Introduction to Network

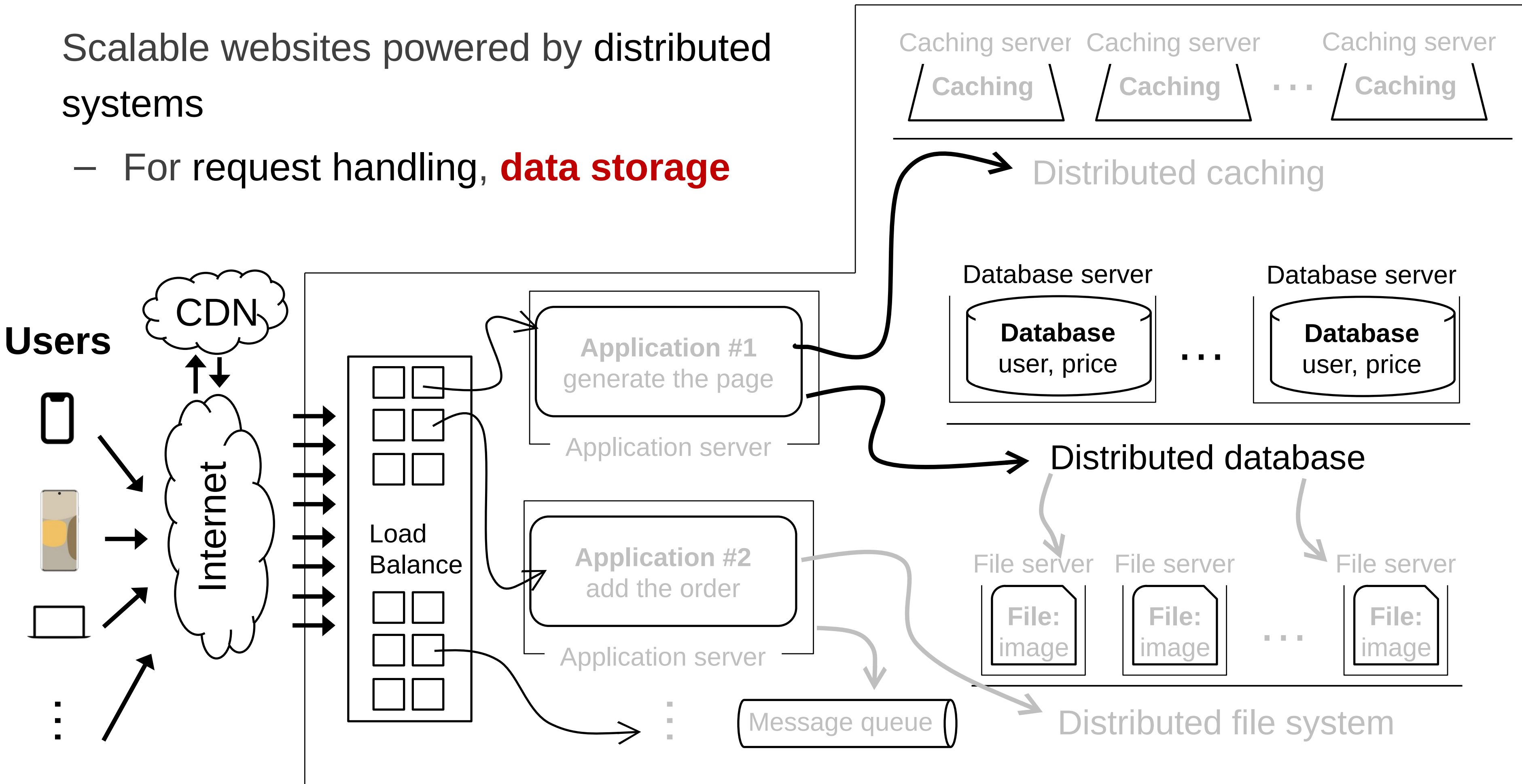
IPADS, Shanghai Jiao Tong University

https://www.sjtu.edu.cn

Review: scalable websites

Scalable websites powered by distributed systems

– For request handling, **data storage**



Layers in Network

Application

- Can be thought of as a fourth layer
- Not part of the network

End-to-end layer

- Everything else required to provide a comfortable application interface

Network layer

- Forwarding data through intermediate points to the place it is wanted

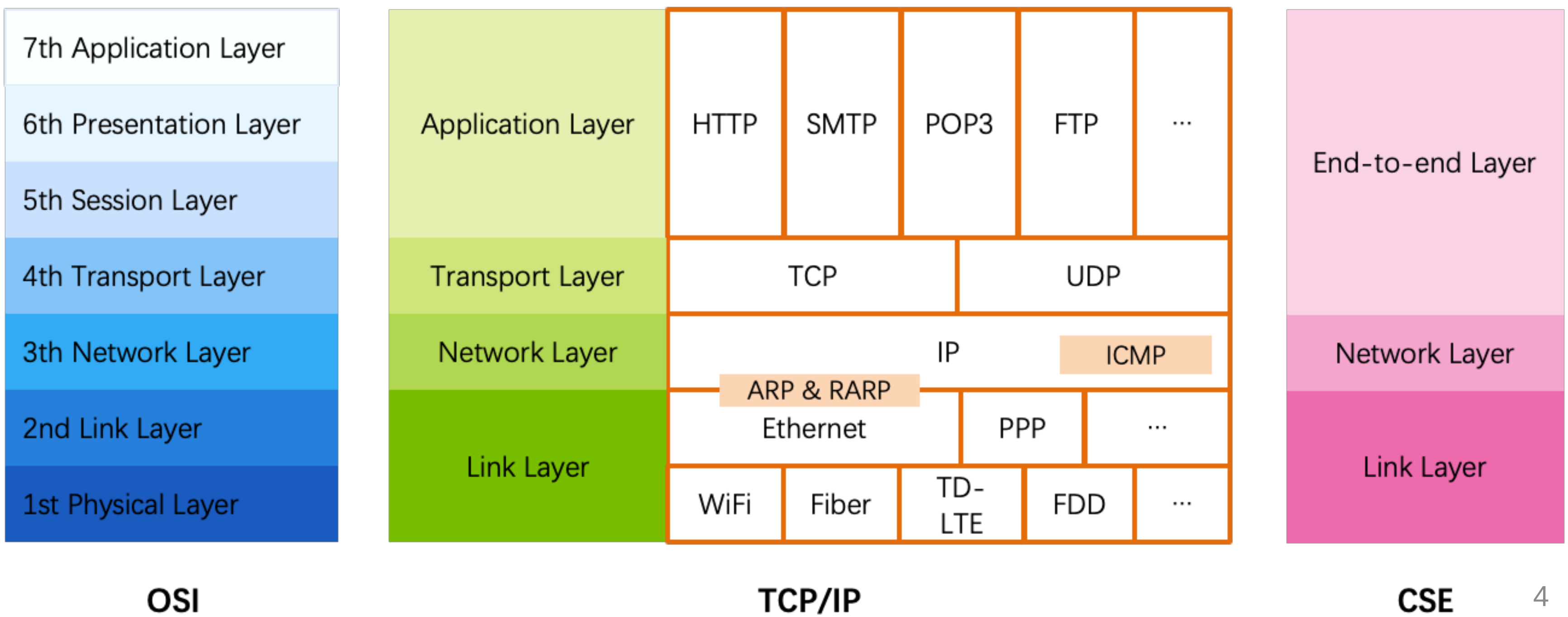
Link layer

- Moving data directly from one point to another

OSI, TCP/IP & Protocol Stack

OSI

– The open systems interconnection (OSI) model
– 7-layer architecture



The Internet "Hour Glass" Protocols

More people, more useful

- Value to me = N
- Value to society is N^2

Network, dumb vs. smart

