The TCP/IP Architecture

Jean-Yves Le Boudec

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Objective
Understand Layered Model of Communication Systems
Know what MAC, IP addresses and DNS names are

Textbook
Chapter 2: Introduction of edition 1
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

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”

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

Web server

GET www.zurich.ibm.com/RZ.html

IP addr = 193.5.61.131

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

1 “to T3: Hello”
2 “From T1: Hello”
The Internet Uses Packet Switching

Data is broken into chunks called IP packets of size $\leq 1500$ 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
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

**Example:**

EPFL’s Network

- **IP Addresses:**
  - 129.132.100.12
  - 129.132.100.27
  - 129.132.35.1
  - 128.178.71.34
  - 128.178.71.23
  - 128.178.71.22
  - 128.178.182.5
  - 128.178.182.1
  - 128.178.182.3

**Binary to Decimal Conversion:**

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

**Network Diagram:**

- **Modem + PPP:** 128.178.84.133
- **stisun1:** 128.178.15.13, 128.178.15.7, 15.221
- **INF11:** 128.178.71.22
- **Komsys:** 129.132 66.46
- **ETHZ-Backbone:** 129.132.100.12, 129.132.100.27, 129.132.35.1
- **Switch:** 130.59.x.x
- **EPFL-Backbone:** 128.178.84.130
- **Switch:** 128.178.47.3, 128.178.47.5
- **LEMA:** 128.178.29.64
- **ETHZ-Backbone:** 128.178.100.12
- **Komsys:** 129.132 66.46
- **LEMA:** 128.178.29.64
- **ETHZ-Backbone:** 128.178.15.13
- **ETHZ-Backbone:** 128.178.47.3
- **ETHZ-Backbone:** 128.178.100.12
There are two network layers: IPv4 and IPv6

The old numbering plan is IPv4 – 32 bits
an EPFL address: 128.178.156.23
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

an EPFL public address:
2001:620:618:1a6:0a00:20ff:fe78:30f9
an EPFL private address:
fd24:ec43:12ca:1a6:0a00:20ff:fe78:30f9

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

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

- Name server (DNS server) 128.178.15.8
- A record (IPv4 address) 128.178.51.13
- AAAA record (IPv6 address) AE:98:34:00

1. Click on ‘ssc.epfl.ch’
2. Click on ‘128.178.15.8’ who is ssc.epfl.ch
3. 128.178.56.9 ssc.epfl.ch is 128.178.51.3
4. 128.178.56.9 OK 100
5. 128.178.56.9 HTTP get /index.htm
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)

MAC address = 08:00:20:71:0d:d4

MAC address = 00:00:c0:3f:6c:a4

Dest Addr = 00:00:c0:3f:6c:a4

A
MAC address = 08:00:20:71:0d:d4

B

C

Router
MAC address = 00:00:c0:3f:6c:a4

WiFi radio system or Ethernet cabling system
Local Area Network = A set of devices that are connected at the MAC layer
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”)

LAN A

router R

LAN B
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: 128.178.71.34

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 rate of a channel = 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, 1 Gb/s = 10^9 b/s; also (improperly) called “bandwidth”
Bit Rate and Bandwidth

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. Information theory gives a bound on the achievable bit rate on a given channel.

For example: Shannon-Hartley law: for a channel of bandwidth $B$ (Hz) submitted to Gaussian noise, the capacity in b/s is:

$$C = B \log_2(1 + SNR)$$

with $SNR = \text{signal to noise ratio (ratio of power of emitted signal over power of noise)}$; for example: ADSL Line: $B = 1 \text{ MHz}$, $SNR = 45 \text{ dB}$, $C = 15 \text{ Mb/s}$

In computer science, many people use “bandwidth” instead of “bit rate”
Propagation between A and B = time for the head of signal to travel from A to B

\[ D = s_i - t_i = \frac{d}{c} = \frac{\text{distance}}{\text{speed of light}} \] (propagation delay for non acoustic channels)

In copper: \( c = 2.3 \times 10^8 \text{ m/s} \); in glass optical fiber: \( c = 2 \times 10^8 \text{ m/s} \);
Rule of thumb: 5 \( \mu \text{s/km} \); around the globe = 200 msec
Time it takes to send one packet of 1kB (8000bits)

<table>
<thead>
<tr>
<th></th>
<th>data center</th>
<th>ADSL</th>
<th>modem</th>
<th>Internet</th>
</tr>
</thead>
<tbody>
<tr>
<td>distance</td>
<td>20 m</td>
<td>2 km</td>
<td>20 km</td>
<td>20’000 km</td>
</tr>
<tr>
<td>bit rate</td>
<td>1Tb/s</td>
<td>10Mb/s</td>
<td>10kb/s</td>
<td>1Mb/s</td>
</tr>
<tr>
<td>propagation</td>
<td>0.1μs</td>
<td>0.01ms</td>
<td>0.1ms</td>
<td>100ms</td>
</tr>
<tr>
<td>transmission</td>
<td>0.008 μs</td>
<td>0.8ms</td>
<td>800ms</td>
<td>8ms</td>
</tr>
<tr>
<td>total</td>
<td>0.108 μs</td>
<td>0.81ms</td>
<td>800.1ms</td>
<td>108ms</td>
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Throughput

**Throughput** = number of useful data bits / time unit

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

- protocol **overhead**: all protocols like UDP use some extra bytes to transmit protocol information.
- protocol **waiting times**.

Same units as a bit rate

- b/s, kb/s, Mb/s
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.

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

A simple protocol used to repair packet losses.

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 $T_1$, then A retransmits.
Performance of the Stop and Go Protocol

$L = \text{packet size}; \ b = \text{channel bit rate}; \ D = \text{propagation delay}$

Best case: always one packet to transmit, no loss.

In one cycle, $L$ useful bits are transmitted.

The cycle lasts $T + 2D + T'$.

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

packet P1 sent
packet P1 acknowledged

overhead

“Bandwidth-Delay Product”
## Throughput of Stop and Go

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<td>800.1ms</td>
<td>108ms</td>
</tr>
<tr>
<td>bw delay</td>
<td>200kb</td>
<td>200b</td>
<td>2b</td>
<td>200kb</td>
</tr>
<tr>
<td>product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>throughput</td>
<td>3.8%</td>
<td>97.56%</td>
<td>99.98%</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

We will see that TCP does better than Stop and Go by using a smarter scheme (sliding window)

* with packets of size 1kB=8’000 bits and assuming overhead is negligible
Putting Things Together

Web server sends a file to Elaine
Elaine

Application

```
read(s1, dataBlock)
```

Transport (TCP)

```
1 2 3 4 5
```

Network (IP)

```
2 3 4 5
```

MAC (WLAN)

```
? 3 4 5
```

Physical

Router

```
1 2 3 4 5
```

Network (IP)

```
1 2 3
```

MAC

```
1 2 3
```

Physical

Web server

Application

```
send(s2, dataBlock)
```

Transport (TCP)

```
1 2 3 4 5
```

Network (IP)

```
1 2 3 4 5
```

MAC (Ethernet)

```
1 2 3 4 5
```

Physical
The Onion View: header and payload
The Onion View: header and payload

MAC header
(destination MAC address + other things)

IP header
(IP destination address + other things)

IP payload

IP packet

Web server
The Onion View: header and payload

Web server

MAC header
(destination MAC address + other things)

IP header
(IP destination address + other things)

TCP segment

TCP header

TCP payload
The Onion View: header and payload

Web server

MAC header
(destination MAC address + other things)

IP header
(IP destination address + other things)

TCP header

Bytes of an HTML file
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:c2:78:36, 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
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 (!)