High performance parallel systems

Lecture 7 – Computer Networks

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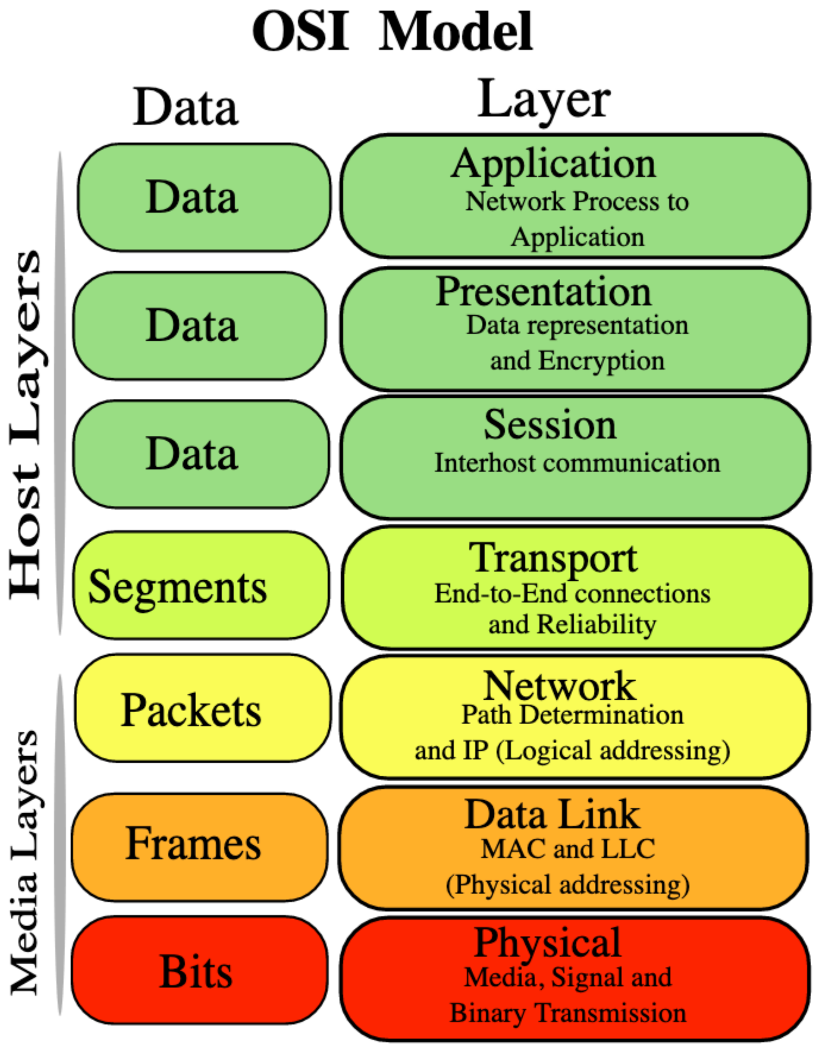
A layered approach



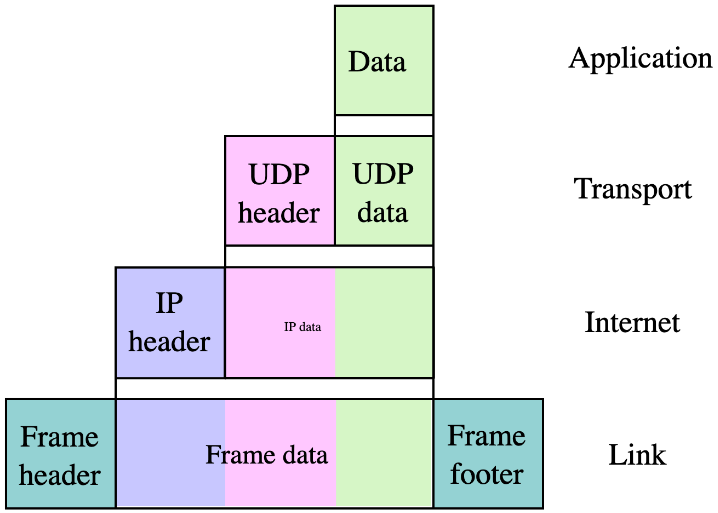
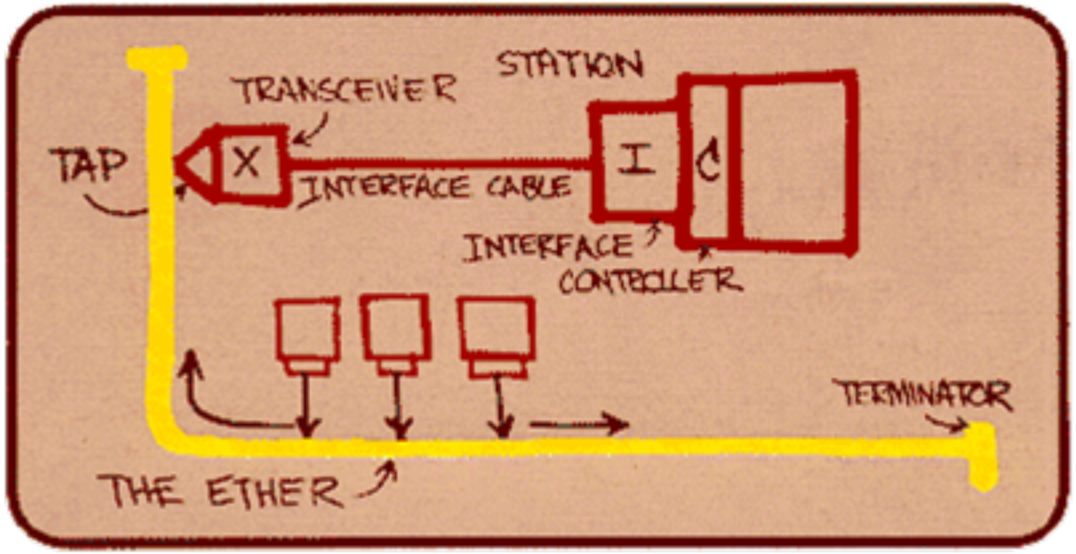


Image from: https://commons.wikimedia.org/wiki/File:UDP_encapsulation.svg

Image from: https://commons.wikimedia.org/wiki/File:Osi-model-jb.svg

Ethernet – From Coax to present day



Drawing by Robert M. Metcalfe in 1976

Sharing a cable

https://www.youtube.com/watch?v=ajh1eZUVuCk

Carrier-sense multiple access with collision avoidance

CSMA/CA

Using exponential backoff

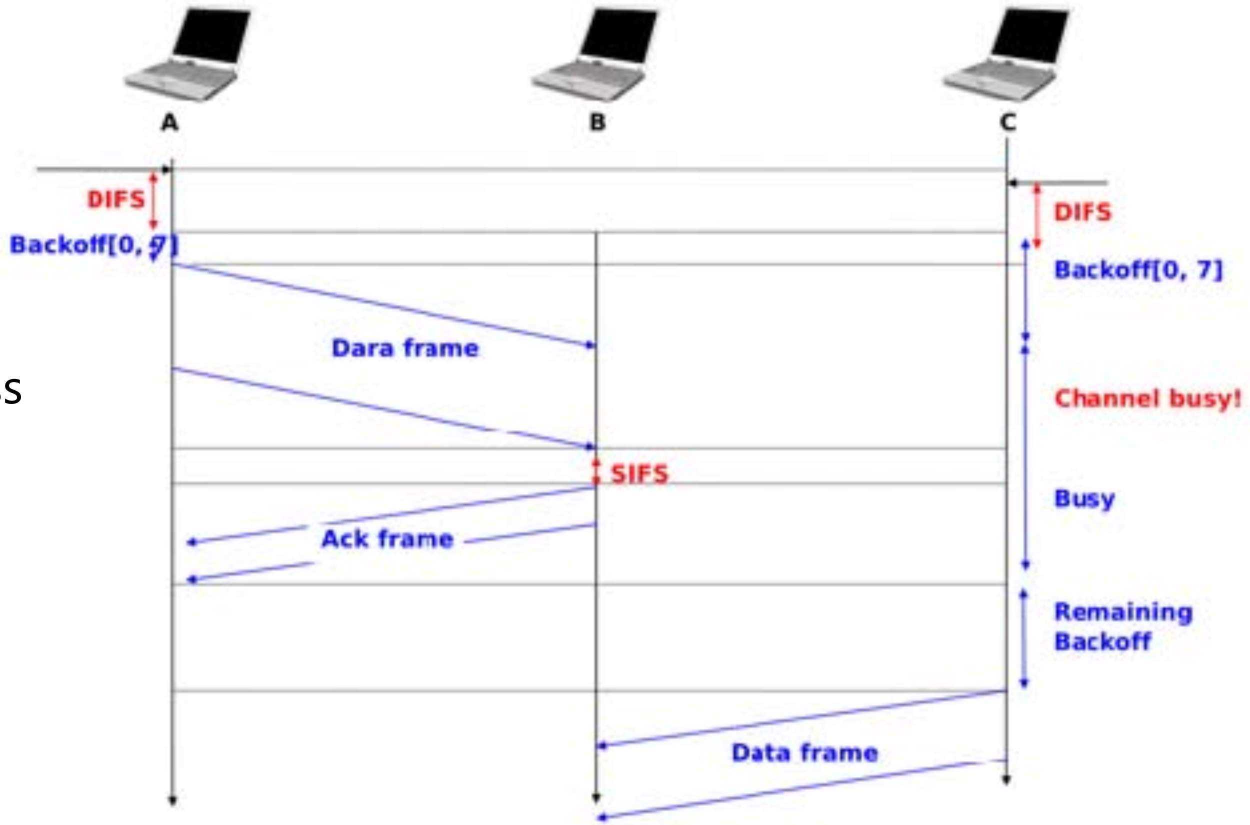
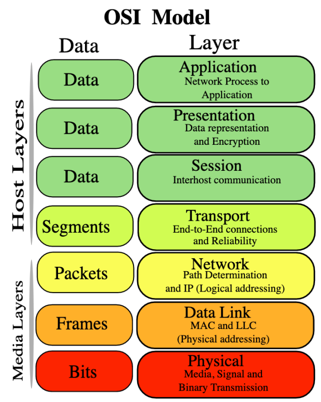
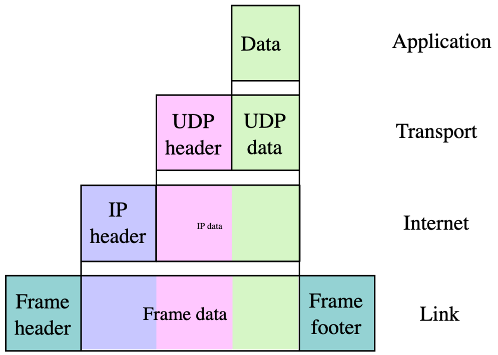


