UNIVERSIDAD
COMPLUTENSE
MADRID

Networking Protocols 1

Presentation and Basic Concepts

Facultad de Informática

Subject and General Organization

- The Networking Protocols subject will be organized as follows
  - Video lectures covering the theory aspects
  - Lab assignments that must be completed by each student
  - All information will be made available to the sutents at the web site https://iot-da.github.io/Subjects/NP1/
  - Lab assignments will be sent by email to the professor
  - Grading:
    - Lab assignments (35%)
    - One personal assignment (35%)
    - Tests (30%)
- Professor
  - Christian Tenllado (tenllado@ucm.es)

Agenda

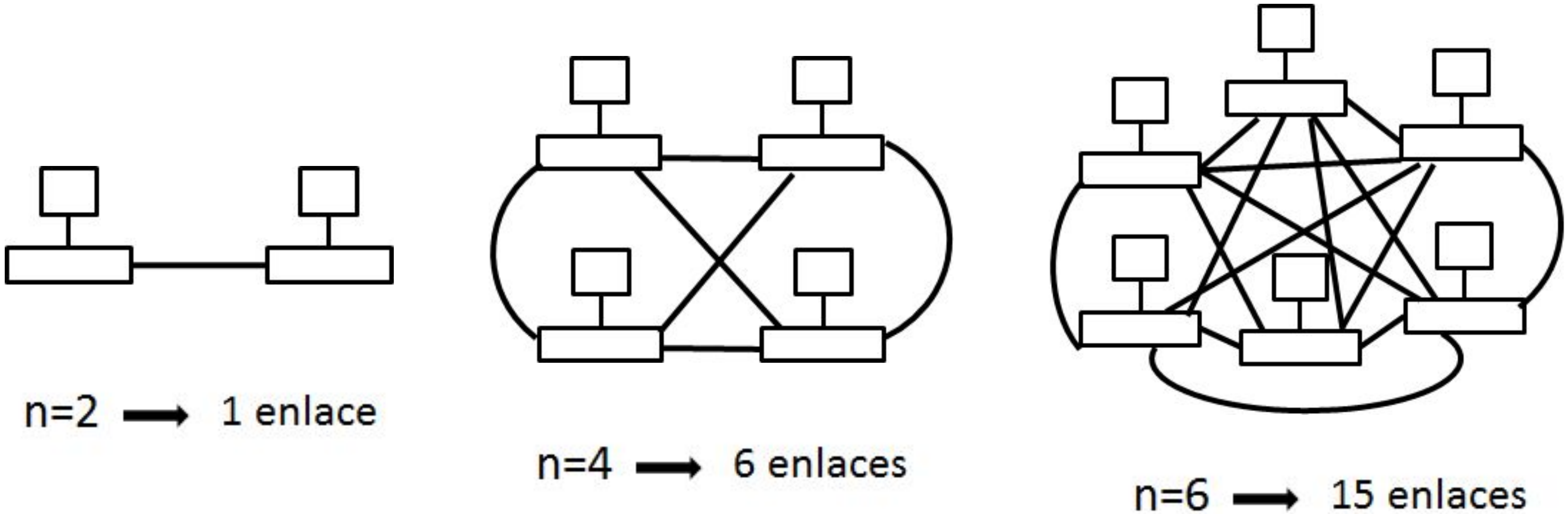
- Basic networking concepts
- Fundamentals of data transmission, a review of basic concepts
- MAC layer
- Network layer
- Networks for IoT

Computer network

- A set of computers interconnected some way with the purpose of communicate with each other
  - Has SW and HW components
- Issues to solve
  - Scalability
  - Addressing
  - Interconnection
  - Routing
  - Reliability
  - Security
  - Privacy

Types of networks: point to point connections

- Easiest and most intuitive way to interconnect computers
- The number of links increases exponentially with the number of devices
  - n devices implies n(n-1)/2 links
    - **Problem:** large amount of cables and I/O ports on each device
    - **Solution:** diffusion/commuted LAN and WAN

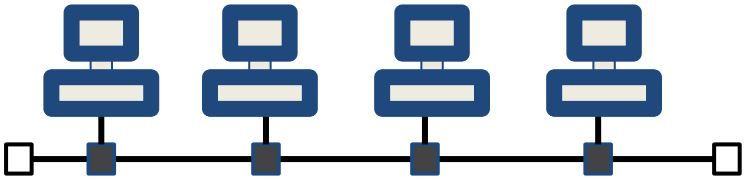


Types of Networks: Local Area Networks

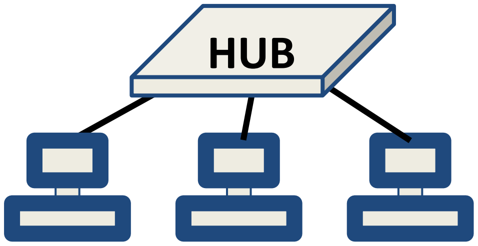
- **Local Area Networks (LAN)**
  - Private
  - Limited coverage
    - Interconnects devices in a home, office or building
  - Each device has a unique identifier in the network: its address
    - Messages are labeled with the source and destination addresses
- **Types of LAN**
  - Broadcast LAN
    - Computers interconnected by a shared transmission medium
    - When a computer wants to send information, it diffused it through the media to all the rest of connected devices
    - If two or more devices transmit simultaneously a collision happens and the resulting information is invalid
  - Switched LAN
    - Computers interconnected through a switch
    - The information is sent only to the destination device
    - Free of collisions

Types of networks: Local Area Networks

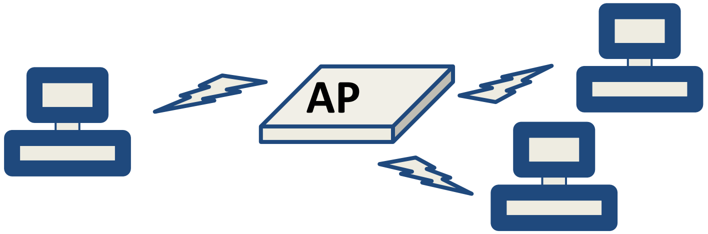
- **LAN topologies**
  - Broadcast LAN
    - Common cable (bus)
      - Example: Ethernet 10Base2



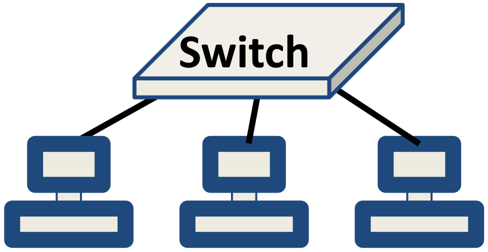
    - Hub (star)
      - The hub is a devices that retransmits what it receives through a port to al the rest of the ports
      - Example: Ethernet 10Base-T



    - Wireless LAN (WLAN)
      - The Access Point (AP) acts as a wireless hub
      - Example: Wi-Fi



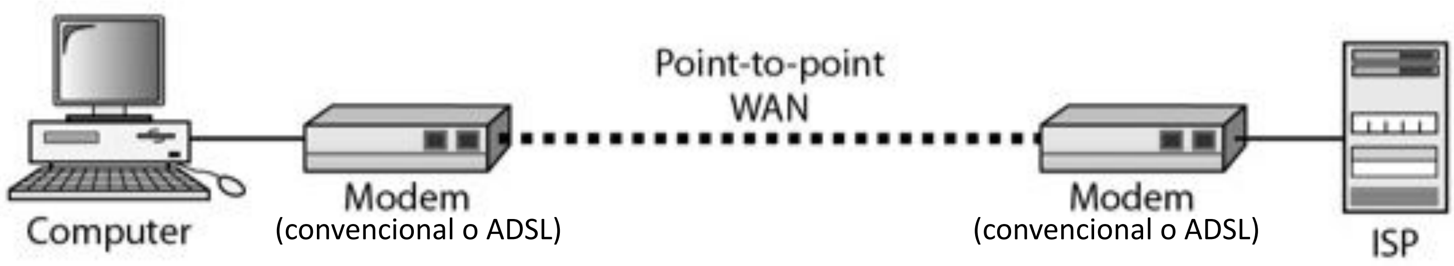
  - Switched LAN
    - Switch (start)
      - Example: Fast Ethernet 100BASE-TX



Types of networks: Wide Area Networks

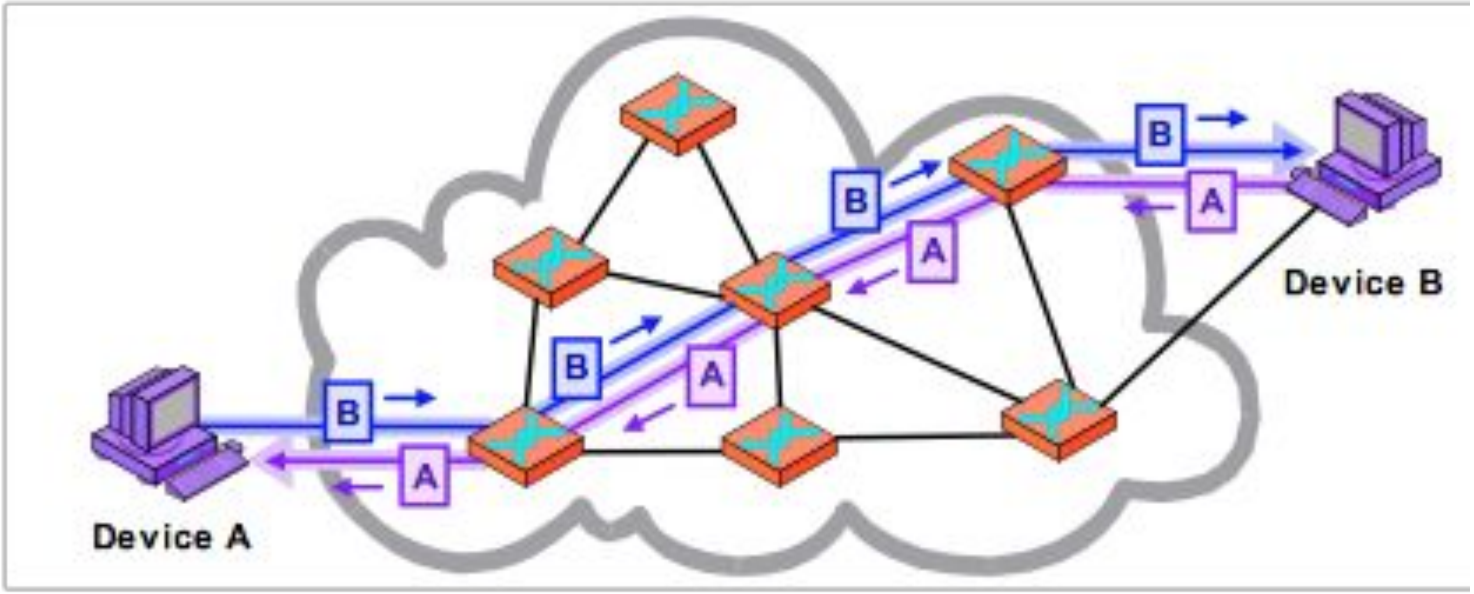
- **Wide Area Network (WAN)**
  - Cover a larger geographical area (city, country or even global)
  - Usually of public access, managed by telecoms

- **Types of WAN**
  - **WAN point to point**
    - Connect **two devices** by a transmission medium (air, cable, optic fiber)
    - Examples: conventional modem or ADSL between the home computer and the Internet Service Provider (ISP)



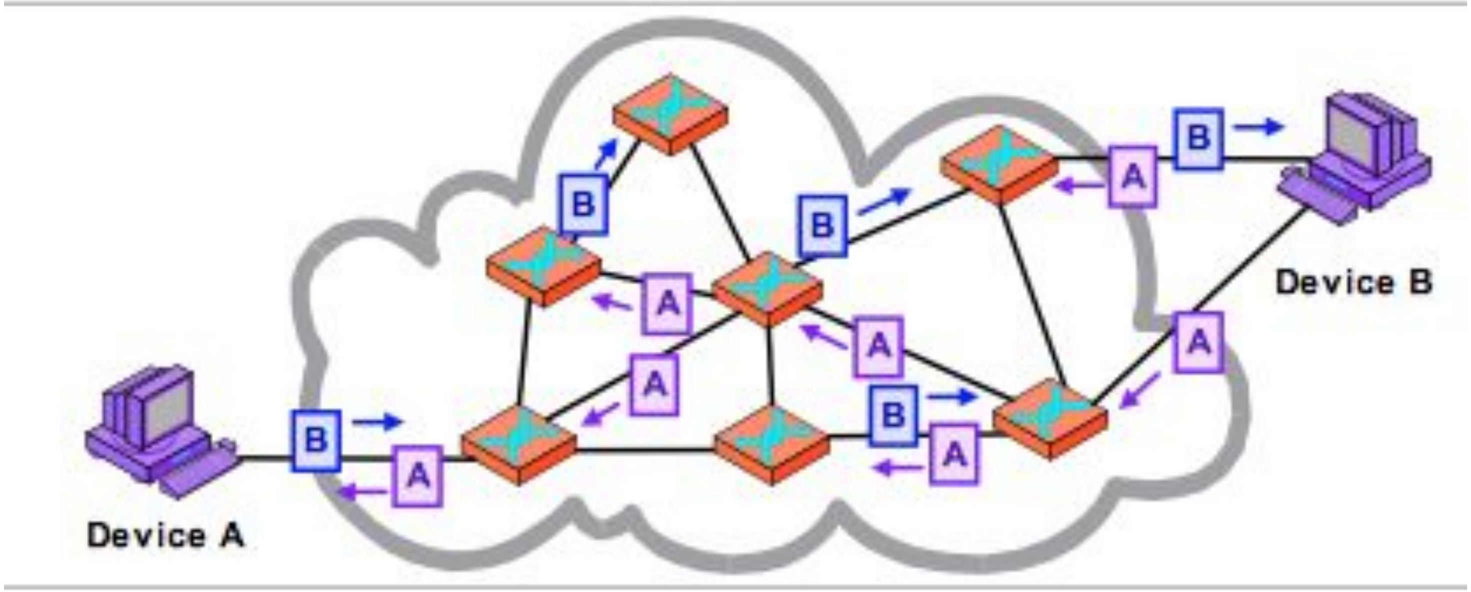
Types of networks: Wide Area Networks

- **Types of WAN (continuation)**
  - **Circuit Switched WAN**
    - A dedicated connection is established (circuit) between the two devices
    - The switches do not process the information
      - They only establish the required circuits for the connection
    - Example: Public Switched Telephone Network (PSTN)



