Communications

- A “thing” always feature communications for “team working”
- The Role of Communications
  - Providing a data link between two nodes
- Communication type:
  - Wireline (e.g. copper wires, optical fibers)
  - Wireless (e.g. RF, IR). RF-based communication is the most popular choice (and also our focus)
- Popular RF-based communication solutions:
  - IEEE 802.15.4 ← used in XM1000 and ZigBee)
  - IEEE 802.11 (or Wifi)
  - Bluetooth
  - Near Field Communication (NFC), e.g. RFID

Networks

- The Roles of Networks
  - Managing nodes (discovery, join, leave, etc).
  - Relaying data packets from the source to the destination node in the network.
- Networks are a distributed system. All nodes need to perform networking related tasks.
- RF-based Network in IoT is usually a Wireless Multi-hop Network. Some examples:
  - Wireless Sensor Networks (WSNs)
  - Mobile Wireless Ad hoc Networks (MANETs)
  - Wireless Mesh Networks (WMNs)
  - Vehicular Ad Hoc Networks (VANETs)
  - and others...
- Main concern: Reliability & Performance

Characteristics (IoT v/s Cellular)

- **IoT communications are or should be:**
  - Low cost,
  - Low power,
  - Long battery duration,
  - High number of connections,
  - Different bitrate requirement,
  - Long range,
  - Low processing capacity,
  - Low storage capacity,
  - Small size devices,
  - Simple network architecture and protocols

IoT?

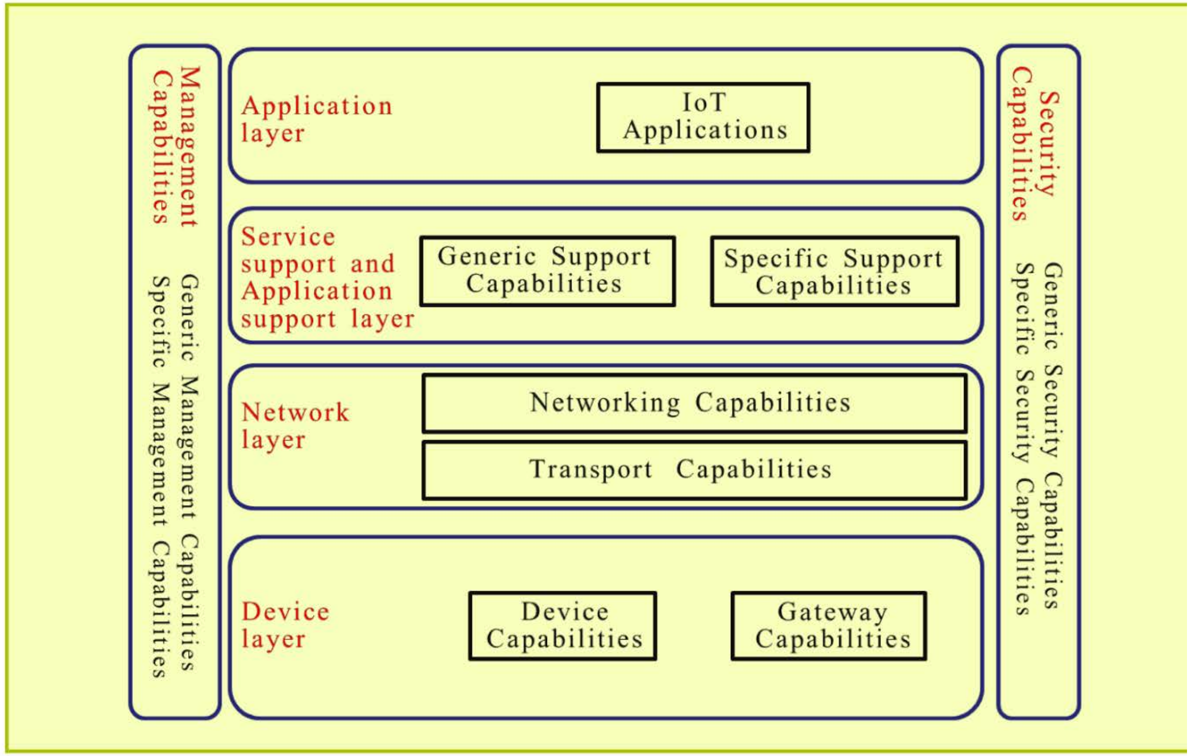
- **Wireless Technologies**

- **Diversity of IoT application requirements:**
  - Varying bandwidth requirements (how much information is sent)
  - Long-range vs short-range
  - Long battery life
  - Various QoS requirements

IoTs and cloud technologies and are the two unstoppable forces promoting digital capabilities

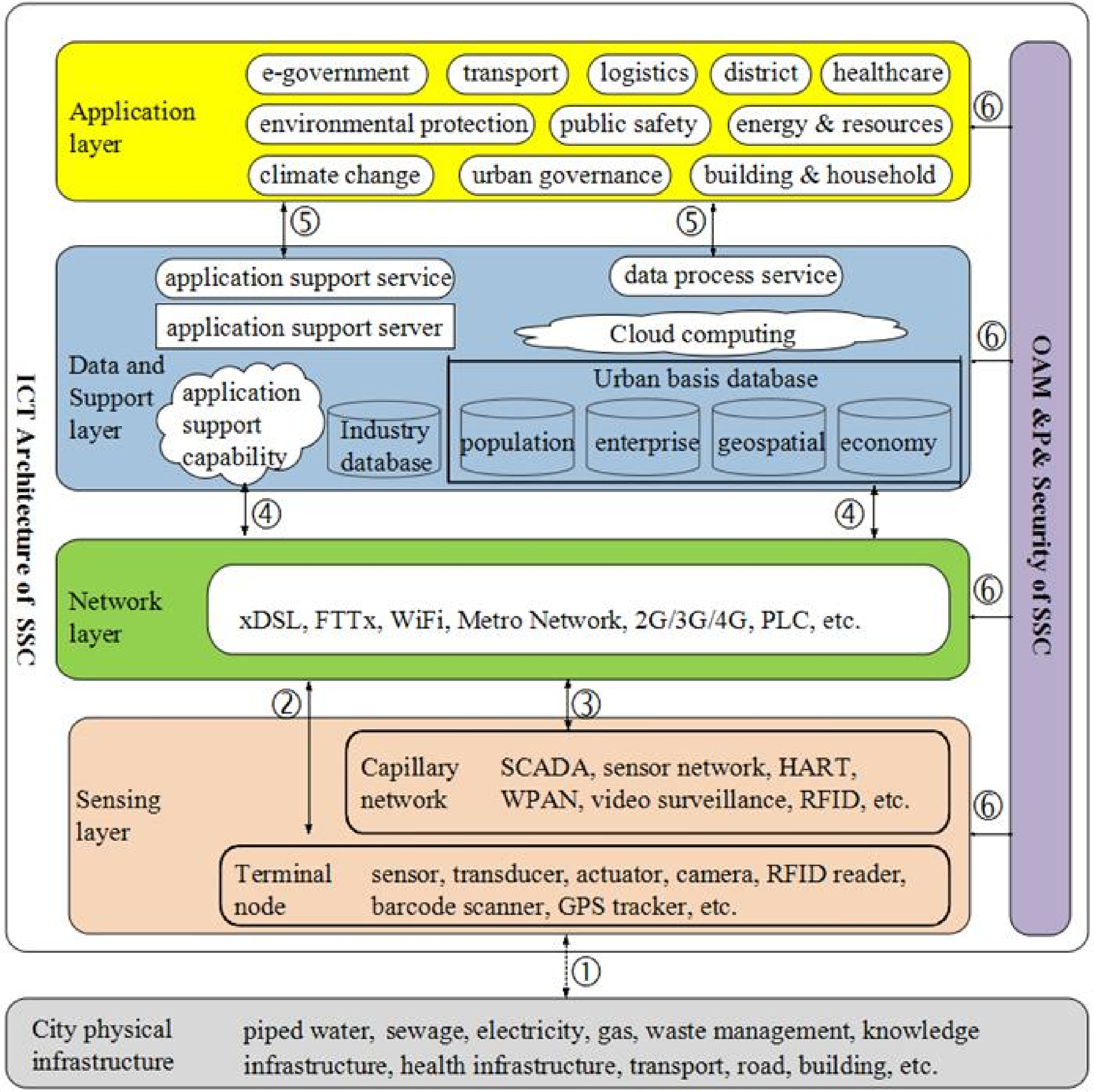
Spectrum needs to be made available in a range of frequency bands to cater for various cases

IoT reference model



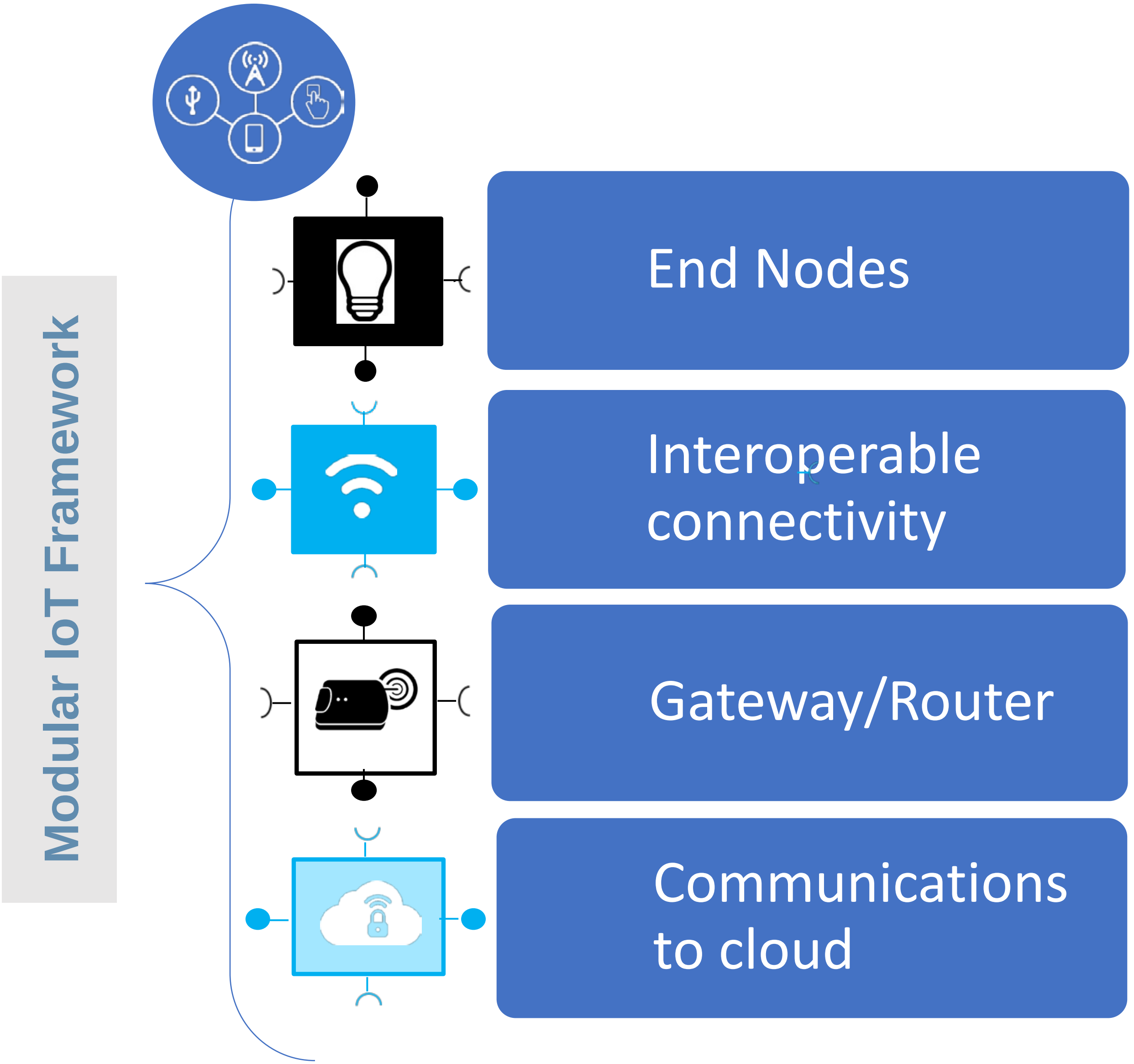
Source: Recommendation **ITU-T Y.2060**

In IoT solutions supporting FC part of the application processing is executed directly at IoT objects and only when needed. More complex and resource-consuming tasks are transferred to higher level units (FC units) or directly to the cloud.



A multi-tier SSC (smart sustainable city) ICT architecture from communication view
Source: ITU-T Focus Group on Smart Sustainable Cities: *Overview of smart sustainable cities infrastructure*

Framework Architecture Enables Fast & Easy Creation of any IoT System



The Many Functional Dimensions of IoT Systems

Edge direct to Tower

Cellular
GSM
LTE
CAT 1
CAT M
NB IOT

SigFox
LoRa

End nodes

Connectivity

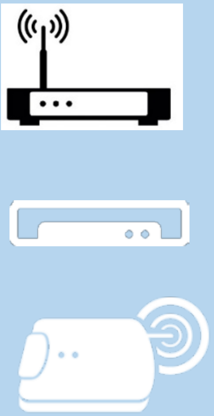
BLE Mesh

Integration/Interfaces/Glue

ZigBee

THREAD

Gateway/ Routing



Communications to the Cloud

Integration/Interfaces/Glue

Cellular
- GSM
- LTE
- CAT 1
- CAT M
- NB IOT

WiFi

Ethernet

SigFox
LoRa

Generic System
Security
OTAP
OOBE Configuration

Cloud Platforms
AWS
Google
Azure
Watson

Application Layer Support
IoTX
OpenAIS
ZCLIP
ZigBee 3.0
OCF
Fairhair
Weave
MQTT
CoAP
BT Profiles

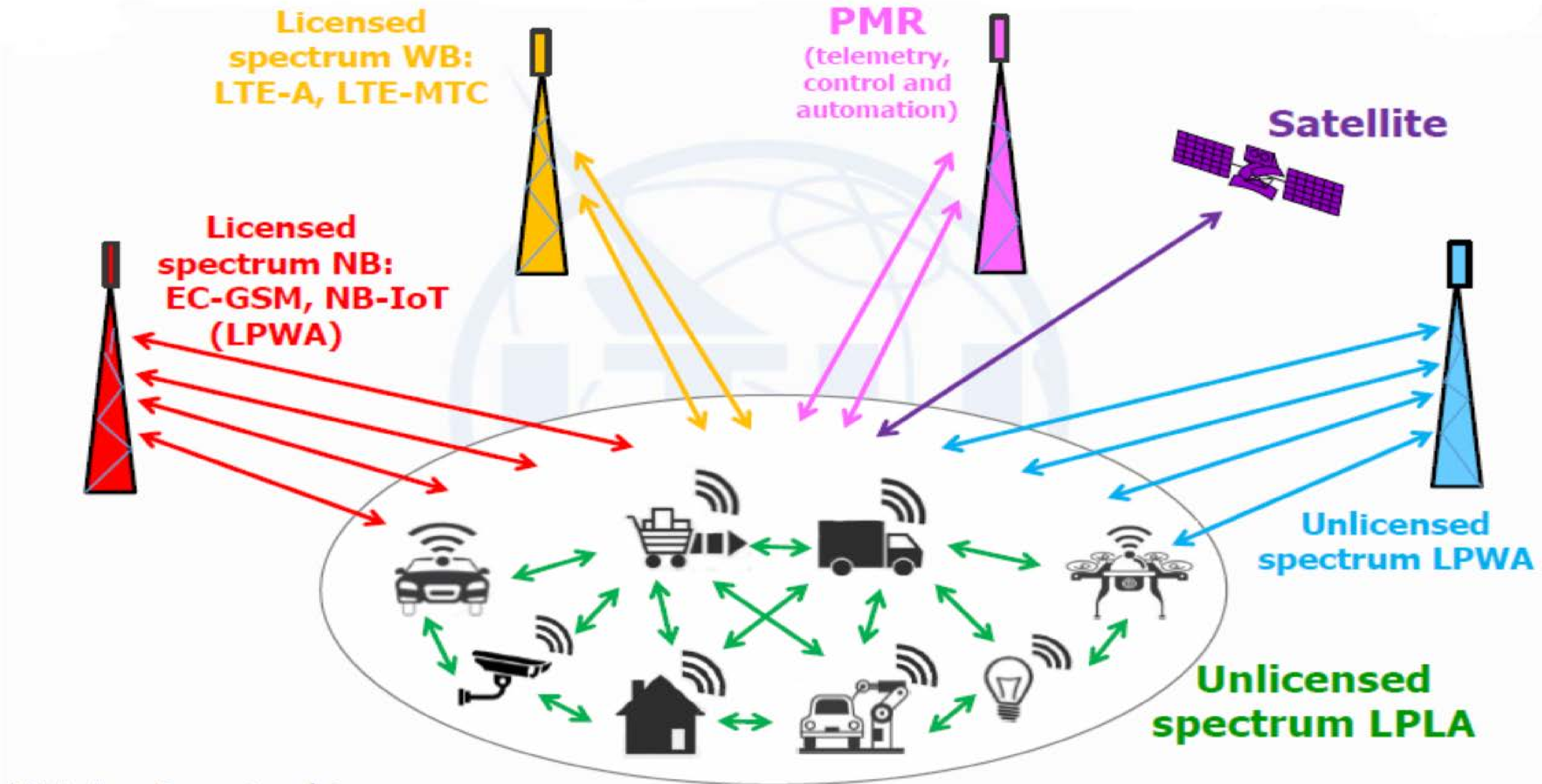
Commissioning
NFC Tap & Connect Commissioning
BLE Commissioning
Intrepid Smart App Commissioning

MCU RTOS
MCUXpresso/FreeRTOS
mbed
Zephyr

MPU OS
Linux
OpenWRT
Android Things
Windows 10

Application HMI

IoT Connectivity Options



LPLA: Low Power Local Area
LPWA: Low Power Wide Area

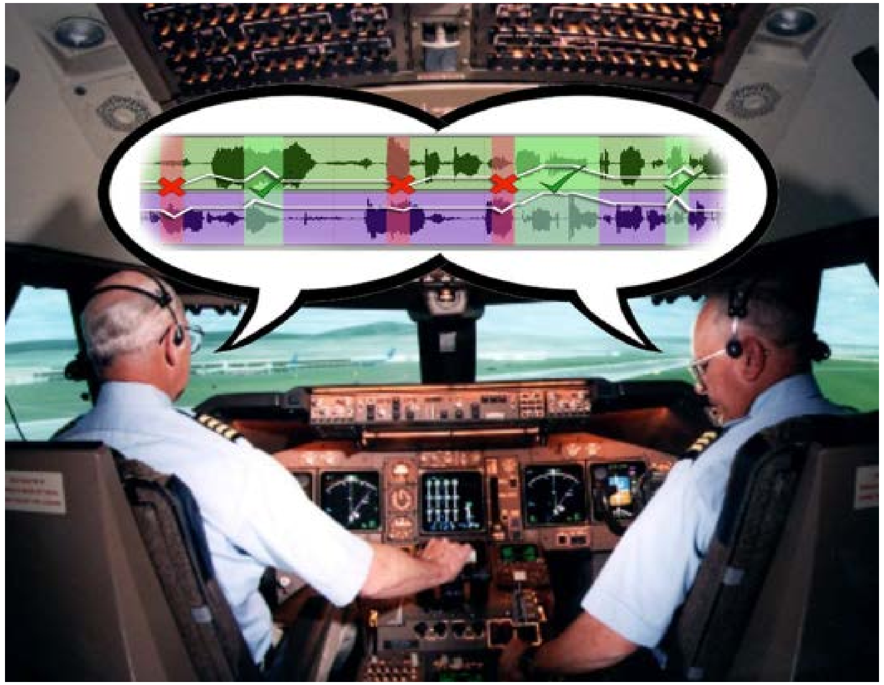
Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva

Telecommunication Signals

Telecommunication signals are variation over ***time*** of voltages, currents or light levels that carry information.

For analog signals, these variations are directly proportional to some physical variable like sound, light, temperature, wind speed, etc.

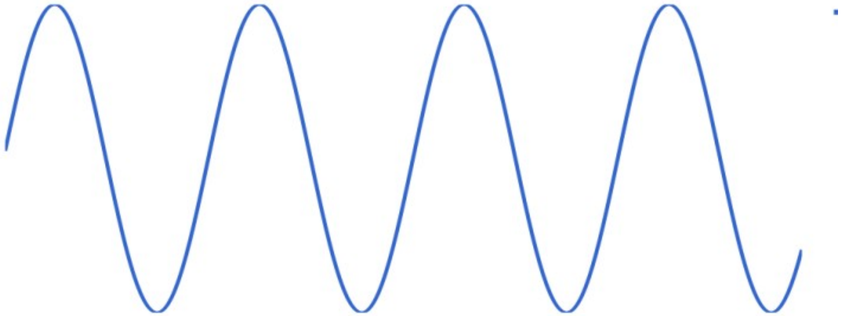
The information can also be transmitted by digital signals, that will have only two values, a digital ***one*** and a digital ***zero***.



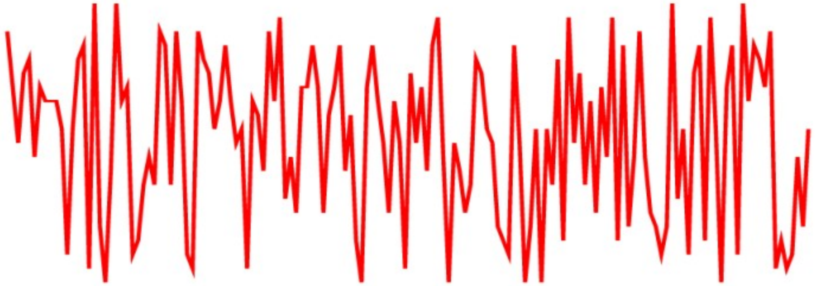
- Any analog signal can be converted into a digital signal by appropriately ***sampling*** it.
- The sampling frequency must be at least ***twice*** the maximum frequency present in the signal in order to carry ***all*** the information contained in it.
- **Random signals** are the ones that are unpredictable and can be described only by statistical means.
- **Noise** is a typical random signal, described by its mean power and frequency distribution.

