

Connectivity 1

Agenda

Intro to communications

IoT/HW specific protocols

Wireless: WiFi, BT 4.0/BLE, LoRa, LTE, Zigbee, Z-wave, NFC, IrDA

Wired: UART/RS485, SPI, I2C, OneWire

Exercises

Intro to communications

What is information?

Data

Datum = something given, a thing

Knowledge

Subject + data = experience

Learning = increasing knowledge

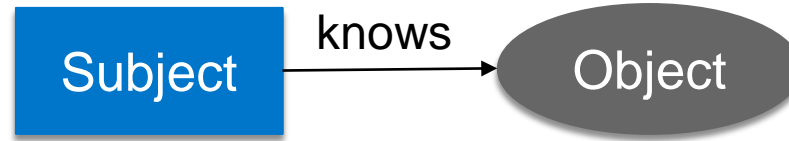
- Reduces uncertainty
- Improves outcome

Information

Conveys knowledge increments

Measured in bits

Entropy (data vs information)



Reducing uncertainty

$$P(A | E) \neq P(A)$$

Improving outcome

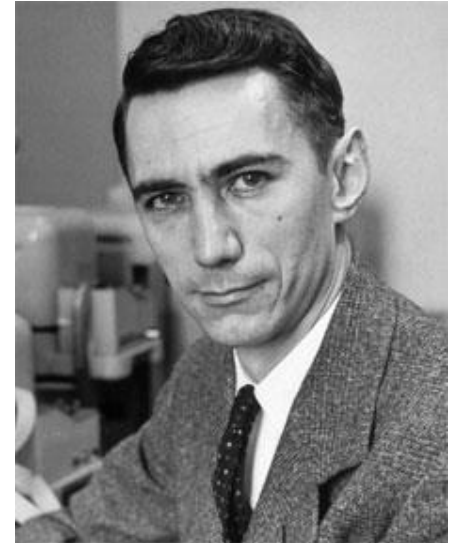
$$O'_T | E > O_T$$

Quantity of information

$$I(m) = \log_2(M) \text{ [bit]}$$

Entropy

$$H = - \sum (P_i \log_2(P_i)) \text{ [bit]}$$



Shannon, Nyquist, Hartley, Mitchell

What is communication?

Communication

Conveying information (knowledge)

Encoding & decoding

Information \leftrightarrow Data

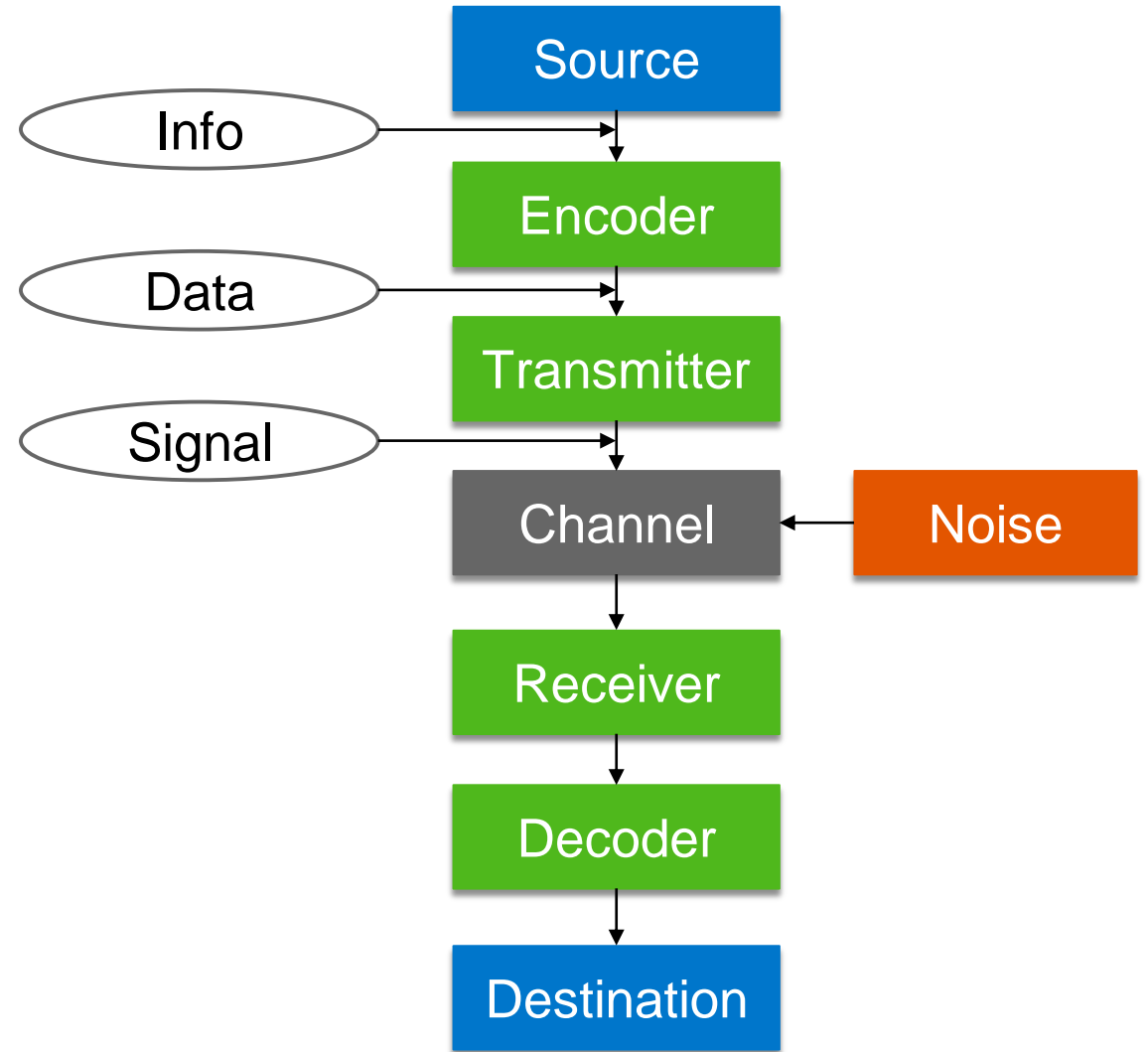
Transmission & reception

Data \leftrightarrow Signal (energy wave)