- Standardize vs. flexibility

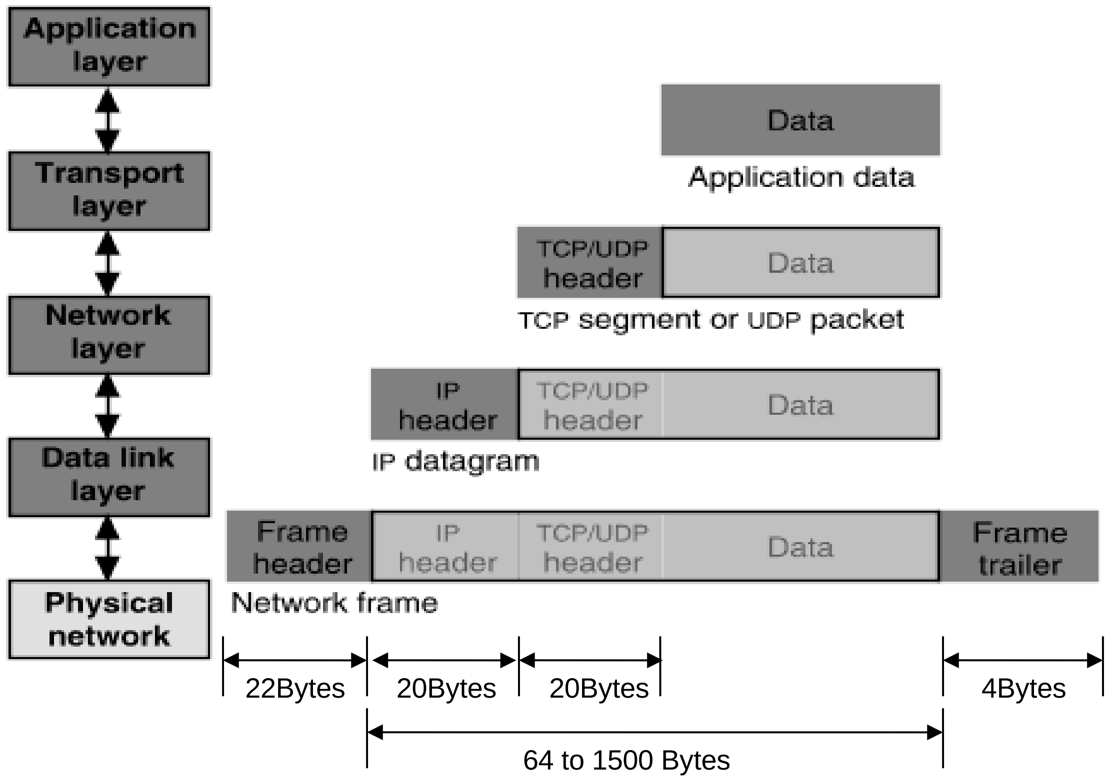
Network is a black box

- Simplify the system that uses it

```
              +------+------+------+------+------+
App           |Email | Web  | VoIP | P2P  | RTSP|
              +------+------+------+------+------+
Transport            | TCP  |  UDP | ICMP |
                     +------+------+------+
Network                     |  IP  |
                     +------+------+------+
                     |Ether |Sonet | ATM  |
Link          +------+------+------+------+------+
              |Fiber | TP   | CAT5 | WiFi | GSM  |
              +------+------+------+------+------+
```

"Everything over IP, and IP over everything"

Packet Encapsulation



Application Layer

Entities
- Client and server
- End-to-end connection

Name space: URL

Protocols
- HTTP, FTP, POP3, SMTP, etc.

