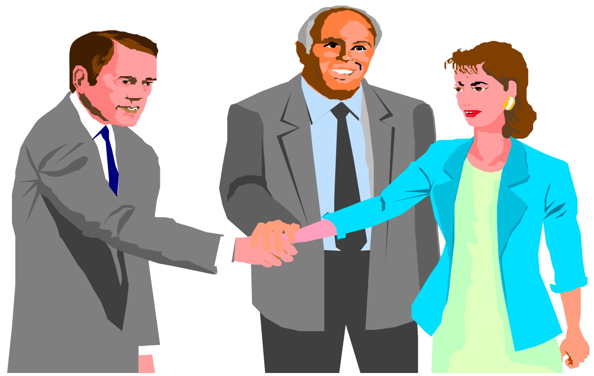
TCP/IP is a layered architecture

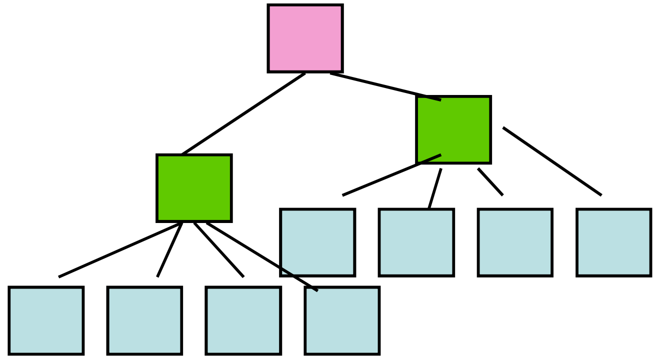
Why ?

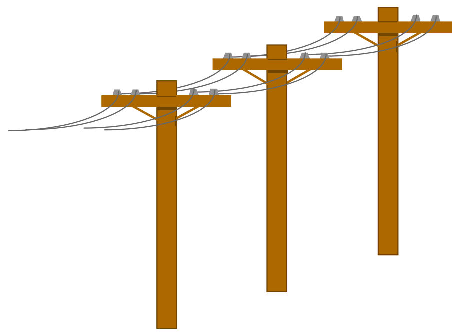
- Divide and conquer – make things manageable

What is it ?

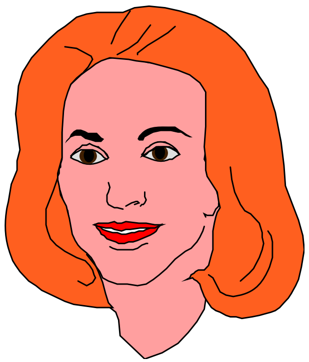
Communication	Application
	Transport
Interconnection	Network
	MAC
Distance	Physical





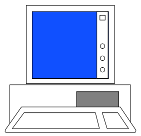


Application Layer helps people and machines communicate



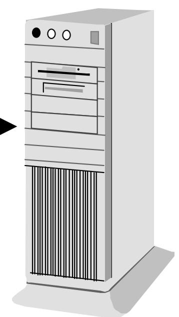
user clicks:
http://www.zurich.ibm.com/RZ.html

- Uses well defined "protocols" (set of rules and messages)
  ex: HTTP
- In the simplest case, involves 2 computers
- If you write an application that uses the network, you define your own "Application Layer"



IP addr = 193.5.61.131
GET www.zurich.ibm.com/RZ.html

Web server



data (HTML page)

Transport Layer helps Application layer

Transport Layer provides programming interface to the application layer

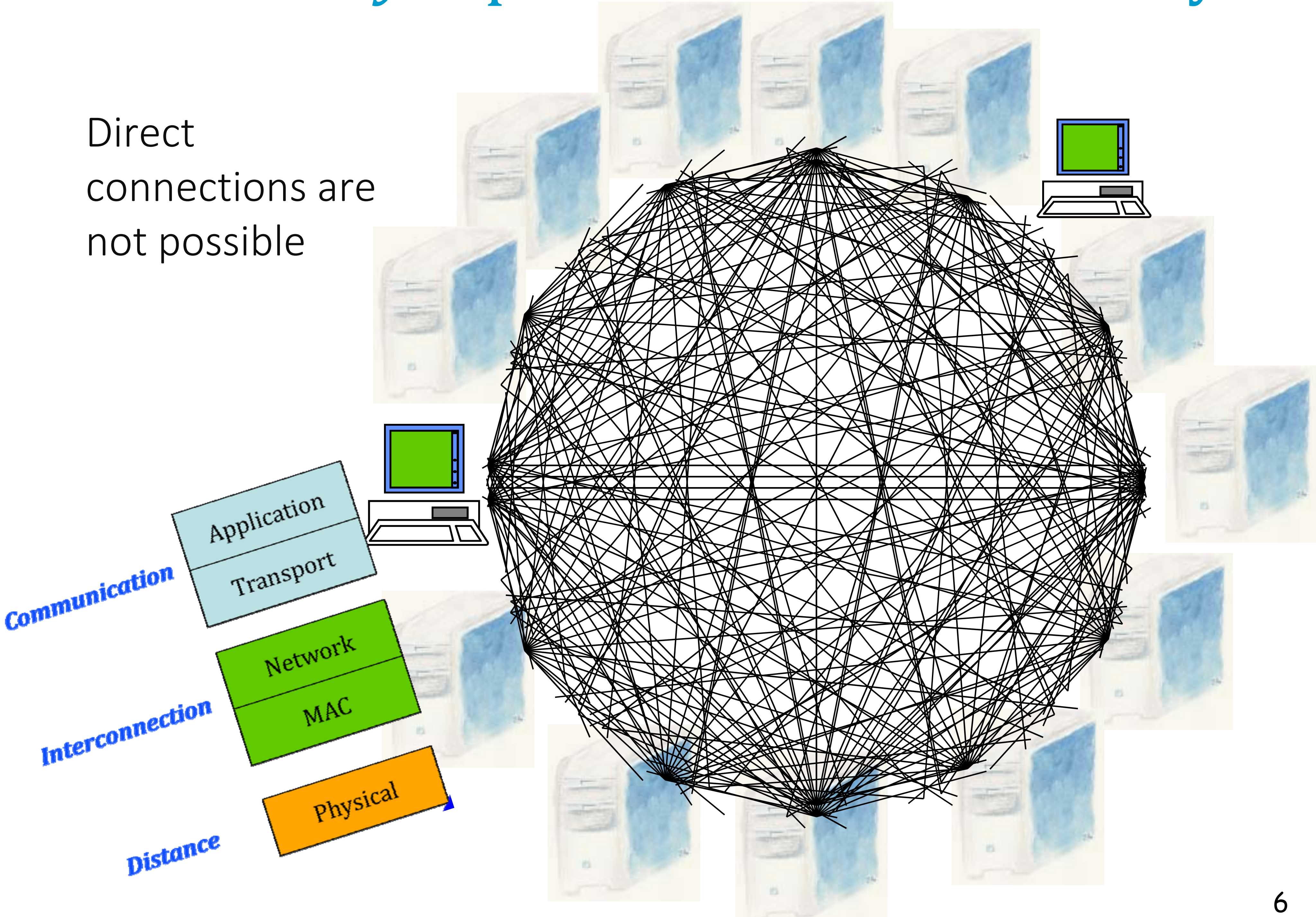
- Relieve programmer from repetitive tasks

In TCP/IP there are two main transport protocols

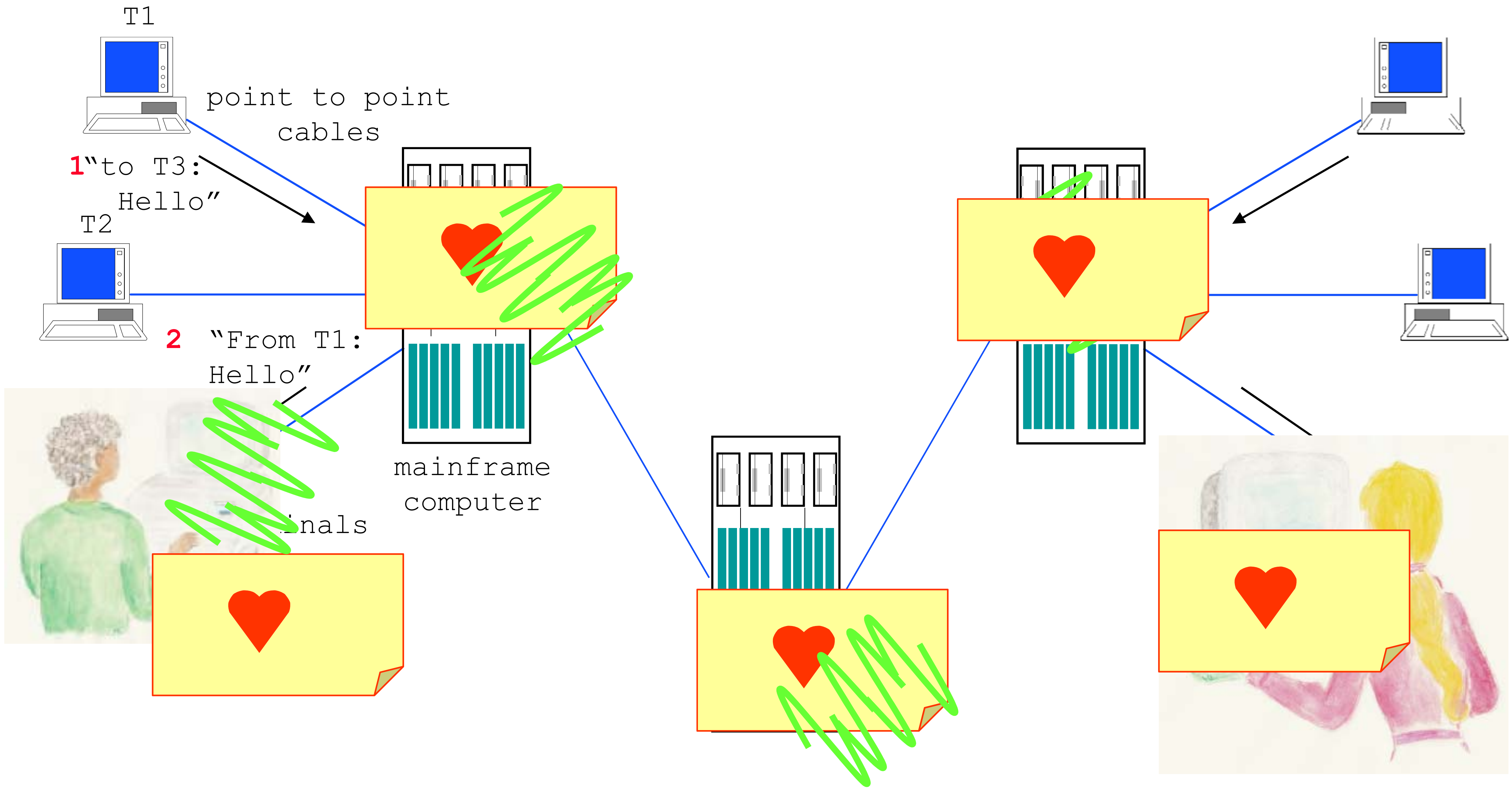
- UDP (User Datagram Protocol)
    - offers a datagram service to the application (unit of information is a message)
    - Unreliable (message may be lost)
    - No sequence guarantee
- TCP (Transmission Control Protocol)
    - Reliable: if some data is lost somewhere, TCP retransmits it
    - Stream service: the data is delivered at destination in the order it was sent by source (sequence guarantee)
    - (but unit of information is a byte; grouping of data into blocks may be different at destination than at source)

