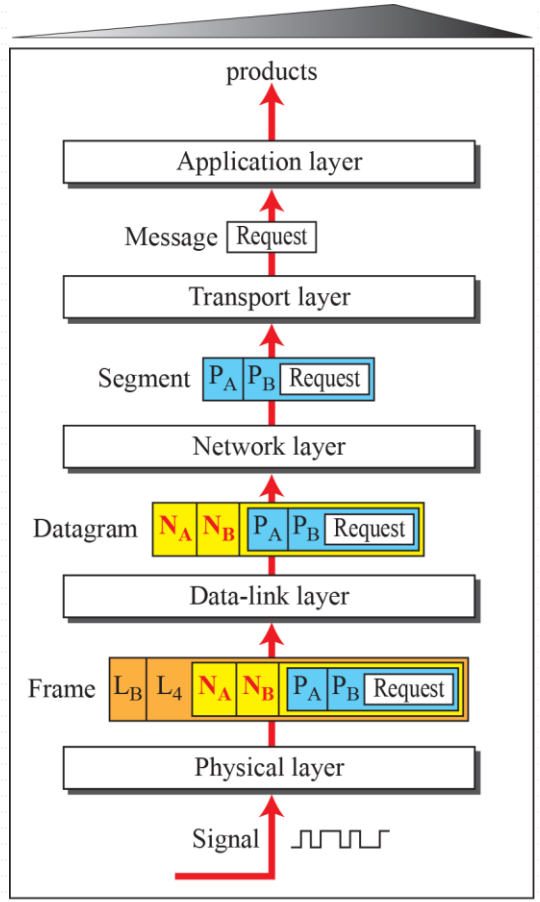
Communication through the Internet





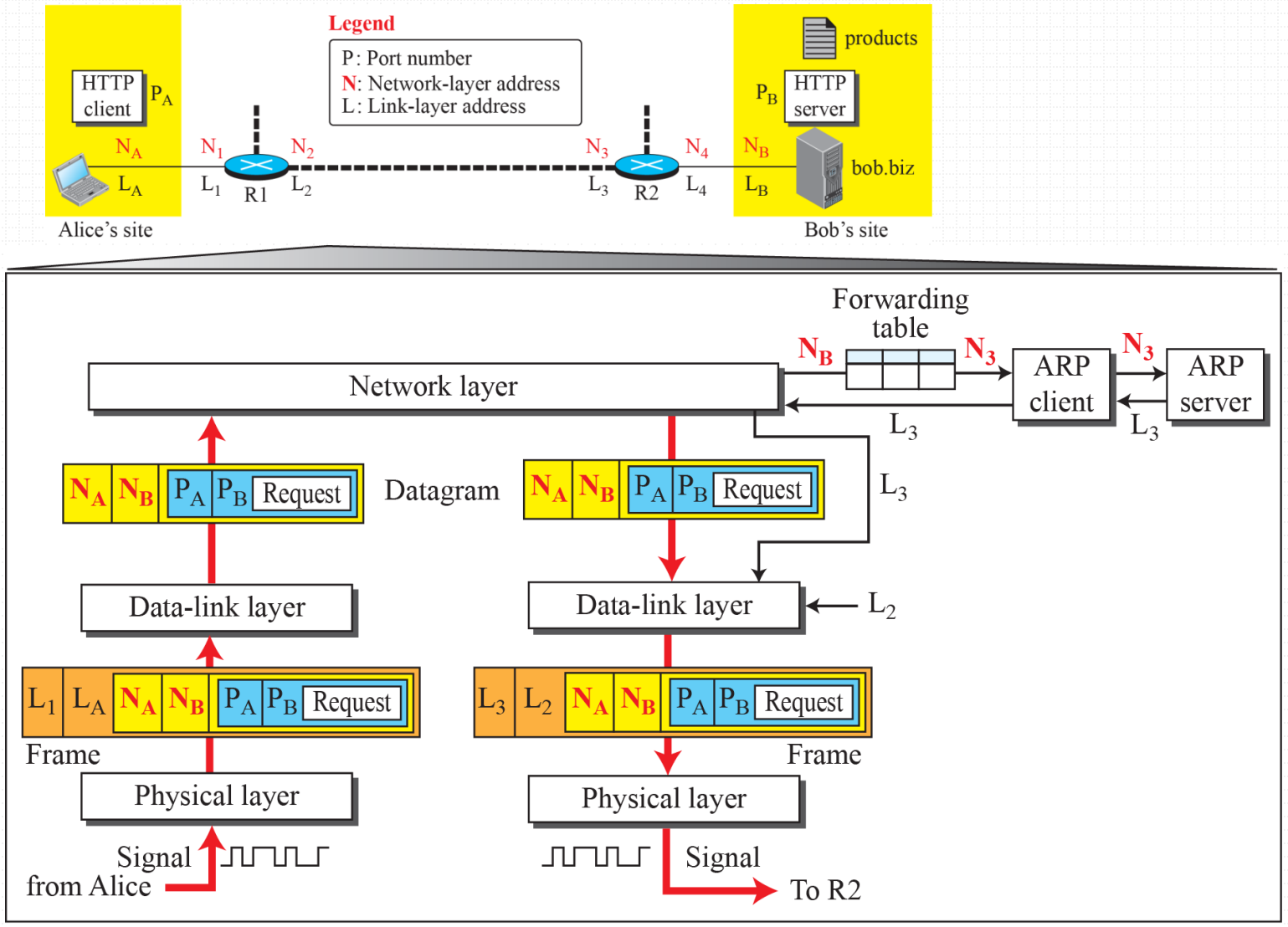
Flow of packets at Alice's computer





Flow of packets at Bob's computer

Communication through the Internet



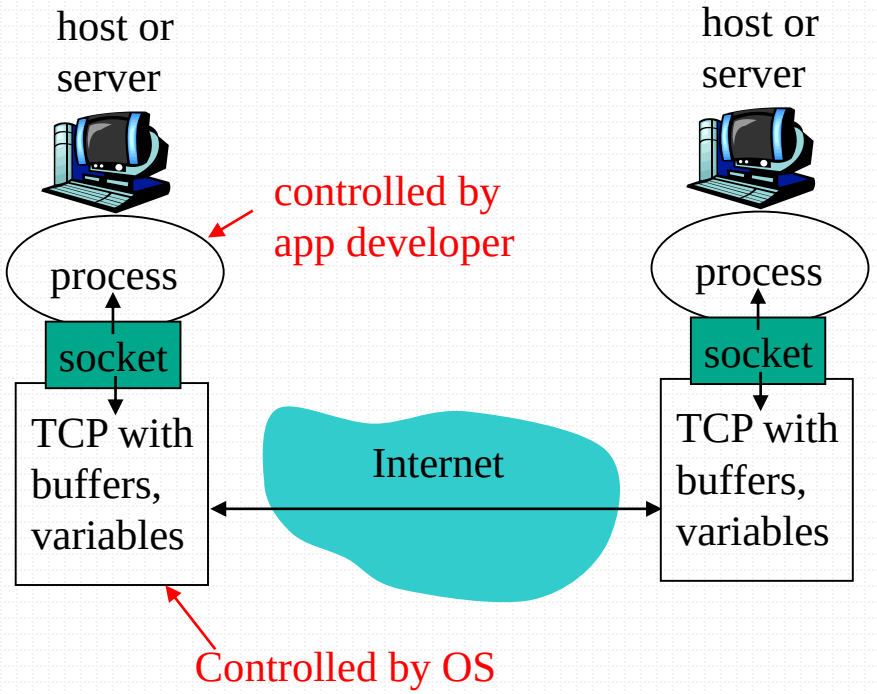
Flow of packets at Router R1

Application-layer

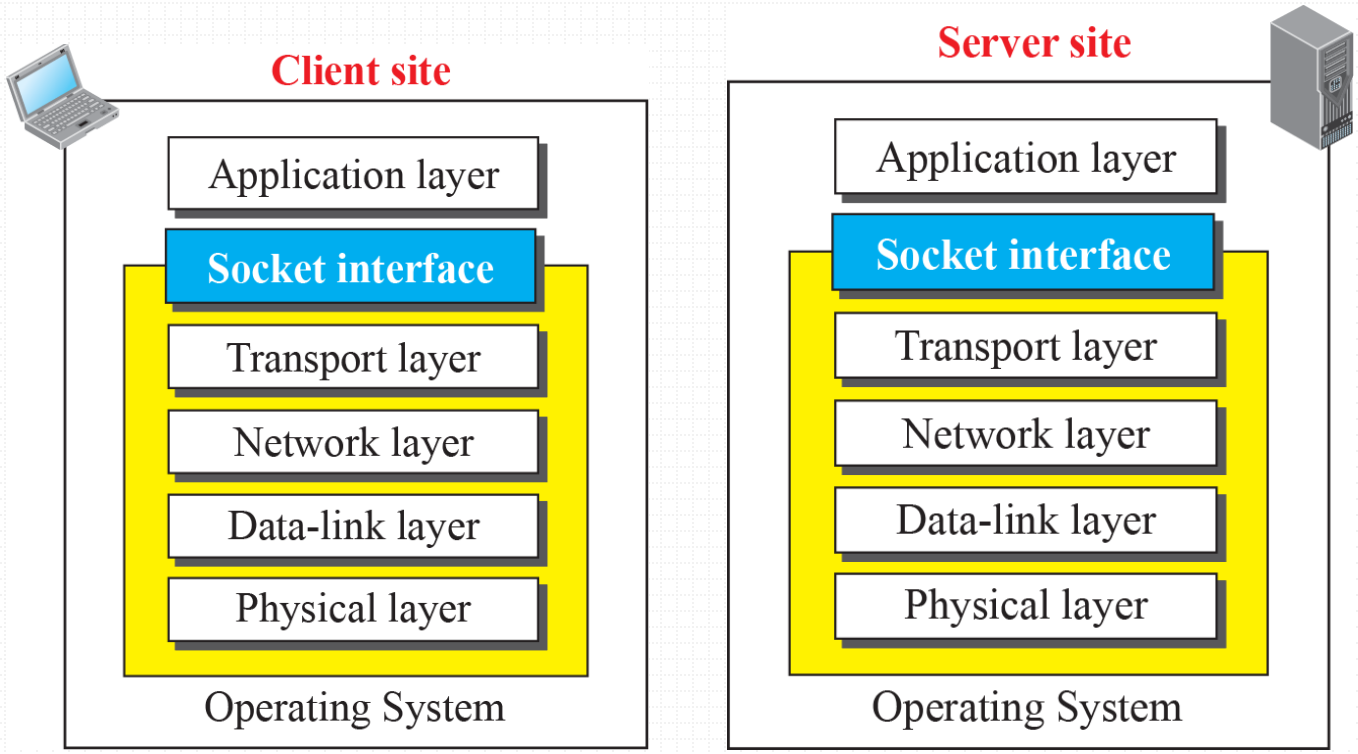
- Network perspective
  - Types of messages exchanged,
    - e.g., request, response
  - Message syntax
    - what fields in messages & how fields are delineated
  - Message semantics
    - meaning of information in fields
  - Rules for when and how processes send & respond to messages
- Operating system (OS) perspective
  - Process
    - program running within a host.
      - Client process: process that initiates communication
      - Server process: process that waits to be contacted
  - Inter-process communication
    - two processes communicate within same host.
  - Messages
    - Processes in different hosts communicate by exchanging messages across the computer network.

Implementation – Socket

- Interface between the process and the computer network
- Process sends/receives messages to/from its socket.