Examples of Signals

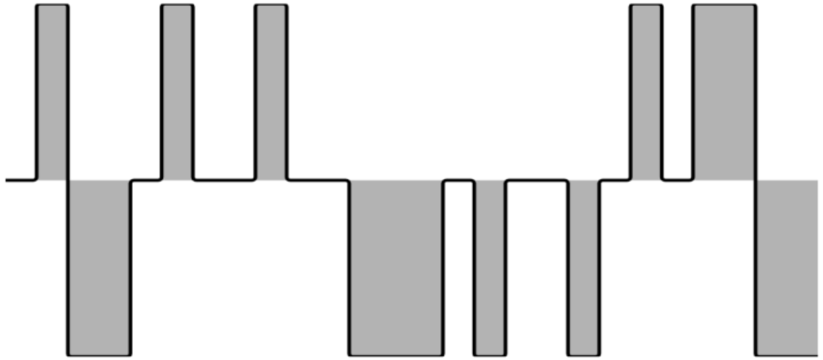
Sinusoidal



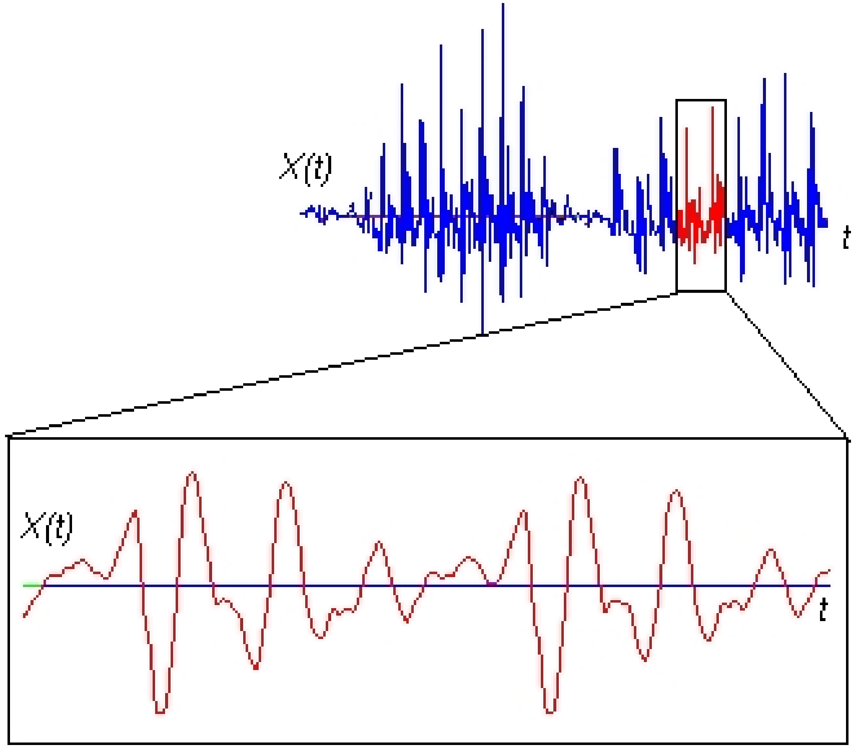
Random



Digital



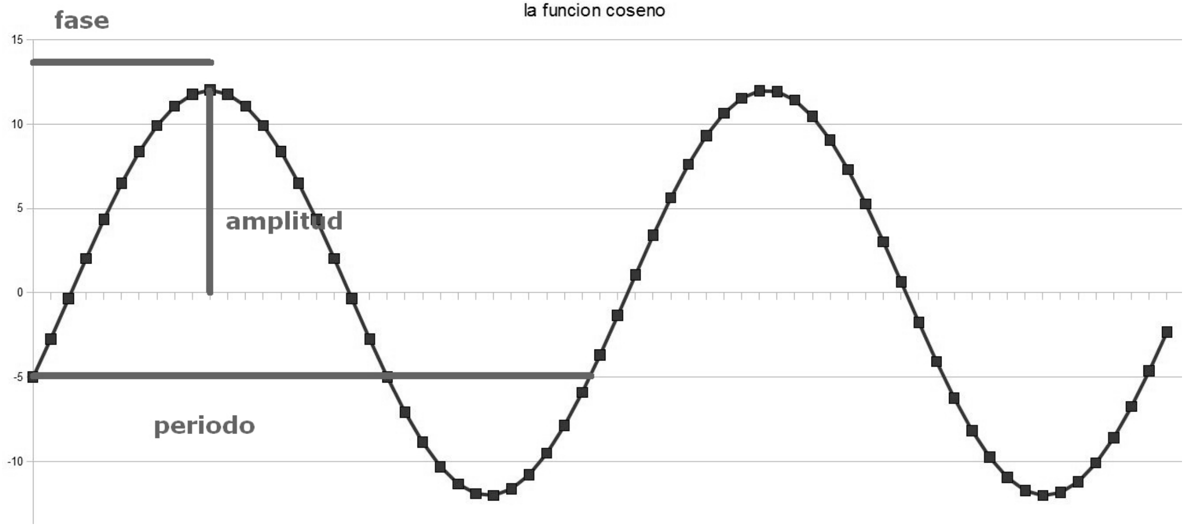
Examples of Signals



Sinusoidal Signal

- Amplitude, volts - A
- Frequency in Hz - f_c
- Phase - ϕ

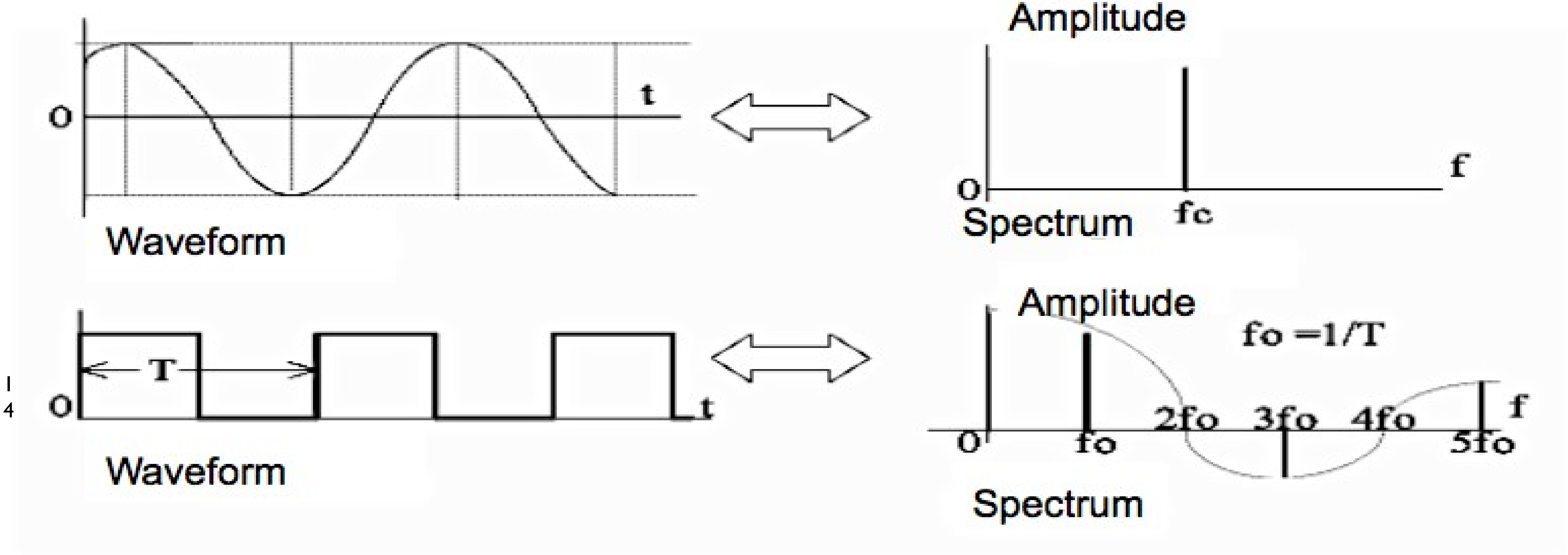
$$S(t) = A\sin(2\pi f_c t + \varphi)$$



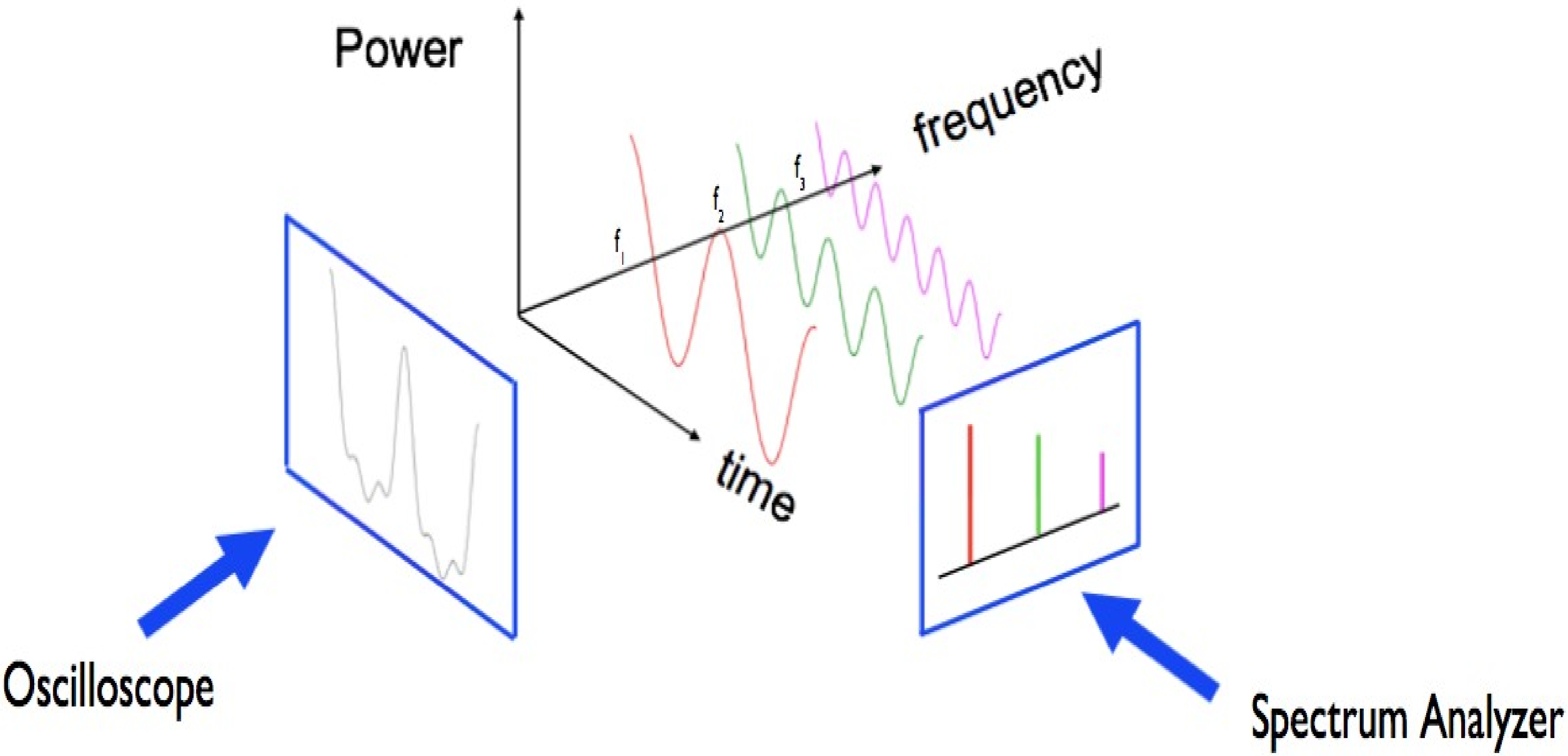
Signal Power

The power of a signal is the product of the current times voltage (VI).
It can also be calculated as V^2/R, where R is the resistance in ohms over which the voltage is applied, or I^2R, where I is the current.

Waveforms and Spectra

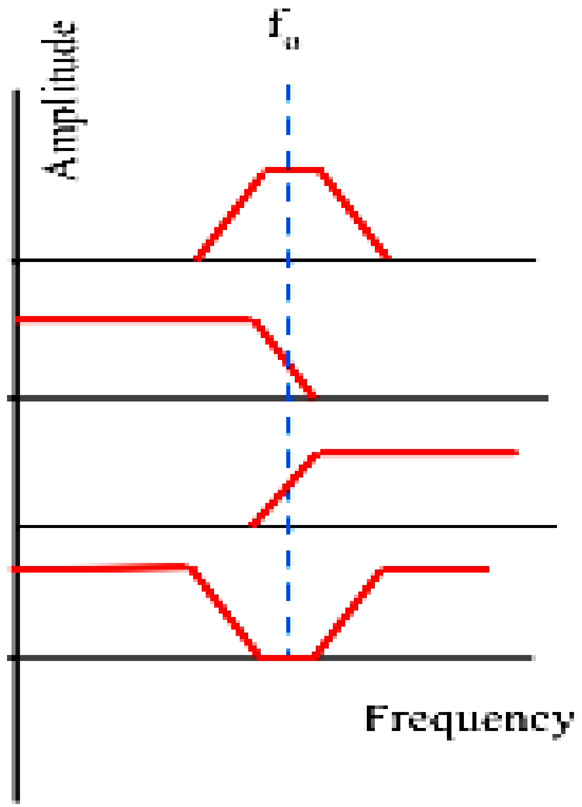


Spectral analysis and filters



Filter Types

- Bandpass
- Lowpass
- High Pass
- Bandstop



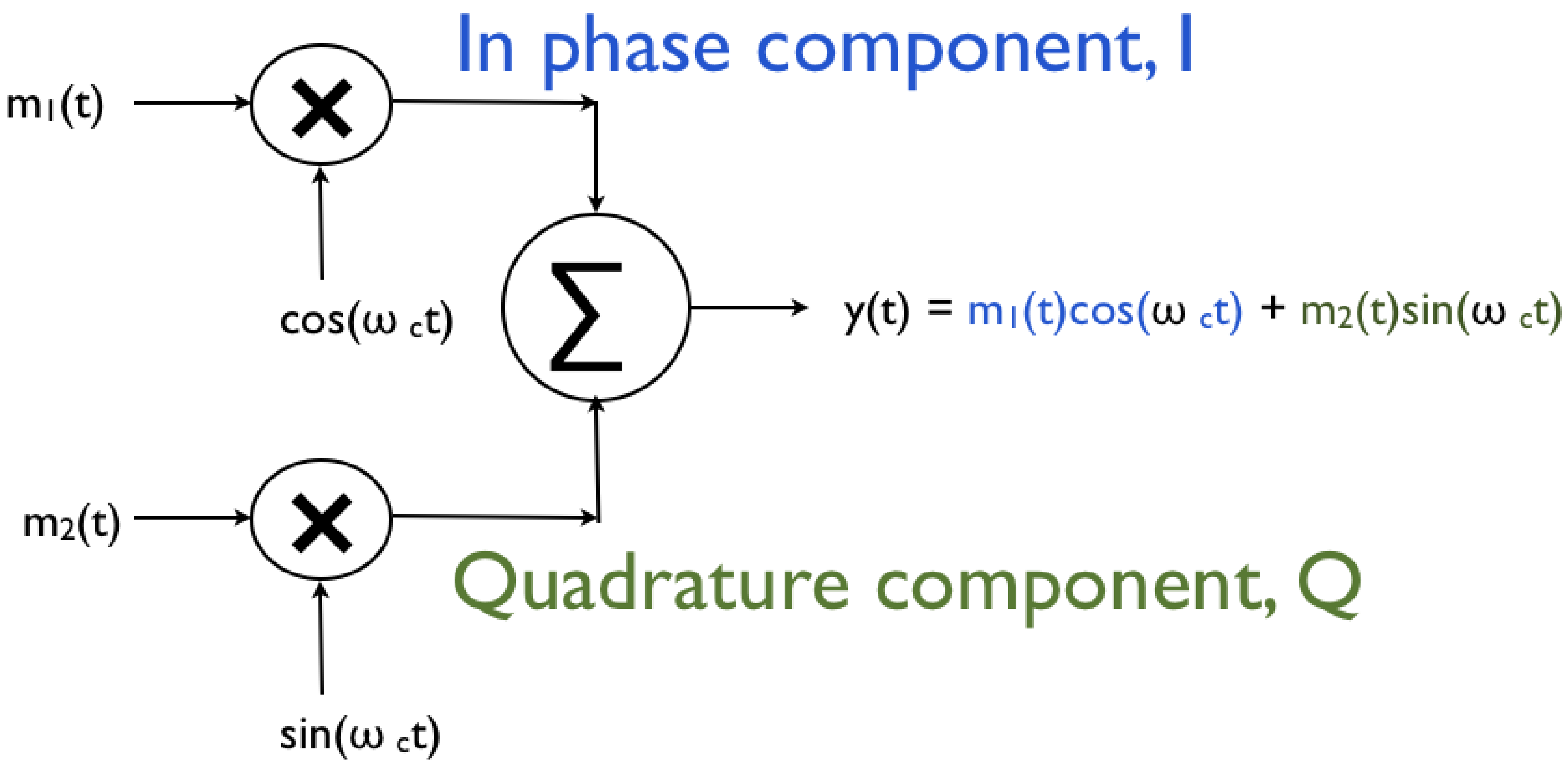
Signals and spectra

Given the time domain description of a signal, we can obtain its spectrum by performing the mathematical operation known as Fourier Transform.

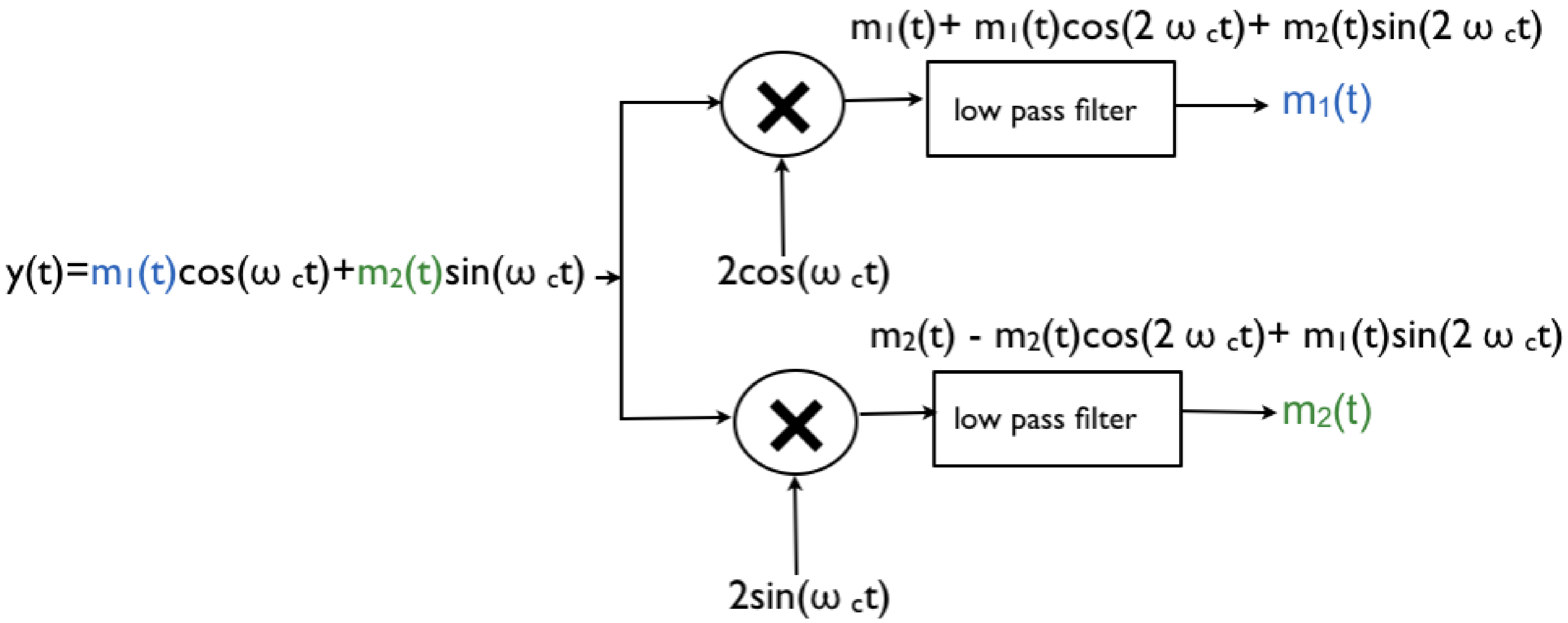
The Fourier transform it is very often calculated digitally, and a well known algorithm to expedite this calculation is the Fast Fourier Transform, FFT.

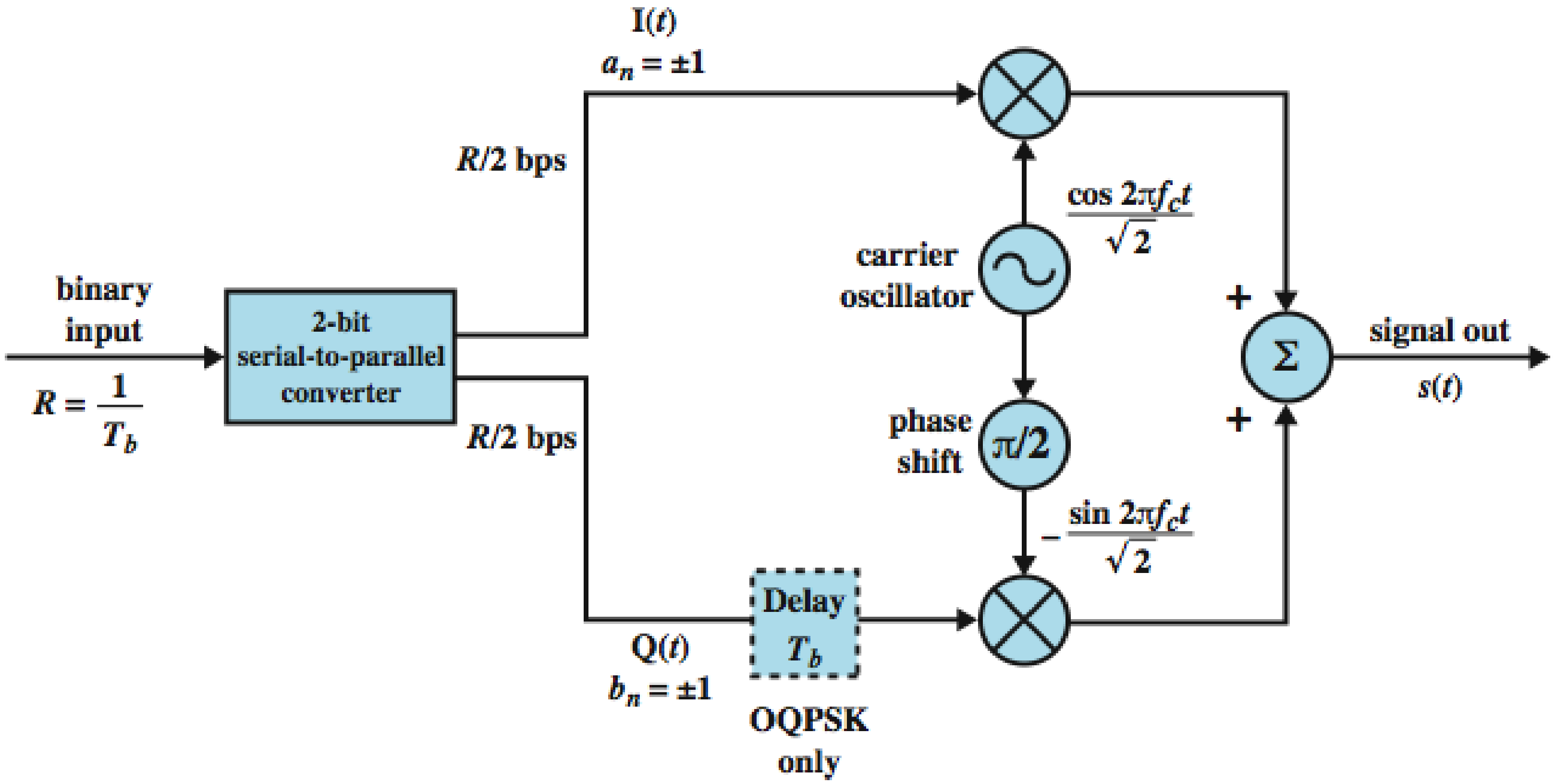
The signal can be obtained from its spectrum by means of the Inverse Fourier Transform.

Orthogonality



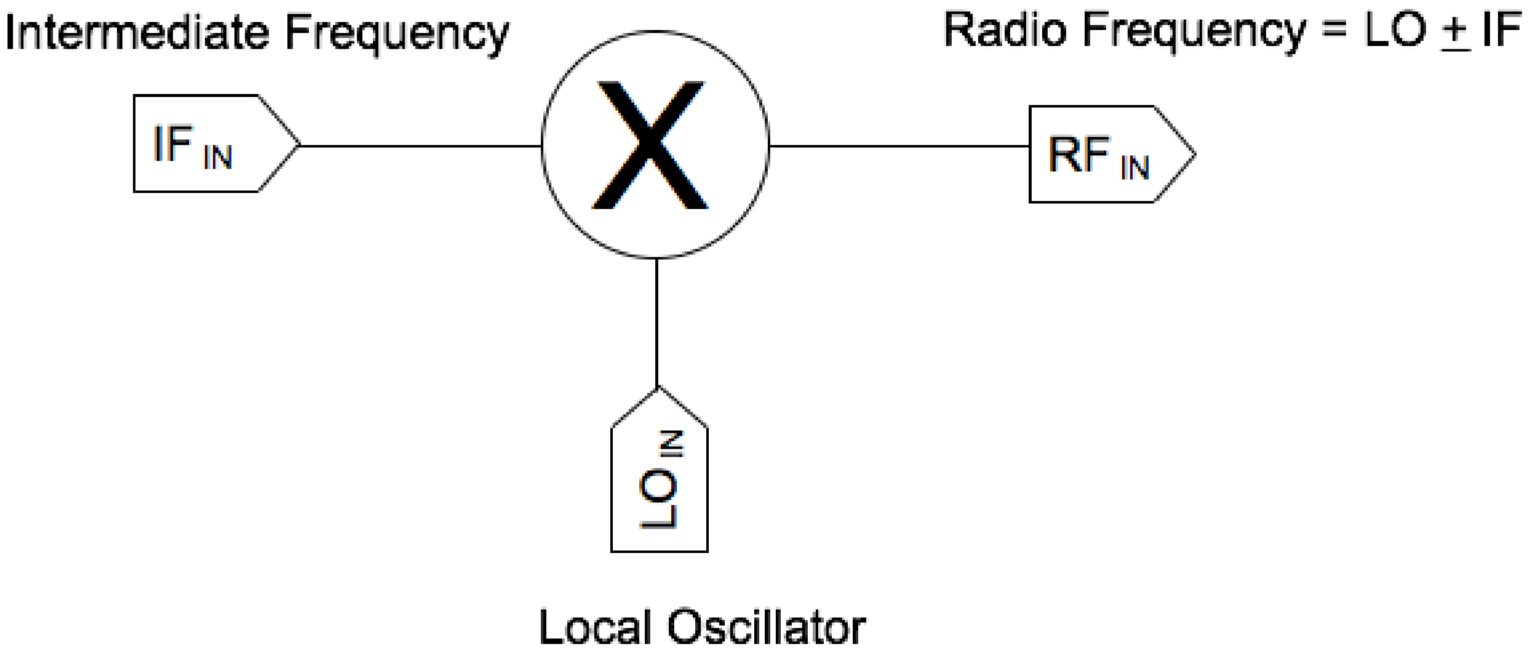
Orthogonality



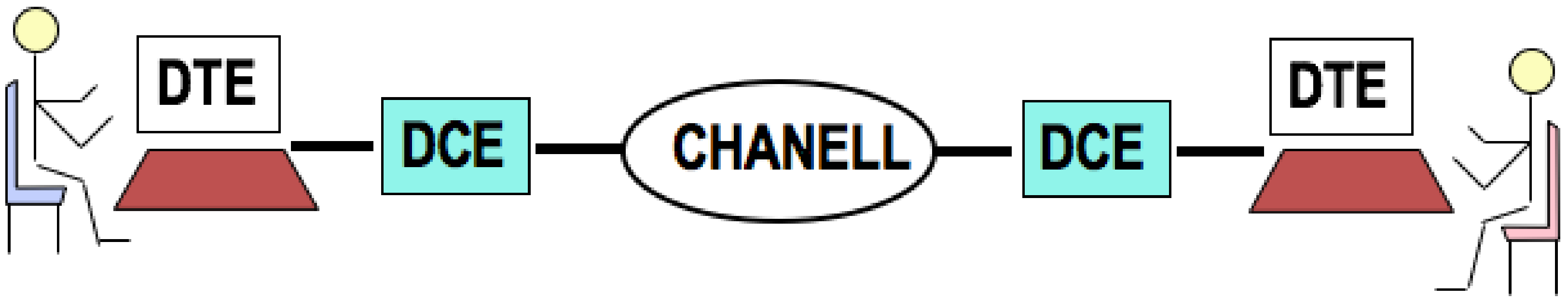

I(t)
$a_n = \pm 1$
R/2 bps
binary
input
$R = \frac{1}{T_b}$
2-bit
serial-to-parallel
converter
R/2 bps
Q(t)
$b_n = \pm 1$
Delay
T_b
OQPSK
only
carrier
oscillator
$\frac{\cos 2\pi f_c t}{\sqrt{2}}$
phase
shift
π/2
$-\frac{\sin 2\pi f_c t}{\sqrt{2}}$
+
+
Σ
signal out
s(t)

Mixers are key components for Frequency Conversion

Can be used for either Up or Down Conversion



Communication System

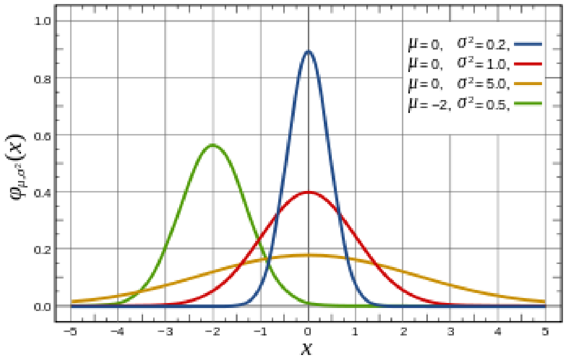


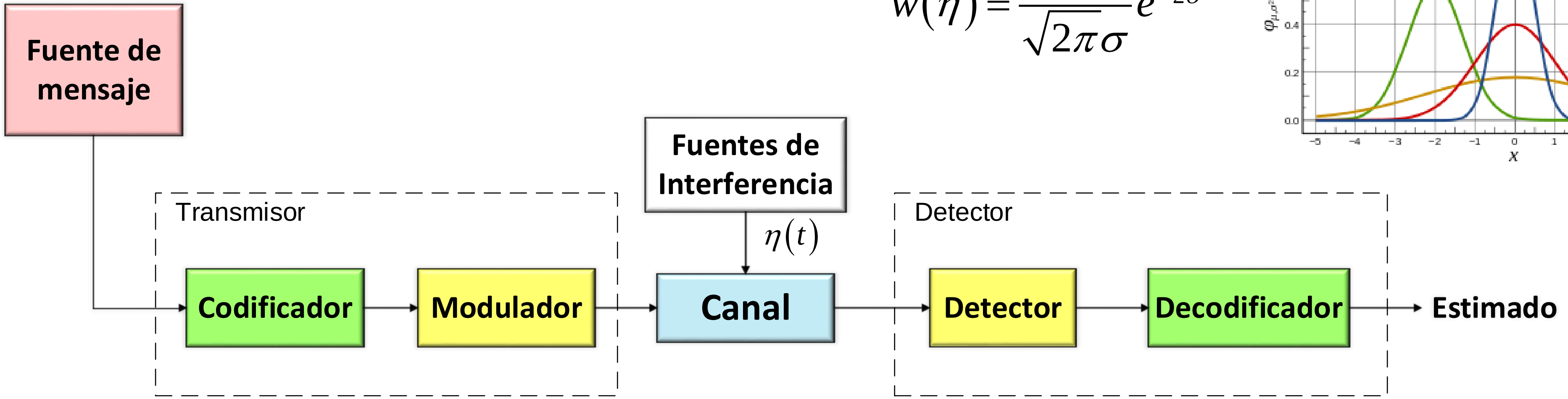
Data terminal equipment

Data circuit-terminating equipment

Estructura de un sistema de comunicación pasobanda

$$w(\eta)=\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{u^2}{2\sigma^2}}$$





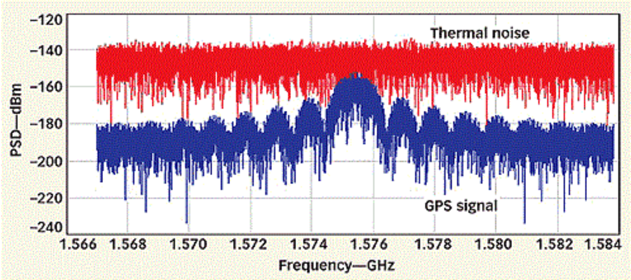
Transmisor
Convertir el mensaje en una señal que puede transmitirse por determinado canal de comunicaciones

Canal
Distorsiona, atenua y agrega ruido
Caracterisiticas:
Linealidad del canal
Ruido de canal:

- Ruido blanco gaussiano aditivo (AWGN, ing. Additive white Gaussian noise)
- Distribución gaussiana: media cero y densidad espectral de apotecia uniforme

Receptor

- Extracción del mensaje de la señal recibida
- Detector y decodificador de transmisión de señal

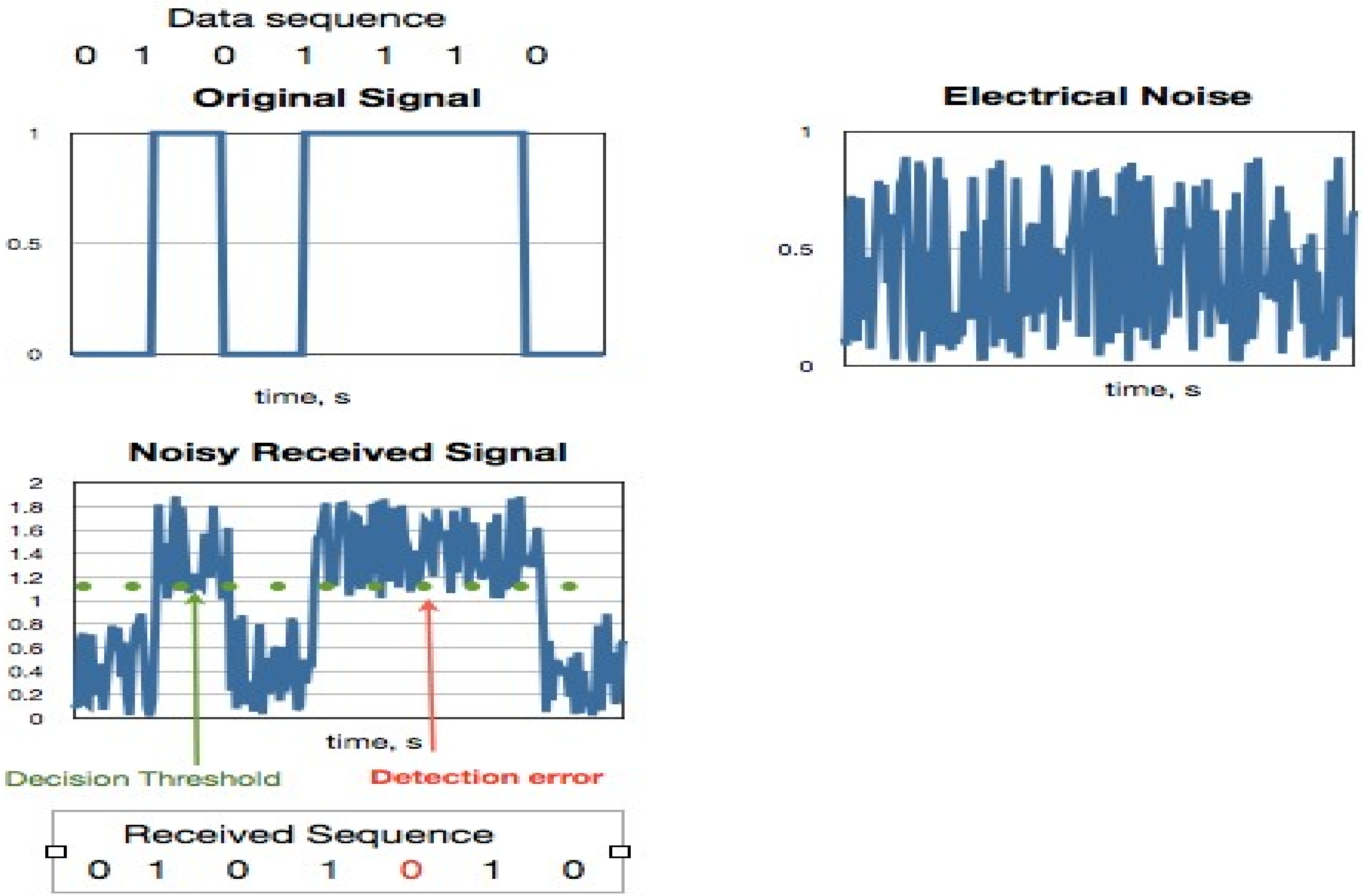


Señal en la salida del canal $y(t)=\mu\cdot s(t)+\eta(t)$

Symbol rate

The symbol rate is defined as the number of symbols per second that a system can transmit.
The unit for symbol rate is the baud.
A baud can pack several bits per second, depending on the type of modulation.
The baud can also be calculated as the inverse of shortest duration of the transmitted signal

Detection of a noisy signal



Detection of a noisy signal

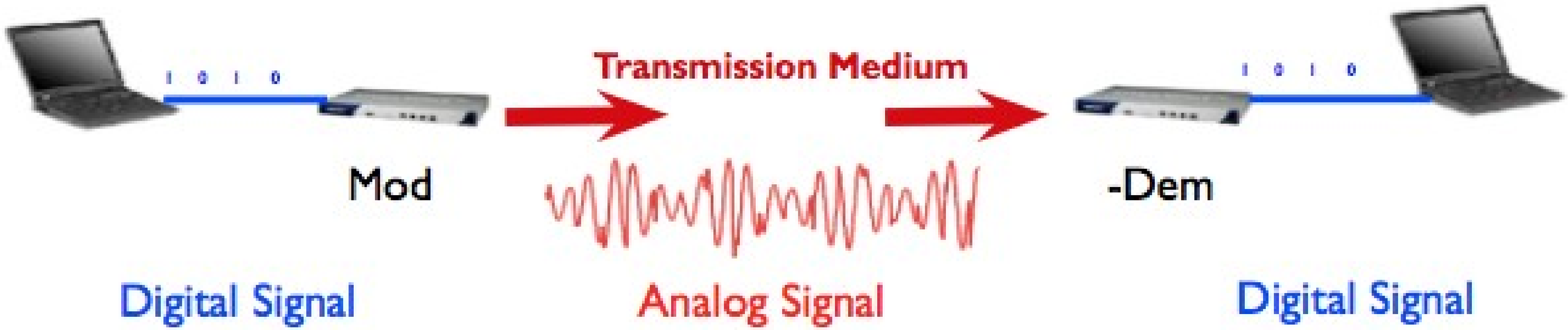
- Detection of a simple binary signal is performed by sampling the received signal, measuring the energy in it and comparing with a detection threshold.
- The value of the threshold is determined by the noise and interference present.
- The key parameter is then Eb/No, the ratio between the energy per bit and the noise spectral density.
- A higher data rate requires a greater Eb/No to achieve the same bit error rate (BER).