Channel

Carries and modifies the signal / data

Information may be affected



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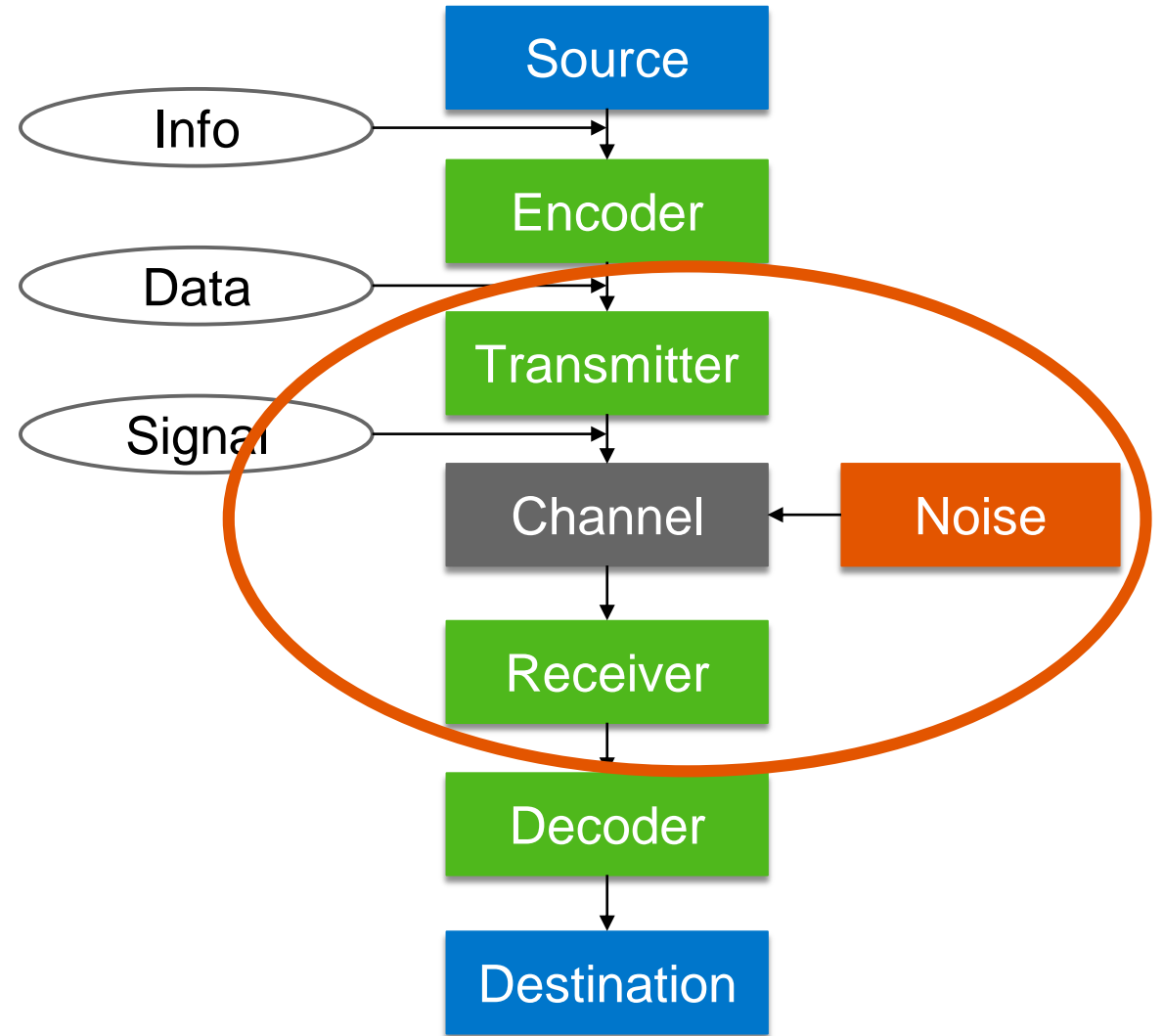
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Carries and modifies the signal / data

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Signal & channel characteristics

Signal

Energy: An energy wave

Spectrum (Fourier sum of sine waves)

Channel

Bandwidth, power, noise, attenuation

Latency

Capacity: $C = B \log_2(1 + P_S/P_N)$ [bit/s]

*P is power in Watts

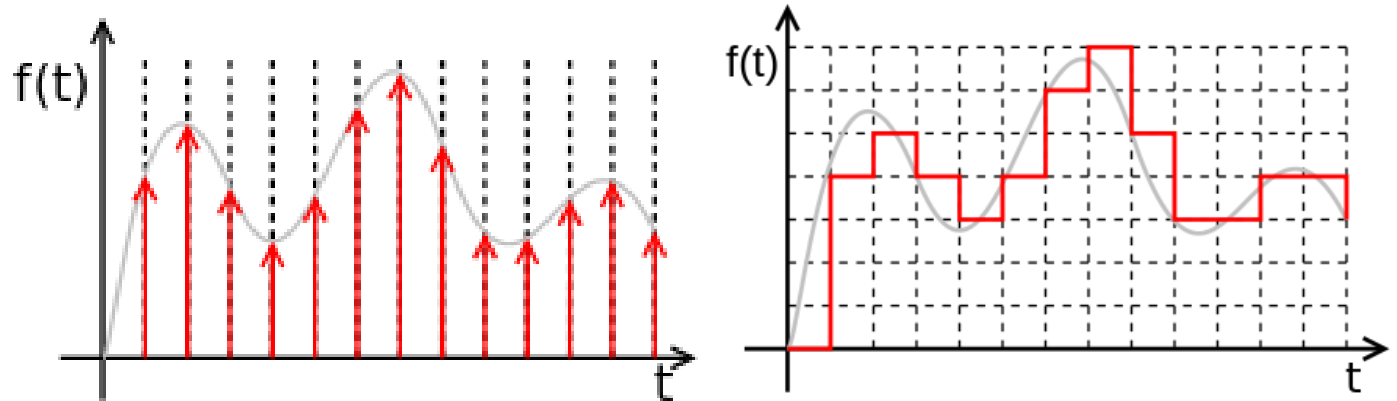
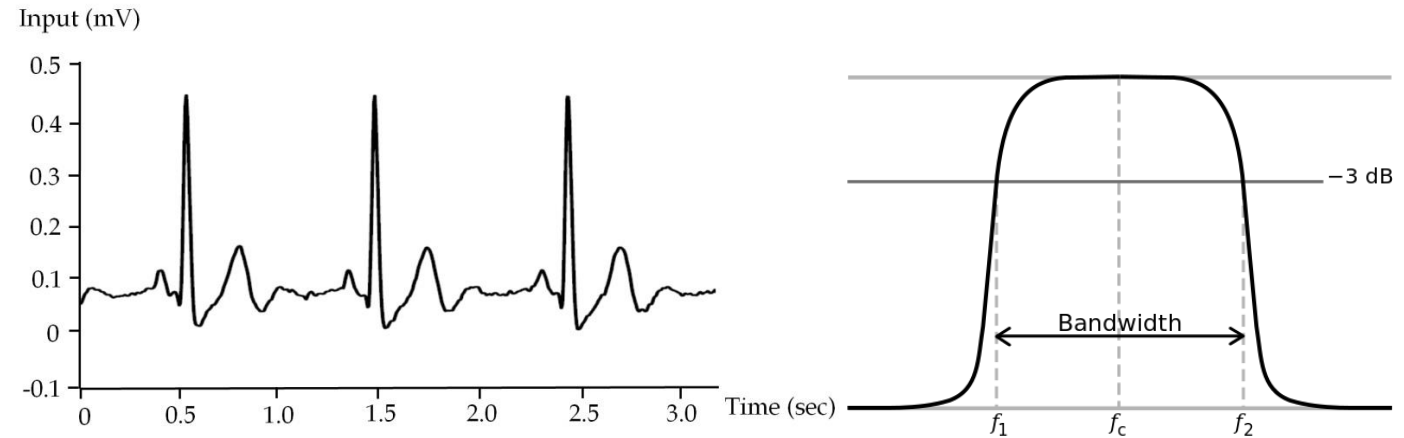
Digital signal