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版



圖片來源：Computer Networks - A Top Down Approach，McGraw-Hill出版

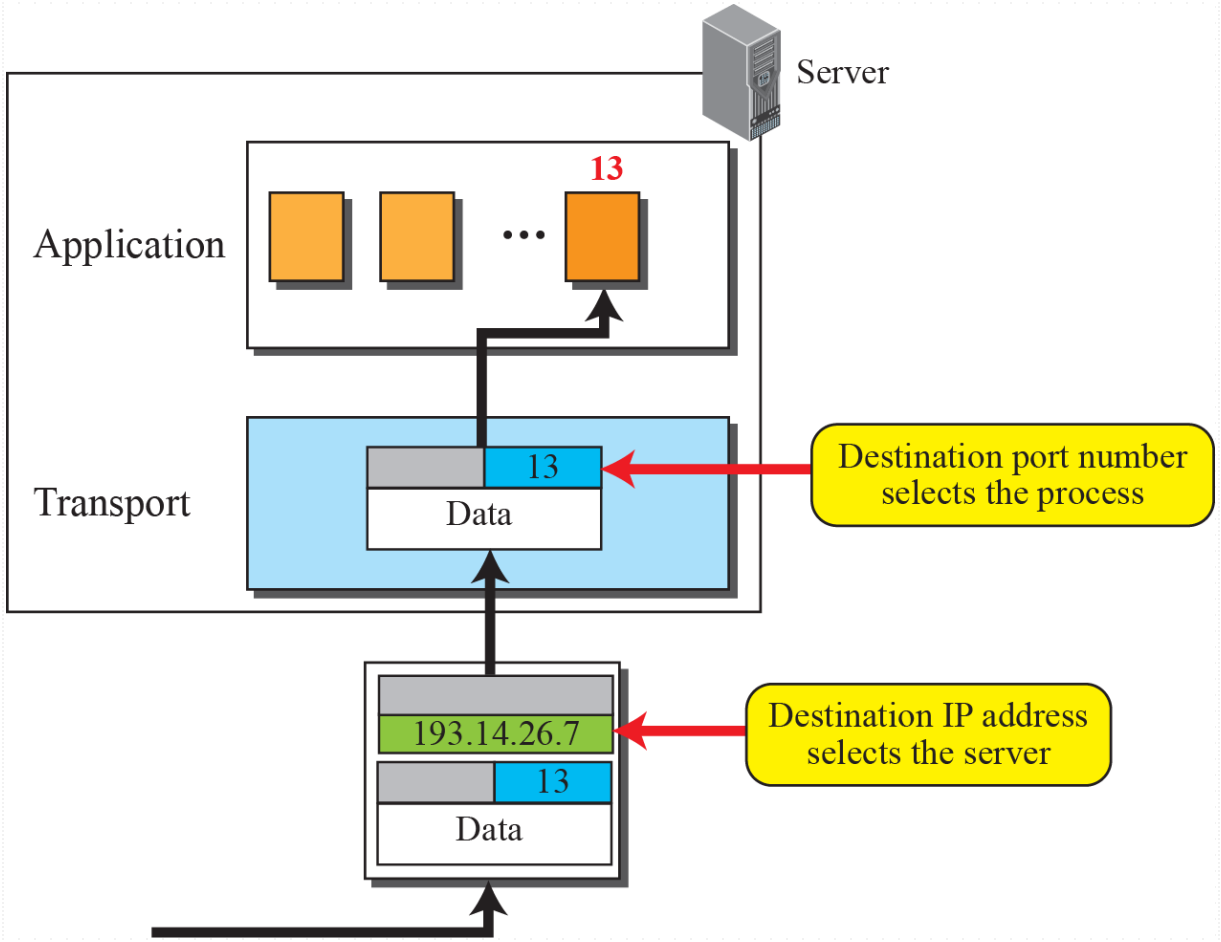
Transport-layer

- Logical communication between application processes running on different hosts.
  - Process-to-Process
- Multiplexing & Demultiplexing
  - Extending host-to-host delivery to process-to-process delivery

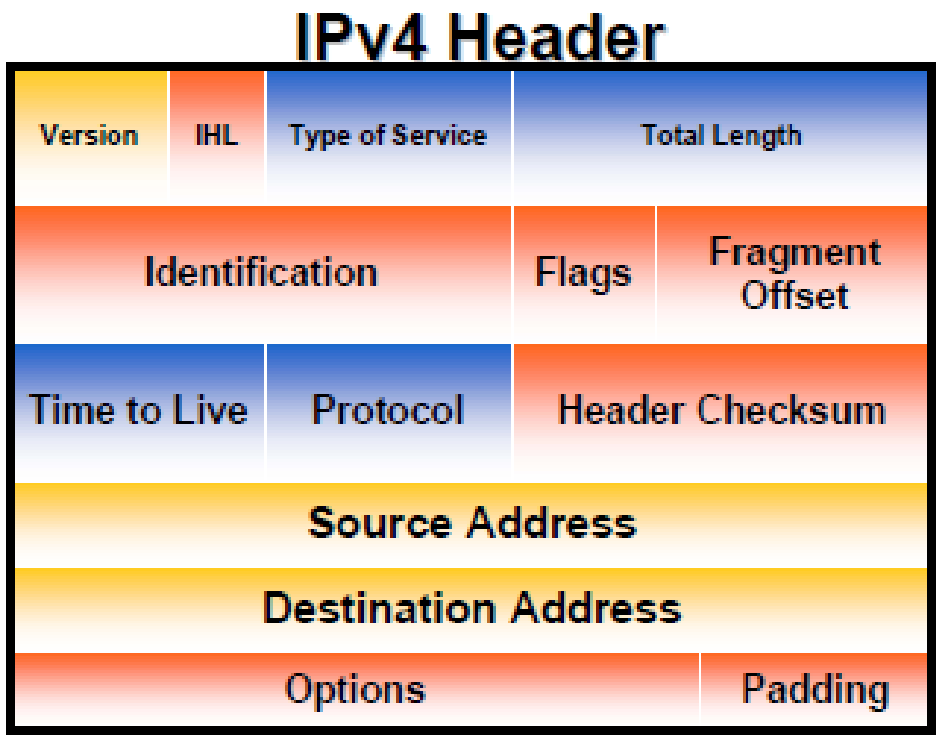
- Transmission Control Protocol (TCP)
  - Reliable, in-order delivery
  - Congestion control
  - Flow control
  - Connection setup
- User Datagram Protocol (UDP)
  - Unreliable, unordered delivery
  - “best-effort”
- Services not available
  - Delay guarantees
  - Bandwidth guarantees