Detection of a noisy signal

An analogy with voice communication helps to understand the detection process.

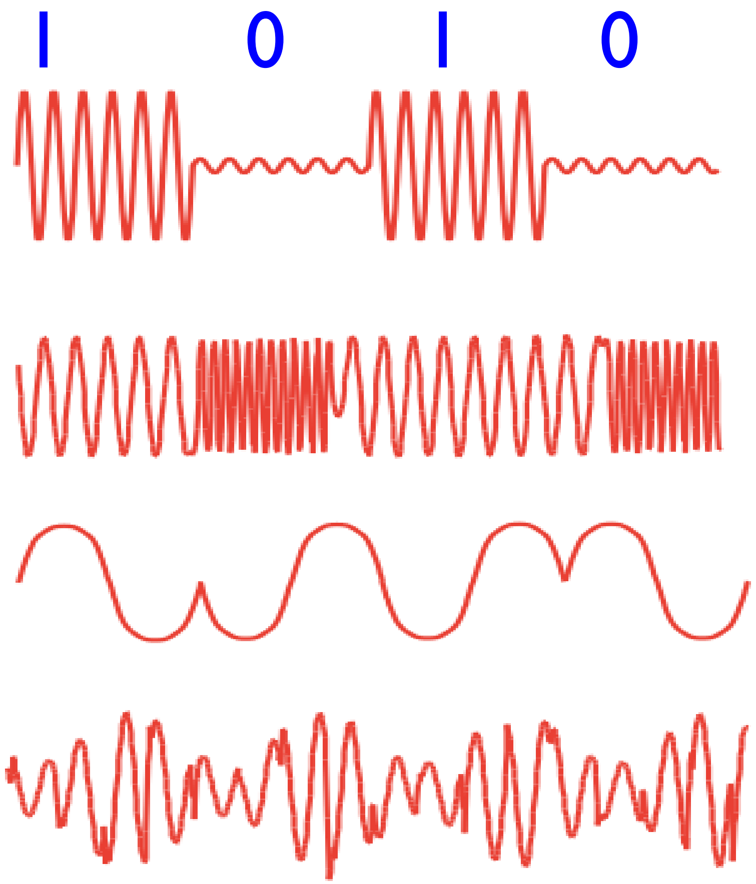
- The stronger the noise in a room, the louder a person must speak to be understood.
- When listening to a foreign language one always think they are speaking too fast, because the "modulation of the signal" is unfamiliar and more processing is required to detect the meaning.
- The faster a person speaks, the louder must speakto be understood.

MoDem



1 0 1 0
Transmission Medium
1 0 1 0
Mod
-Dem
Digital Signal
Analog Signal
Digital Signal

Comparison of modulation techniques



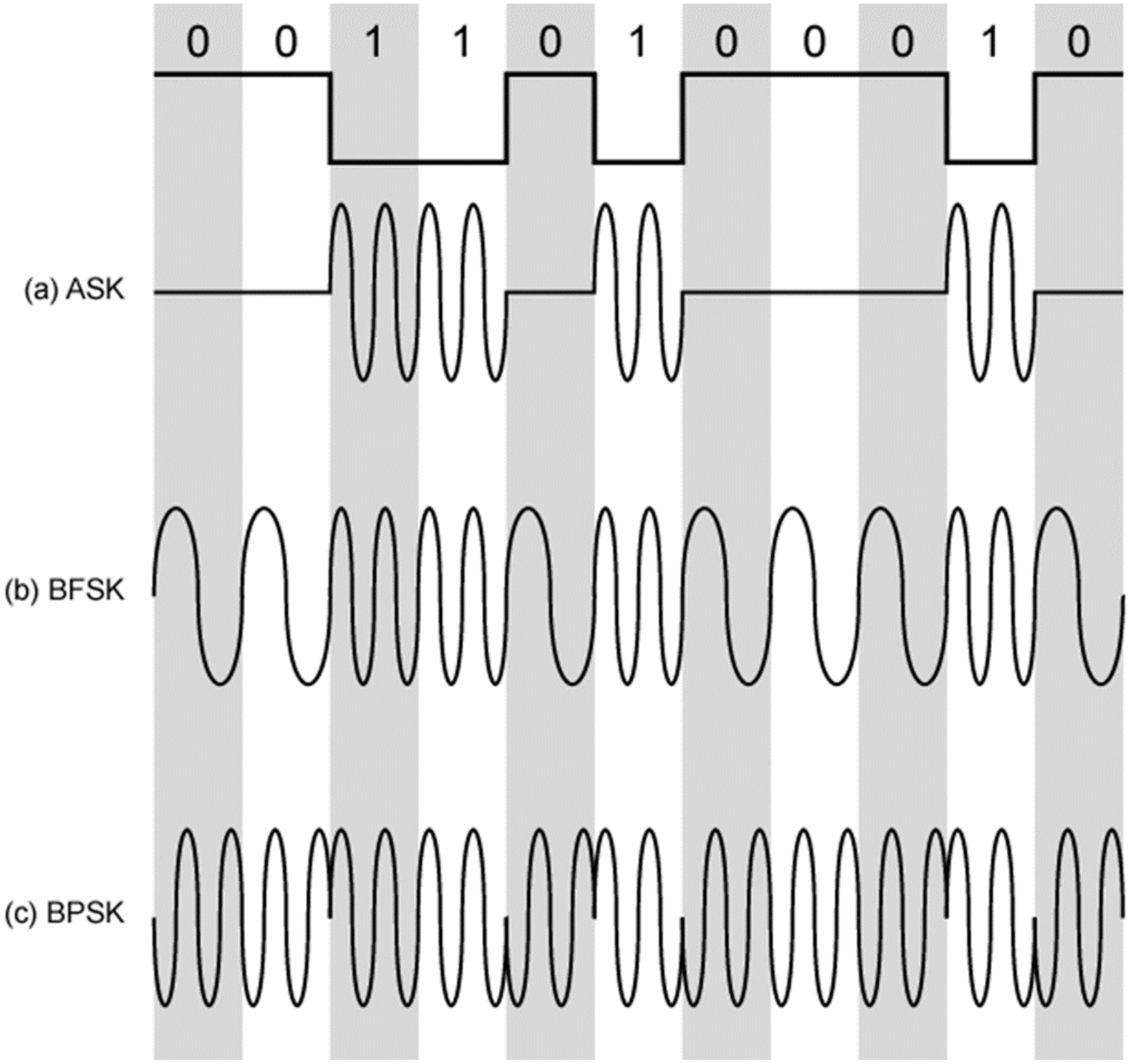
Digital Sequence

ASK modulation

FSK modulation

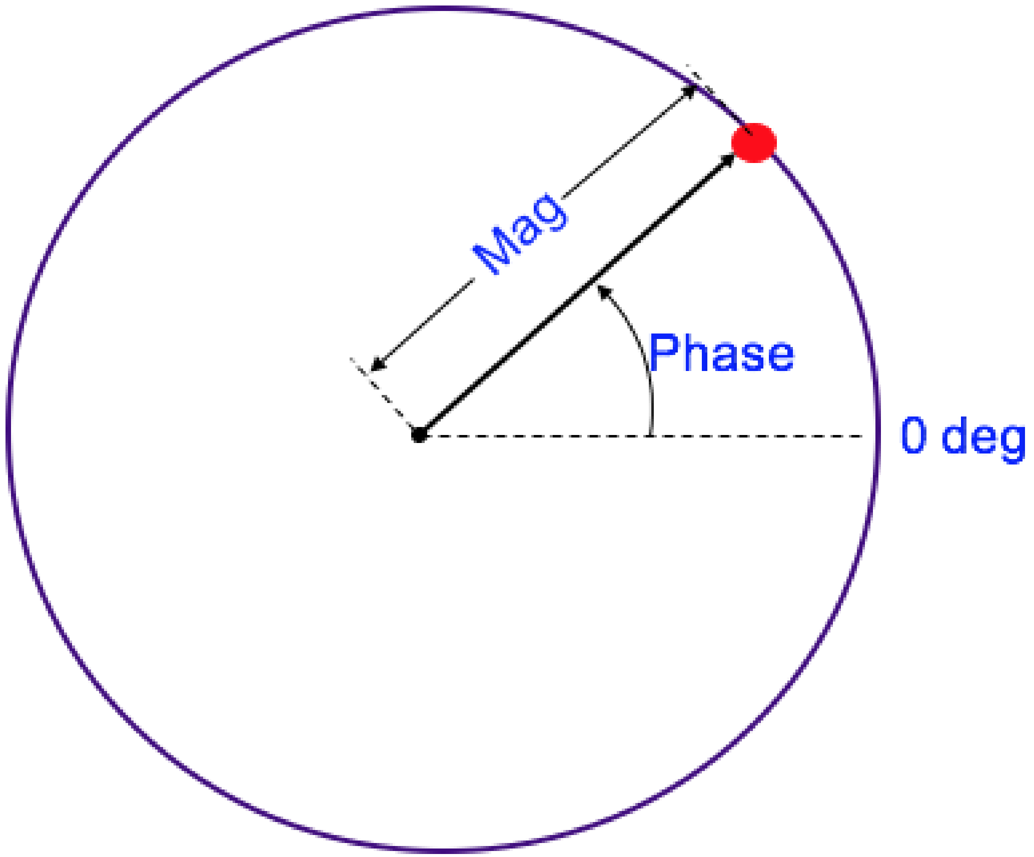
PSK modulation

QAM modulation, changes
both amplitude and phase


0 0 1 1 0 1 0 0 0 1 0
(a) ASK
(b) BFSK
(c) BPSK

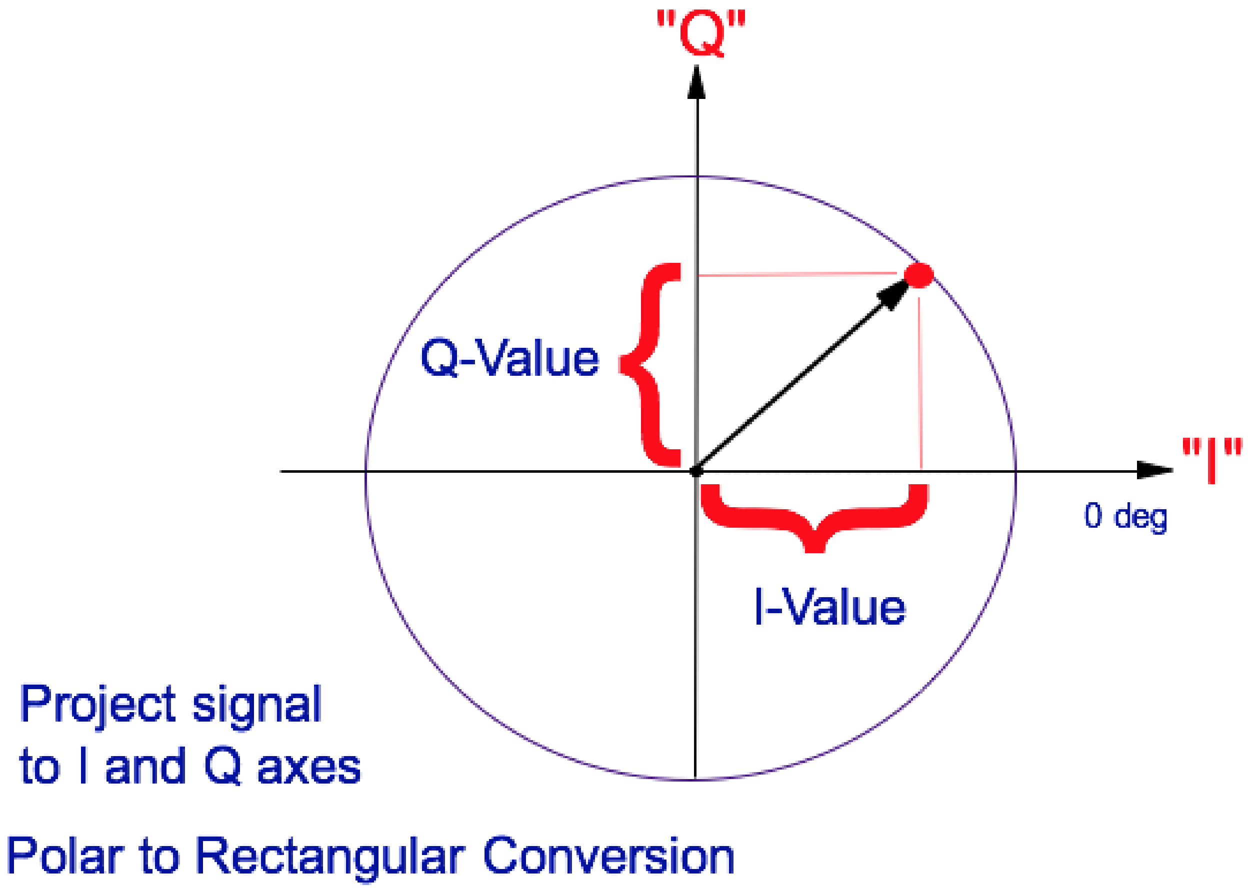
Digital Modulation

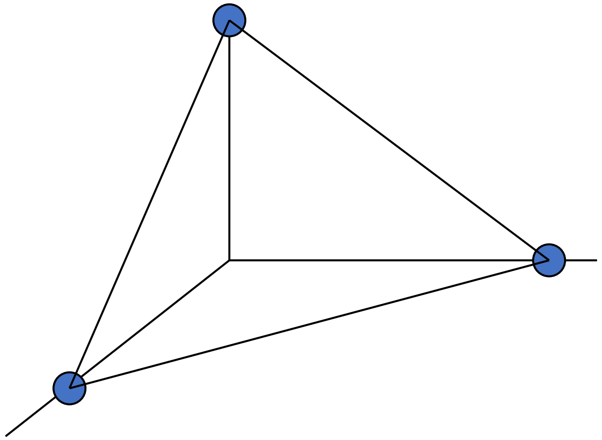
Polar Display: Magnitude & Phase Represented Together



- Magnitude is an absolute value
- Phase is relative to a reference signal

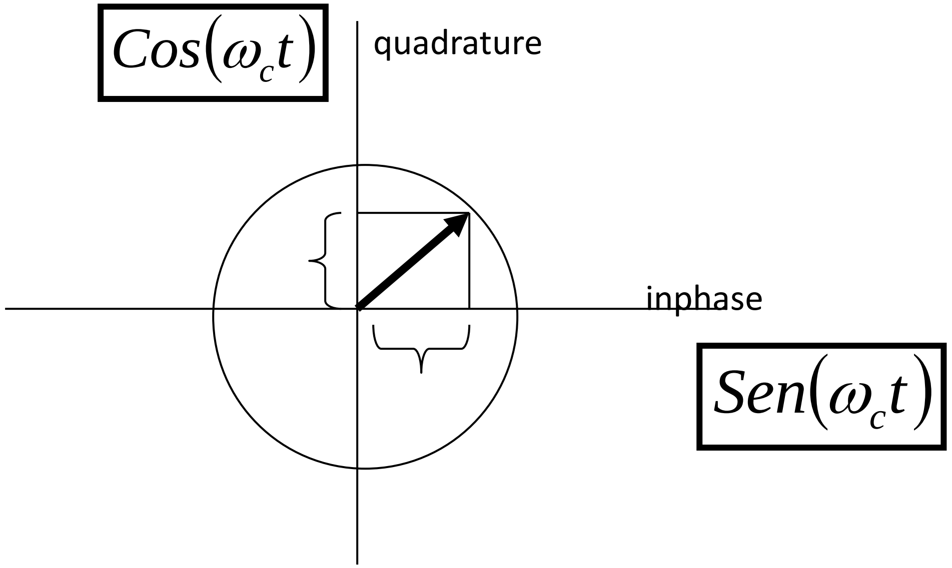
Digital Modulation Polar vs. I/Q representation





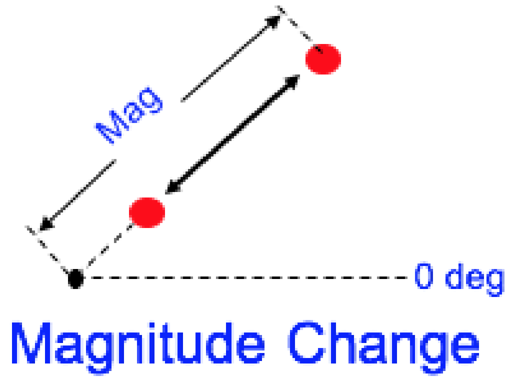
$$e^{j2\pi fct}=\cos(2\pi f_c t)+j\sin(2\pi f_c t)$$

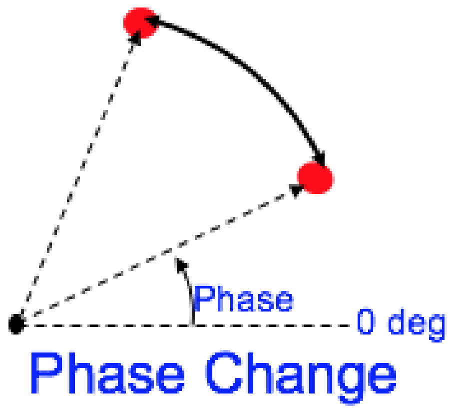
$$\boxed{Sen(\omega_c t+90)=Cos(\omega_c t)}$$