Time discretization (Nyquist): $F_S > 2B$

Amplitude quantization:

$$SQNR = 20 \log_{10}(2^Q) = 6.02 Q \text{ [dB]}$$

* Signal to quantization noise ratio: Q bits



Common media types

Electrical wires

Twisted pair: 10 GB/s, 100 m, 0.5 EUR/m

Coaxial: 10 MB/s, 450m, 0.5 EUR/m

Optical fibers

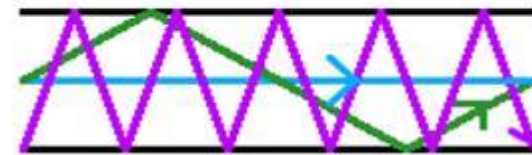
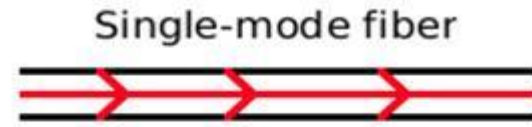
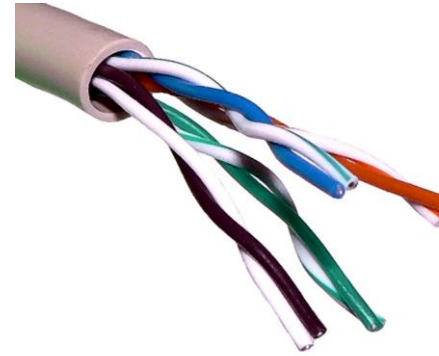
Single mode: 100TB/s, ~150 km, 0.06 EUR/m

Multi-mode: 1GB/km, ~2 km, 0.3 EUR/m

Radio (e.g. ISM bands)

2.4 / 5GHz: 300MB/s, 50 m

433 / 868 MHz: 64KB/s, 20 km



Multi-mode fiber



More about radio

Propagation

Direction & Multi path

Penetration

Polarization

Antennas

Omni and directed

Connectors: SMA, UF.L, BNC, F ...

Regulations

Standard bodies: FCC(US), ETSI (EU) ...

Restrictions: Frequency, power, duty cycle



| Connector | Frequency | Impedance |
|-----------|-----------|-----------|
| SMA | < 17 GHz | 50Ω |
| UF.L | < 6 GHz | 50Ω |
| BNC / F | < 3 GHz | 50Ω, 75Ω |

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Communication

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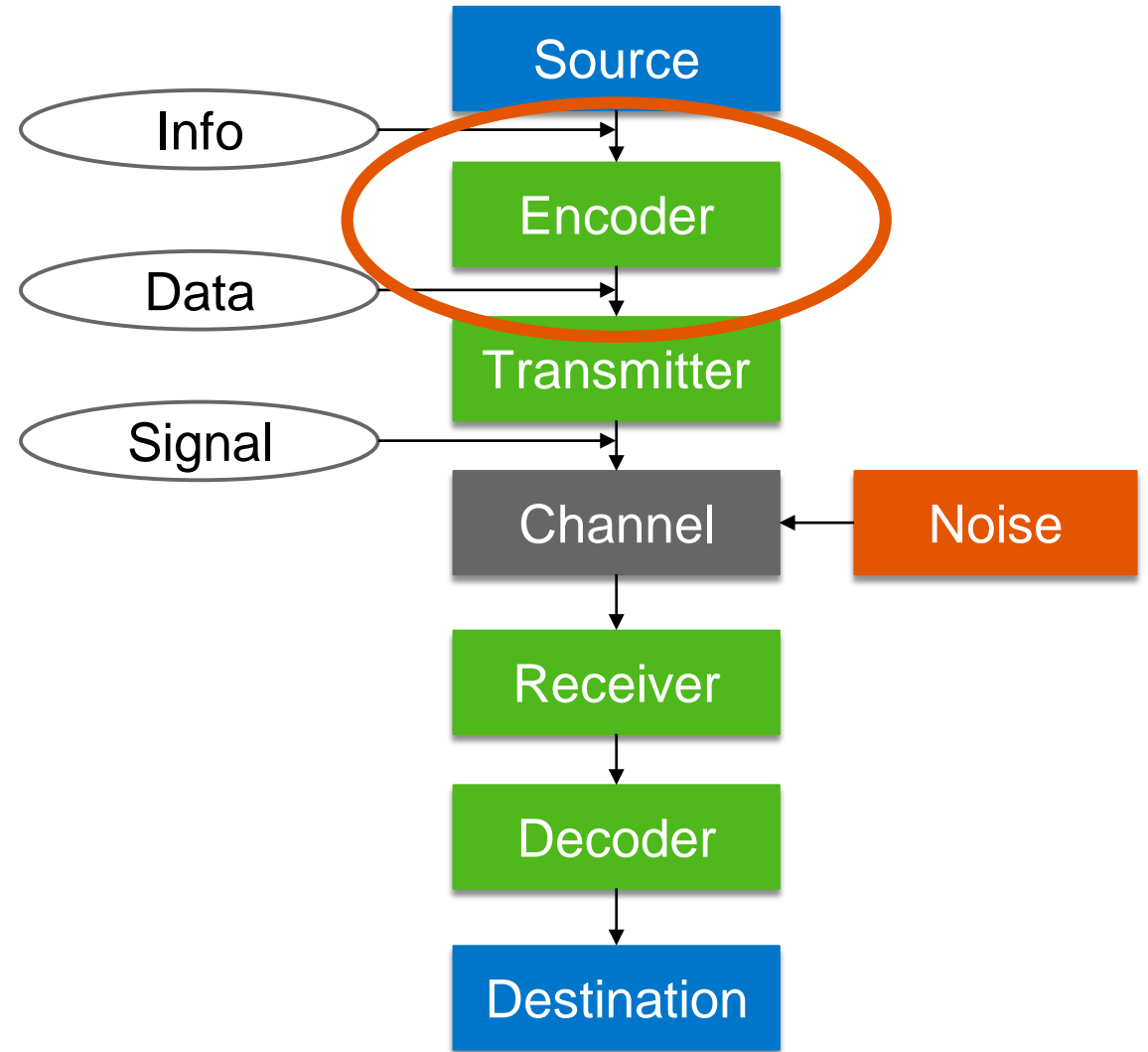
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Encoding & Error control

Encoding

Text: Morse, ASCII, UTF8, CP1251 ...