Network Layer provides full connectivity

Direct connections are not possible



The Very First Computer Networks (Bitnet, SNA) used Store and Forward

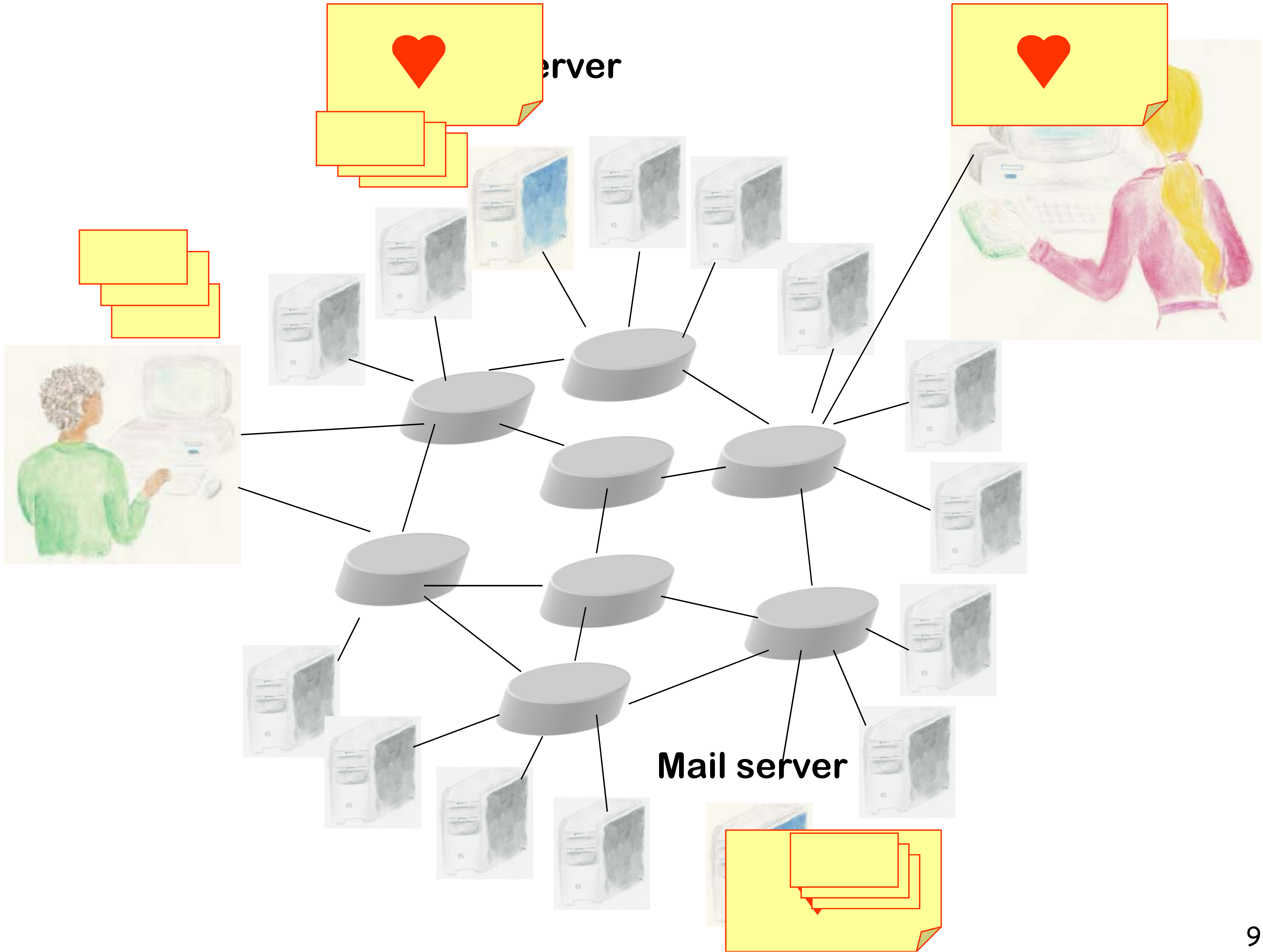


The Internet Uses Packet Switching

Data is broken into chunks called IP packets of size ≤ 1500 bytes

One packet $\approx$ postcard, contains source and destination addresses

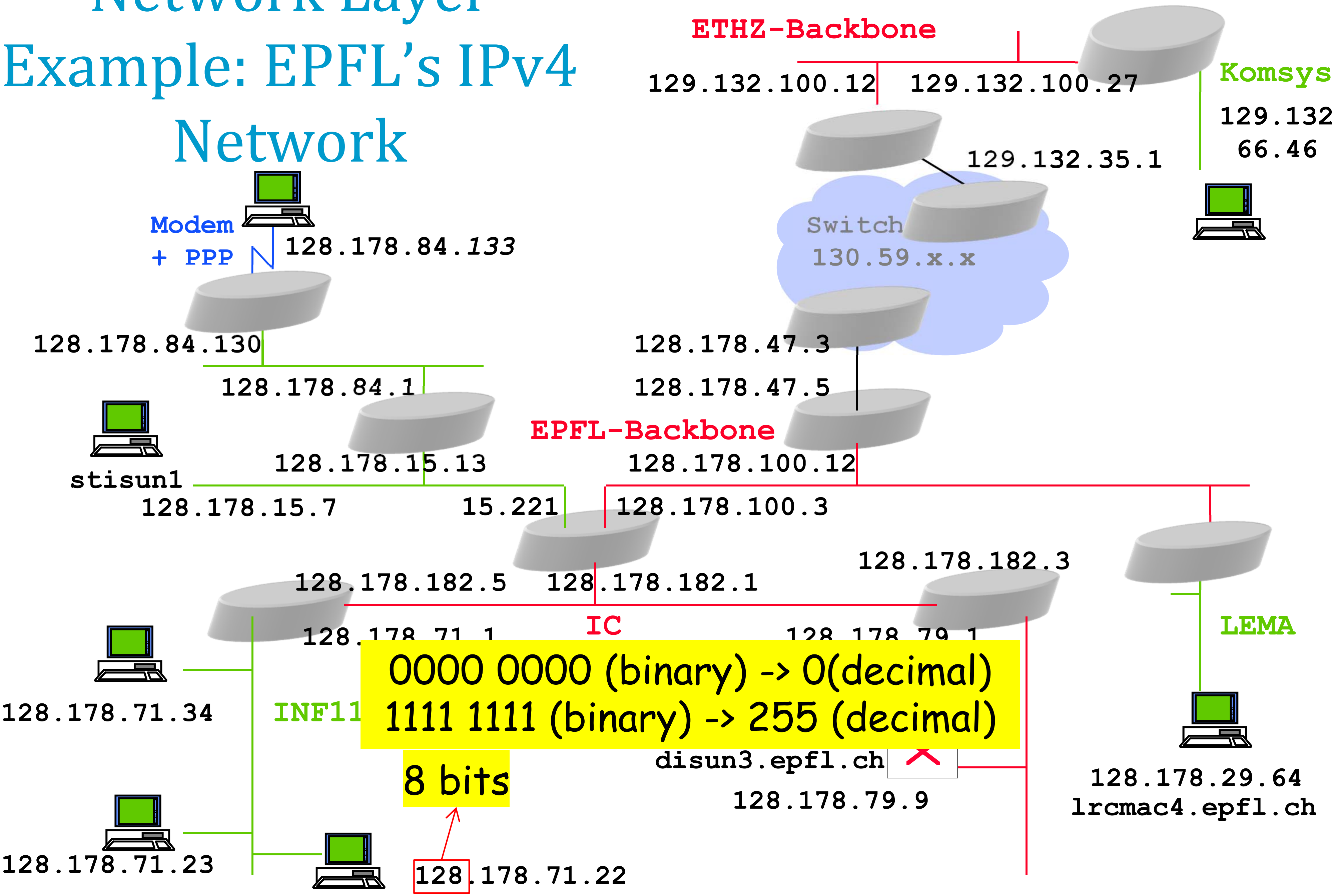
Louis Pouzin 1973, first datagram network, Cyclades, France
Vint Cerf and Bob Kahn, TCP/IP,May 74


erver
Mail server

Why packet switching?

A. It reduces buffer required in routers
B. It reduces the bit error rates
C. It increases capacity
D. I don't know

Network Layer Example: EPFL's IPv4 Network



0000 0000 (binary) -> 0(decimal)
1111 1111 (binary) -> 255 (decimal)

8 bits

There are two network layers: IPv4 and IPv6

The old numbering plan is IPv4 – 32 bits

a private address: 192.168.1.23, 172.16.3.4, 10.201.121.98,

The new numbering plan is IPv6 – 128 bits

uses hexadecimal notation, blocks of 4 hex digits

IPv4 and IPv6 network layers are distinct and incompatible

→ see later

Adresses and Names

Names are human readable synonyms for IPv4 or IPv6 addresses

Examples:

- ssc.epfl.ch
- smtp.sunrise.ch

ssc.epfl.ch www.nzherald.co.nz www.newzealand.com

goo.gl

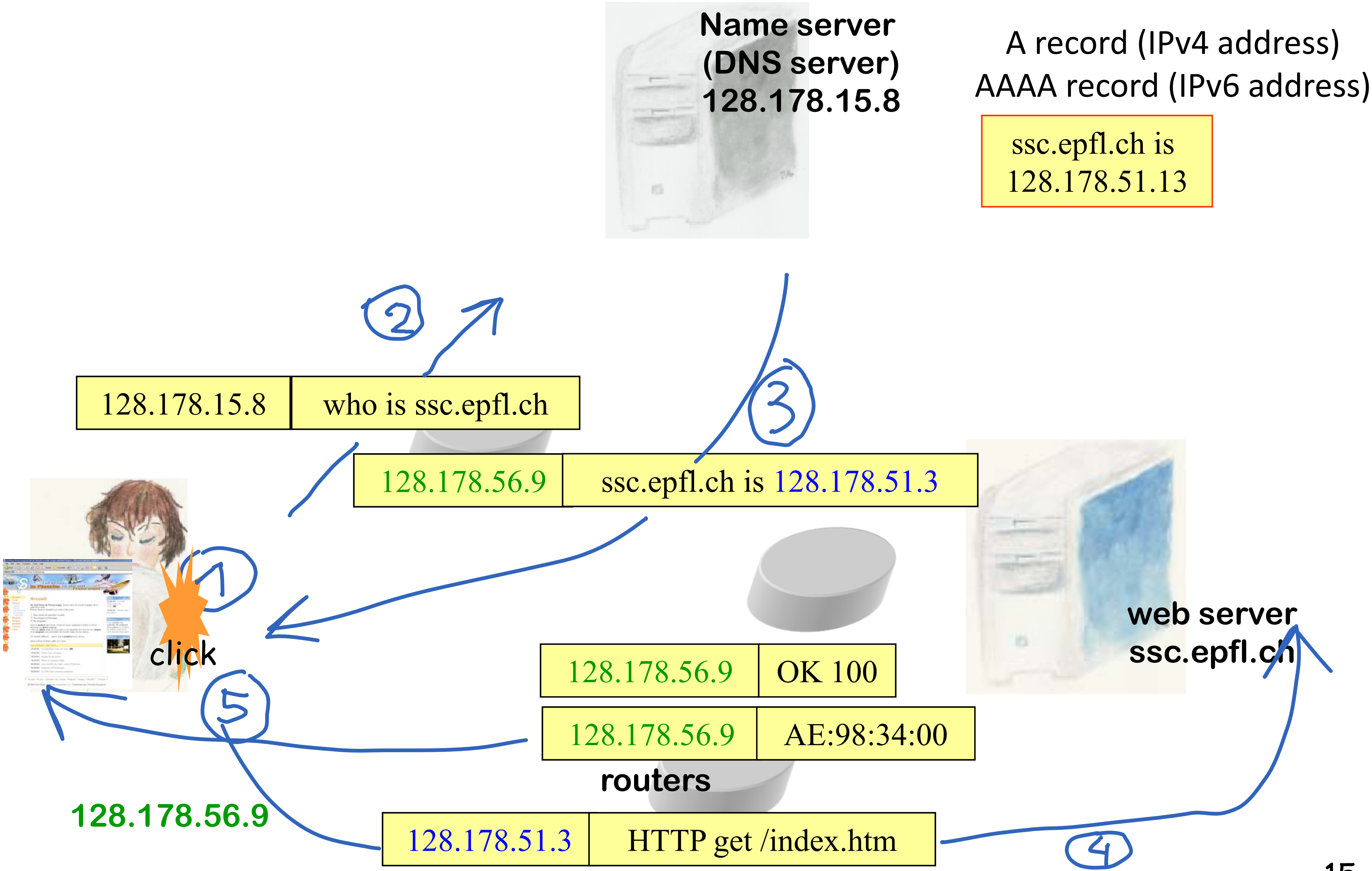
2 letters = country code

.com = commerce

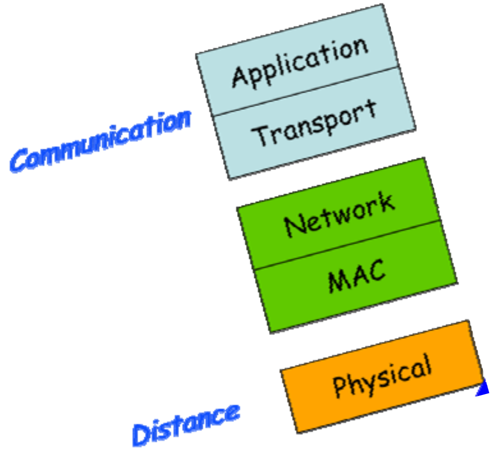
apple.sucks

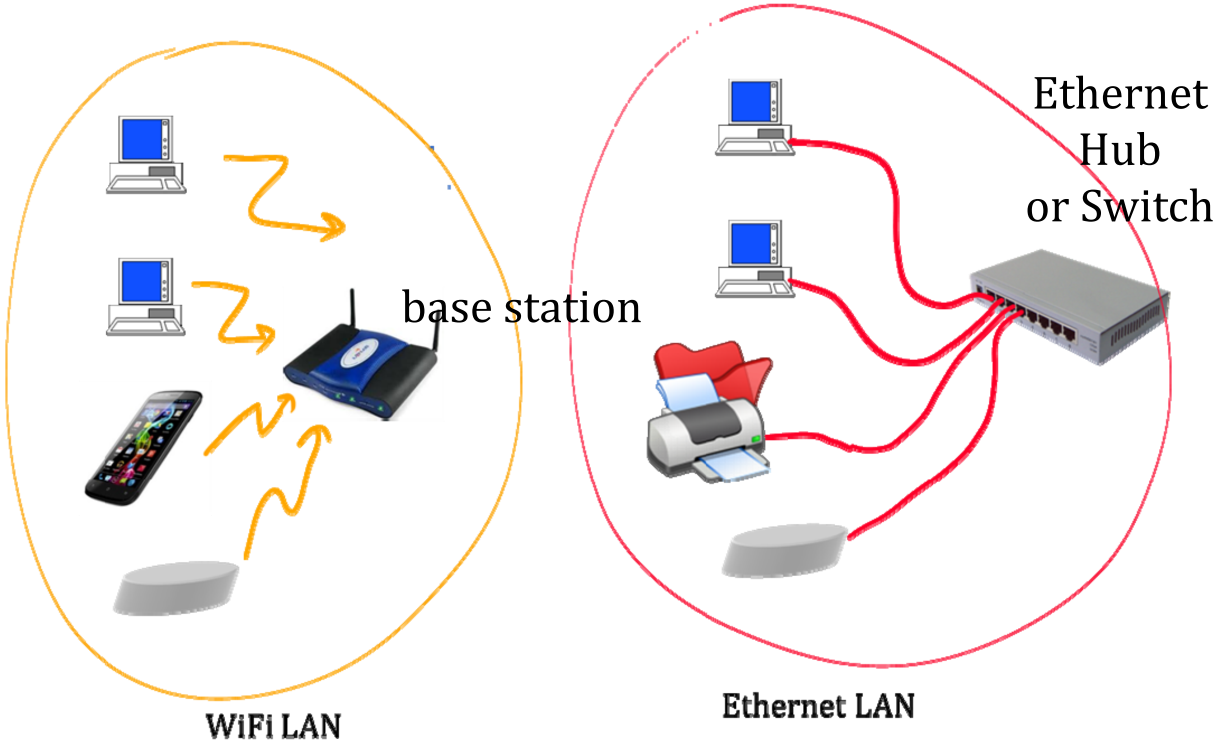
.sucks = a private domain owned by a bogus company

Names are mapped to addresses by DNS servers – not present in IP headers



Link Layer = MAC layer interconnects a small number of devices without any configuration





Using either Wireless or Cabled (Ethernet) or combination

Uses a method to avoid collisions (see later) + uses *MAC addresses*

MAC = Medium Access Control

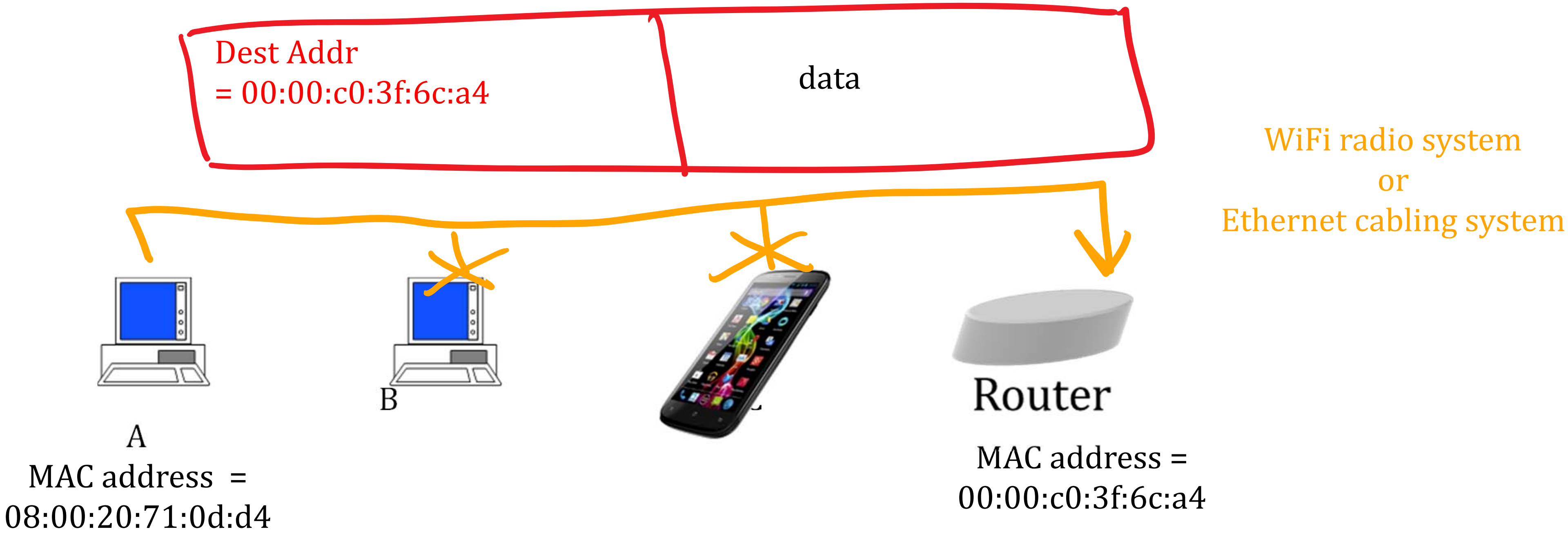
MAC Addresses are Hardware Addresses

MAC address: 48 bits = set by manufacturer, unique, in principle

sender puts destination MAC address in a frame

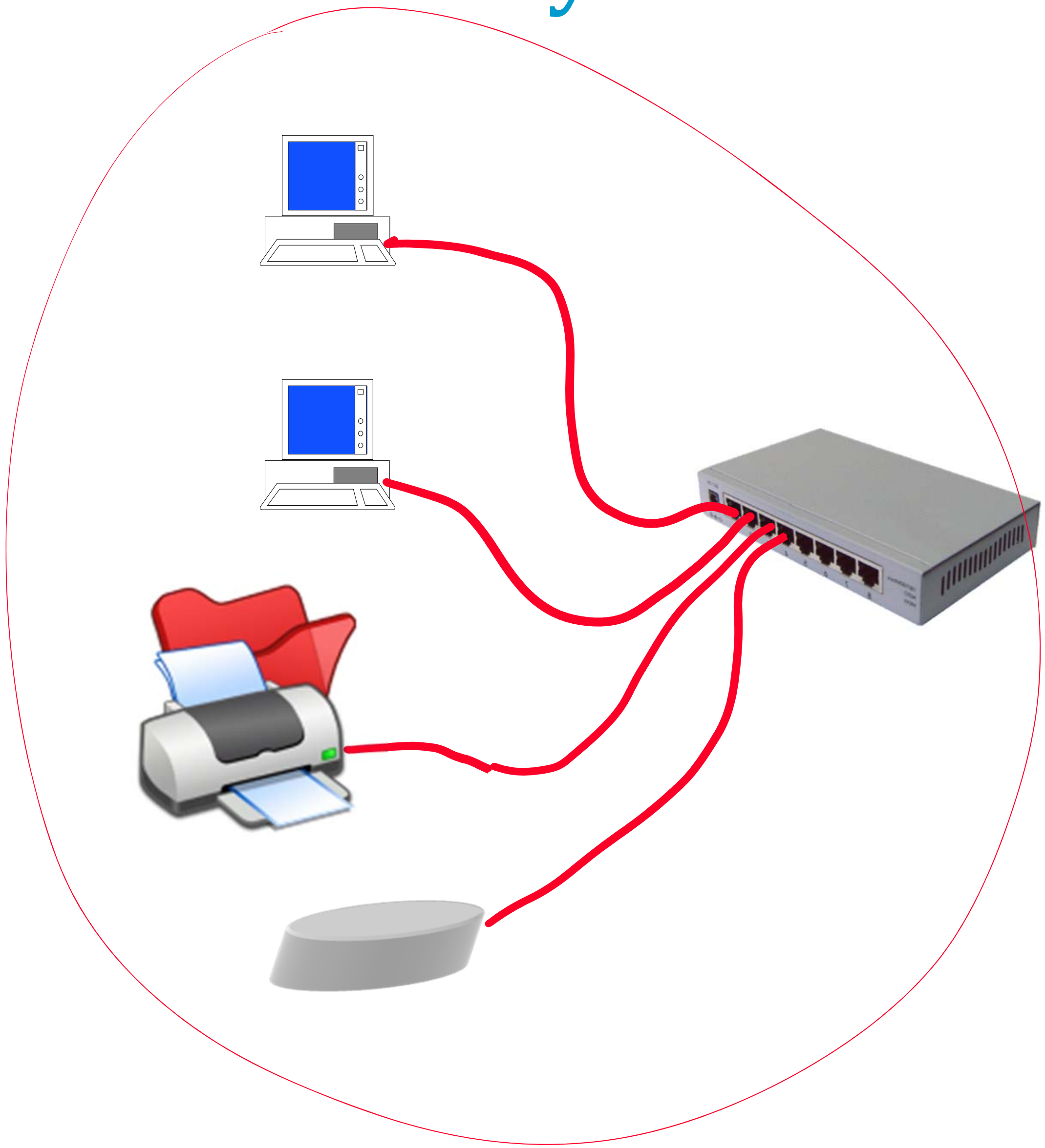
all stations within the local area read all frames; keep only if destination address matches (true for WiFi as well as Ethernet)

Destination MAC Address is sent in the clear, no encryption (but data can be encrypted)