What to care?
- Content of the data: video, text, …


```
<html>
  <head>
    <title>Google</title>

<script>window.google=…..
    </script>
  </head>
  <body>  …  </body>
</html>
```

Transport Layer

Entities

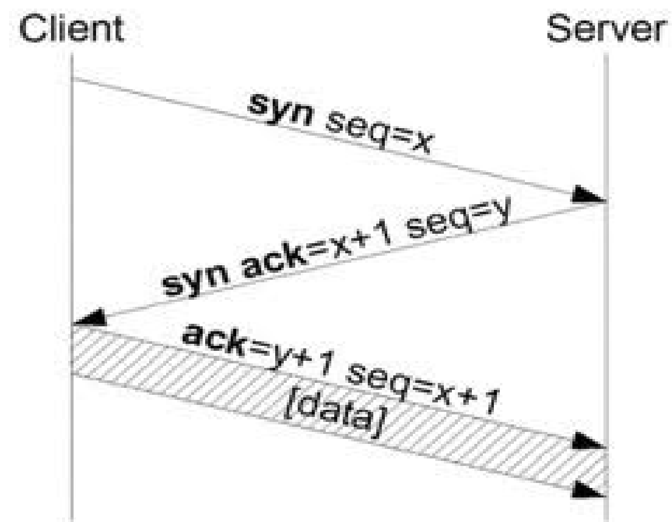
- Sender and receiver
- Proxy, firewall, etc.
- End-to-end connection

Name space: port number

Protocols: TCP, UDP, etc.

What to care?

- TCP: Retransmit packet if lost
- UDP: nothing



Packet Format of TCP & UDP

TCP Segment Header Format

<table>
<tr><th>Bit #</th><th>0</th><th>7</th><th>8</th><th>15</th><th>16</th><th>23</th><th>24</th><th>31</th></tr>
<tr><td>0</td><td colspan="4">Source Port</td><td colspan="4">Destination Port</td></tr>
<tr><td>32</td><td colspan="8">Sequence Number</td></tr>
<tr><td>64</td><td colspan="8">Acknowledgment Number</td></tr>
<tr><td>96</td><td>Data Offset</td><td>Res</td><td colspan="2">Flags</td><td colspan="4">Window Size</td></tr>
<tr><td>128</td><td colspan="4">Header and Data Checksum</td><td colspan="4">Urgent Pointer</td></tr>
<tr><td>160...</td><td colspan="8">Options</td></tr>
</table>

UDP Datagram Header Format

<table>
<tr><th>Bit #</th><th>0</th><th>7</th><th>8</th><th>15</th><th>16</th><th>23</th><th>24</th><th>31</th></tr>
<tr><td>0</td><td colspan="4">Source Port</td><td colspan="4">Destination Port</td></tr>
<tr><td>32</td><td colspan="4">Length</td><td colspan="4">Header and Data Checksum</td></tr>
</table>

Network Layer (the Internet Layer, IP Layer)

Network entities

- Gateway, bridge
- Router, etc.

Name space

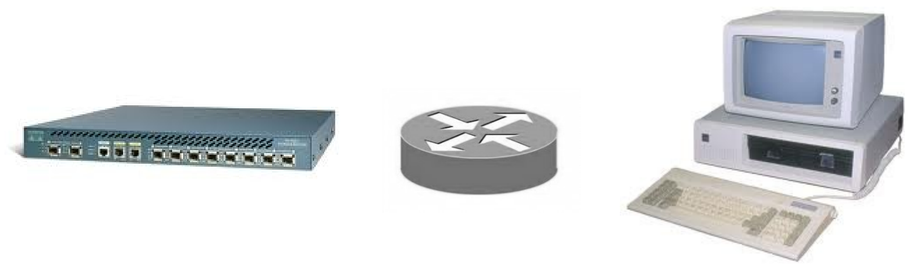
- IP address

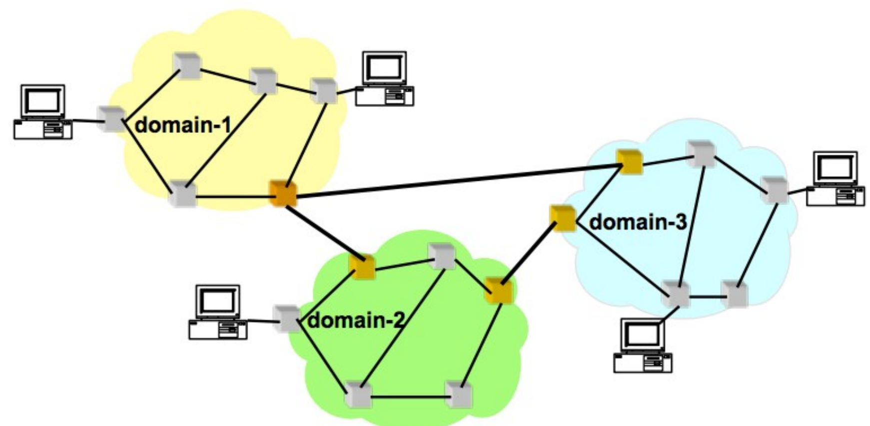
Protocols

- IP, ICMP (ping)

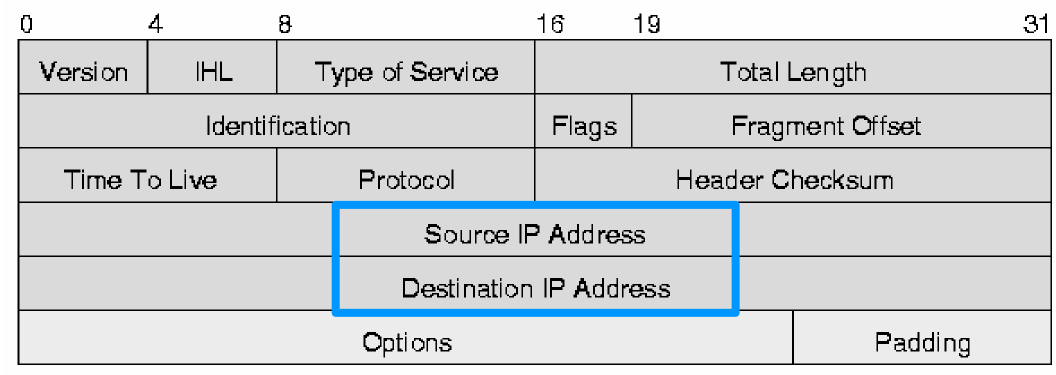
What to care?

