



UNIVERSIDAD
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Networks and Protocols 1

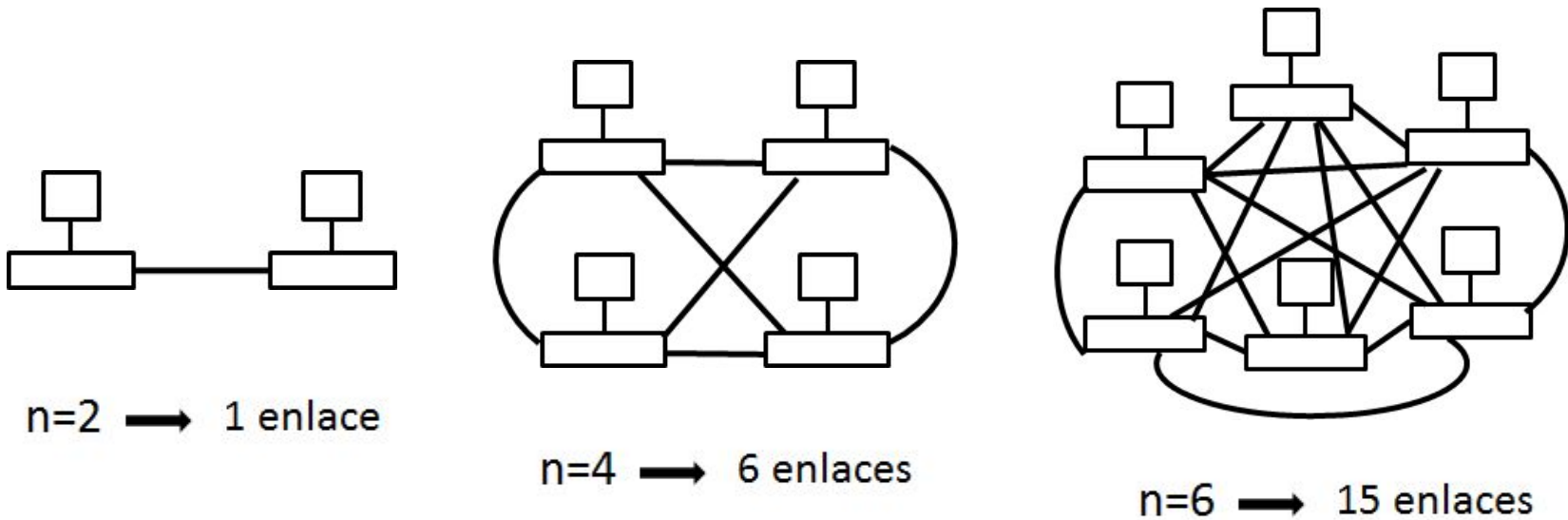
Basic Concepts

Facultad de Informática

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

- 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

- 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



- **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**

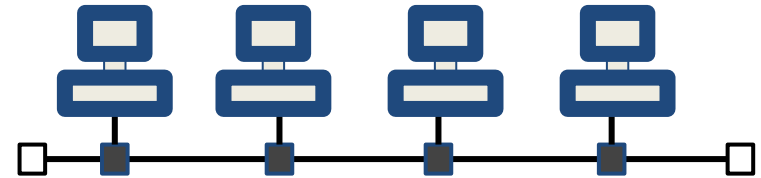
- Broadcast LAN
 - Computers interconnected by a shared transmission medium
 - When a computer wants to send information, it diffused it through the media to all the rest of connected devices
 - If two or more devices transmit simultaneously a collision happens and the resulting information is invalid
- Switched LAN
 - Computers interconnected through a switch
 - The information is sent only to the destination device
 - Free of collisions

- **LAN topologies**

- Broadcast LAN

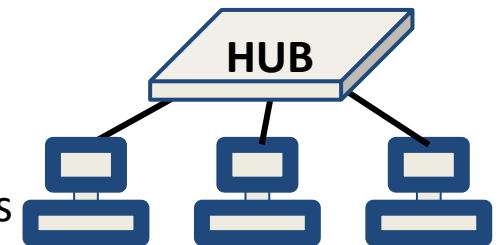
- Common cable (bus)

- Example: Ethernet 10Base2



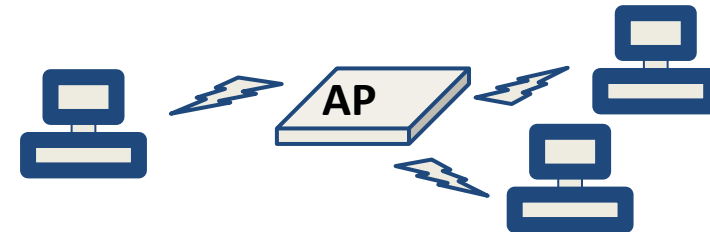
- Hub (star)

- The hub is a device that retransmits what it receives through a port to all the rest of the ports
 - Example: Ethernet 10Base-T



- Wireless LAN (WLAN)

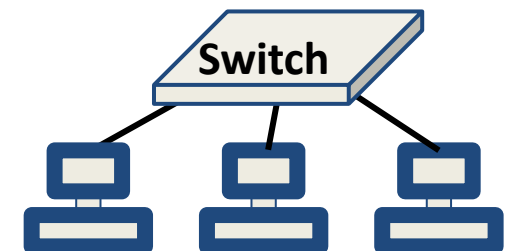
- The Access Point (AP) acts as a wireless hub
 - Example: Wi-Fi



- Switched LAN

- Switch (star)

- Example: Fast Ethernet 100BASE-TX

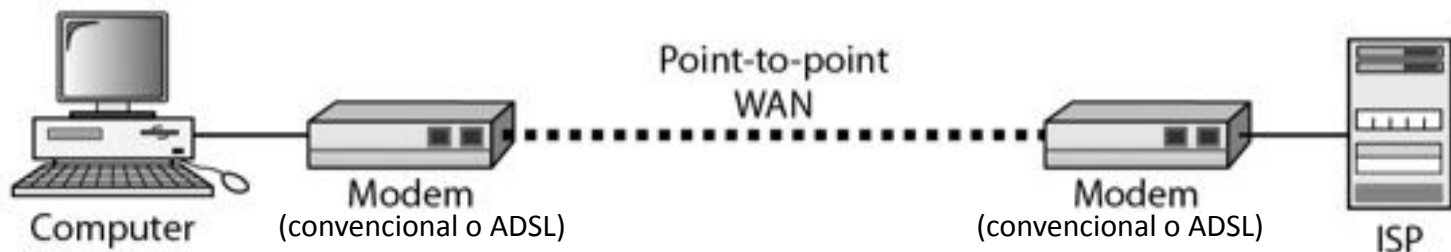


- **Wide Area Network (WAN)**

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

- **Types of WAN**

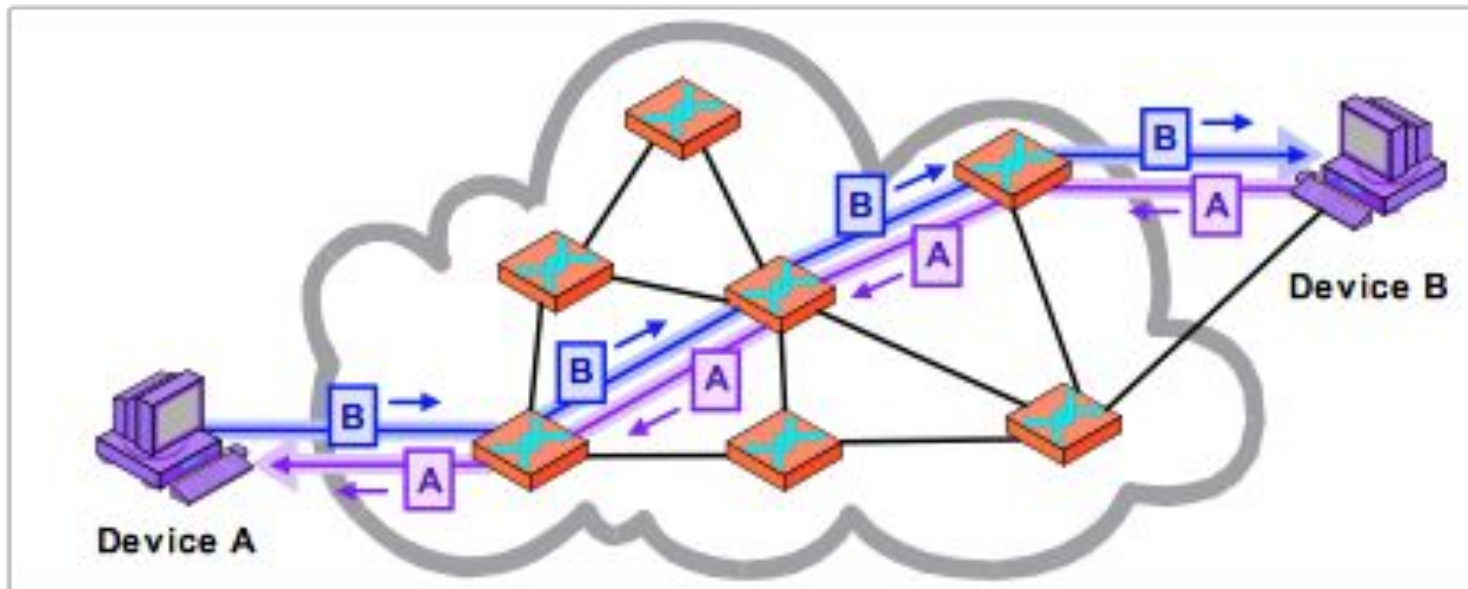
- **WAN point to point**
 - Connect **two devices** by a transmission medium (air, cable, optic fiber)
 - Examples: conventional modem or ADSL between the home computer and the Internet Service Provider (ISP)



- **Types of WAN (continuation)**

- **Circuit Switched WAN**

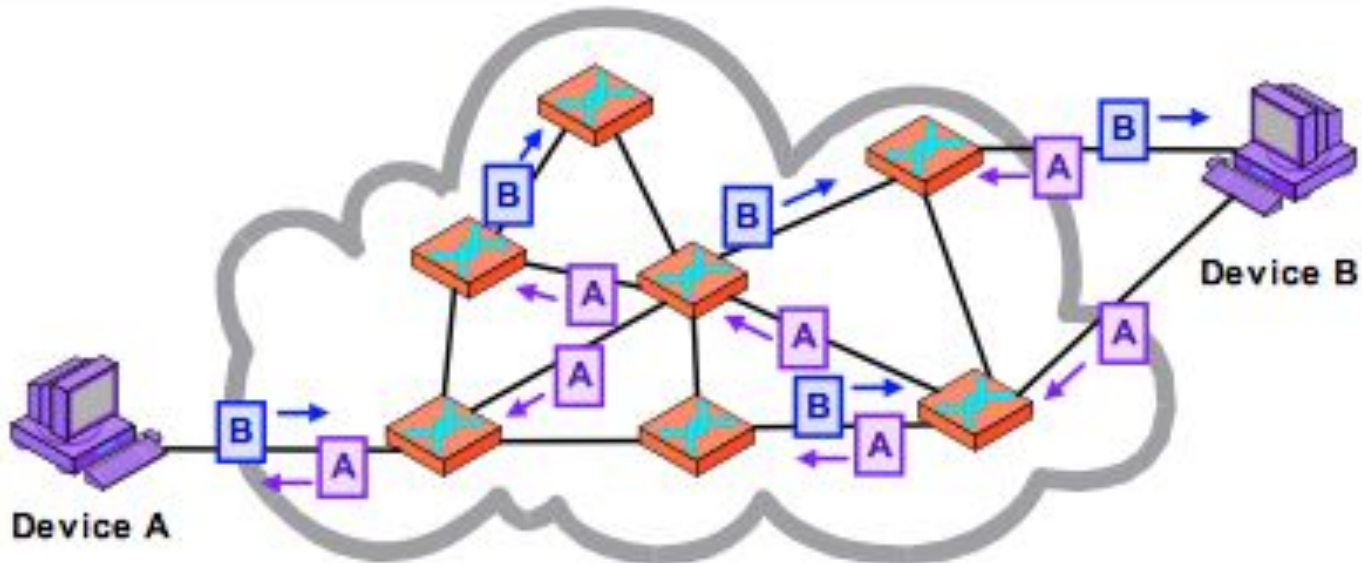
- A dedicated connection is established (circuit) between the two devices
 - The switches do not process the information
 - They only establish the required circuits for the connection
 - Example: Public Switched Telephone Network (PSTN)