Images: BMP, GIF, JPEG ...

Sound: MPEG/MP3, Flac, Vorbis, Speex ...

Video: VP9, H265 ...

Error control

Detection: Parity bit, Checksum, Hash...

Correction:

- ACK/ARQ
- FEC: Hamming, Reed-Solomon, Turbo code, LDPC

| ASCII Alphabet | | | |
|----------------|---------|---|---------|
| A | 1000001 | N | 1001110 |
| B | 1000010 | O | 1001111 |
| C | 1000011 | P | 1010000 |
| D | 1000100 | Q | 1010001 |
| E | 1000101 | R | 1010010 |
| F | 1000110 | S | 1010011 |
| G | 1000111 | T | 1010100 |
| H | 1001000 | U | 1010101 |
| I | 1001001 | V | 1010110 |
| J | 1001010 | W | 1010111 |
| K | 1001011 | X | 1011000 |
| L | 1001100 | Y | 1011001 |
| M | 1001101 | Z | 1011010 |

IoT wired protocols

UART (Universal Async Receive Transmit – aka Serial)

Overview

Point to point

Several varieties

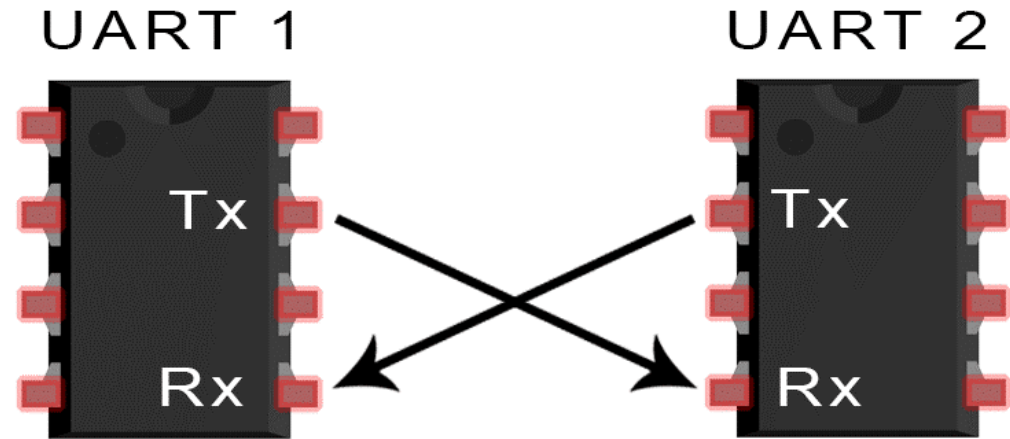
- UART (3.3 / 5 V, few meters)
- RS232 (9600 bps/ 15m)
- RS485 (100kbps / 1200m)

Applications

Serial monitor

Legacy devices (industry)

Some sensors



I2C

Overview

Distance: 1 – 10 m

Data and Clock lines

Synchronous bus (master clock)

Multi-master & up to 1008 slaves

Half-duplex, 100 kbit – 3.2mbit/s

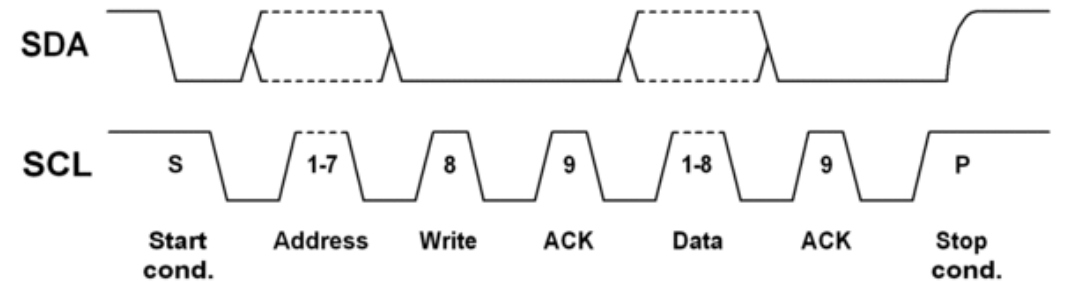
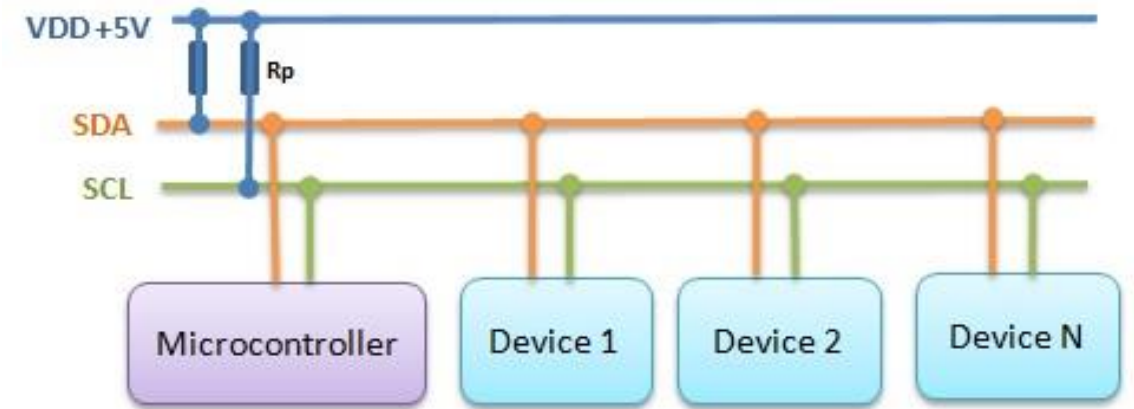
Programming

Slave address: 7/10 bit

Open address

Write data

Read data



SPI (Serial peripheral interface)

Overview

Distance: 1 – 10 m

Data, Clock and Select lines

Synchronous bus (master clock)

