Introduction to Computer Networks

Foundation

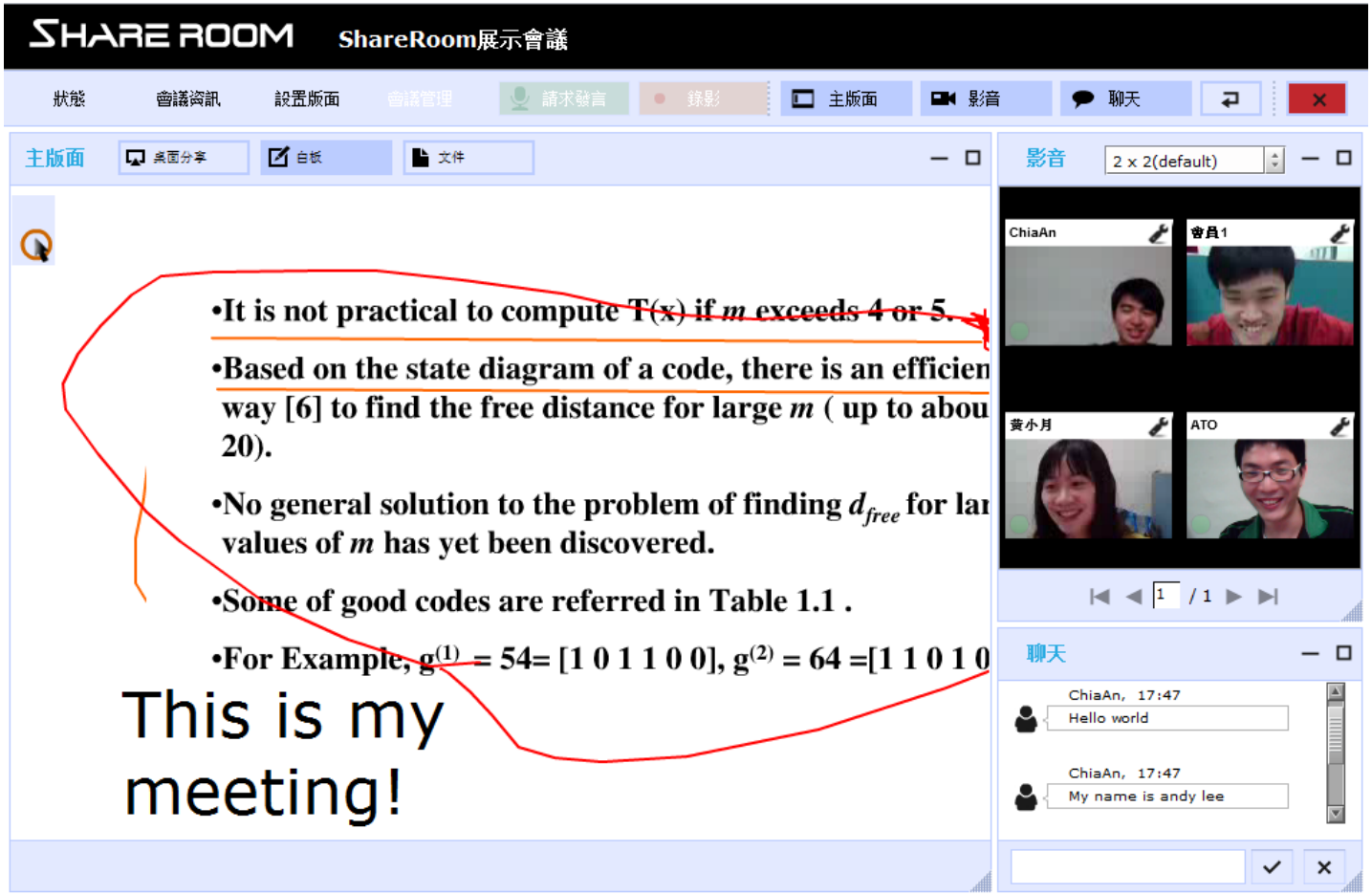
Outline

- Applications
- Network Connectivity
- Network Architecture
- Network Performance

Applications

- Most people know about the Internet (a computer network) through applications
  - World Wide Web
  - On line games
  - Email (Gmail, hotmail,…)
  - Online Social Network (Facebook, twitter,…)
  - Streaming Audio Video (Youtube, ppstream, kkbox, …)
  - File Sharing (dropbox, …)
  - Instant Messaging (Skype, IM+, MSN, Line, WeChat,…)
  - …

Example of an application



A multimedia application including video-conferencing

Application Protocol

- URL
  - Uniform resource locater
  - http://www.sharecourse.net/sharecourse/
- HTTP
  - Hyper Text Transfer Protocol
- TCP
  - Transmission Control Protocol
- 17 messages for one URL request
  - 6 to find the IP (Internet Protocol) address
  - 3 for connection establishment of TCP
  - 4 for HTTP request and acknowledgement
    - Request: I got your request and I will send the data
    - Reply: Here is the data you requested; I got the data
  - 4 messages for tearing down TCP connection

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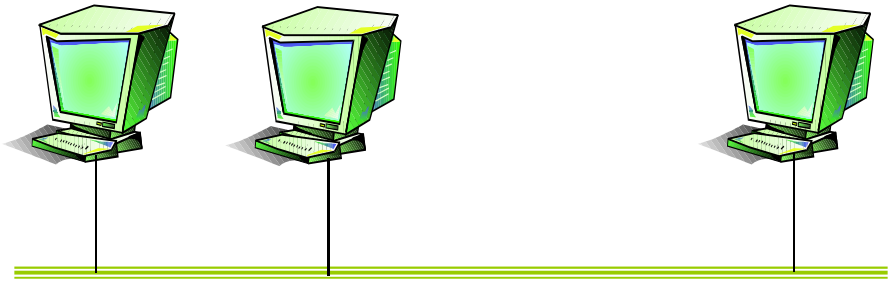
- Network Performance

Network Connectivity

- Important terminologies
  - Link
  - Nodes
  - Point-to-point
  - Multiple access
  - Switched Network
    - Circuit Switched
    - Packet Switched
  - Packet, message
  - Store-and-forward

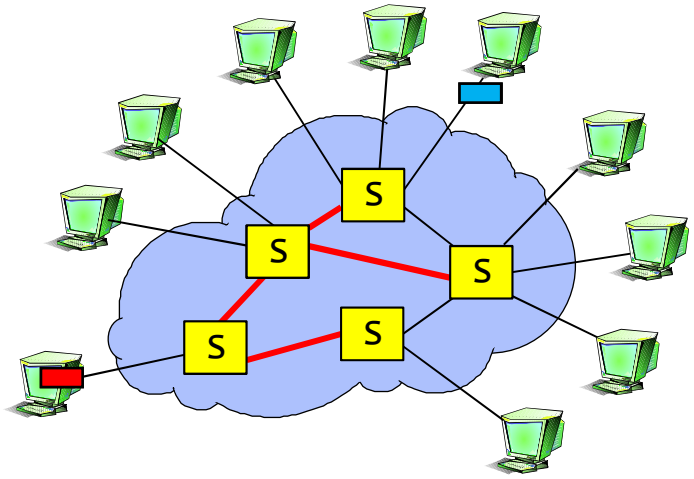
Point-to-point



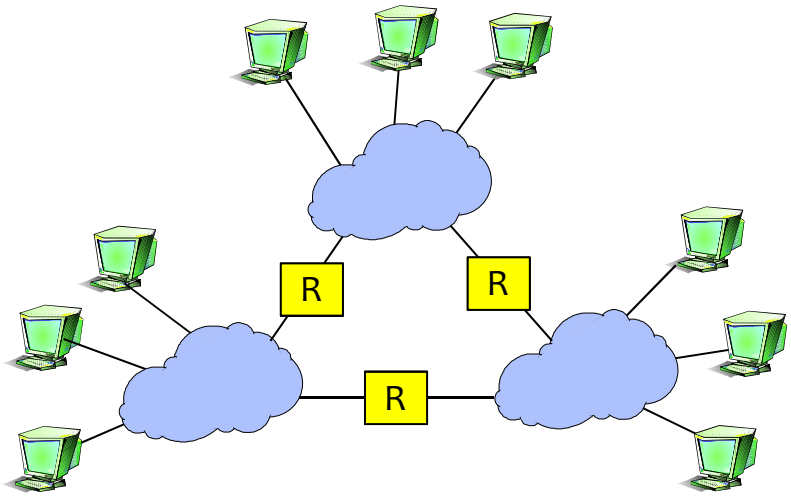
Multiple access

Network Connectivity

- Terminologies (contd.)
  - Hosts
  - Switches
  - Spanning tree
  - internetwork
  - Router/gateway
  - Host-to-host connectivity
  - Address
  - Routing
  - Unicast/broadcast/multicast
  - LAN (Local Area Networks)
  - MAN (Metropolitan Area Networks)
  - WAN (Wide Area Networks)