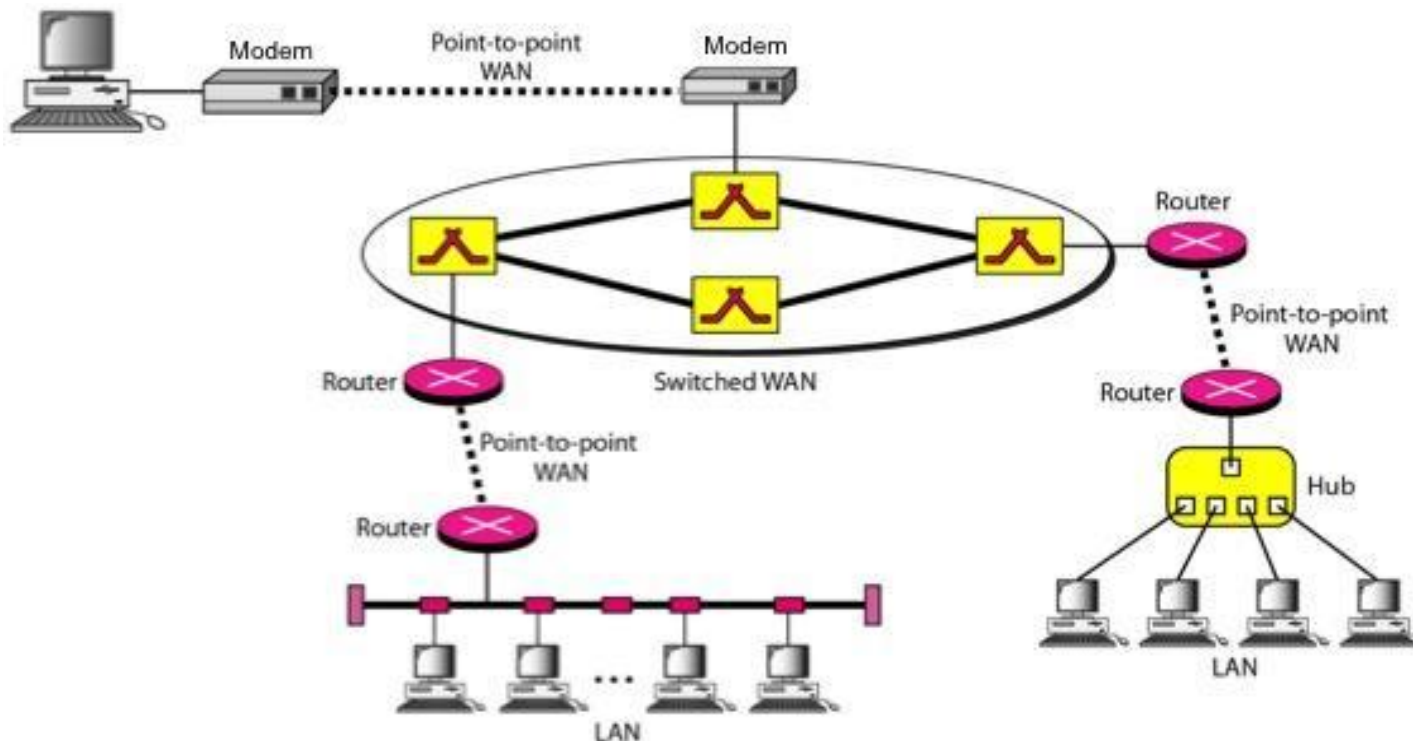
- **Types of WAN (continuation)**

- **Packet Switched WAN**

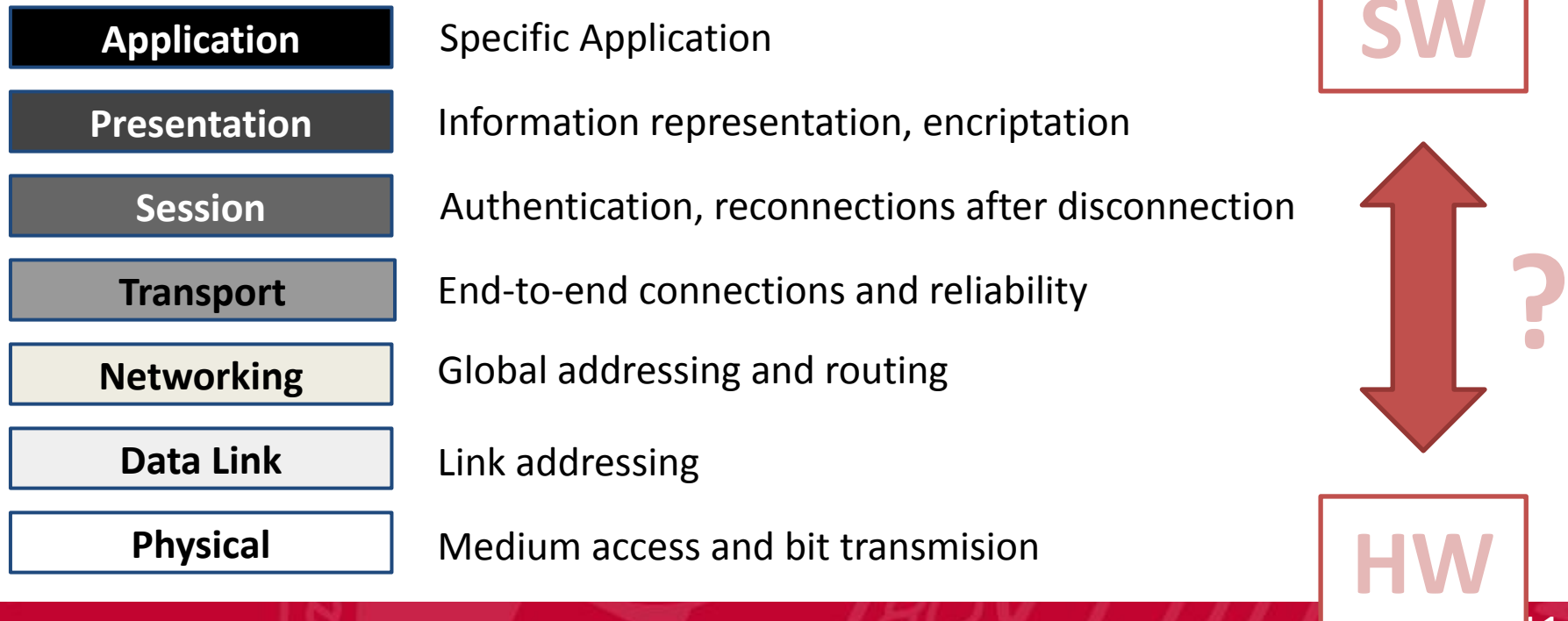
- The information is divided in blocks (packets or segments)
 - The switches process the packets performing two basic functions:
 - **Packet routing:** decide which is the best route from source to destination
 - **Packet forwarding:** select the next node to send a packet based on the routing information



- 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)



- 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
 - Each layer is meant to include specific purpose protocols



OSI Model

Application
Presentation
Session
Transport
Network
Data Link
Physical

TCP/IP 5 layer
Model (generic)

Application
TCP-UDP
IP
MAC
Física

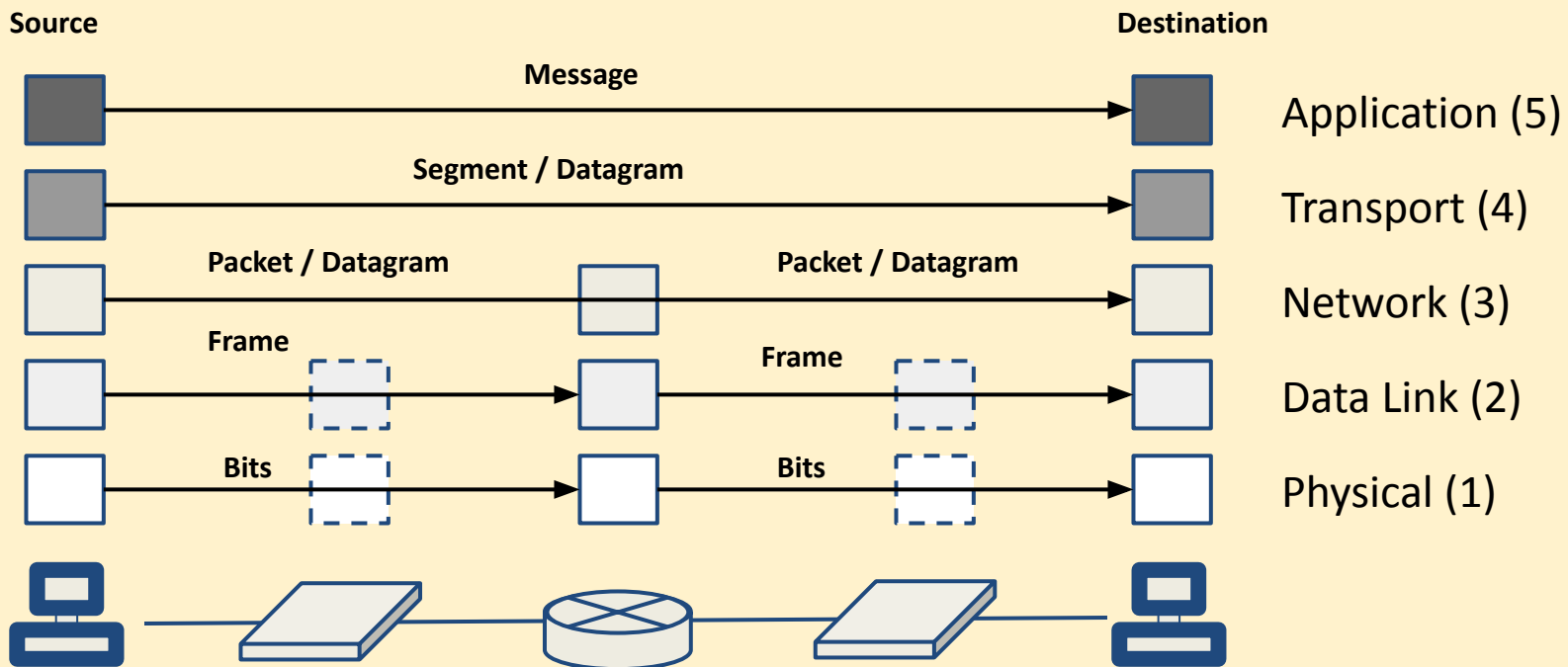
TCP/IP on
Ethernet

Application
TCP-UDP
IP
Ethernet
10BASE-T, 100BASE-TX, ...

TCP/IP on
Public phone

Application
TCP-UDP
IP
PPP
dial-up modem o ADSL

- 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)



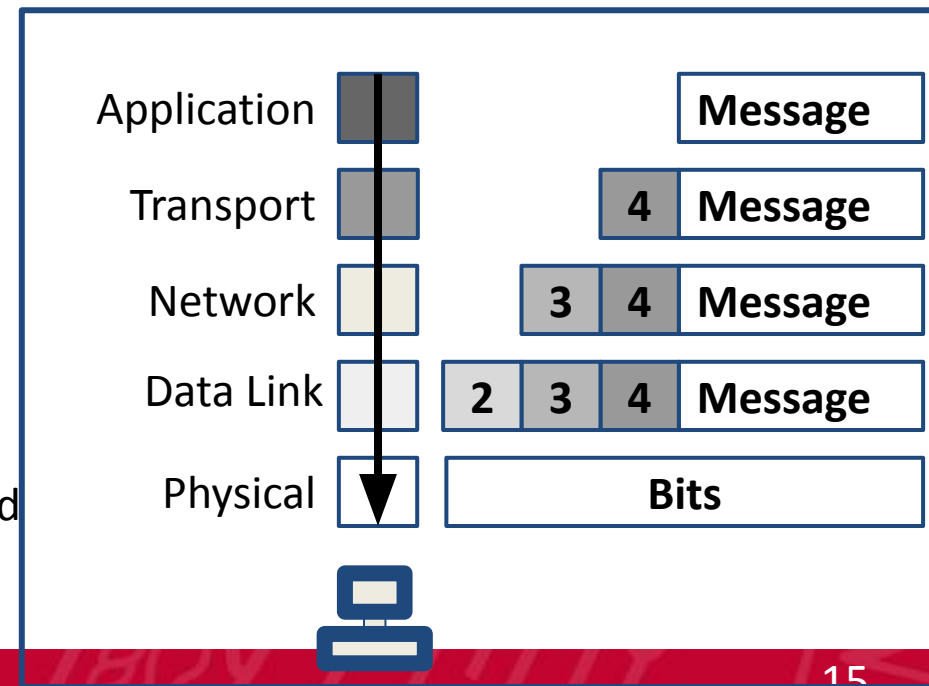
- **Hubs:** Work at the physical layer (level 1)
 - Retransmit bit by bit what they receive through one port to the rest of its ports
 - They can connect devices or network segments of the same type and speed
- **Switches:** are devices that work at the data link layer (level 2)
 - Send a frame to the 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

Encapsulation

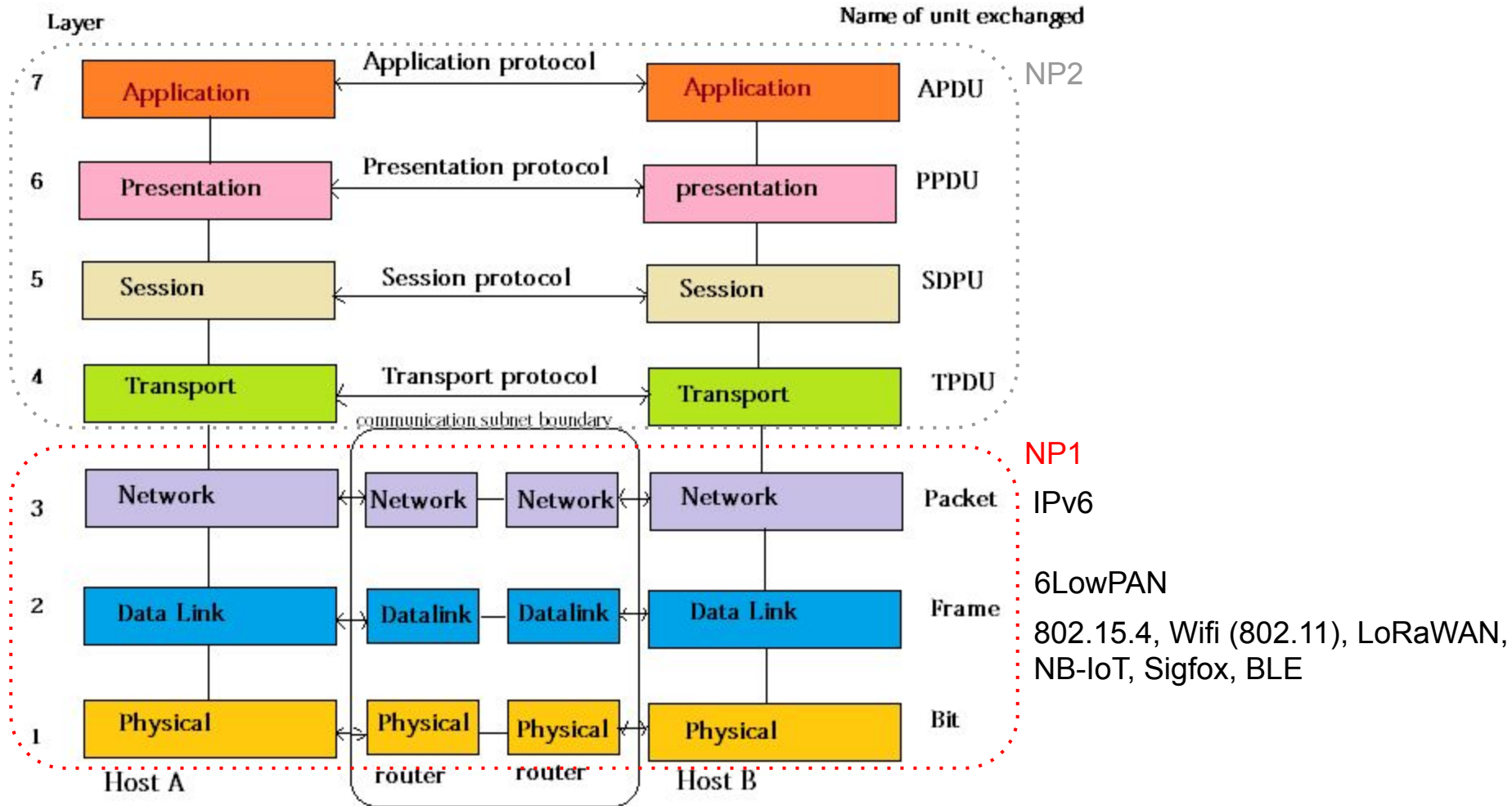
- At each level the protocol adds a header to the message (payload) that contains information specific for that protocol
- The transport header includes information of the source and destination processes, error control (e.g. checksums) or flow control
- The network layer adds information about the source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