- Next hop decided by route table





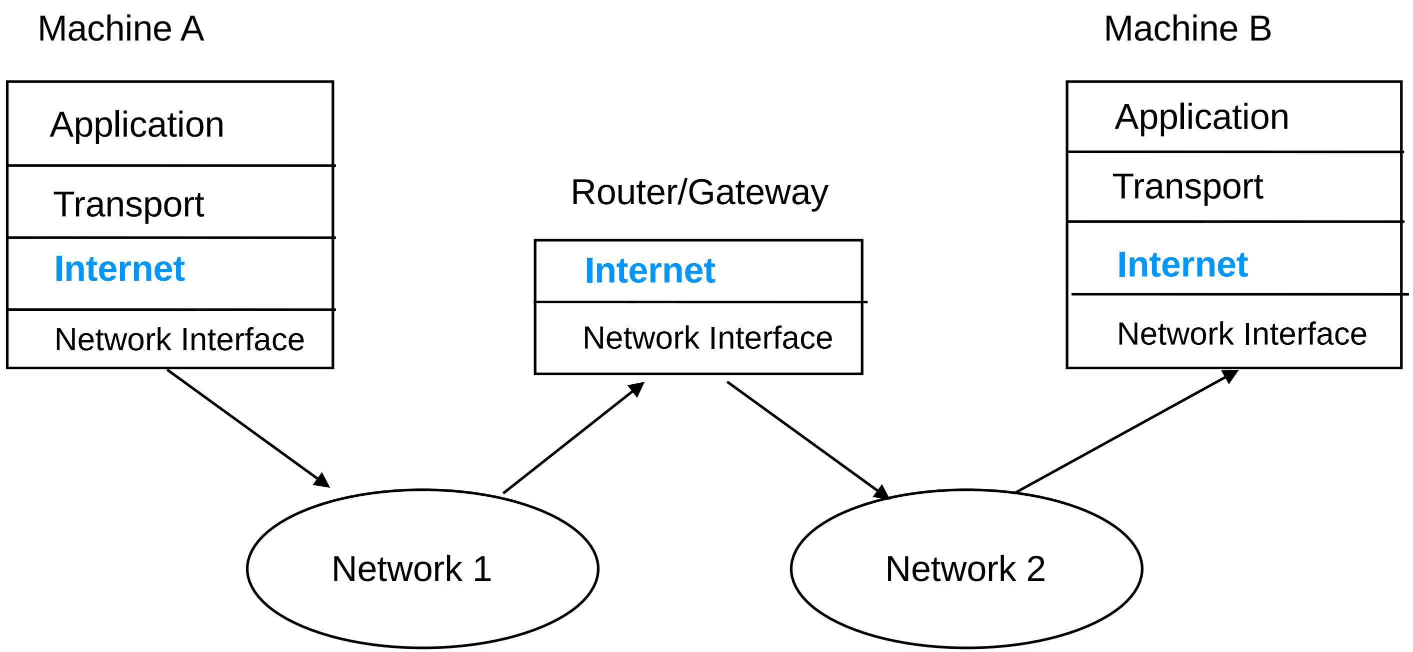
IP Datagram (Packet, Package)



Header

10101011101010101010010101010100101010100
1101001010101001010111111010000011101111
10100001011101010100110101011110100000101
00100000000010101000011010000011111010101
.... 1011011001010100011001001010110
Data

TCP/IP Architecture



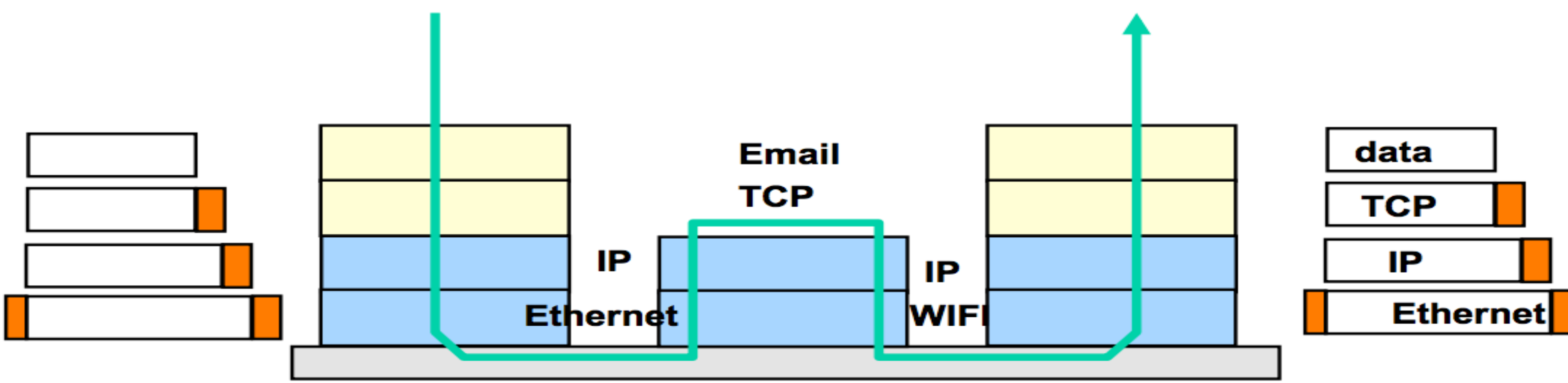
TCP/IP Architecture

Each layer adds/strips off its own header

Each layer may split up higher-level data

Each layer multiplexes multiple higher layers

Each layer is (mostly) transparent to higher layers



Link Layer

From a node to its physical neighbor

The Link Layer

The bottom-most layer of the three layers

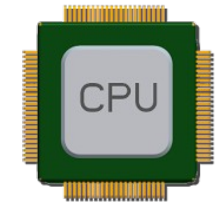
Purpose: moving data directly from one physical location to another

- 1. Physical transmission
- 2. Multiplexing the link
- 3. Framing bits & bit sequences
- 4. Detecting transmission errors
- 5. Providing a useful interface to the up layer