Image from: http://www.opentextbooks.org.hk/ditatopic/3611

Sending a packet over ethernet cable





Preamble
AA AA AA AA AA AA AB

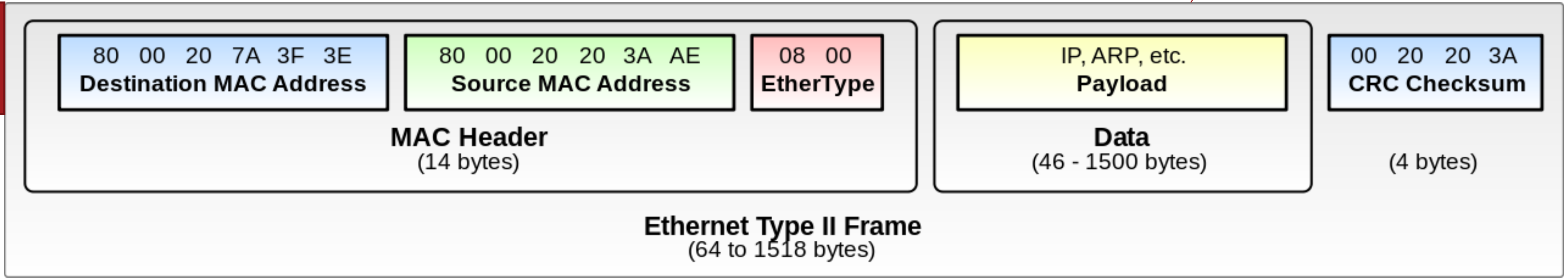
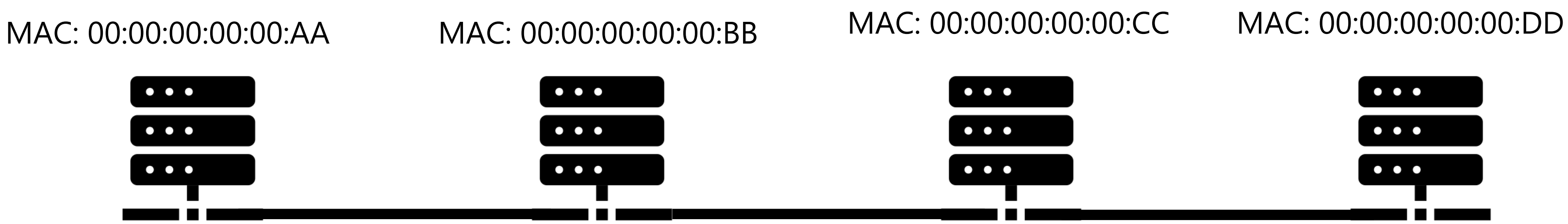


Image from: https://commons.wikimedia.org/wiki/File:Ethernet_Type_II_Frame_format.svg

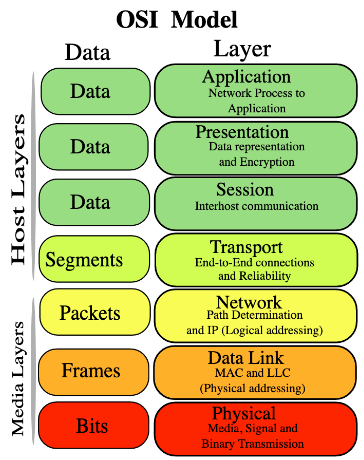
10101010 10101010 10101010 10101010 10101010 10101010 10101010 10101011

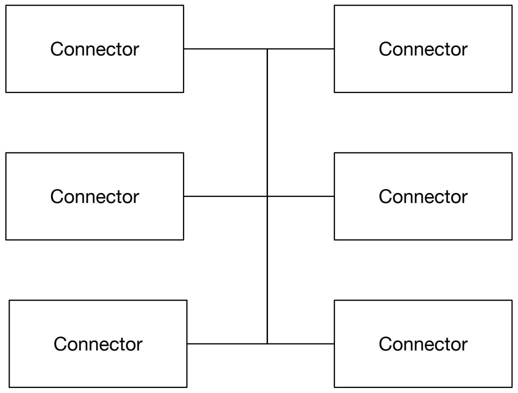
Sending messages on a local network

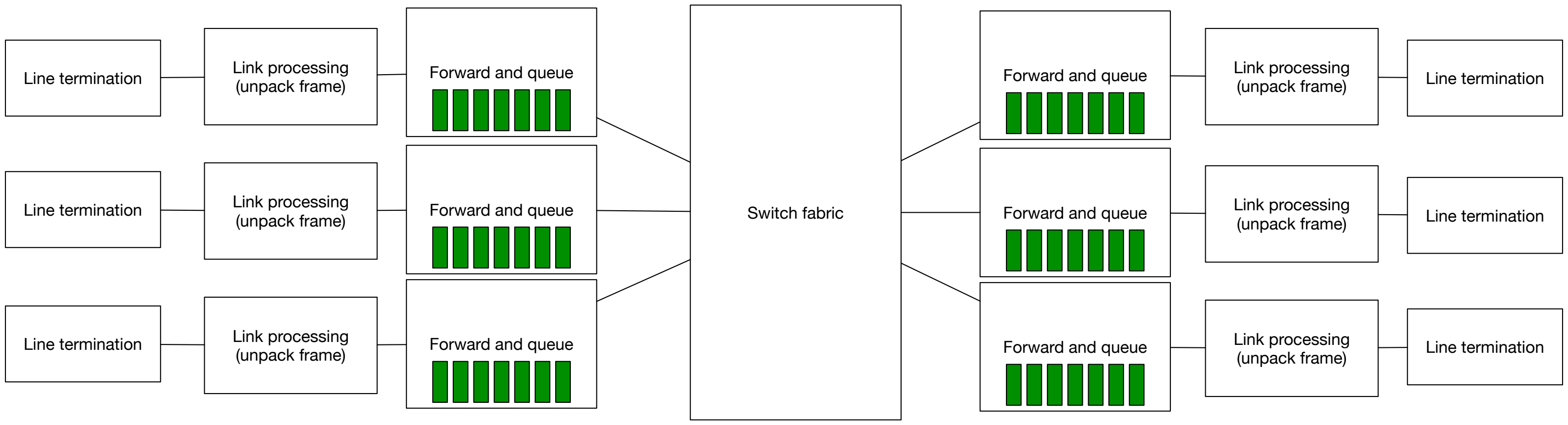



```
FROM:    ….:AA
TO:      ….:CC
Payload: ……
```

Connecting ethernet – Switches and Hubs







Ethernet – One protocol fits all (speeds)

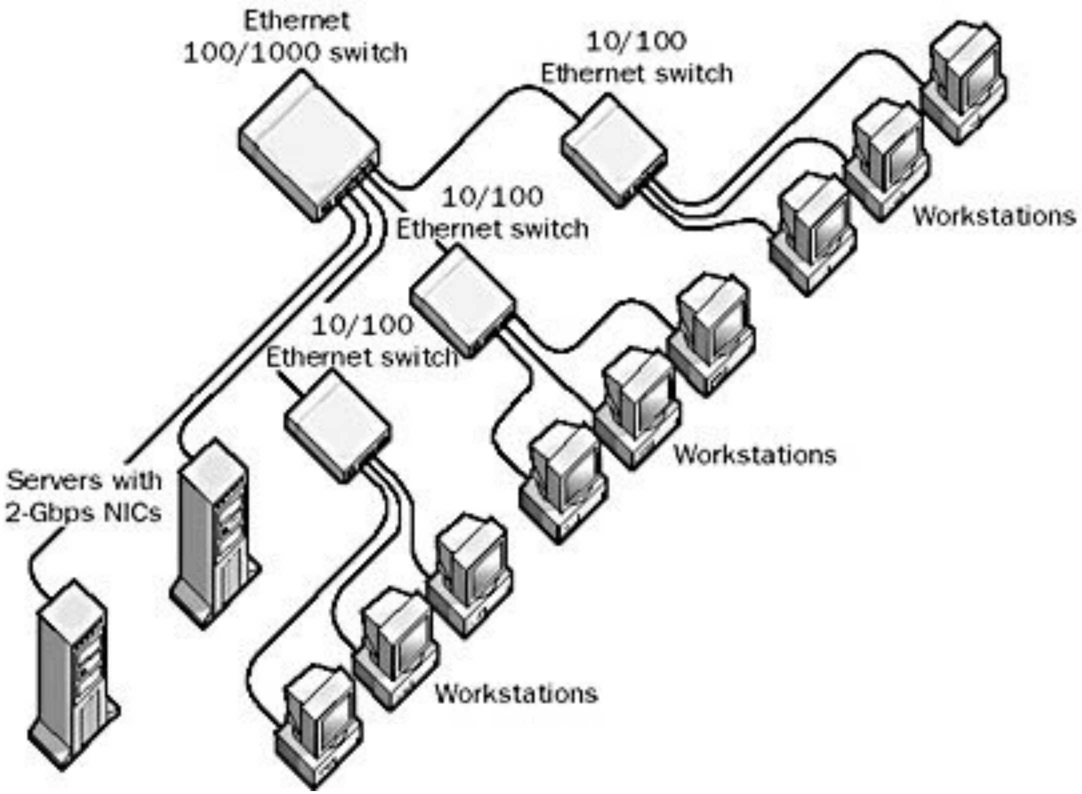
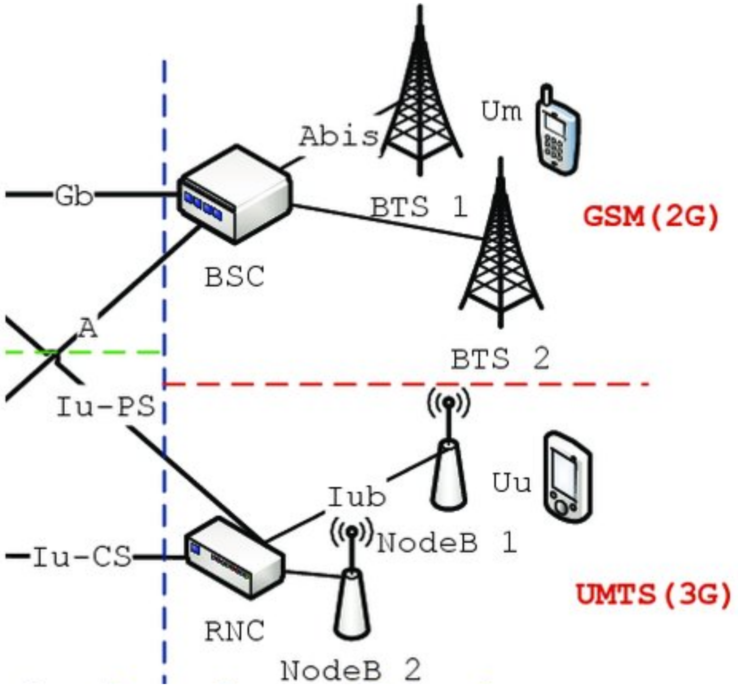


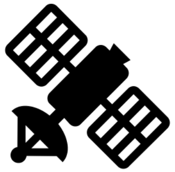
Image from: https://networkencyclopedia.com/gigabit-ethernet/

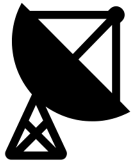
Alternatives to Ethernet: WiFi, 3/4/5G, etc