Single master / multi slave

Full duplex, up to 50Mbit/s

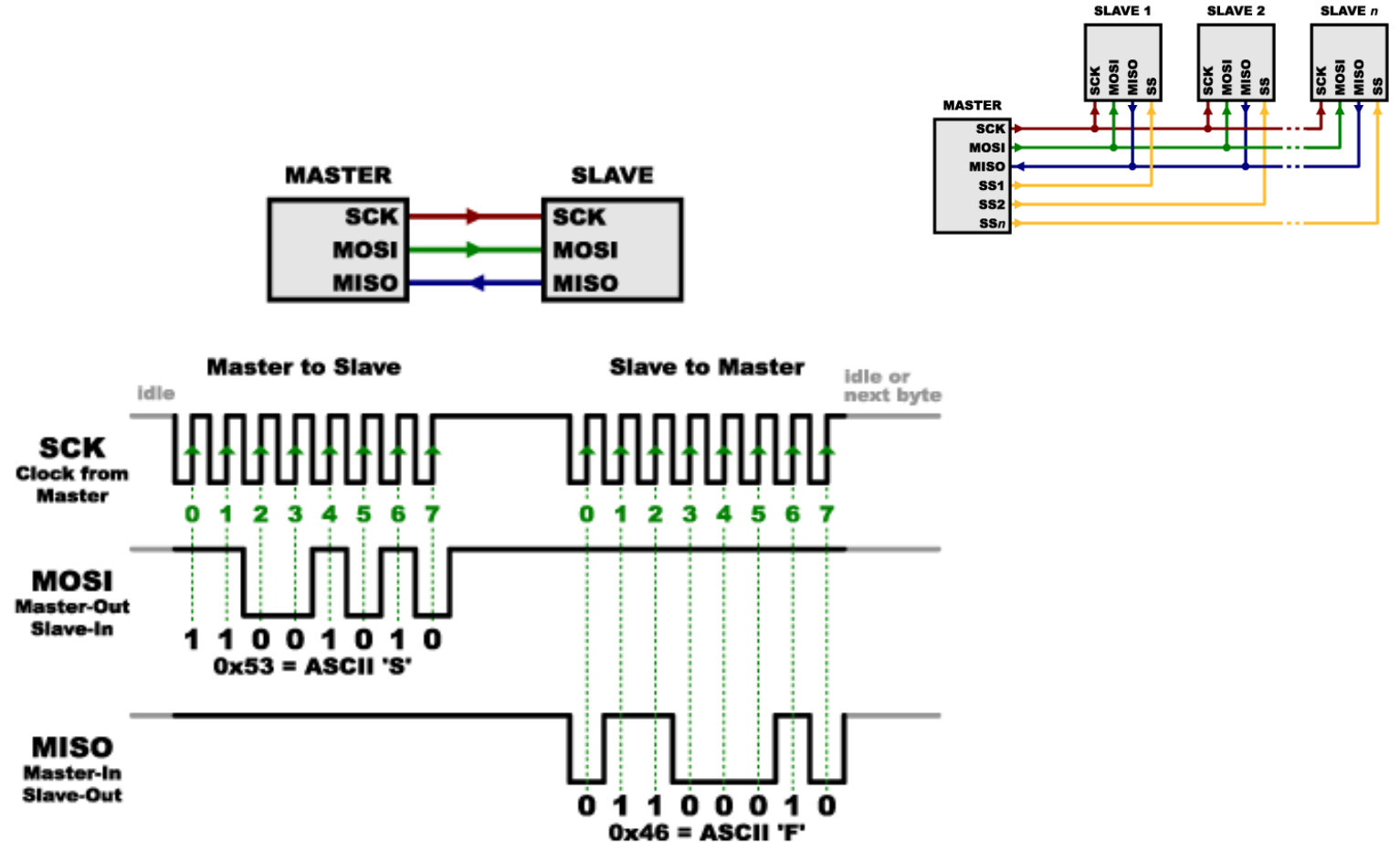
Programming

Software vs Hardware SPI

Bit order (LSB/MSB)

Data mode (rising/falling edge)

Clock speed (divider)



OneWire et al

Overview

Distance: 10 to 100s of meters

- Radius & weight

Half-duplex, 16 kbit / 125 kbit (overdrive)

Data line only (2/3 wire interface)

Single master / up to 100s of slaves

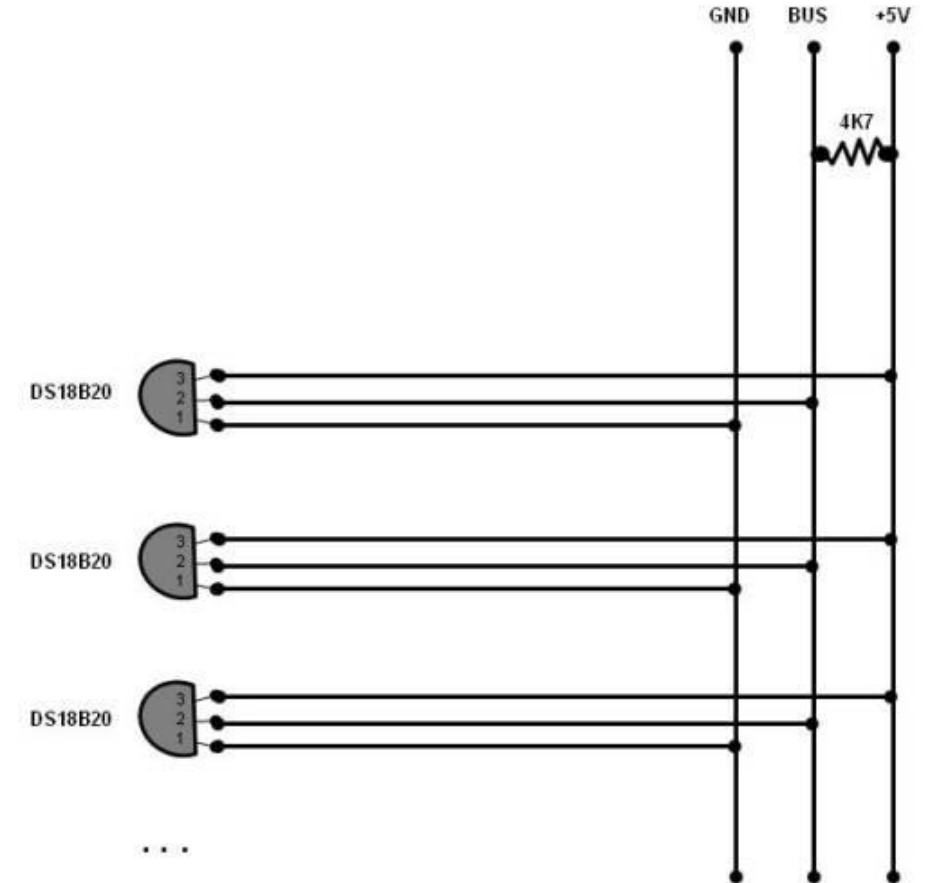
Programming

64bit slave IDs

Parasitic power (charge up)