Physical Transmission using Shared Clock

Example-1: moving a bit from register-1 to register-2

on the same chip



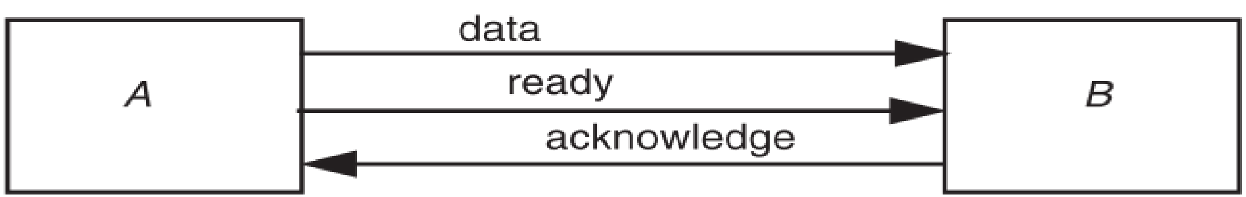
- Run a wire to connect output of reg-1 to input of reg-2
- Wait till reg-1's output has settled & signal has propagated to reg-2
- Reg-2 read input the next clock tick
- **Assumption**: propagation can be done within one clock

How to send data between two modules without sharing a clock?

Physical Transmission without Shared Clock

Three-wire ready/acknowledge protocol

- 1. **A** places data on data line
- 2. **A** changes value on the ready line
- **B** sees the ready line change, reads value on the data line, then changes the acknowledge line



B: when to look at the data line? (*ready* is set)

A: when to stop holding the bit value on the data line? (*ack* is set)

Parallel Transmission

Propagation time Δt

- It takes more than 2xΔt to send one bit
- The max data rate is 1/(2Δt)

Parallel transmission

- Use N parallel data lines to achieve N/(2Δt)
- E.g., SCSI, printer, etc.

Serial Transmission

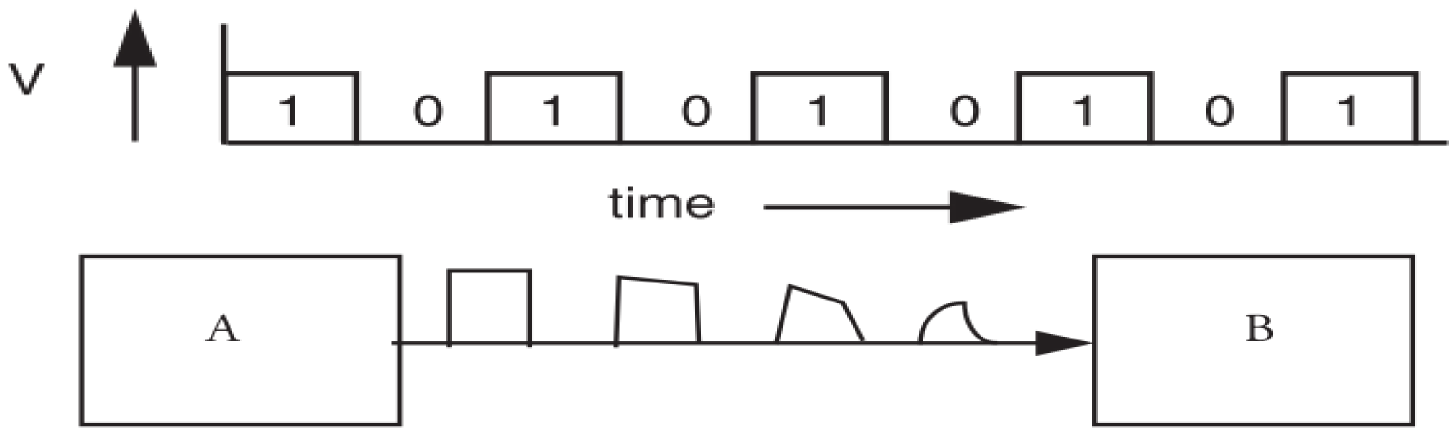
Ready/acknowledge protocol

- Δt grows significantly, which limits the data rate

Serial transmission

- Send a **stream** of bits down a single line
- Without waiting for any response from the receiver
- Expect the receiver can recover the bits with no additional signal
- Higher rates, longer distance, fewer wires
- E.g., USB, SATA

Signal Transmission on Analog Line



It is hard for B to understand the signal

– B doesn't have a copy of A's clock, so when to sample the signal?

VCO: Voltage Controlled Oscillator

How to make two ends agree on the data rate without clock line?

The receiver run a VCO at about the same data rate

- VCO's output is multiplied by the voltage of incoming signal
- The product is suitably filtered and sent back to adjust the VCO
- VCO will finally be **locked** to both the frequency and phase of the arriving signal: phase-locked loop
- Then the VCO becomes a clock source for the receiver

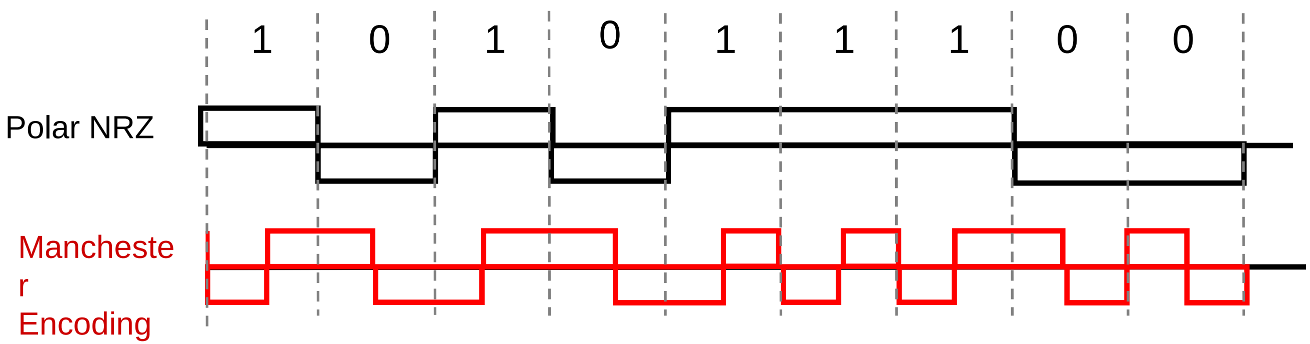
Problem: if no transition in the stream (e.g., a lot of zero), the phase-locked loop cannot synchronize

Manchester Code

Solution: sender encodes the data to ensure transitions

Phase encoding: at least 1 level transition for a bit

- Manchester code: 0 -> 01, 1 -> 10
- Max data rate is only half, but simple enough



How to Share a Connection?