CSMA/CA



From: DOI: 10.1109/ISCIT.2012.6381046

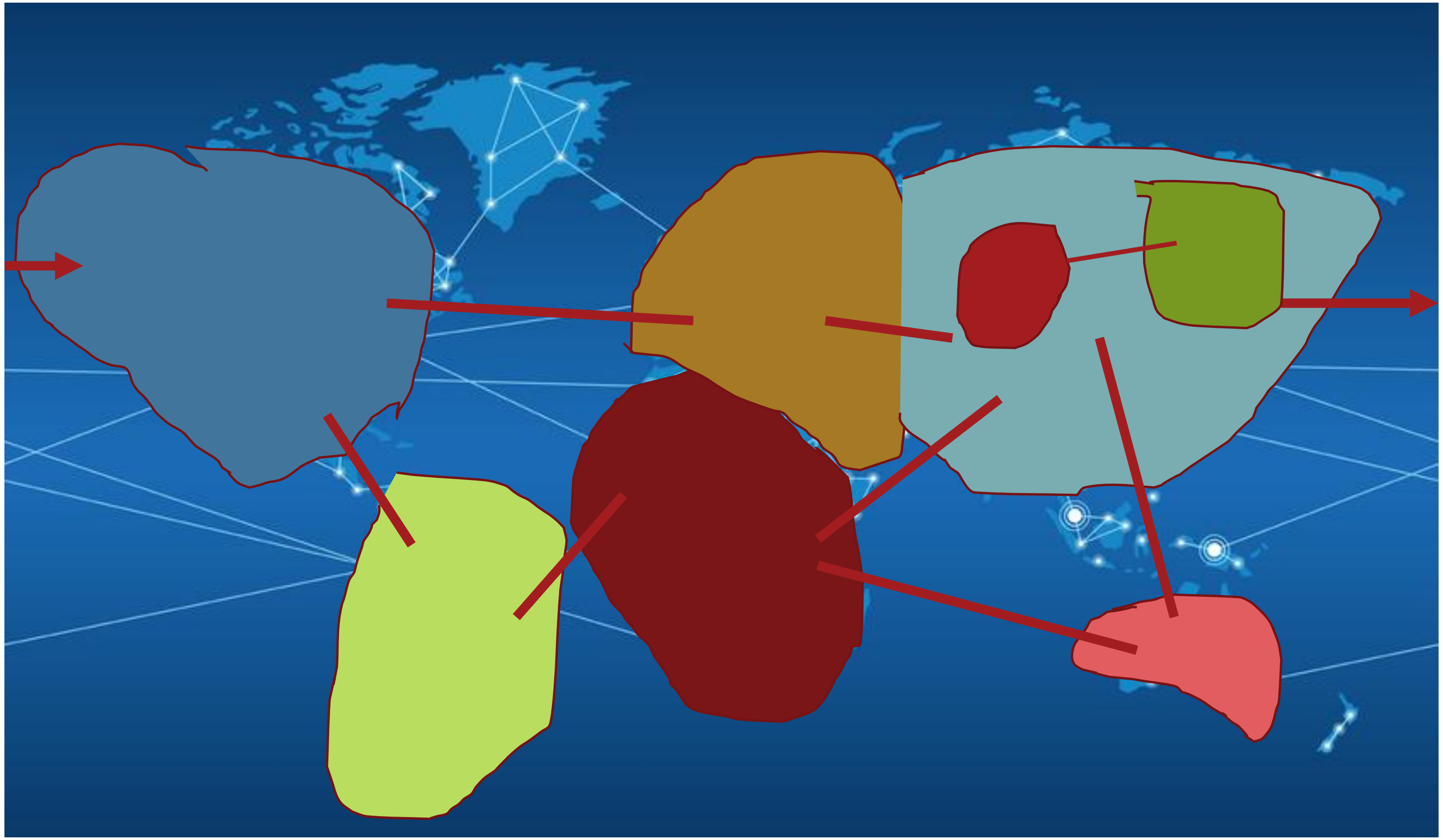




Internet Protocol

Image from: https://www.vecteezy.com/vector-art/376244-seamless-map-of-the-global-network-system

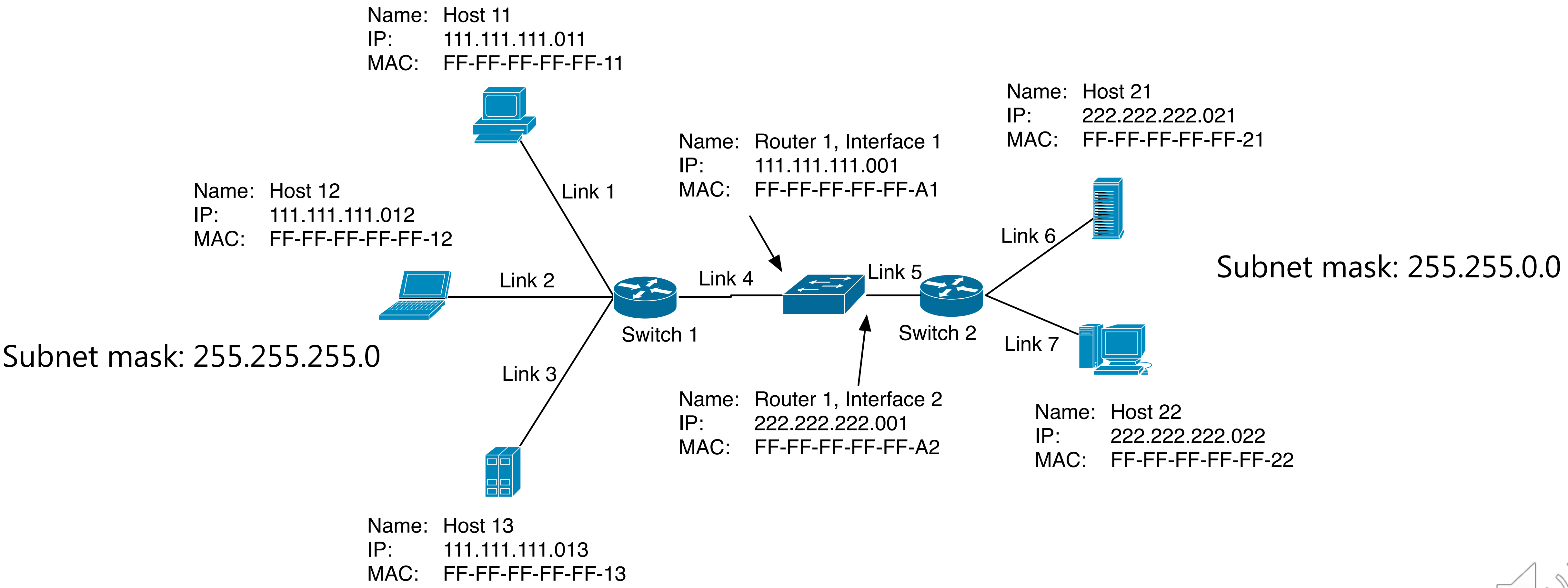
Internet Protocol



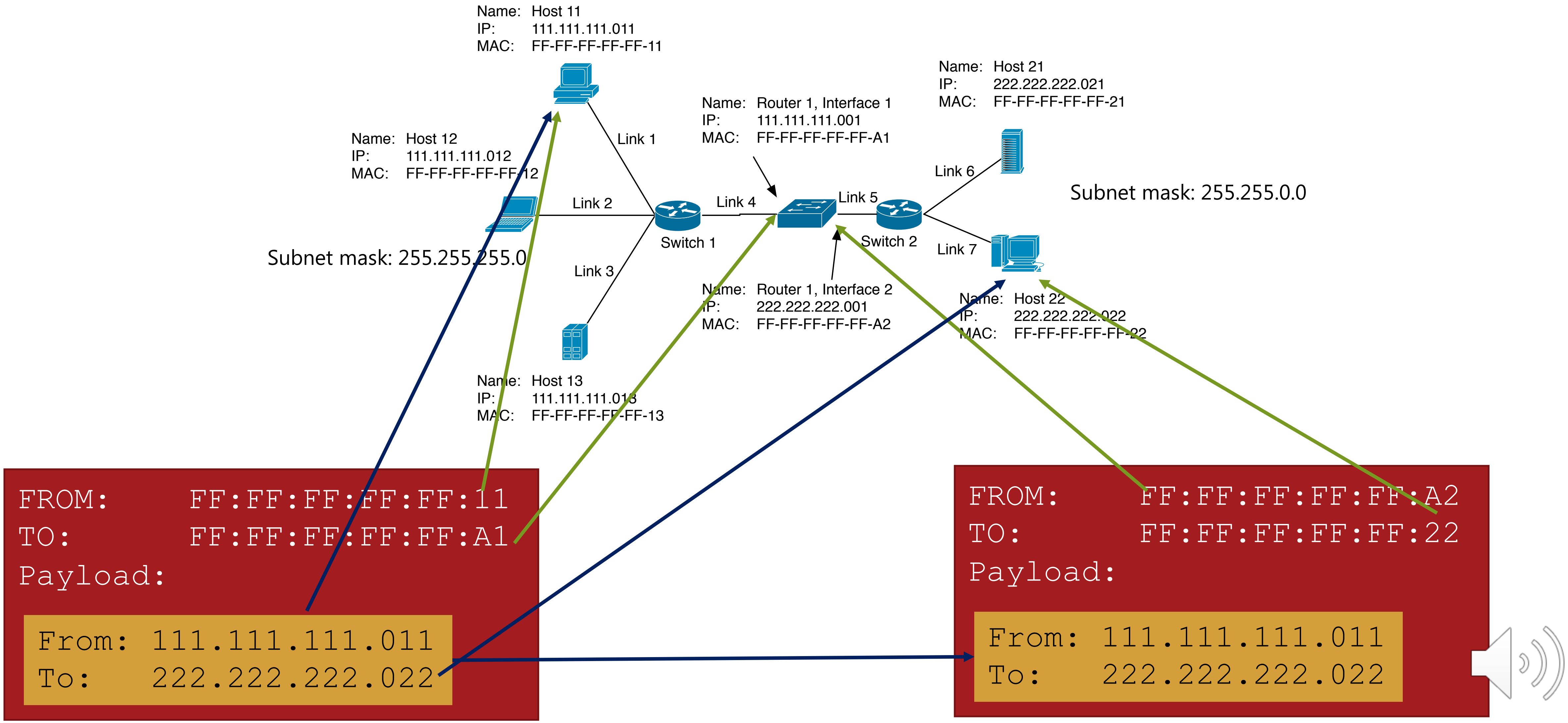
OSI Model

	Data	Layer
Host Layers	Data	Application Network Process to Application
	Data	Presentation Data representation and Encryption
	Data	Session Interhost communication
	Segments	Transport End-to-End connections and Reliability
Media Layers	Packets	Network Path Determination and IP (Logical addressing)
	Frames	Data Link MAC and LLC (Physical addressing)
	Bits	Physical Media, Signal and Binary Transmission

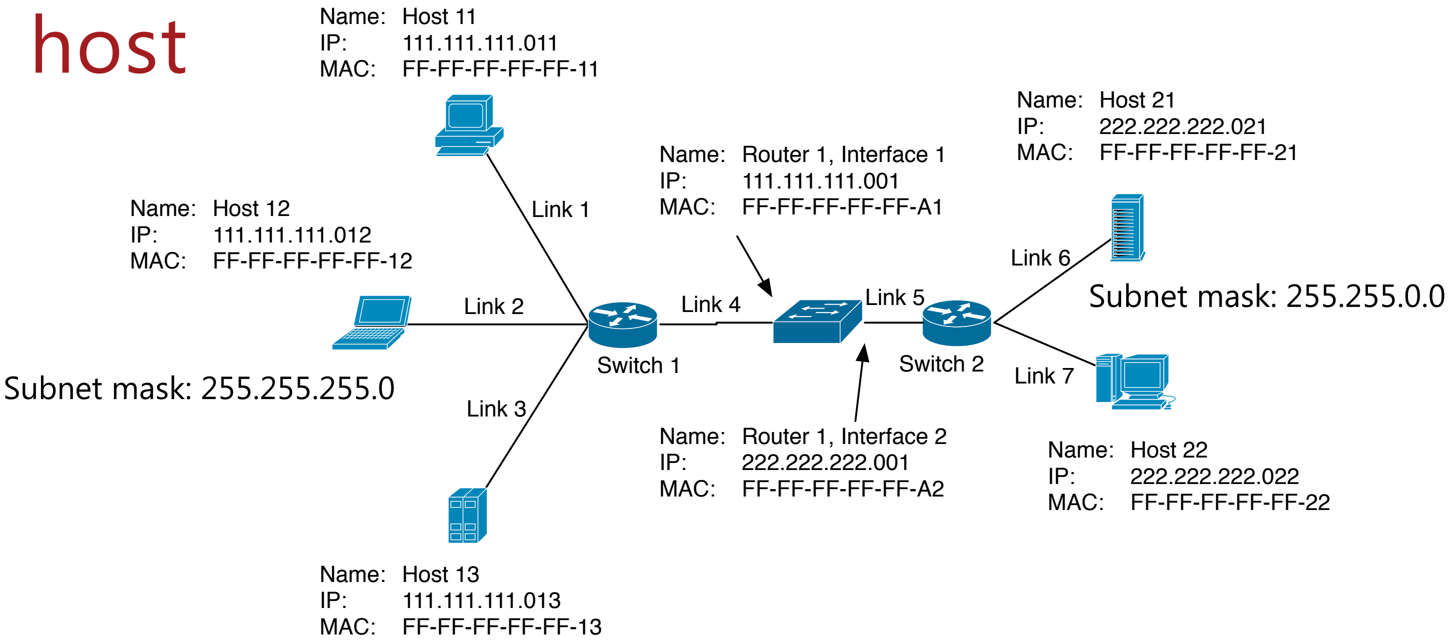
Introducing routers and IP addresses



Routing with subnets



Routing as seen from a host



Own IP:	111.111.111.011	111.111.111.011
Target IP:	111.111.111.012	222.222.222.022
Subnet mask:	255.255.255.0	255.255.255.0
Own masked:	111.111.111.0	111.111.111.0
Target masked:	111.111.111.0	222.222.222.0
	Own subnet	*Other subnet*