Local Area Network = A set of devices that are connected at the MAC layer

WiFi LAN

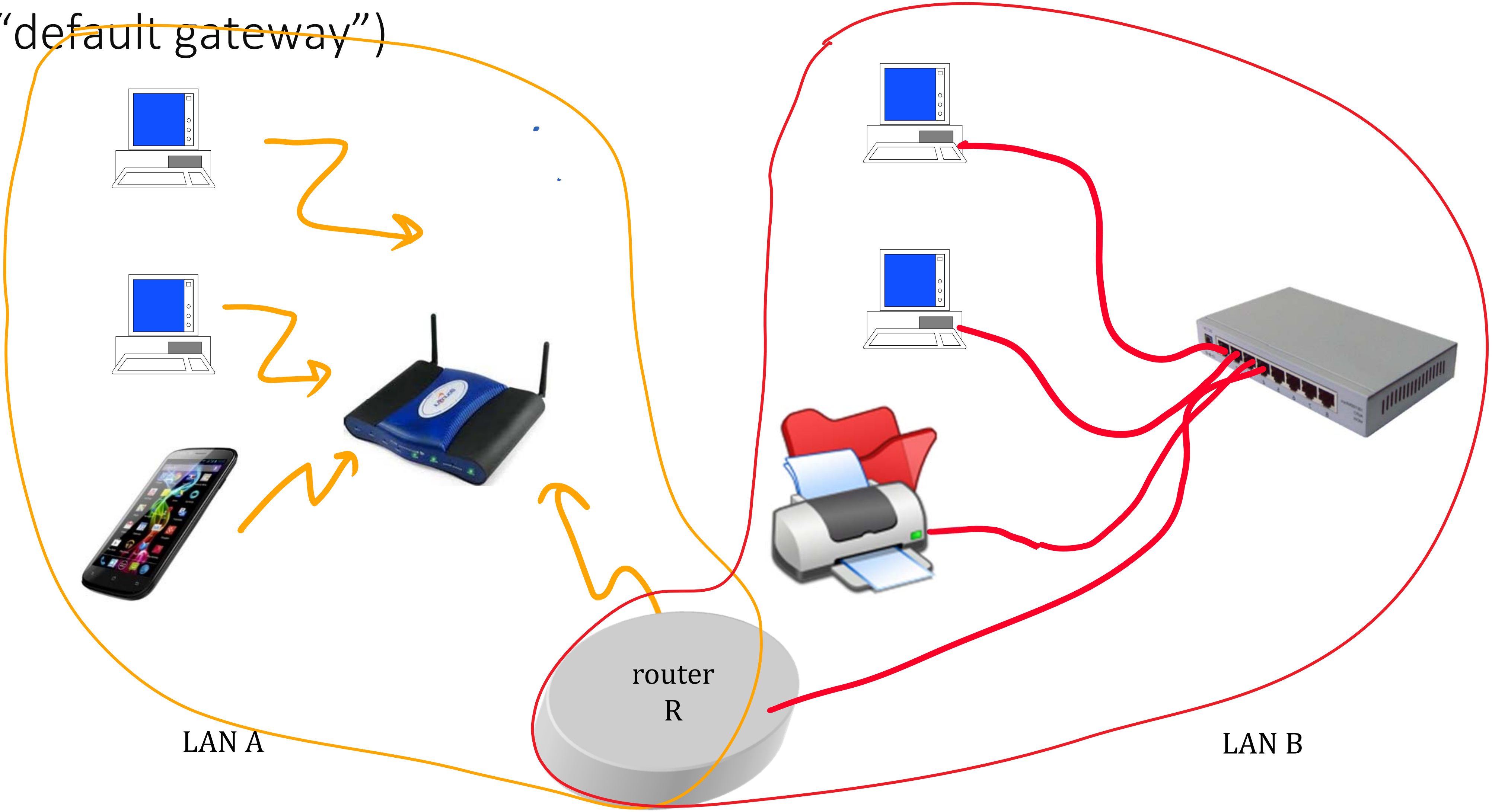


Ethernet LAN

How MAC and IP interact

LANs can be interconnected by *routers*

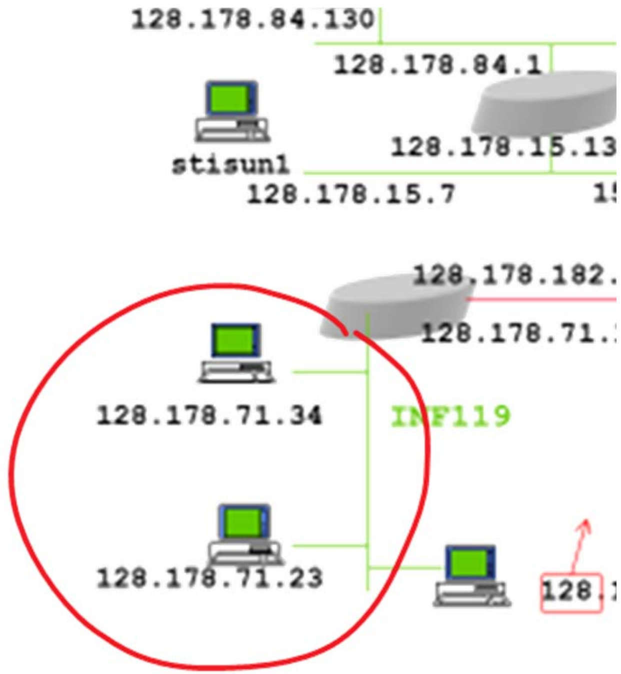
Every machine must know the IP address of the next router (called "default gateway")



Network Masks

All machines that are in the same LAN are said to be in the same subnetwork

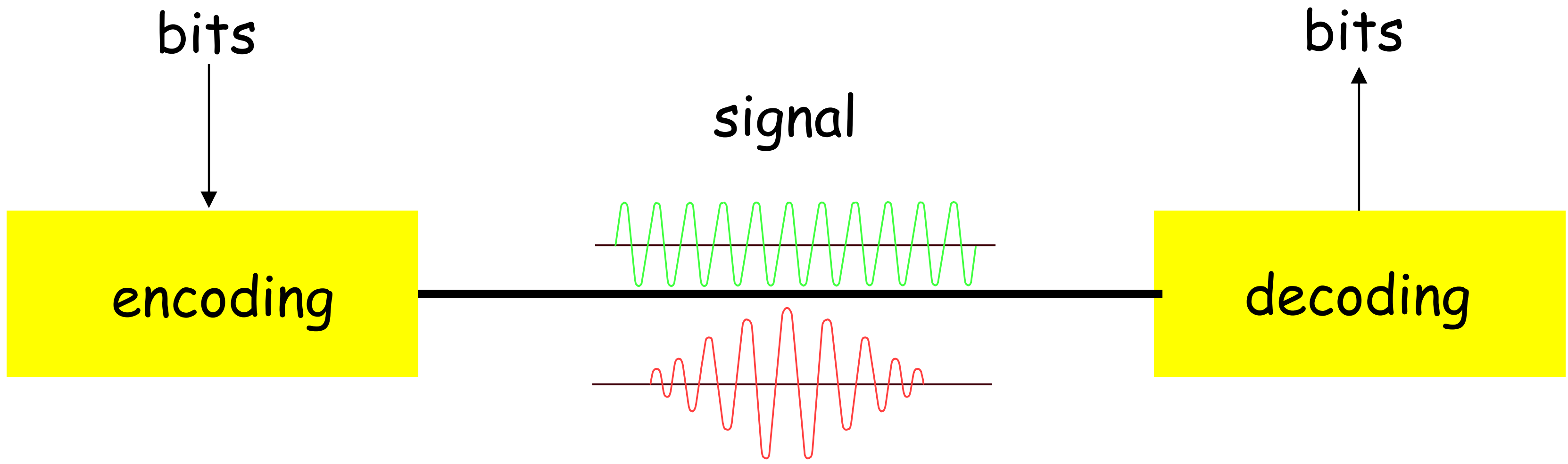
The IP addresses of all machines in one subnetwork must have the same prefix (called "network part")
ex: 128.178.71



The size (in bits) of the network part is not always the same; it must be specified in the machine together with the address; at EPFL-IPv4, size of network part is always 24 bits:
Example: 128.178.71.34 /24

For historical reasons the size of the network part is often specified using a network mask
Mask = sequence of bits where 1s indicate the position of the prefix. At EPFL-IPv4, network mask is always
1111 1111 1111 1111 1111 1111 0000 0000
which is written in decimal notation as 255.255.255.0;
Example: address =128.178.71.34, mask =255.255.255.0

Physical Layer Transforms Bits and Bytes into Electromagnetic Waves



Encoding of bits as physical signals, usually electromagnetic

Is technology specific: there are several Ethernet §physical layers, several WLAN 802.11 physical layers

Acoustic instead of electromagnetic used under water

Bit Rates

Bit Rate of a transmission system = number of bits transmitted per time unit; is measured in **b/s**, 1 kb/s = 1000 b/s, 1 Mb/s = 10^6 b/s, 1Gb/s=10^9 b/s

The bit rate of a channel is the number of bits per second. The bandwidth is the width of the frequency range that can be used for transmission over the channel. The bandwidth limits the maximal bit rate that can be obtained using a given channel. The purpose of information theory is to find the best possible bit rate on a given channel.

For example: Shannon-Hartley law: $C_{max} = B \log_2 (1 + S/N)$*, with B = bandwidth (Hz), S/N = signal to noise ratio (not expressed in dB); for example: telephone circuit: B = 3 kHz, S/N = 30 dB,* C_{max} *= 30 kb/s*

In computer science, many people use "bandwidth" instead of "bit rate.

Practical Bit Rates:

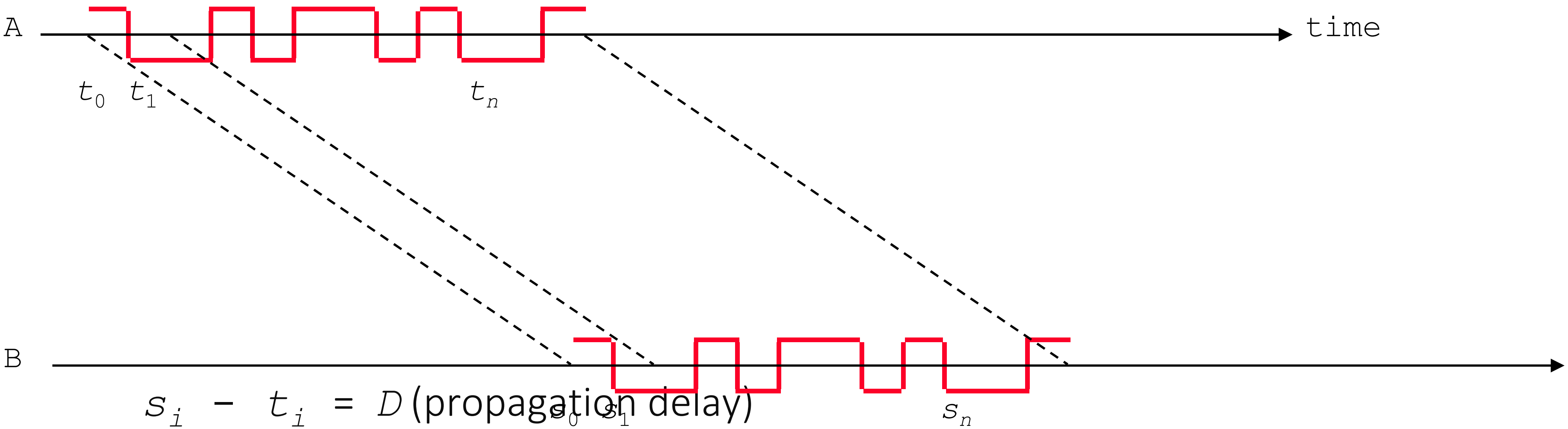
- modem: 2.4 kb/s to 56kb/s
- ADSL line: 124 kb/s to 10 Mb/s
- Ethernet: 10 Mb/s to 100Gb/s
- Wireless LAN: 1 to 1.3 Gb/s
- cellular: 8 kb/s to 1 Gb/s
- Optical carriers: 155 Mb/s to 1 Tb/s

Transmission Time = time to send *x* bits at a given bit rate
Q. time to send 1 MB at 10 kb/s = ?