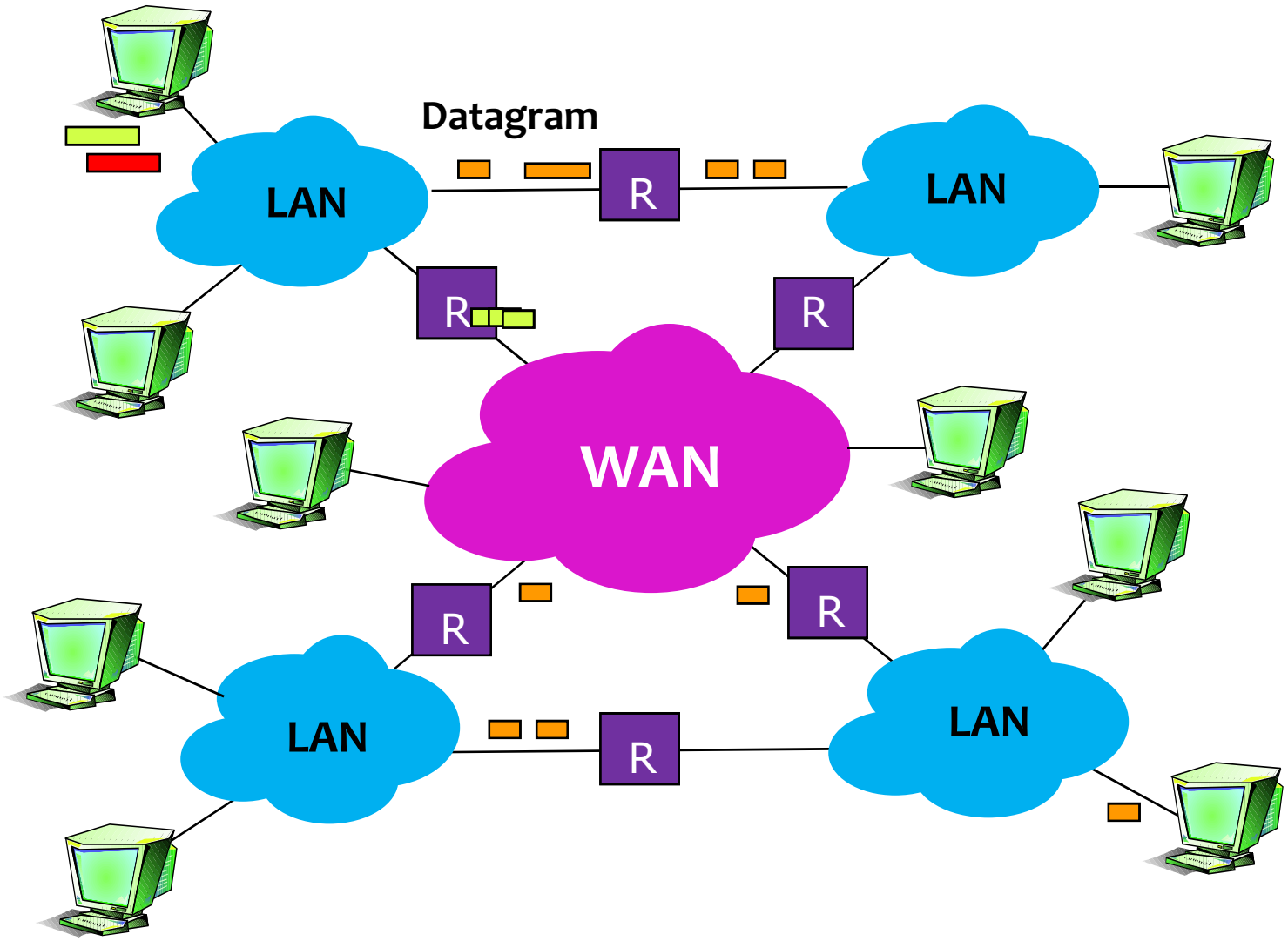


(a) A switched network



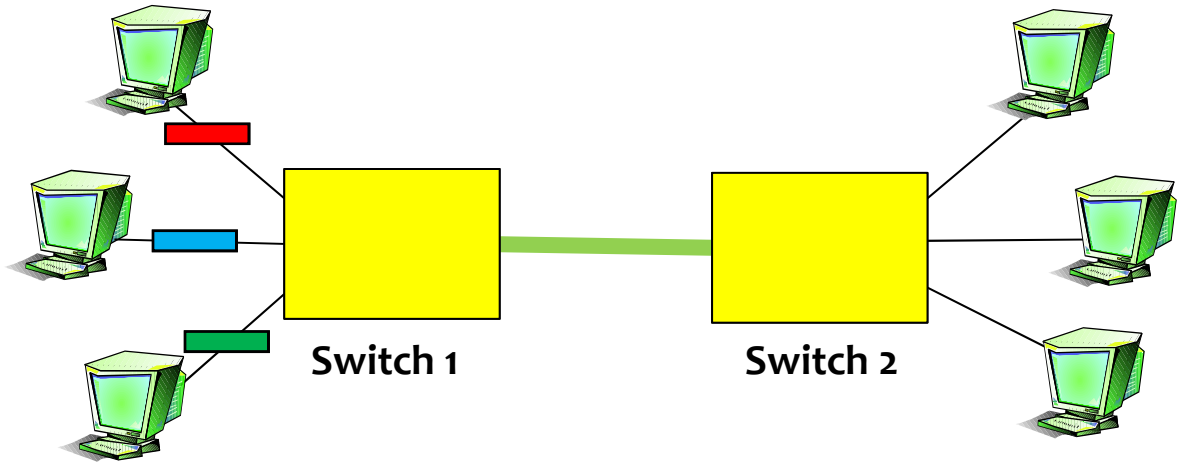
(b) Interconnection of networks

How datagrams are delivered in an Internet ?



Cost-Effective Resource Sharing

- Resource: links and nodes
- How to share a link ?
  - Multiplexing
  - De-multiplexing



Multiplexing multiple logical flows over a single physical link

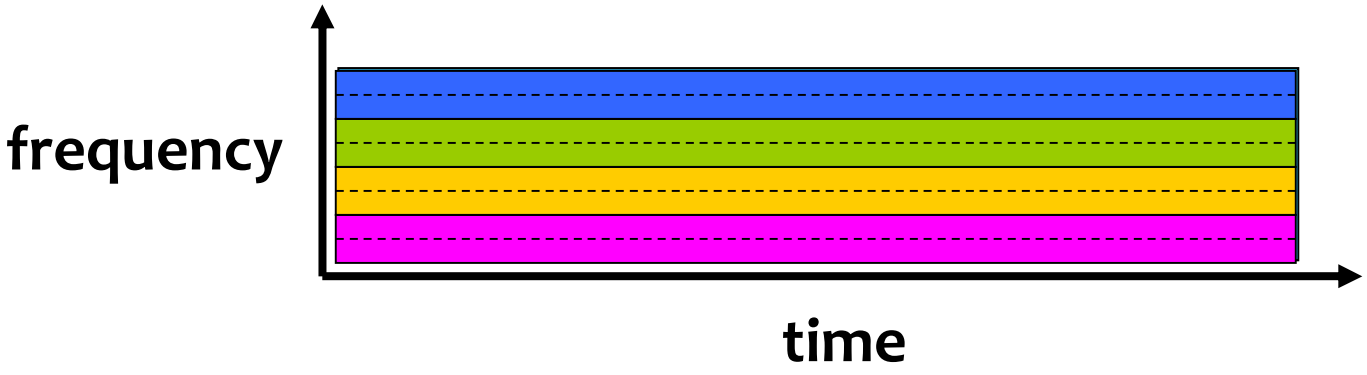
Cost-Effective Resource Sharing

- FDM: Frequency Division Multiplexing

FDM

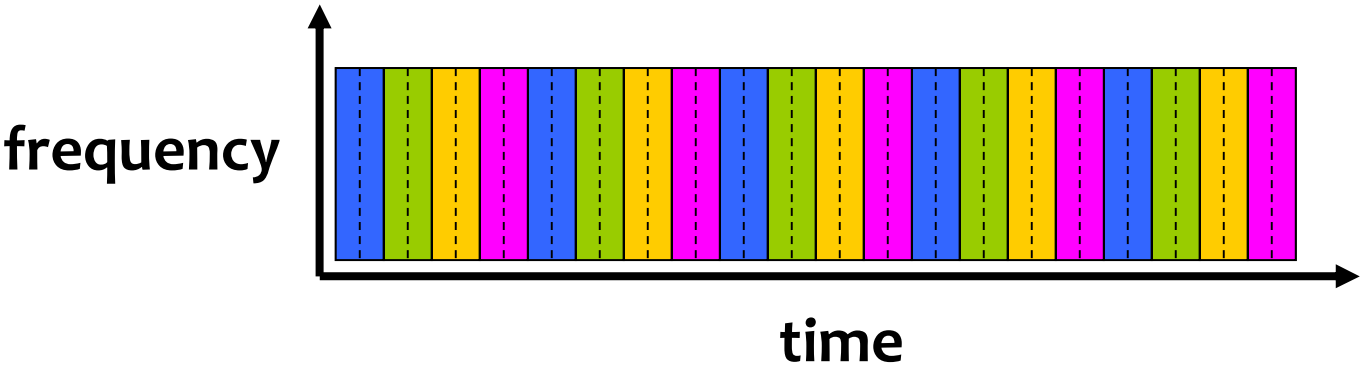
Example:

4 users



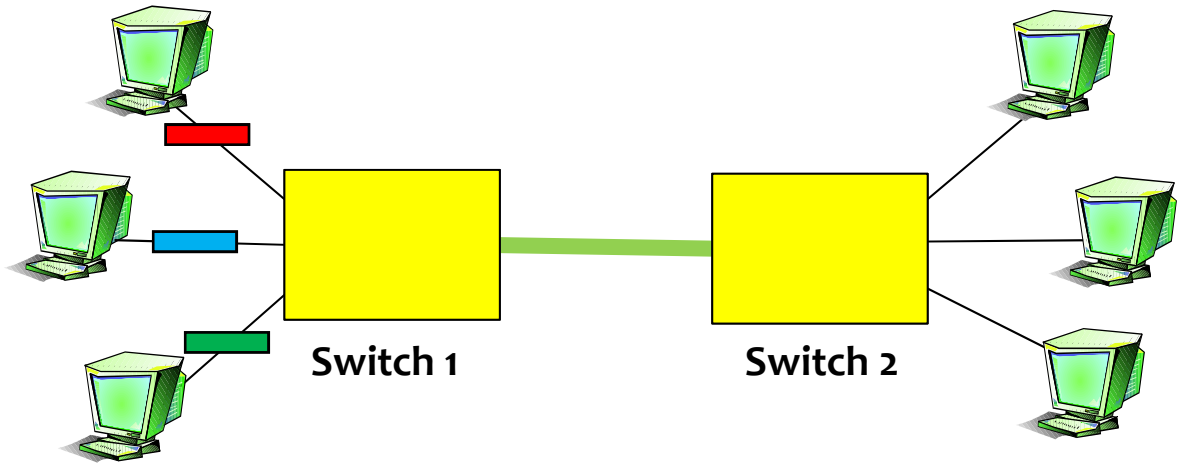
- Synchronous Time-division Multiplexing (TDM)
  - Time slots/data transmitted in predetermined slots

TDM



Cost-Effective Resource Sharing

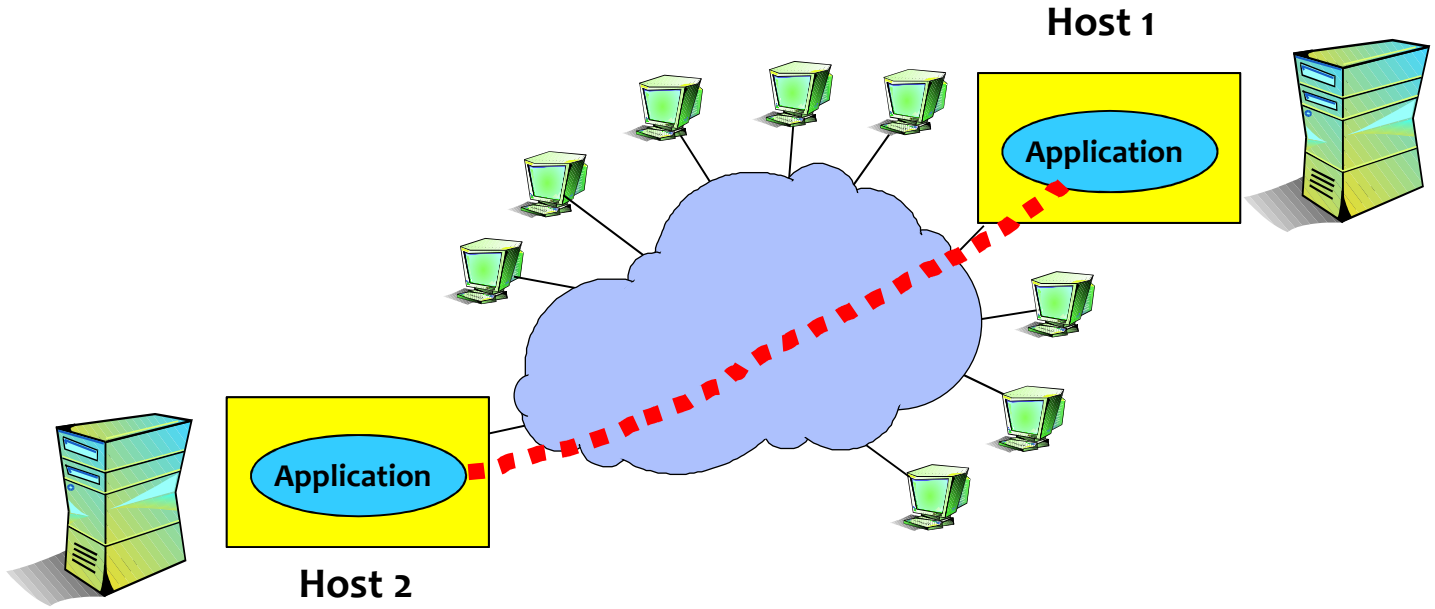
- **Statistical Multiplexing**
  - Data is transmitted based on demand of each flow.
  - What is a flow?
  - Packets vs. Messages
  - FIFO, Round-Robin, Priorities (Quality-of-Service (QoS))
  - Congested ?



A switch multiplexing packets from multiple sources onto one shared link

Logical Channels

- Logical Channels
  - Application-to-Application communication path or a pipe



Process communicating over an abstract channel

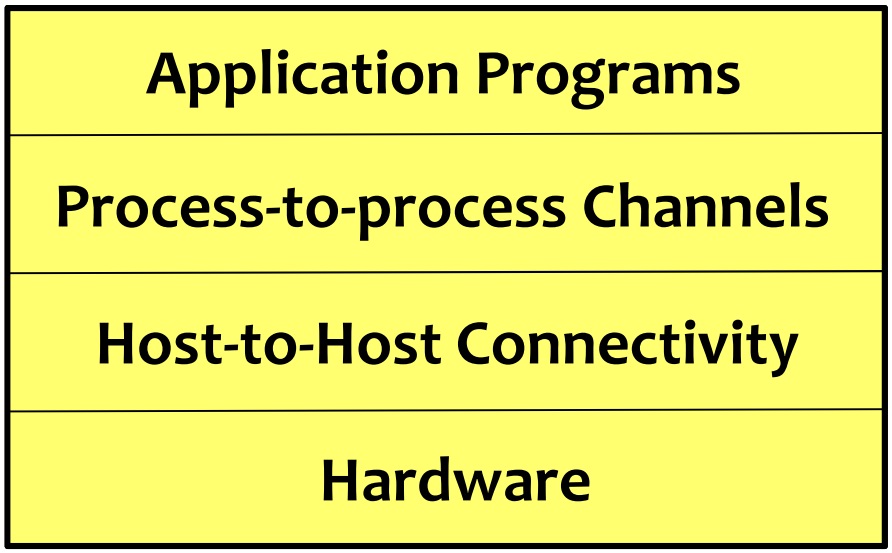
Network Reliability

- Network should hide the errors
- Bits are lost
  - Bit errors (1 to a 0, and vice versa)
  - Burst errors – several consecutive errors
- Packets are lost (Congestion)
- Links and Node failures
- Messages are delayed
- Messages are delivered out-of-order
- Third parties eavesdrop

Outline

- Applications
- Network Connectivity
- Network Architecture
- Network Performance