Special IP addresses

CIDR block	Subnet mask	Comment
10.0.0.0/8	255.255.255.0	Private network
127.0.0.0/8	255.255.255.0	Local host - 127.0.0.1
172.16.0.0/12	255.255.240.0	Private network
192.168.0.0/16	255.255.0.0	Private network

Try it yourself – IP addresses

A host has IP 192.168.0.2 and subnet mask 255.255.255.240.
For each of these target IPs figure out if it sends to the router:

- 192.168.0.12
- 192.168.0.63
- 192.168.1.03

How many hosts can be in a subnet with these ranges:

- 10.0.0.0/8
- 172.16.0.0/12
- 192.168.0.0/16
- 255.0.0.0

What is the smallest IP and largest IP in these ranges:

- 10.0.0.0/8
- 172.16.0.0/12
- 192.168.0.0/16
- 88.5.6.7 subnet mask 255.0.0.0

Try it yourself – IP addresses

A host has IP 192.168.0.2 and subnet mask 255.255.255.240.
For each of these target IPs figure out if it sends to the router:

- 192.168.0.12 Local
- 192.168.0.63 Router
- 192.168.1.03 Router

```
240 = 0b1111 0000
2   = 0b0000 0010

12  = 0b0000 1100
63  = 0b0011 1111
3   = 0b0000 0011
```

How many hosts can be in a subnet with these ranges:

- 10.0.0.0/8 $2^{(32-8)}$ = 16.777.216 (- 2)
- 172.16.0.0/12 $2^{(32-12)}$ = 1.048.576 (- 2)
- 192.168.0.0/16 $2^{(32-16)}$ = 65.536 (- 2)
- 255.0.0.0 2^{24} = 16.777.216 (- 2)

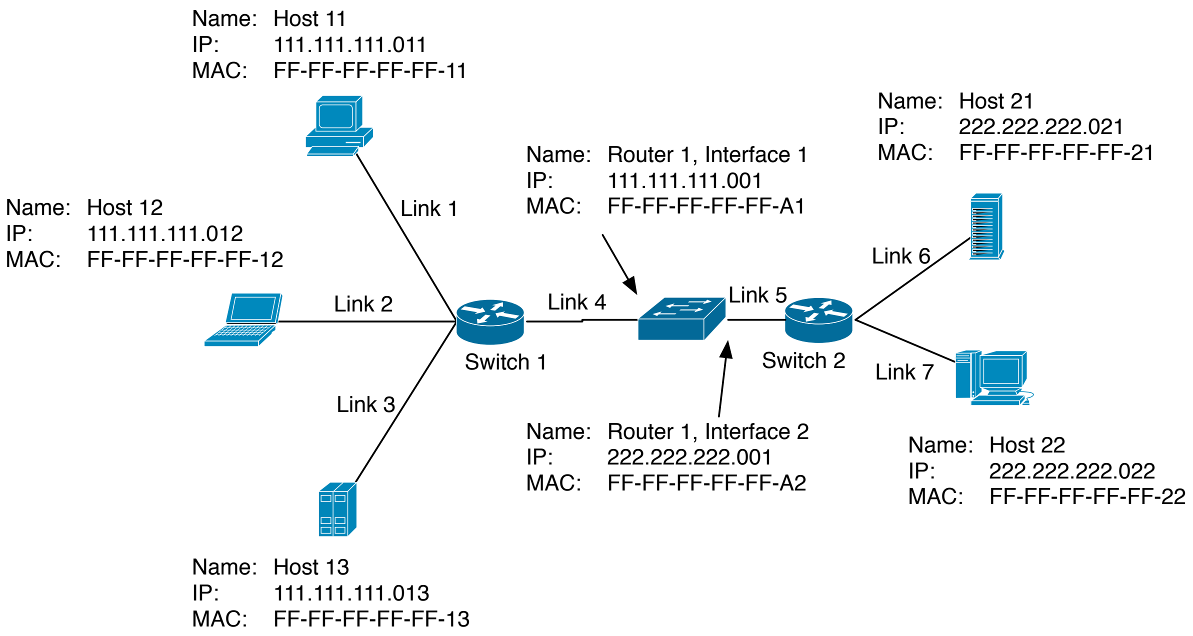
What is the smallest IP and largest IP in these ranges:

- 10.0.0.0/8
- 172.16.0.0/12
- 192.168.0.0/16
- 88.5.6.7 subnet mask 255.0.0.0

10.0.0.0 – 10.255.255.255
172.16.0.0 – 172.31.255.255
192.168.0.0 - 192.168.255.255
88.0.0.0 – 88.255.255.255

DHCP – Dynamic setup

Response contains:
- IP Address
- Subnet mask
- Gateway IP
- DNS hosts
- Network parameters



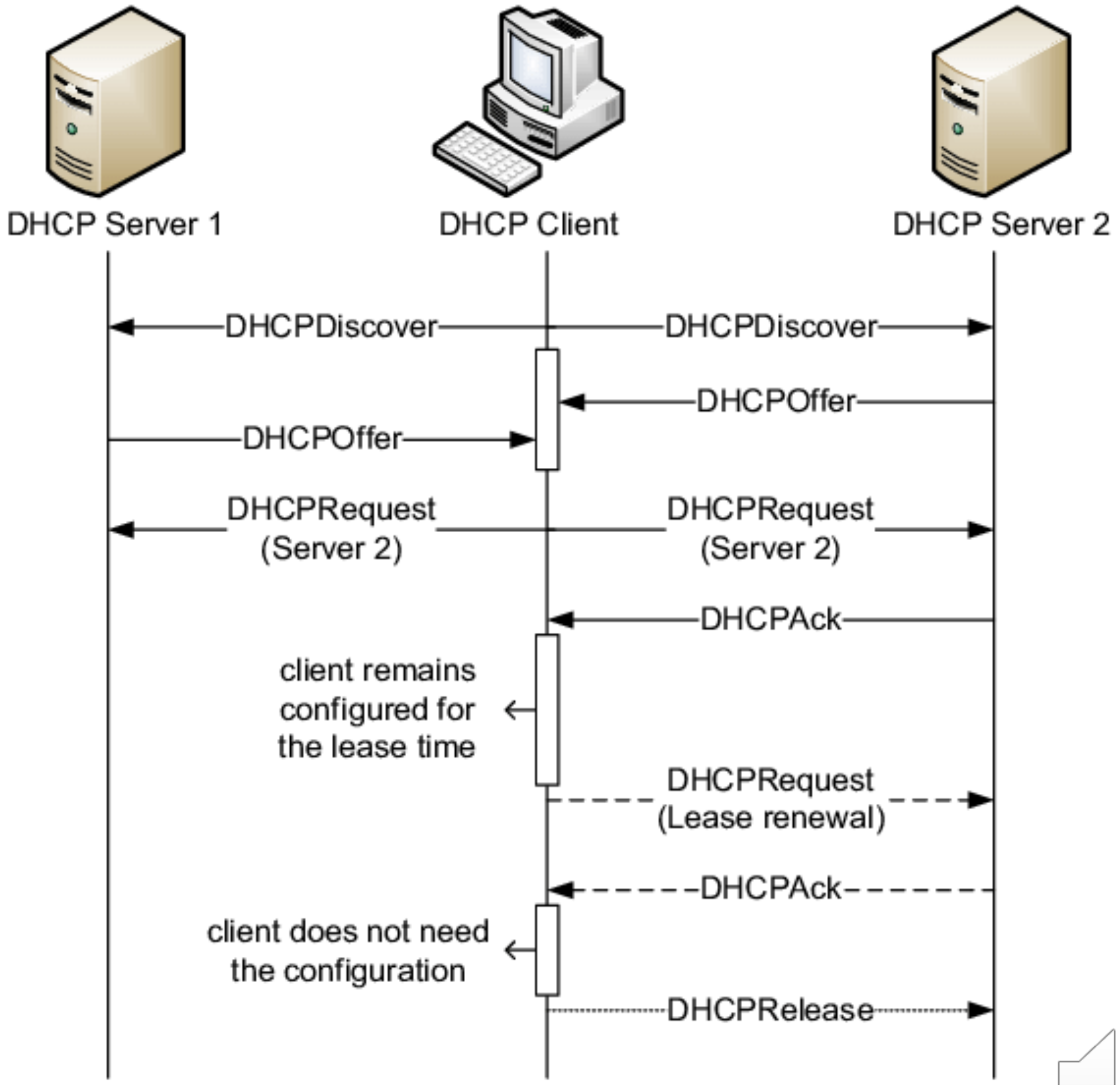
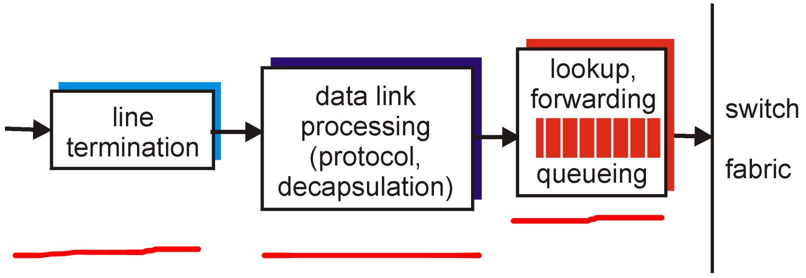
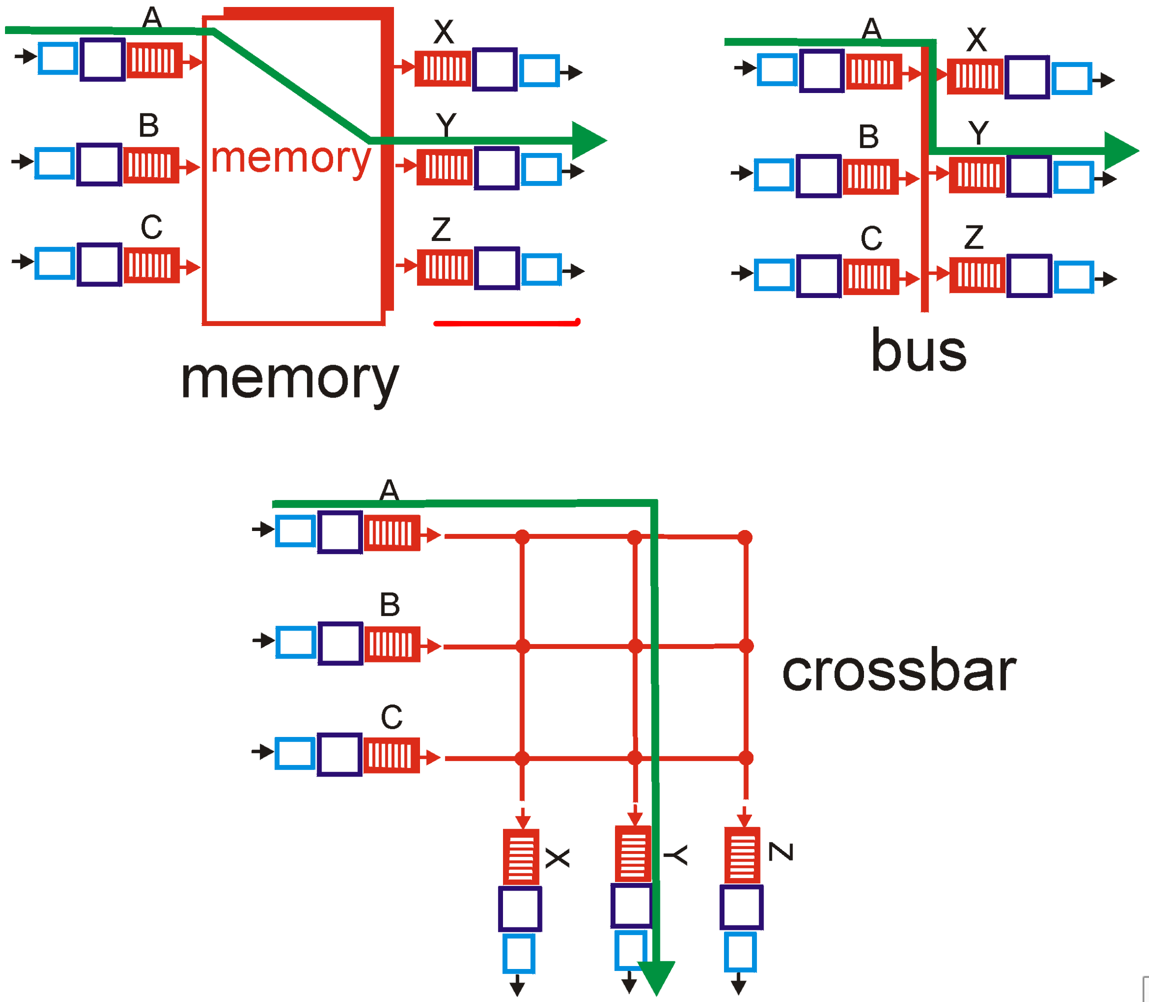