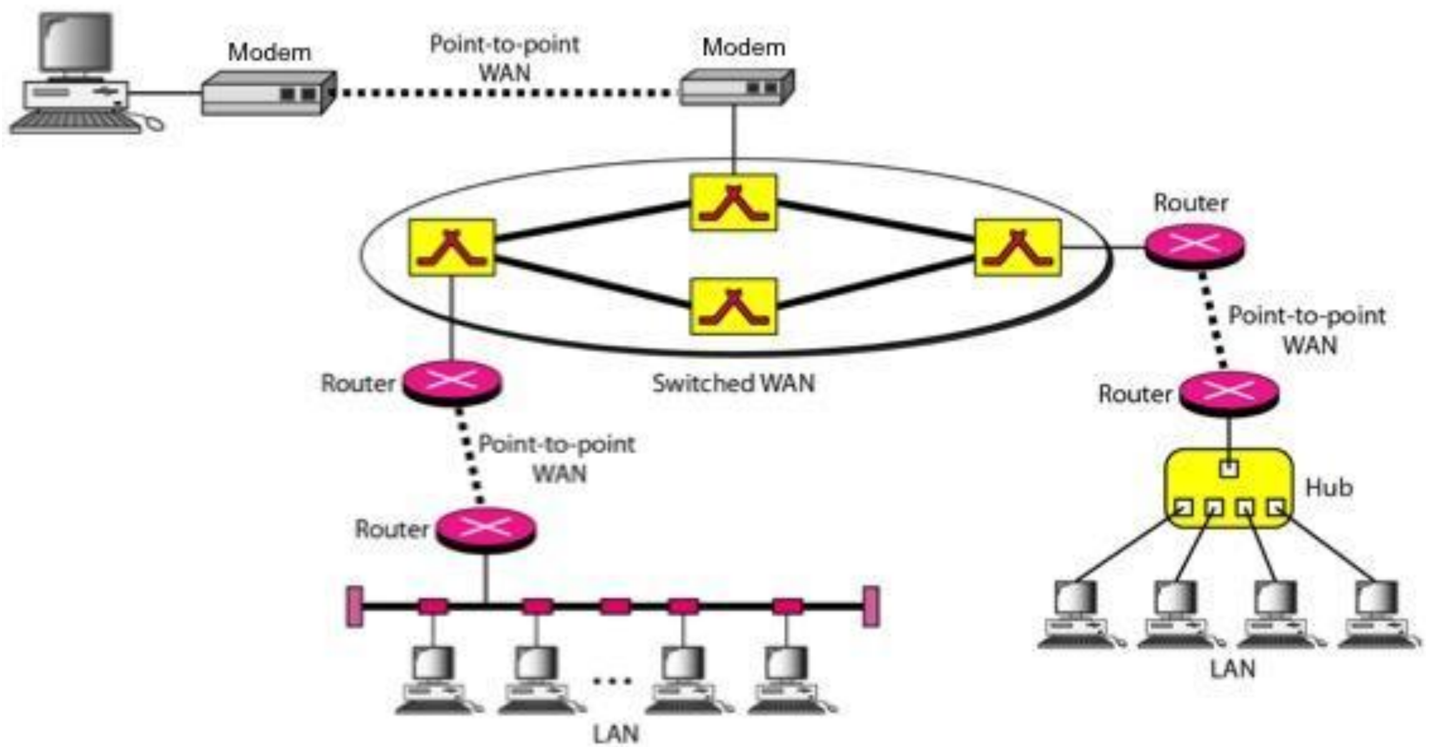
Types of networks: Wide Area Networks

- **Types of WAN (continuation)**
  - **Packet Switched WAN**
    - The information is divided in blocks (packets or segments)
    - The switches process the packets performing two basic functions:
      - **Packet routing**: decide which is the best route from source to destination
      - **Packet forwarding**: select the next node to sent a packet based on the routing information



Scalability

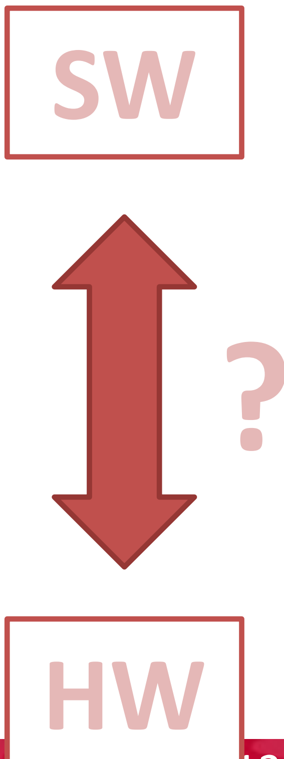
- A internet is formed by connecting several networks
- Nodes are connected locally forming LANs, these are interconnected by WANs
- Specific nodes are used to organize the traffic (routers/gateways)



The OSI Model

- OSI (Open Systems Interconnection), developed by the International Organization for Standardization (ISO)
  - Covers all the aspects involved in communications (late 70’s)
  - Its goal is to enable the communication of two devices regardless of the subjacent technologies
- It is a model for the development of protocols
  - …er is meant to include specific purpose protocols

Application	Specific Application
Presentation	Information representation, encriptation
Session	Authentication, reconnections after disconnection
Transport	End-to-end connections and reliability
Networking	Global addressing and routing
Data Link	Link addressing
Physical	Medium access and bit transmision

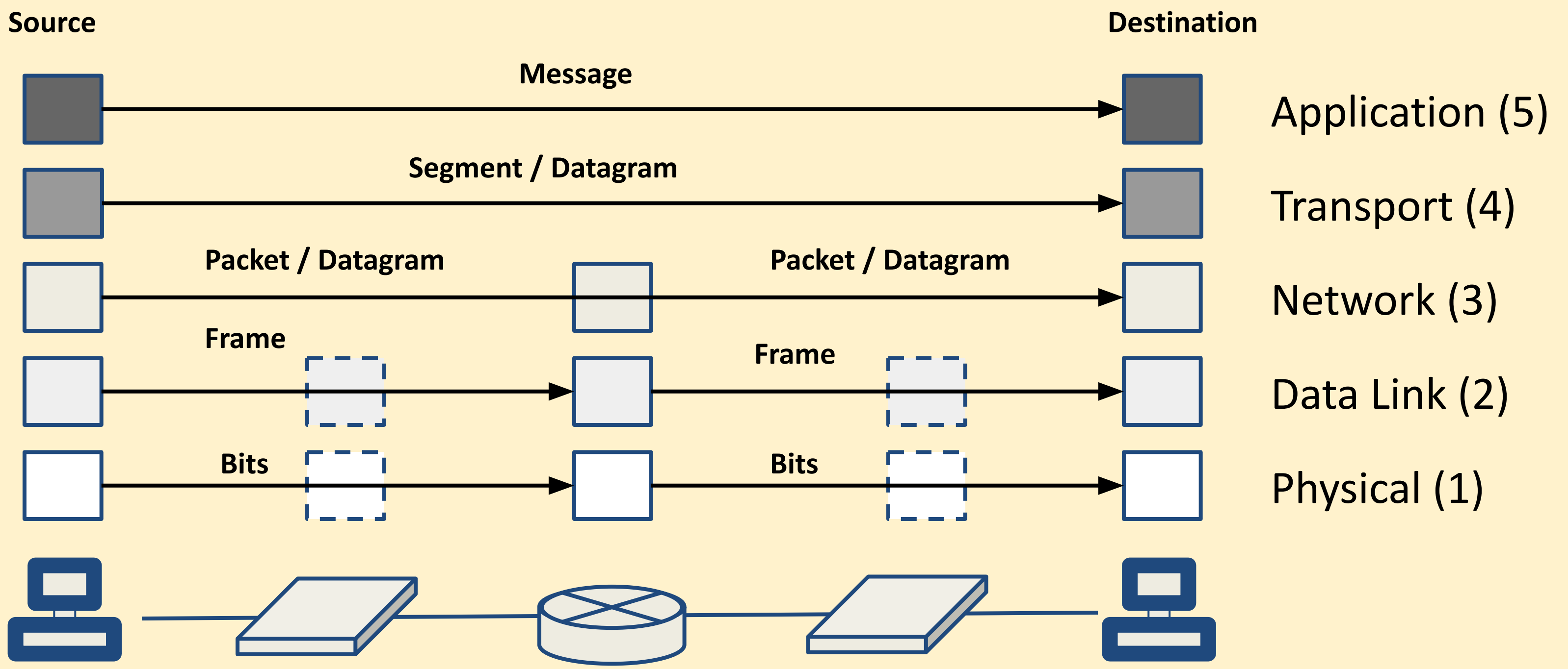


OSI vs. TCP/IP

OSI Model	TCP/IP 5 layer Model (generic)	TCP/IP on Ethernet	TCP/IP on Public phone
Application Presentation Session	Application	Application	Application
Transport	TCP-UDP	TCP-UDP	TCP-UDP
Network	IP	IP	IP
Data Link	MAC	Ethernet	PPP
Physical	Física	10BASE-T, 100BASE-TX, ...	dial-up modem o ADSL

TCP/IP architecture

- Layers 5, 4 and 3 are end-to-end (internet)
- Layers 2 and 1 are step-by-step, between host and router or between routers (link)



Main network devices

- **Hubs:** Work at the physical layer (level 1)
  - Retransmit bit by bit what they receive through one port to the rest of its ports
  - They can connect devices or network segments of the same type and speed
- **Switches:** are devices that work at the data link layer (level 2)
  - Send a frame to the corresponding output according to the destination MAC address
  - Can store the complete frame and check for errors
  - Can interconnect devices and networks of the same type, even if they work at different speeds (e.g. 100Base-TX and 1000Base-T)
- **Routers:** are devices that work at the network layer (level 3)
  - Can interconnect networks of different types
  - They perform two basic operations:
    - Format conversions
    - Routing

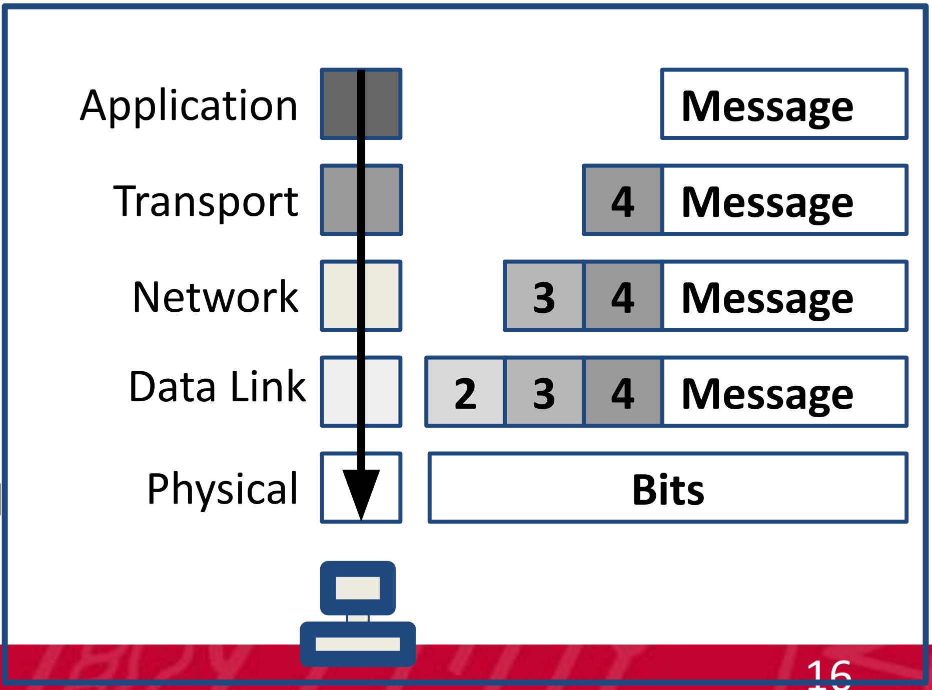
TCP/IP protocols architecture

Encapsulation

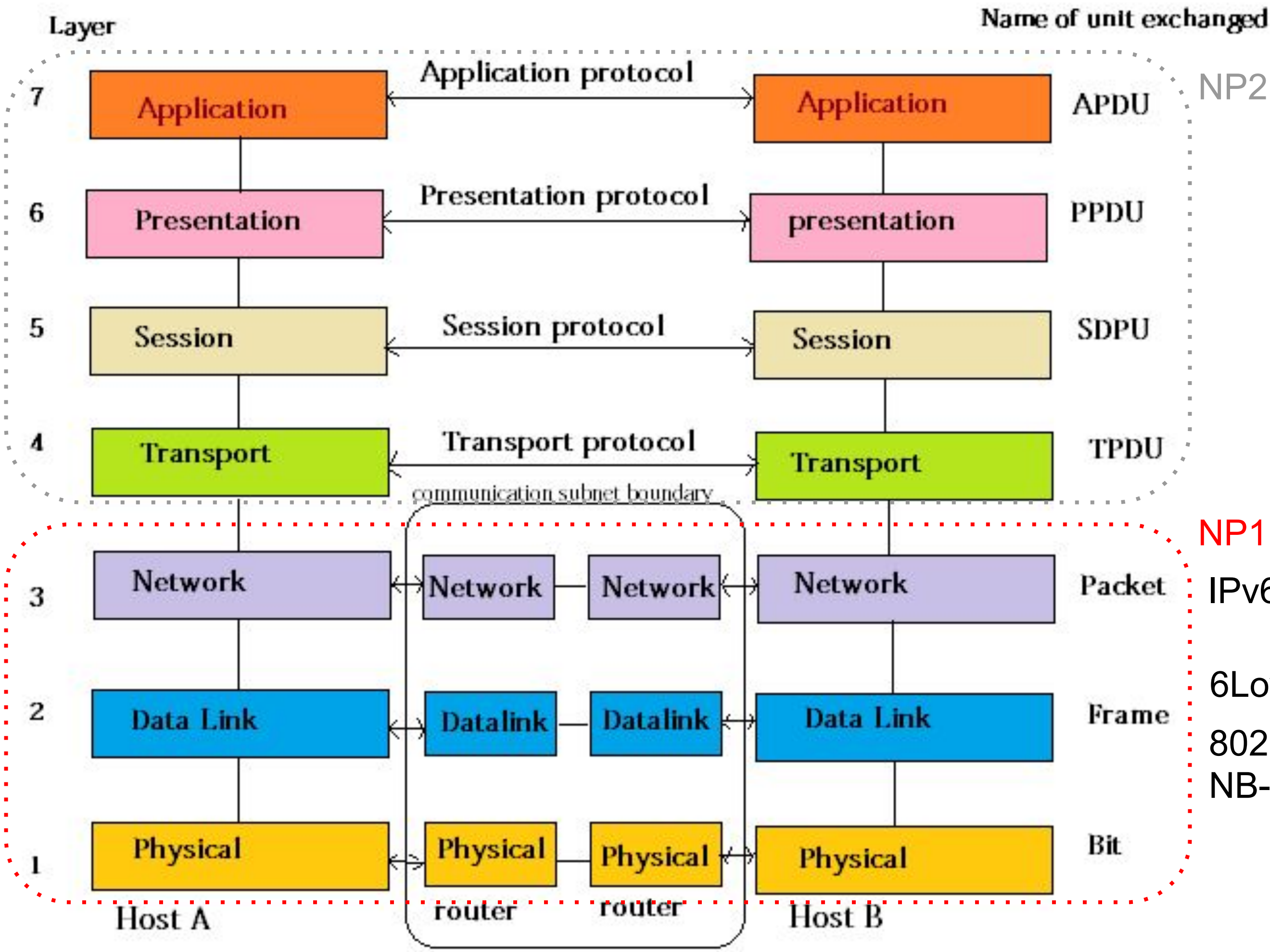
- At each level the protocol adds a header to the message (payload) that contains information specific for that protocol
- The transport header includes information of the source and destination processes, error control (e.g. checksums) or flow control
- The network layer adds information about the source and destination devices, error control and fragmentation
- The MAC layer includes the L2 addresses of the two devices communicating at that step

Reception

- Each layer processes its corresponding header and sends the payload to the next layer protocol
- Errors are checked at each level
- Routers can assemble a new packet for the next step, the datagram (3) is barely modified