Network Architecture

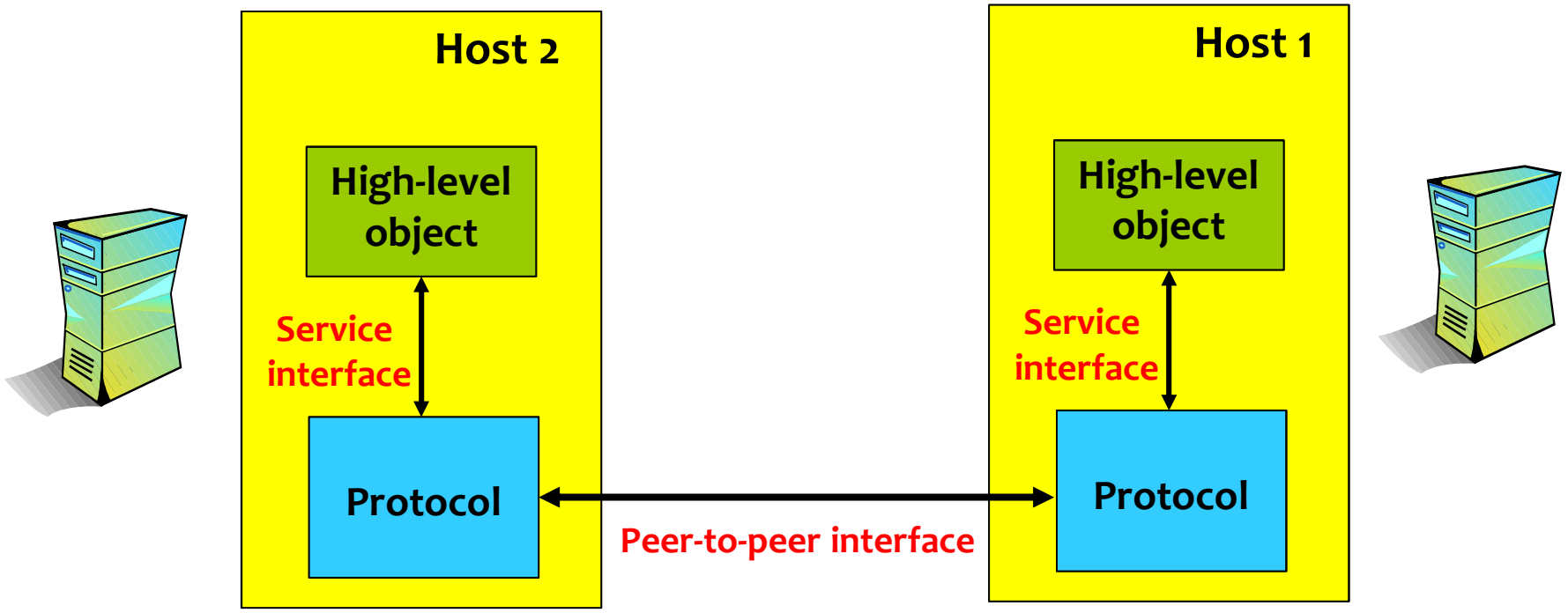


Example of a layered network system

Protocols

- Protocol defines the interfaces between
  - the layers in the same system and with
  - the layers of peer system
- Building blocks of a network architecture
- Each protocol object has two different interfaces
  - Service interface: operations on this protocol
  - Peer-to-peer interface: messages exchanged with peer

Protocol Interfaces

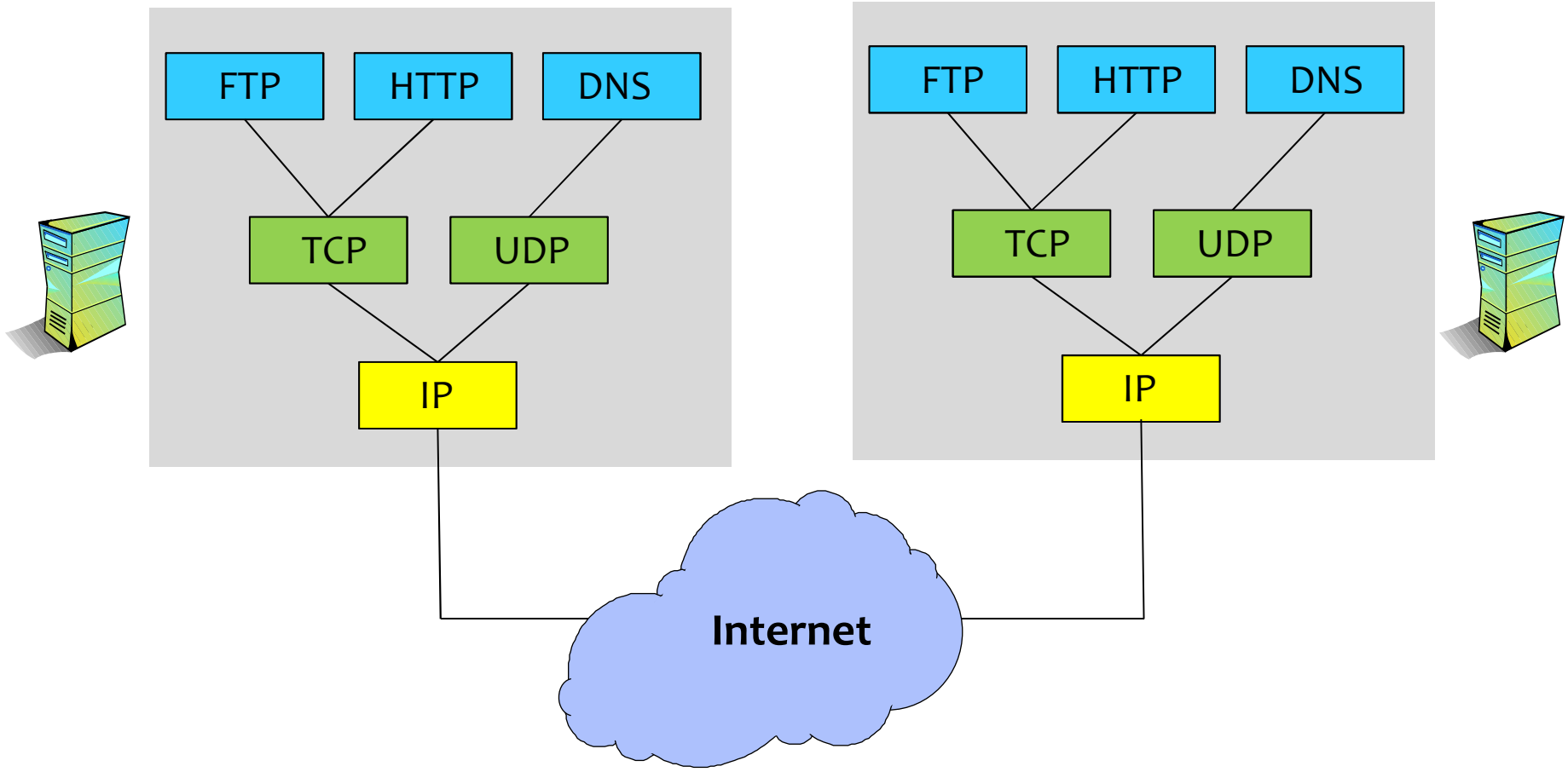


Service and Peer Interfaces for a protocol

Protocols

- **Protocol Specification**: pseudo-code, state transition diagram, message format
- **Interoperable**: when two or more protocols that implement the specification accurately
- IETF: Internet Engineering Task Force
  - Define Internet standard protocols