Image from: DOI: 10.1016/j.cose.2013.03.004

Routing an IP package



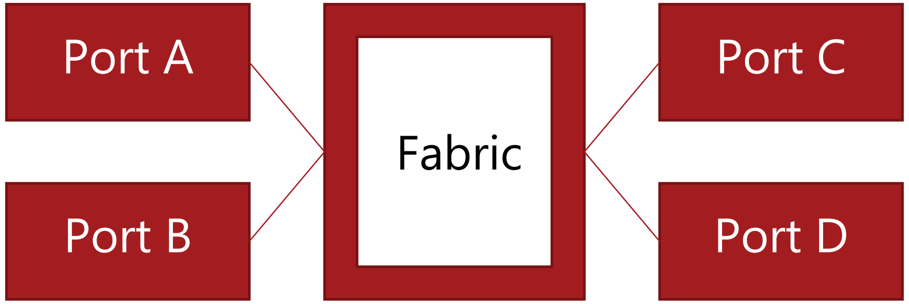


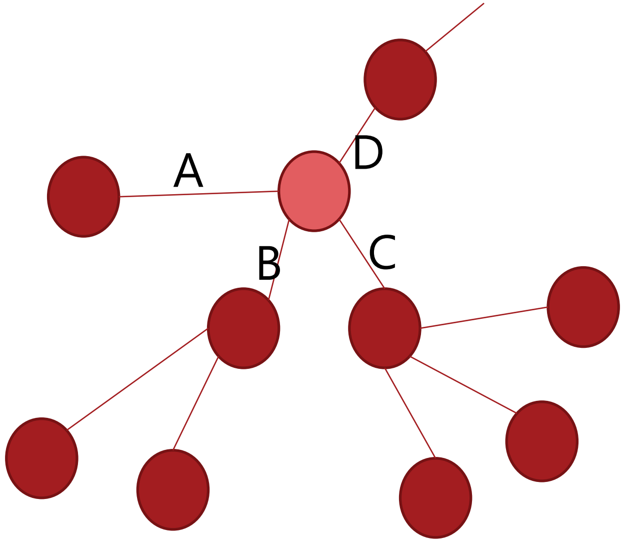
Drops packages on overload
May split (fragment) packages

Images from: http://www2.ic.uff.br/~michael/kr1999/4-network/4_06-inside.htm

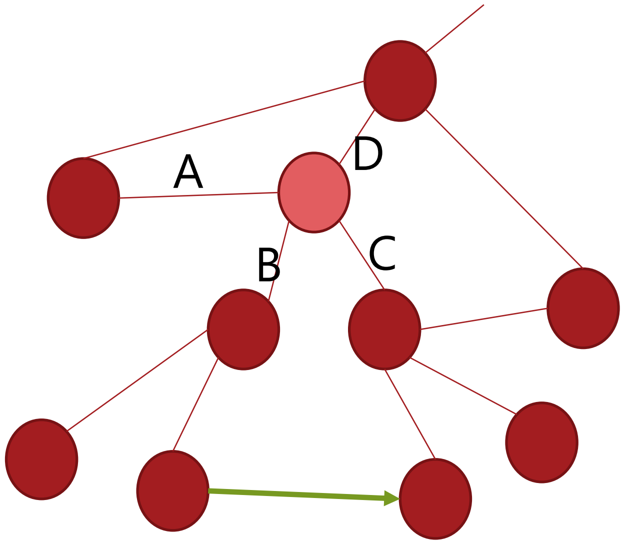
Routing from a router perspective

A = 1.0.0.0/24
B = 2.0.0.0/24
C = 3.0.0.0/24
D = others



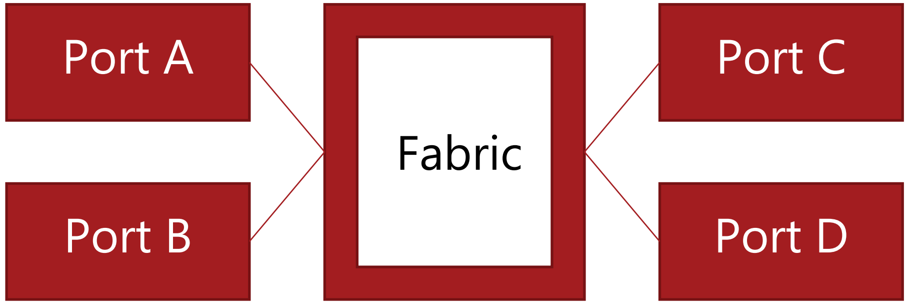


Routing from a router perspective



1.0.0.0/24 = A
2.0.0.0/24 = B
3.0.0.0/24 = C
2.2.3.0/8 = C
D = others

0000 0001 0000 0000 0000 0000 0000 0000
0000 0010 0000 0000 0000 0000 0000 0000
0000 0011 0000 0000 0000 0000 0000 0000
0000 0010 0000 0010 0000 0011 0000 0000



Longest matching prefix rule

Allows dynamic updating of the routes

Packets in a sequence may use different routes

IPv6 arriving soon?

IPv4	IPv6
32 bits address, 2^{32} ~= $4*10^6$	128 bits address, 2^{128} ~= $3.4*10^{32}$
Dotted decimal: **123.456.789.012**	Hex: **0123:4567:89ab:cdef:0123:4567:89ab:cdef**
Allows fragmentation	Does not allow fragmentation
Allows QoS	Allows QoS

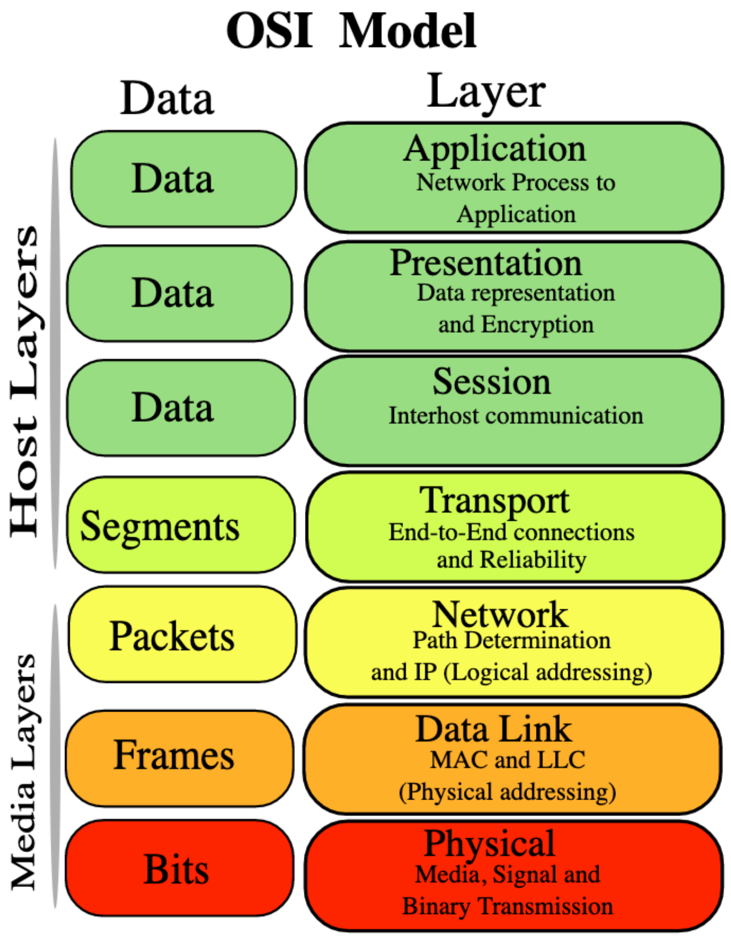
IPv4 cannot address IPv6 host

- Proposed fixed with NAT-like router translating, e.g. 1.1.1.1 => 1:1:1:1:0:0:0:0