NP1: networking infrastructure



IPv6

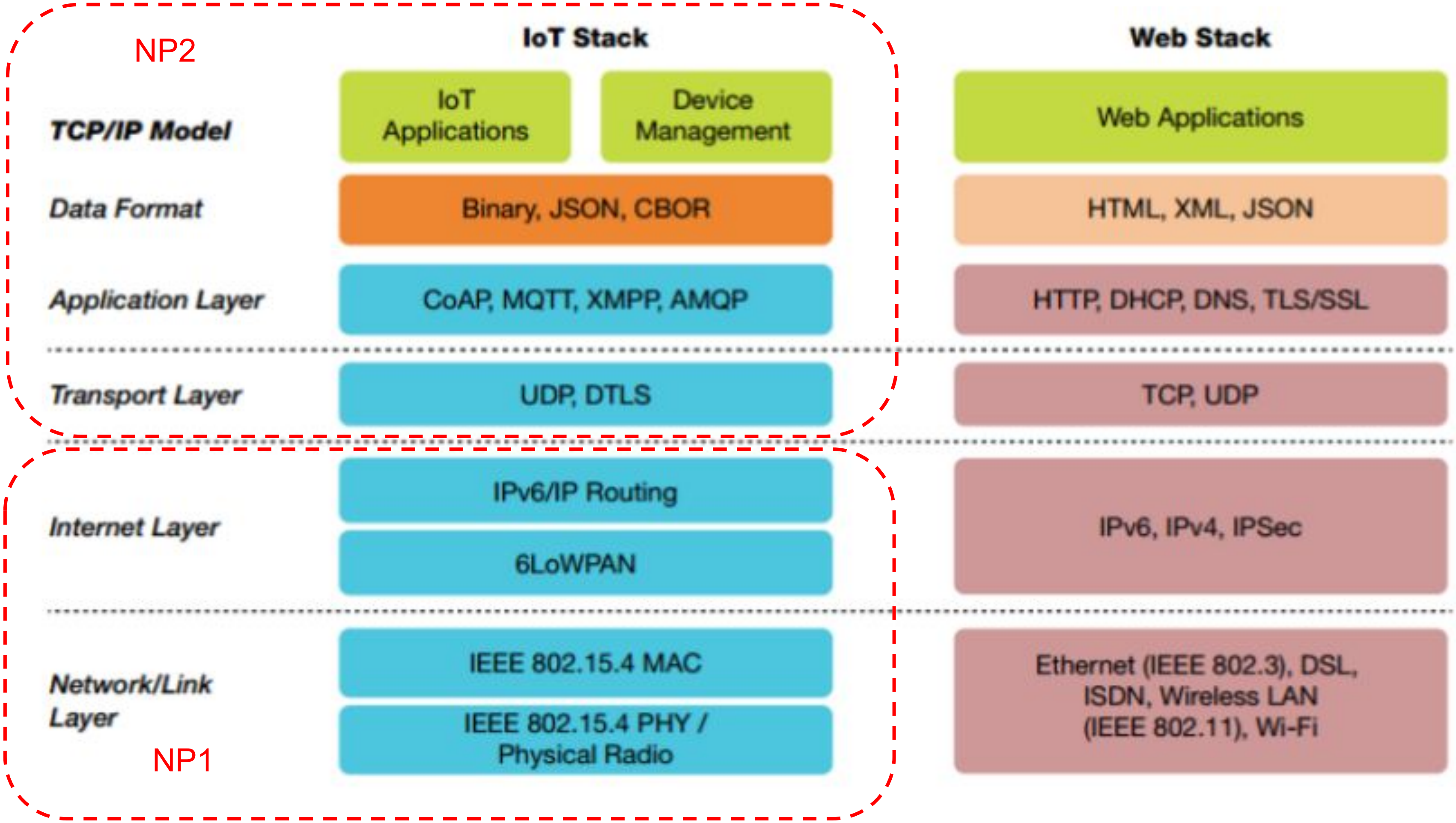
6LowPAN

802.15.4, Wifi (802.11), LoRaWAN, NB-IoT, Sigfox, BLE

UNIVERSIDAD COMPLUTENSE MADRID

What is covered in NP1

New Protocols adapted to IoT



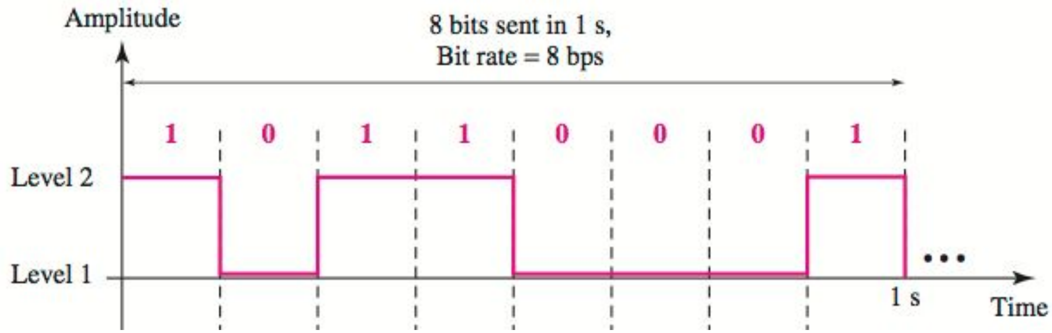
Agenda

- Basic networking concepts
- **Fundamentals of data transmission, a review of basic concepts**
- MAC layer
- Network layer
- Networks for IoT

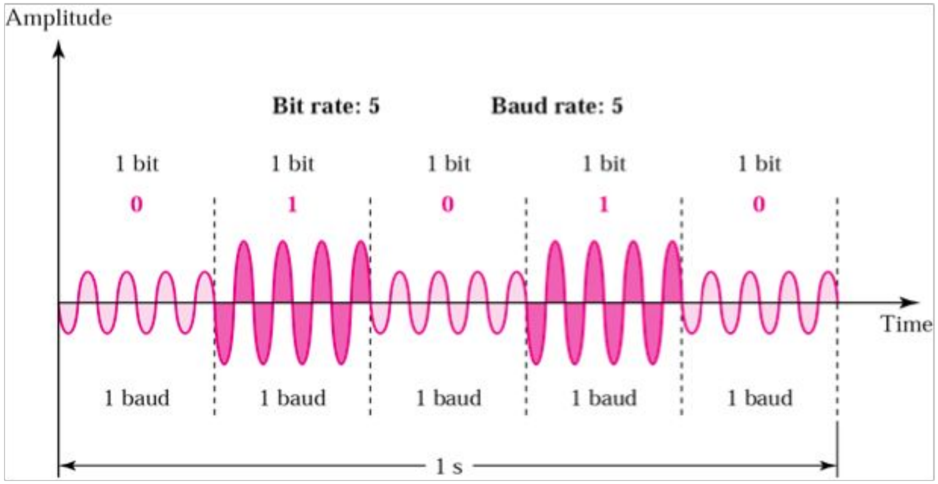
Digital communication: data and signals

- **Data**: transmitted information, sequence of bits
  - e.g.: 10110001
- **Signals**: electromagnetic codification used to send information through a medium

Digital: base band

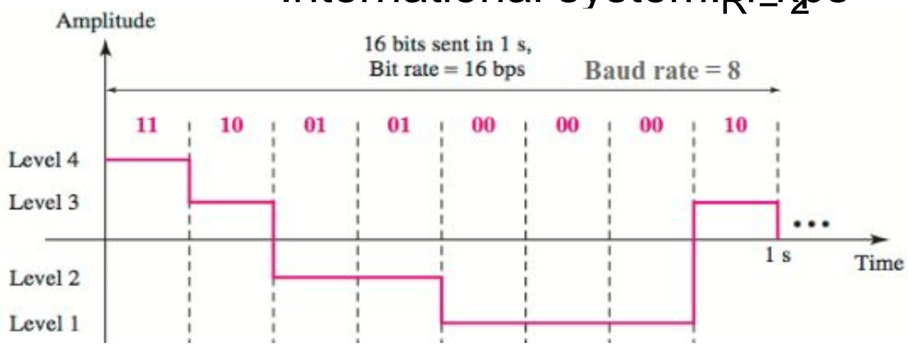


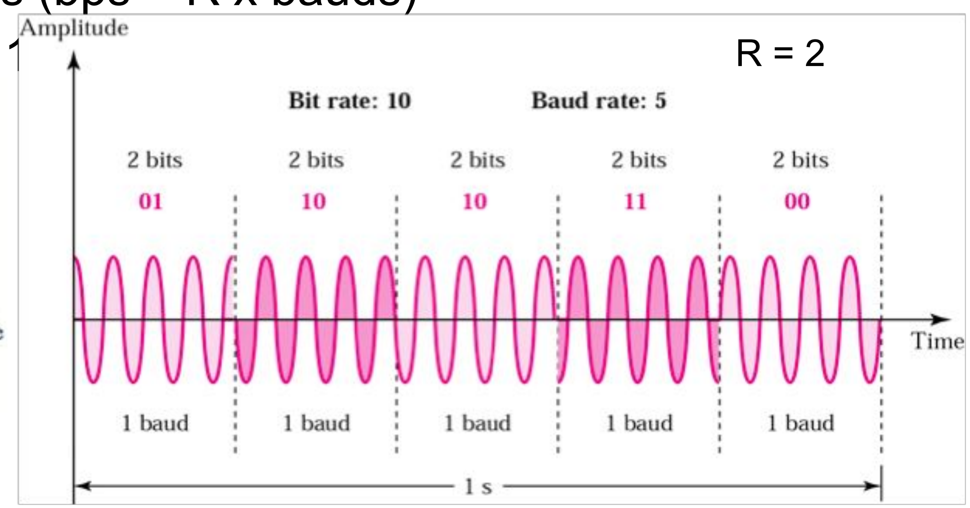
Analog: digital signal modulates an analog carrier signal



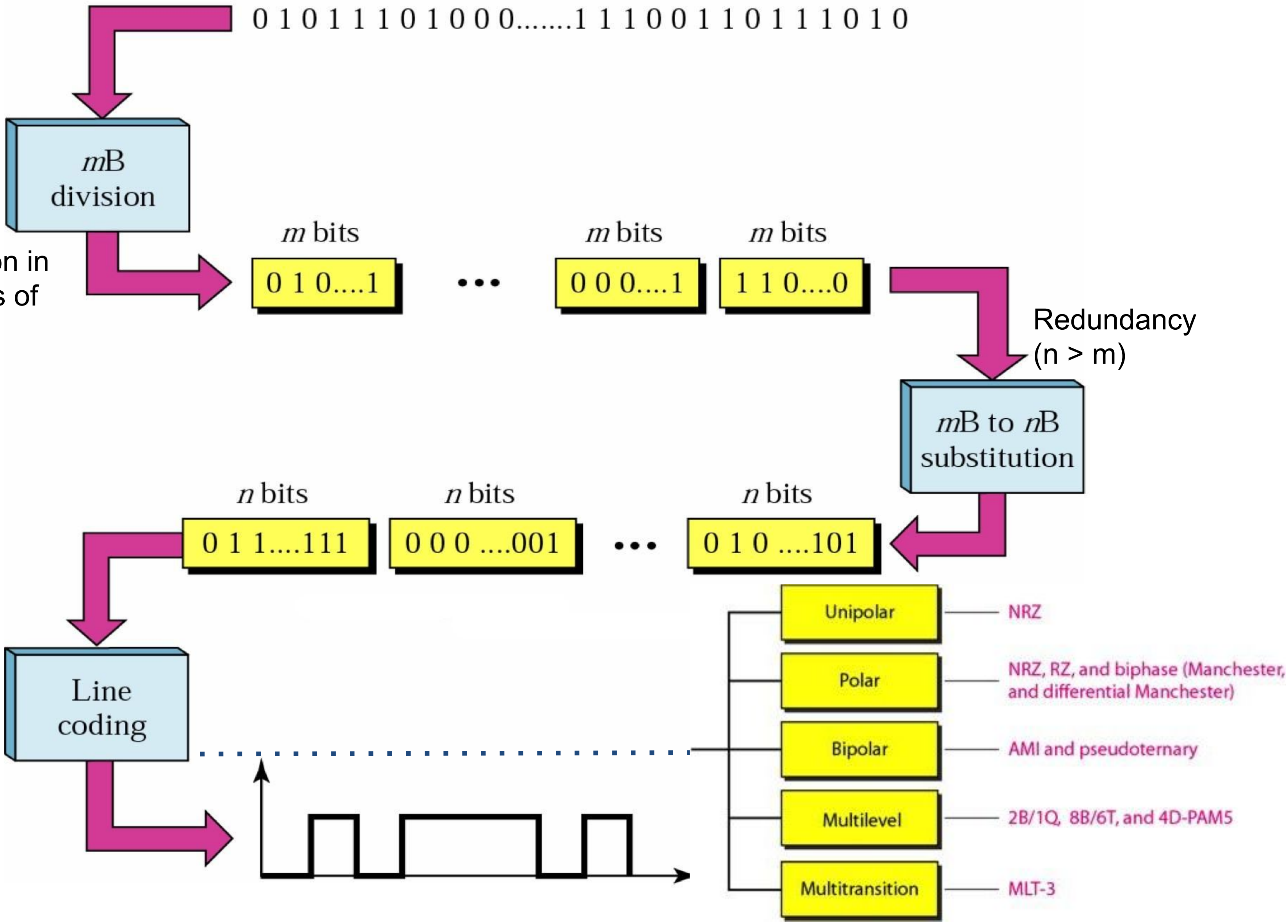
Signal and data elements

- Data elements: binary digit - bit -
- Signal elements:
  - Symbol: waveform used to represent the bits
    - It has a certain time duration
  - With $V = 2^R$ different symbols we can represent R bits per symbol
    - R < 1: more than one symbol is used to represent one bit (redundancy)
- Transmission rate
  - Bauds: transmission rate in symbols/s
  - bps: transmission rate in bits/s (bps = R x bauds)
  - International system: 1 kps = 1





Digital transmission (base band)



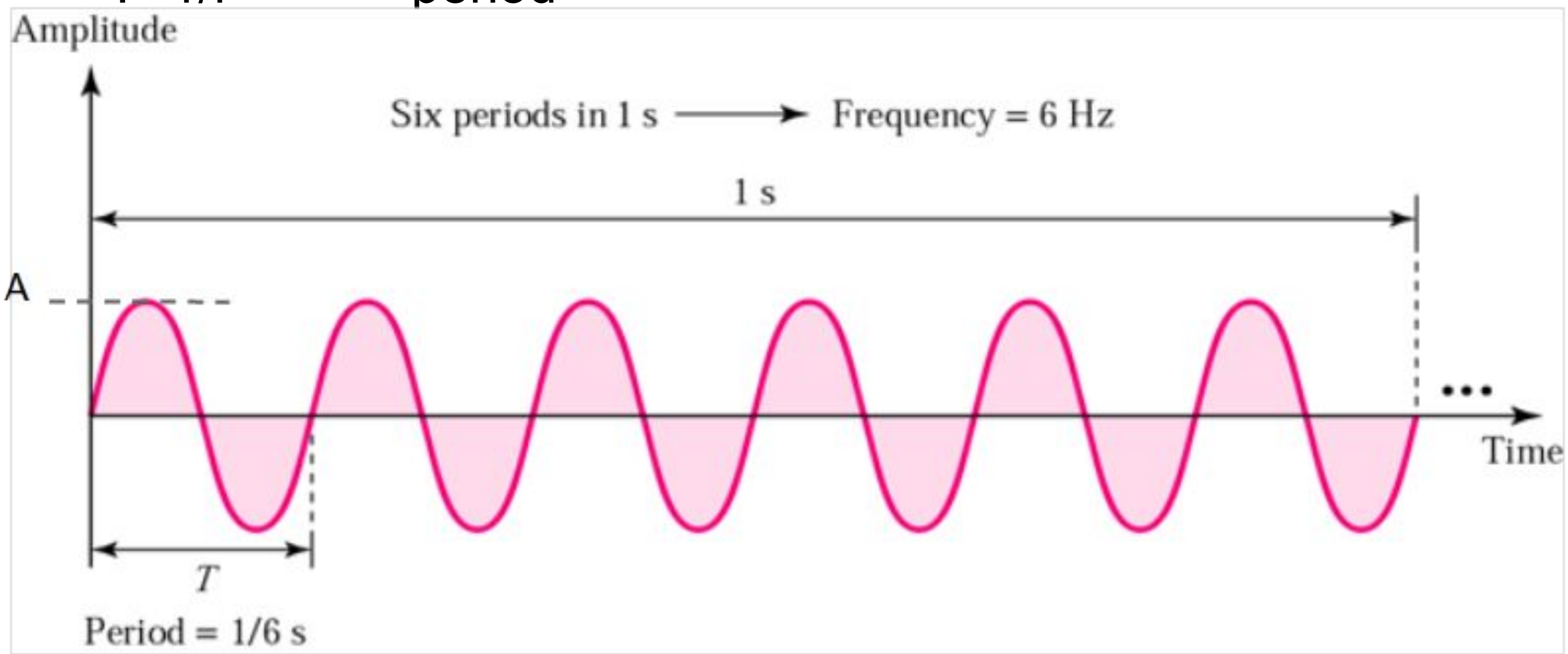
Division in groups of m bits

Redundancy (n > m)