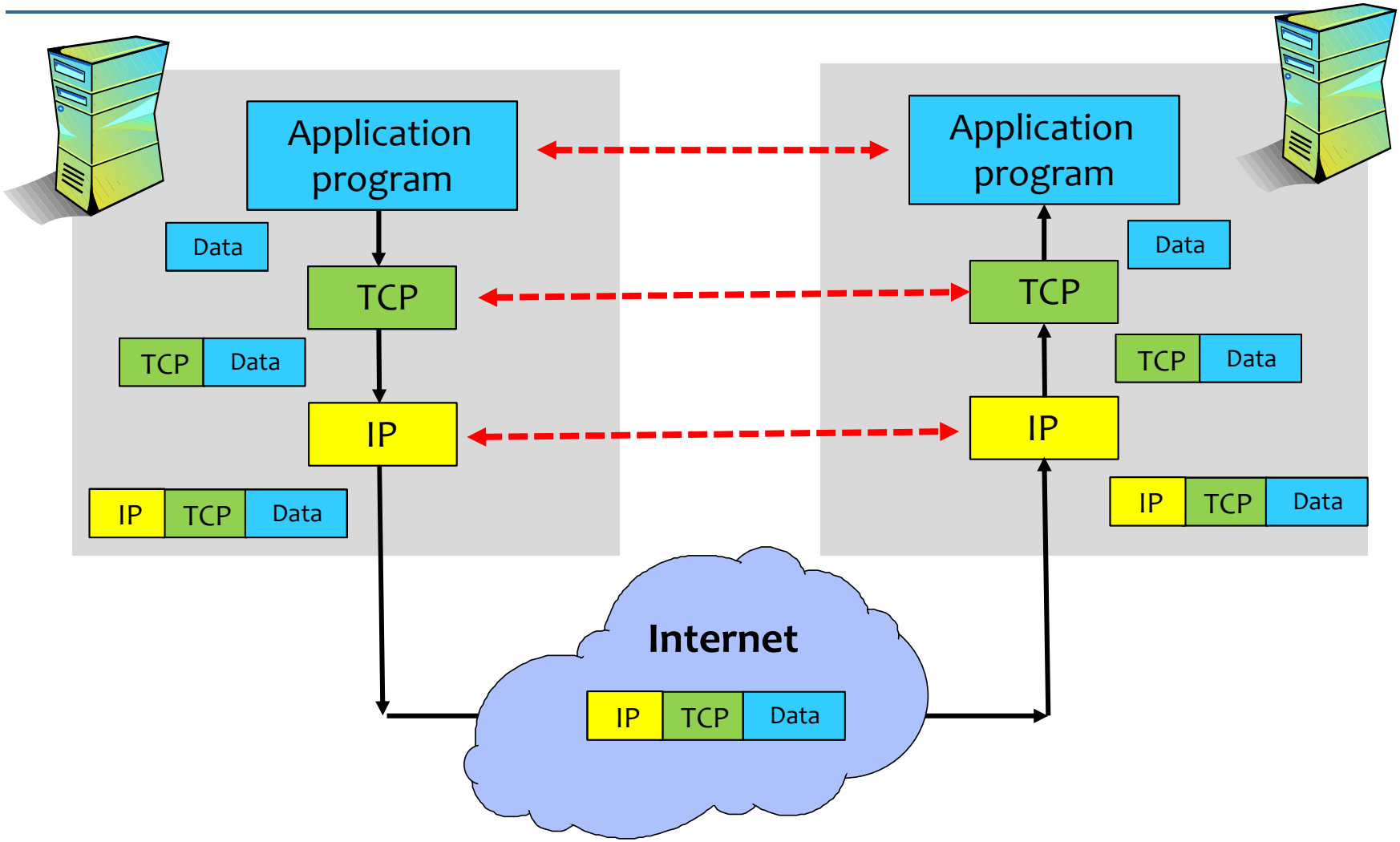
Protocol Architecture



Example of a protocol architecture

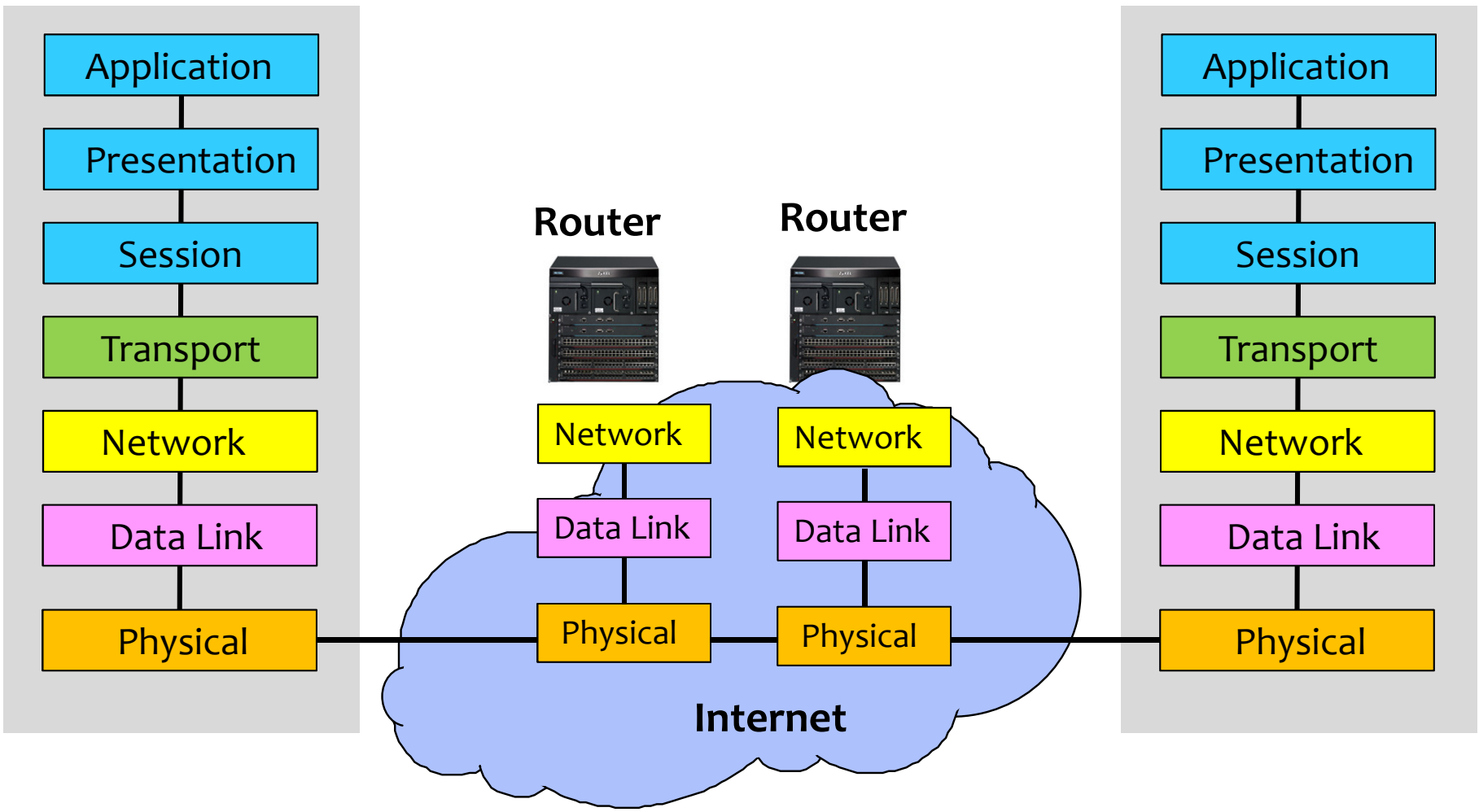
nodes are the protocols and links the "depends-on" relation