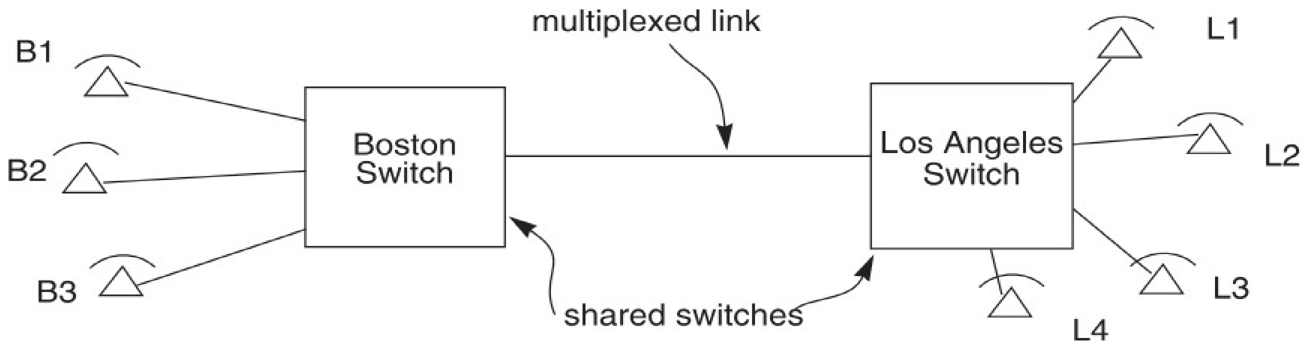
Isochronous communication (telephone communication)

- Needs prior arrangement between switches
- Connection: set up and tear down
- **Stream**: continuous bits flows out of a phone

Asynchronous communication (data communication)

- **Message**: burst, ill-suited to fixed size and spacing of isochronous frames
- Connectionless, asynchronous

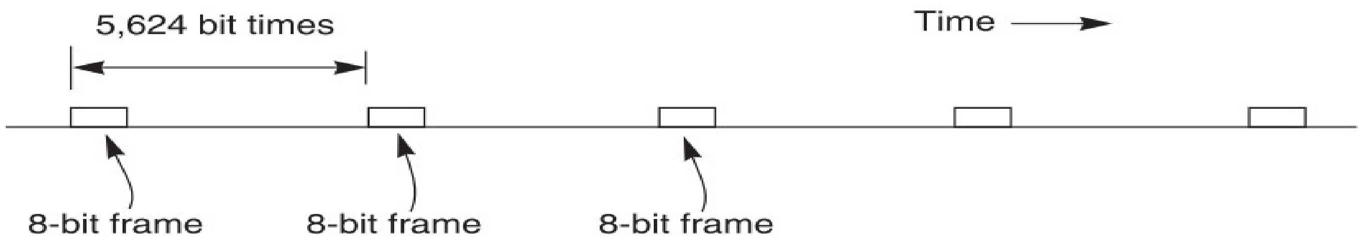
Isochronous Multiplexing



Telephone network

- Leverage "virtual link" for connection
- "network is busy" when no available time slot

Isochronous - TDM



64 Kbps each phone, 45 Mbps link

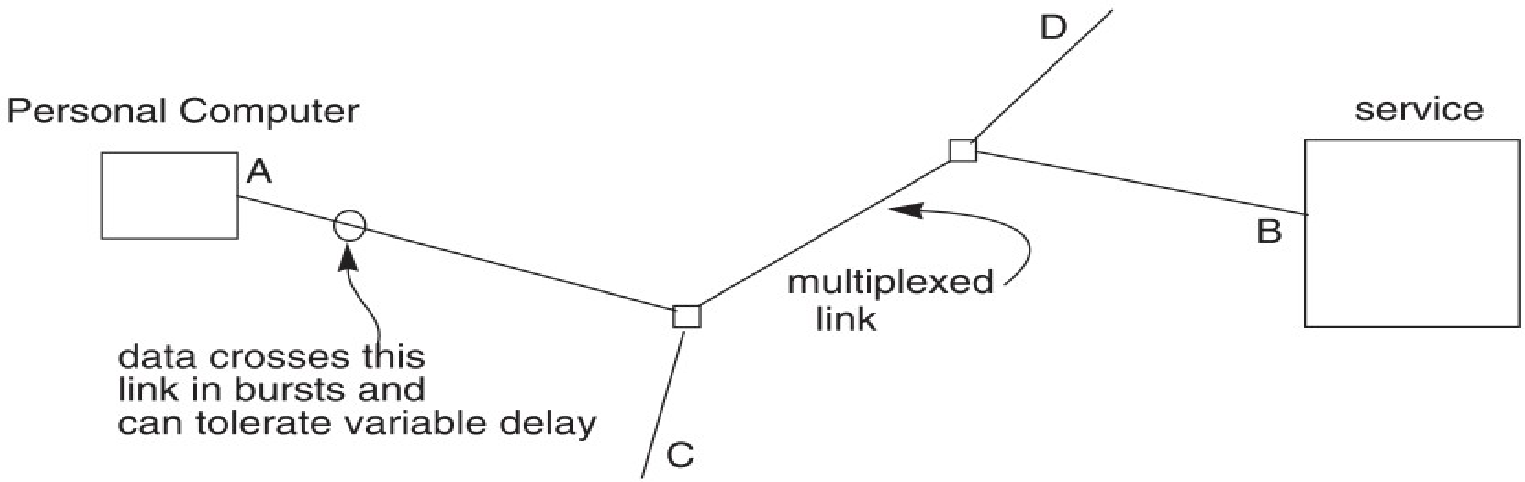
8-bit block (frame), 8000 frames per second

5624 bit times or 125 us

703 simultaneous conversations (what if there is a 704th calling?)