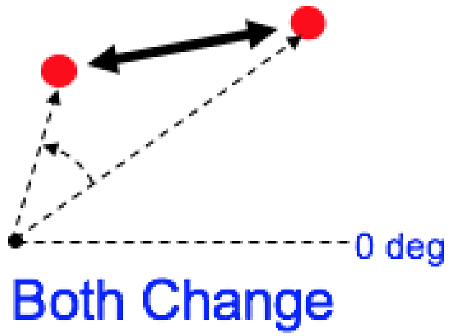


Digital Modulation

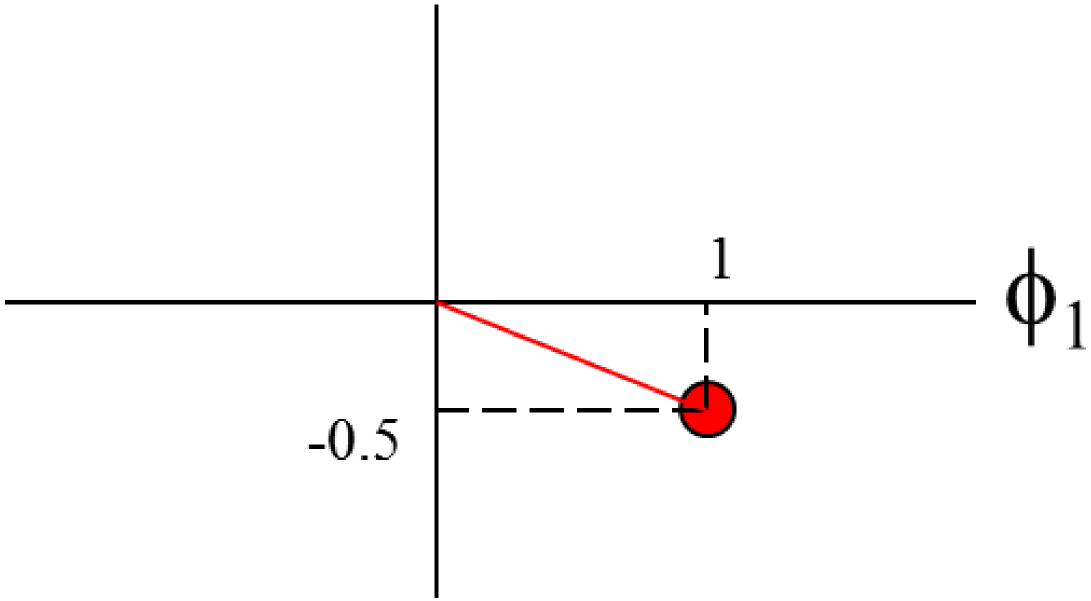
Signal Changes or Modifications

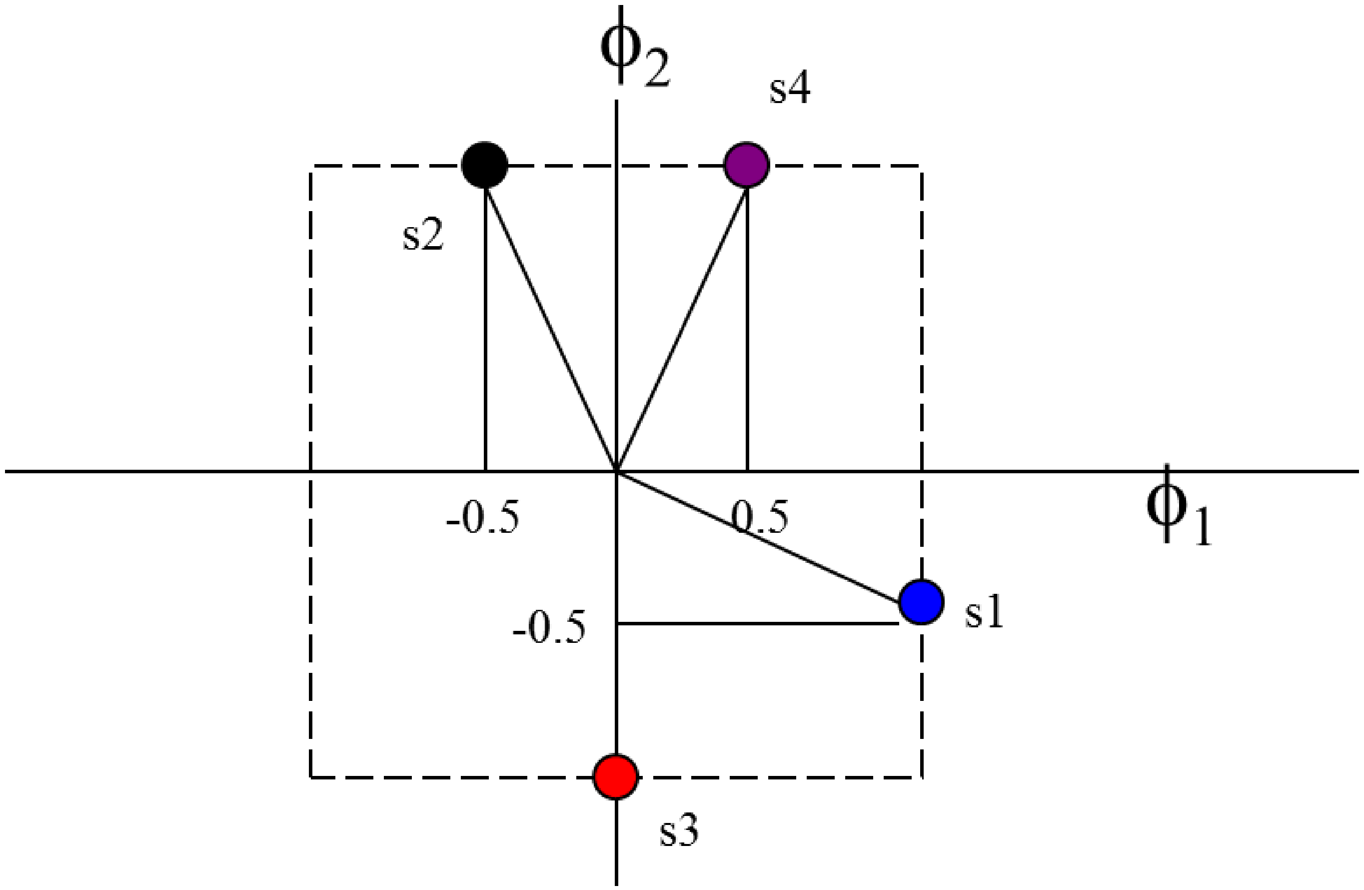




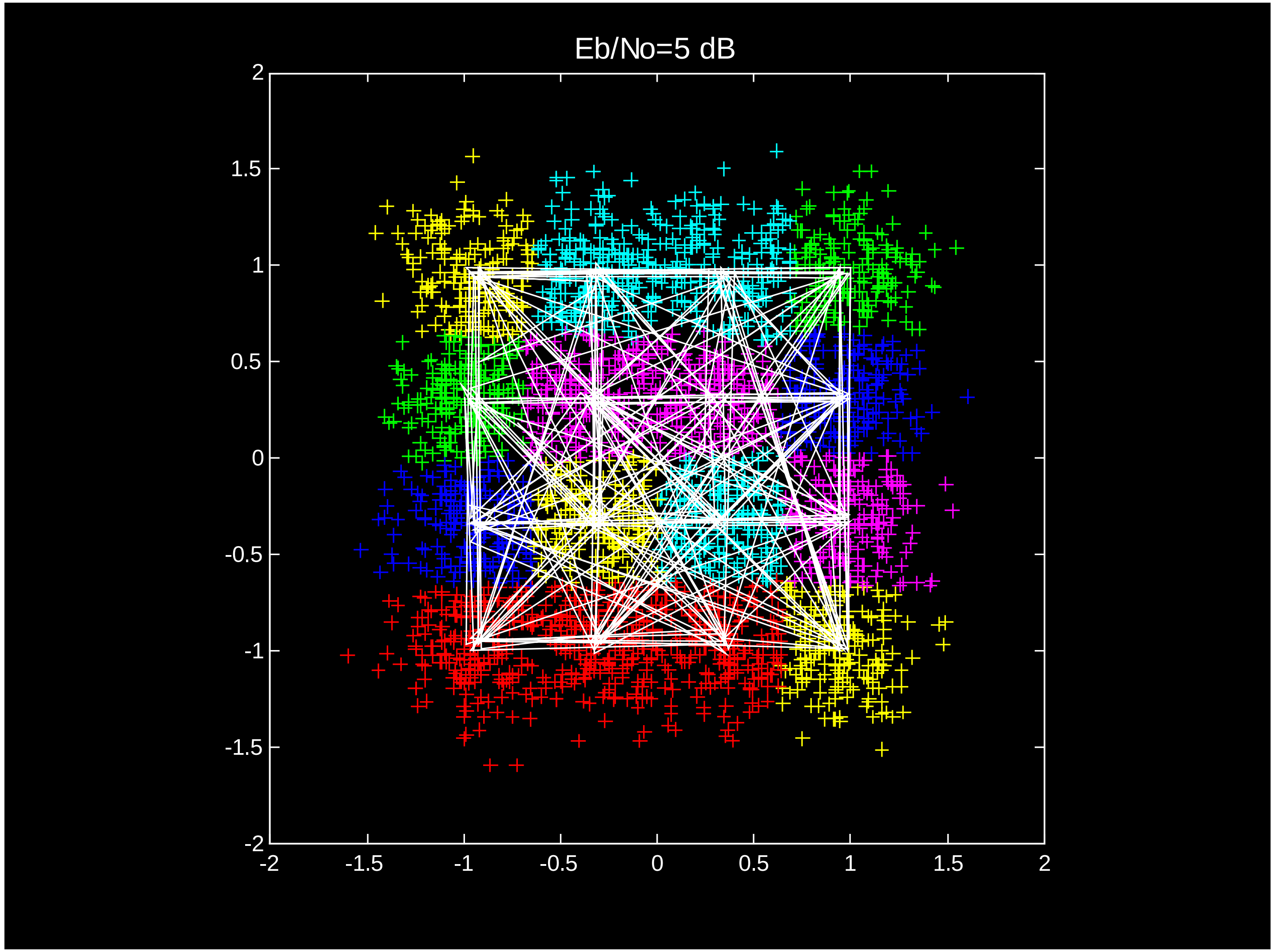


$$s_1(t)=(1)\phi_1(t)+(-0.5)\phi_2(t)$$

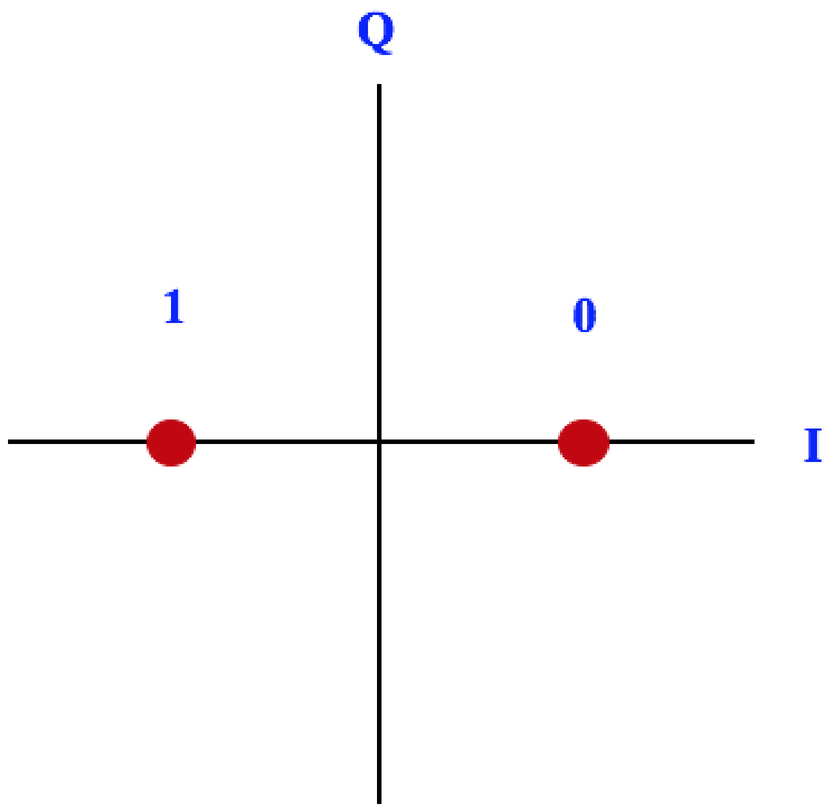




ϕ_2
s4
s2
-0.5
0.5
ϕ_1
s1
-0.5
s3

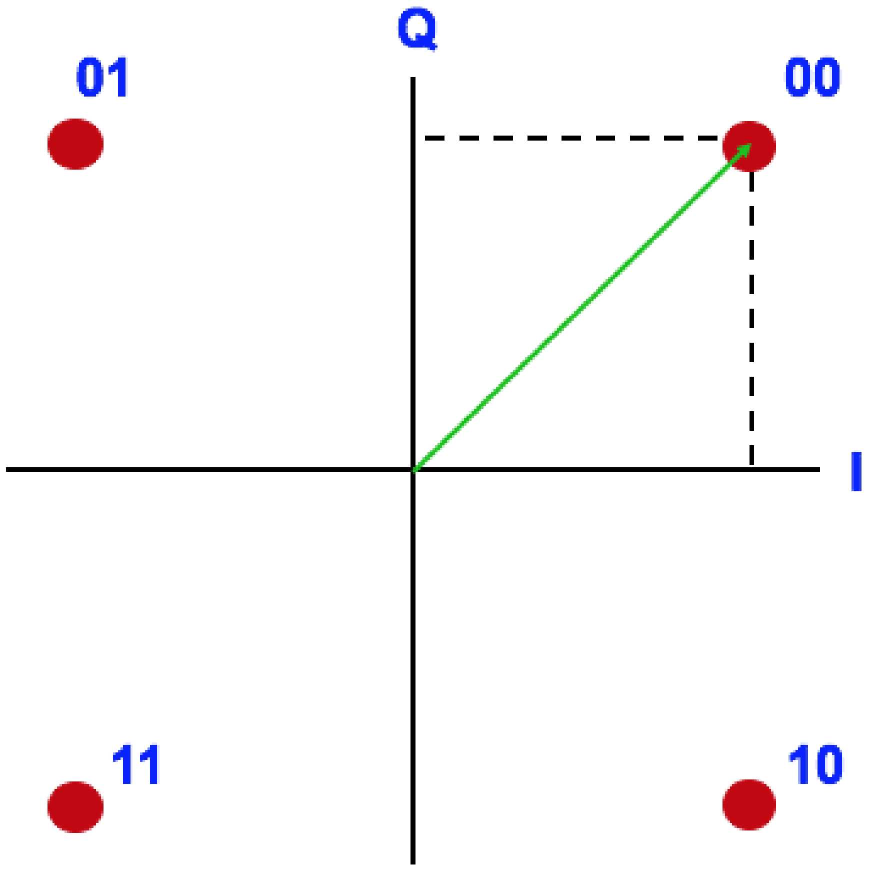

Eb/No=5 dB
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Digital Modulation
Binary Phase Shift Keying (BPSK) I/Q Diagram



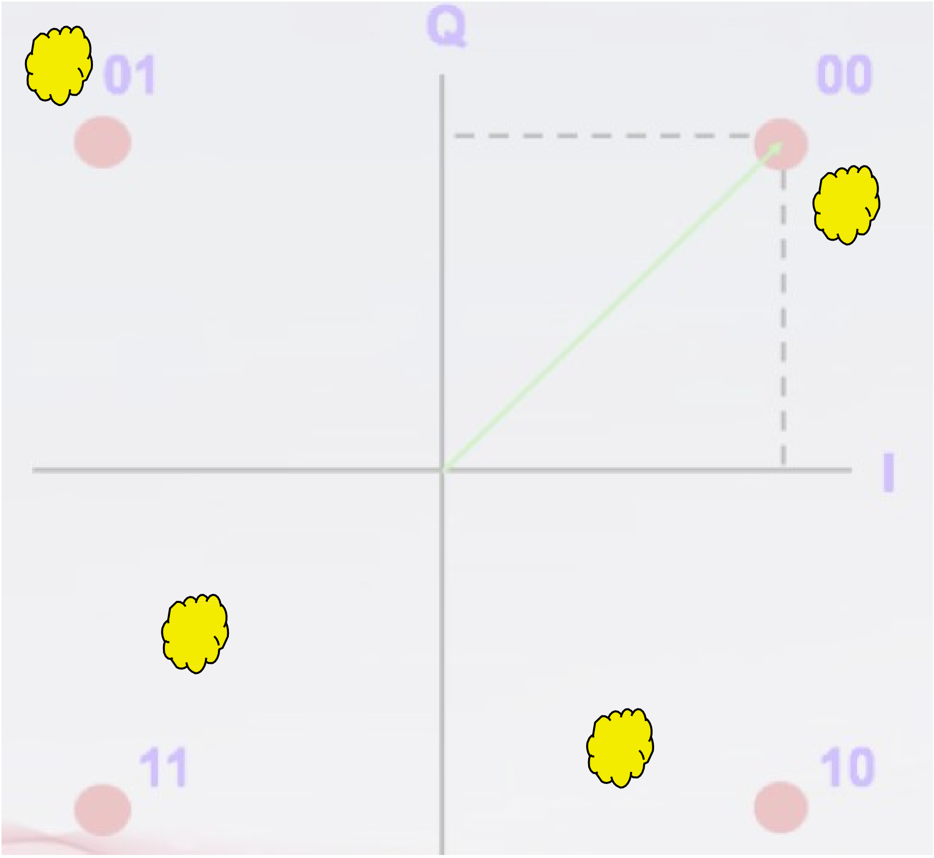
Digital Modulation

Quadrature Phase Shift Keying (QPSK) IQ Diagram

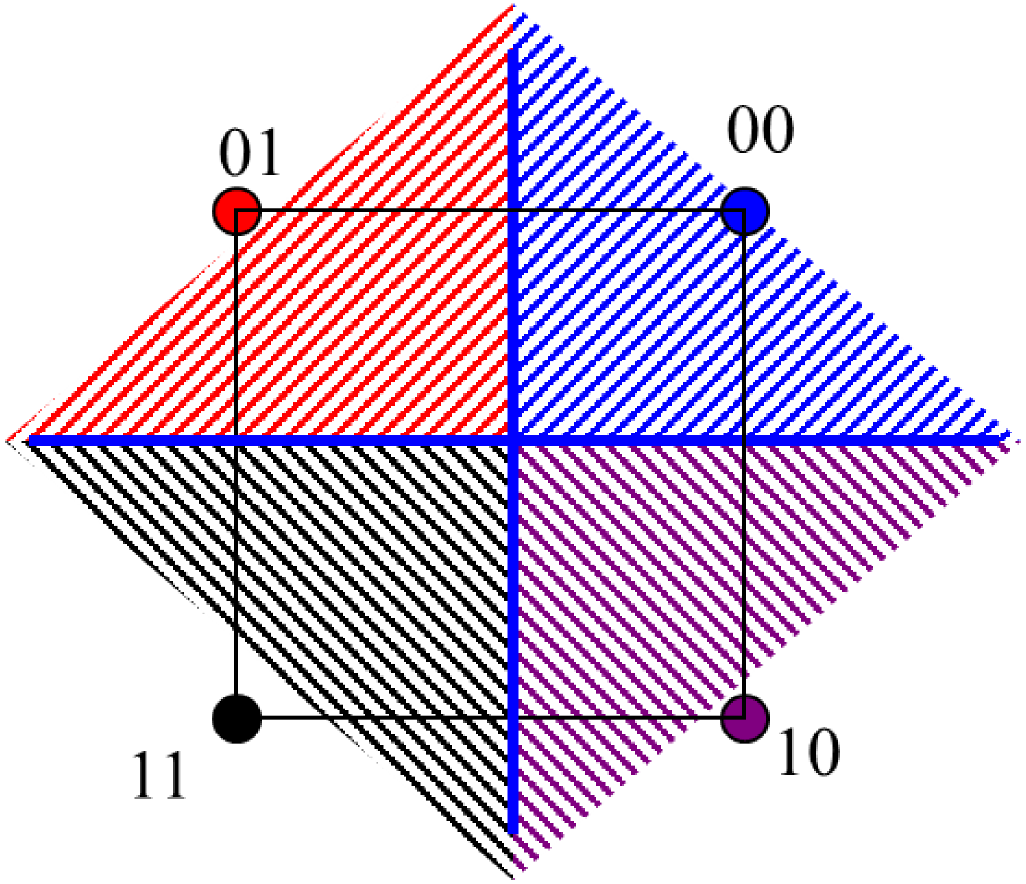


Digital Modulation: QPSK

Effect of the noise in the received signal
This kind of diagram is called a constellation because of the fuzziness of the points

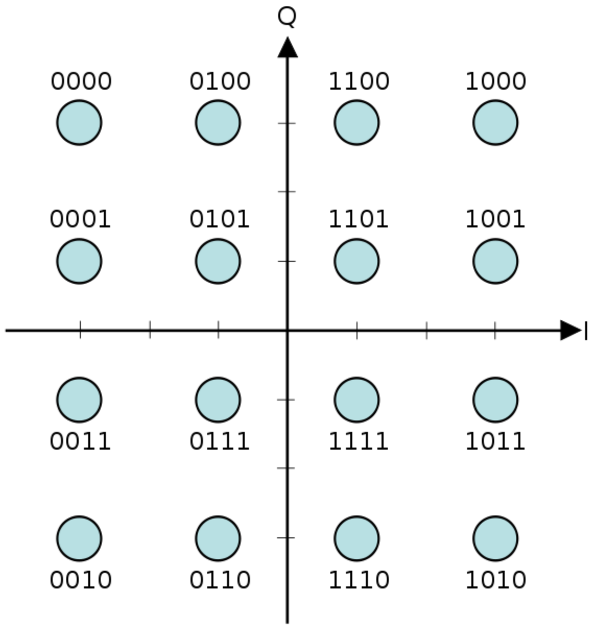


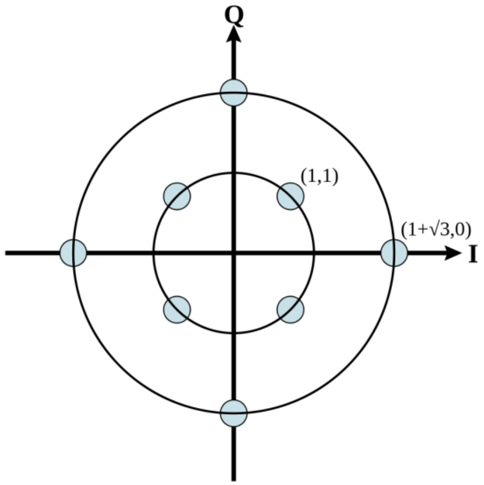
QPSK decision regions



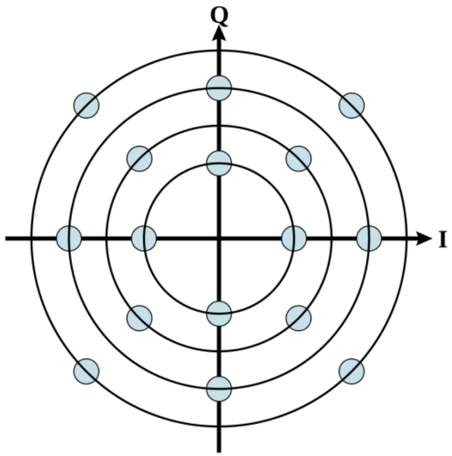
Decision regions re color-coded

Quadrature Amplitude Modulation (QAM)



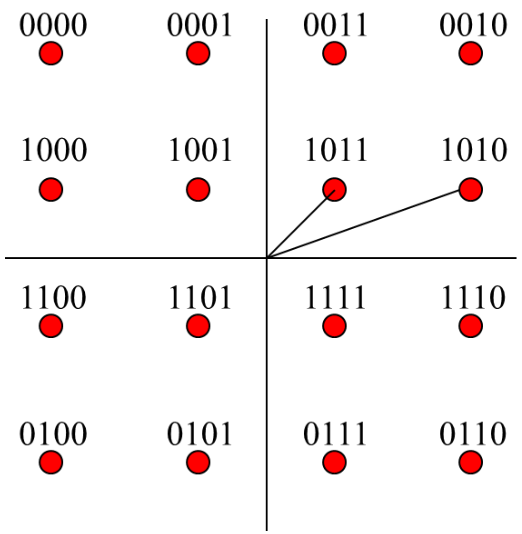


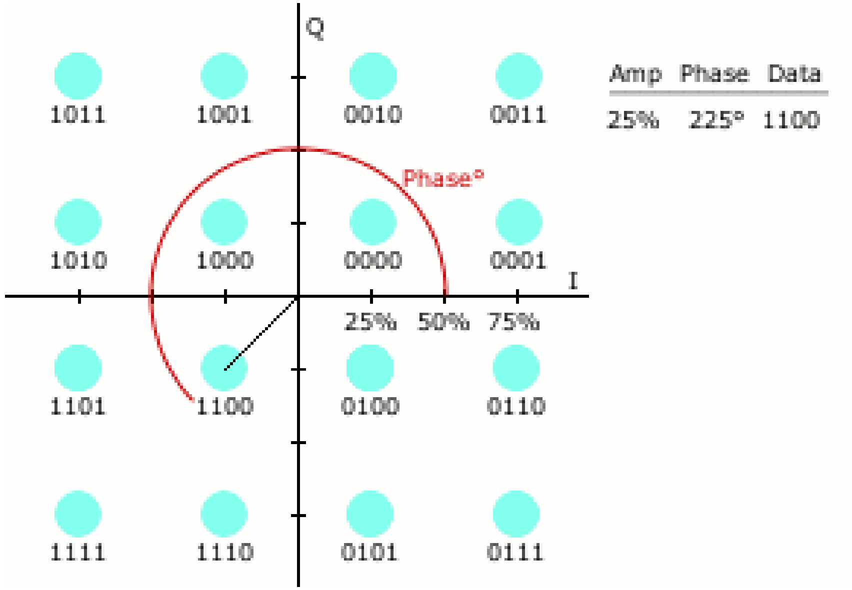
8-QAM circular

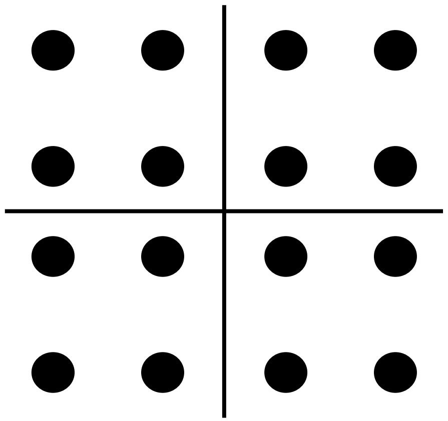


16-QAM circular

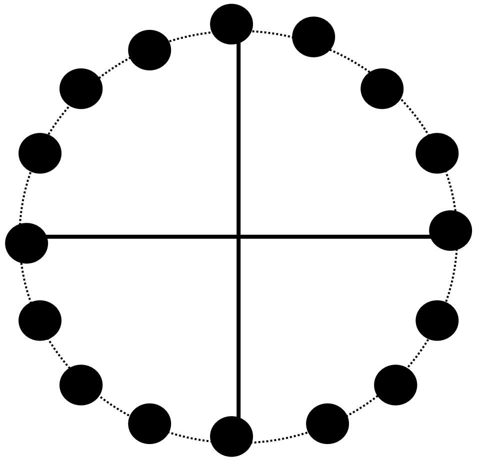
Constellation 16-QAM using the Gray code



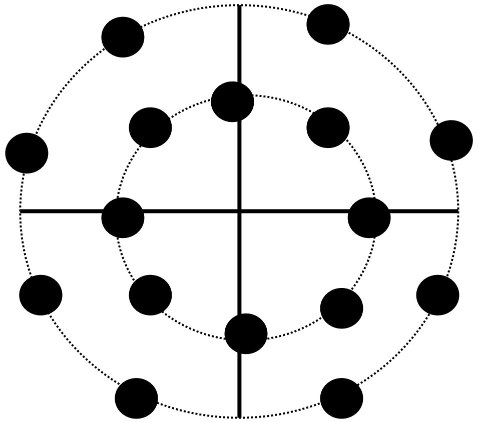




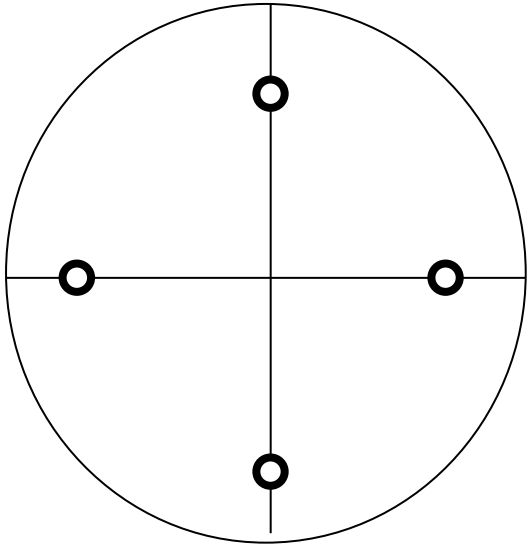
16 QAM



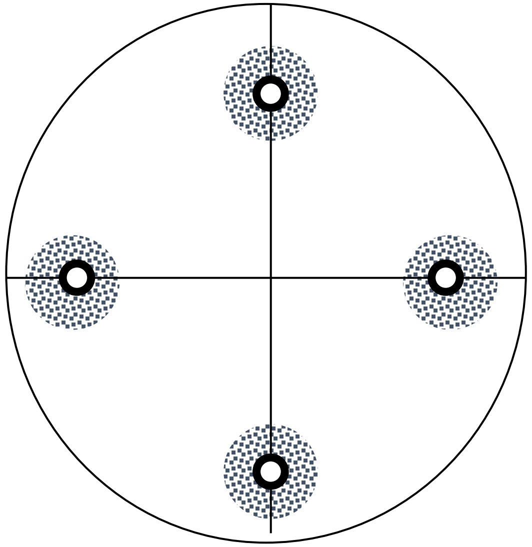
16 PSK



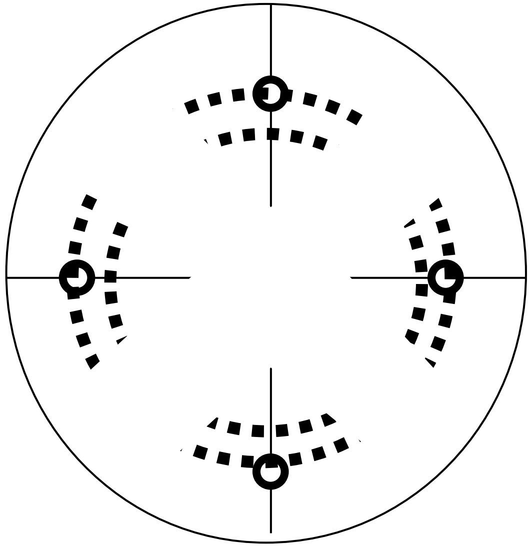
16 APSK



Perfect channel



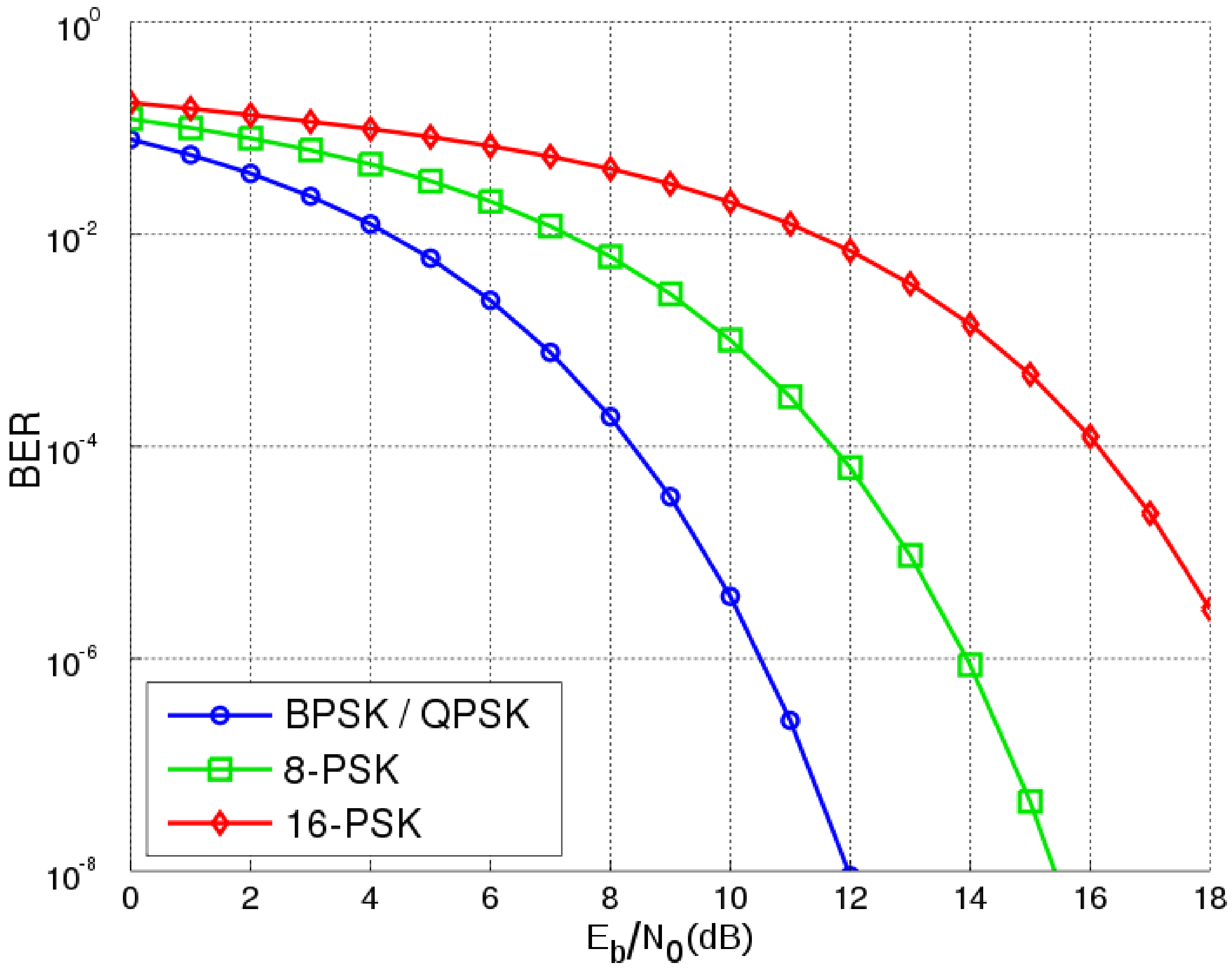
White noise



Phase jitter

Relationship between BER and E_b/N_o

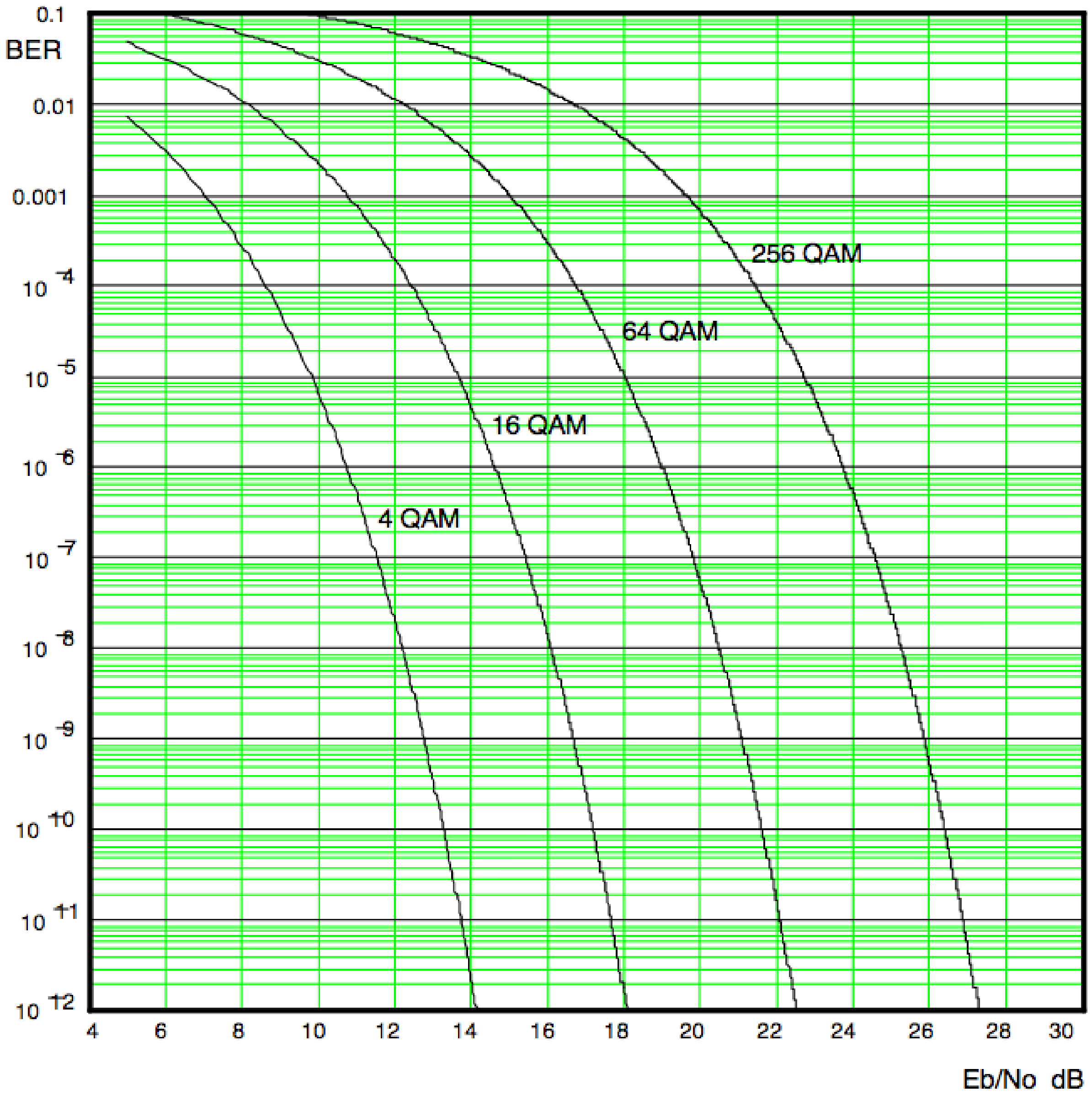
- BPSK and QPSK are noise tolerant but can transmit only 1b/s per symbol.
- 16 PSK transmits 4 bits per symbol, but requires a much higher E_b/N_o to achieve the same BER