Encapsulation



High-level messages are encapsulated inside of low-level messages

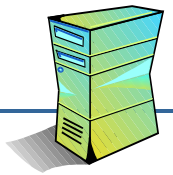
OSI Architecture

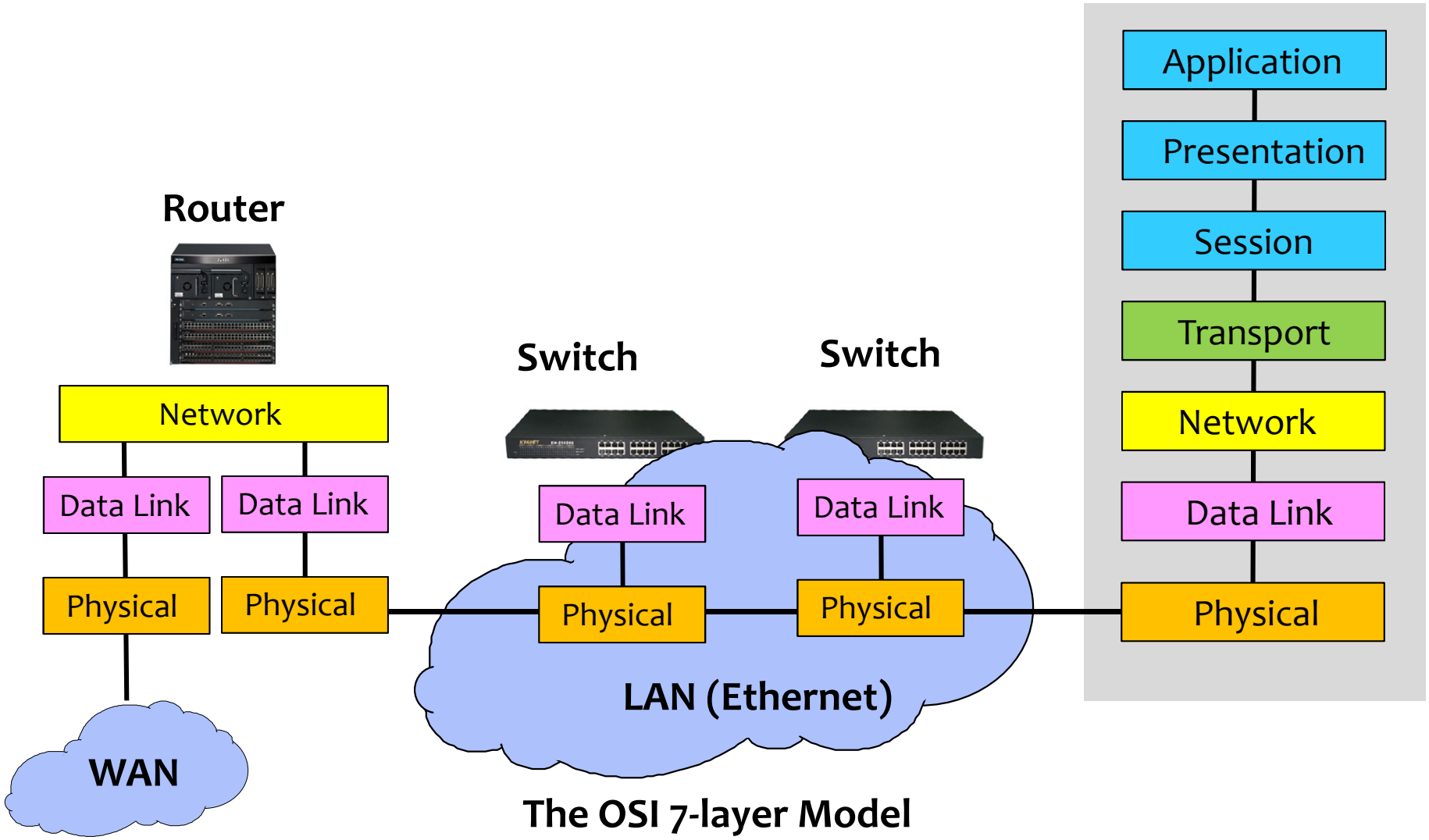


The OSI 7-layer Model

OSI – Open Systems Interconnection

OSI Architecture





The OSI 7-layer Model

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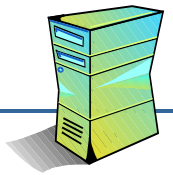
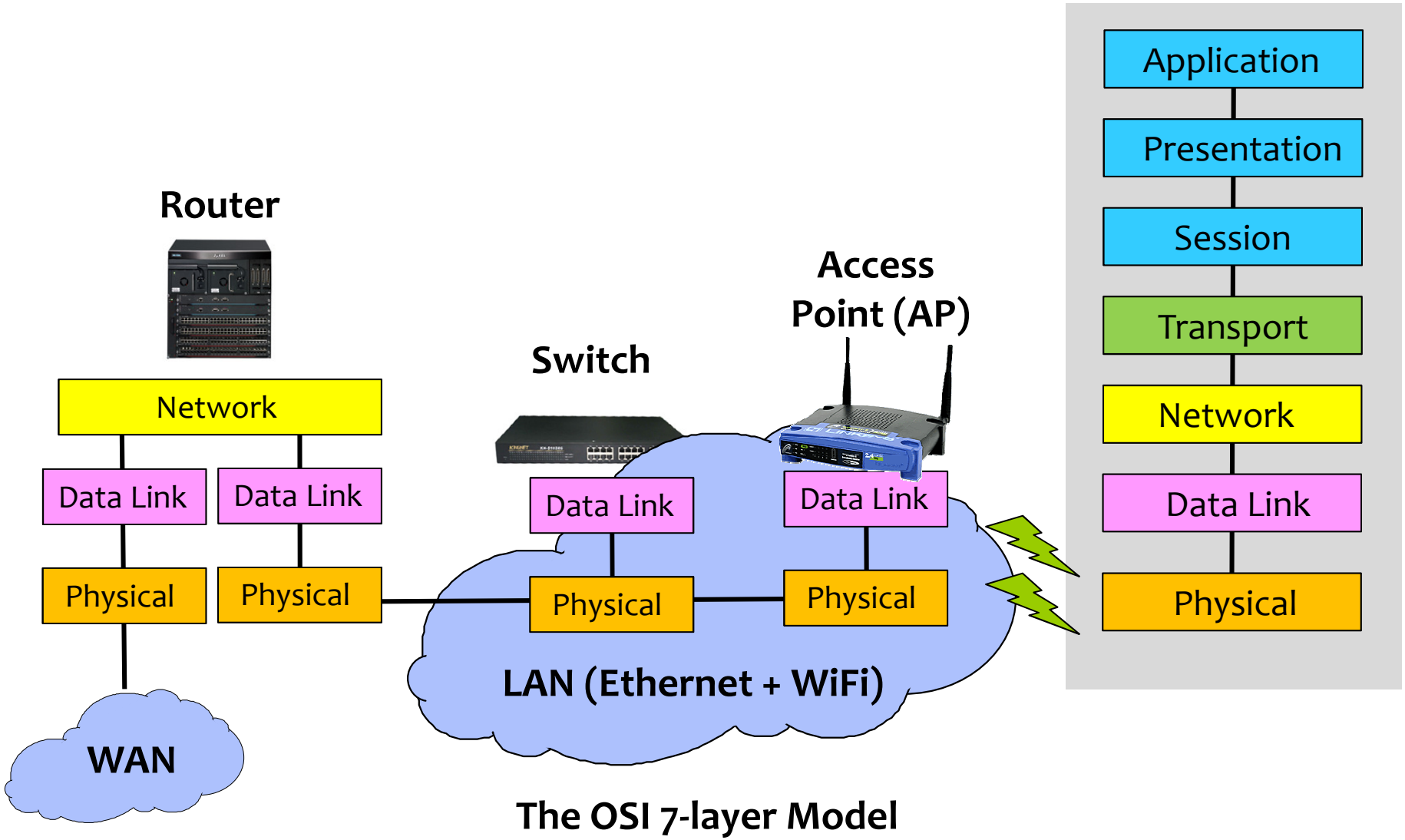
OSI Architecture



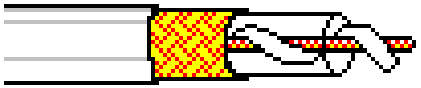


The OSI 7-layer Model

OSI – Open Systems Interconnection

Description of Layers

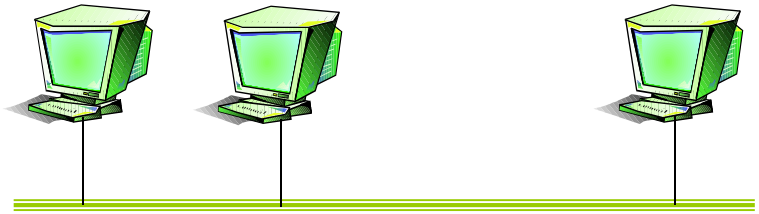
- **Physical Layer (如何將原始資料在 link 上傳輸)**
  - Handles the transmission of raw bits over a communication link
    - Coaxial cable
    - Twisted pair
    - Optical Fiber
    - Air space (wireless radio channel)
  - Different Signal Coding schemes



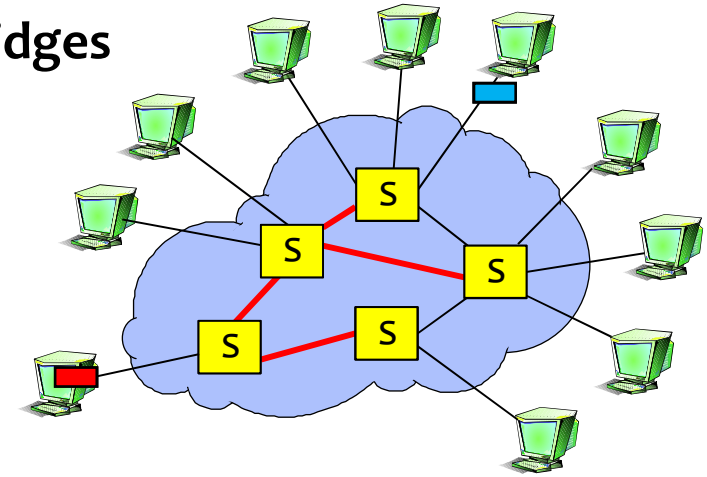
Description of Layers

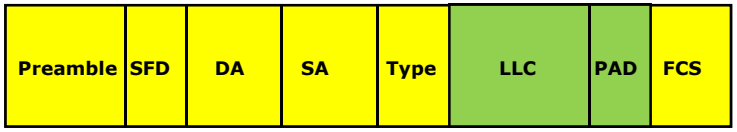
- **Data Link Layer (如何將 frame 傳給直接相連的主機或設備)**
  - Collects a stream of bits into a *frame*
  - How to transmit a frame to a directly connected host (destination) ?
  - MAC (Media Access Control Protocol)
    - CSMA/CD (IEEE 802.3 Ethernet)
    - CSMA/CA (IEEE 802.11 Wireless LAN)
  - Layer 2 devices
  - Switches
  - Bridges