Q: Why the voice is still *continuous*, instead of *fragmented*?

Data Communication Network



Data communication network usually contains burst communication

Different from the telephone network

Frame and Packet: Asynchronous Link

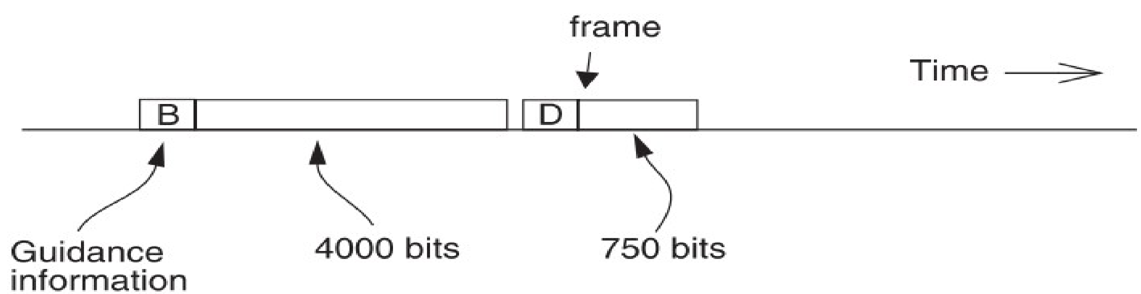
Frame can be of any length, carried at any time that the link is free

Packet: a variable-length frame with its guidance info

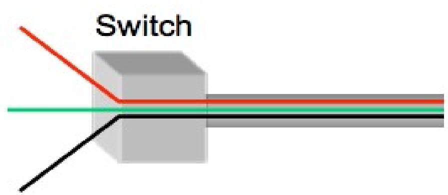
Connectionless transmission: no state maintained

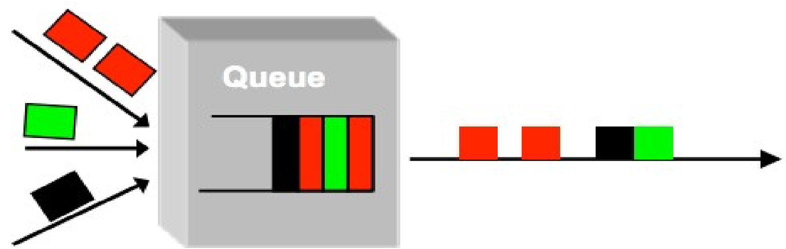
Segment and reassemble

Packet voice: replacing many parts of isochronous network



Multiplexing / Demultiplexing





Multiplex using a queue: switch need memory/buffer

Demultiplex using information in packet header

- Header has destination
- Switch has a forwarding table that contains information about which link to use to reach a destination

Framing Frames

Where a frame begins and ends

Independent from framing bits

- Some model separates link layer to 2: one for bits and one for frames

Simple method

- Choose a pattern of bits, e.g., 7 one-bits in a row, as a frame-separator
- Bit stuffing: if data contains 6 ones in a row, then add an extra bit (0)

Error Handling

Error detection code

- Adding redundancy: e.g., checksum at the end

What to do if detect an error

- Error correction code: with enough redundancy
  - Where noise is well understood, e.g., disk
- Ask sender to resend: sender holds frame in buffer
- Let receiver discard the frame
- Blending these techniques

Coding: Incremental Redundancy

Forward error correction

- Perform coding before storing or transmitting
- Later decode the data without appealing to the creator

Hamming distance

- Number of 1 in $A \oplus B$, $\oplus$ is exclusive OR (XOR)
- If H-distance between every legitimate pair is 2
  - 000101, can only detect 1-bit flip
- If H-distance between every legitimate pair is 3
  - Can only correct 1 bit flip
- If H-distance between every legitimate pair is 4
  - Can detect 2-bit flip, correct 1-bit flip

100101
000111

100101
010111

Example-1: Simple Parity Check

2 bits -> 3 bits

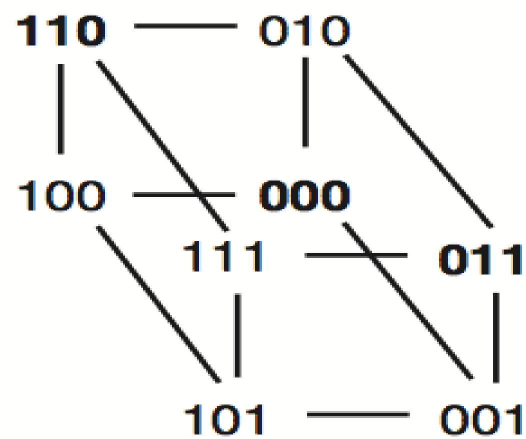
- Detect 1-bit errors
- 8 patterns total

Only 4 correct patterns

- 00 -> 000
- 11 -> 110
- 10 -> 101
- 01 -> 011

Hamming distance of this code is 2

- 1-bit flipping will cause incorrect pattern



Example-2: 4-bit -> 7-bit

4 bits -> 7 bits (56 using only extra 7)

- 3 extra bits to distinguish 8 cases
- e.g. 1101 -> 1010101

$$P_1 = P_7 \oplus P_5 \oplus P_3$$
$$P_2 = P_7 \oplus P_6 \oplus P_3$$
$$P_4 = P_7 \oplus P_6 \oplus P_5$$

Correct 1-bit errors

- 1010101 -> 1010001 : P1 & P4 not match
- 1010101 -> 1110101 : P2 not match

1	2	3	4	5	6	7
1	0	1	0	1	0	1
1	0	1	0	1	0	1
1	0	1	0	1	0	1

Not Match	Error
None	None
P1	P1
P2	P2
P4	P4
P1 & P2	P3
P1 & P4	P5
P2 & P4	P6
P1 & P2 & P4	P7