Analog transmission (wide band)

Sinusoid signal components:

- s(t) = A sin(2 π f t + Φ), where:
- A → amplitude
- f → frequency
- Φ → phase
- T=1/f → period



Analog transmission: modulation

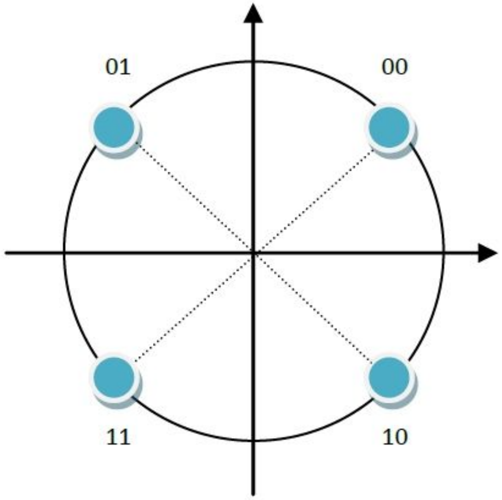
Basic schemes

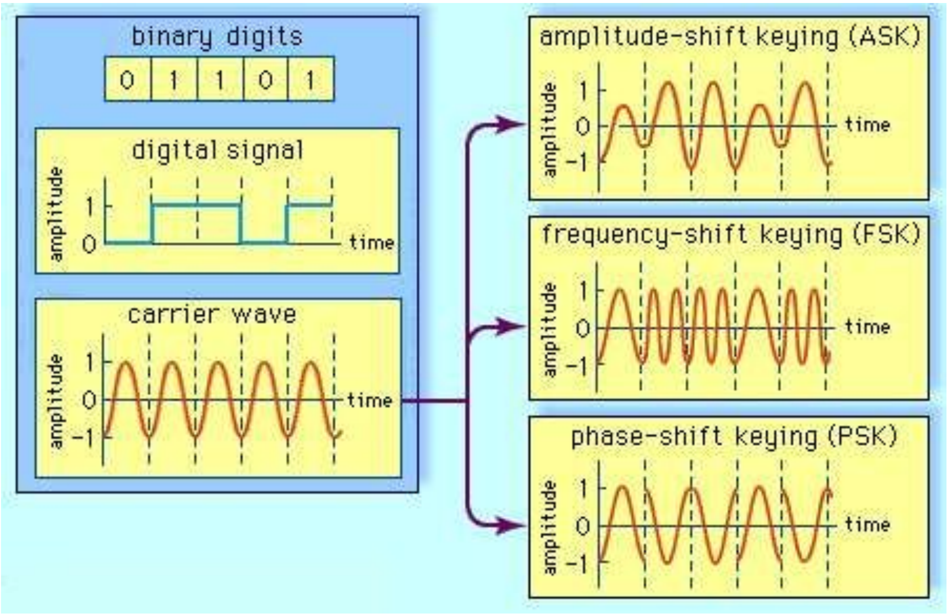
- ASK (Amplitude Shift Key)
- FSK (Frequency Shift Key)
- PSK (Phase Shift Key)

Advanced schemes:

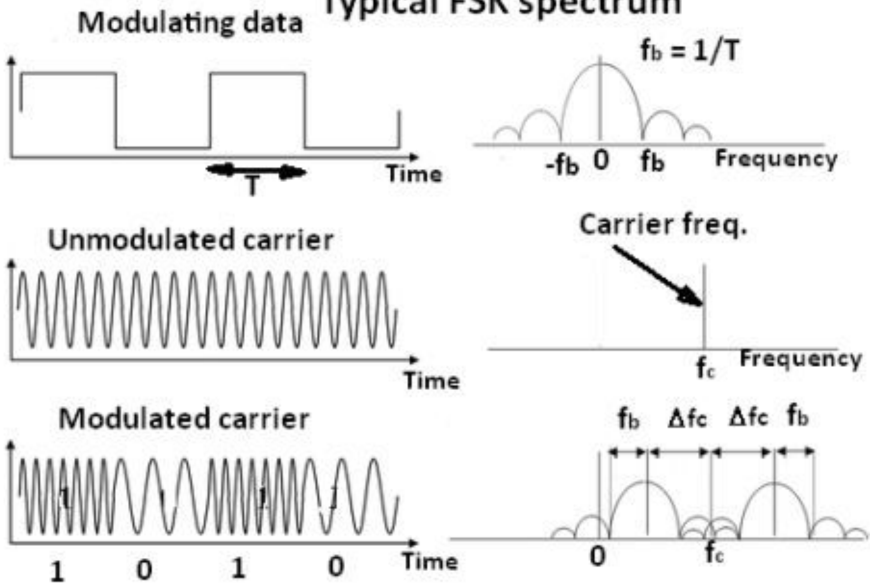
- QPSK
- 8-QAM
- ...

Constellation QPSK

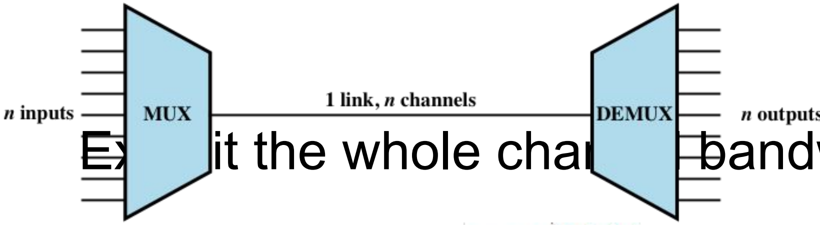




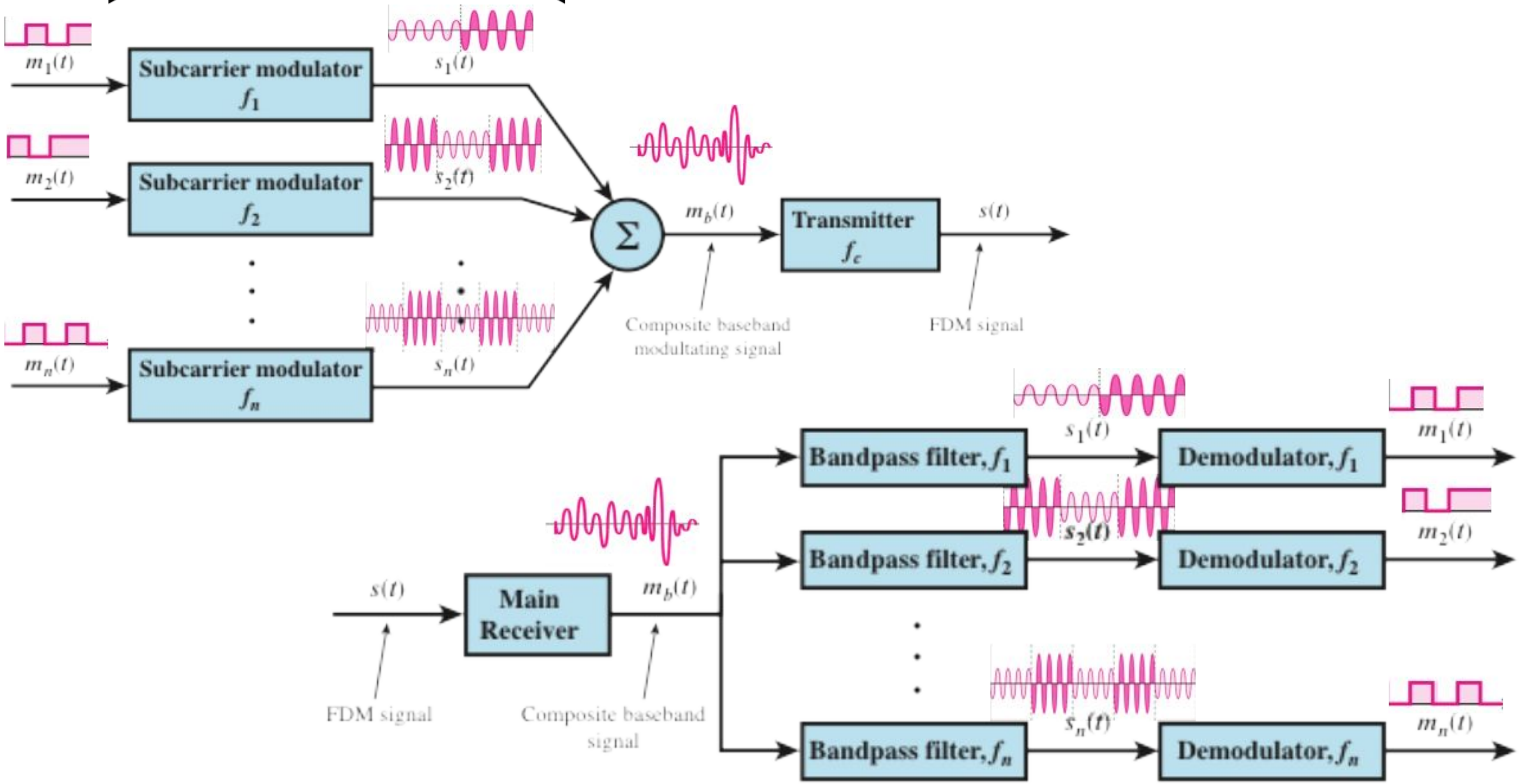
Typical FSK spectrum



Frequency Division Multiplexing (FDM)



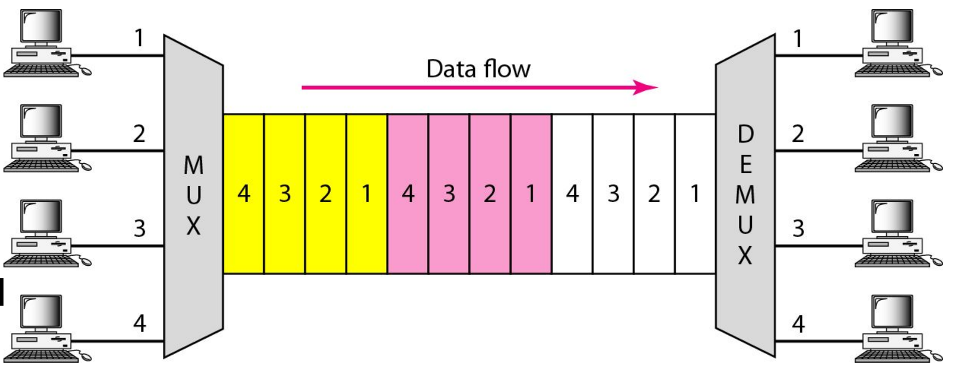
- Ex it the whole cha bandwidth



Time Division Multiplexing (TDM)

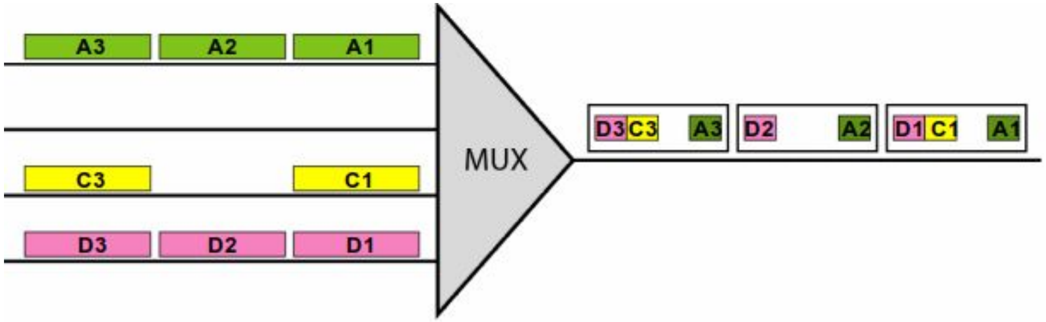
Temporal split of the channel

- Time is splitted in slots
- Each slot is assigned to a sou



Two alternatives

- Synchronous: static slot

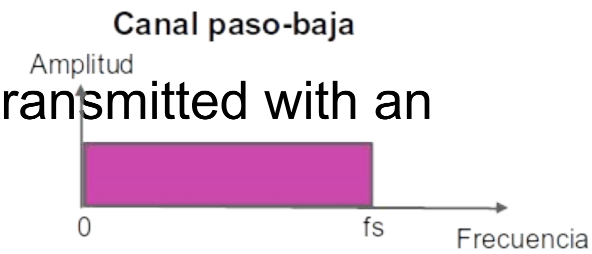


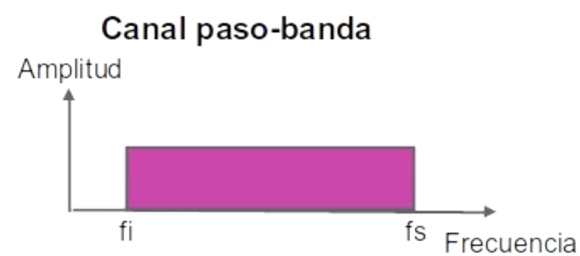
- Statistical: dynamic slot as

Channel properties

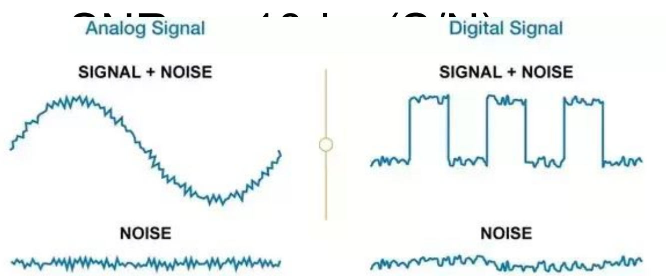
- Attenuation:
  - $A_{dB} = 10 \cdot \log(P_R/P_T)$

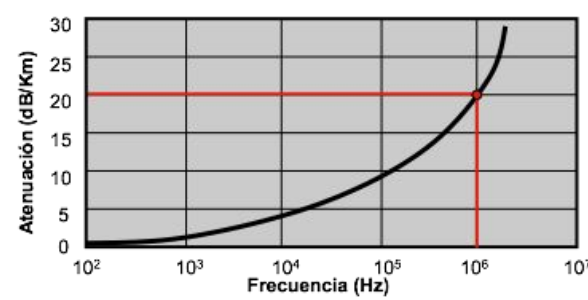
- Band width: frequency range that can be transmitted with an acceptable attenuation
  - H = fs – fi
  - Low pass: fi == 0
  - Band pass: fi != 0
    - Modulation required





- Noise:
  - SNR = 10·log(S/N)