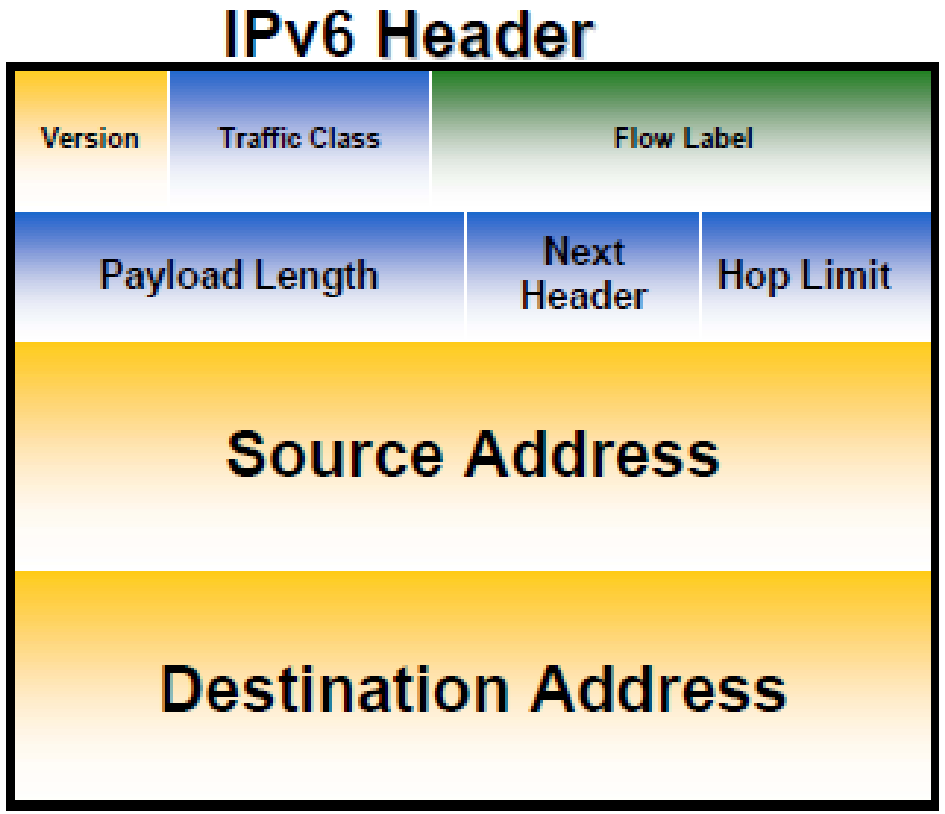
Network Layer

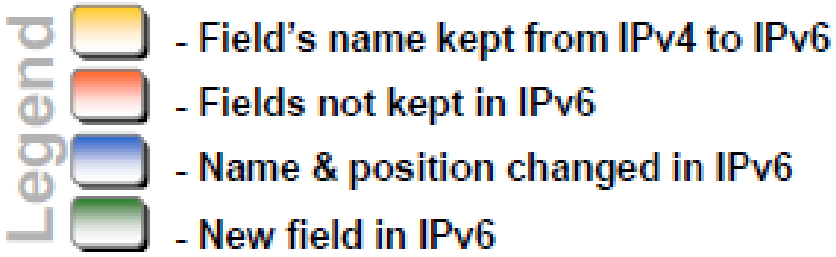
- Transport segments from sending hosts to receiving hosts. (End-to-End)



IPv4 v.s. IPv6


IPv4 Header
Version
IHL
Type of Service
Total Length
Identification
Flags
Fragment Offset
Time to Live
Protocol
Header Checksum
Source Address
Destination Address
Options
Padding


IPv6 Header
Version
Traffic Class
Flow Label
Payload Length
Next Header
Hop Limit
Source Address
Destination Address