A. 800 s
B. 100 s
C. 12.5 s
D. 1 s
E. 12.5 ms
F. 1 ms
G. I don’t know

Propagation

Propagation between A and B = time for the head of signal to travel from A to B



$s_i - t_i = D$ (propagation delay)

$D = d/c$, where d = distance, c =signal celerity (speed of light)

copper: c= 2.3e+08 m/s; glass: c= 2e+08 m/s;

Rule of thumb: 5 μs/km; example:

time through circuits also adds to propagation delays

Lausanne - Copenhagen over acoustic channel. D = ???

What is the propagation time around the Earth (using copper cables) ?

A. 200 s
B. 100 s
C. 200 ms
D. 100 ms
E. 2 ms
F. 1 ms
G. I don’t know

Time to send 1 kB (one packet)

distance	20 km	20000 km	2 km	20 m
bit rate	10 kb/s	1 Mb/s	10 Mb/s	1 Gb/s
propagation	0.1ms	100 ms	0.01 ms	0.1μs
transmission	800 ms	8 ms	0.8 ms	8 μs
reception time	800.1 ms	108 ms	0.81 ms	8.1 μs

Throughput

Throughput = number of useful data bits / time unit

It is *not* the same as the bit rate. Why ?

- protocol overhead: protocols like UDP use some bytes to transmit protocol information. This reduces the throughput. If you send one byte messages with UDP, then for every byte you create an Ethernet packet of size 1 + 8 + 20 + 26 = 53 bytes, thus the maximum throughput you could ever get at the UDP service interface if you use a 64 kb/s channel would be 1.2 kb/s.
- protocol waiting times: some protocols may force you to wait for some event, as we show on the next page.

Same units as a bit rate

b/s, kb/s, Mb/s

Pigeon outruns South African ADSL

11 September 2009 | 14:28

A South African information technology company has proved it's faster for them to send data by carrier pigeon than using the country's leading internet provider.

Winston the pigeon has easily outpaced South Africa's leading broadband netw ork it moving data (AAP)

A South African information technology company has proved it's faster for them to transmit data by carrier pigeon than to send it using Telkom, the country's leading internet service provider.

Internet speed and connectivity in Africa's largest economy are poor because of a bandwidth shortage. It is also expensive.

An 11-month-old pigeon, Winston, took one hour and eight minutes to fly the 80 km (50 miles) from Unlimited IT's offices near Pietermaritzburg to the coastal city of Durban with a data card strapped to its leg.

Including downloading, the transfer took two hours, six minutes and 57 seconds -- the time it took for only four percent of the data to be transferred using a Telkom line.

Example. The Stop and Go Protocol

Packets may be lost during transmission:

bit errors due to channel imperfections, various noises.

Computer A sends packets to B; B returns an acknowledgement packet immediately to confirm that B has received the packet;

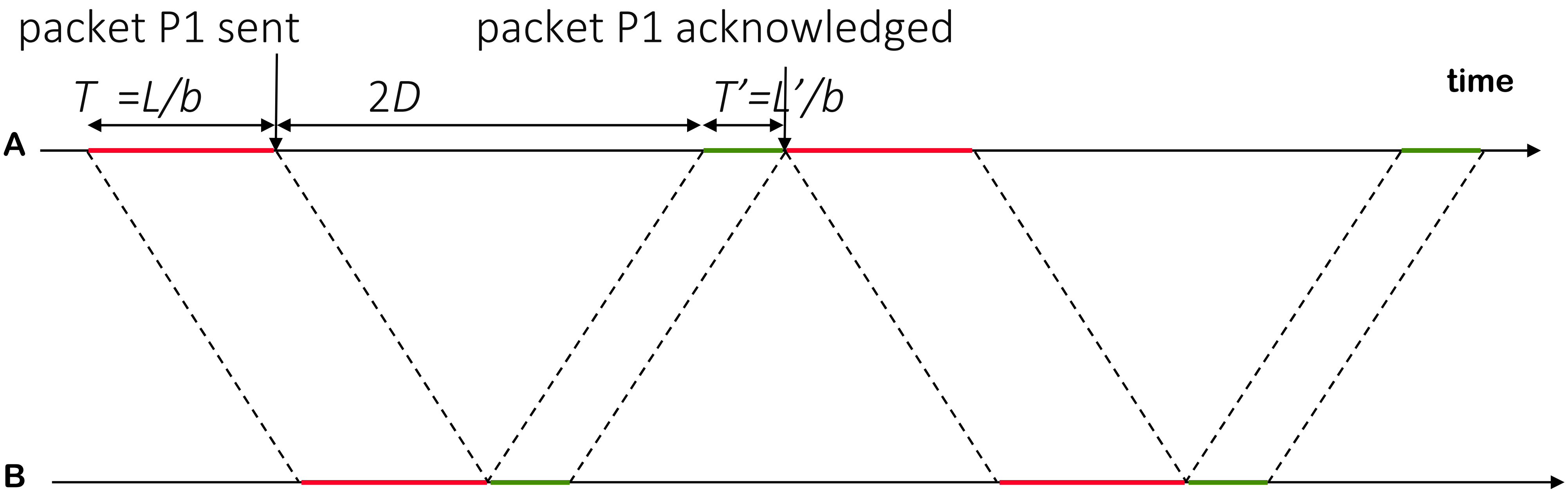
A waits for acknowledgement before sending a new packet; if no acknowledgement comes after a delay *T1*, then *A* retransmits

Example: What is the maximum throughput assuming that there are no losses ?

notation:

- packet length = L, constant (in bits);
- acknowledgement length = L', constant
- channel bit rate = b;
- propagation delay = D
- processing time is negligible

Performance of The Stop and Go Protocol



$$\text{Cycle Time} = T + 2D + T'$$

$$\text{useful bits per cycle time} = L$$

overhead

$$\text{throughput} = \frac{L}{T+2D+T'} = \frac{b}{1+\frac{L'}{L}+\frac{2Db}{L}}$$