Find devices

Communicate



Some other protocols

Industrial

CAN

Ethernet (PROFINET)

Modbus (PLCs), Profibus, 4-20 mA

I2S

HiFi sound

IoT wireless protocols

Common network topologies

P2P

Simplest

Star (Star of stars)

Common in public deployments

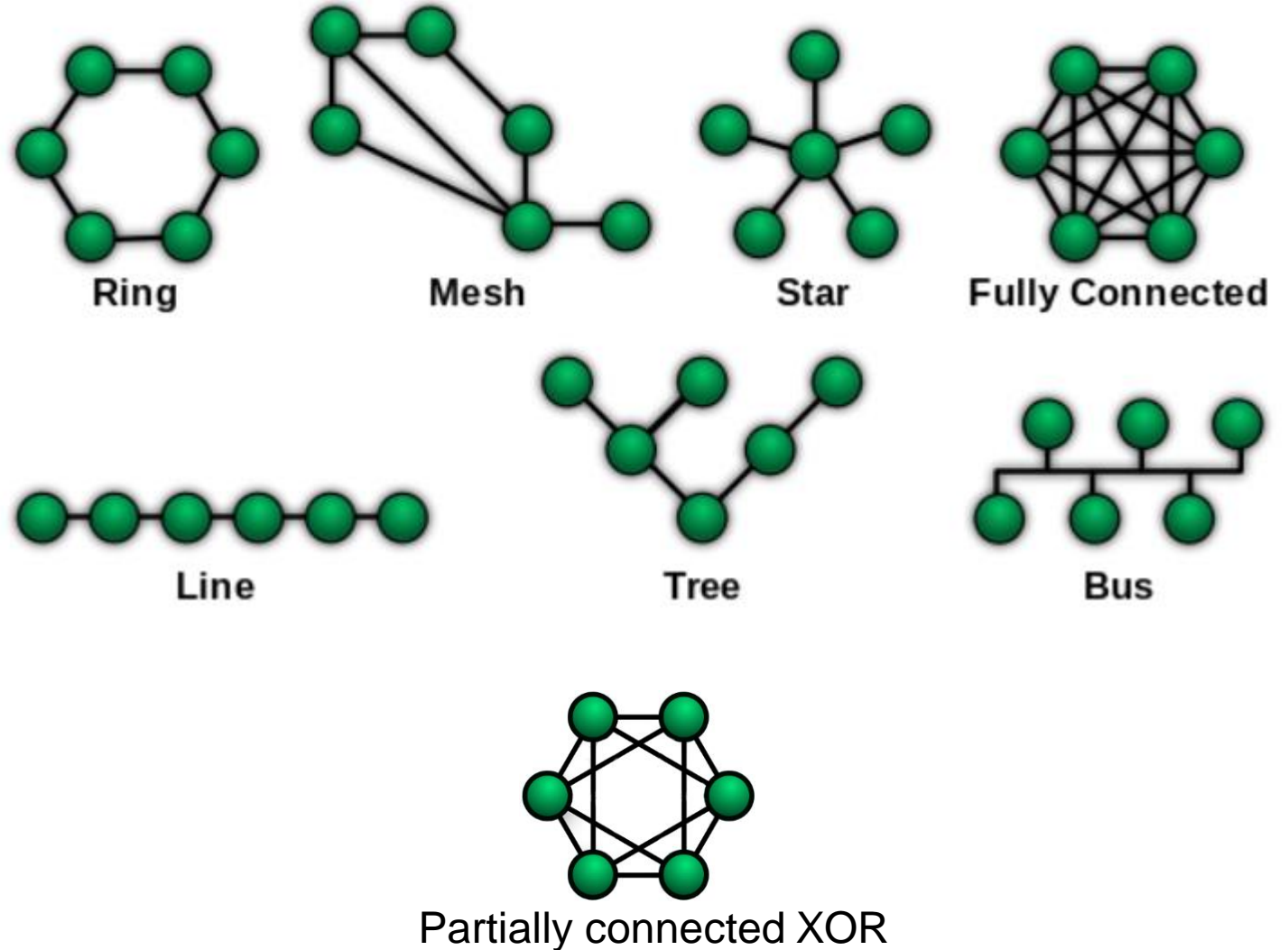
Mesh

Complex

Potentially more reliable

Partially connected with XOR distance

(Petar Maymounkov – DHT)



Bluetooth 4 (BLE)