NETWORK LAYER

IP: Best-effort Network

1. Best-effort network

- If it cannot dispatch, may discard a packet

2. Guaranteed-delivery network

- Also called store-and-forward network, no discarding data
- Work with complete messages rather than packets
- Use disk for buffering to handle peaks
- Tracks individual message to make sure none are lost

In real world

- No absolute guarantee
- Guaranteed-delivery: higher layer; best-effort: lower layer

Duplicate Packets and Suppression

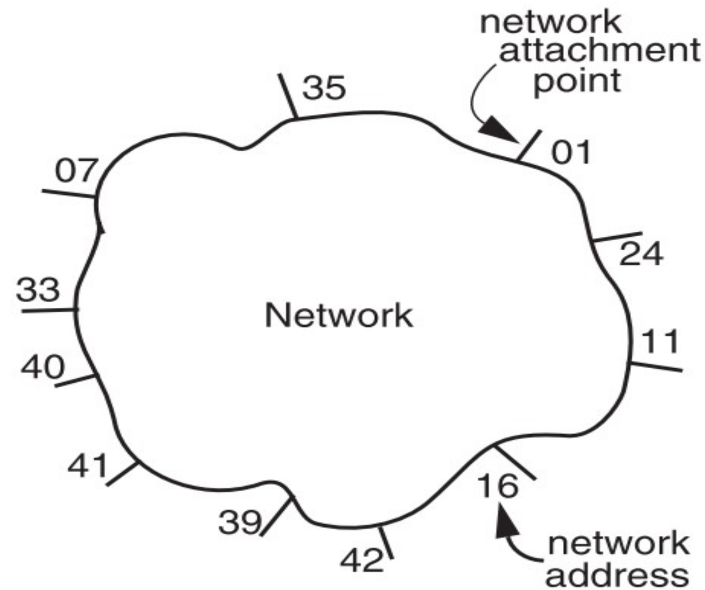
Discarding packets is common case

- Many network protocol includes timeout and resend mechanism

When a congested forwarder discards a packet

- Client does not receive a response as quickly as originally hoped
- Users may prepared for duplicate requests and responses
- Detecting duplicates may or may not be important

The Network Layer



Addressing interface

- Network attachment points
- Network address
- Source & destination

NETWORK_SEND (segment_buffer, destnation, network_protocol, end_layer_protocol)

NETWORK_HANDLE (packet, network_protocol)

Managing the Forwarding Table: Routing

Routing (or path-finding)

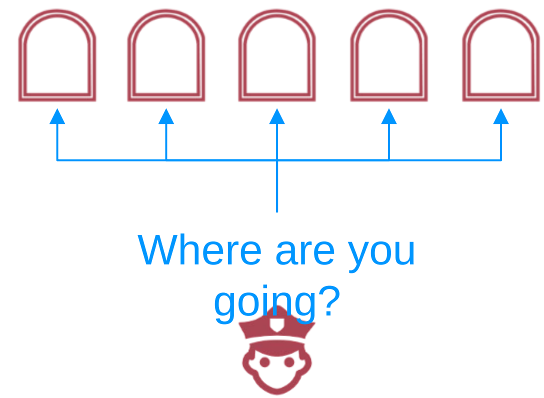
- Constructing the tables

Impractical by hand

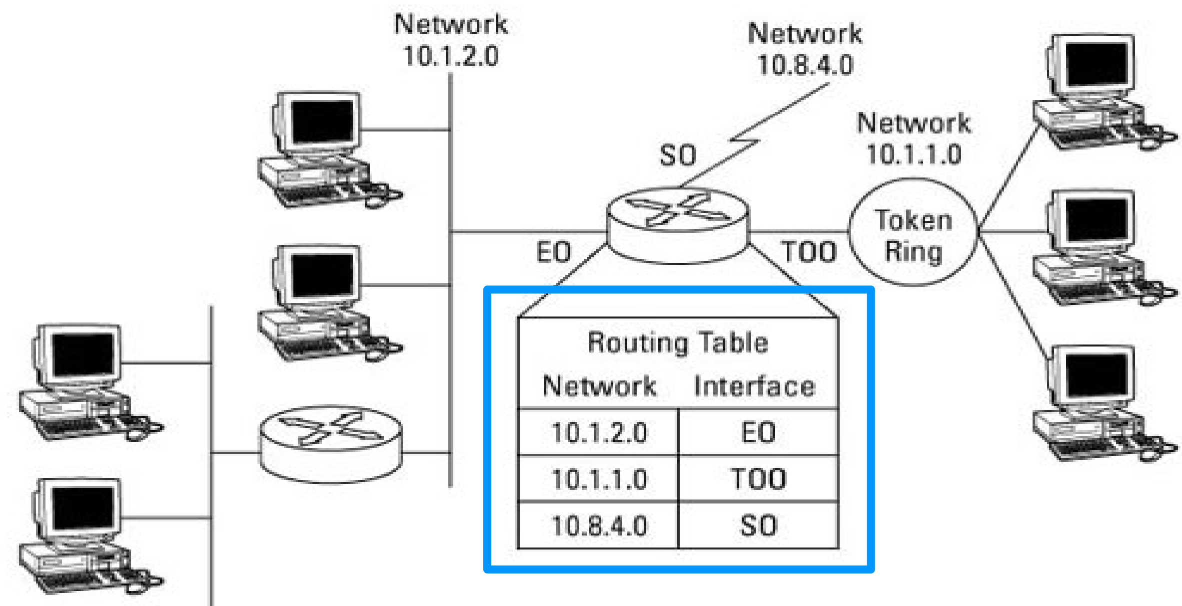
- Determining the best paths requires calculation
- Recalculating the table when links change
- Recalculating the table when link fails
- Adapt according to traffic congestion

Static routing vs. adaptive routing

- Adaptive routing requires exchange of info



IP Route Table



Interface 1 … Interface N

Control-plane VS. Data-plane

Control-plane

- Control the data flow by defining rules
- E.g., the routing algorithm

Data-plane

- Copies data according to the rules
- Performance critical
- E.g., the IP forwarding process