IPv4 can be tunneled inside IPv6

Transport layer – TCP and UDP

Mostly using TCP, sometimes UDP and rarely others

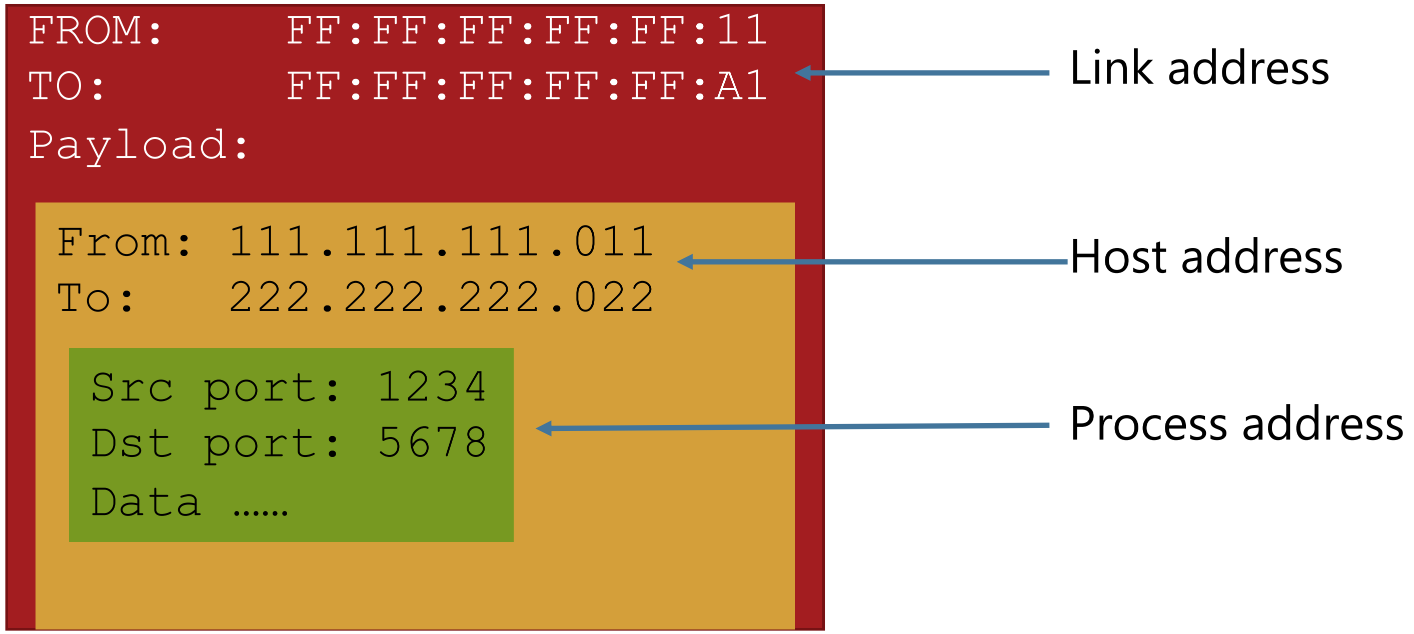


UDP segments

UDP segment header consist of 4 fields each 2 bytes (16 bits)

- Source port
- Destination port
- Length in bytes (excluding header)
- Checksum

Data bytes follow



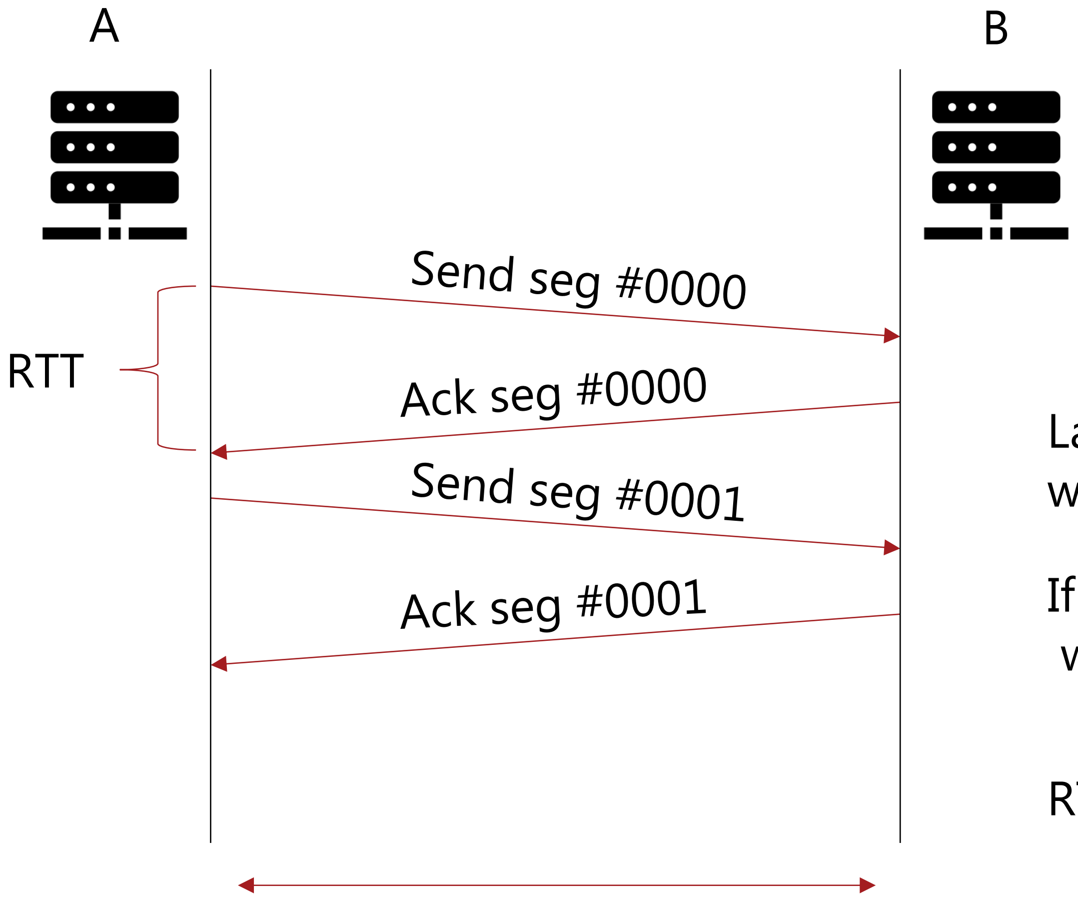
TCP – Internet workhorse

Described in RFC 675 in 1974 by Vinton Cerf & others

- Uses ports like in UDP
- Has guarantees for delivery
- Supports out-of-order delivery