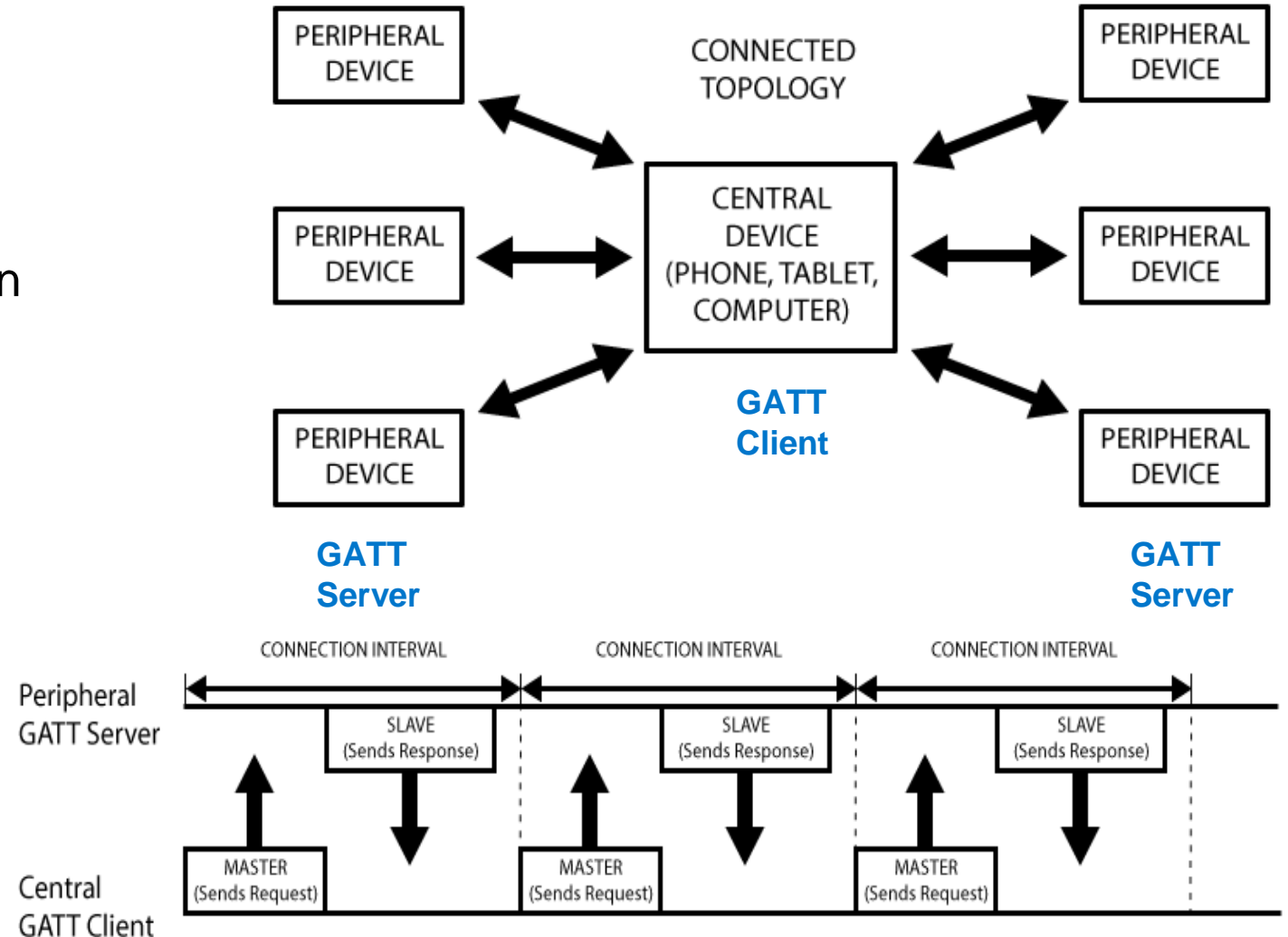
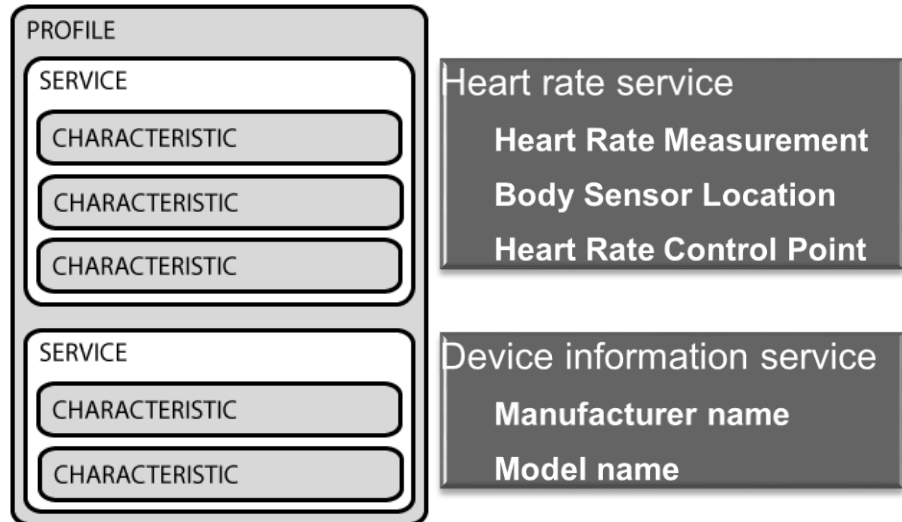
GATT (generic attribute profile)

Designed for low power

Peripherals advertise themselves

Central device initiates two way connection

Profiles, Services & Characteristics



Bluetooth 5

Already here and compatible with Bluetooth 4

Samsung Galaxy S8, S8+, Note, S9, S9+, iPhone 8, some boards

Longer range (~ 4x)

12dB improved sensitivity, 500kbps or 125kbps modes with Coded PHY

Higher data throughput (~5x)

2x LE (up to 2Mbps) by changes in physical / radio layer

Data Length Extensions (DLE)

Increased broadcasting capacity (Advertising Extensions)

Less congestion, extended advertising payloads

Periodic advertising & long range connections (e.g. for way-finding, indoor navigation, asset tracking)



Some other protocols

Cellular

3G, LTE, 4G, Sigfox ...

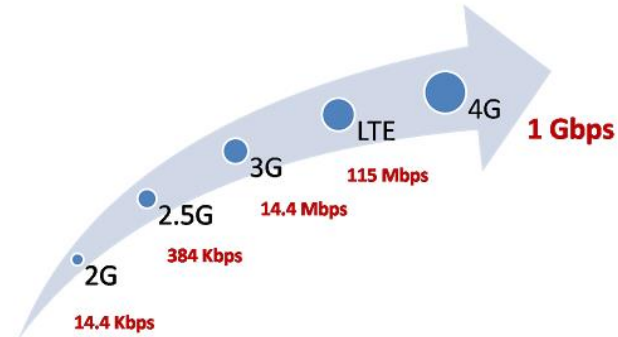
IEEE 802.15.4

ZigBee (popular in EU)

- 2.4 GHz, Mesh, many vendors = Interop. problems
- Use cases: Home automation, Smart buildings, meters ...

Z-wave (popular in US)

- 868MHz, Mesh, single vendor
- Use cases: Home automation, Smart buildings



Internet refresher ...

TCP/IP

IP

Private & public addresses

Routing, NAT and Firewalls

Host names (DNS)

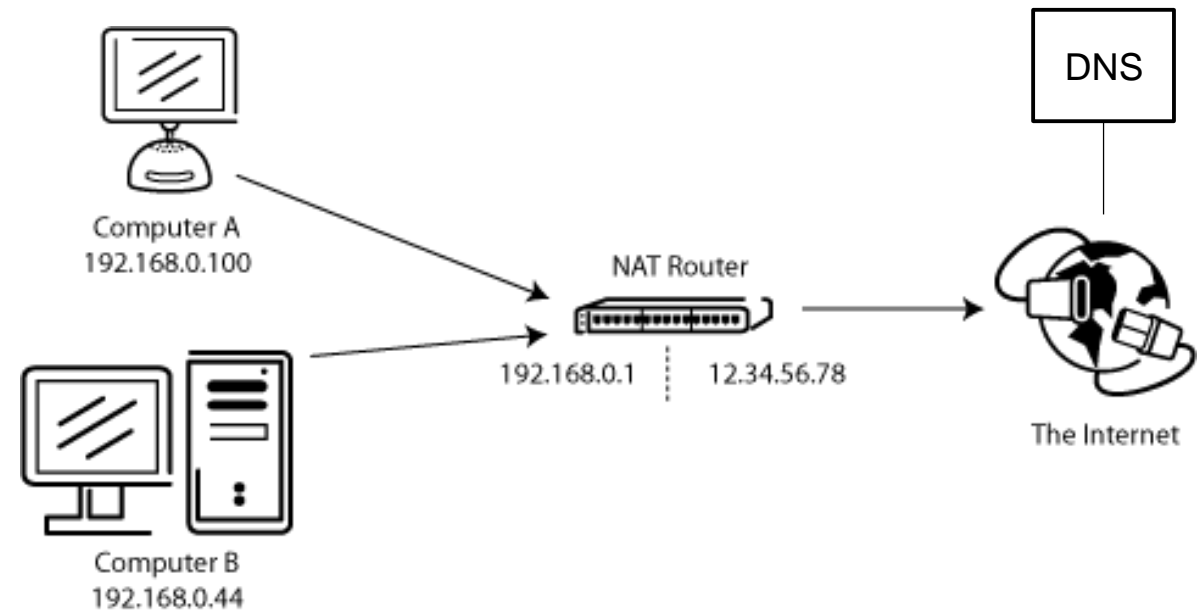
Load balancing

- DNS round robin
- Virtual IP

TCP & UDP

Ports (services)

Error control & ordering



HTTP Request

Method

GET, POST, PUT, DELETE ...