Reception

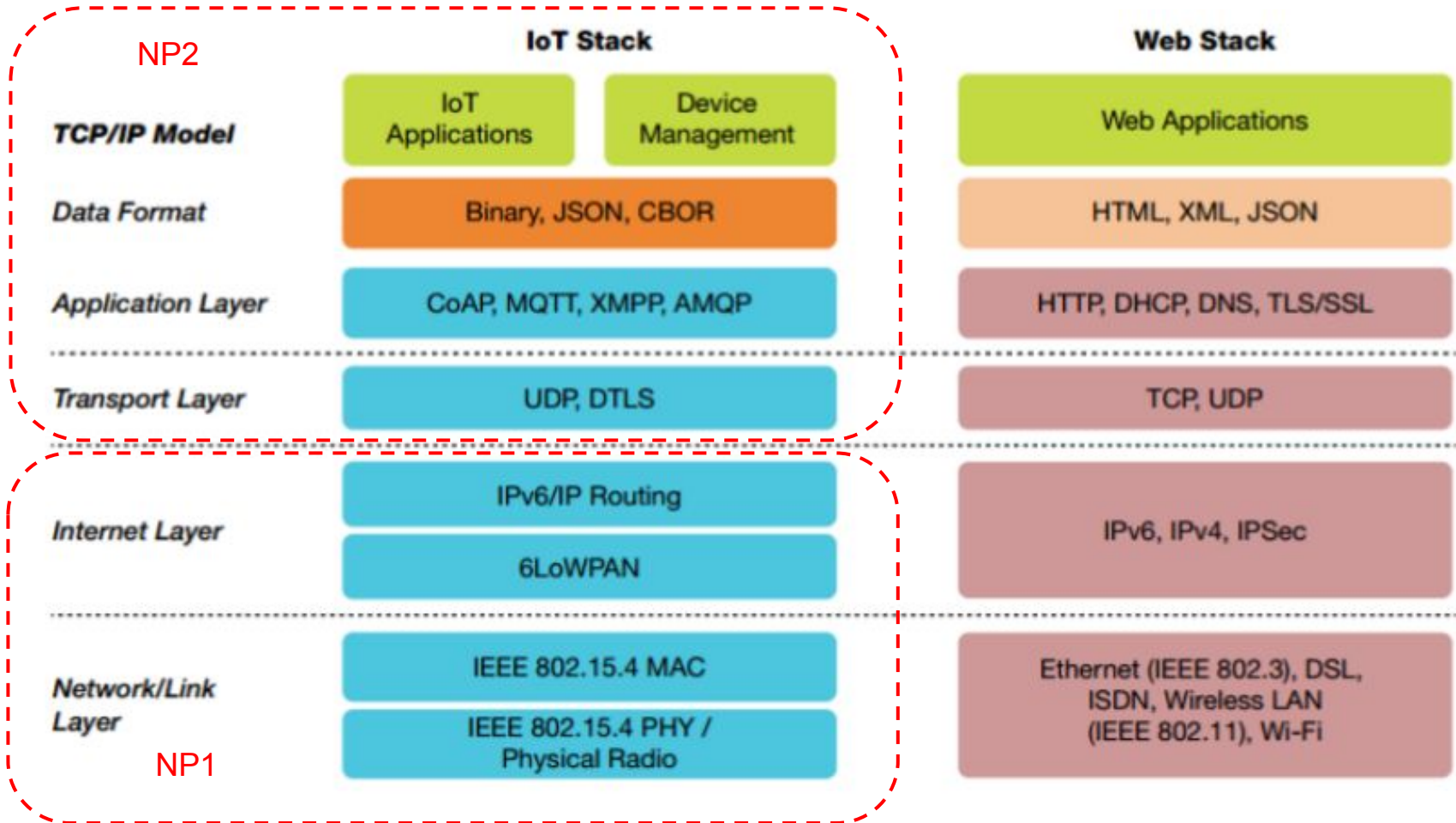
- Each layer processes its corresponding header and sends the payload to the next layer protocol
- Errors are checked at each level
- Routers can assemble a new packet for the next step, the datagram (3) is barely modified



NP1: networking infrastructure



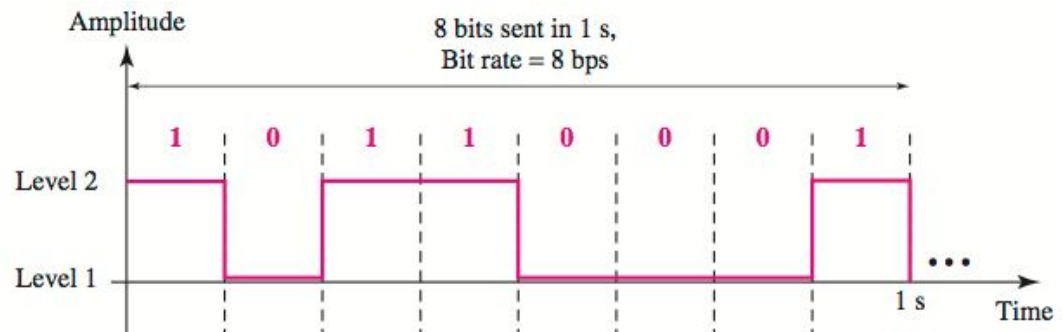
New Protocols adapted to IoT



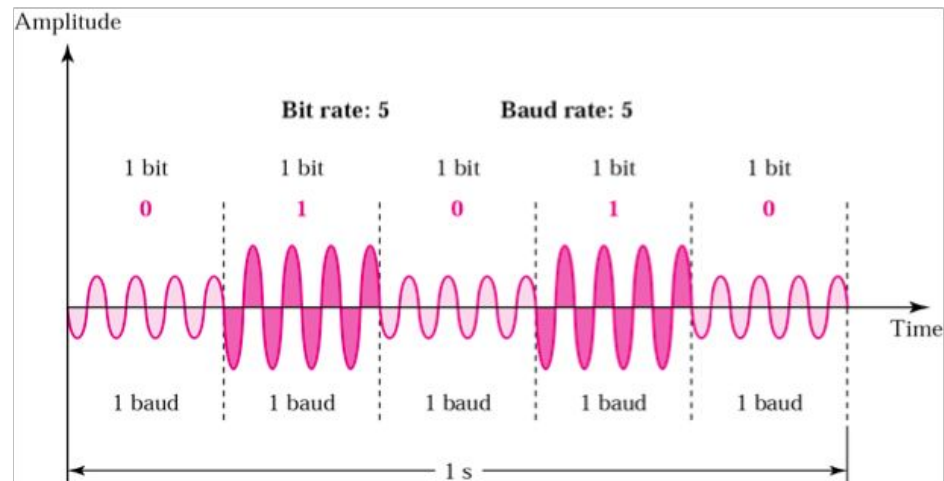
- Basic networking concepts
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- **Data:** transmitted information, sequence of bits
 - e.g.: 10110001
- **Signals:** electromagnetic codification used to send information through a medium

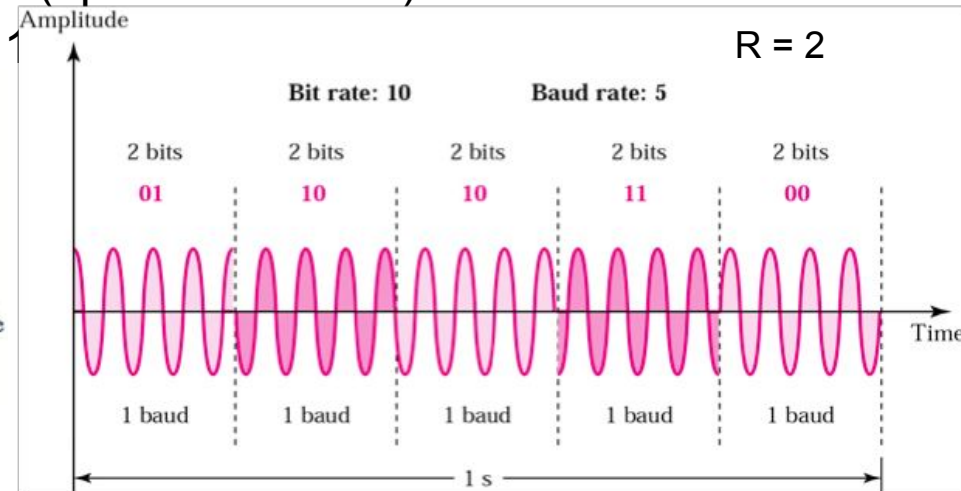
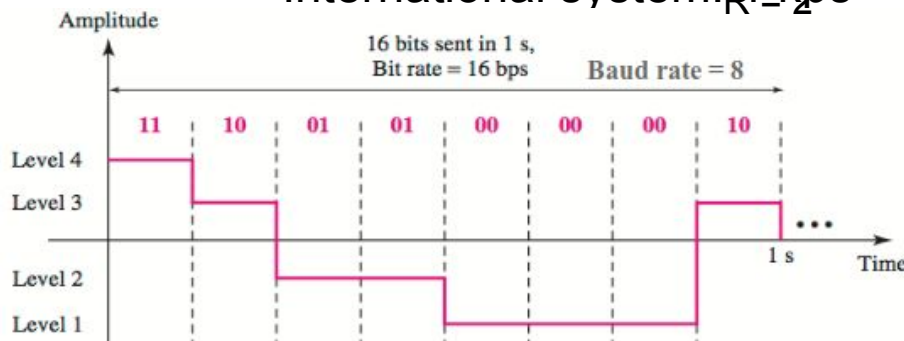
Digital: base band



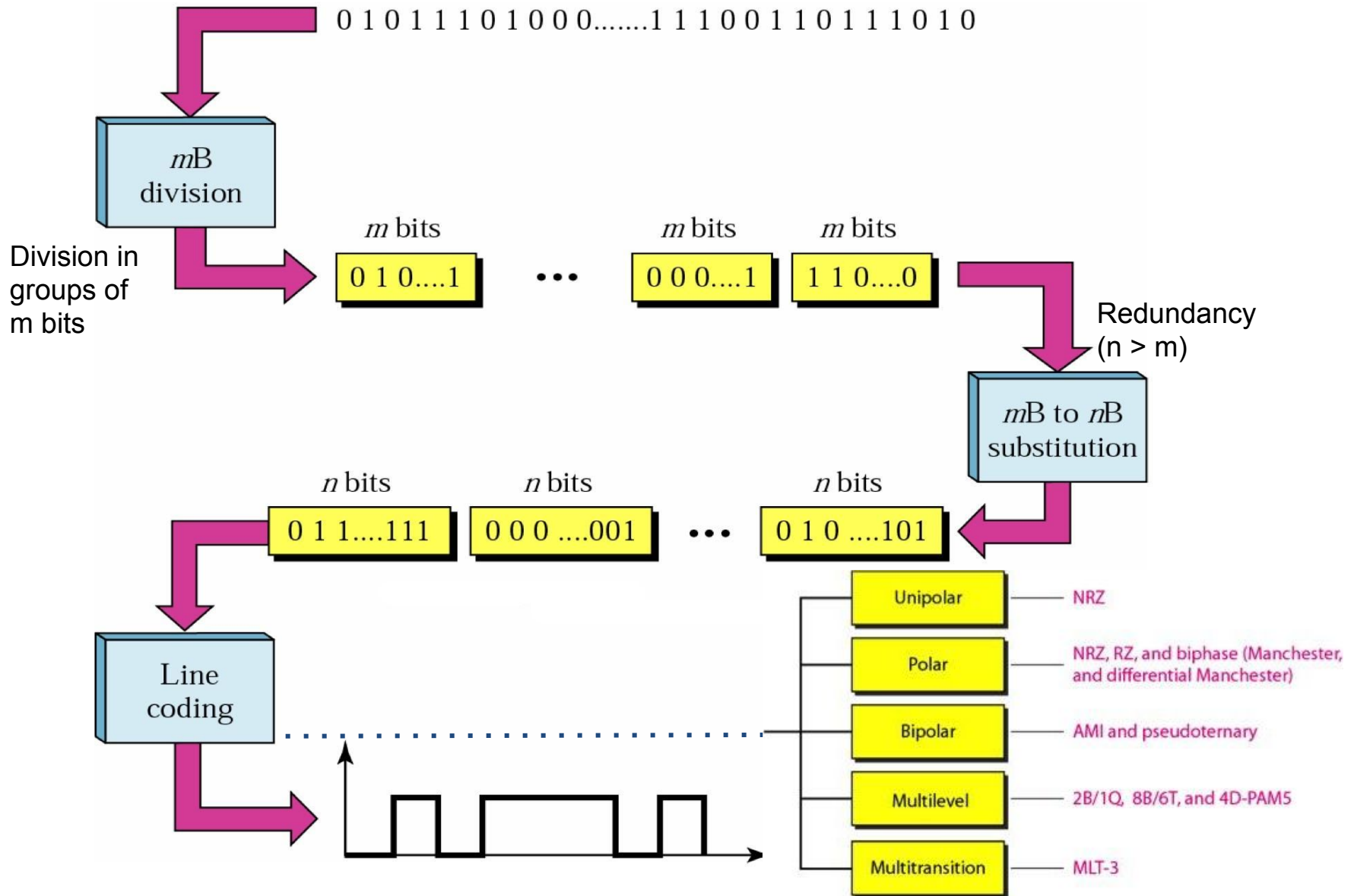
Analog: digital signal modulates an analog carrier signal



- 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 ($\text{bps} = R \times \text{bauds}$)
 - International system: $R = \frac{\text{bps}}{\text{bauds}}$