BER versus E_b/N_o in dB for QAM

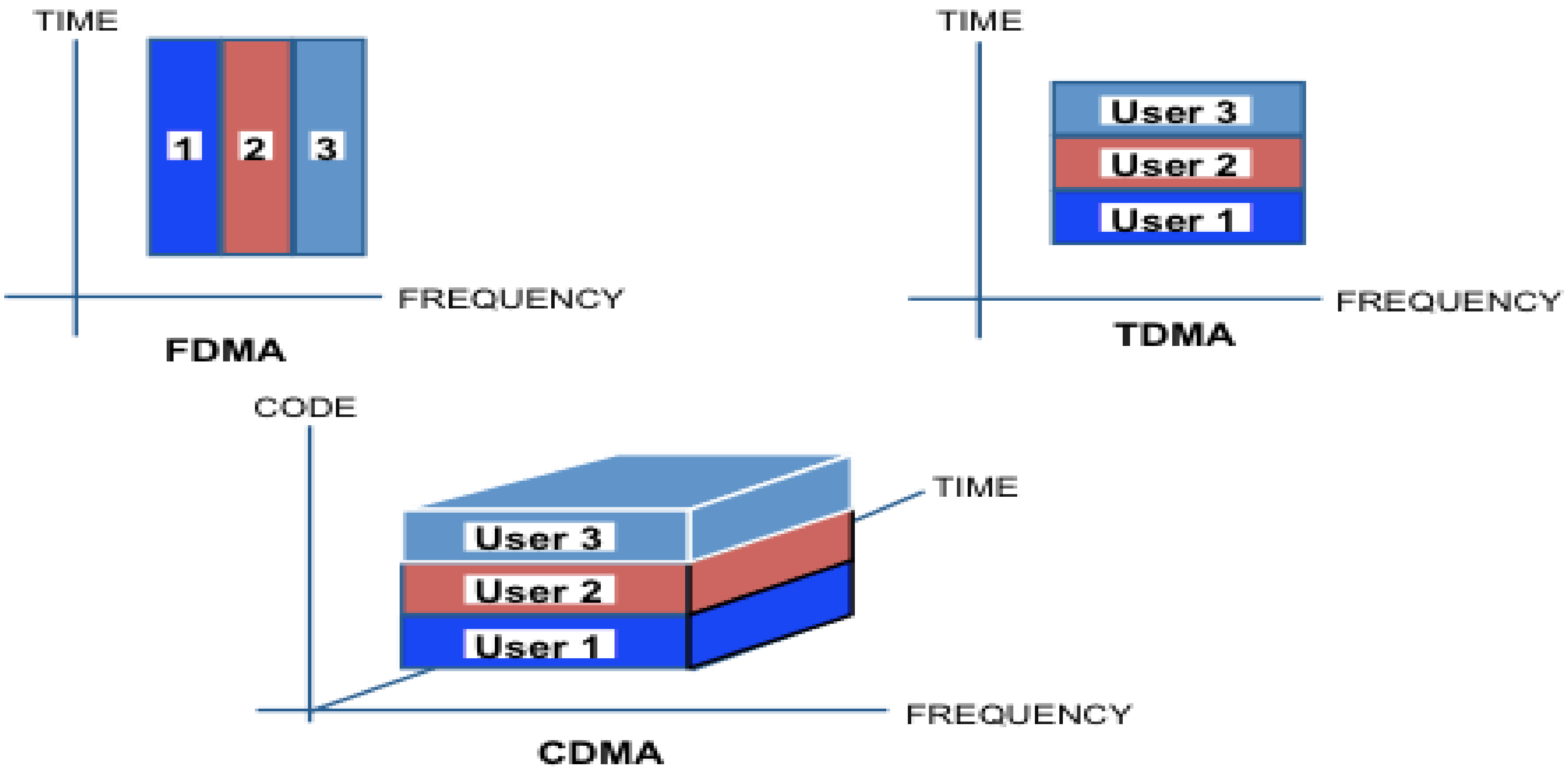
A 10^{-5} BER requires an E_b/N_o of 10 dB for 4QAM, 13.5 dB for 16QAM, 18 dB for 64 QAM and 23 dB for 256QAM.

The latter transmits 8 bits per symbol.

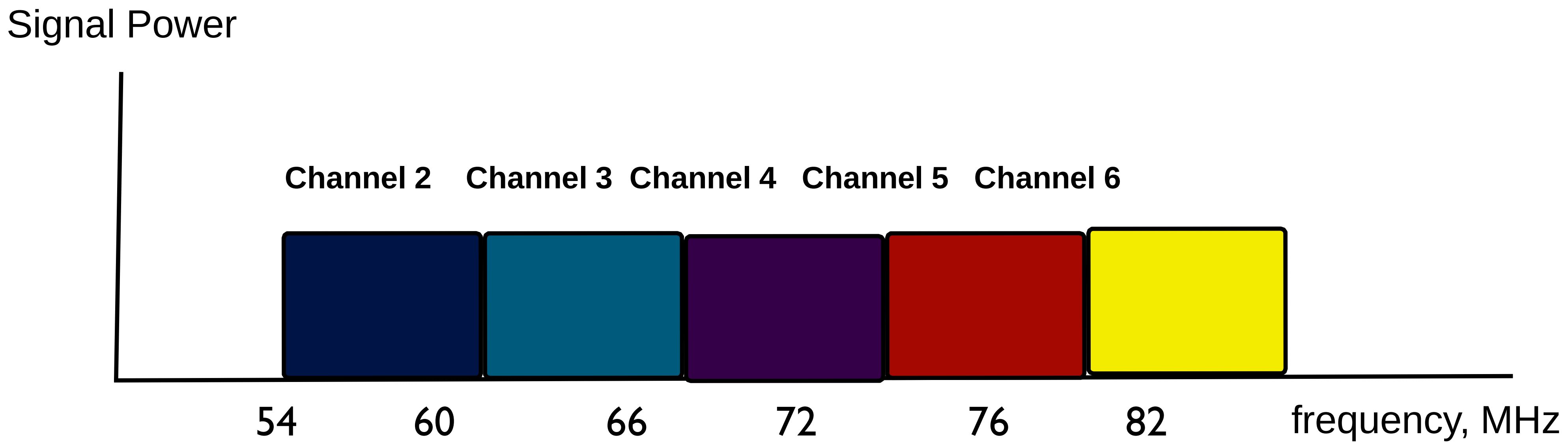


Modulation Format	Bandwidth efficiency C/B	Log2(C/B)	Error-free Eb/No
16 PSK	4	2	18dB
16 QAM	4	2	15dB
8 PSK	3	1.6	14.5dB
4 PSK	2	1	10dB
4 QAM	2	1	10dB
BFSK	1	0	13dB
BPSK	1	0	10.5dB

Medium sharing techniques



Example:
U.S. Television Channels Allocation



Duplexing

Simplex:
One way only, example: TV Broadcasting
Half-duplex:
The corresponding stations have to take turns to access the medium, example: walkie-talkie. Requires hand-shaking to coordinate access. This technique is called **TDD** (Time Division Duplexing)
Full-duplex:
The two corresponding stations can transmit simultaneously, employing different frequencies. This technique is called **FDD** (Frequency Division Duplexing). A guard band must be allowed between the two frequencies in use.

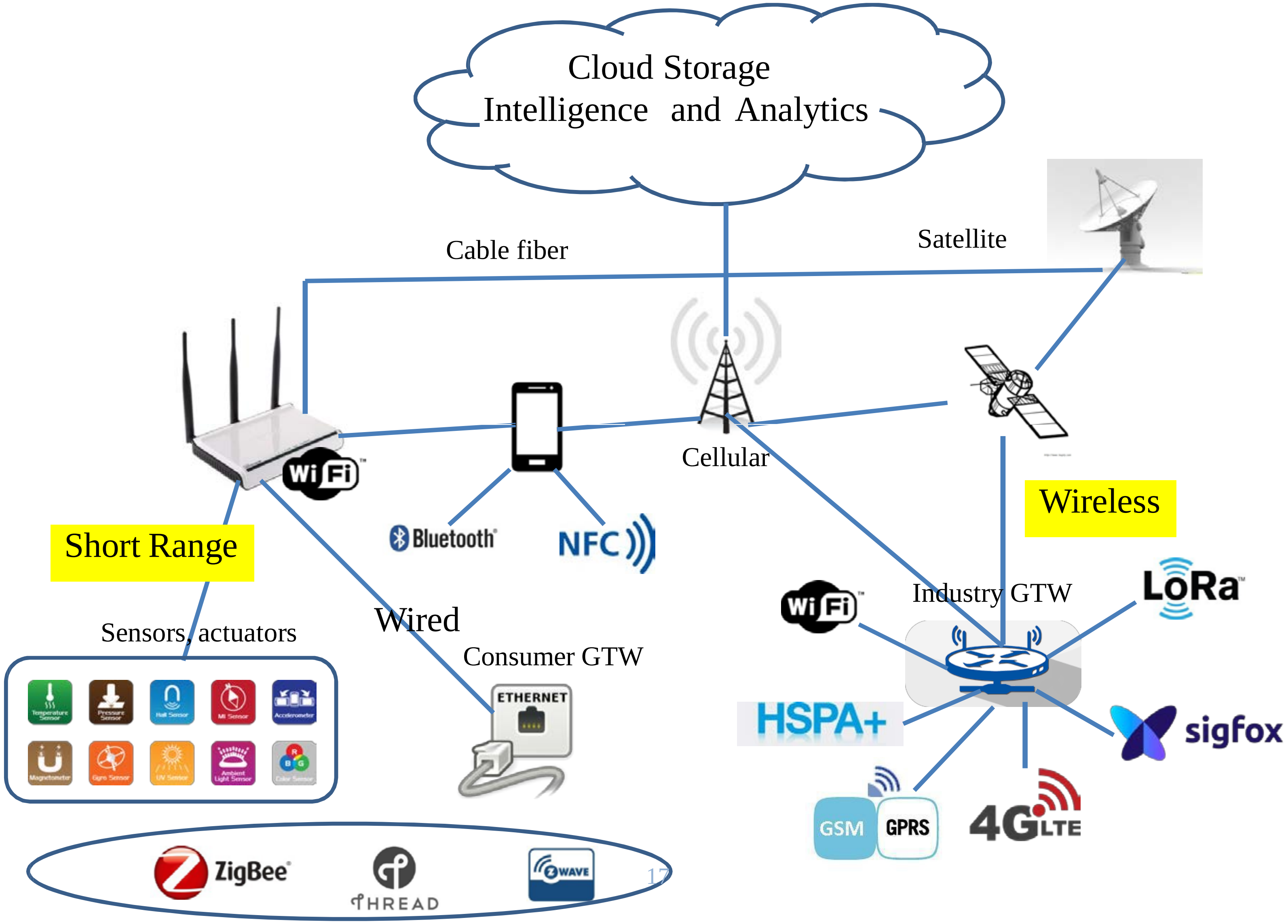
IoT design requirements

IoT Network	Impact on IoT Systems Design
Scale	**Tens of thousand sensors in a given site; or millions distributed geographically** More pressure on application architectures, network load, traffic types, security, non-standard usage pattern
Heterogeneous end-points	**Vast array of sensors, actuators, and smart devices – IP or non-IP** Diverse data rate exchange, form factor, computing and communication capabilities, legacy protocols
Low Capex and Opex requirement	**May be deployed before activation, maybe or cannot-be accessed once deployed** • Low numbers of gateways Link budget: e.g: UL: 155 dB (or better), DL: Link budget: 153 dB (or better) • Devices deliver services with little or no human control, difficult to correct mistakes, device management is key
Criticality of services	**Human life critical (Healthcare), Critical infrastructure (Smart Grid)** Stringent latency (10ms for SG) and reliability requirements, may challenge/exceed network capabilities of today
Intrusiveness	**Things with explicit intent to better manage end-users (eHealth, Smart Grid)** Issues of Privacy become major obstacles
Geography	**Movement across borders** Issues of numbering for unique identification

IoT network connectivity requirements

IoT Network	Impact on IoT Systems Design
Resource-constrained endpoints	**Severely resource constrained (memory, compute)** Cost motivation: compute/memory several orders of magnitude lower, limited remote SW update capability, light protocols, security
Low Power	**Some end-point types may be mostly 'sleeping' and awakened when required** • Sensors cannot be easily connected to a power source • Reduced interaction time between devices and applications (some regulations state duty cycle of no more than 1%) • Idle mode most of the time (energy consumption of around 100 µW). Connected mode just for transmission (mA) • < 100 MHz clock frequency • Embedded memory of few Mb
Embedded	**Smart civil infrastructure, building, devices inside human beings** Sensors deployed in secure or hostile operating conditions, difficult to change without impacting system, Security
Longevity	**Deployed for life typically, have to build-in device redundancy** Very different lifetime expectancy, rate of equipment change in IoT business domains much lower than ICT Industry
High Sensitivity on reception	**Gateways and end-devices with a high sensitivity around** -150 dBm/-125 dBm with Bluetooth lower than -95 dBm in in cellular

IoT: General Architecture?



Spectrum Needs of IoT

What are the spectrum needs of IoT?

- Determined by each application’s throughput requirements, but also latency
  - *For a given spectral efficiency (b/s/Hz), the lower the latency requirements the larger the bandwidth needed to send a given amount of data*
- While many IoT applications might not need high speed connections and/or have very stringent latency requirements, some do (e.g. remote surgery)

In what frequency bands?

- Determined by each IoT application’s range and coverage requirements, but also bandwidth needs of the applications
- Range and coverage requirements also depend on deployment scenarios
  - *Point-to-point, mesh, broadcast, multi-cast, etc.*

Spectrum Licensing for IoT

Spectrum for MTC/IoT applications

Unlicensed spectrum

- *Low cost /no license fees Regulatory limits (EIRP restrictions)*
- *Non-guaranteed QoS*

- All devices can have access to spectrum, subject to compliance with technical conditions as specified in regulations
- Short range and delay-tolerant applications are typical use cases

Licensed spectrum

- *Better Inference management*
- *Network Security*
- *Reliability*

Mobile operator Network

Reuse cellular infrastructure and device eco-system for M2M/ IoT apps

- IMT spectrum can be used for supporting NB-IoT, eMTC and LTE-V2N (eNB-to–vehicle)
- MBB spectrum can also be used for M2M/IoT

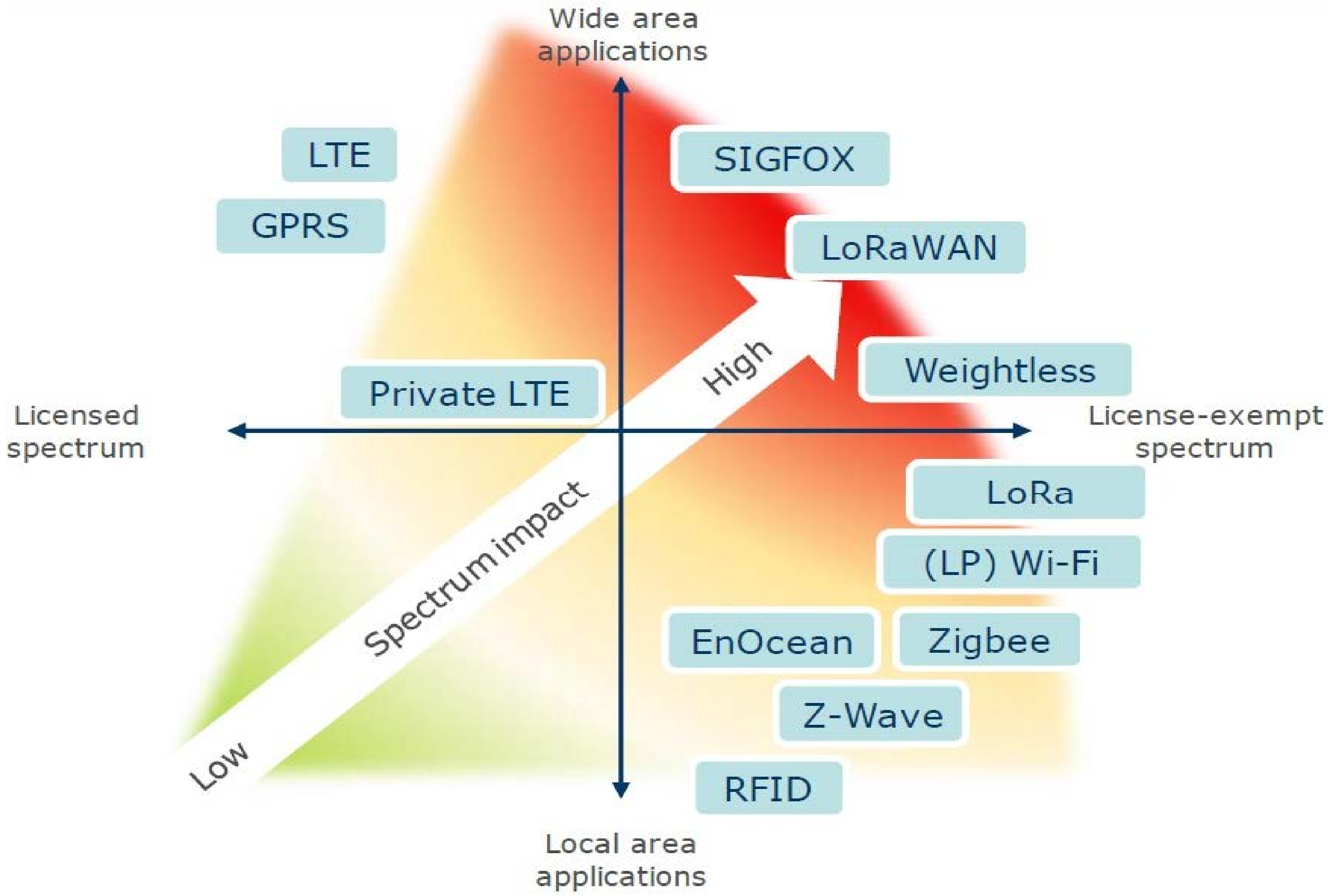
Dedicated Network

Private network customized for specific M2M/IoT apps.

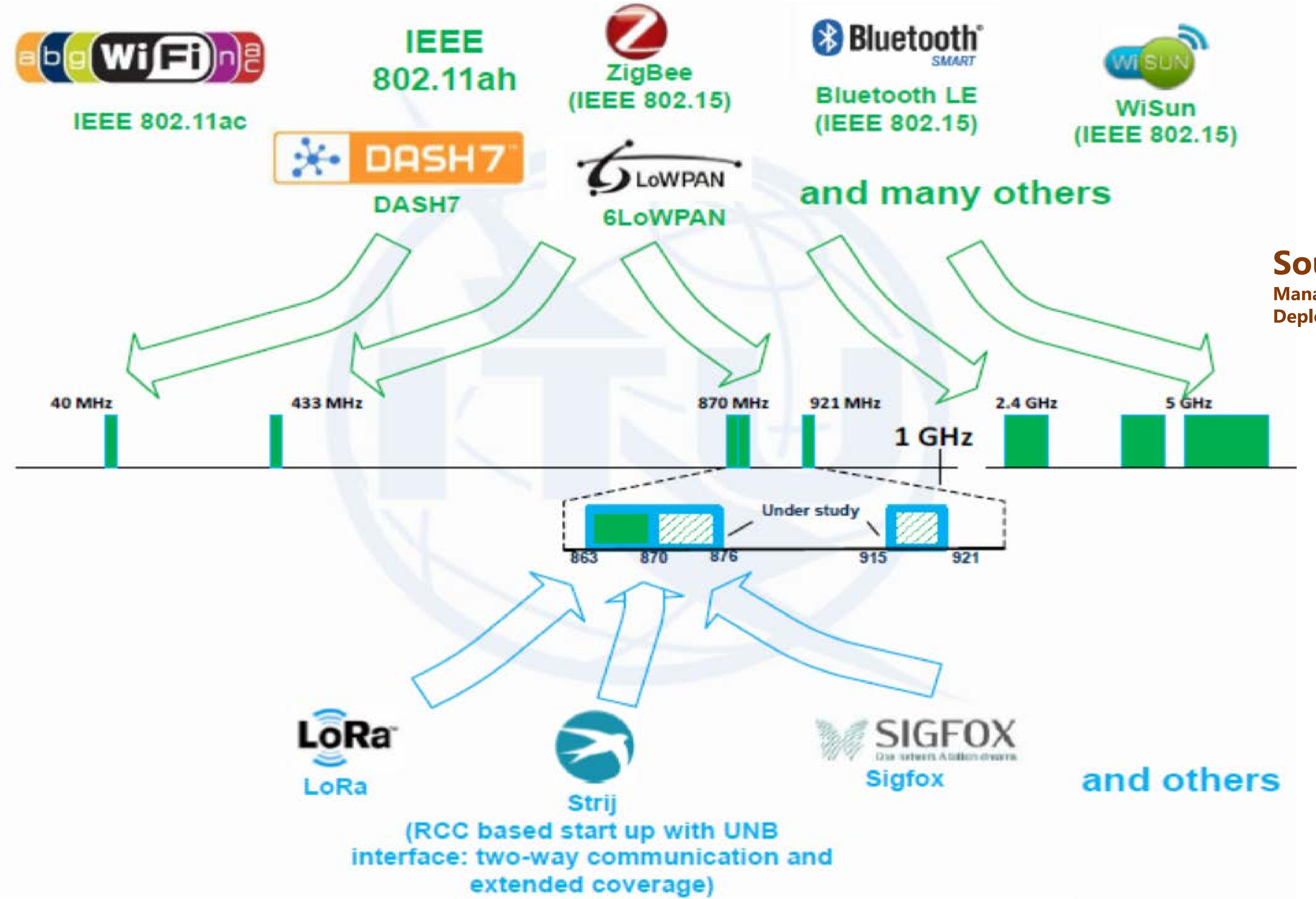
Example: In **China** New bands for M2M:

- 5 905 -5 925 MHz for LTE-V2X trials
- 2 x 2.3 MHz in 800MHz can be used for NB-IoT

IoT technologies summary

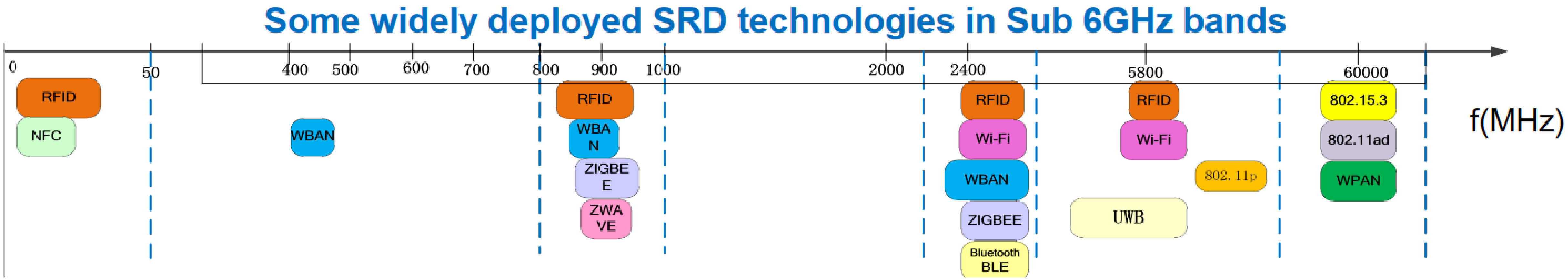


Spectrum usage for IoT - SRDs



Source: ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva

Spectrum usage for IoT - SRDs



Source: **ITU Workshop on Spectrum Management for Internet of Things Deployment, 22 November 2016, Geneva**

Spectrum Needs of IoT

M2M
Radiocommunication Technologies

Technology	Spectrum band
NB-IoT	MBB bands
eMTC	MBB bands
Sigfox	868MHz
LTE-V2X	MBB bands (Uu)
	5.8,5.9GHz (PC5)
Bluetooth	2.4GHz
ZigBee	868/2450MHz
RFID	13.56/27.12/433/860MHz ...
NFC	13.56MHz
Z-WAVE	868 MHz
Ingenu	2.4GHz

Frequency range

- Sub-1 GHz band are most suitable for efficient provision of wide area coverage;

Authorization

- Sharing spectrum with unlicensed authorization to achieve low cost and low power requirements
- Licensed (exclusive) spectrum is more suitable for wide area coverage and/or higher reliability requirements for delay sensitive applications

IoT Technical Solutions

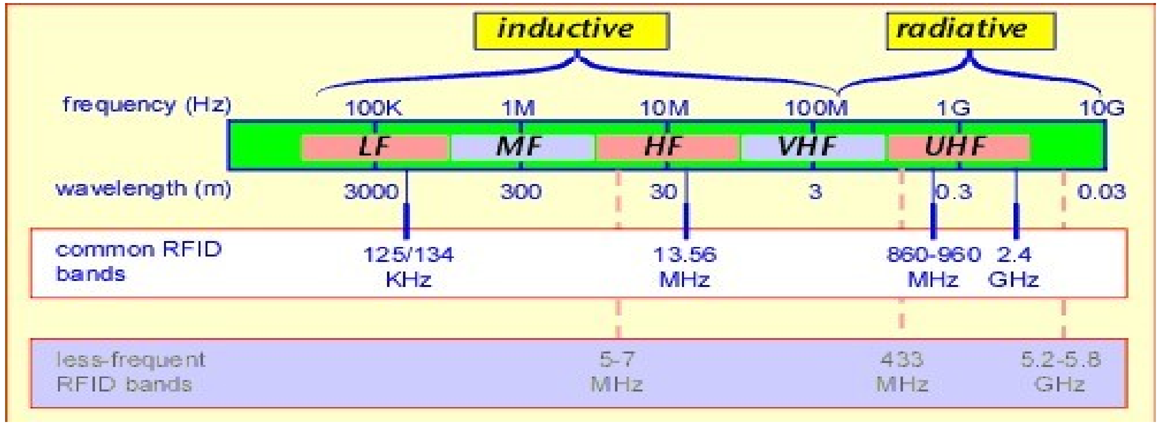
- **Fixed & Short Range**
  - RFID
  - Bluetooth
  - Zigbee
  - WiFi
  - ….
- **Long Range technologies**
  - Non 3GPP Standards (LPWAN)
  - 3GPP Standards