Point-to-point



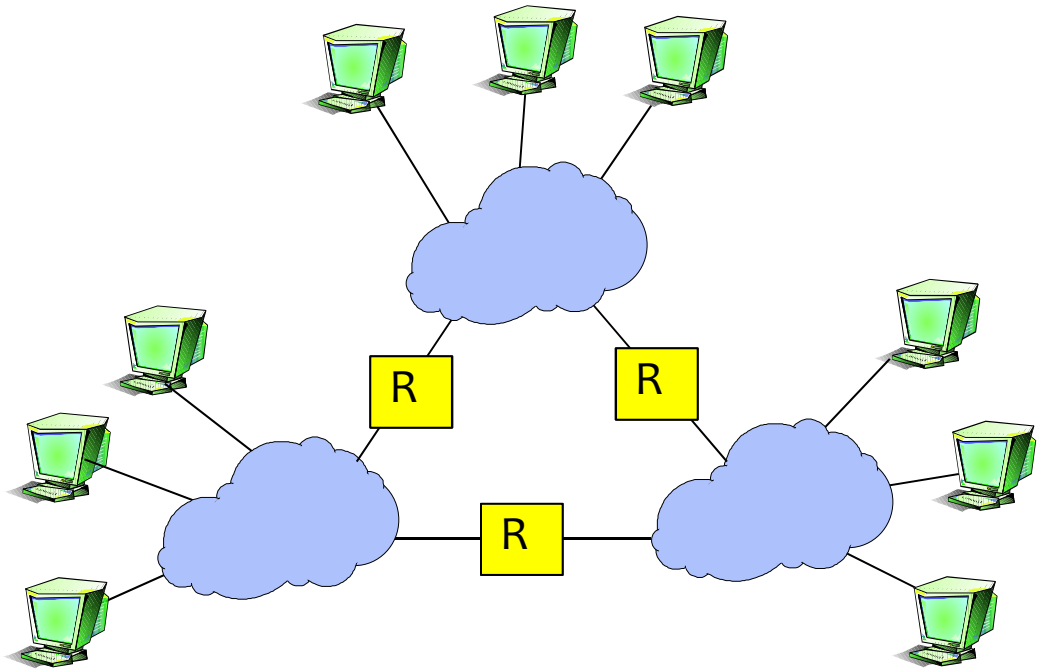
Multiple access





Description of Layers

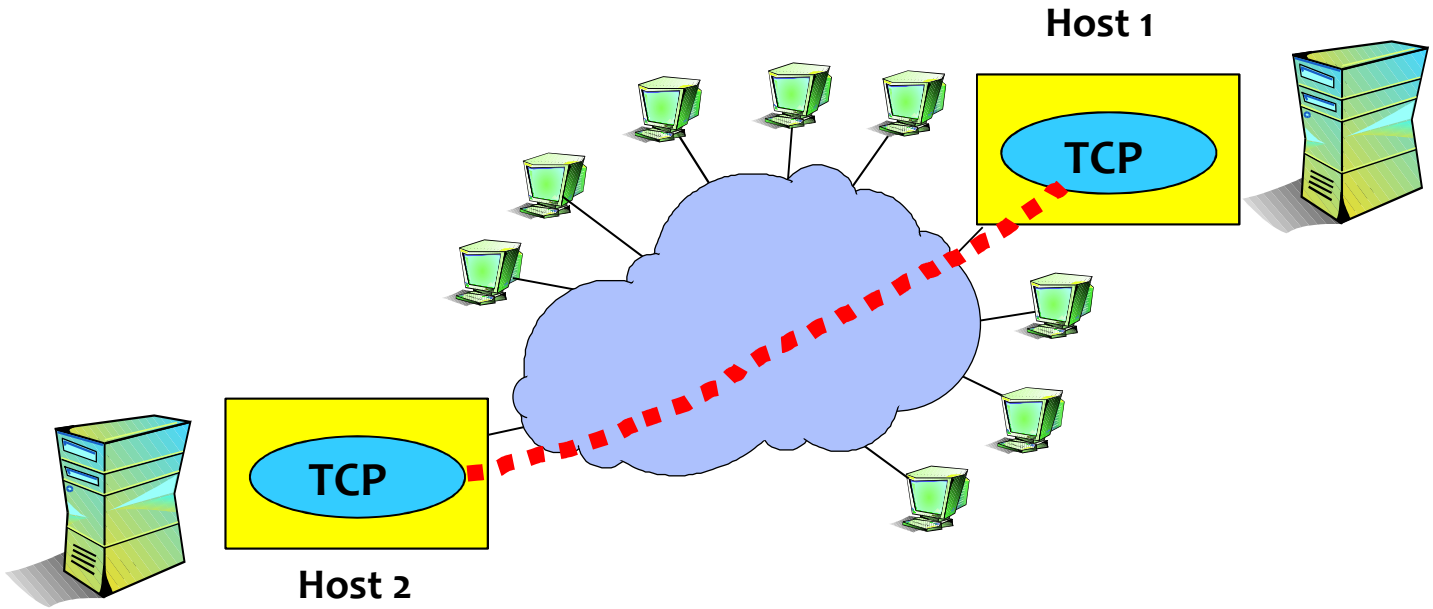
- **Network Layer (如何將封包透過 Internet 送給目的地主機)**
  - How to transmit frames to a host via the Internet ?
  - Handles routing among nodes within a packet-switched network
  - Data exchanged between nodes in this layer is called a *packet*
  - *IP protocol*
  - *Routers*
  - *Routing protocols*
    - *RIP*
    - *OSPF*
    - *BGP*
  - *Routing Tables*



Interconnection of networks

Description of Layers

- **Transport Layer (提供不同主機 processes 之間的資料傳送)**
  - **Implements a process-to-process channel**
  - **Unit of data exchanges in this layer is called a *message***
  - ***TCP (Transmission Control Protocol) – Reliable service***
  - ***UDP (User Datagram Protocol) – Unreliable service***



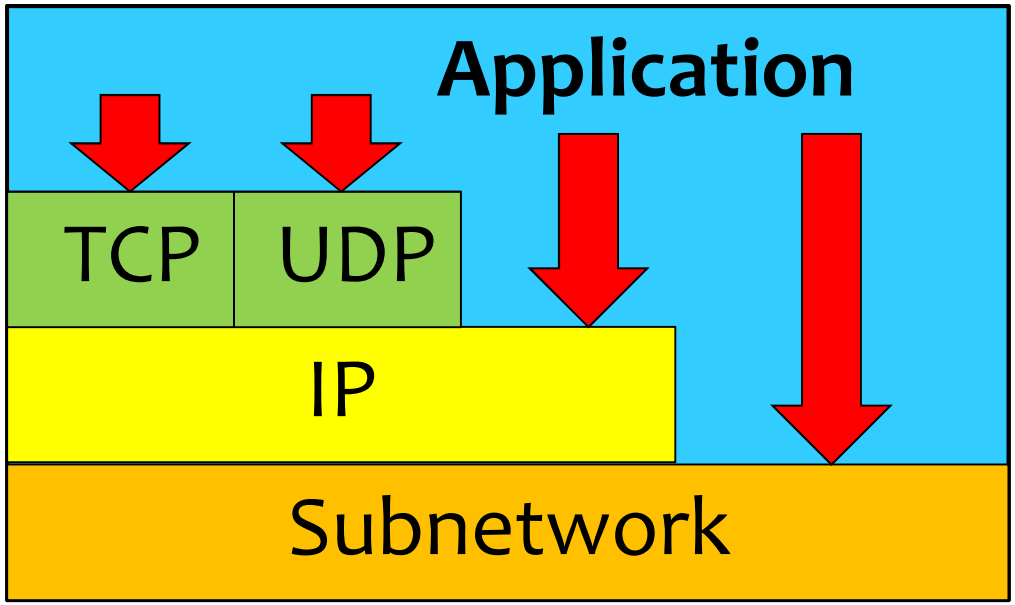
Description of Layers

- **Session Layer**
  - Provides a name space that is used to tie together the potentially different transport streams that are part of a single application
- **Presentation Layer**
  - Concerned about the format of data exchanged between peers
- **Application Layer**
  - Standardize common type of exchanges
  - FTP/E-mail/DNS/HTTP/Browsers/FB, ….

The transport layer and the higher layers typically run only on end-hosts and not on the intermediate switches and routers

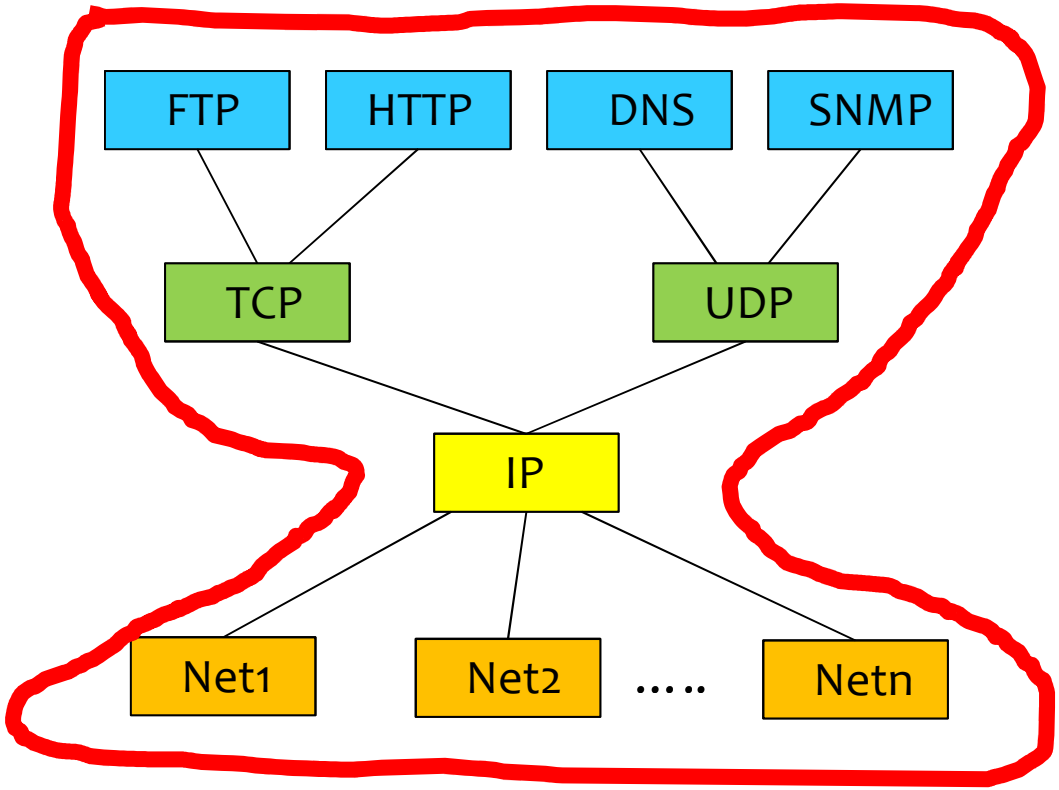
Internet Architecture

- Defined by IETF
- Three main features
  - Does not imply strict layering. The application is free to bypass the defined transport layers and to directly use IP or other underlying networks



Internet Architecture

- **An hour-glass shape – wide at the top, narrow in the middle and wide at the bottom. IP serves as the focal point for the architecture**



Internet Architecture

Internet Architecture

- In order for a new protocol to be officially included in the architecture, there needs to be both a protocol specification and at least one (and preferably two) representative implementations of the specification