Intermingled with IP specification to form TCP/IP

TCP – Starting out

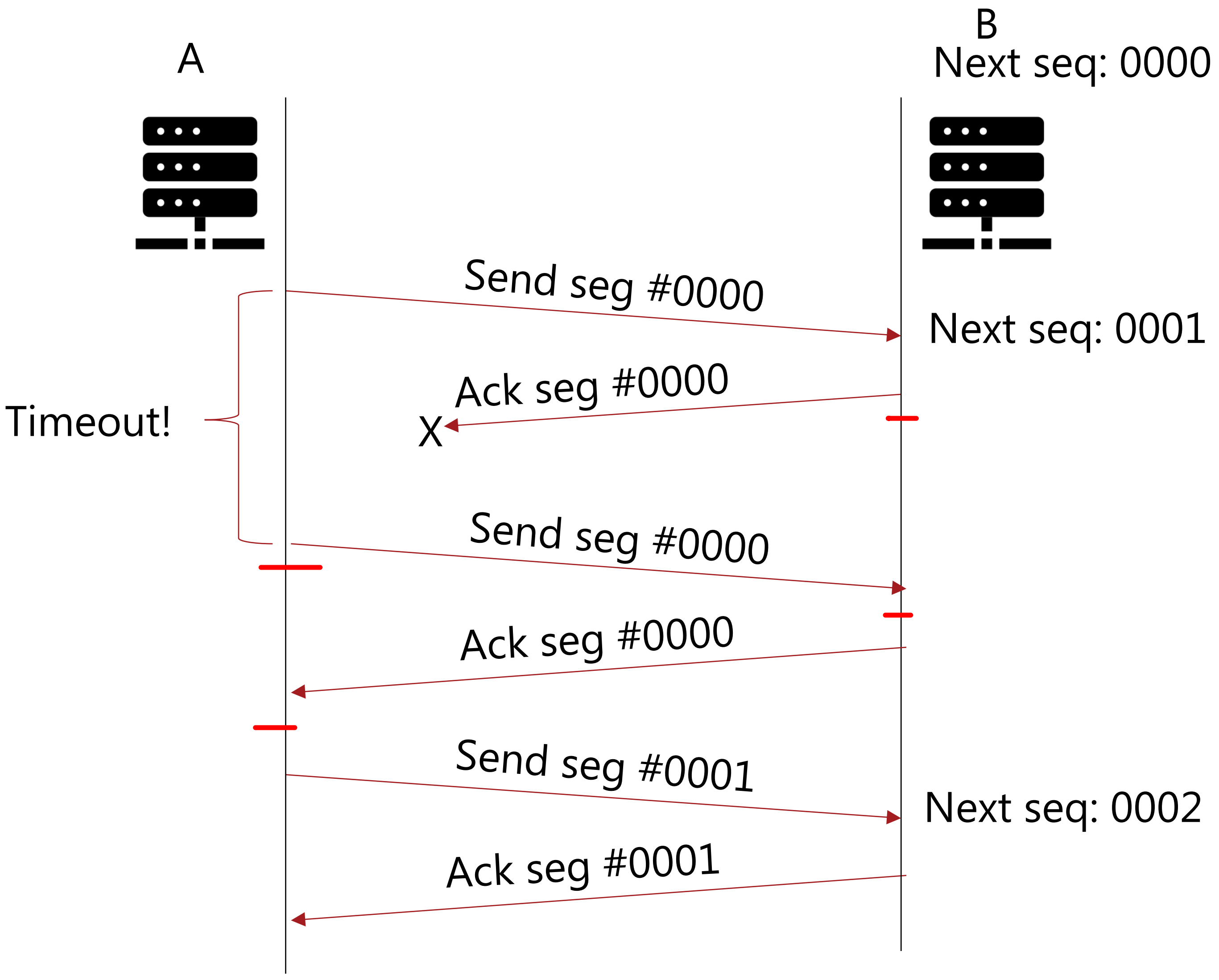


Latency, usually given as round-trip time, RTT
where latency = RTT/2

If RTT = 1 sec and package size is 10KiB,
we get at most 10KiB/s

RTT=10ms, MTU=1500 => ~146 KiB/s

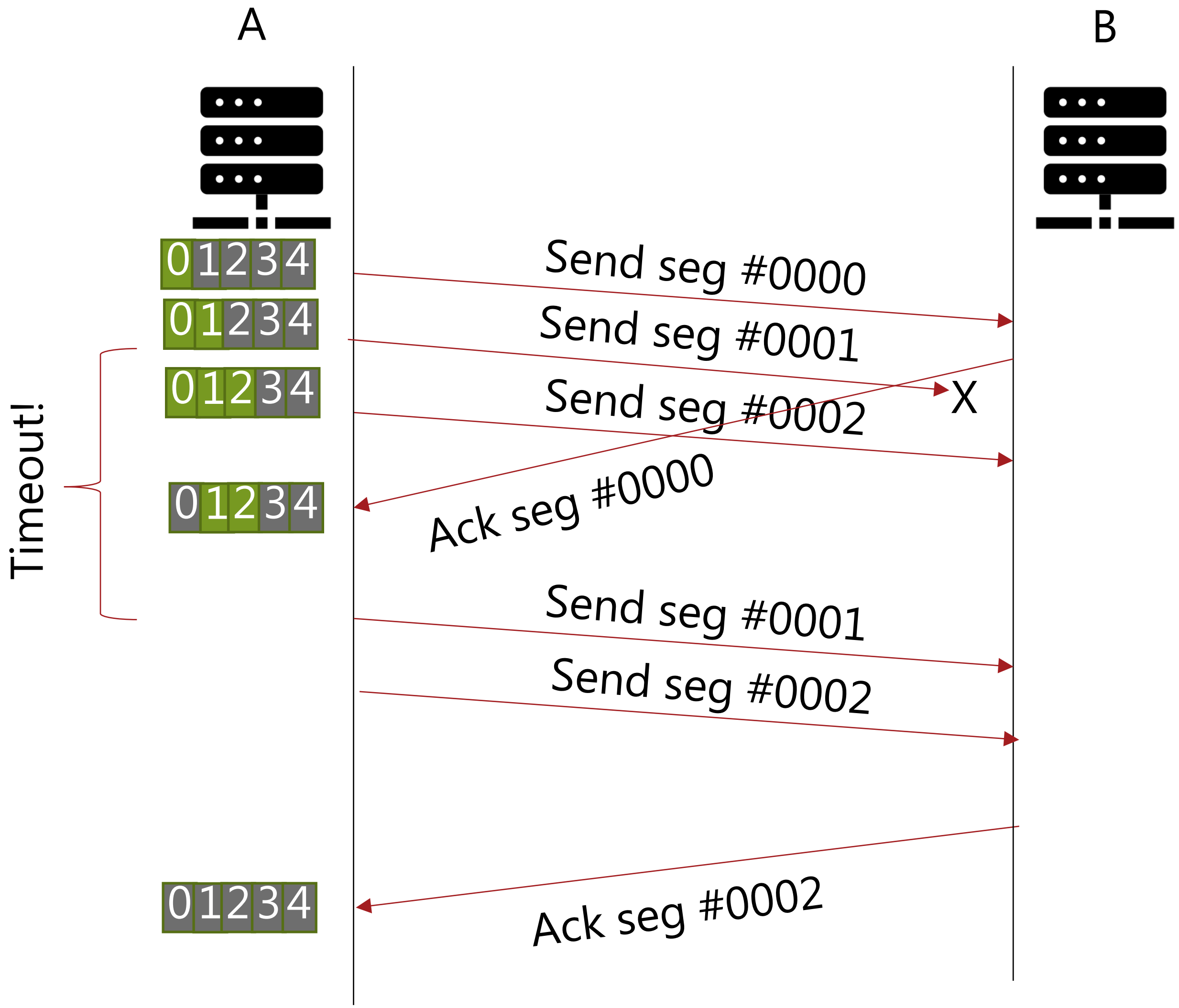
TCP – Handling package loss



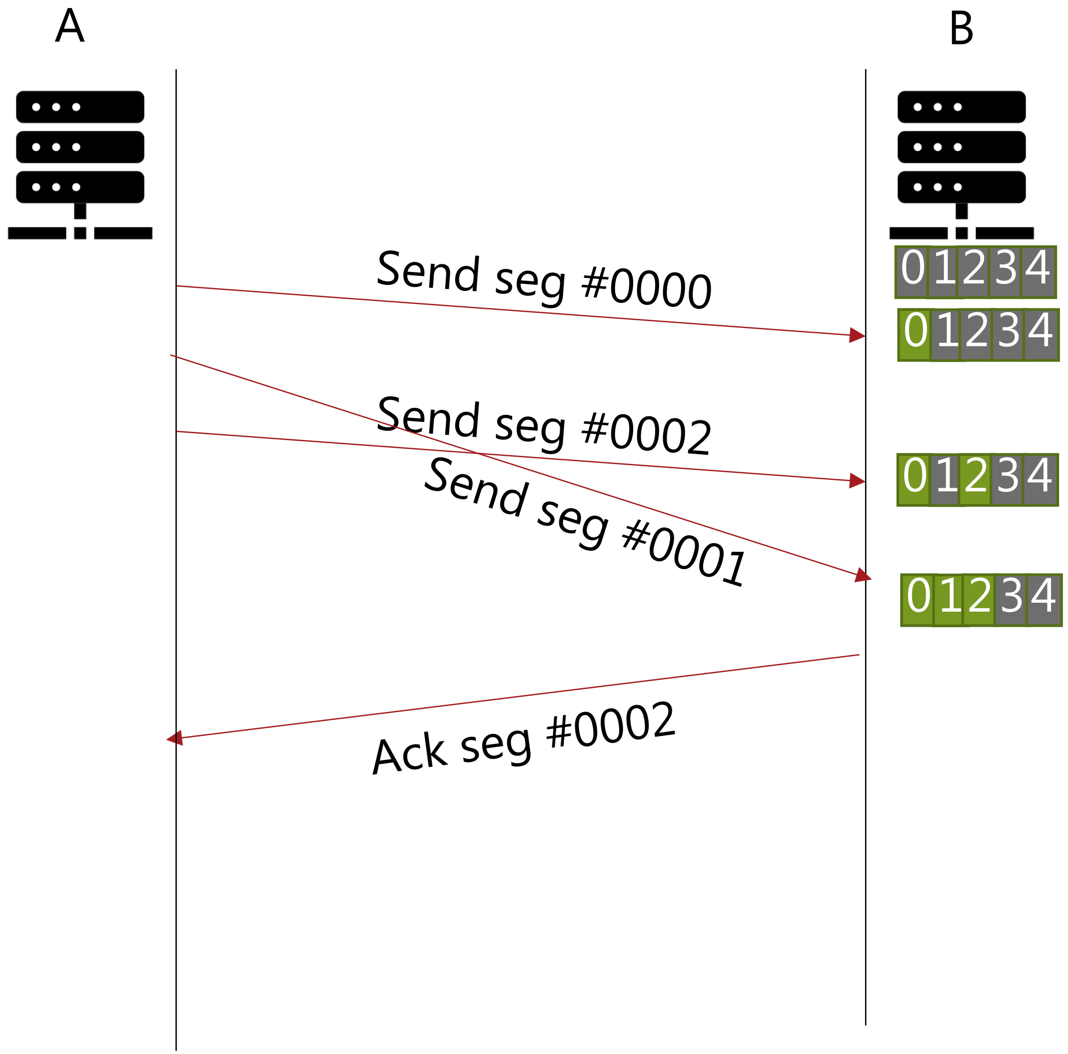
TCP – Send & Receive Windows

Cumulative ACK

TCP – Send Window



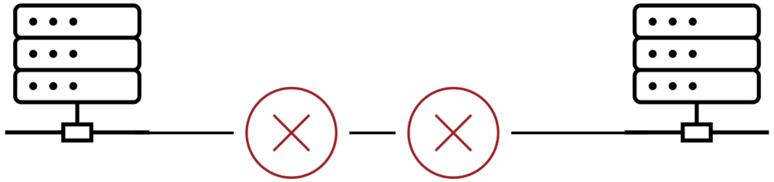
TCP – Receive Window



Triple ACK for same SEQ would indicate single missing package

TCP – Flow & Congestion Control

Related concepts, but different goals and implementations



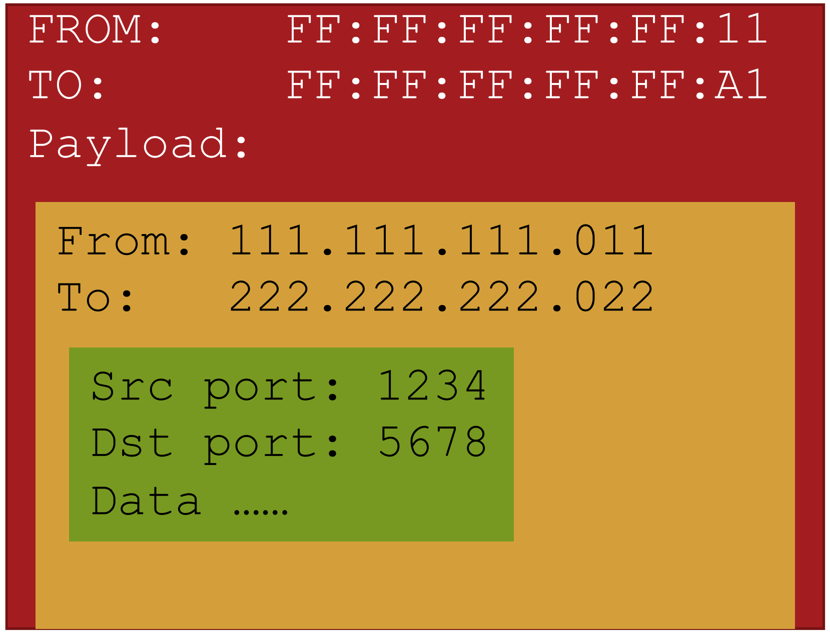
Flow control
Avoid sending data that receiver cannot store

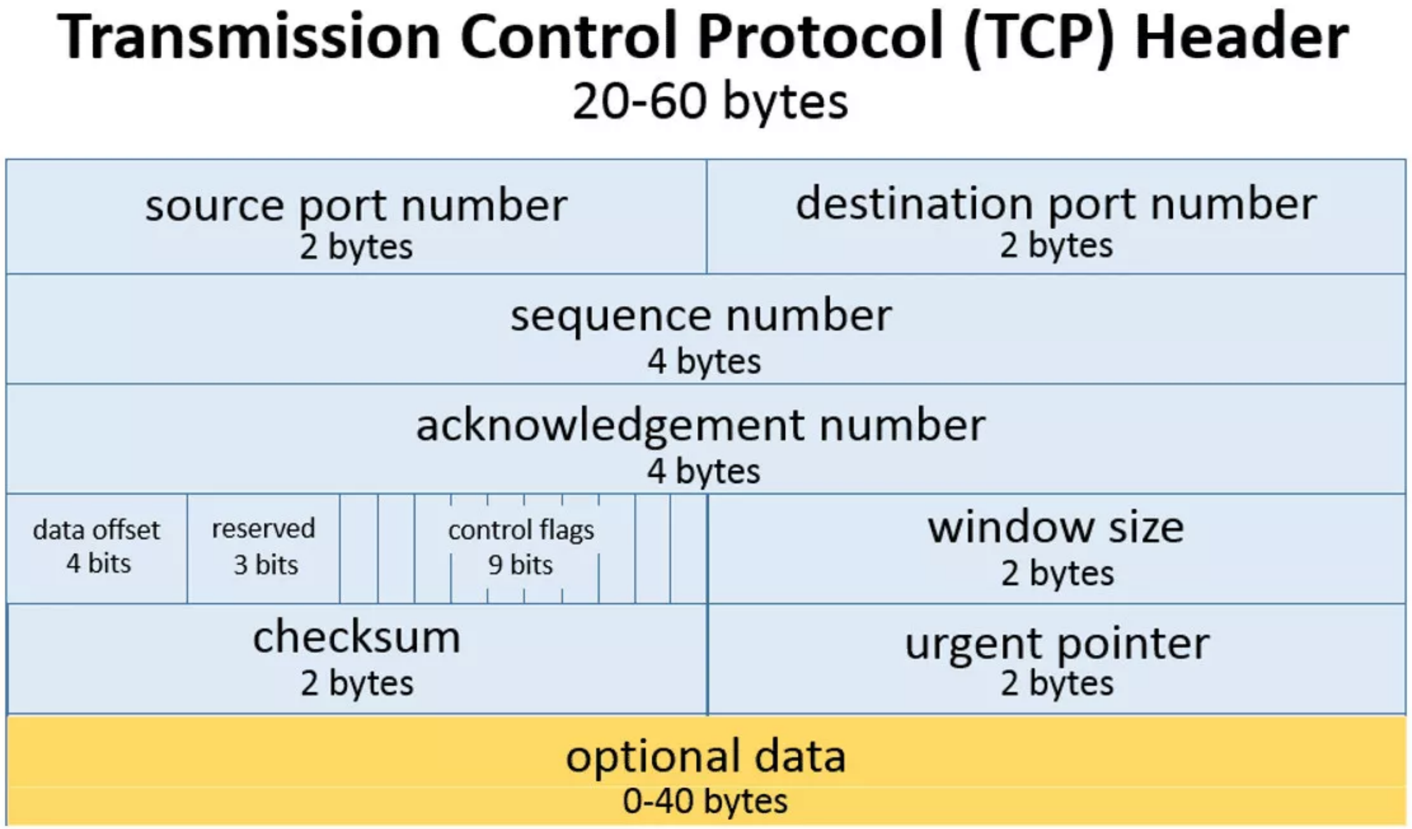
- Receiver sends buffer space indication with ACK
- Sender throttles based on projected buffer space
- When buffer space is 0, sender waits for space
  - After a timeout it sends one segment to test

Congestion control
Avoid clogging the network

- Receiver is not actively involved
- Sender measures network events
  - can use package loss (Tahoe)
  - or use ACK delay (Vegas)
- Sender throttles based on estimated network congestion

TCP header


FROM: FF:FF:FF:FF:FF:11
TO: FF:FF:FF:FF:FF:A1
Payload:
From: 111.111.111.011
To: 222.222.222.022
Src port: 1234
Dst port: 5678
Data ......