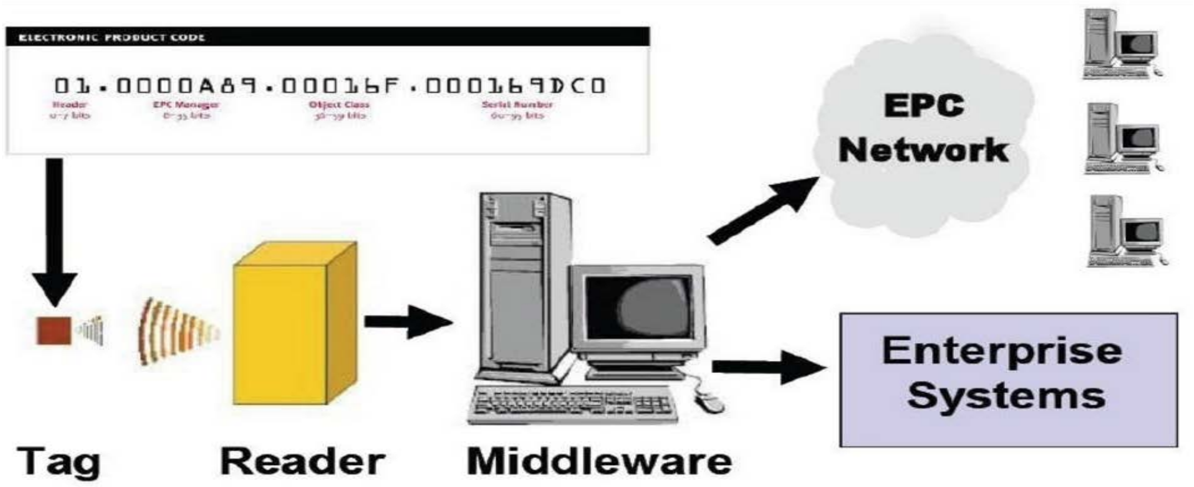
Short Range IoT Solutions

- RFID
- Bluetooth
- ZigBee
- WiFI

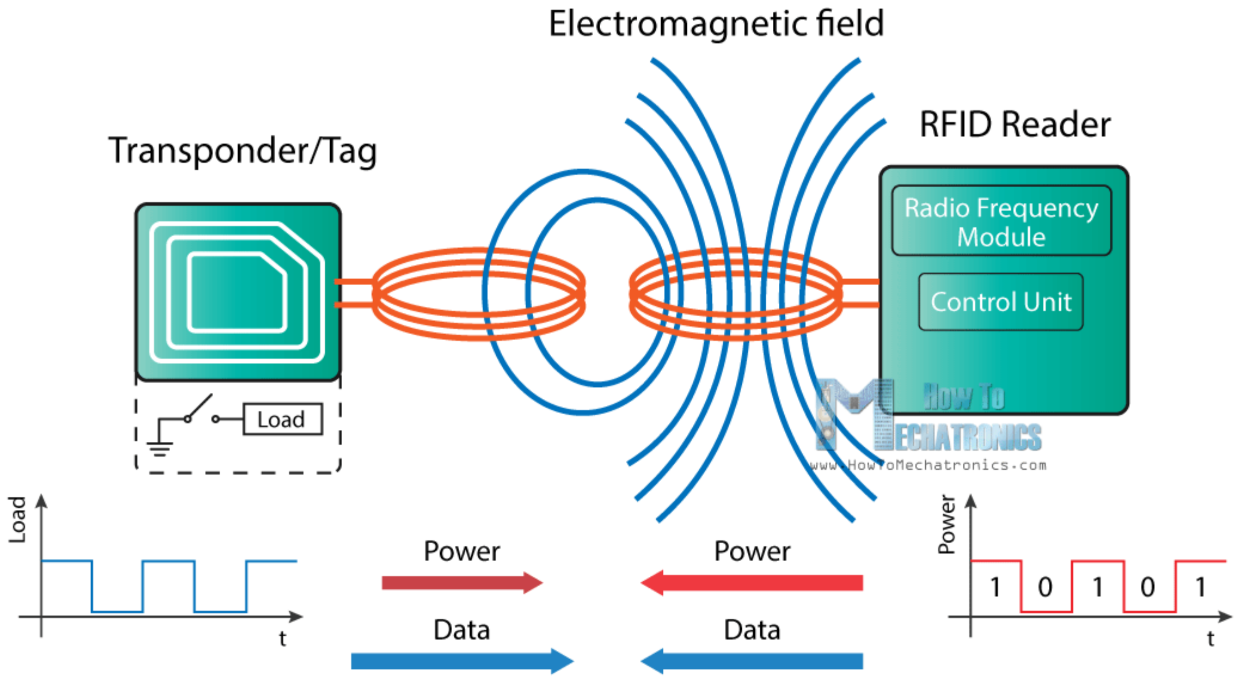
RFID: Radio Frequency Identification

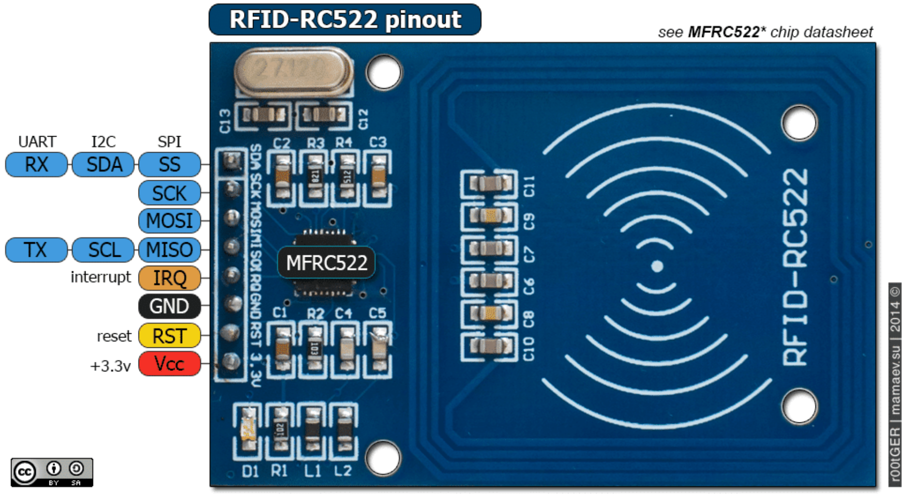
- **Appeared first in 1945**
- **Features:**
  - Identify objects, record metadata or control individual target
  - More complex devices (e.g., readers, interrogators, beacons) usually connected to a host computer or network
  - Radio frequencies from 100 kHz to 10 GHz
- **Operations:**
  - Reading Device called Reader (connected to banckend network and communicates with tags using RF)
  - One or more tags (embedded antenna connected to chip based and attached to object)

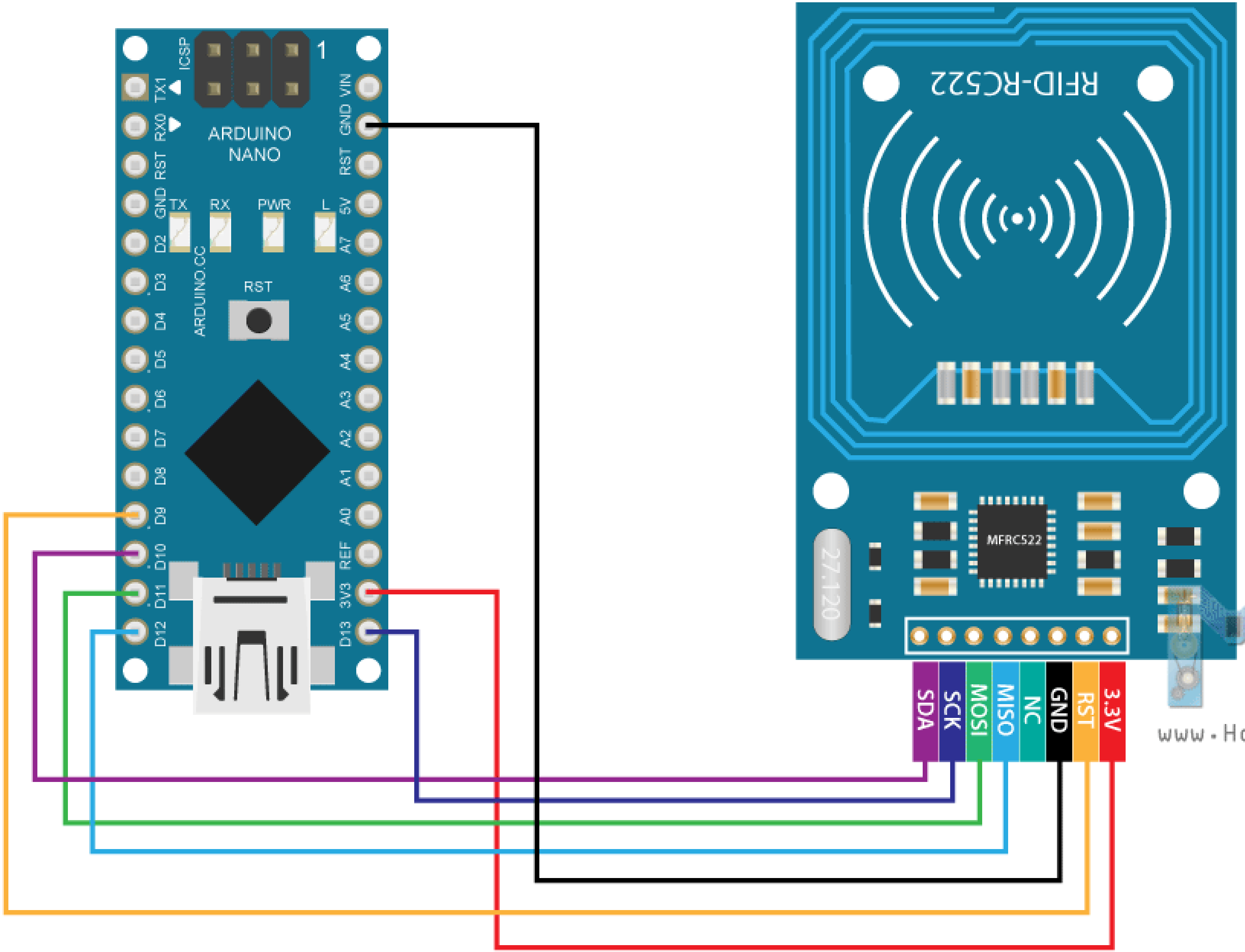





RFID Tag
Antenna
RFID Reader
www.HowToMechatronics.com


Electromagnetic field
Transponder/Tag
RFID Reader
Radio Frequency Module
Control Unit
Load
Load
t
Power
Data
Power
Data
Power
1 0 1 0 1
t
www.HowToMechatronics.com


RFID-RC522 pinout
see MFRC522* chip datasheet
UART
I2C
SPI
RX
SDA
SS
SCK
MOSI
TX
SCL
MISO
interrupt
IRQ
GND
reset
RST
+3.3v
Vcc
MFRC522
RFID-RC522
r00tGER | mamaev.su | 2014 ©



RFID Module	Arduino
3.3V	Pin 3.3v
RST	Pin 9
GND	GND
NC	No Connection
MISO	Pin 12
MOSI	Pin 11
SCK	Pin 13
SDA	Pin 10

Bluetooth

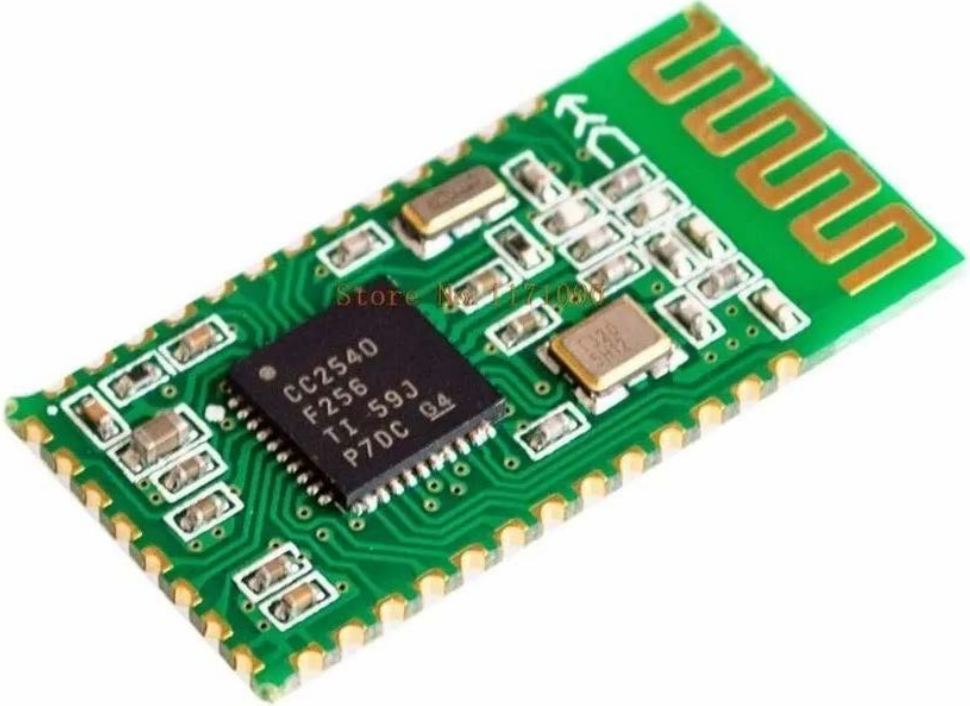
Features:

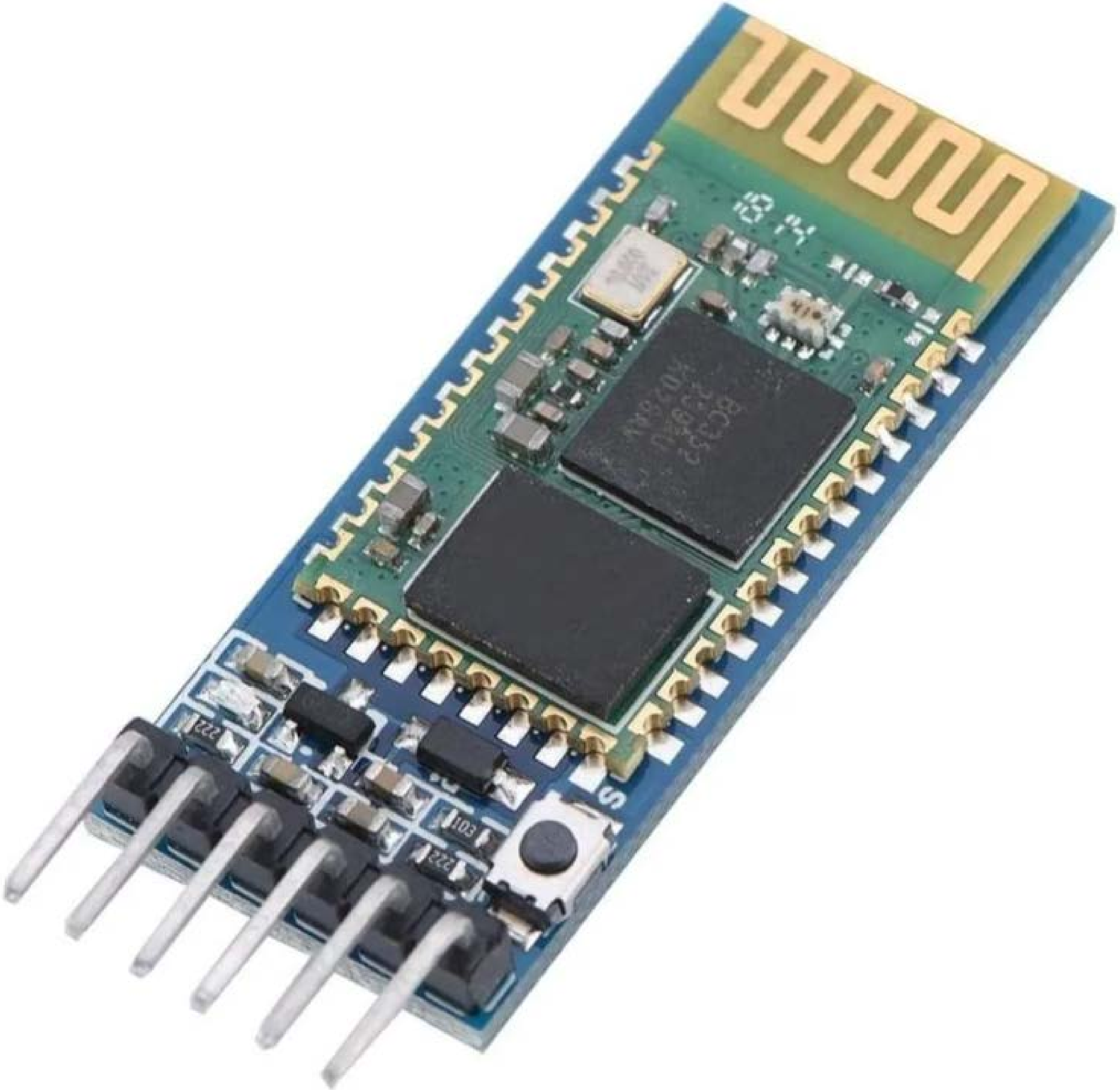
- Low Power wireless technology
- Short range radio frequency at 2.4 GHz ISM Band
- Wireless alternative to wires
- Creating PANs (Personal area networks)
- Support Data Rate of 1 Mb/s (data traffic, video traffic)
- Uses Frequency Hopping spread Spectrum

Bluetooth 5:

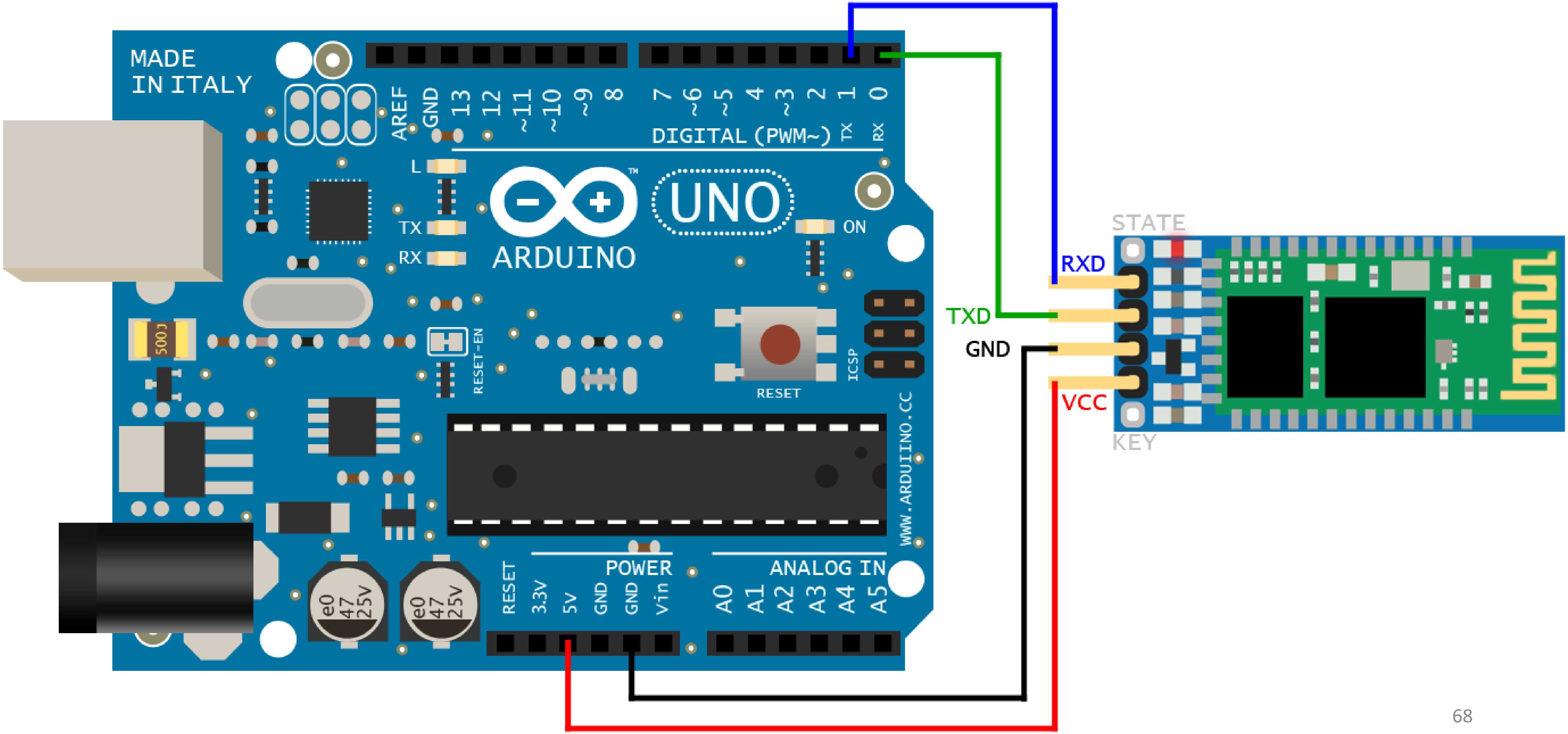
- 4x range, 2x speed and 8x broadcasting message capacity
- Low latency, fast transaction (3 ms from start to finish) Data Rate 1 Mb/s: sending just small data packets

Class	Maximum Power	Range
1	100 mW (20 dBm)	100 m
2	2,5 mW (4 dBm)	10 m
3	1 mW (0 dBm)	1 m


CC2540
F256
TI 59J
P7DC G4



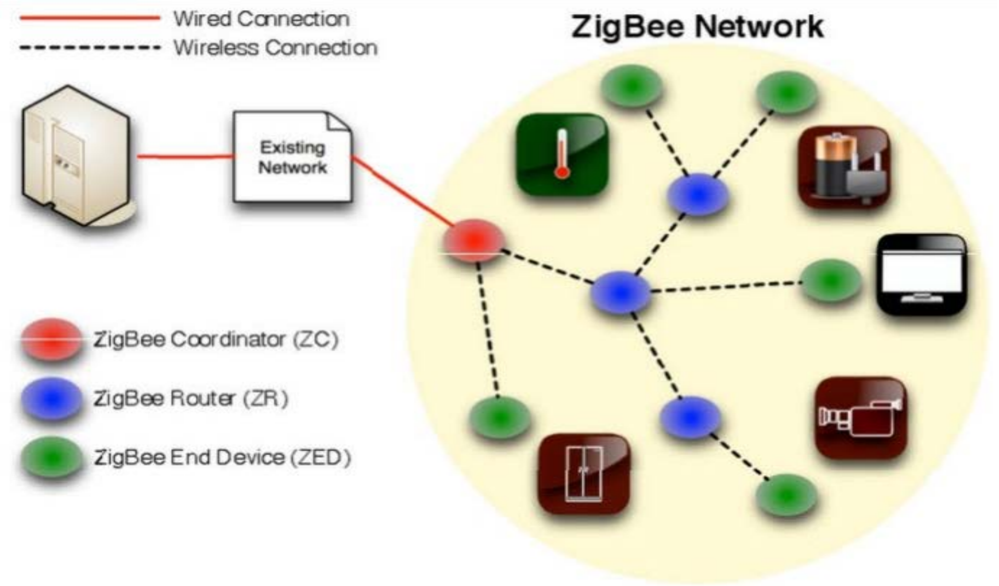
Bluetooth HC-06 y HC-05 Android

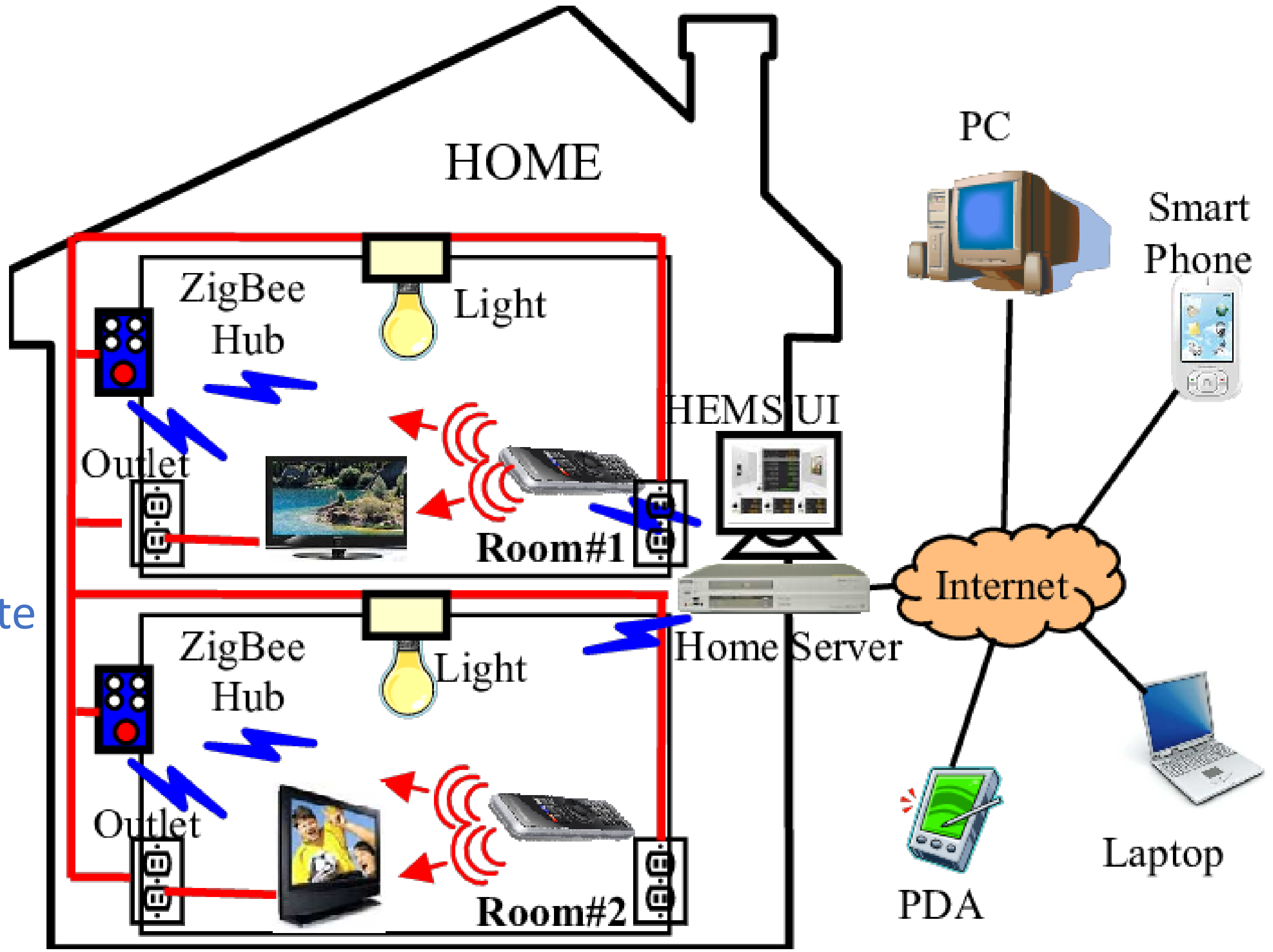


Tarjeta Desarrollo ESP32 Wifi Y Bluetooth

ZigBee

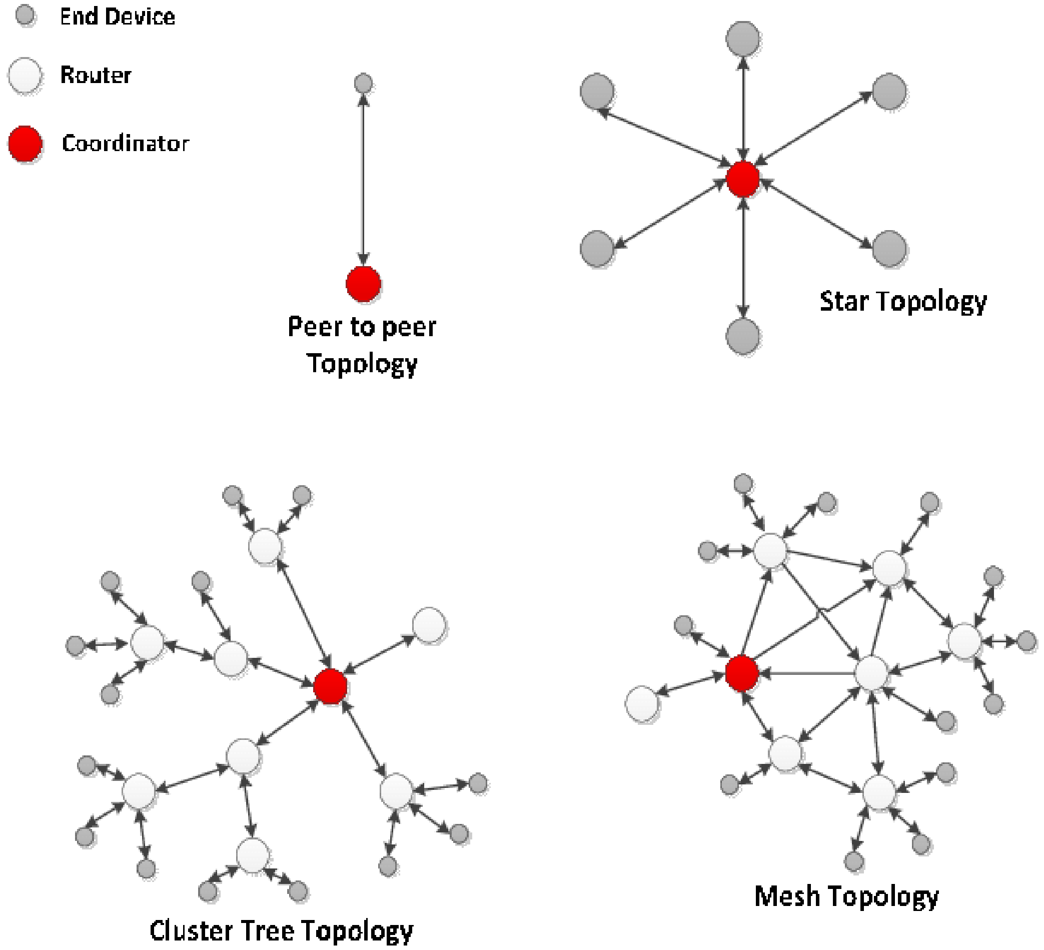
- **Operations:**
  - **Coordinator**: acts as a root and bridge of the network
  - **Router**: intermediary device that permit data to pass to and through them to other devices
  - **End Device:** limited functionality to communicate with the parent nodes