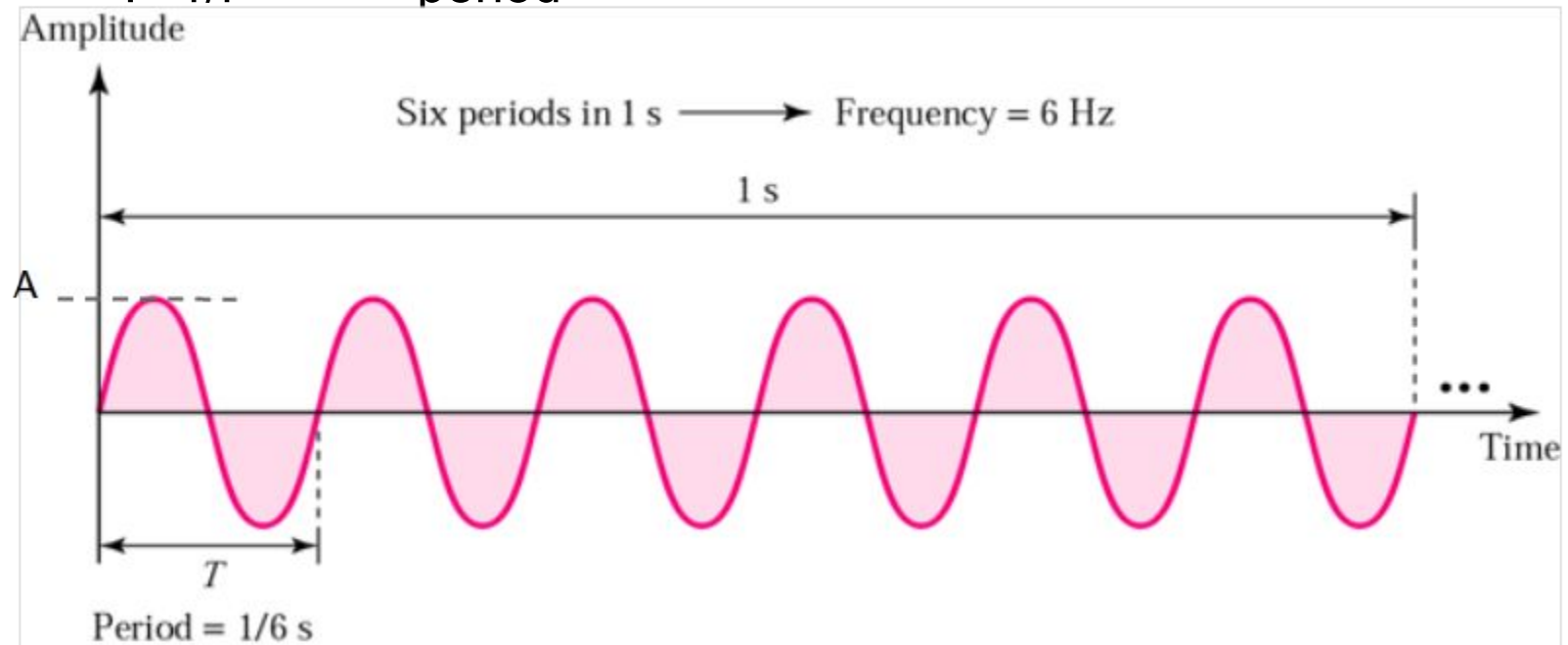


Digital transmission (base band)



Sinusoid signal components:

- $s(t) = A \sin(2 \pi f t + \Phi)$, where:
- $A \rightarrow$ amplitude
- $f \rightarrow$ frequency
- $\Phi \rightarrow$ phase
- $T=1/f \rightarrow$ period



Analog transmission: modulation

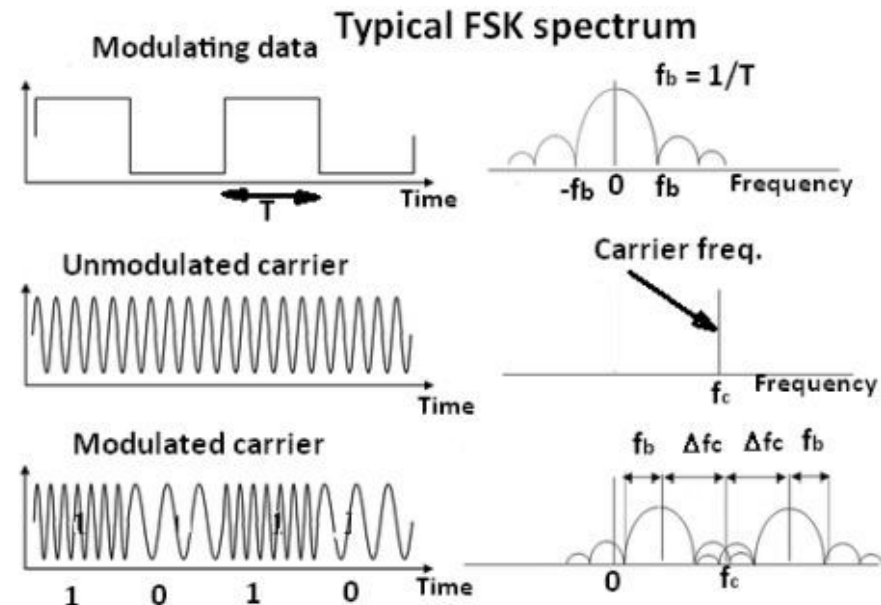
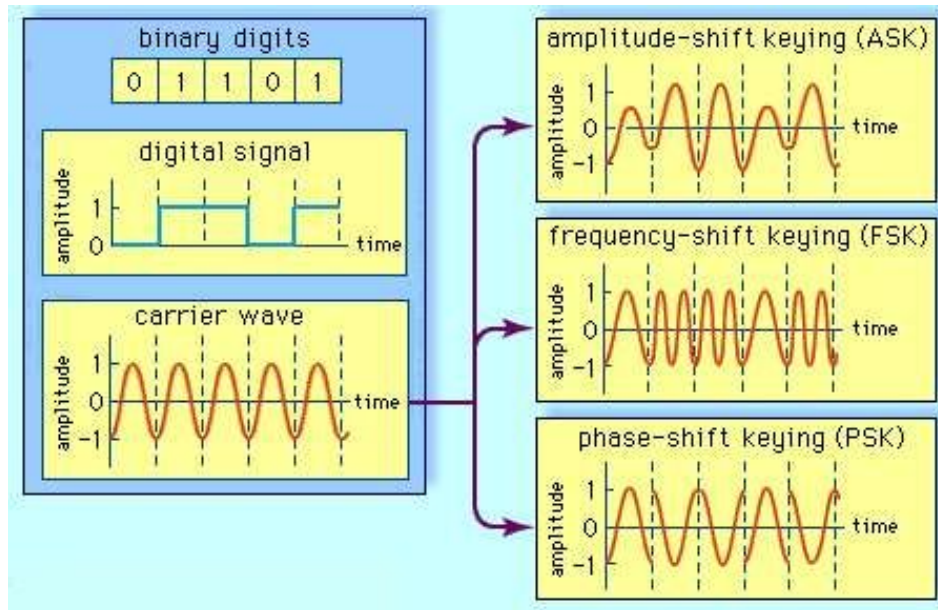
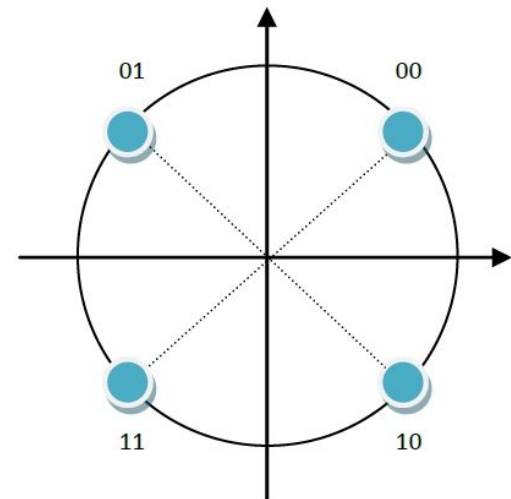
Basic schemes

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

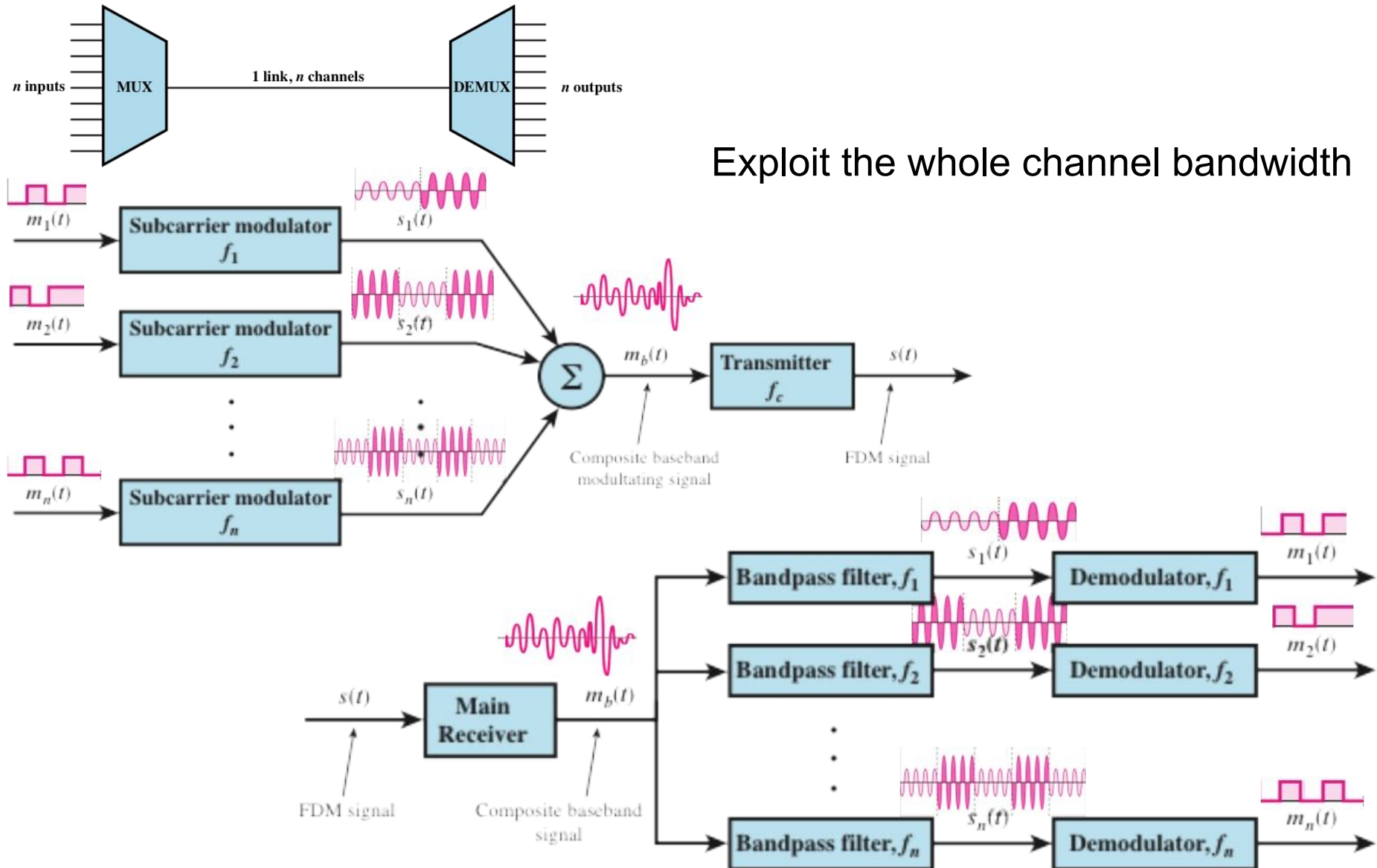
Advanced schemes:

- QPSK
- 8-QAM
- ...

Constellation QPSK



Frequency Division Multiplexing (FDM)

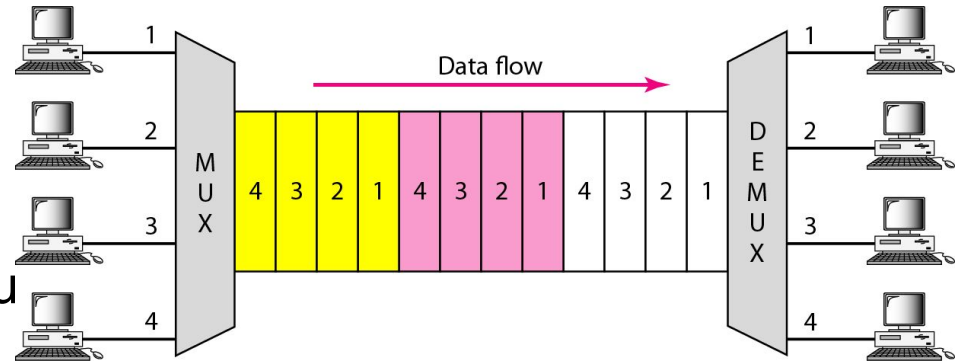


Exploit the whole channel bandwidth

Time Division Multiplexing (TDM)