Transmission Control Protocol (TCP) Header
20-60 bytes
source port number
2 bytes
destination port number
2 bytes
sequence number
4 bytes
acknowledgement number
4 bytes
data offset
4 bits
reserved
3 bits
control flags
9 bits
window size
2 bytes
checksum
2 bytes
urgent pointer
2 bytes
optional data
0-40 bytes

TCP/IP and NAT

Internal host	External port
10.0.0.1:6789	4455

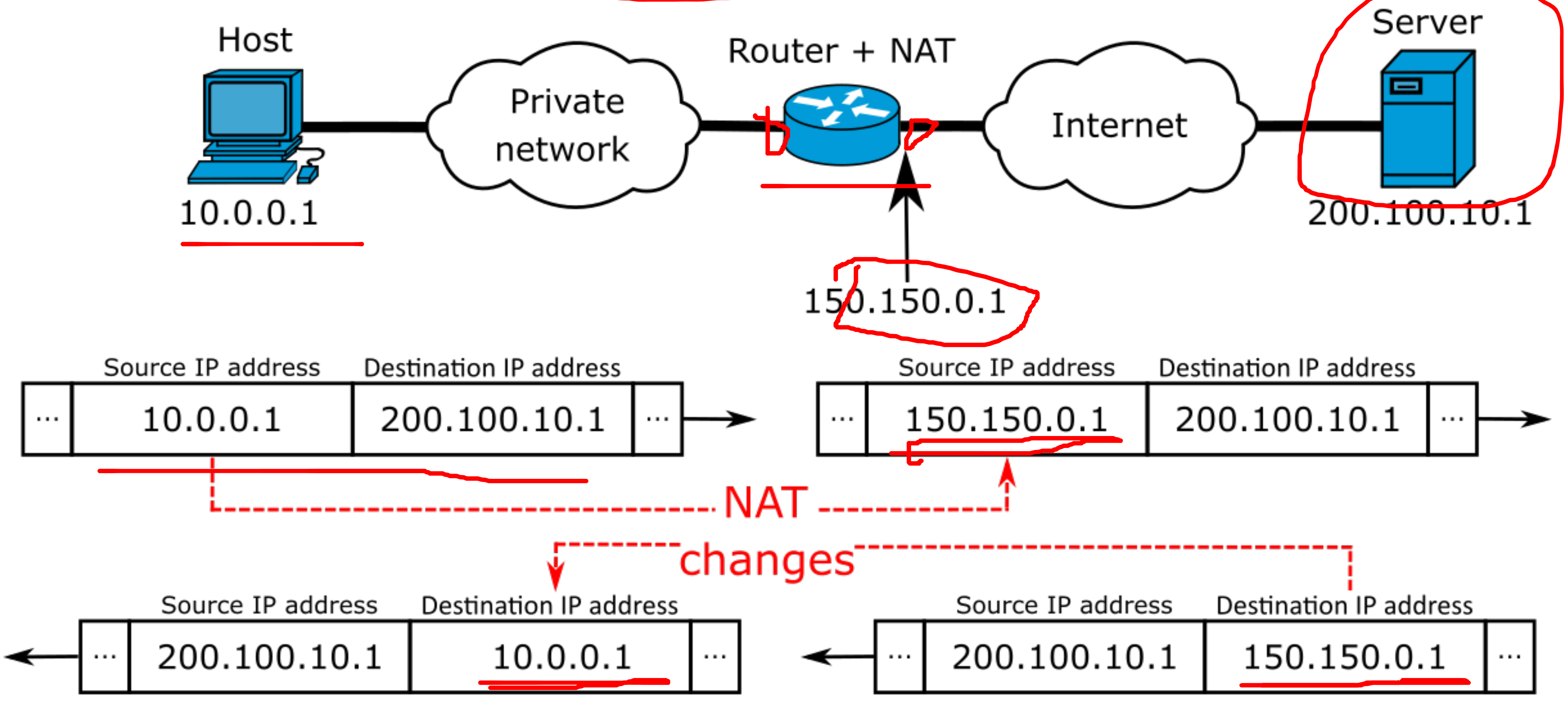
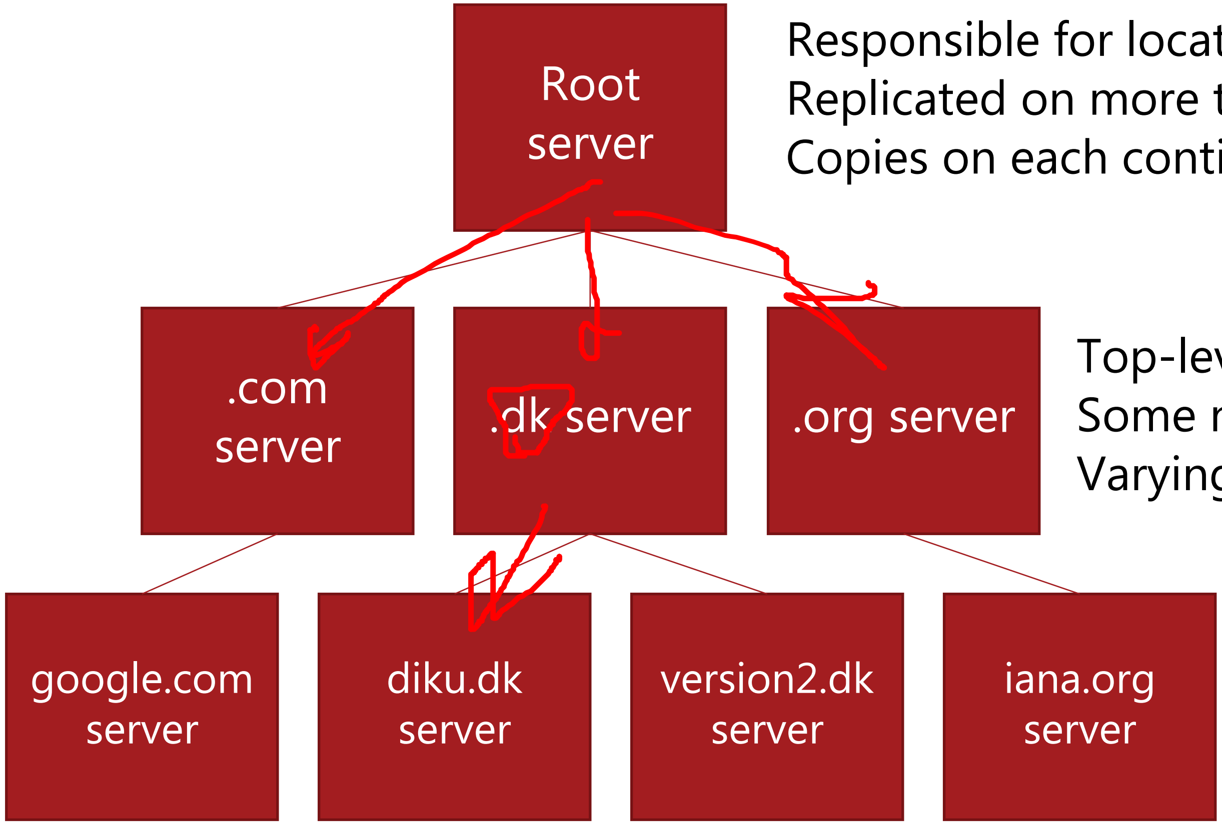


Image from: https://commons.wikimedia.org/wiki/File:NAT_Concept-en.svg

DNS – domain names

You can consider DNS a phone book for machines

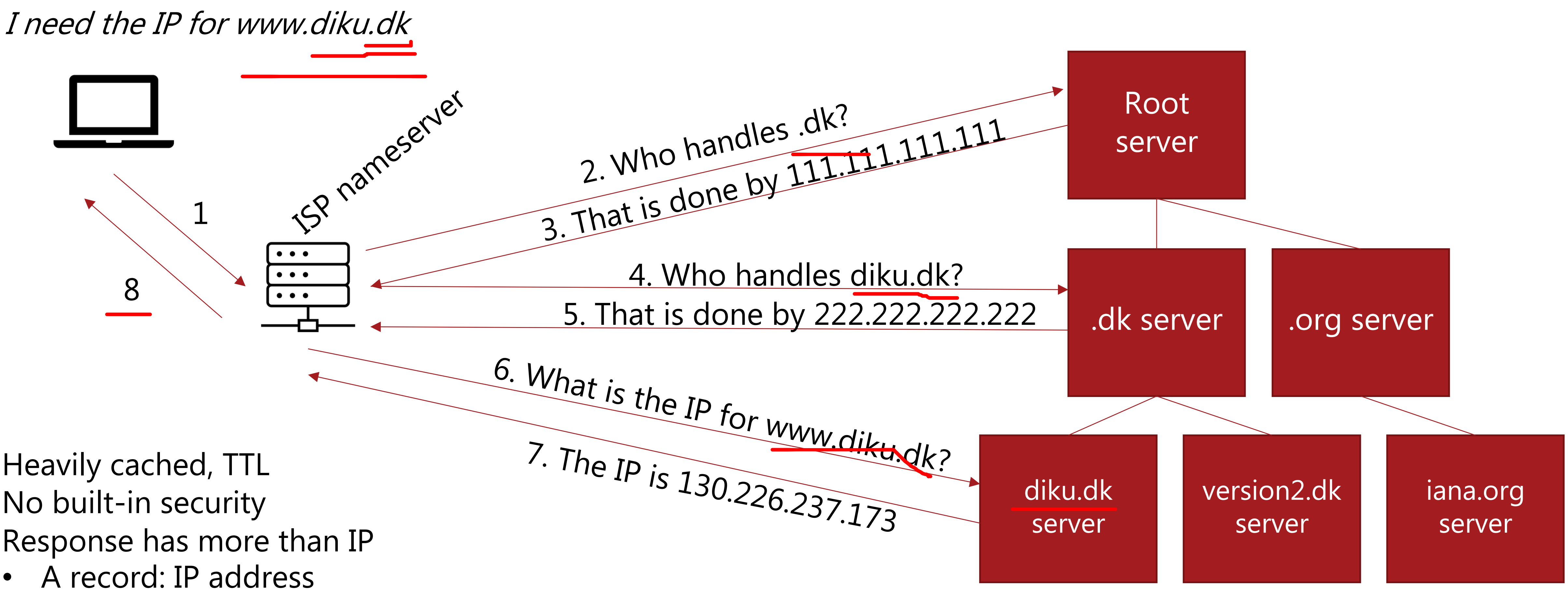


Responsible for locating top-level servers
Replicated on more that 700 nodes
Copies on each continent

Top-level servers
Some national, some private
Varying redundancy levels

Domain servers return host information, e.g www.diku.dk = 130.226.237.1[illegible]3

DNS – a lookup process



Heavily cached, TTL
No built-in security
Response has more than IP

- A record: IP address
- AAA record: IPv6 address
- MX record: email server
- …

Applications on the network

HTTP / Web based

Custom protocol