Legend
- Field's name kept from IPv4 to IPv6
- Fields not kept in IPv6
- Name & position changed in IPv6
- New field in IPv6

Data Link Layer

- Transferring datagram from one node to adjacent node over a link. (Node-to-Node)
- Link access
  - Medium access control (MAC)
    - The rules by which a frame is transmitted onto the link.
  - MAC addresses used in frame headers
    - Different from IP address

Multiple Access Protocols

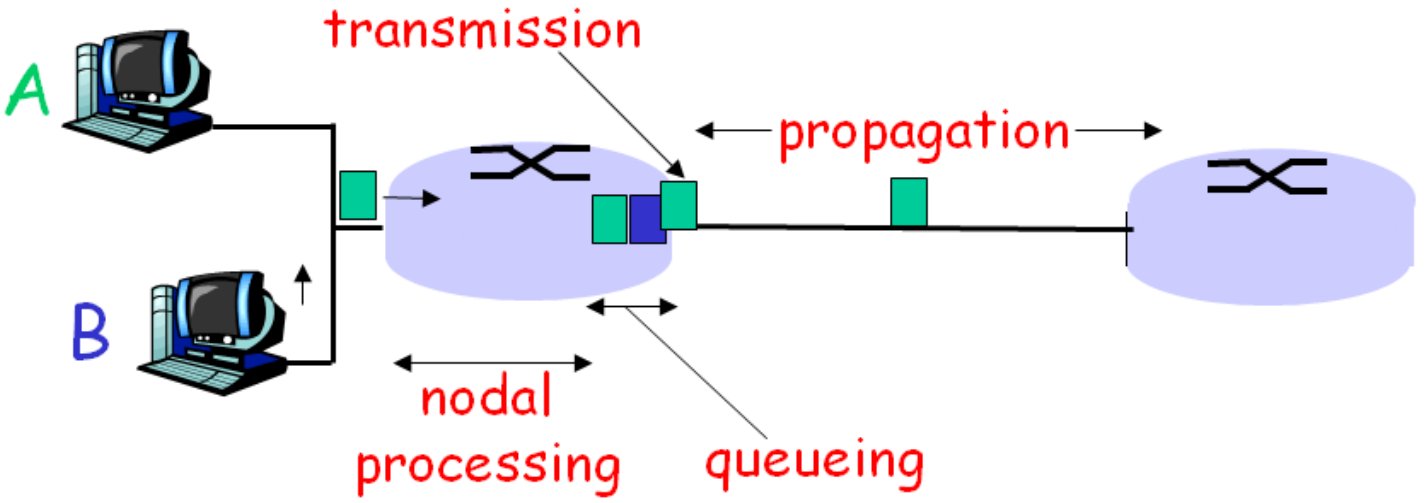
- Distributed algorithm that determines how nodes share a channel, i.e., determine when a node can transmit.
  - Channel Partitioning
    - divide channel into smaller “pieces”
    - allocate piece to node for exclusive use
  - Random Access
    - channel not divided, allow collisions
    - “recover” from collisions
  - Taking Turns
    - nodes take turns

網路效能參數
(Performance Metrics)

NTUT NESL

Performance Metric – Delay

- Processing delay (d_{proc})
  - Time to examine the packet's header
- Queueing delay (d_{queue})
  - Time to wait at output link for transmission
- Transmission delay (d_{trans})
  - R=link bandwidth (bps)
  - L=packet length (bits)
  - L/R =time to send bits into link
- Propagation delay (d_{prop})
  - d=length of physical link
  - s=propagation speed in medium
  - d/s =time to pass through a link



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

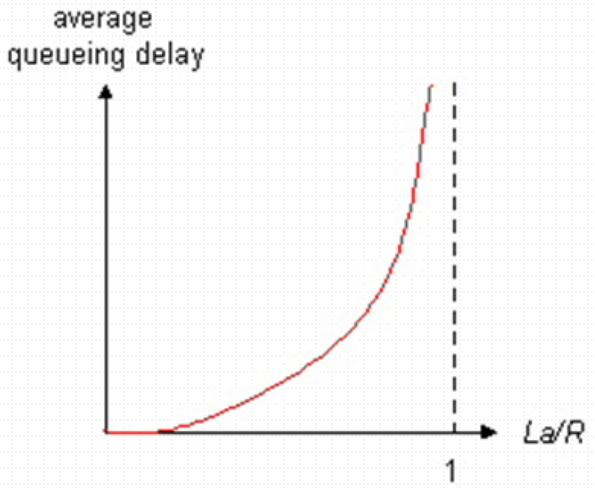
Performance Metric – Delay

- Nodal delay (D_{nodal})