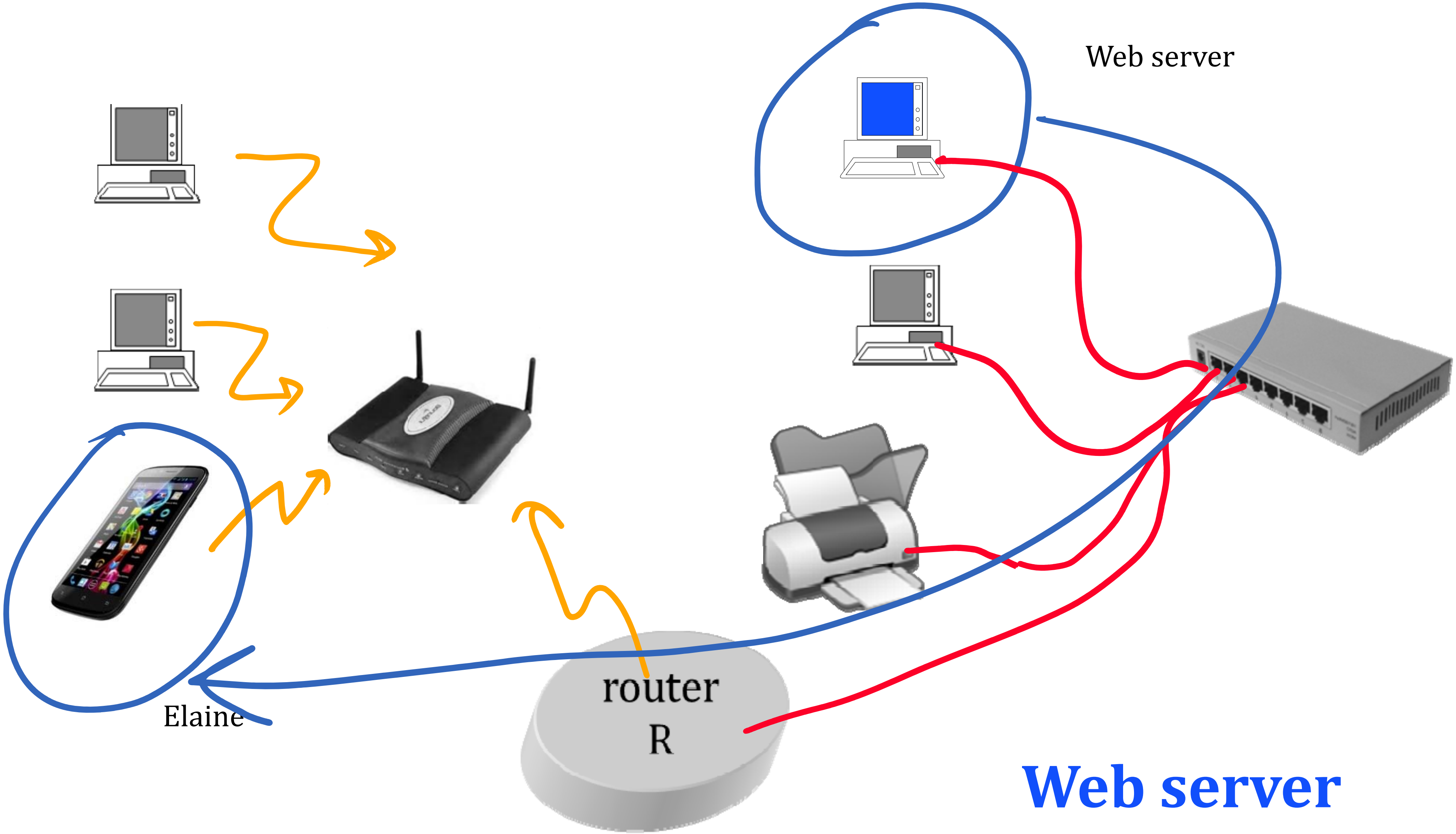
« bandwidth »-delay product

Throughput with Stop and Go

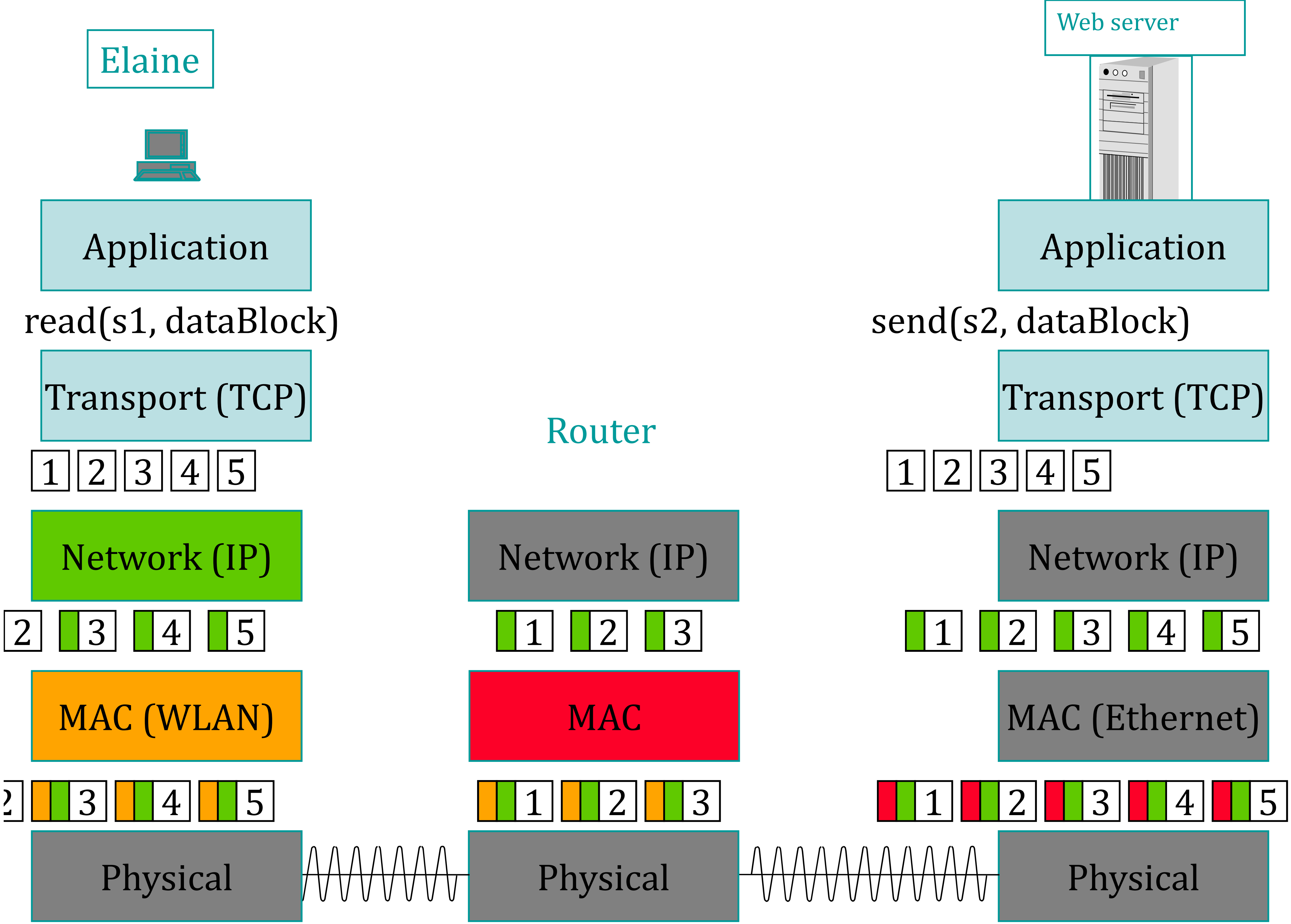
distance	20 km	20000 km	2 km	20 m
bit rate	10 kb/s	1 Mb/s	10 Mb/s	1 Gb/s
propagation	0.1ms	100 ms	0.01 ms	0.1µs
transmission	800 ms	8 ms	0.8 ms	8 µs
reception time	800.1 ms	108 ms	0.81 ms	8.1 µs
	GSM	*WAN*	*WiMax LAN*	*Gb LAN*
bw delay product	2 bits	200 000 bits	200 bits	200 bits
throughput = $b \times$	99.98%	3.8%	97.56%	97.56%

TCP uses a smarter scheme than Stop and Go and has a better performance

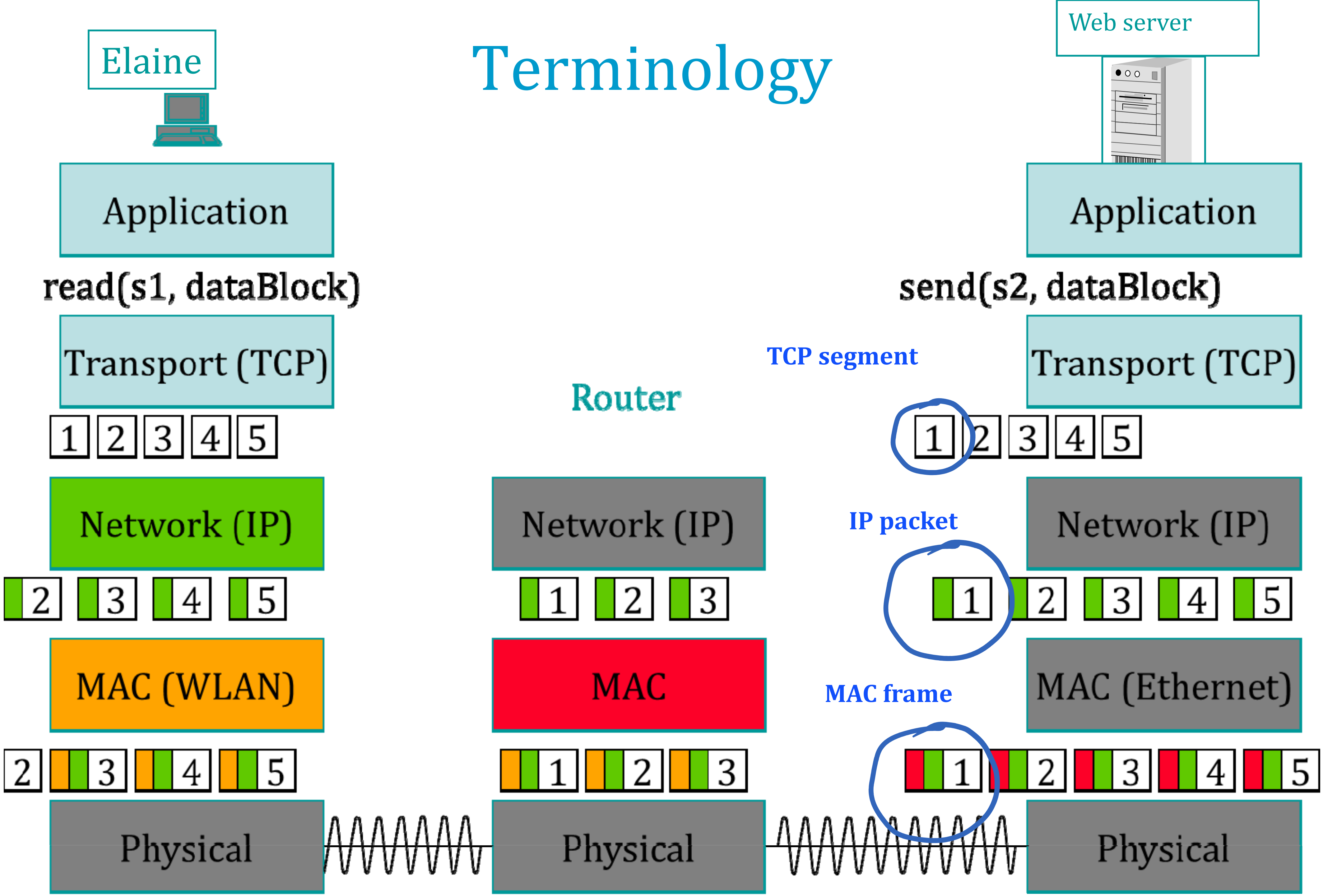
Putting Things Together



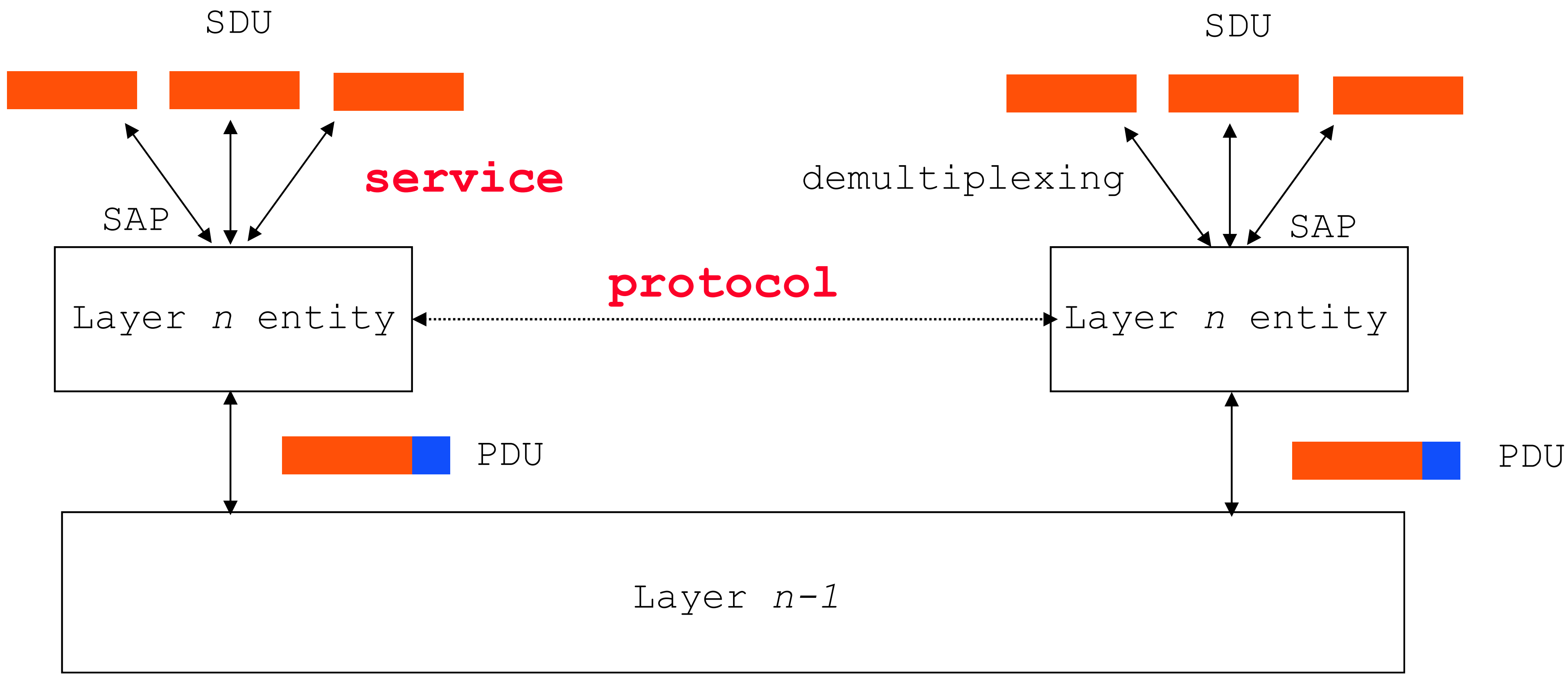
Web server sends a file to Elaine


Elaine
Web server
Application
Application
read(s1, dataBlock)
send(s2, dataBlock)
Transport (TCP)
Transport (TCP)
Router
1 2 3 4 5
1 2 3 4 5
Network (IP)
Network (IP)
Network (IP)
2 3 4 5
1 2 3
1 2 3 4 5
MAC (WLAN)
MAC
MAC (Ethernet)
3 4 5
1 2 3
1 2 3 4 5
Physical
Physical
Physical

Terminology



Protocol versus Service, PDU, SDU



layer *n* uses the **service** of layer *n-1* and offers a service to layer *n+1*.
entities at the same layer are said **peer entities**
operation rules between peer entities are called **protocol**
PDU = Protocol Data Unit, **SDU** = Service Data Unit
Layer 3 PDU = IP packet, layer 2 PDU = MAC frame