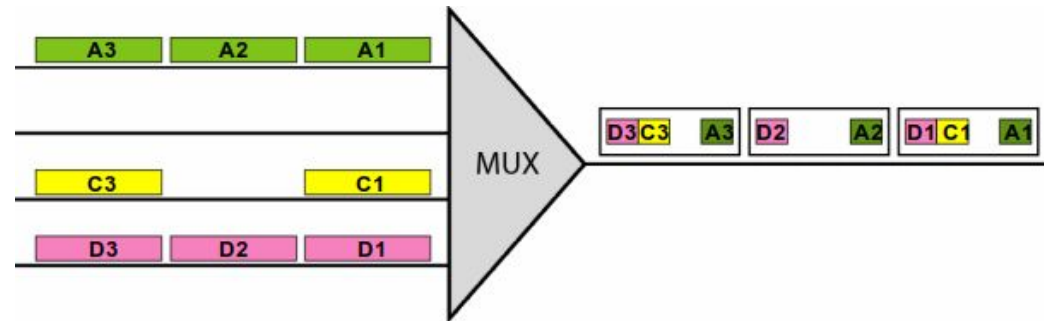
Temporal split of the channel

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

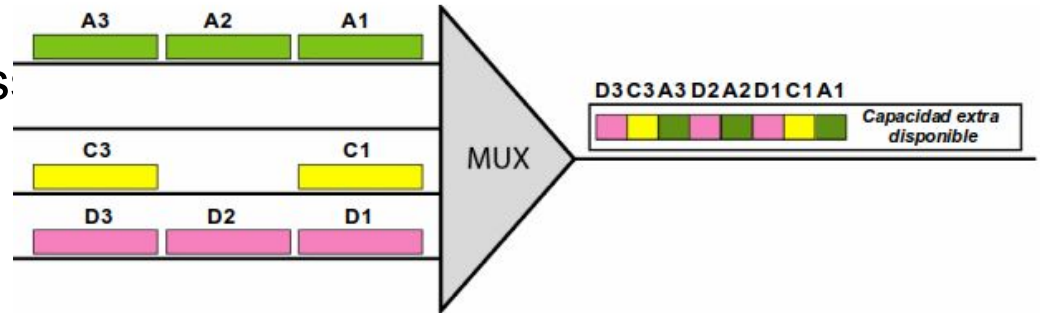


Two alternatives

- Synchronous: static slot



- Statistical: dynamic slot as



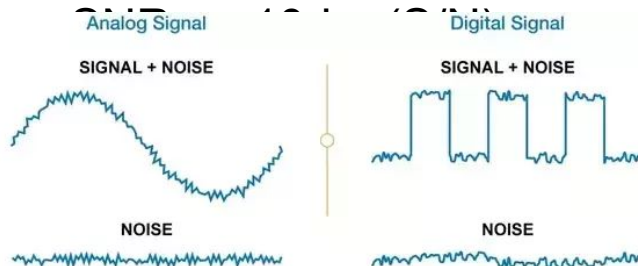
- **Attenuation:**

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

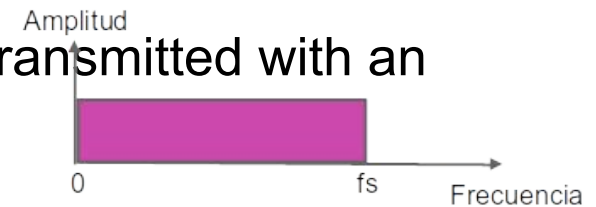
- **Band width:** frequency range that can be transmitted with an acceptable attenuation

- $H = f_s - f_i$
 - Low pass: $f_i == 0$
 - Band pass: $f_i != 0$
 - Modulation required

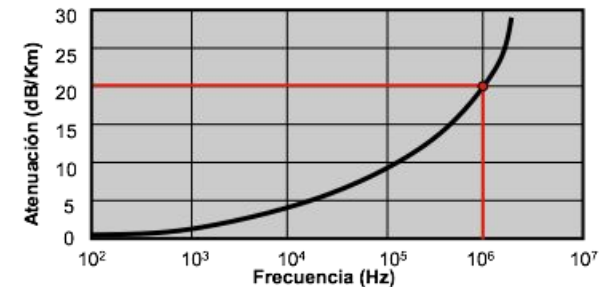
- **Noise:**



Canal paso-baja



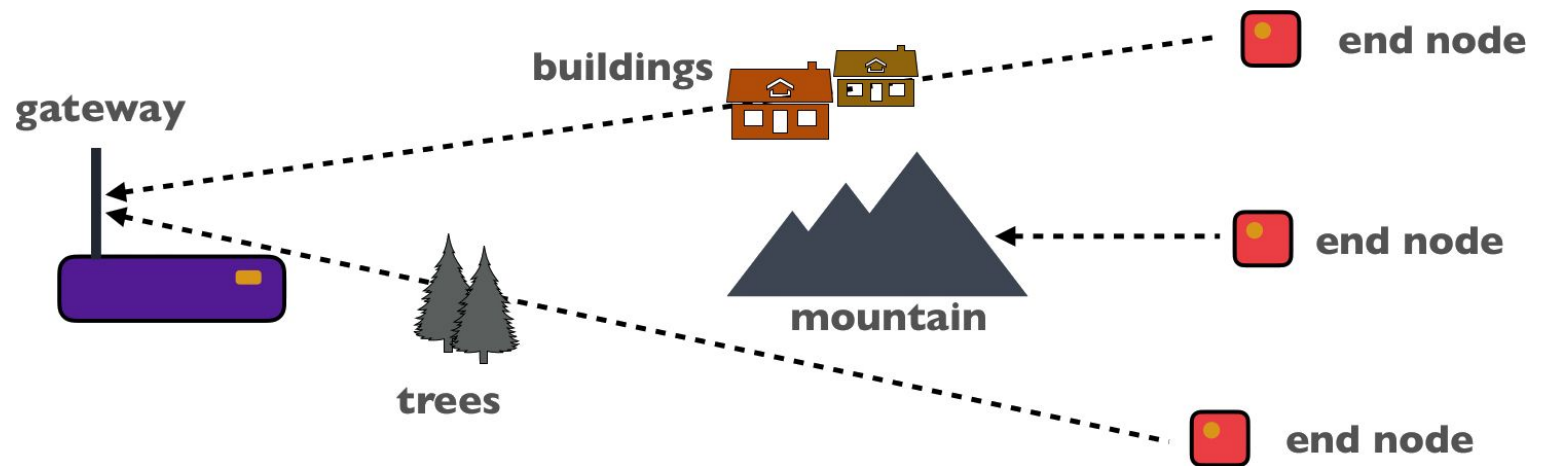
Canal paso-banda



- 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



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. $f = 868\text{MHz}$

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

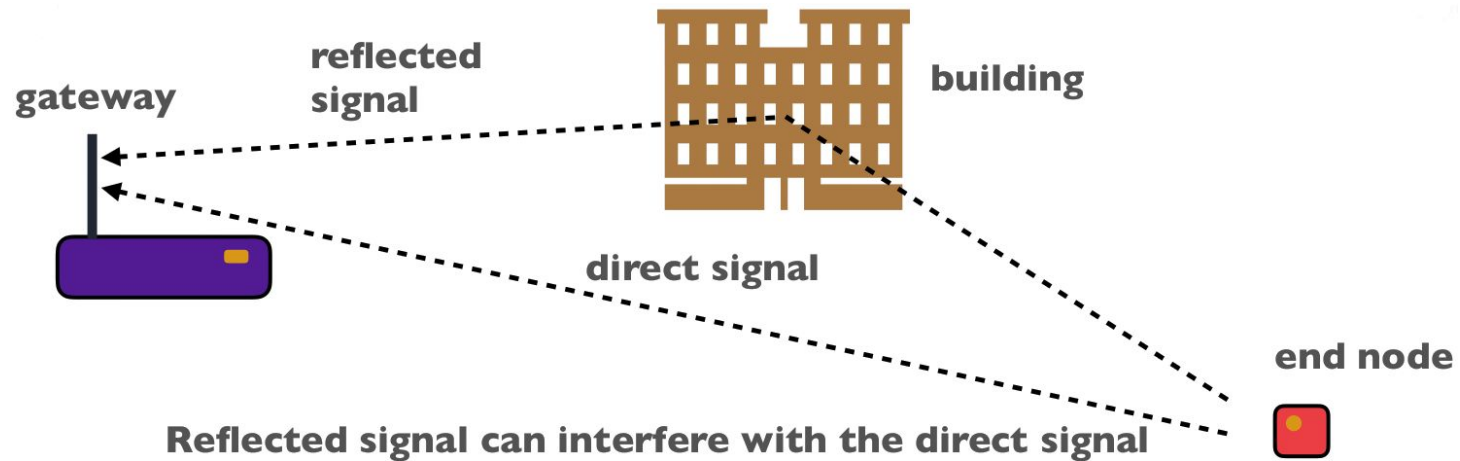
$$D = 0.05 \text{ km}, L_{fs} = 32.45 + 20 \log(0.05) + 20 \log(868) = 65 \text{ dB}$$

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

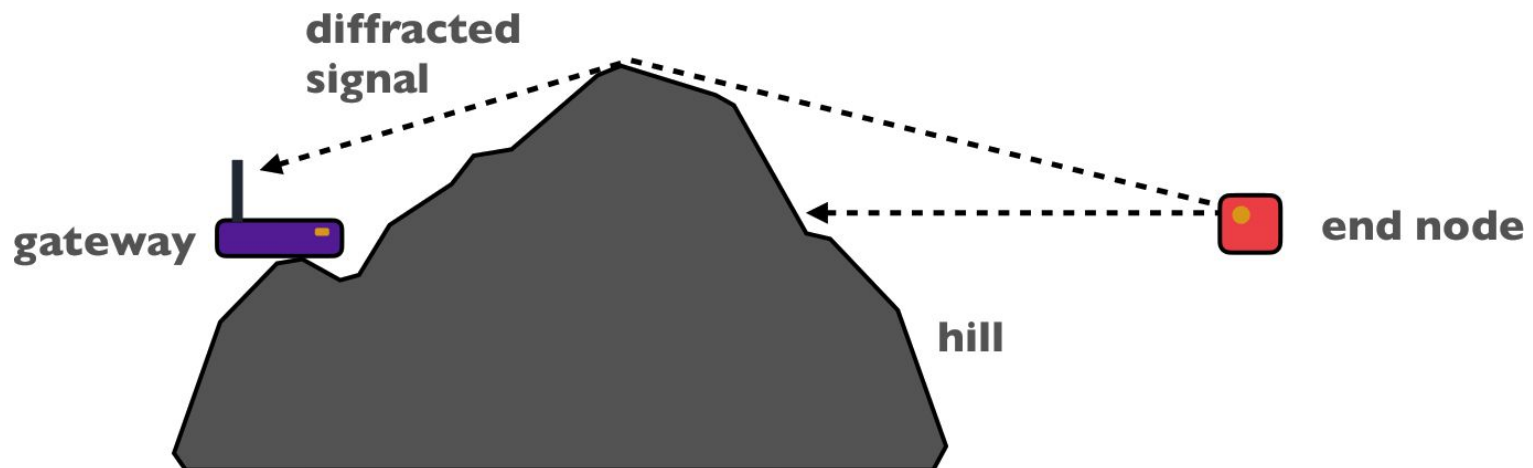
$$D = 0.50 \text{ km}, L_{fs} = 32.45 + 20 \log(0.50) + 20 \log(868) = 85 \text{ dB}$$

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

- Obstacles can also reflect waves



- Or diffract the transmitted signal



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

$$D = d1 + d2$$

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

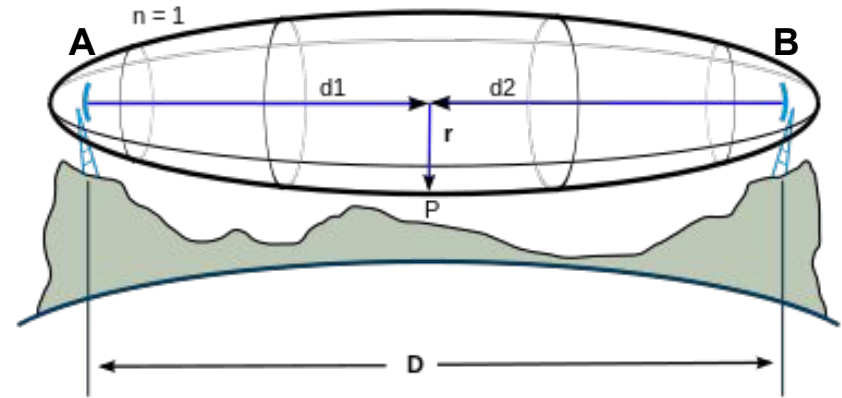
$$\sqrt{r_n^2 + d1^2} + \sqrt{r_n^2 + d2^2} - D = n \frac{\lambda}{2}$$

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

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

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

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



In the mid point:

$$d1 = d2 = D/2$$

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

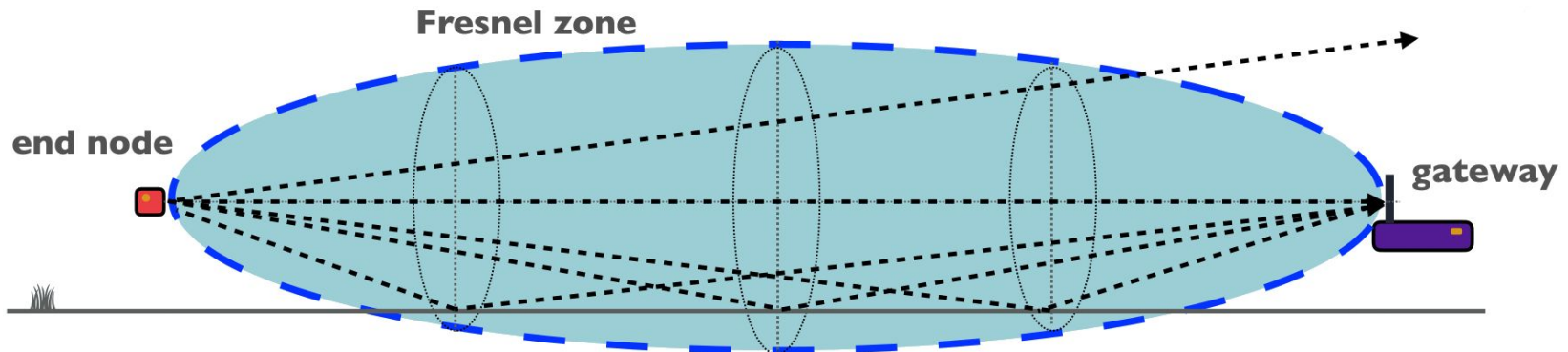
$$r_n = 8.657 \sqrt{n \frac{D}{f}}$$

D in km
f in GHz

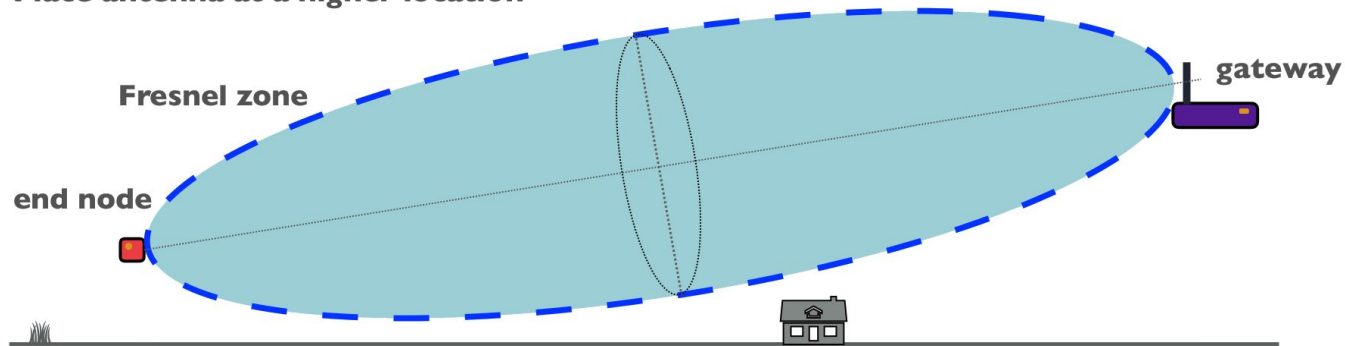
Obstacles should be avoided in the first Fresnel zone