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

圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

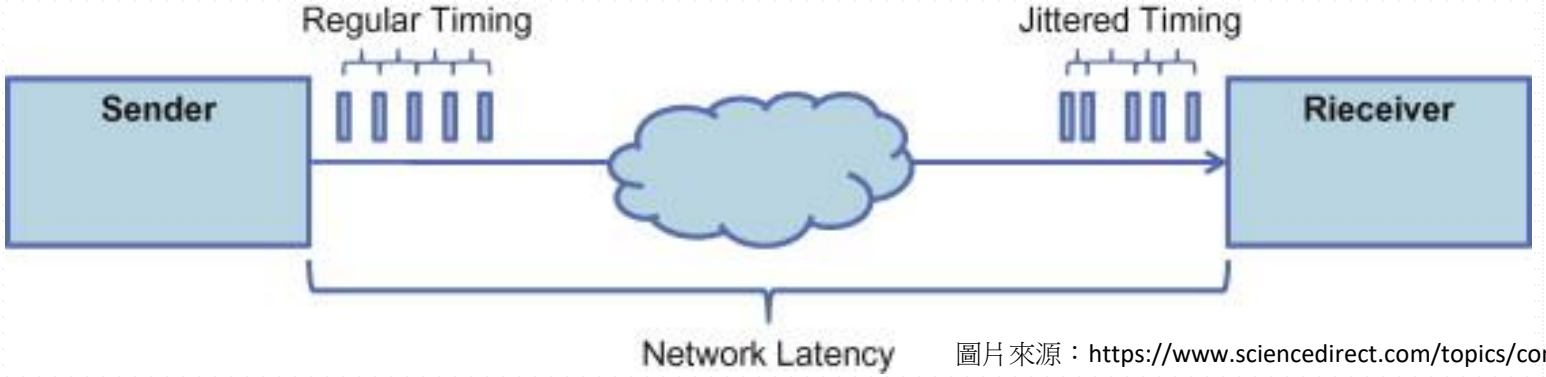
- Traffic intensity = La/R
  - R=link bandwidth (bps)
  - L=packet length (bits)
  - a=average packet arrival rate



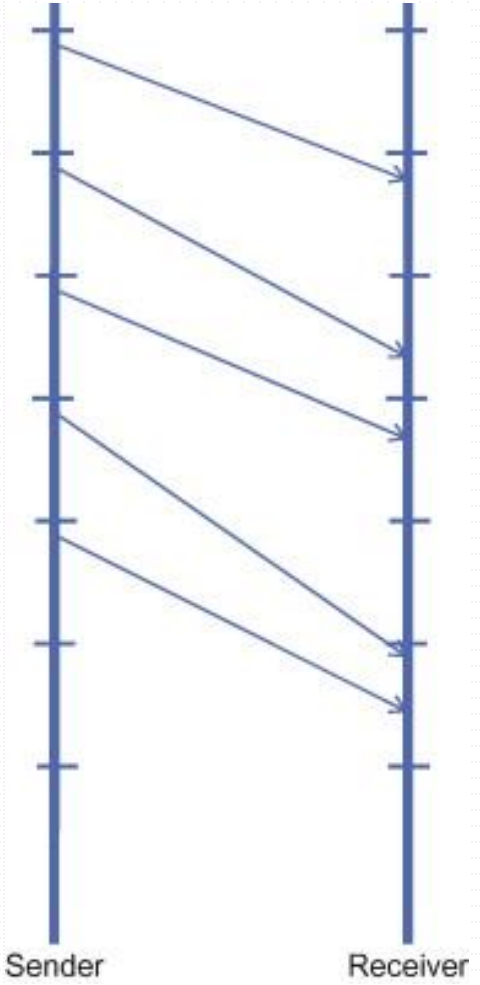
- La/R ~ 0
  - average queueing delay small
- La/R → 1
  - delays become large
- La/R > 1
  - more “work” arriving than can be serviced, average delay infinite!

Performance Metric – Jitter

- Jitter is the variance in network latency due to network state.