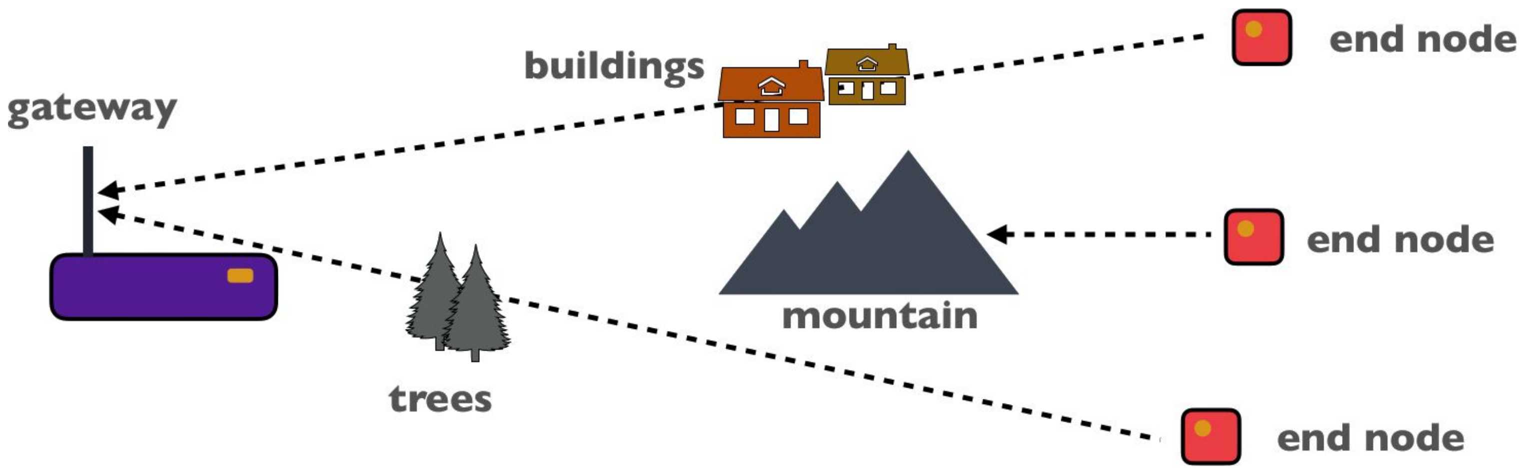




Electromagnetic wave propagation

- Line of sight: direct transmission between sender and receiver, without obstacles
  - Signals are attenuated with the distance

- Obstacles: signals are attenuated by the obstacles
  - The absorption increases with material conductivity



Electromagnetic wave propagation

Free Space Loss en dB:

$$L_{fs} = 32.45 + 20 \log D + 20 \log f$$

D: Distance between the sender and receiver in Km

f: frequency in MHz

E.g. f = 868MHz

$D = 0.01$ km, $L_{fs} = 32.45 + 20 \log(0.01) + 20 \log(868) = 51$ dB

$D = 0.05$ km, $L_{fs} = 32.45 + 20 \log(0.05) + 20 \log(868) = 65$ dB

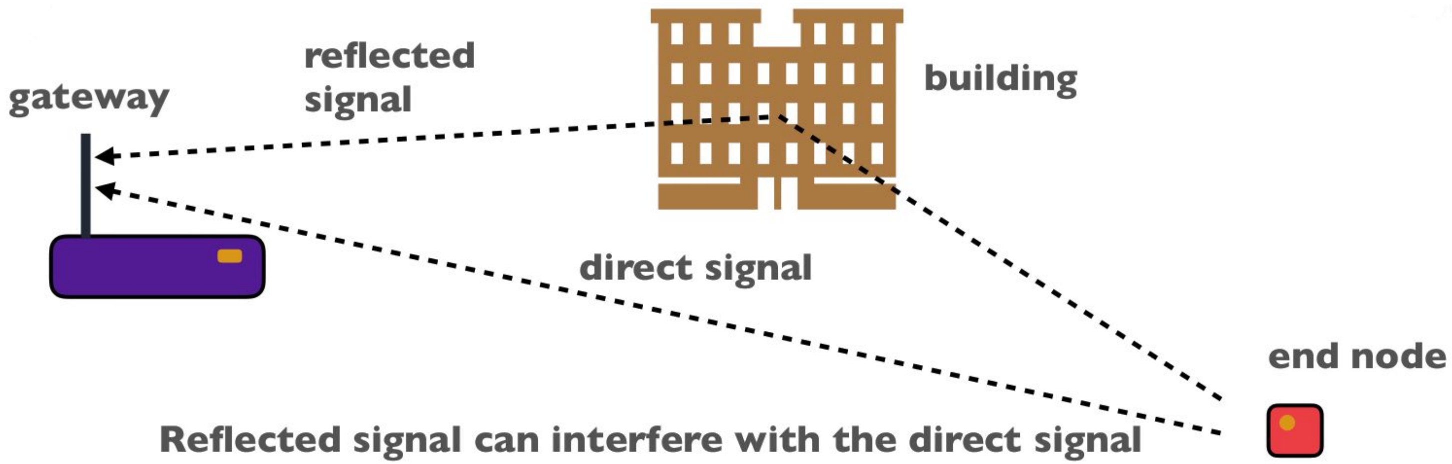
$D = 0.10$ km, $L_{fs} = 32.45 + 20 \log(0.10) + 20 \log(868) = 71$ dB

$D = 0.50$ km, $L_{fs} = 32.45 + 20 \log(0.50) + 20 \log(868) = 85$ dB

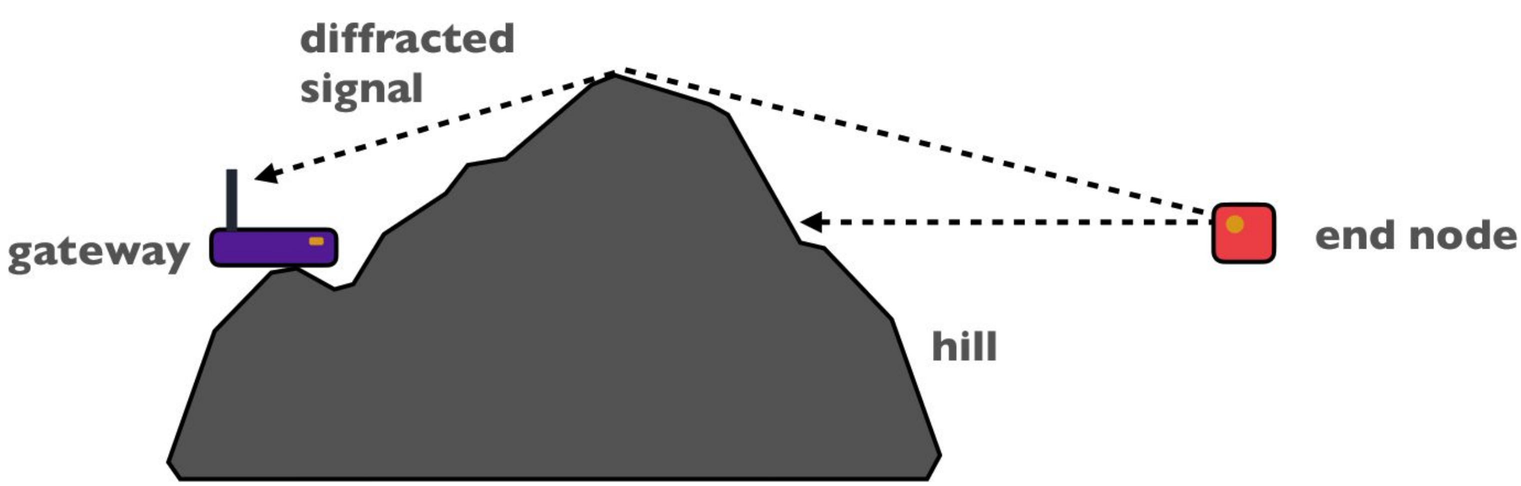
$D = 1.00$ km, $L_{fs} = 32.45 + 20 \log(1.00) + 20 \log(868) = 91$ dB

Electromagnetic wave propagation

- Obstacles can also reflect waves



- Or diffract the transmitted signal



Fresnel Zones

Points of space in which a reflection produces a shift in phase proportional to λ/2 with respect to the direct wave:

$$D = d1 + d2$$

$$\overline{AP} + \overline{PB} - D = n\frac{\lambda}{2}$$

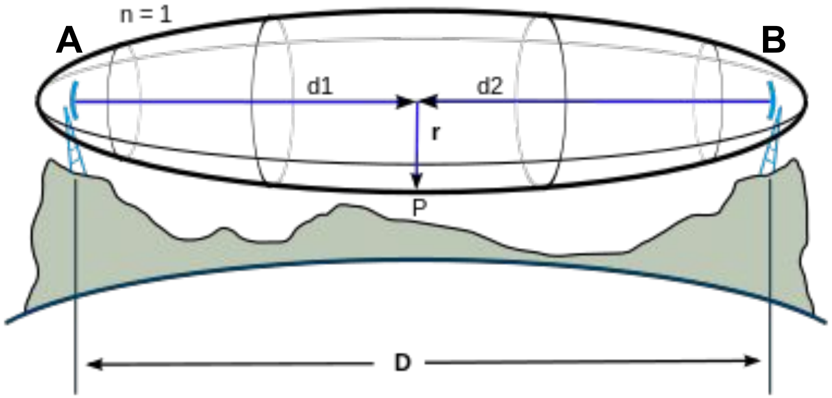
$$\sqrt{r_n^2 + d1^2} + \sqrt{r_n^2 + d1^2} - D = n\frac{\lambda}{2}$$

$$\sqrt{1 + x^2} \approx 1 + \frac{x^2}{2}$$

$$d1(1 + \frac{r_n^2}{2d1^2}) + d2(1 + \frac{r_n^2}{2d2^2}) - D = n\frac{\lambda}{2}$$

$$r_n^2(\frac{1}{d1} + \frac{1}{d2}) = n\lambda$$

$$r_n = \sqrt{n\lambda\frac{d1d2}{d1+d2}}$$



In the mid point:

$$d1 = d2 = D/2$$

$$r_n = \sqrt{n\lambda D/4} = \sqrt{\frac{nc}{4}\frac{D}{f}}$$

$$\boxed{r_n = 8.657\sqrt{n\frac{D}{f}}}$$

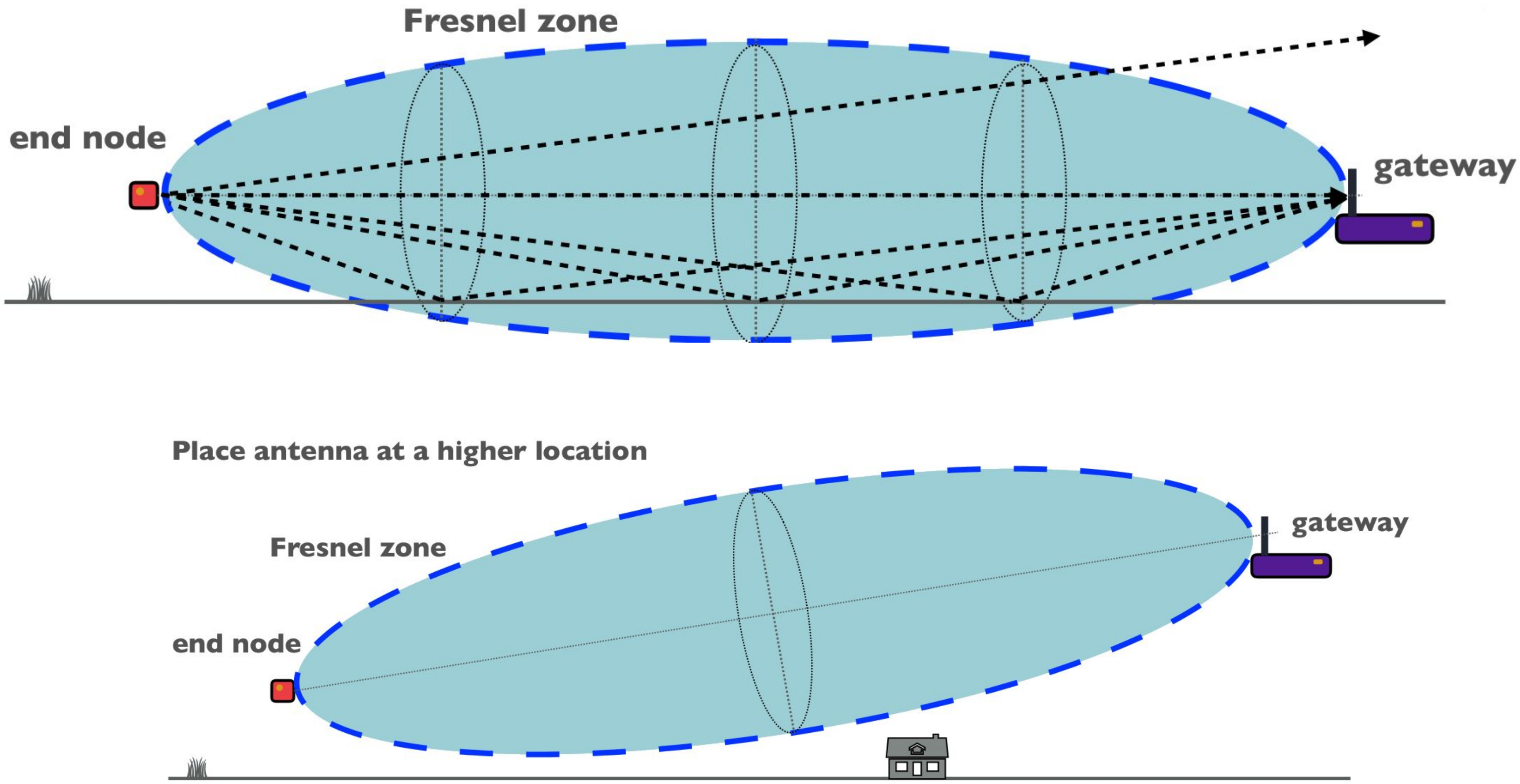
D in km
f in GHz

Obstacles should be avoided in the first Fresnel zone

Fresnel Zones

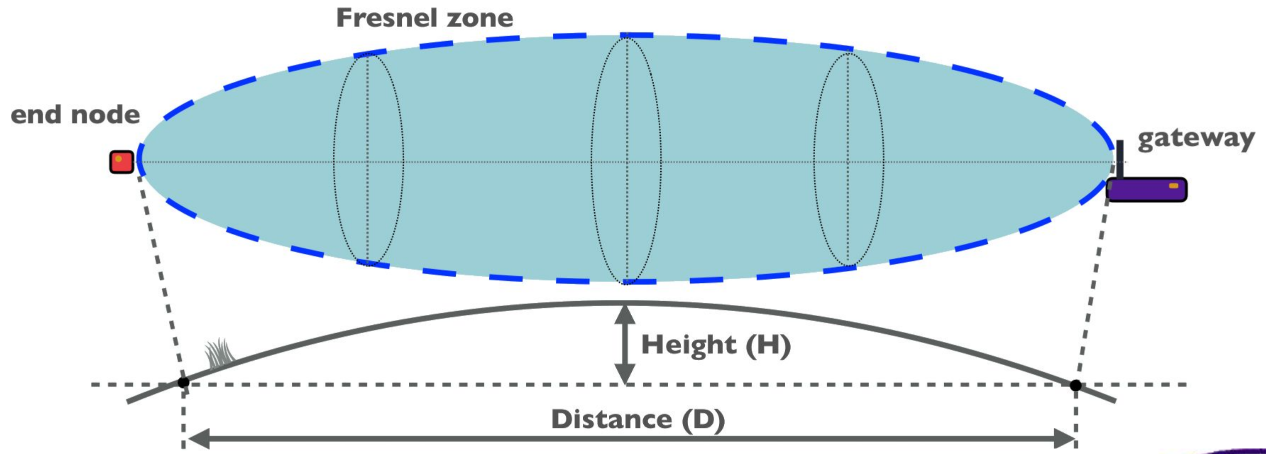
The radius of the fresnel zones increase with the distance

- Antennas can be lifted up to avoid reflexions with the ground and other obstacles