The radius of the fresnel zones increase with the distance

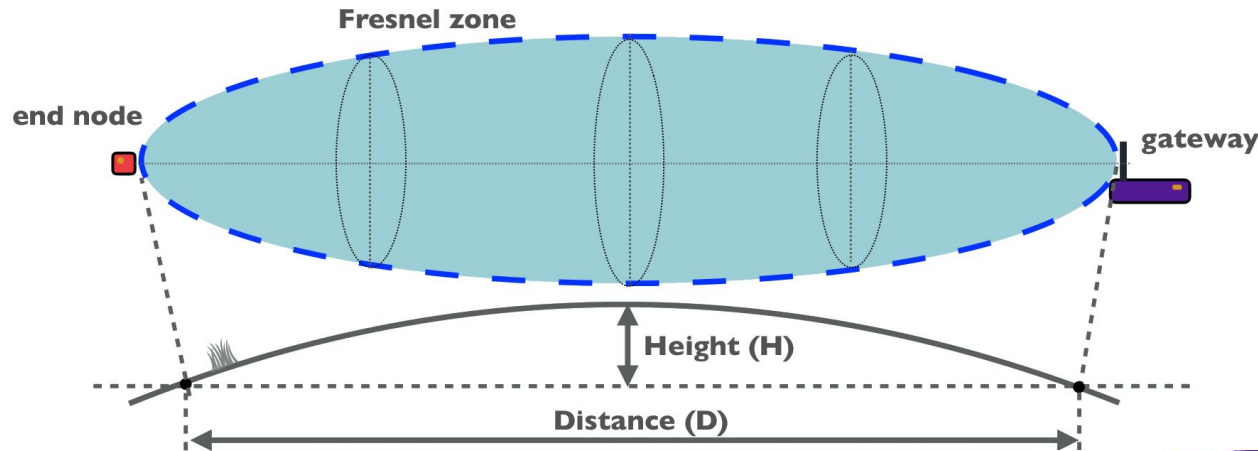
- Antennas can be lifted up to avoid reflexions with the ground and other obstacles



Place antenna at a higher location



The expression $r = 8.657 \times \sqrt{D / f}$ does not take the earth curvature into account

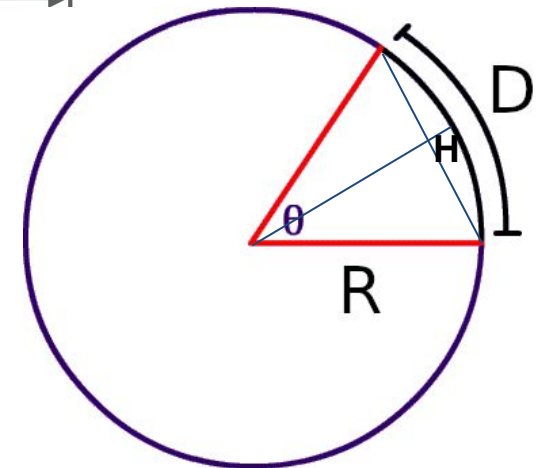


$$\theta = D/R$$

$$H = R - R \cos(\theta/2)$$

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

$$H = D^2/(8R)$$



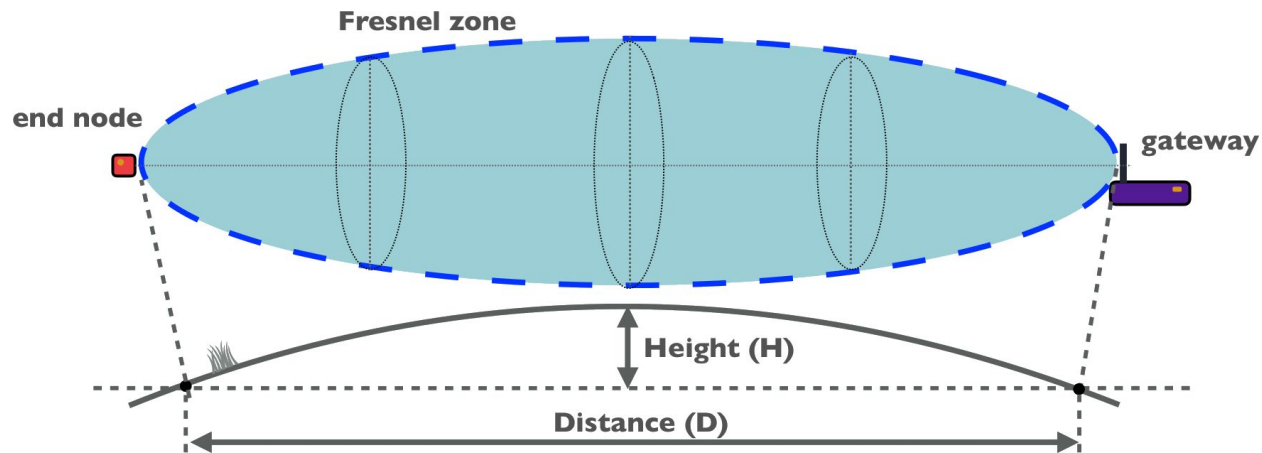
$$H = 1000 \cdot D^2/(8 \cdot R)$$

H height in km

R earth radius (6371 km)

D Distance between sender and receiver in km

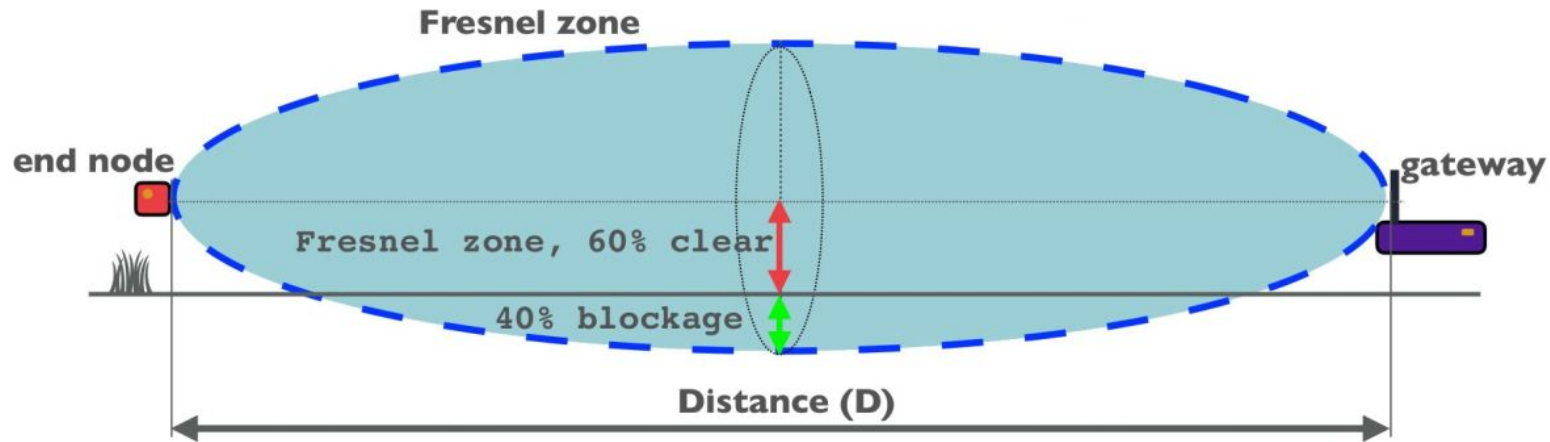
<https://www.zytrax.com/tech/wireless/calc.htm#fresnel>



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

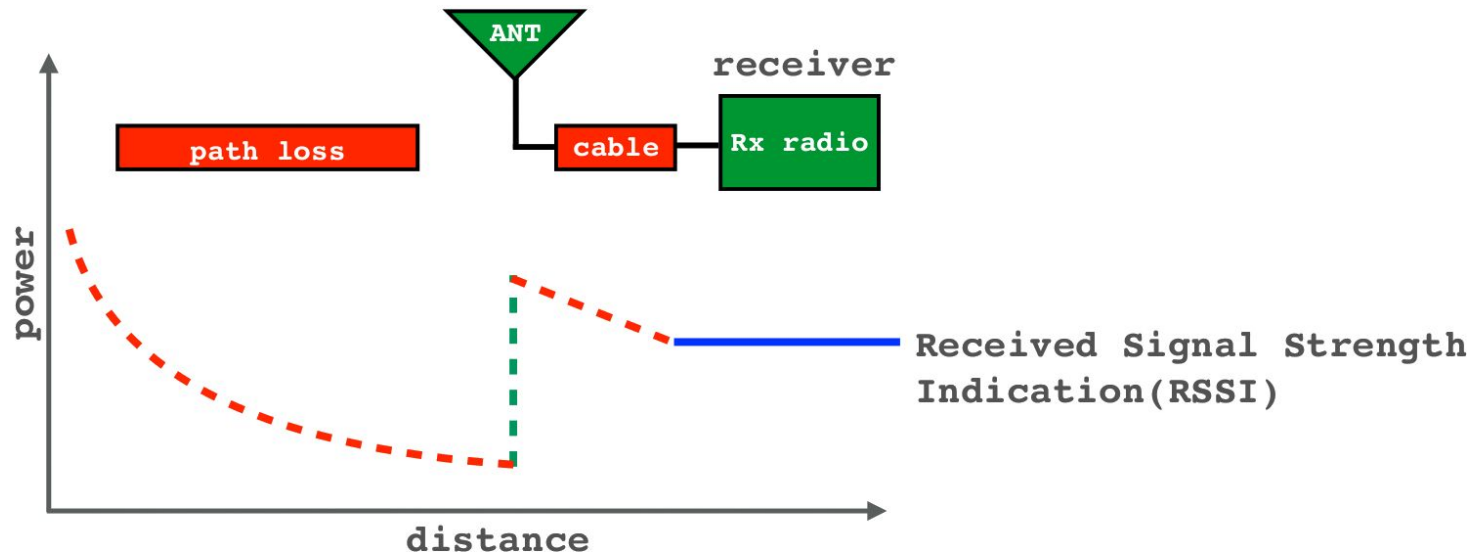
A good compromise is to have at least 60% of the first fresnel zone free of obstacles