圖片來源：https://www.sciencedirect.com/topics/computer-science/jitter

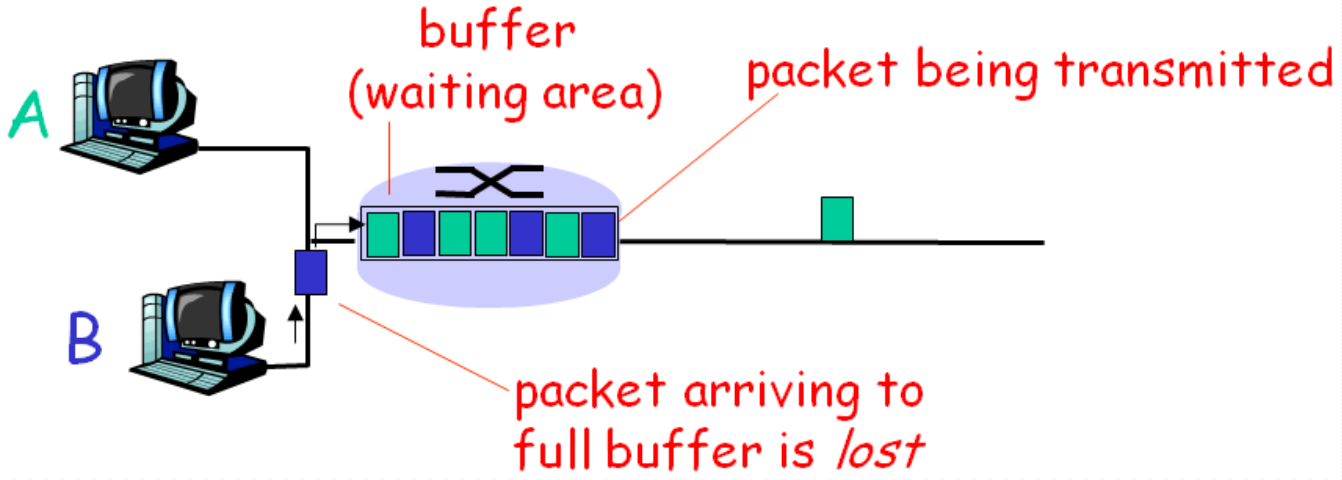


- This causes additional delay in representation.
  - The sender and receiver are running at the same rate.
  - The sender sends regularly spaced packets, but jitter causes them to arrive at different points of receiver's update cycle.

Performance Metric – Loss

- Wired
  - Queue (buffer) has finite capacity.
  - A packet arriving to a full queue will be dropped (lost).

- Wireless
  - Signaling oscillation

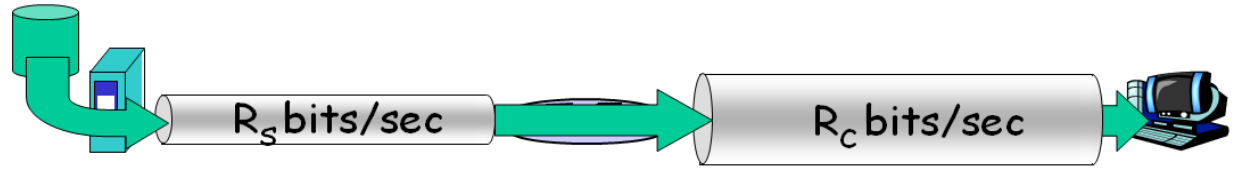


圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

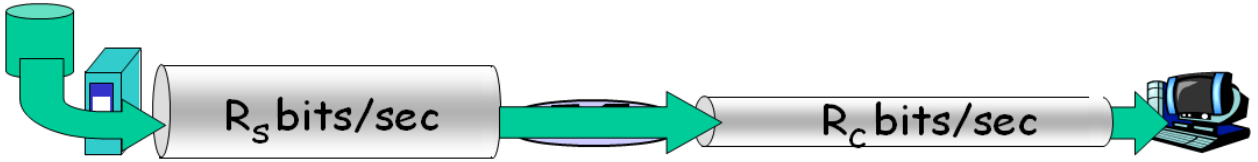
Performance Metric – Throughput

- Rate (bits/time unit) at which bits transferred between sender/receiver
  - Instantaneous
    - rate at given point in time
  - Average
    - rate over long(er) period of time

- $R_s < R_c$



- $R_s > R_c$
  - bottleneck link



圖片來源：Computer Networking - A Top-Down Approach，Addison-Welsey出版

NTUT NESL

總結

- Network Structure
  - Network edge
    - Hosts
    - Access networks
  - Network core
    - Packet-switching v.s. Circuit-switching
- Protocol layers and service models
- Network performance
  - Loss
  - Delay
  - Jitter
  - Throughput