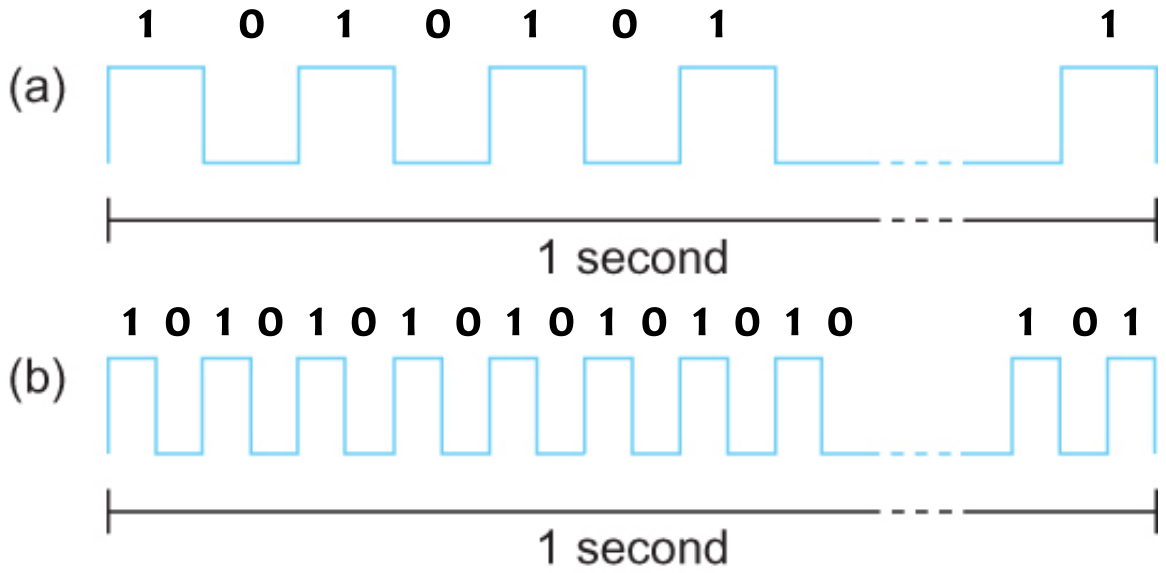
Outline

- Applications
- Network Connectivity
- Network Architecture
- Network Performance

Network Performance

- **Bandwidth**
  - Width of the frequency band
  - Number of bits per second that can be transmitted over a communication link
- 1 Mbps: 1×10^6 bits/second
- 1×10^{-6} seconds to transmit each bit or imagine that a timeline, now each bit occupies 1 micro second space.
- On a 2 Mbps link the width is 0.5 micro second.
- Smaller the width more will be transmission per unit time.

Bandwidth



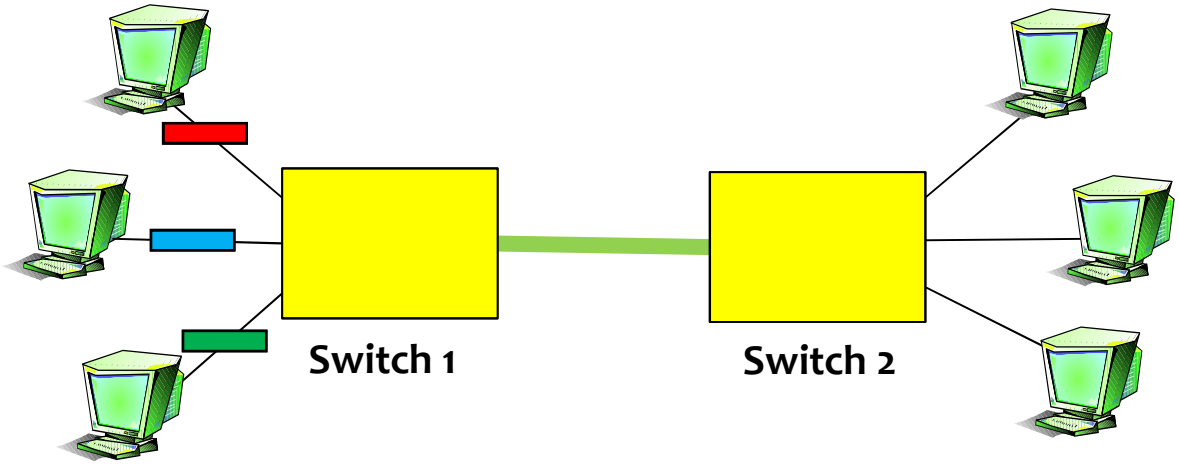
Bits transmitted at a particular bandwidth can be regarded as having some width:

(a) bits transmitted at 1Mbps (each bit 1 µs wide);

(b) bits transmitted at 2Mbps (each bit 0.5 µs wide).

Network Performance

- **Latency** = Propagation time + transmission time + queuing time
- **Propagation** time = distance/speed of light
- **Transmission time** = size/bandwidth



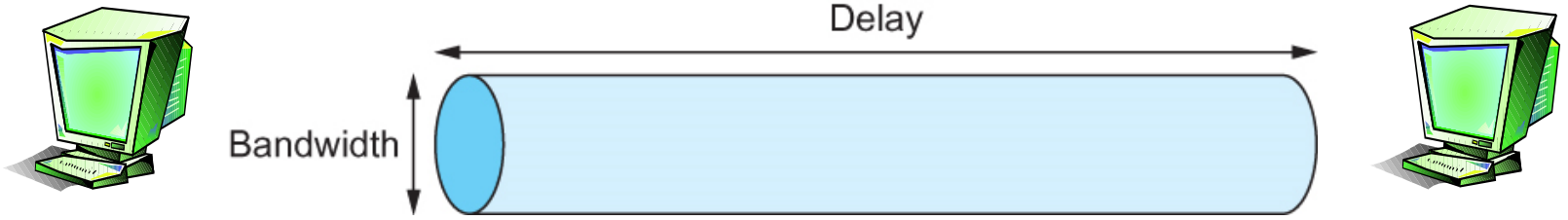
- One bit transmission => propagation is important (短資料很快就送完, 但需要長時間才能傳到對方, 資料已送完, 但前導資料還未到達對方)
  - Propagation time >> transmission time
- Large bytes transmission => bandwidth is important (長資料很慢才能送完, 未送完前, 前導資料已到對方)
  - Transmission time >> propagation time

Delay X Bandwidth

- The channel between a pair of processes can be viewed as a pipe
- Latency (delay): length of the pipe
- Bandwidth: width of the pipe
- Delay x Bandwidth means how many data can be stored in the pipe
- For example, delay of 80 ms and bandwidth of 100 Mbps

$\Rightarrow$ 80 x 10^{-3} seconds x 100 x 10^{6} bits/second

$\Rightarrow$ 8 x 10^{6} bits = 8 M bits = 1 MB data.



Network as a pipe

Delay X Bandwidth

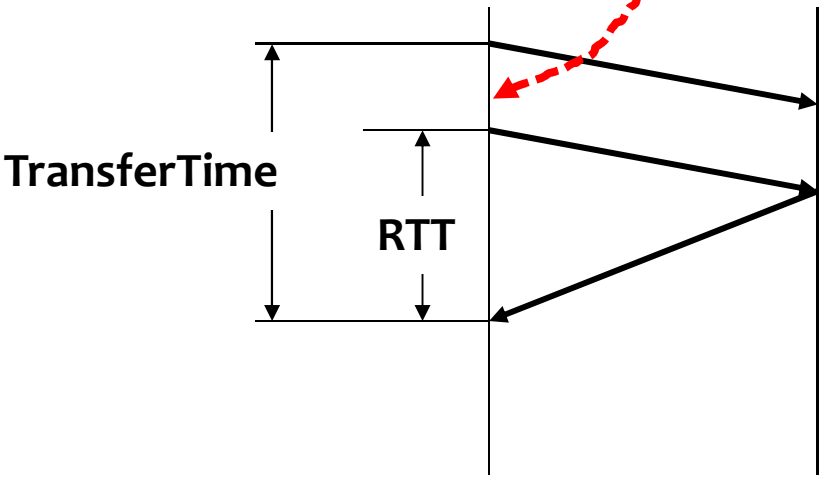
- Relative importance of bandwidth and latency depends on application
  - For large file transfer, bandwidth is critical
  - For small messages (HTTP, NFS, etc.), latency is critical
  - Variance in latency (jitter) can also affect some applications (*e.g.*, audio/video conferencing)

Delay X Bandwidth

- if the sender keeps the pipe full, delay x bandwidth is the number of bits the sender must transmit before the first bit arrives at the receiver
- Takes another one-way latency to receive a response from the receiver
- The sender will not fully utilize the network if the sender does not fill the pipe
  - send a whole delay × bandwidth product's worth of data before it stops to wait for a signal
  - 在停下來等對方回應之前應該要傳送 delay × bandwidth 的資料量

Throughput

- Infinite bandwidth
  - RTT (Round Trip Time) dominates
  - Throughput = TransferSize / TransferTime
  - TransferTime = RTT + TransferSize/Bandwidth
  - Its all relative
  - 1-MB file to 1-Gbps link looks like a 1-KB packet to 1-Mbps link



Summary

- A layered architecture for computer network
  - Physical Layer
  - Data Link Layer
  - Network Layer
  - Transport Layer
  - Session layer / Presentation Layer /Application layer
- Two performance metrics used to analyze the performance of computer networks
  - Bandwidth
  - Delay