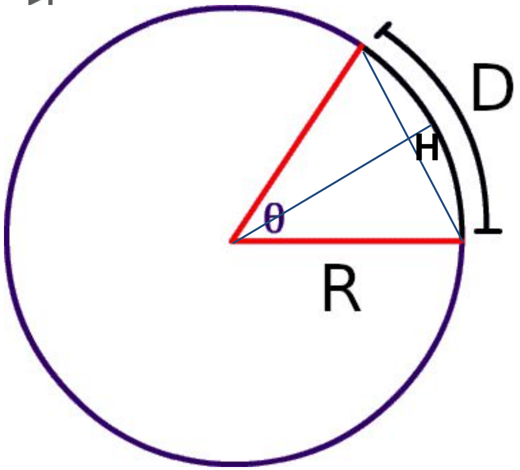


Earth curvature

The expression r = 8.657 x sqrt(D / f) does not take the earth curvature into account



$\theta = D/R$
$H = R - R\cos(\theta/2)$
$\cos(\theta/2) \cong 1 - (\theta/2)^2/2 = 1 - \theta^2/8 = 1 - D^2/(8R^2)$
$H = D^2/(8R)$

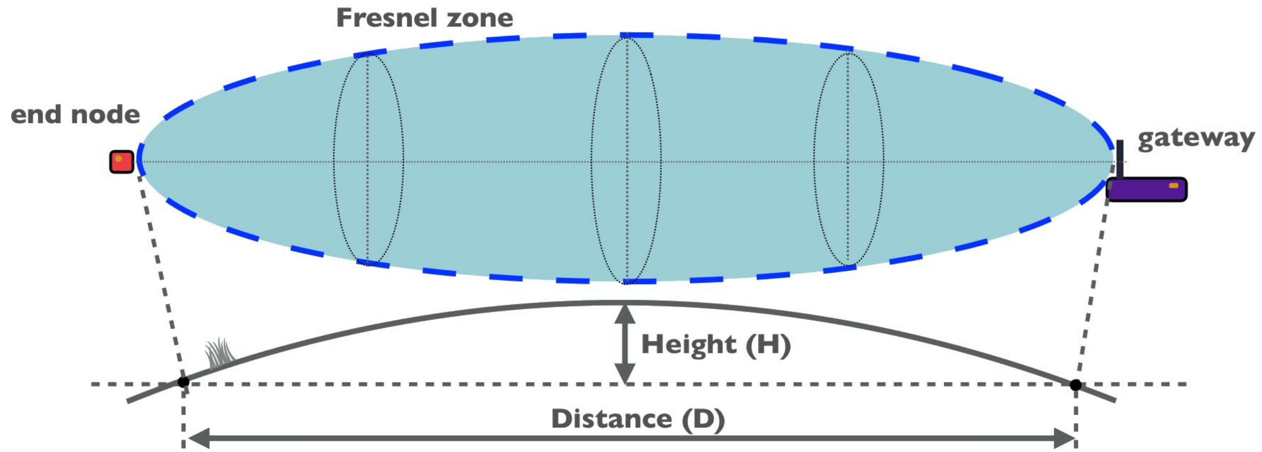


$$\boxed{H = 1000 \cdot D^2/(8 \cdot R)}$$

H height in km
R earth radius (6371 km)
D Distance between sender and receiver in km

Earth Curvature

https://www.zytrax.com/tech/wireless/calc.htm#fresnel

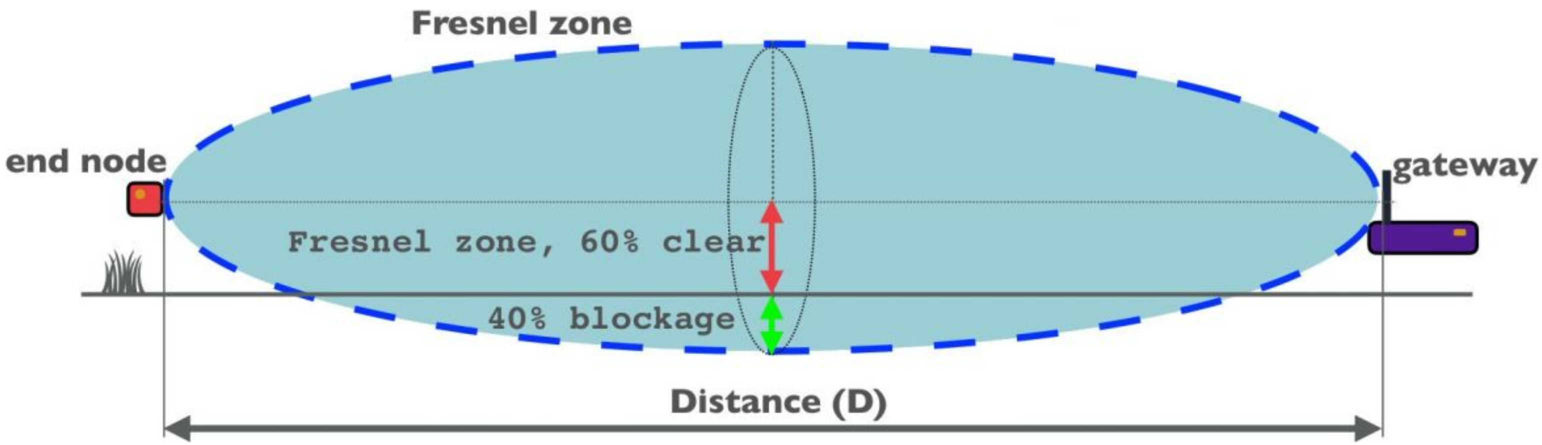


D (km)	H (m)
0.1	negligible
0.5	negligible
1	negligible
2	negligible
5	0.49

D (km)	H (m)
10	1.96
15	4.41
20	7.84
25	12.26
30	17.65

Fresnel zone: rule of thumb 60/40

A good compromise is to have at least 60% of the first fresnel zone free of obstacles

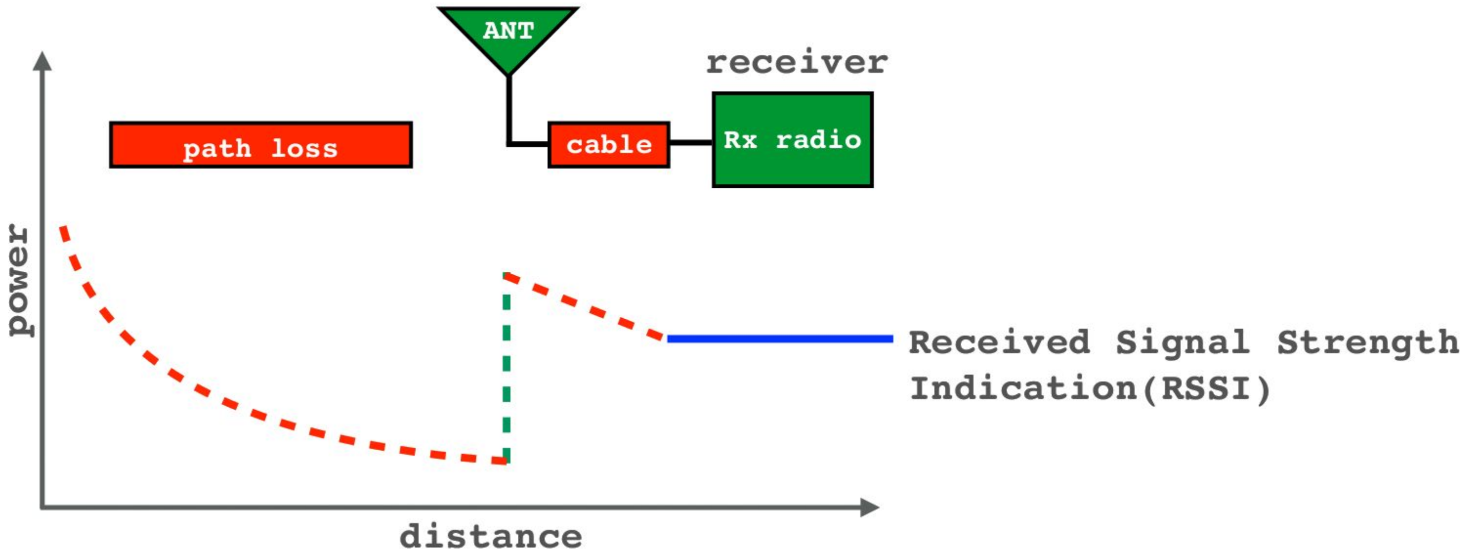


f = 868MHz

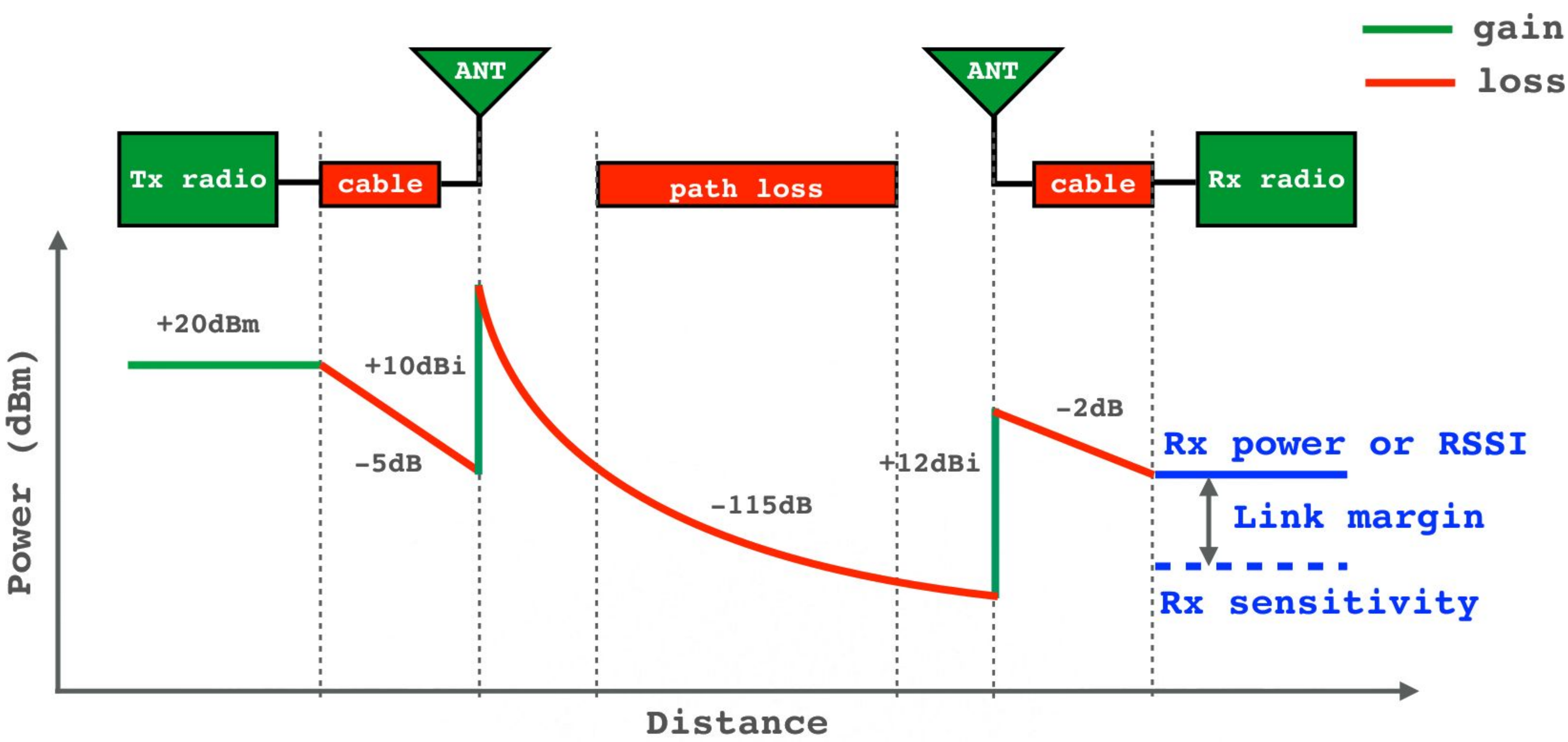
D (km)	r (m)	H (m)	0.6 r (m)	0.6r + H (m)
0.1	2.94	0.0002	1.76	1.76
0.5	6.57	0.0049	3.94	3.95
1	9.29	0.0196	5.57	5.59
2	13.14	0.0785	7.88	7.96
5	20.78	0.4905	12.47	12.96
10	29.38	1.9620	17.63	19.59

Received Signal Strength Indication (RSSI)

- Received power, expressed in dBm
- Is an indication of how well the emitted signal is received
  - Usually a negative value, the closer to zero the better