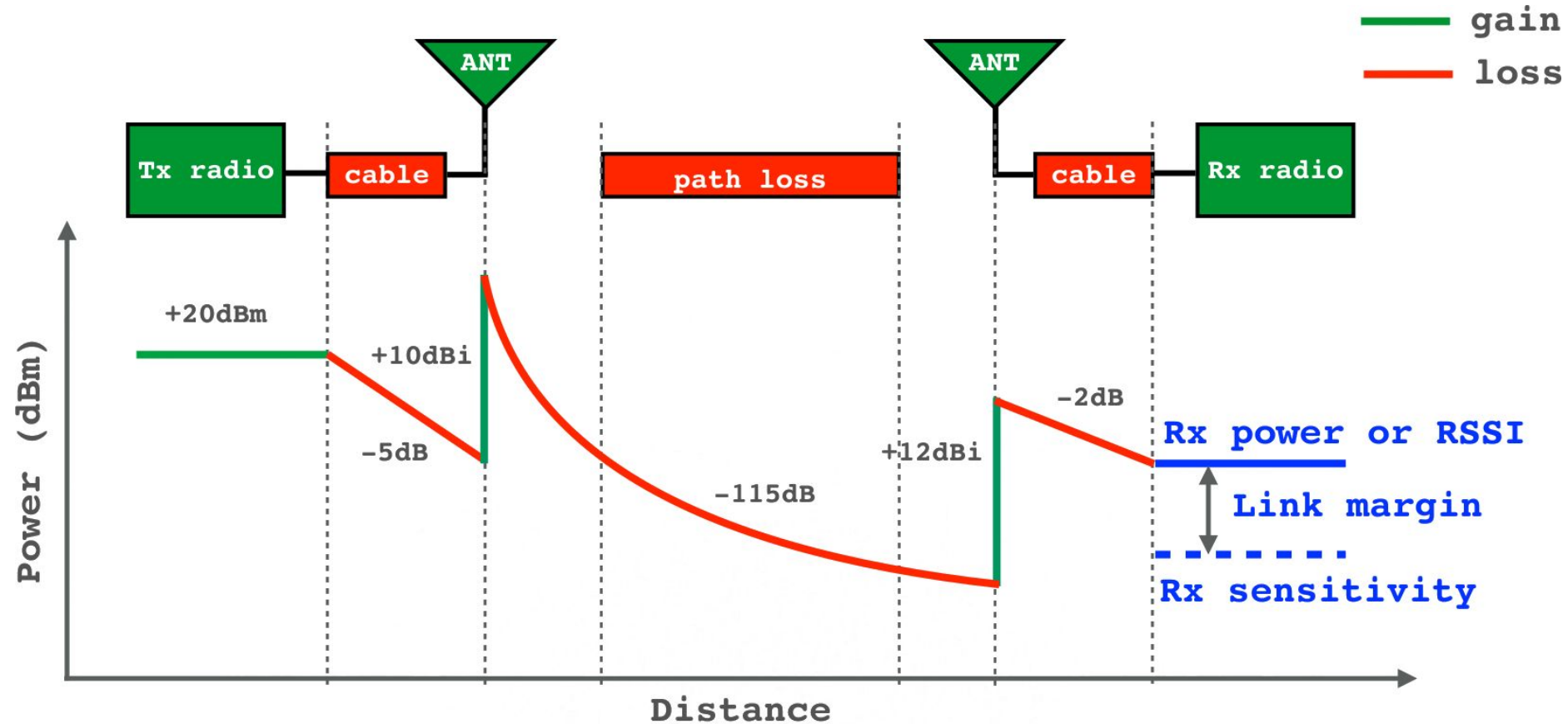


$f = 868\text{MHz}$

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

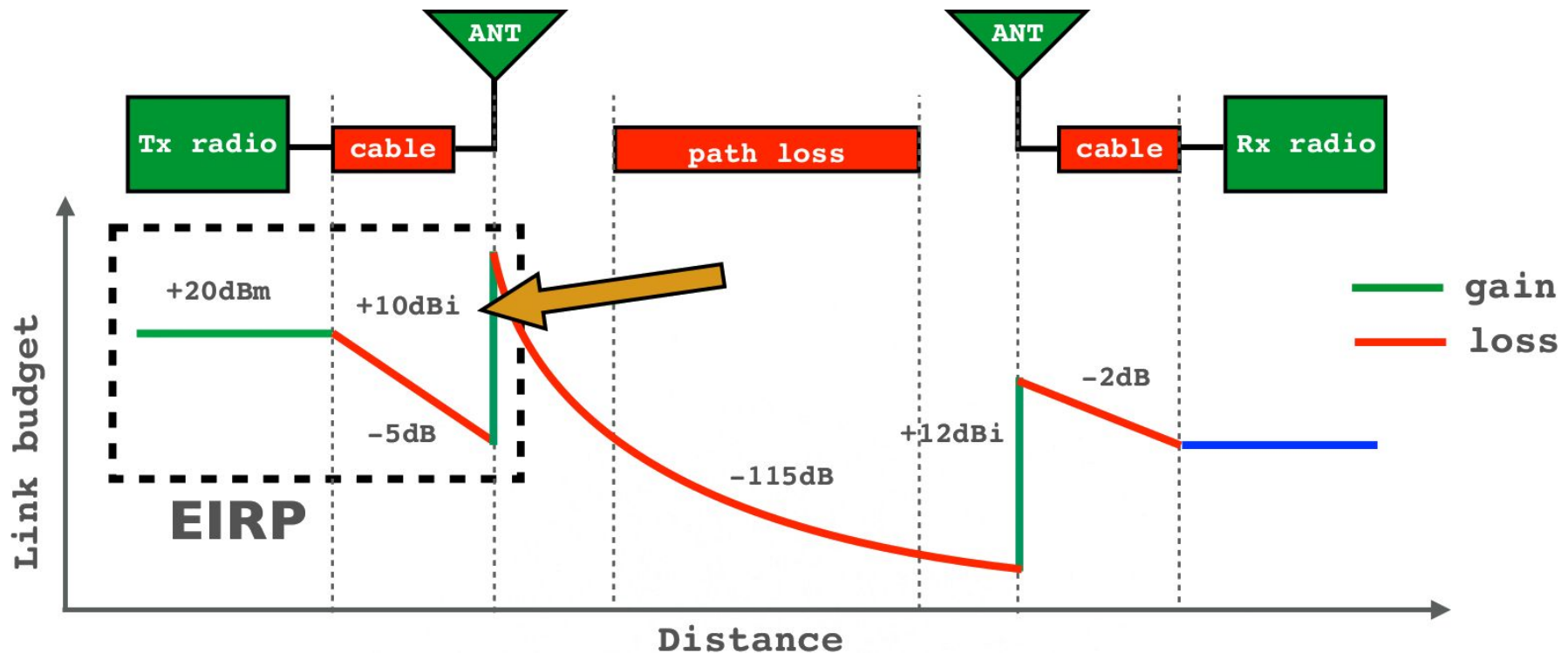
- Received power, expressed in dBm
- Is an indication of how well the emitted signal is received
 - Usually a negative value, the closer to zero the better





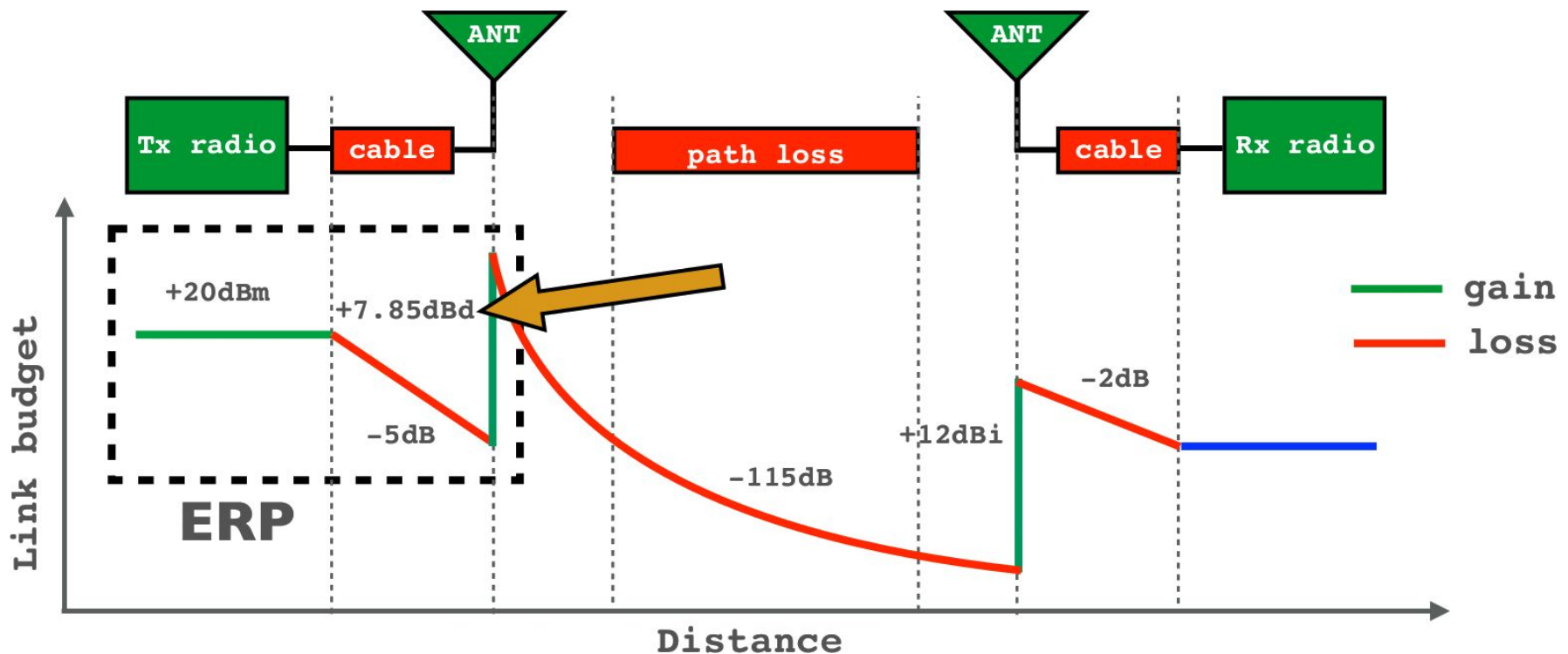
RSSI - Received Signal Strength Indication

- 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 ($\lambda/2$)
 - The gain of the emitter antenna is expressed in dBd



$$\text{ERIP (dBm)} = \text{ERP (dBm)} + 2.15$$

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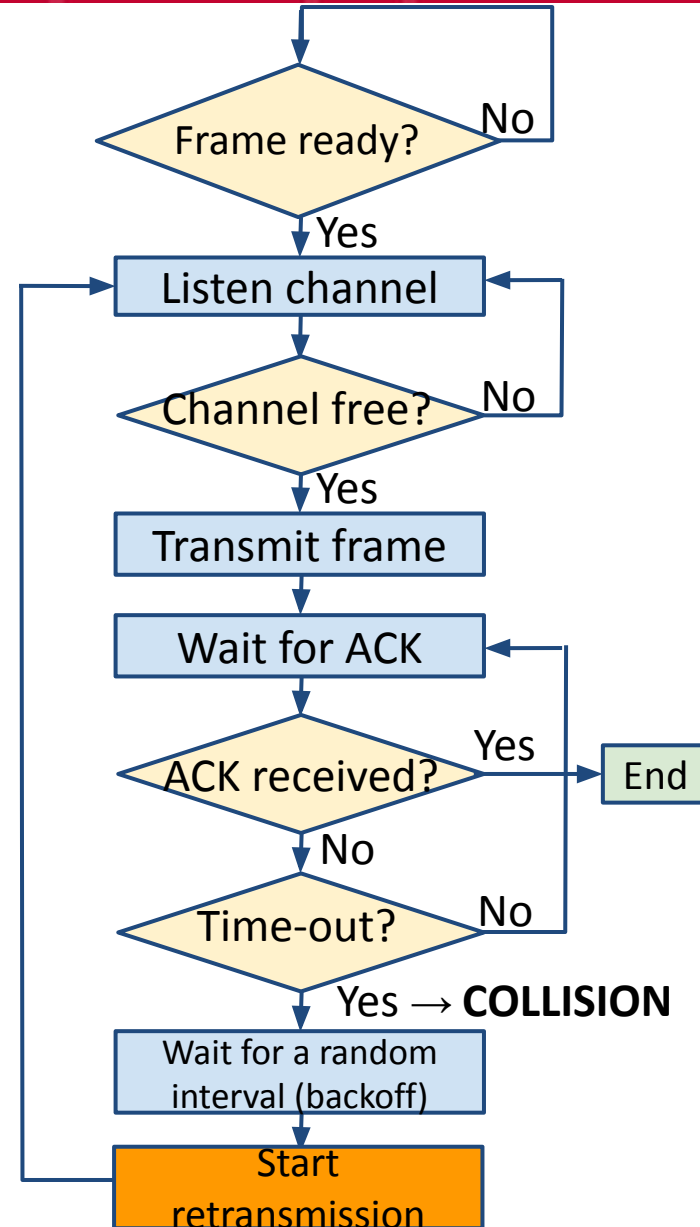
Responsibilities:

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

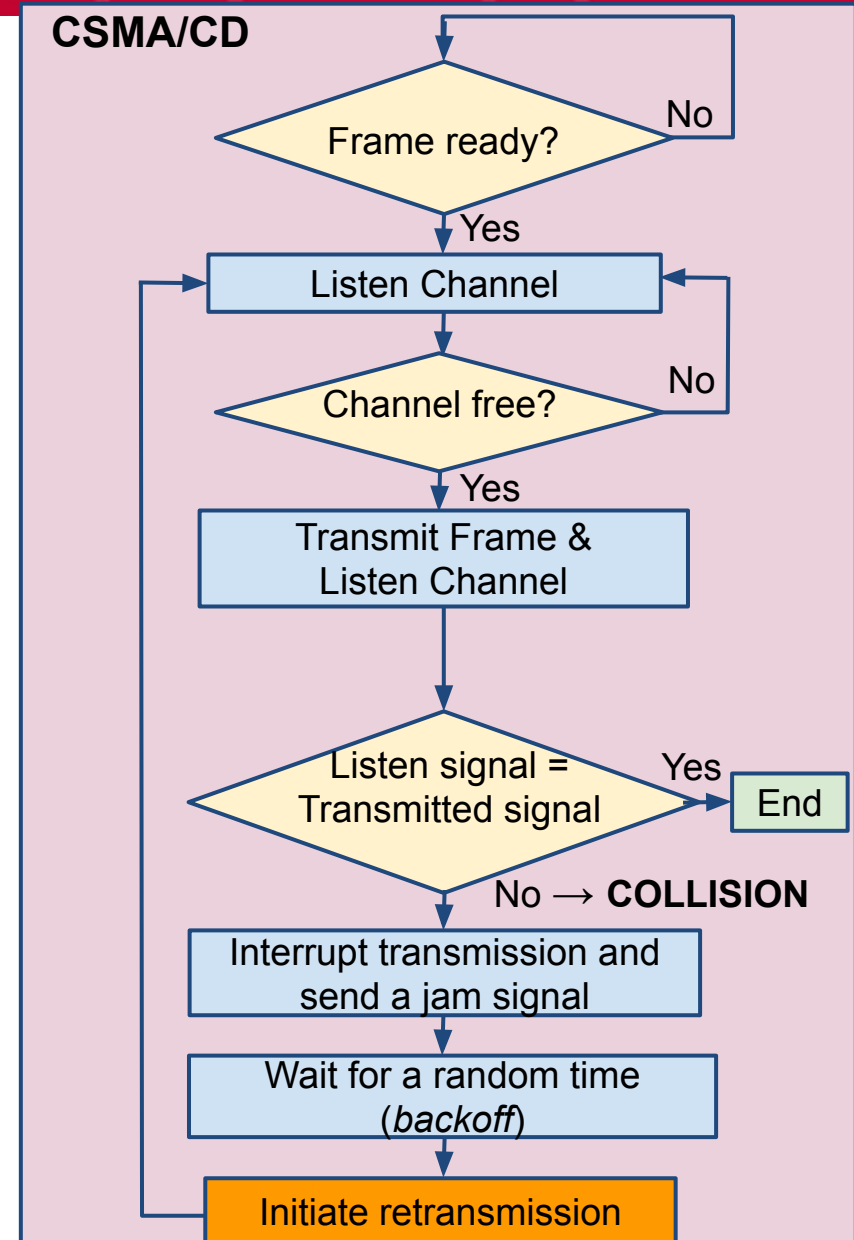
- **Ethernet MAC protocol**

- 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

- 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



- 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



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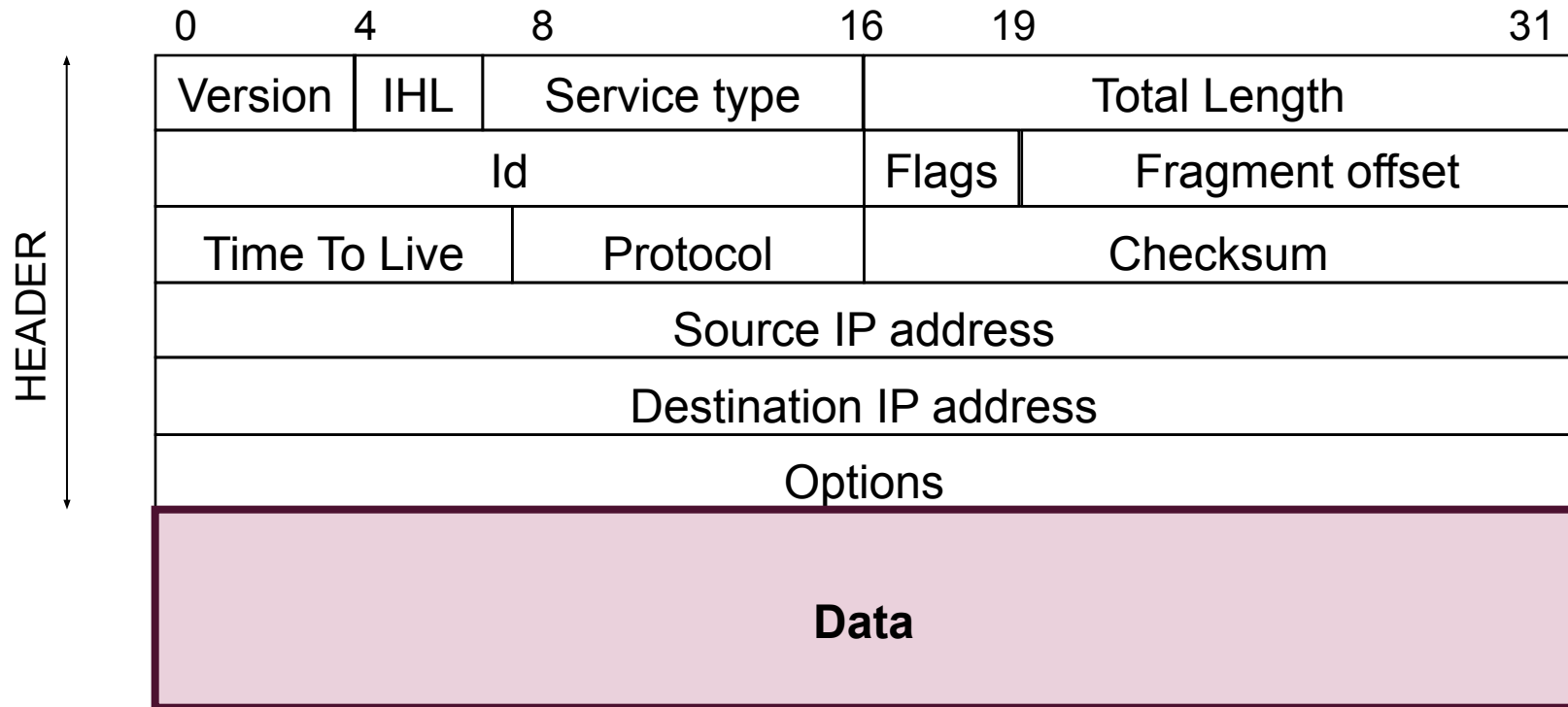
Internet Network Protocol

- 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

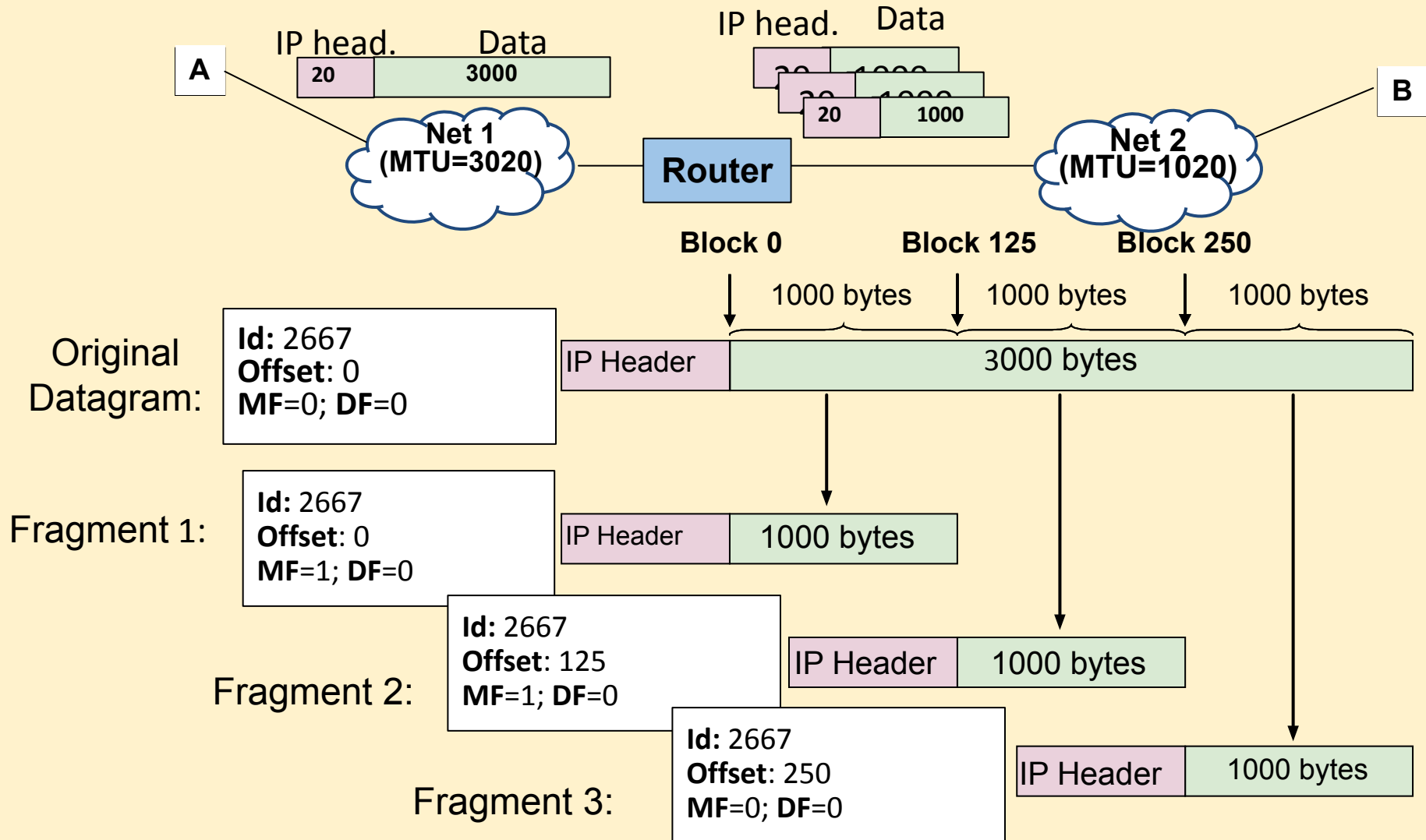
Basic responsibilities of the IP protocol

- **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



Fragmentation Example



- 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: 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

Local Routing:

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

Static Routing:

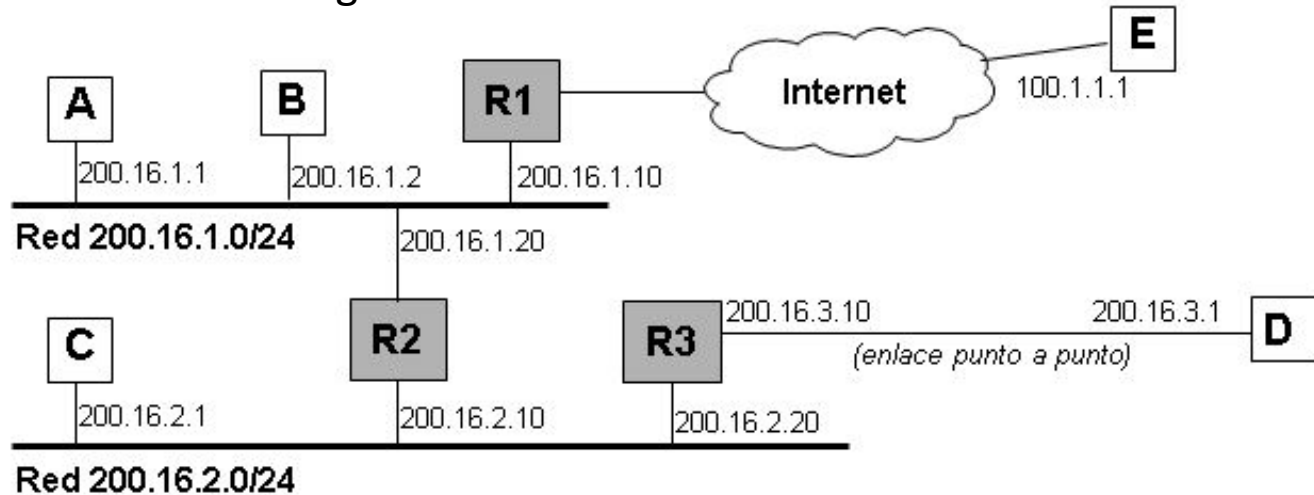
- The network administrator manually decides the routing tables based on his knowledge of the network topology
- The network cannot adapt automatically to changes in the topology

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

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

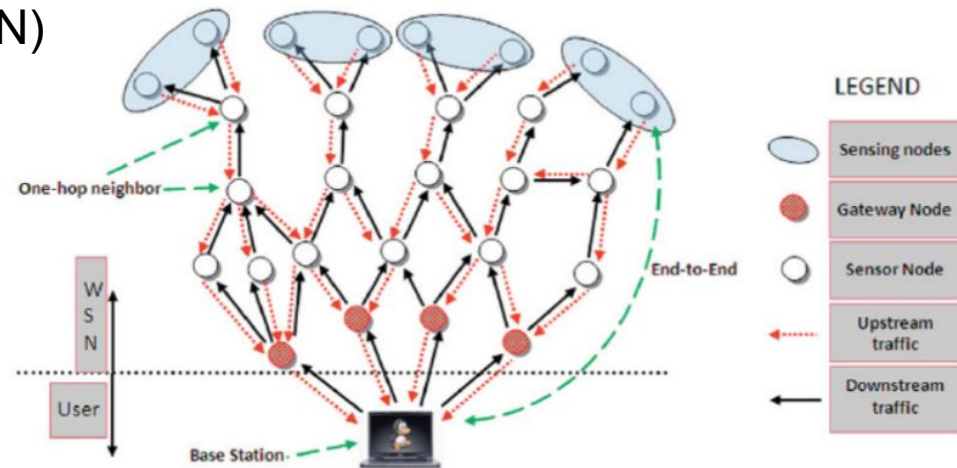
	Destination	Gateway	Genmask	Flags	Iface
1---	200.16.1.0	0.0.0.0	255.255.255.0	U	eth0
2---	200.16.2.0	200.16.1.20	255.255.255.0	UG	eth0
3---	200.16.3.1	200.16.1.20	255.255.255.255	UGH	eth0
4---	0.0.0.0	200.16.1.10	0.0.0.0	UG	eth0

- IPv4 uses 32 bits addresses
 - Máximo 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!!!

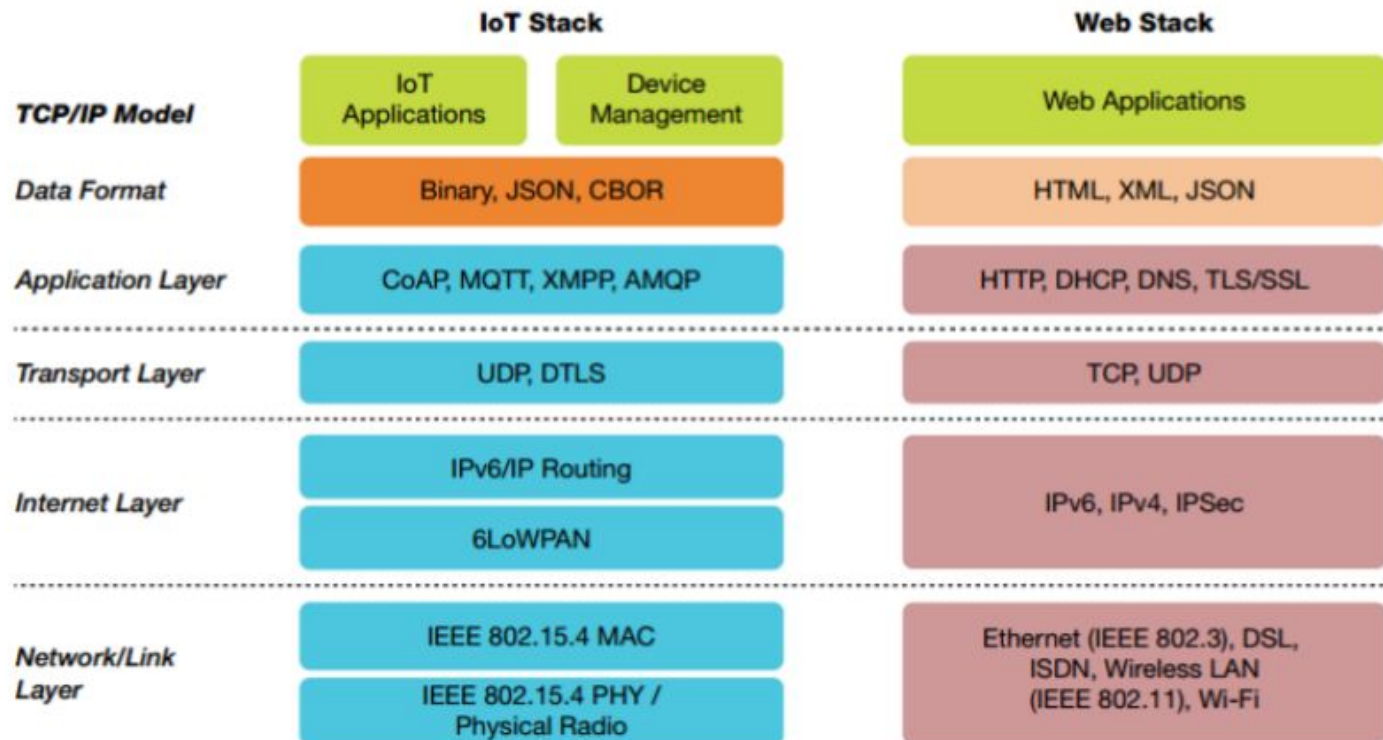
- Basic networking concepts
- Fundamentals of data transmission, a review of basic concepts
- MAC layer
- Network layer
- **Networks for IoT**

- 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



LAN 


**Short Range
Communicating Devices**






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**






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**

10% SOM

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