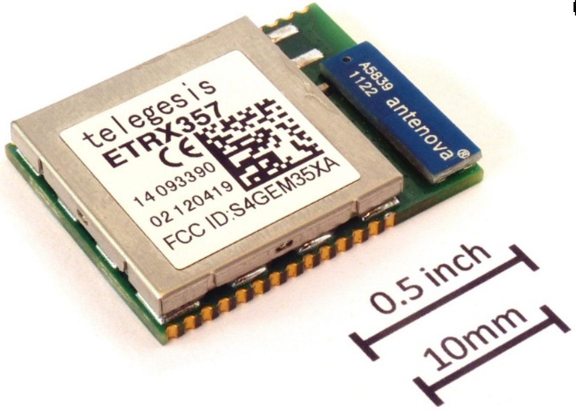




Low cost and available


XBee
Digi International
www.libelium.com
www.arduino.cc


End Device
Router
Coordinator
Peer to peer Topology
Star Topology
Cluster Tree Topology
Mesh Topology


telegesis
ETRX357
FCC ID:S4GEM35XA
antenova
0.5 inch
10mm

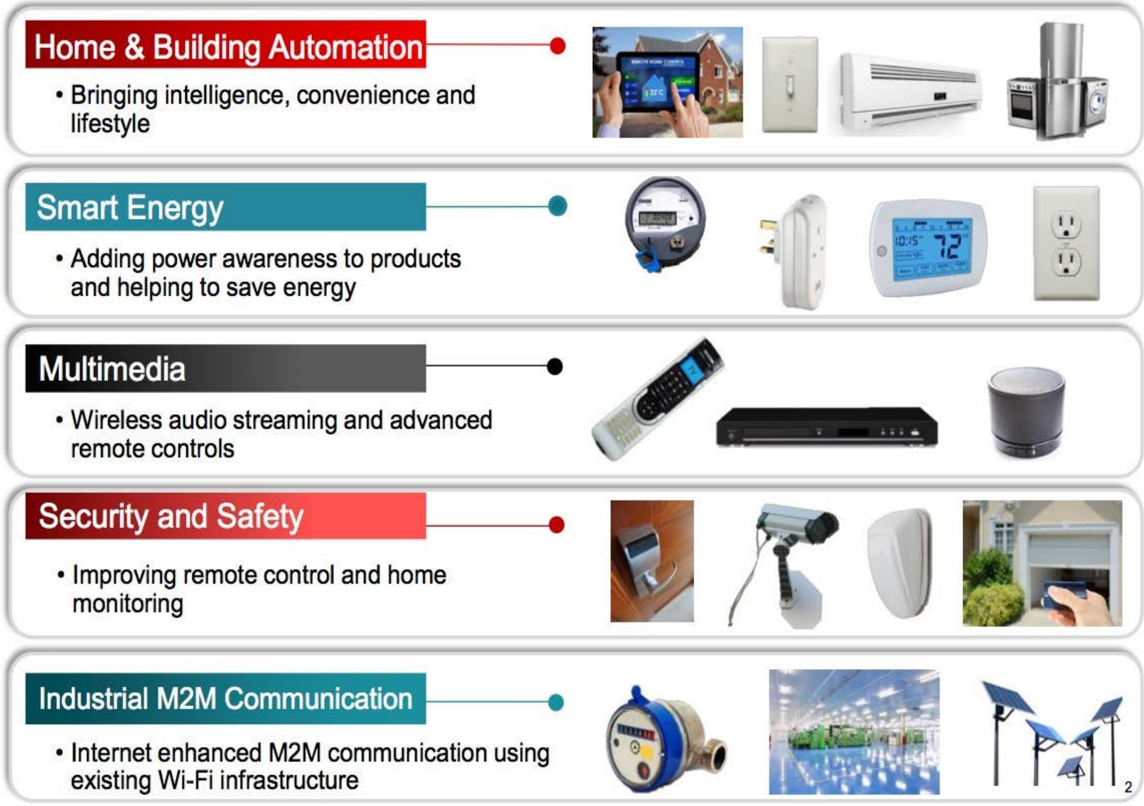
ZigBee and Bluetooth Low Energy

- Business comparison:
  - ZigBee is older. It has gone through some iterations
  - ZigBee has market mindshare, but not a lot of shipments yet.
  - Market barriers: connectivity – ZigBee is not in PCs or mobile phones yet.
- Technical comparison:
  - Zigbee is low power; Bluetooth LE is even lower. Detailed analysis depends on specific applications and design detail, no to mention chip geometry.
  - ZigBee stack is light; the Bluetooth LE/GATT stack is even simpler
- Going forward:
  - ZigBee has a lead on developing applications and presence
  - Bluetooth low energy has improved technology, and a commanding presence in several existing markets: mobile phones, automobiles, consumer electronics, PC industry
  - Replacing “classic Bluetooth ” with “dual mode” devices will bootstrap this market quickly

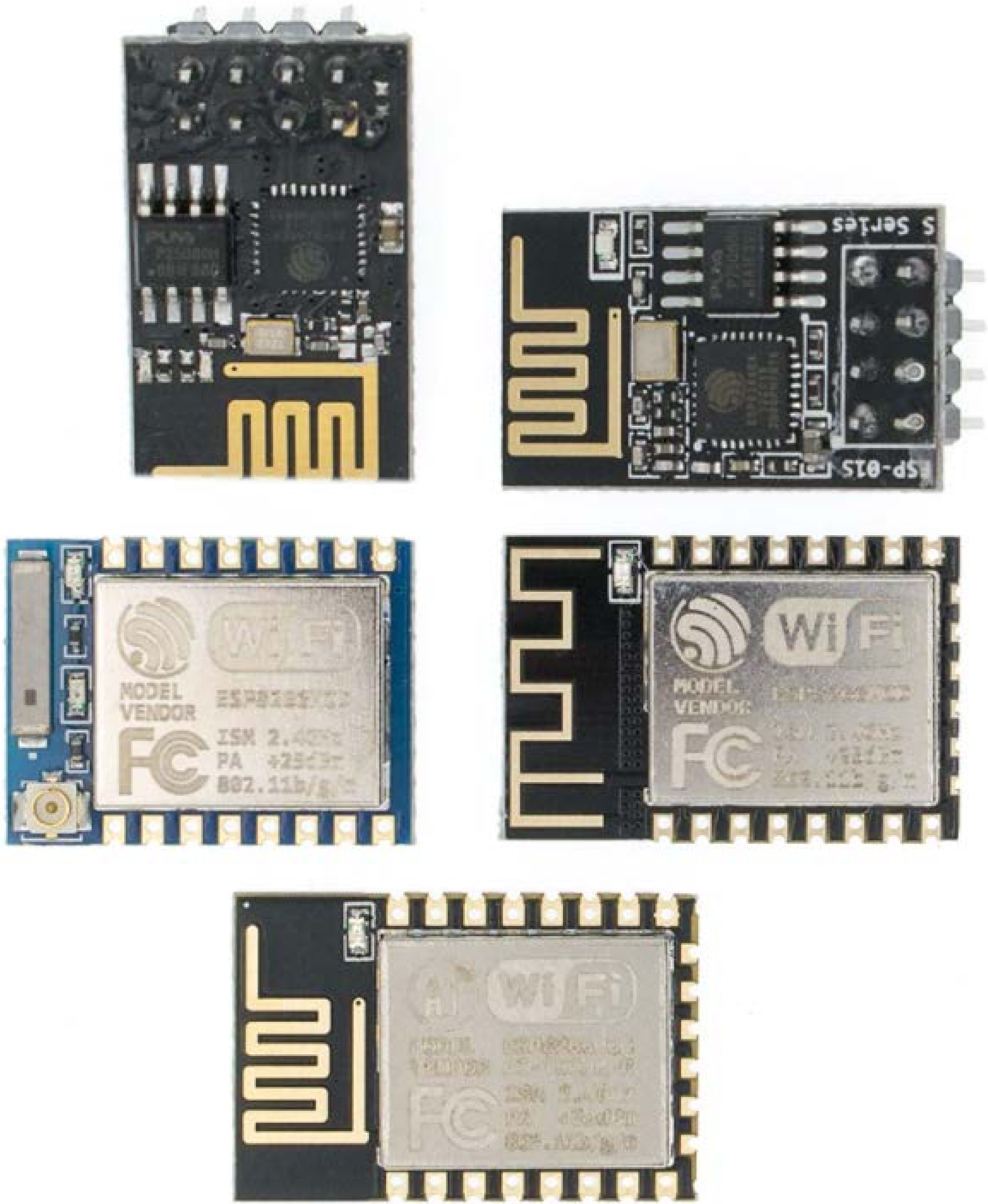
WiFi

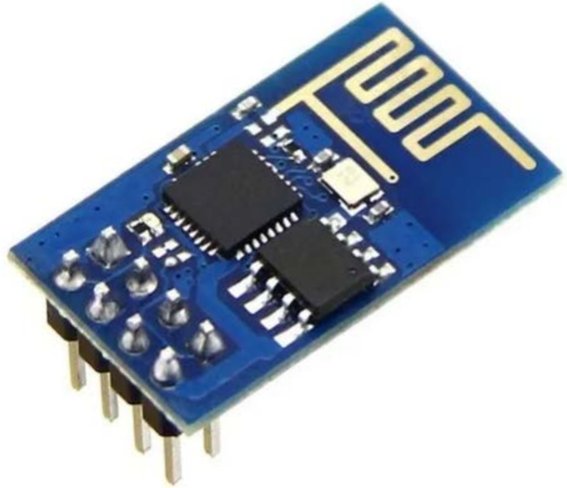
- Wireless Alternative to Wired Technologies
- Standardized as IEEE 802.11 standard for WLANs

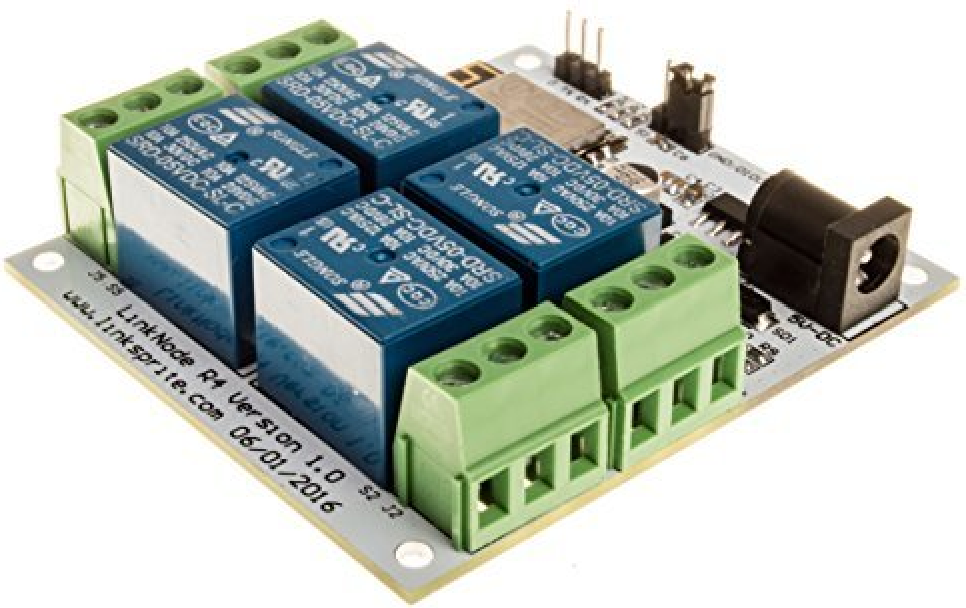
Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	8 Mbit/s	100 M



Modulo Wifi Serial Esp826







WiFi HaLow

802.11ah HaLow

A new low-power, long-range version of Wi-Fi that bolsters IoT connections

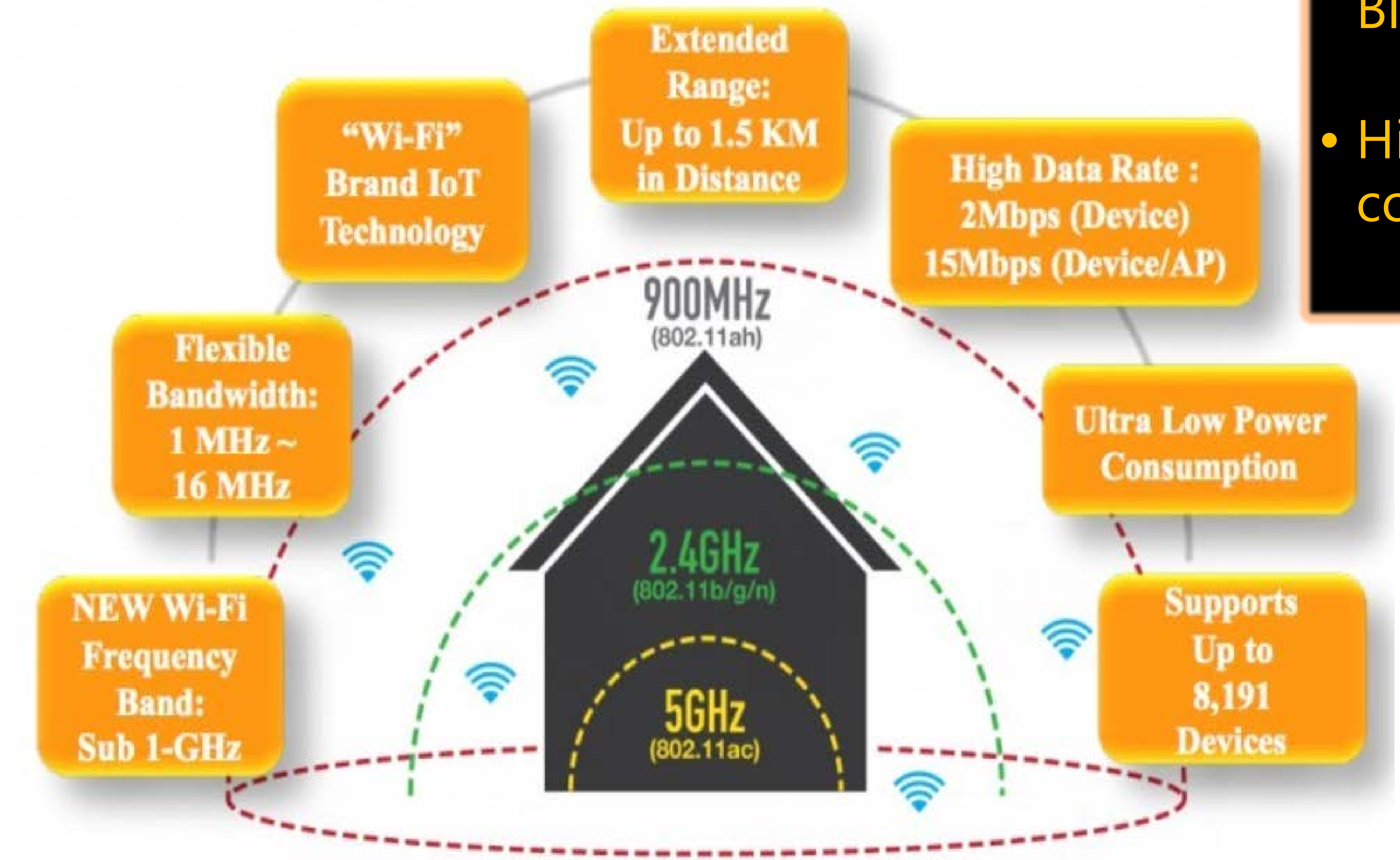
Wi-Fi HaLow is based on the **IEEE 802.11ah** specification

Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band

Its range will be nearly double today's available Wi-Fi (1 kilometer)

- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range

WiFi HaLow



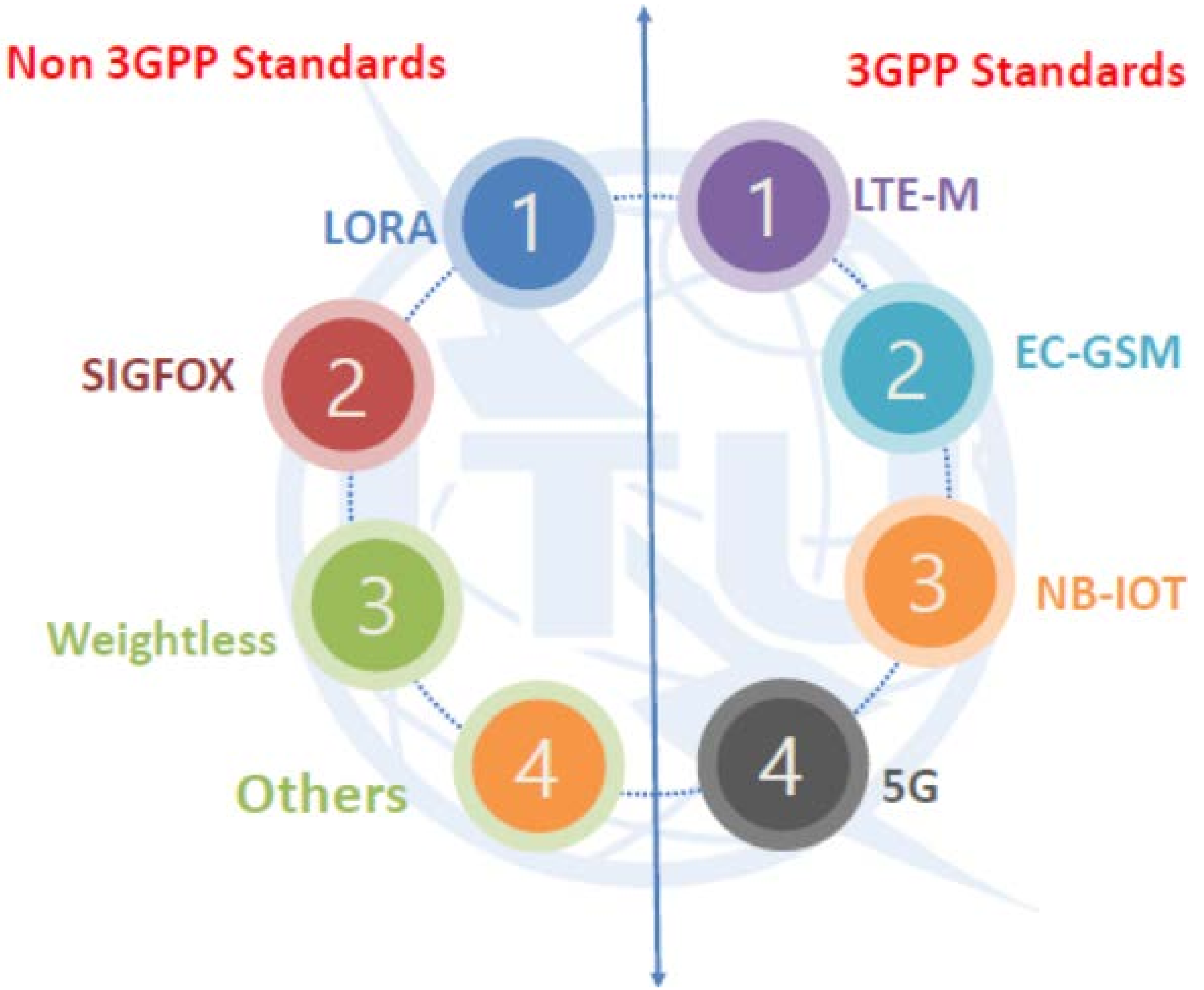
- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range

Picture Source: Newracom

Long Range IoT Solutions

- Non 3GPP
- 3GPP

IoT Long Range Technical Solutions



A GLOBAL INITIATIVE

The 3rd Generation Partnership

Popularity of Low Power Wide Area Network

Long Range

Low Power

Low Data Rate

LPWAN is becoming popular day-by-day

LPWAN Characteristics

Constrained and challenged network (as defined RFC 7228)

License-exempt or Licensed bands

Property industrial deployments, huge potential

Battery powered devices with limited communications

Deep Coverage

LPWAN Technologies

Asymmetric Lines

Small message size

Limit number of messages per device and per day

Complex Device and Network management

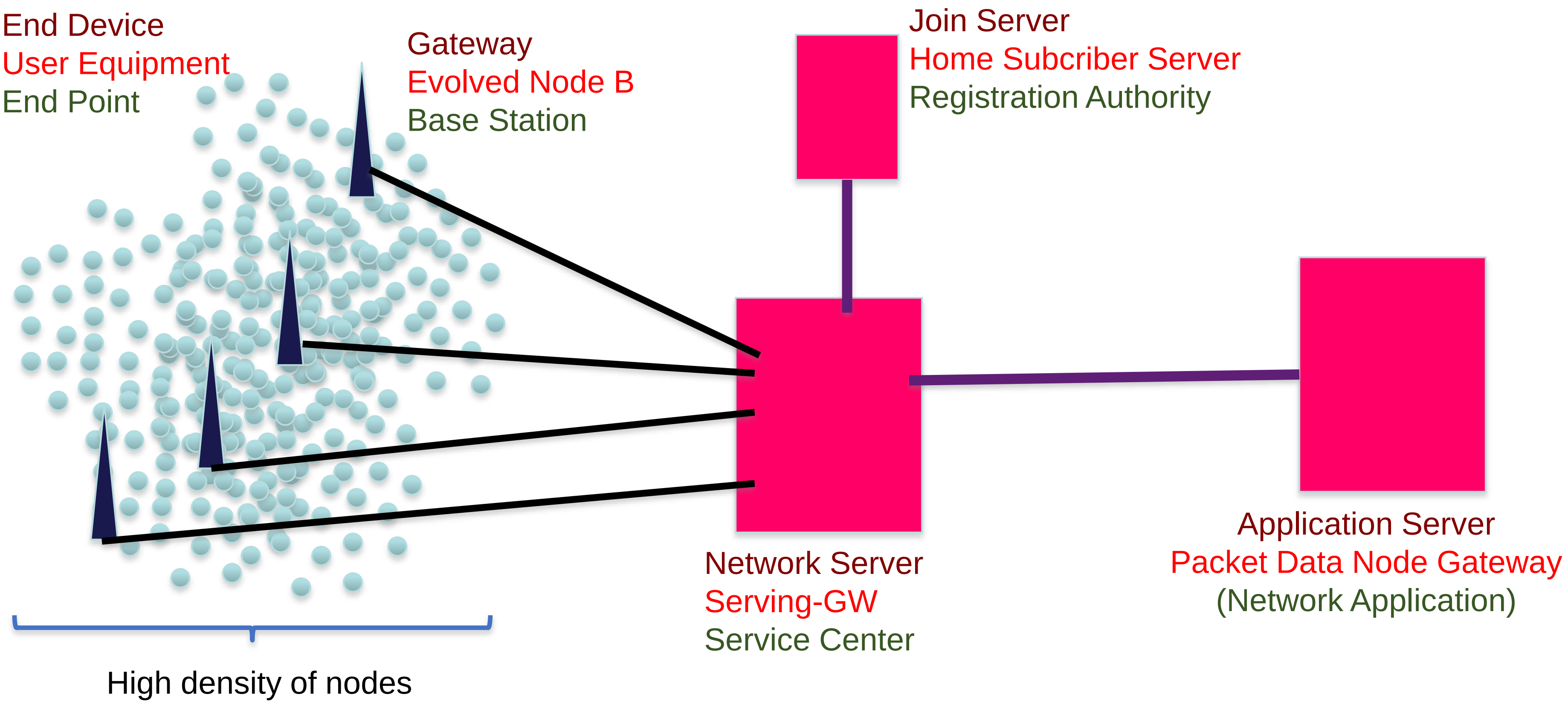
Acknowledgement management

NO
IP CAPABILITIES

Different LPWANs

LoRa is one of the most popular LPWANs

Similar architecture: Lorawan NB-IoT SIGFOX



LORA

2010

Cycleo developed LoRa technology

2013

Semtech develop LoRaWAN network

2015

Creation of LoRa alliance

LoRa Alliance
Wide Area Networks for IoT

Jun 2015

Amsterdam become the first city covered by the LoRaWAN network

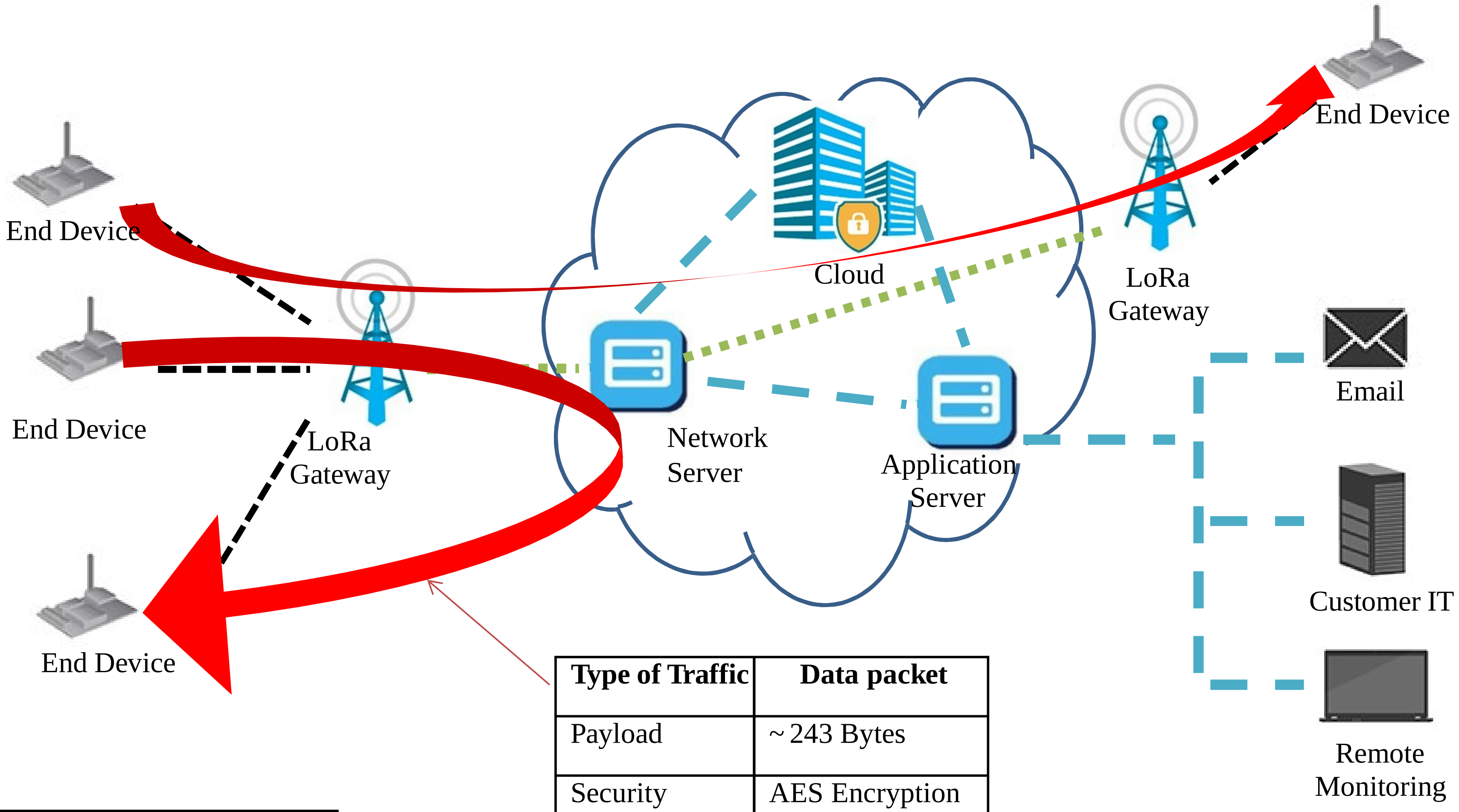
By the end of 2016

All France territory covered by LoRaWAN network: Bouygues Telecom

LORA - Features

- **LoRaWAN is a Low Power Wide Area Network**
- **Modulation:** a version of Chirp Spread Spectrum (CSS) with a typical channel bandwidth of 125KHz
- **High Sensitivity:** End Nodes: Up to -137 dBm, Gateways: up to -142 dBm
- **Long range:** up to 15 Km
- **Strong indoor penetration:** With High Spreading Factor, Up to 20dB penetration (deep indoor)
- **Robust** Occupies the entire bandwidth of the channel to broadcast a signal, making it robust to channel noise
- **Resistant to Doppler effect multi-path and signal weakening.**