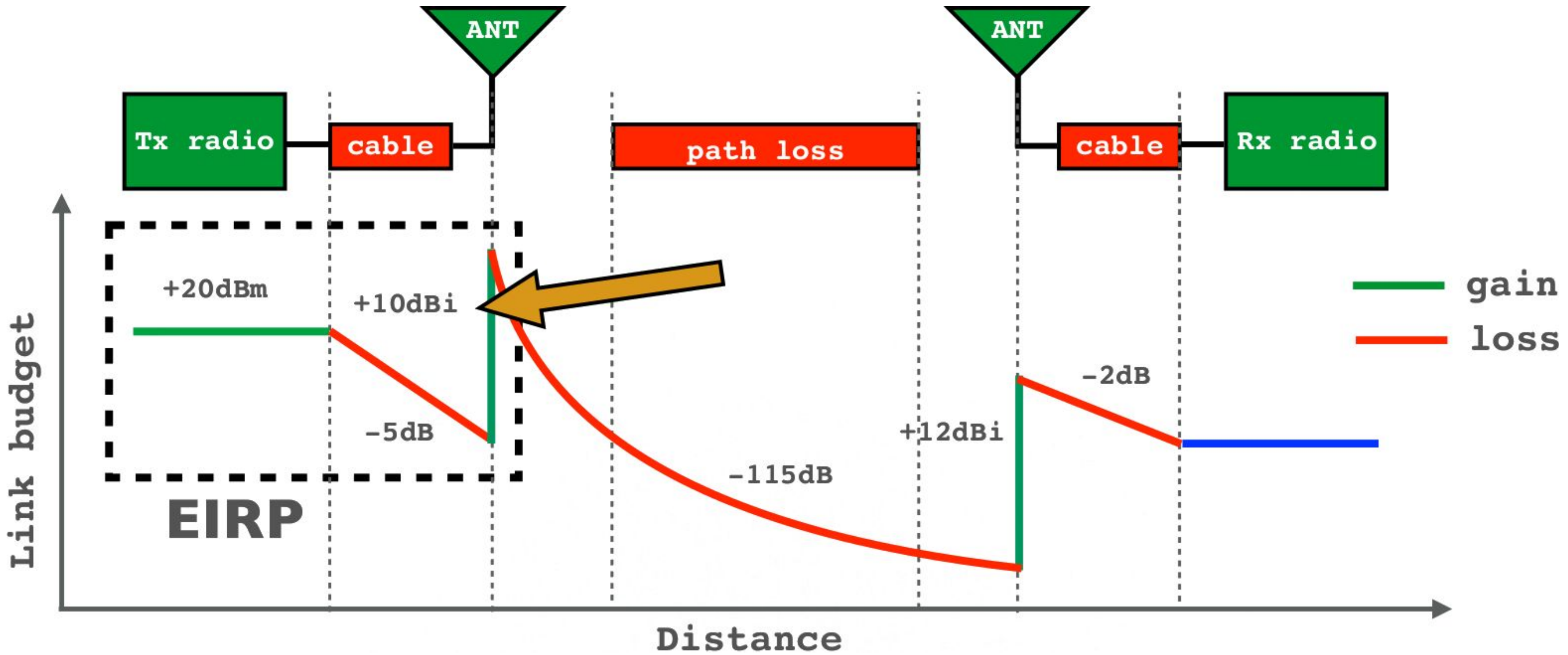
Link Margin



RSSI - Received Signal Strength Indication

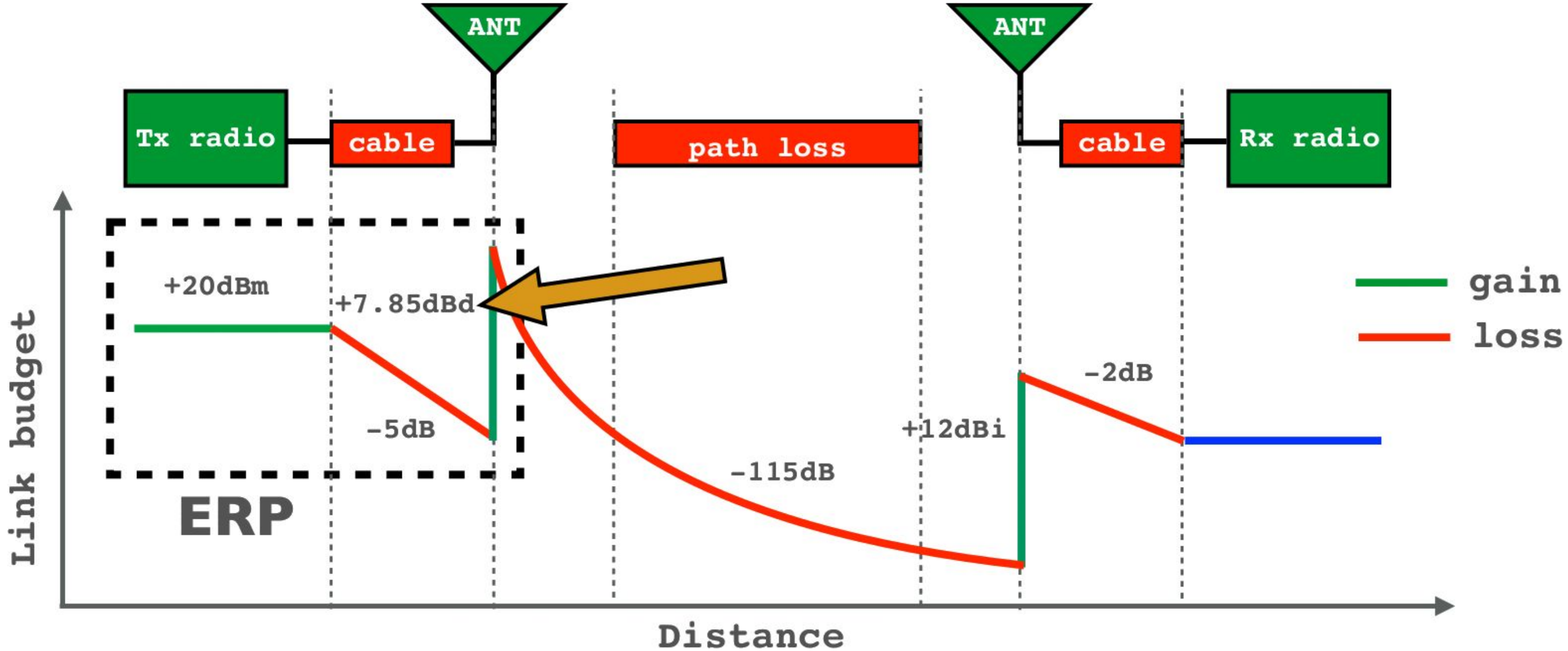
Effective Isotropic Radiated Power (EIPR)

- Effective radiated power with respect to a hypothetical isotropic antenna
  - The gain of the emitter antenna is expressed in dBi



Effective Radiated Power (ERP)

- Effective radiated power with respect to an half wave dipole antenna (λ/2)
  - The gain of the emitter antenna is expressed in dBd



ERIP (dBm) = ERP (dBm) + 2.15

Agenda

- Basic networking concepts
- Fundamentals of data transmission, a review of basic concepts
- **MAC layer**
- Network layer
- Networks for IoT

MAC layer

Responsibilities:

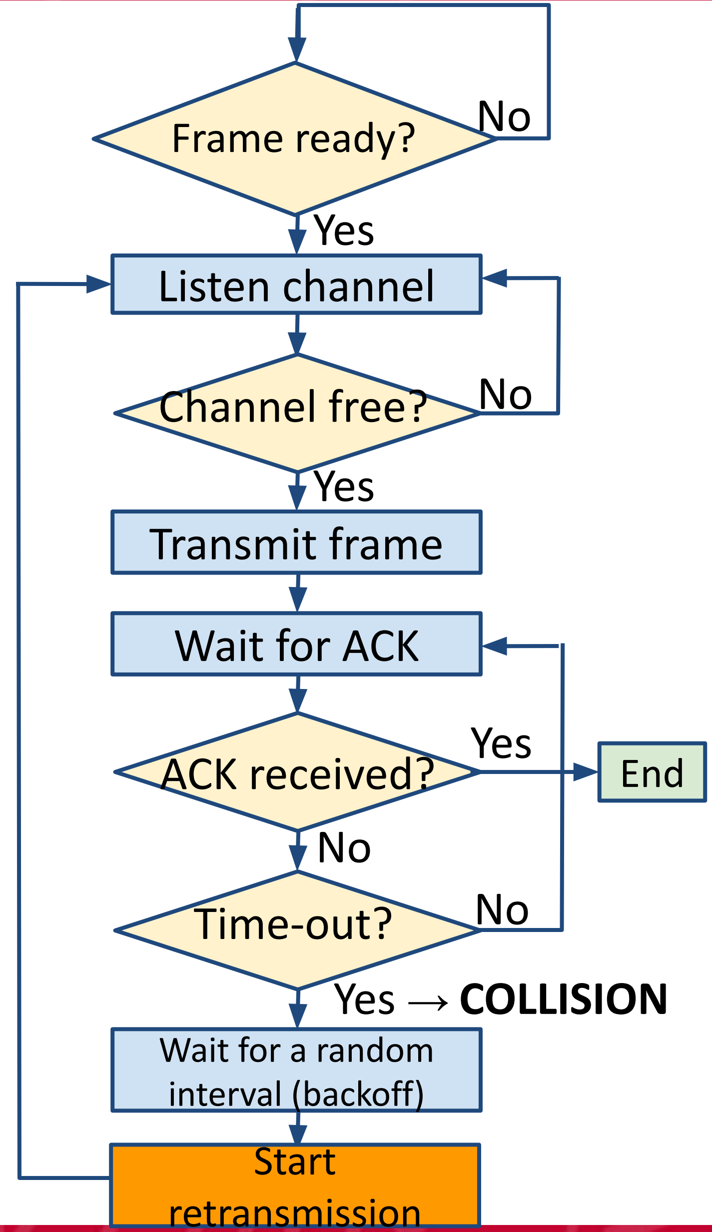
- Framing
- Identification (seq. numbers and MAC addressing)
- Error detection
- Medium access and collision detection

Ethernet networks

- **Ethernet MAC protocol**
  - Ethernet uses CSMA/CD as MAC protocol, which is based on CSMA
    - CSMA = *Carrier Sense Multiple Access*
    - CSMA/CD = *Carrier Sense Multiple Access / Collision Detection*
    - Both are distributed protocols and collisions are possible
    - CSMA/CD is more efficient as it can detect collisions and effectively react to them

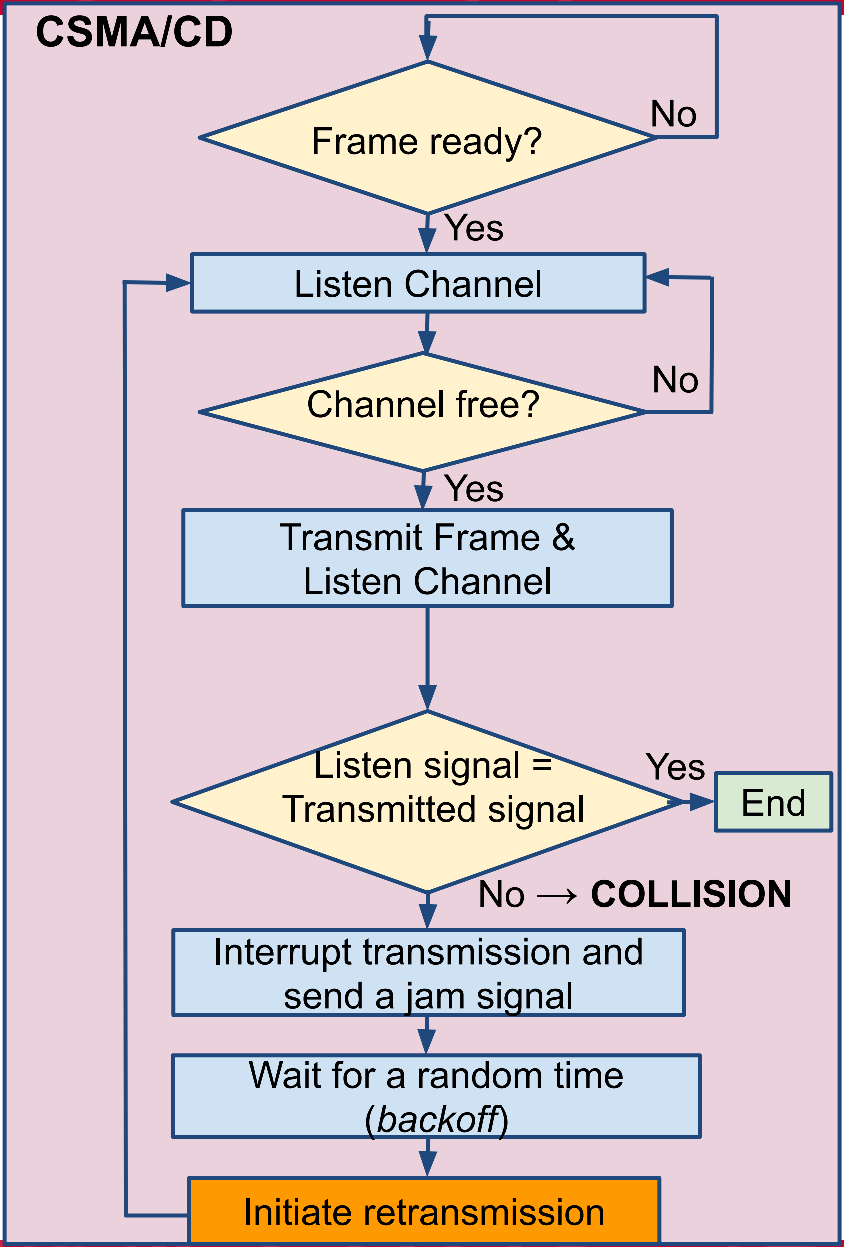
CSMA

- When a computer has a frame ready to be sent, it first listens the channel, and sends only if it is free
- Each frame must be acknowledged (ACK) by the receiver to confirm a correct reception without collisions
- In case of collisions:
  - If the computers involved retransmit immediately after the time-out for an ACK reception, a collision will happen again
  - To avoid it the computers must wait a random backoff time to start a new transmission



CSMA/CD

- The emitter listen the channel while the frame is being send
- If the listened signal differs from the send signal, a collision is detected
- The transmission must last long enough for a transmission started at the farthest point be perceived before the end of the frame transmission



Agenda

- Basic networking concepts
- Fundamentals of data transmission, a review of basic concepts
- MAC layer
- **Network layer**
- Networks for IoT

Network layer: IP protocol

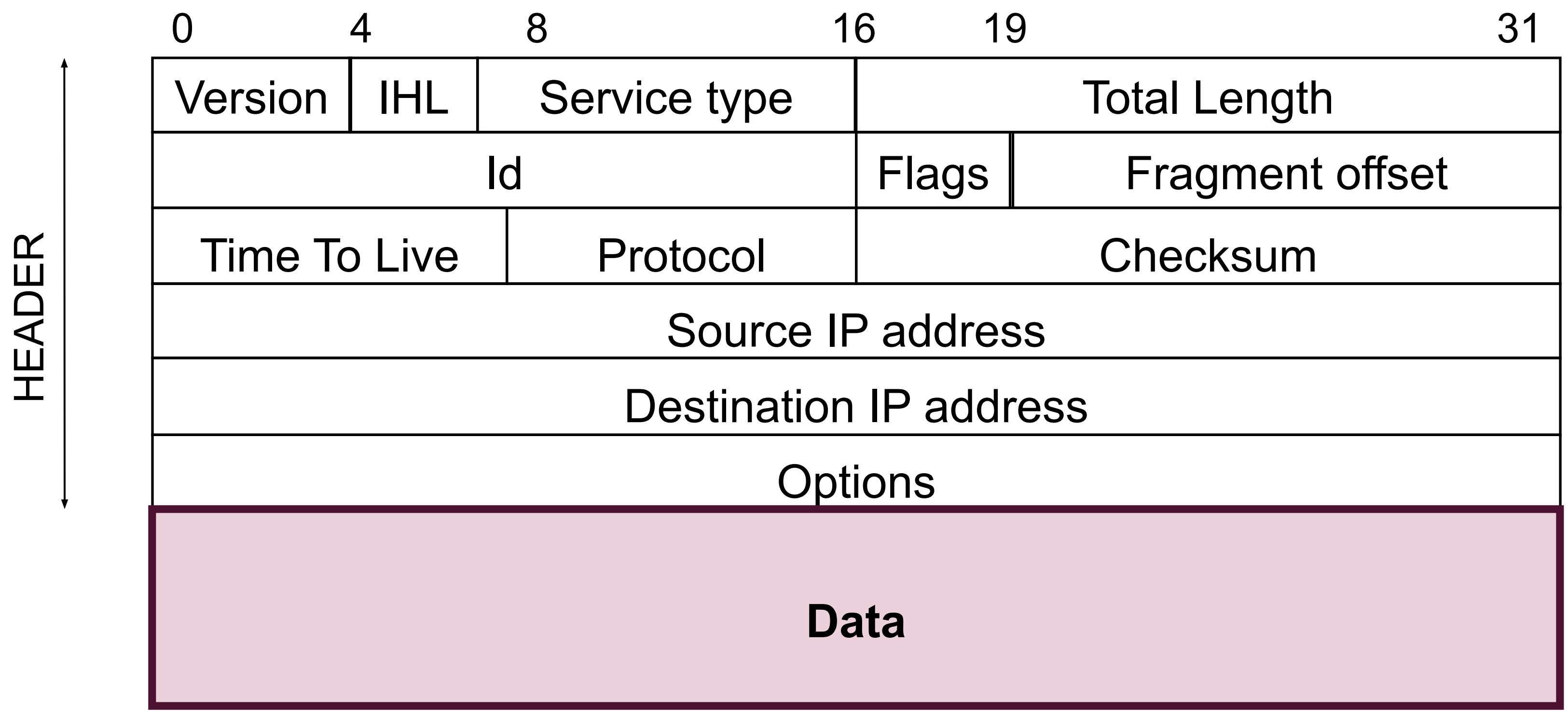
Internet Network Protocol

- Provides a basic datagram delivery service
  - TCP/IP networks are build on top of this service
- It is a connectionless oriented protocol (not reliable)
  - It does not detect nor recover lost or erroneous datagrams
  - Datagrams are not guaranteed to arrive in order
  - Duplicate datagrams are not detected/removed