Headers

Accept (content type, encoding)

Authorization

Cache-Control

Cookies

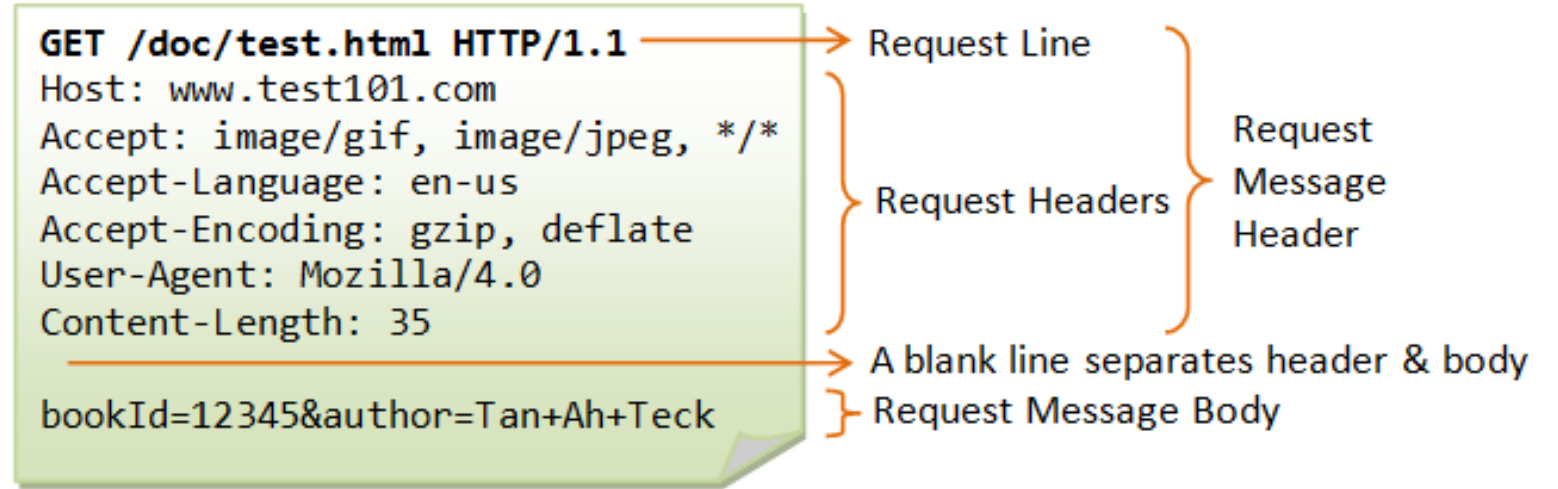
Content-Type

Host

Body

Application specific (e.g. JSON, XML ...)

Usually POST and PUT methods only



HTTP Response

Status line

Protocol version

Status

Headers

Access-Control-Allow-Origin

Cache-Control

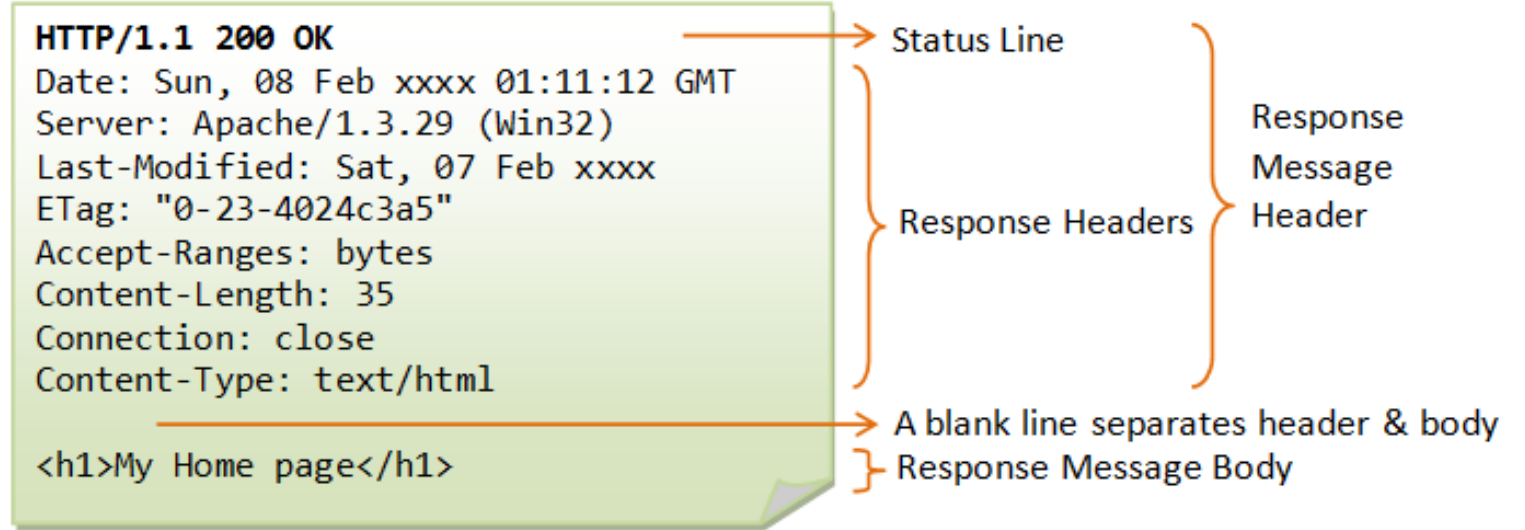
Content-Type

Set-Cookie

...

Body

Application specific (e.g. JSON ...)



Exercises

OneWire

DS18B20 temperature sensors

WiFi modes

ESP Access point + HTTP server -> fire an LED upon HTTP request

Bluetooth 4 / BLE

Connect two devices and send data