Switches, Routers and Bridges

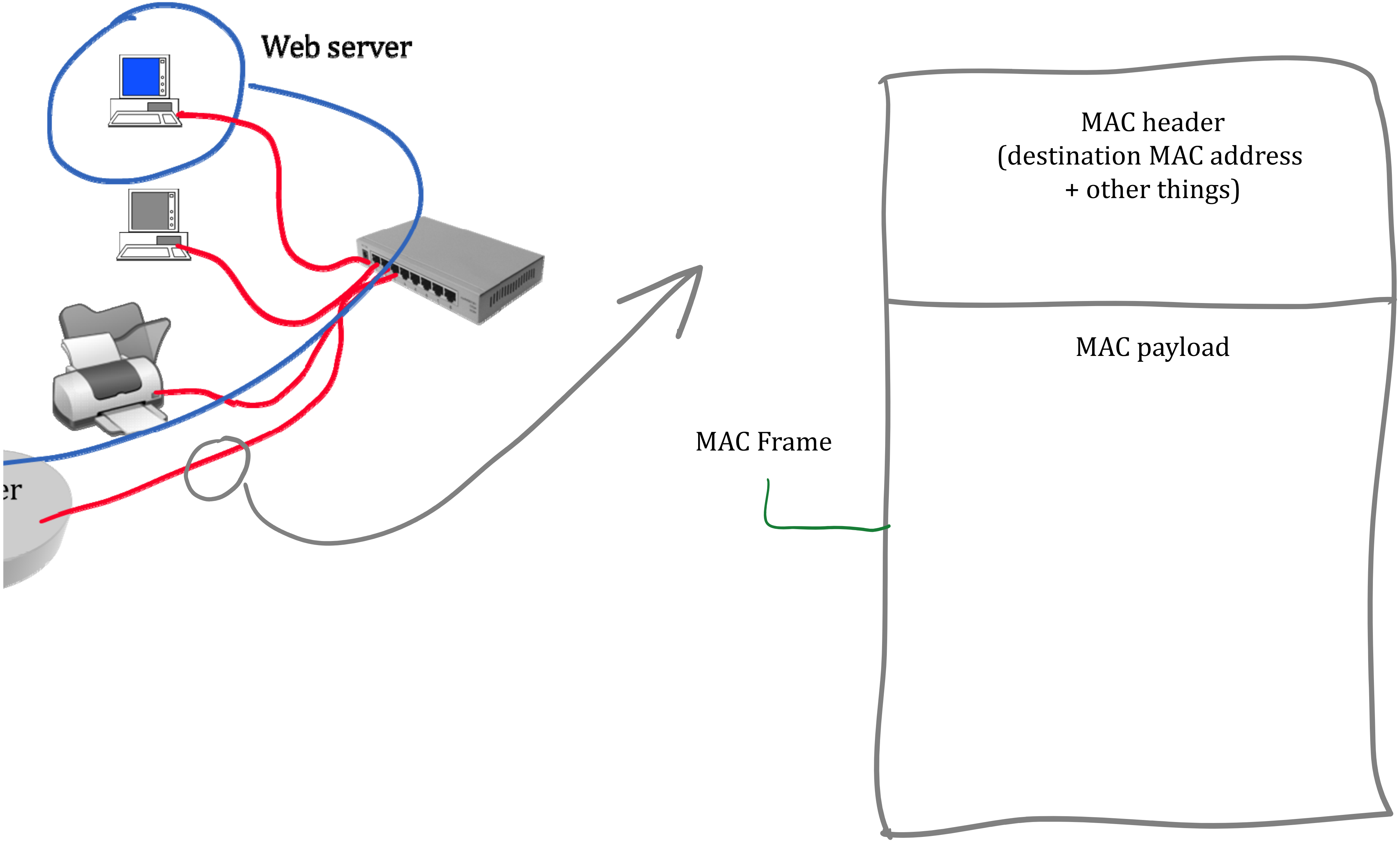
Router = a system that forwards packets based on IP addresses
can be a dedicated box or software in a PC

Bridge = a system that forwards packets based on MAC addresses
is usually a dedicated box, but can also be software in a PC

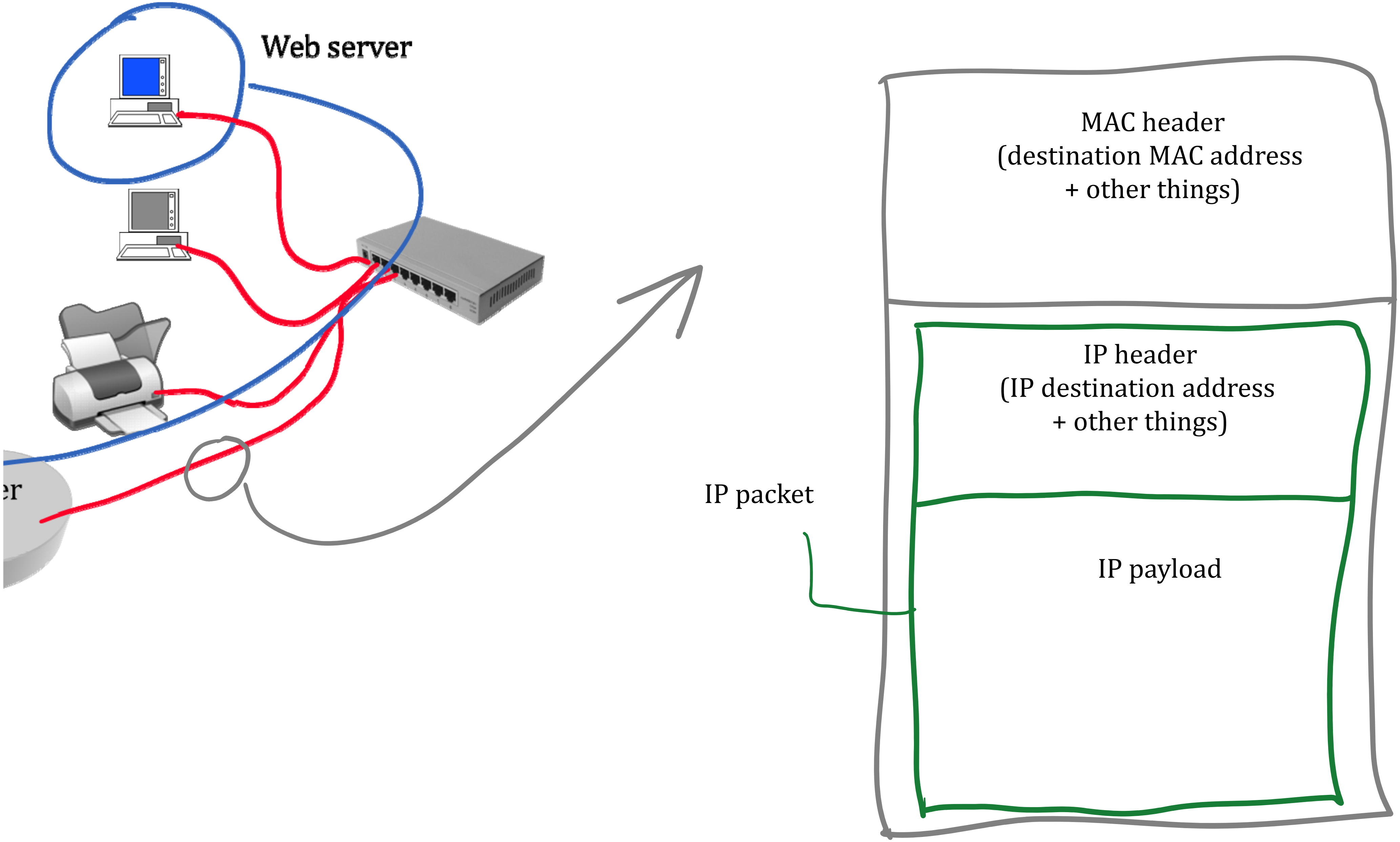
Switch = a hardware bridge

Layer-3 switch = a router, usually in the context of an entreprise network inside a room or a building (!)