Basic responsibilities of the IP protocol

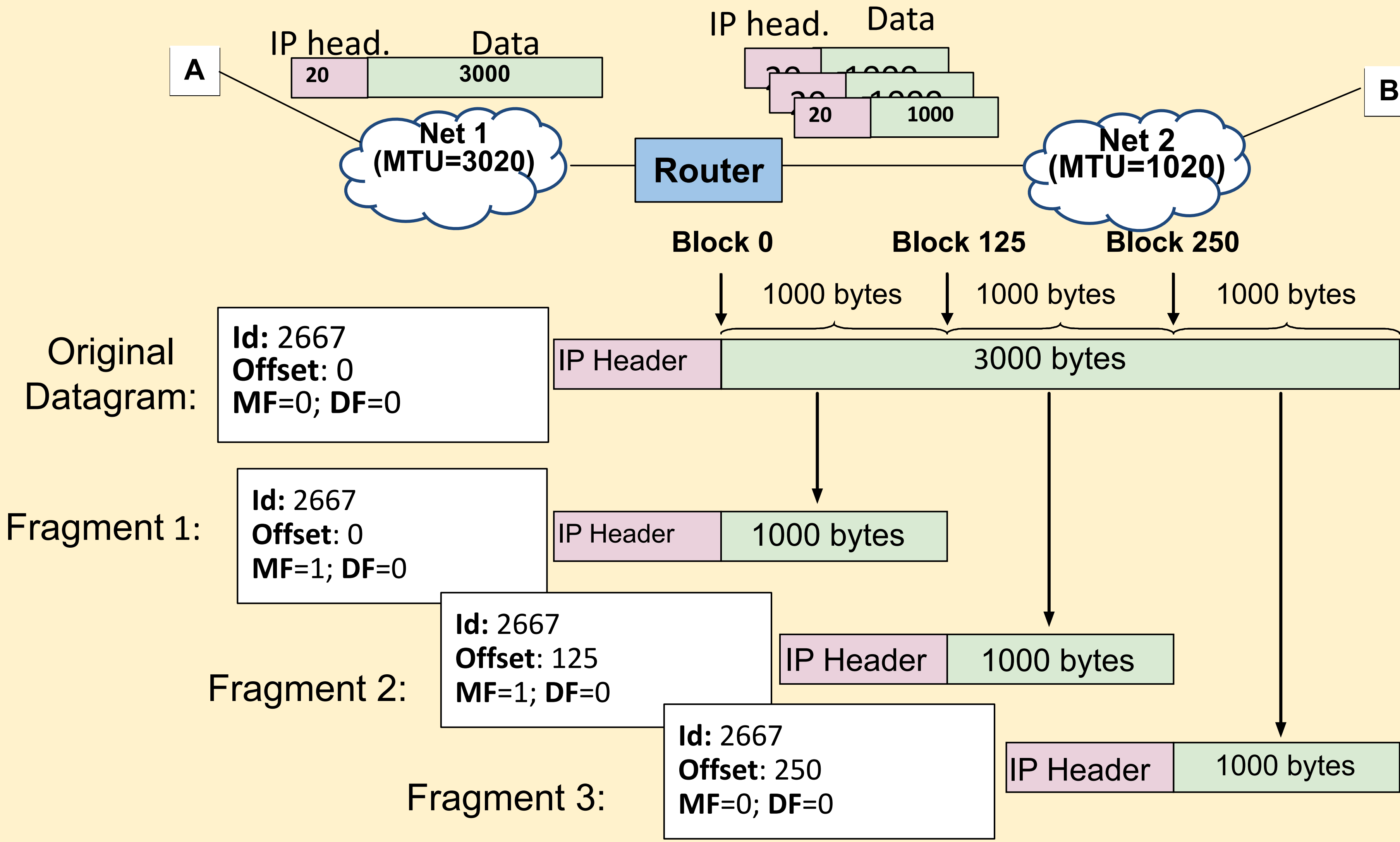
- **Global addressing**
  - Unique address in the Internet
- **Datagram Fragmentation and reassembly**
  - Datagram is divided into fragments of the appropriate size for the underlying network
- **Forwarding** of datagrams
  - Forwarding is done based on the routing information stored in routing tables
  - The information in routing tables can be:
    - Static: manually filled by system administrator
    - Dynamic: filled by some routing protocol that uses the IP services, like RIP, OSPF, BGP, etc.

IPv4: datagram format



IPv4: Fragmentation

Fragmentation Example



IPv4 addresses

- IPv4 addresses are 4 bytes (32 bits)
  - Dot Notation: each byte in decimal notation, with dot separator between bytes
  - Example: 128.2.7.9 = 10000000 . 00000010 . 00000111 . 00001001
- Types of addresses
  - Unicast: a single host
  - Multicast: a group of hosts
  - Broadcast: All hosts in my local network

Routing: Introduction to

- Routing: in a packet switched network the routing algorithm must find a path from source to destination traversing the intermediate switches or routers
- In caso of more than one valid path, the “best” one must be selected
- A metric must be selected to choose which path is the “best”
    - **Number of hops**: takes into account the number of intermediate routers that must be traversed to reach the destination
    - **Geographical distance**: takes into account the distance (in km) of the path
    - **Average latency**: usually equivalent to geographical distance, as latency is usually proportional to the length of the lines
    - **Band width**: takes into account the band width of each of the networks that must be traversed
    - **Amount of traffic**: takes into account the average usage of the lines in the path, trying to avoid saturation/congestion

Routing: Introduction to

Local Routing:

- No information of the network topology
- E.g. flooding

Static Routing:

- The network administrator manually decides the routing tables based on his knowledge of the network topology
- The network cannot adapt automatically to changes in the topology

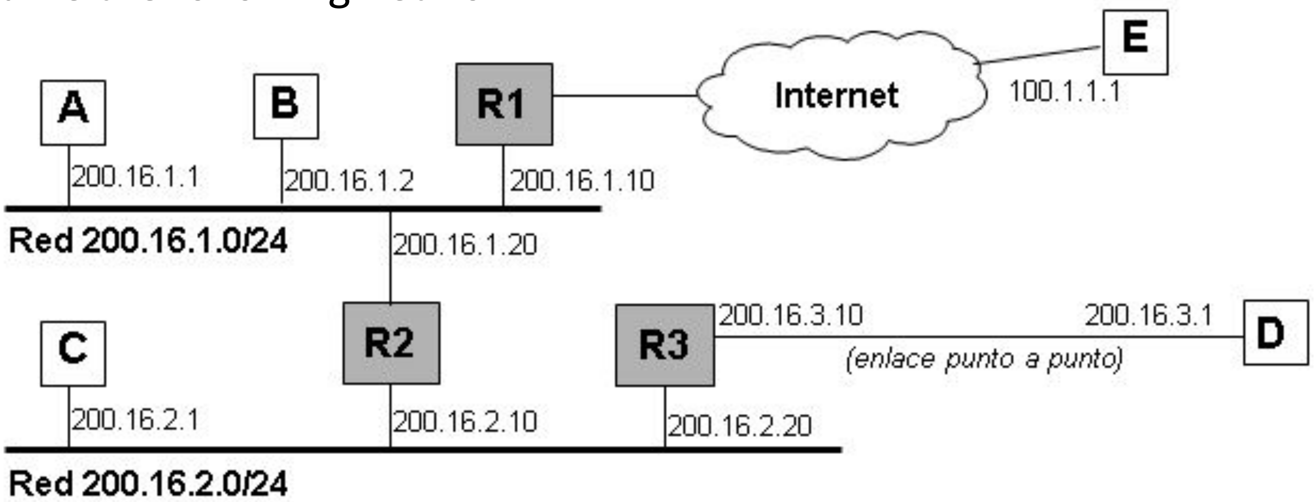
Dynamic Routing:

- The routing tables are build automatically, based on periodic information interchange between the routers in the network
- No need for manual configuration
- They adapt automatically to changes in the network
- Two common approaches
  - Distance vector algorithms: e.g. RIP
  - Link state algorithms: e.g. OSPF

IPv4 forwarding

Routing tables in IPv4

- Example: assume the following network



  - The routing table for host A could be the following:

```
      # route -n
      Kernel IP routing table
      Destination   Gateway       Genmask          Flags   Iface
1---> 200.16.1.0    0.0.0.0       255.255.255.0    U       eth0
2---> 200.16.2.0    200.16.1.20   255.255.255.0    UG      eth0
3---> 200.16.3.1    200.16.1.20   255.255.255.255  UGH     eth0
4---> 0.0.0.0       200.16.1.10   0.0.0.0          UG      eth0
```

IPv4 is obsolete

- IPv4 uses 32 bits addresses
  - Máximum of 4.294.967.296 different addresses
  - Class addressing does not allow to use them all (~250 million)
- Problem with *class* addressing
  - A lot of class B addresses are required, we have run out of them
  - Several consecutive class C addresses have been used as a superclass network address to solve this problem
  - Routing tables growth too large
- CIDR (Classless Interdomain Routing) alleviates the problem
  - The routing tables store also the network mask
    - Helps to reduce the number of entries required in the routing tables
    - We can assign blocks of addresses better suited to the required size
- NAT (Network Address Translation) is used to save public IP addresses
  - A router hides a local network from the rest of the Internet.
  - The routers appears as a single machine with only one public IP address to the rest of the Internet
- CG-NAT (Carrier Grade NAT) used by ISP as a double NAT
  - Your router has no more a public IP, you cannot serve from home!

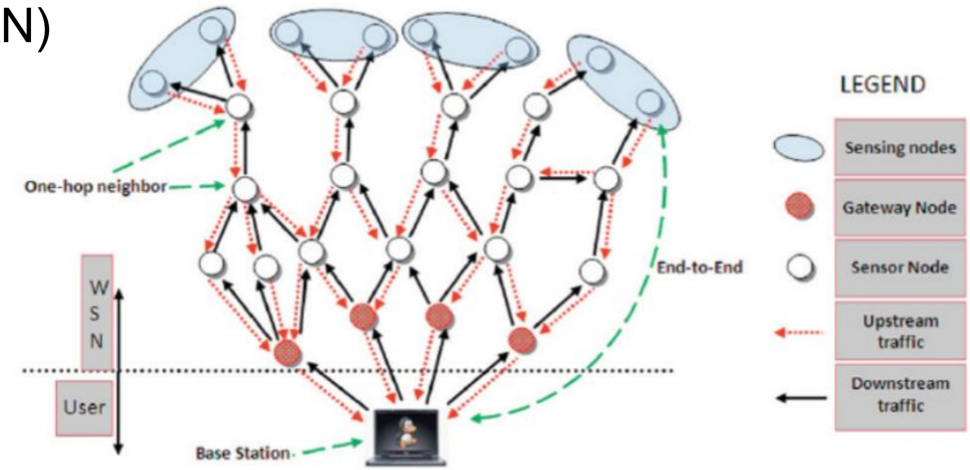
WE RUNNED OUT OF IPv4 ADDRESSES!!!

Agenda

- Basic networking concepts
- Fundamentals of data transmission, a review of basic concepts
- MAC layer
- Network layer
- **Networks for IoT**

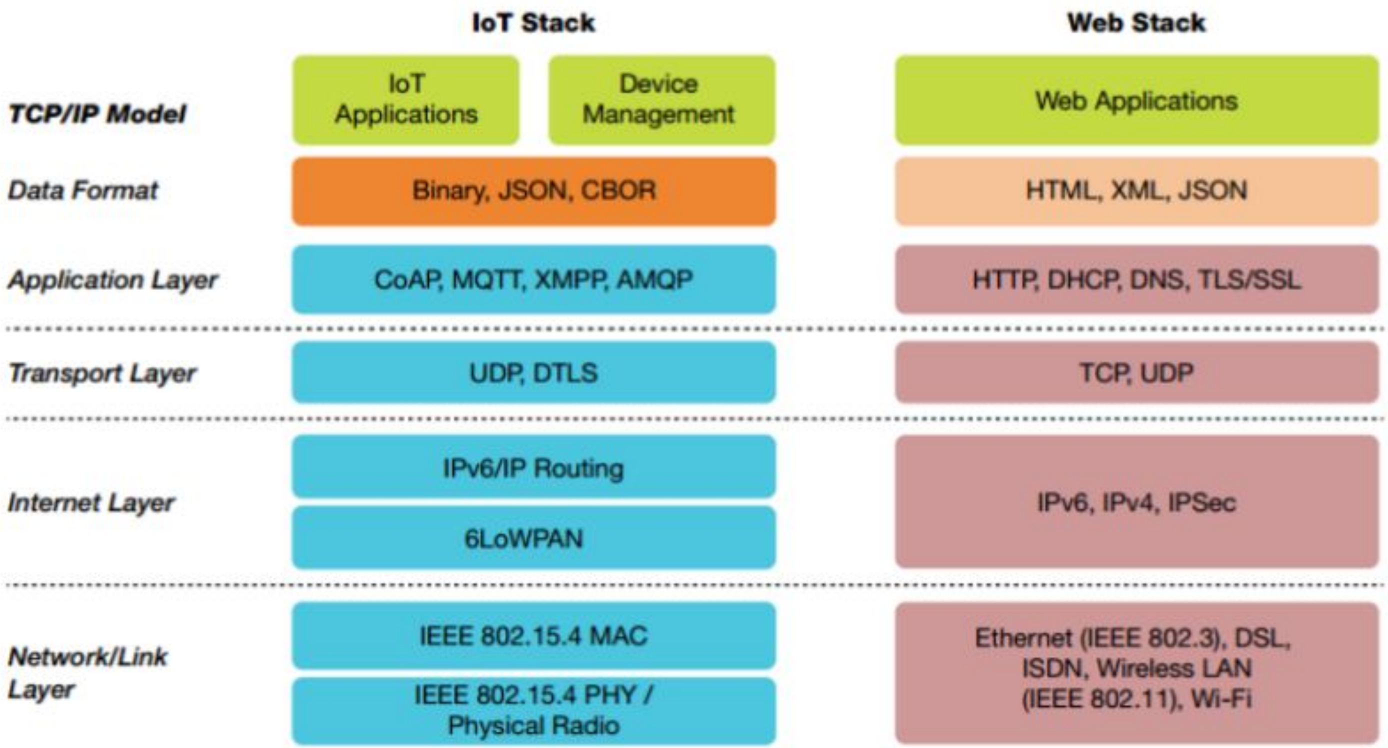
Wireless networks for IoT

- Simple protocols, with low bandwidth and low power consumption
  - Efficient bandwidth exploitation is key
  - Simple nodes, low computational capabilities, battery powered
- Disparity of ranges
  - Personal Area Networks (PAN)
  - Wide area Networks (WAN)
- Large number of nodes, with low bandwidth
  - Gateway, interface with the exterior
  - Limited Bandwidth
  - Several topologies possible



Specific IoT stacks

- IETF (Internet Engineering Task Force) has developed alternative protocols (designed specifically) for IoT on top of IPv6
- The IPSO (Internet Protocol for Smart Objects) Alliance has published alternative standards and protocols for each layer of the TCP/IP stack



Global perspective

LAN

Short Range
Communicating Devices

Bluetooth 4.0 · WiFi

35% SOM

- ✓ **Well established standards**
- ✓ **Good for:**
  - Mobile devices
  - In-home
  - Short range
- ❑ **Not good:**
  - Battery life
  - Long range

LPWAN

Long Range w/ Battery
Internet of Objects

LoRa

55% SOM

- ✓ **Emerging PHY solutions**
- ✓ **Good for:**
  - Long range
  - Long battery
  - Low cost
  - Positioning
- ❑ **Not good:**
  - High data-rate

Cellular

Long Range w/Power
Traditional M2M

3G+ · H+ · GSM · 4G

10% SOM

- ✓ **Well established standards**
- ✓ **Good for:**
  - Long range
  - High data-rate
  - Coverage
- ❑ **Not good:**
  - Battery life
  - Cost