LORA - Architecture



Type of Traffic	Data packet
Payload	~ 243 Bytes
Security	AES Encryption

Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	~ 50 Kbps

LORA – Device Classes

Classes	Description	Intended Use	Consumption	Examples of Services
A (« all »)	Listens only after end device transmission	Modules with no latency constraint	The most economic communication Class energetically.. Supported by all modules. Adapted to battery powered modules	• Fire Detection • Earthquake Early Detection
B (« beacon »)	The module listens at a regularly adjustable frequency	Modules with latency constraints for the reception of messages of a few seconds	Consumption optimized. Adapted to battery powered modules	• Smart metering • Temperature rise
C (« continuous »)	Module always listening	Modules with a strong reception latency constraint (less than one second)	Adapted to modules on the grid or with no power constraints	• Fleet management • Real Time Traffic Management

Any LoRa object can transmit and receive data

Sigfox – Development

2012

Launch of the Sigfox network

2013

First fundraising of Sigfox company to cover France

2014

All France territory is covered by Sigfox network

Mar 2016

San-Francisco become the first US. State covered by Sigfox

2017

42 countries, 1000 customers

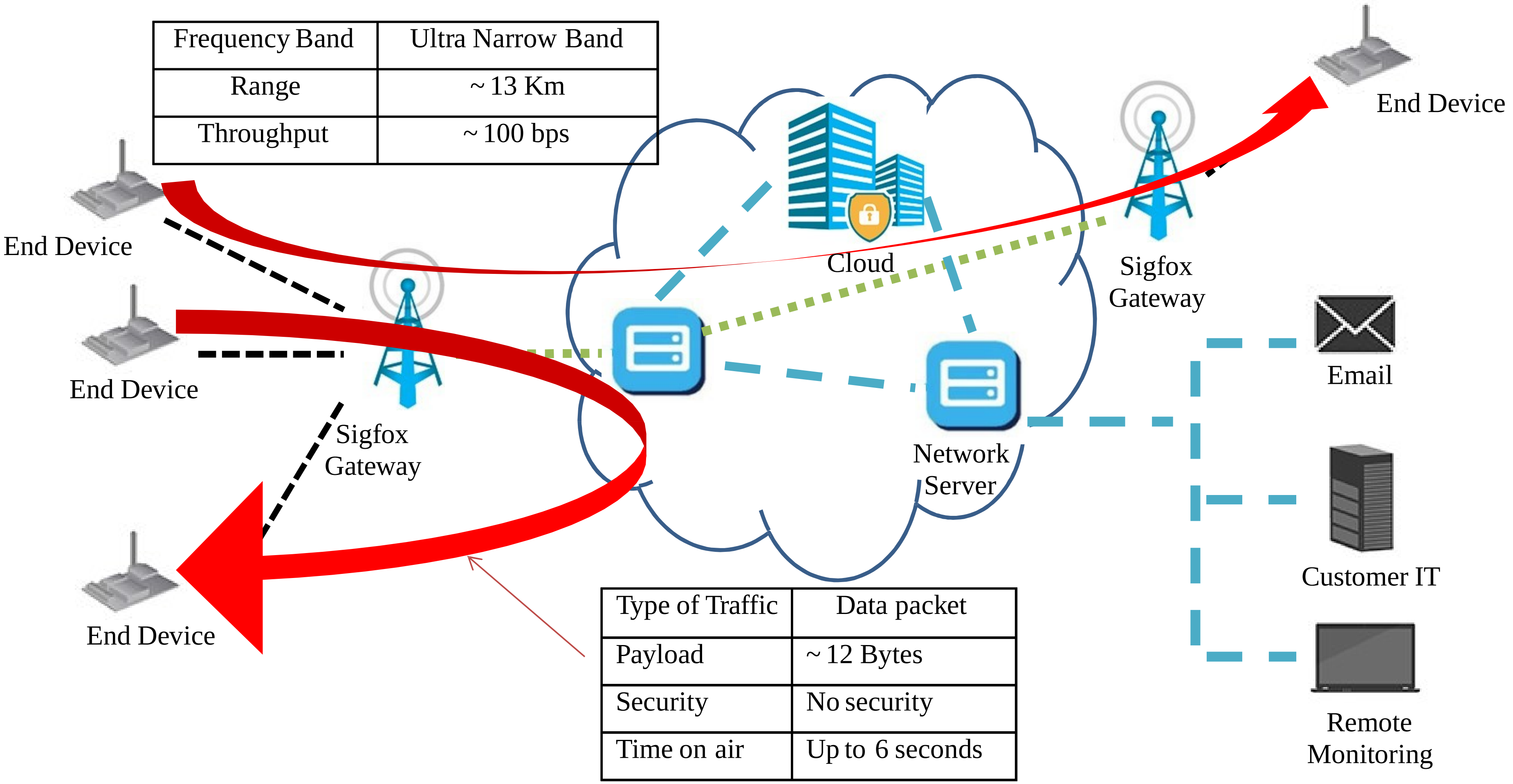
60 countries covered by the end of 2018

Sigfox – Overview

- **First LPWAN Technology (BPSK based transmission)**
- **The physical layer based on an Ultra-Narrow band wireless modulation**
- **Proprietary system**
- **Low throughput (~100 bps)**
- **Low power**
- **Extended range (up to 50 km)**
- **140 messages/day/device**
- **Subscription-based model**
- **Cloud platform with Sigfox –defined API for server access**
- **Roaming capability**
- **Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data**

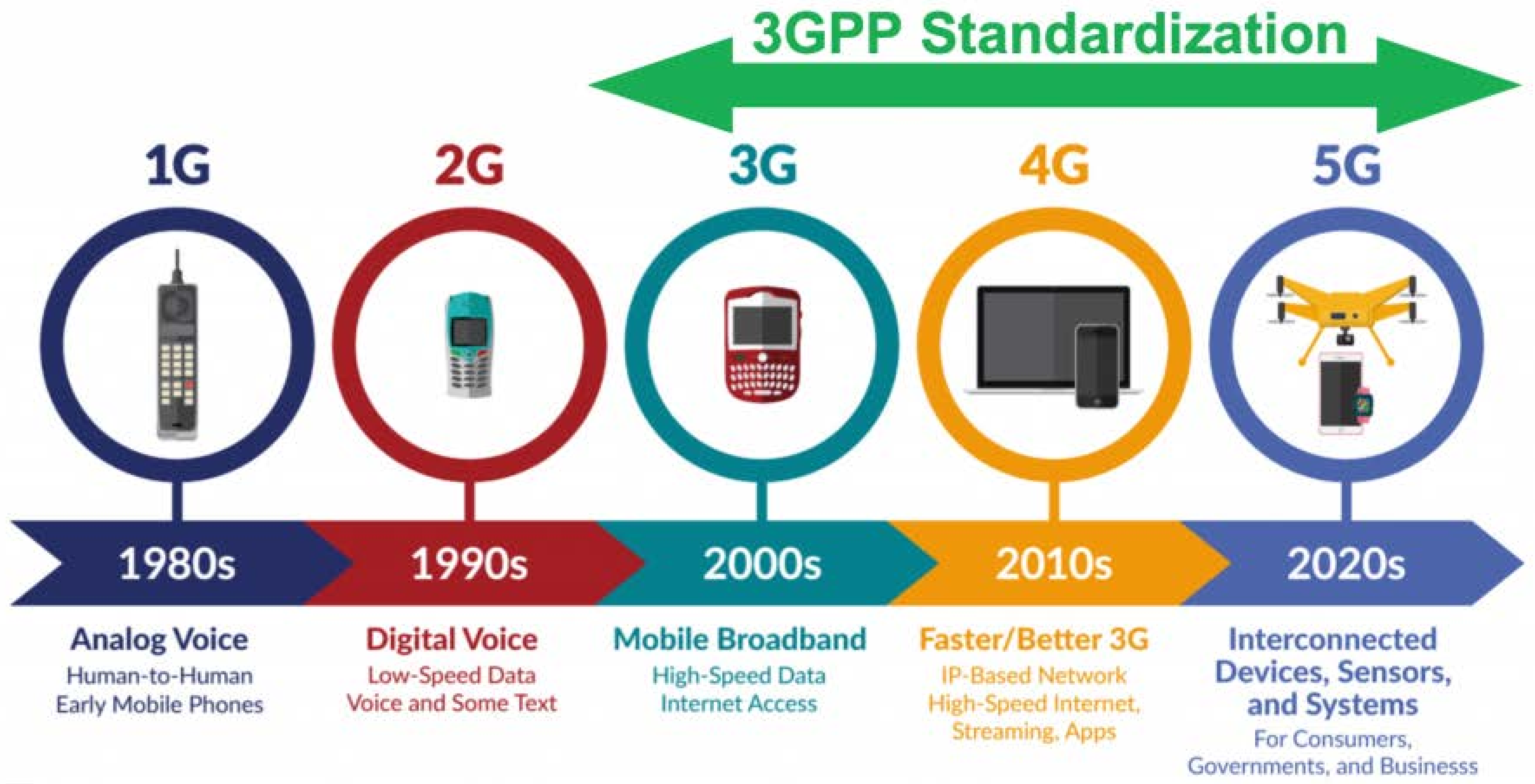
Sigfox - Architecture

Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps



Type of Traffic	Data packet
Payload	~ 12 Bytes
Security	No security
Time on air	Up to 6 seconds

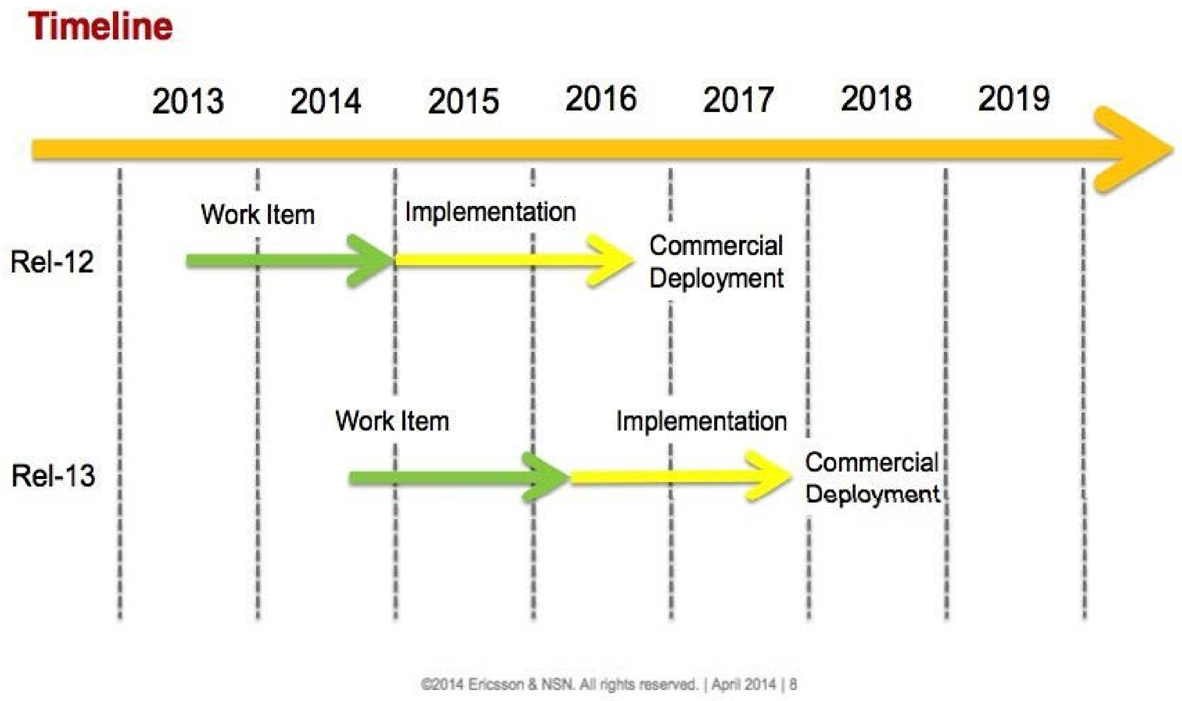
LTE-M - Overview



LTE-M (LTE-MTC [Machine Type Communication])

LTE-M - Overview

- Evolution of LTE optimized for IoT
- Low power consumption and autonomous
- Easy Deployment
- Interoperability with existing LTE networks
- Coverage upto 11 Km
- Max Throughput ≤ 1 Mbps



- ✓ First released in Rel.1 in 2 Q4 2014
- ✓ Optimization in Rel.13
- ✓ Specifications completed in Q1 2016
- ✓ Available since 2017

LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	1	1
Uplink peak rate (Mbps)	50	5	1	1
Number of antennas (MIMO)	2	2	1	1
Duplex Mode	Full	Full	Half	Half
UE receive bandwidth (MHz)	20	20	20	1.4
UE Transmit power (dBm)	23	23	23	20

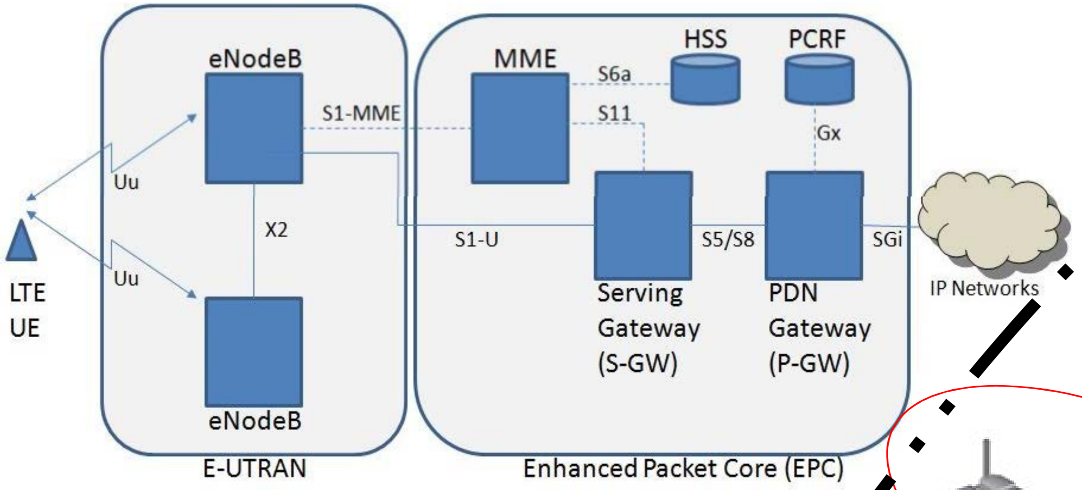
Release 12

- New category of UE ("Cat-0"): lower complexity and low cost devices
- Half duplex FDD operation allowed
- Single receiver
- Lower data rate requirement (Max: 1 Mbps)

Release 13

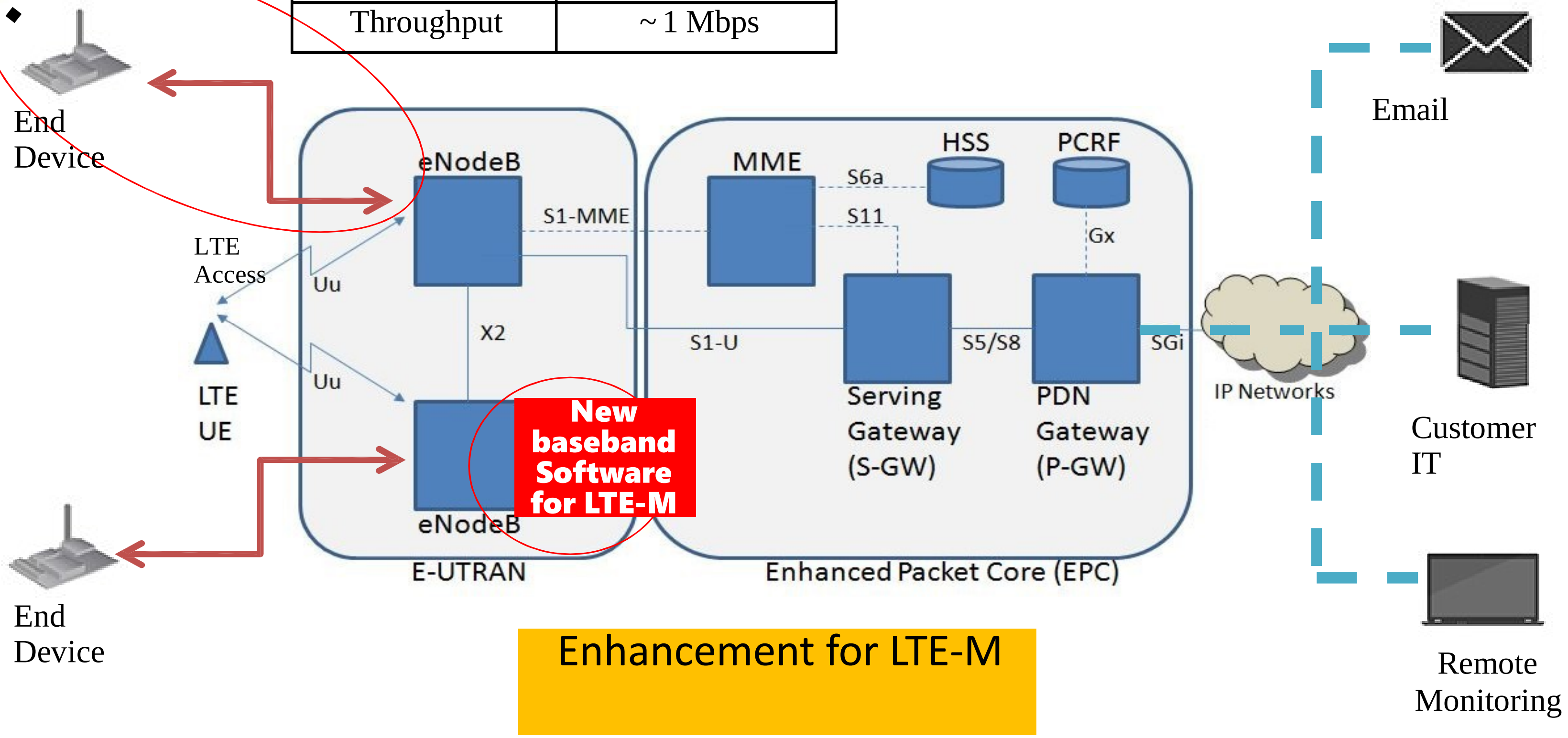
- Reduced receive bandwidth to 1.4 MHz
- Lower device power class of 20 dBm
- 15dB additional link budget: better coverage
- More energy efficient because of its extended discontinuous repetition cycle (eDRX)

LTE to LTE-M - Architecture



Present LTE Architecture

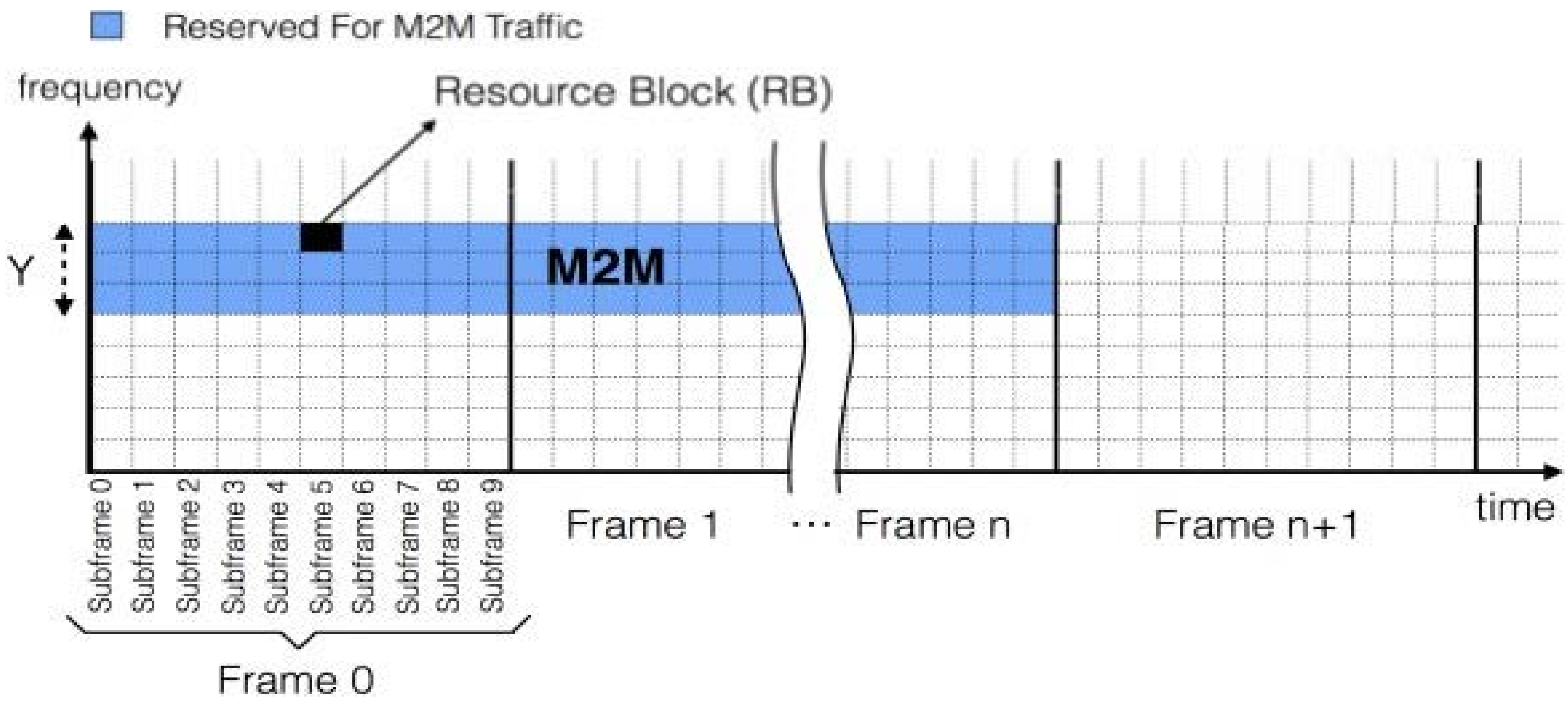
Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps



Enhancement for LTE-M

LTE-M

- Licensed Spectrum
- Frequency Bands: 700-900 MHz for LTE
- Some resource blocks are allocated to IoT on LTE bands



NB-IoT

April 2014	Narrowband proposal to Connected Living
May 2014	3GPP 'Cellular IoT' Study Item
March 2015	GSMA Mobile IoT created
August 2015	3GPP alignment on single standard
November 2015	1st ive pre-standard NB-IOT message NB-IoT
Jun 2015	Full 3GPP Standard Released
2017+	Commercial rollout

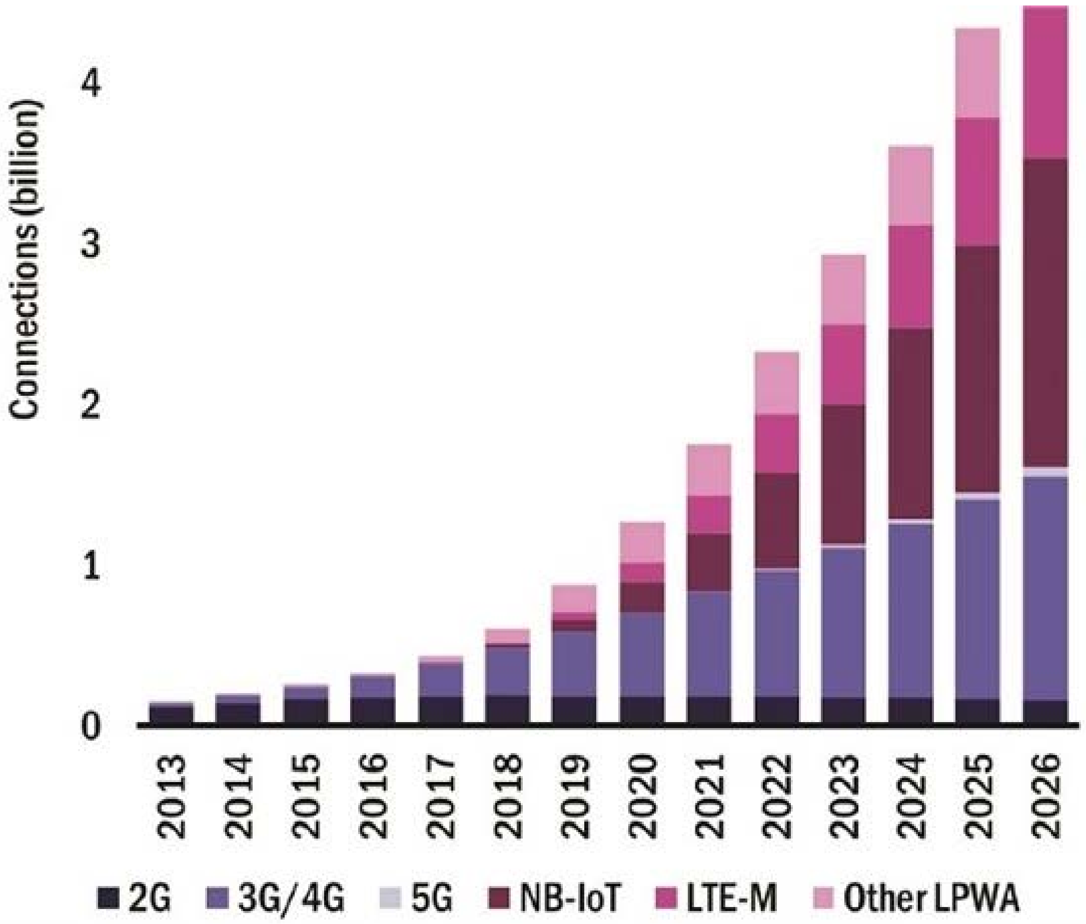
A GLOBAL INITIATIVE

NB-IoT

- **Uses LTE design extensively** e.g. DL: FDMA, UL: SC-FDMA
- **Lower cost** than eMTC (Narrow band: supports 180 KHz channel)
- **Extended coverage:** 164 dB maximum coupling loss or link budget (at least for standalone) in comparison to GPRS link budget of 144dB and LTE of 142.7 dB
- **Low Receiver sensitivity** = -141 dBm
- **Long battery life**: 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- **Support for massive number of devices**: at least 50.000 per cell
- **3 modes of operation:**
  - **Stand-alone**: *stand-alone carrier, e.g. spectrum currently used by GERAN (GSM Edge Radio Access Network) systems as a replacement of one or more GSM carriers*
  - **Guard band:** *unused resource blocks within a LTE carrier's guard-band*
  - **In-band:** *resource blocks within a normal LTE carrier*

Some Facts and forecasts

- **Analysys Mason:**
  - 3G and 4G will capture a 27% market share in 2026
  - 5G will constitute just over 1% of the total connections in 2026, but this will be the average across all application groups. For automotive and embedded SIMs specifically, 5G will have a 4% share of the total connections.



NB-IoT will be the dominant network for IoT in 2026 (Analysys Mason)

Chipset Costs

LoRAWAN	NB-IoT	LTE-M
1. MICROCHIP **Interface**: UART **Stack / MAC**: LoRaWAN **Stack implementation**: Microchip proprietary **Price**: **$14.27 @ single unit** **$10.90 @ 1000 units** **2. MULTITECH** **Interface**: UART **Stack / MAC**: LoRaWAN **Stack implementation**: MultiTech proprietary (XBEE compatible) **Price**: ~**$30 @ single unit**	**1. NB-IoT Quectel BC95** **3GPP Rel-13** **Interfaces** SIM/USIM 1 **Transmission** 100bps **Price: $ 40,00** **2. Digi XBee Cellular NB-IOT** **Up to ~60Kbps Downlink, 25Kbps Uplink** 1 antenna design, 200 mW (23 dBm) Band 20 (800MHz) Band 8 (900MHz **$30-60 Single unit** **3. Quectel Module** **GSM/GPRS/UMTS/HSPA/NB-IoT** **$ 68,00Single unit**	**Digi International XBee™ Cellular LTE-M Embedded Modem** 200mW (23dBm) Tx power 3.0V to 4.3V supply voltage Up to 384kbps RF throughput Up to 1Mbps DL or UL speed **NB-IoT Ready with a future over-the-air update** **$ 69Single unit**



Source: ITU IoT Planning workshop Bandung 2018