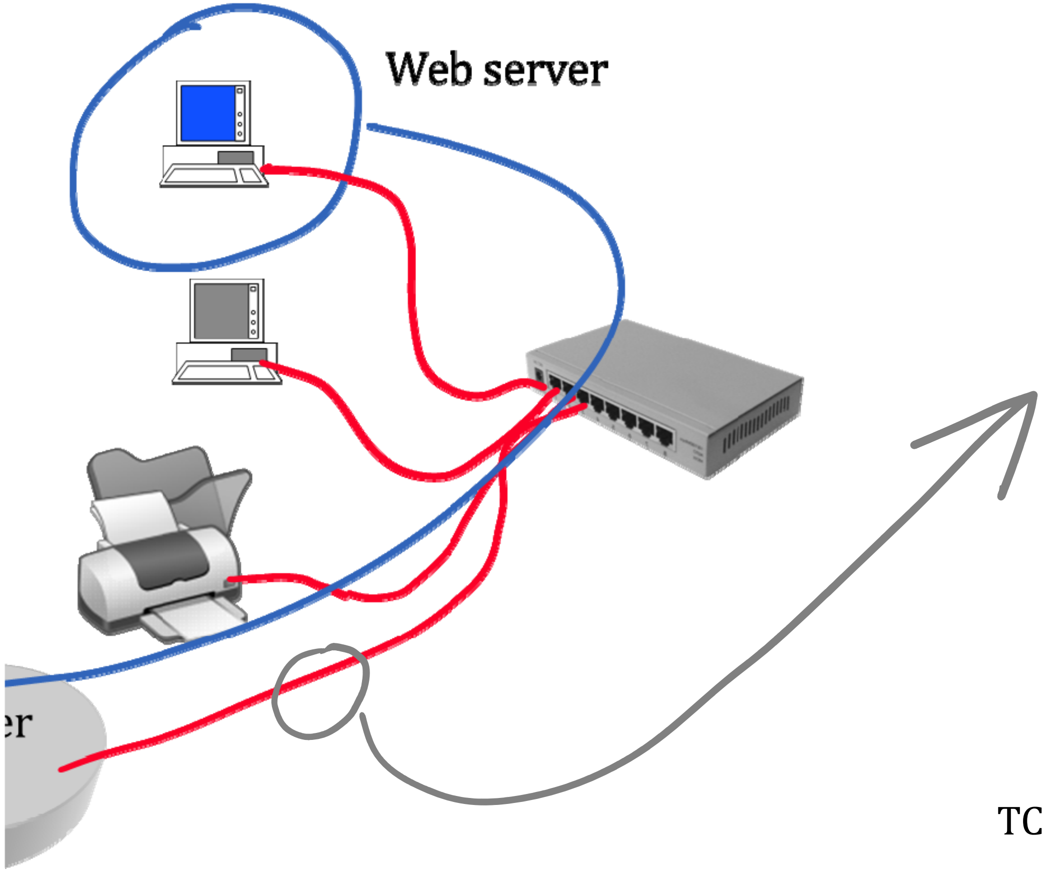
The Onion View: header and payload

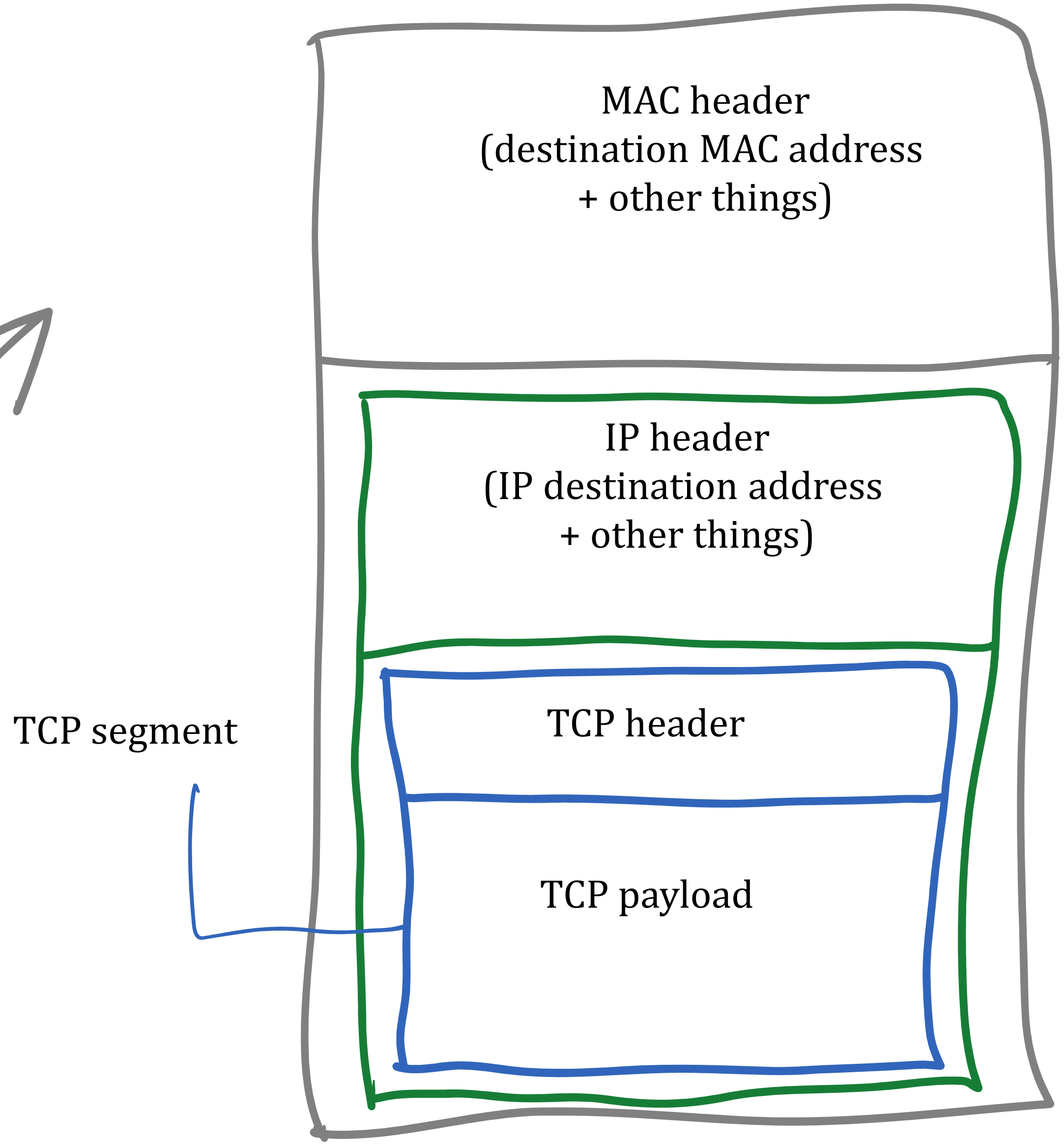


The Onion View: header and payload

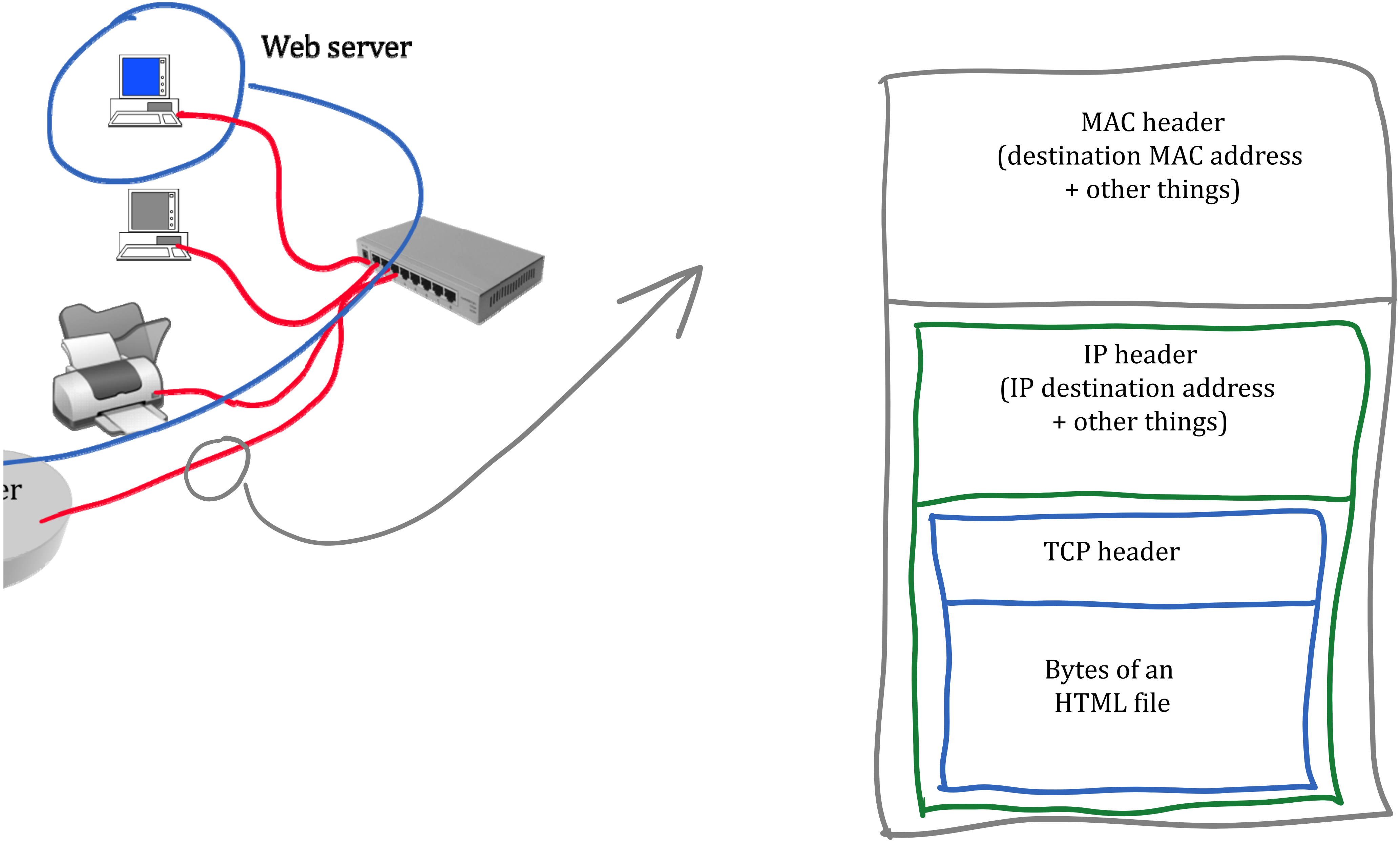


The Onion View: header and payload





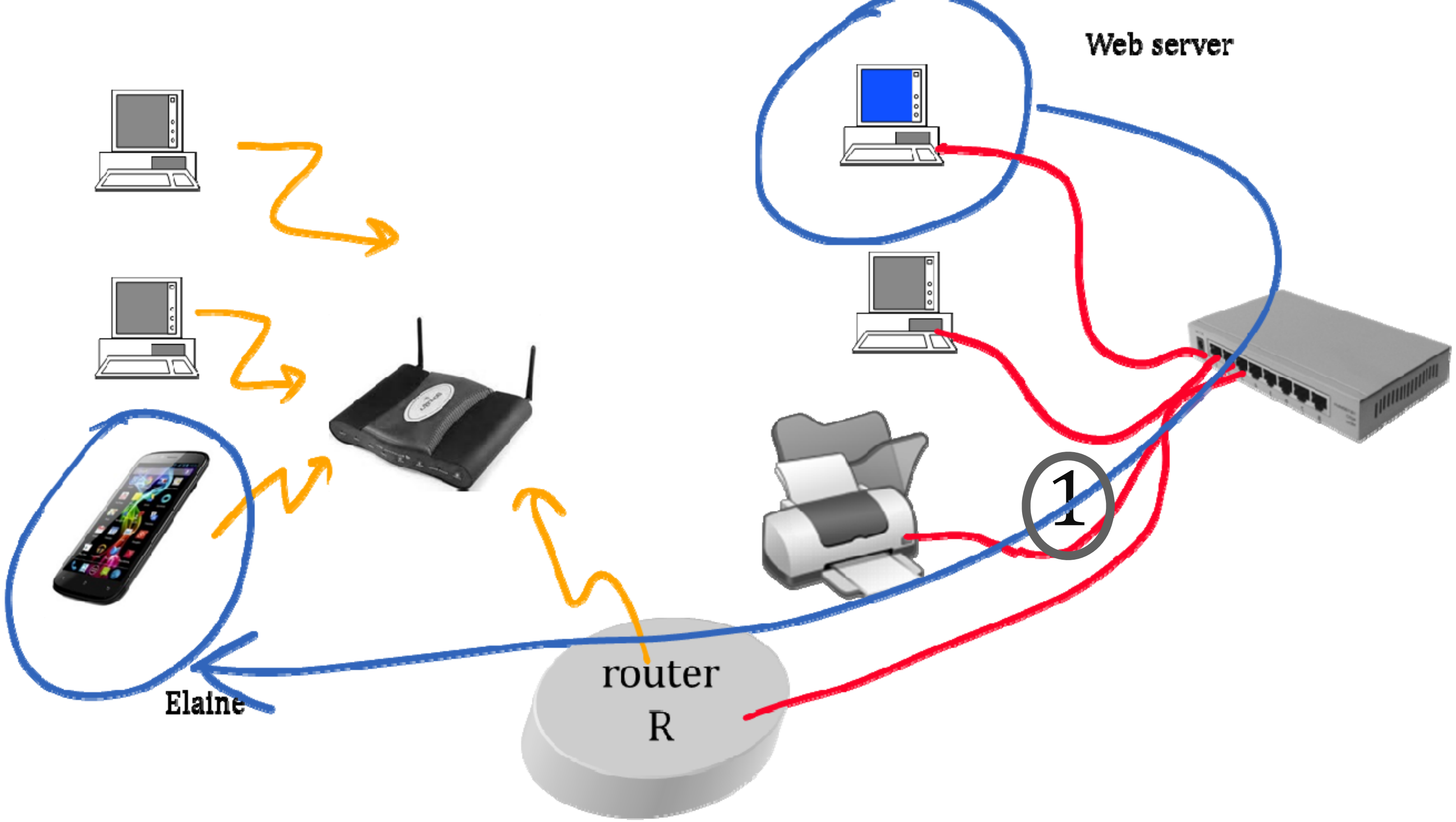
The Onion View: header and payload



A Packet captured and prettily displayed

```
ETHER:  ----- Ether Header -----
ETHER:
ETHER:  Packet 4 arrived at 19:03:32.40
ETHER:  Packet size = 60 bytes
ETHER:  Destination = 0:0:c:2:78:36, Cisco
ETHER:  Source      = 0:0:c0:b8:c2:8d, Western Digital
ETHER:  Ethertype = 0800 (IP)
ETHER:
IP:   ----- IP Header -----
IP:
IP:   Version = 4
IP:   Header length = 20 bytes
IP:   Type of service = 0x00
IP:         xxx. .... = 0 (precedence)
IP:         ...0 .... = normal delay
IP:         .... 0... = normal throughput
IP:         .... .0.. = normal reliability
IP:   Total length = 44 bytes
IP:   Identification = 2948
IP:   Flags = 0x0
IP:         .0.. .... = may fragment
IP:         ..0. .... = last fragment
IP:   Fragment offset = 0 bytes
IP:   Time to live = 64 seconds/hops
IP:   Protocol = 6 (TCP)
IP:   Header checksum = cec2
IP:   Source address = 128.178.156.7, lrcpc3.epfl.ch
IP:   Destination address = 129.132.2.72, ezinfo.ethz.ch
IP:   No options
IP:
TCP:  ----- TCP Header -----
TCP:
TCP:  Source port = 1268
TCP:  Destination port = 23 (TELNET)
TCP:  Sequence number = 2591304273
TCP:  Acknowledgement number = 0
TCP:  Data offset = 24 bytes
TCP:  Flags = 0x02
```

We observe a packet from Web server to Elaine at 1; Say what is true



A. The destination MAC address is the MAC address of the router
B. The destination IP address is the IP address of the router
C. Both A and B
D. None
E. I don’t know