Wireless standards for IoT: WiFi, BLE, SigFox, NB-IoT and LoRa
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International Centre for Theoretical Physics

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Goals

- Describe the technologies that can be used to build IoT networks.
- Explain the LPWAN solutions that currently show more traction and those poised to attain it.
- Describe the most common solutions for IoT connectivity

IoT connectivity issues

- Wireless, except for some applications
- Low power consumption, years of battery duration required in many applications
- Small size
- Low device cost and operating expenses to allow for massive deployment
- Legacy Cellular Technologies do not meet these requirements

Many IoT nodes can accept:

- Low throughput
- Very sparse datagrams
- Delays
- Long Sleeping times

Capacity of a digital communications channel

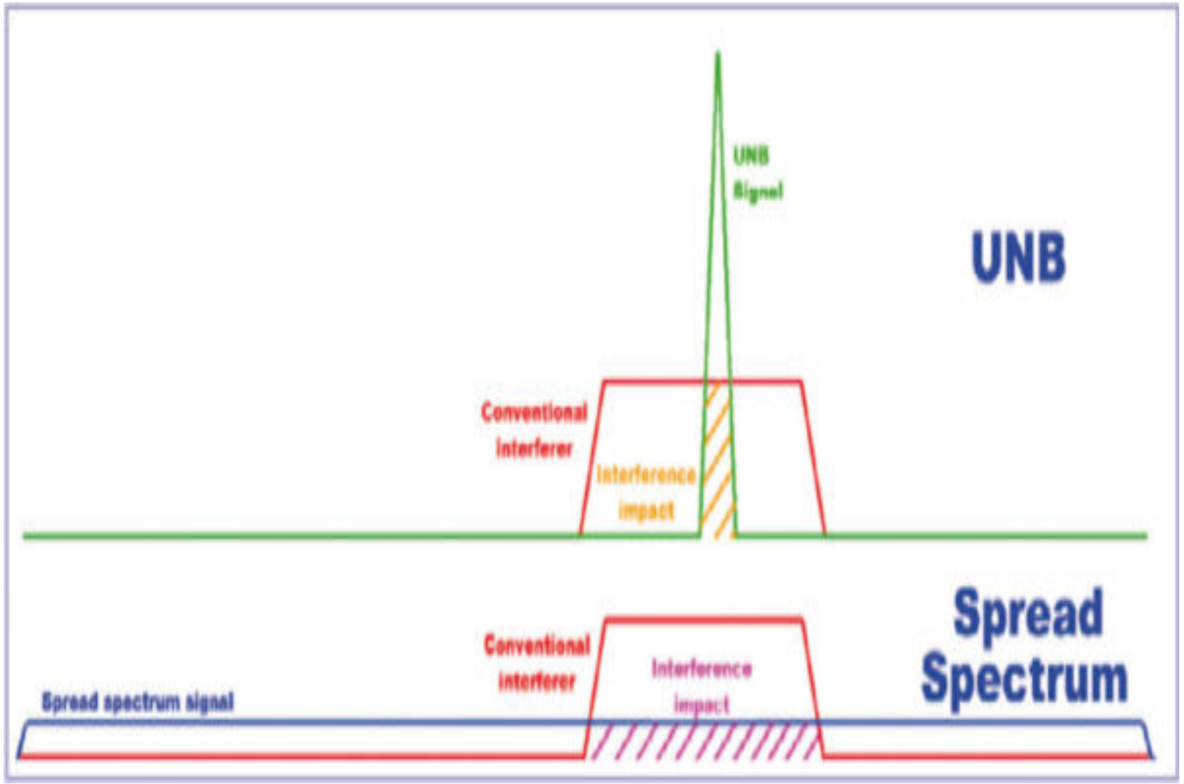
$$C = B\mathrm{Log}_2\,(1 + Eb/N_oB)$$

C, number of bits/s
B, receiver bandwidth, Hz
Eb, energy per bit in J, = P/t, (Power divided by bit transmission time)
N_o, noise spectral density, J/s

The number of bits per second that can be received is determined by the ratio between the energy per bit received and the energy of the noise entering the receiver during a bit interval.

The same amount of energy per bit can be obtained using different strategies:

- Narrowing the receiver bandwidth to limit the amount of noise and using a higher transmitted power
- Spreading the spectrum over a large frequency span at lower transmitted power
- Either techniques can limit the interference impact



Capacity of a digital communications channel

The maximum number of bits per second that can be received can also be calculated in terms of the ratio between the signal power and the power of the noise at the receiver. It depends on the effective transmitted power, receiver sensitivity, interference and data rate.

$$C = B\mathrm{Log}_2\,(1 + S/N)$$

C, number of bits/s
B, receiver bandwidth, Hz
S, Received signal power, W
N_o, noise power, W

Noise Power

- There are many sources of electrical noise entering any receiver, but one that cannot be avoided is the thermal noise
- Thermal noise power is given by KTB, where K is Boltzmann constant , T is the absolute temperature in kelvins and B is bandwidth in Hz
- At room temperature the noise power in dBm is then:
  $N[dBm] = -174 + 10 \log_{10}(B)$
- For a 1MHz channel the noise power at room temperature is
  $-174+10 \log_{10}(10^6) = -114$ dBm

Receiver sensitivity, Rs

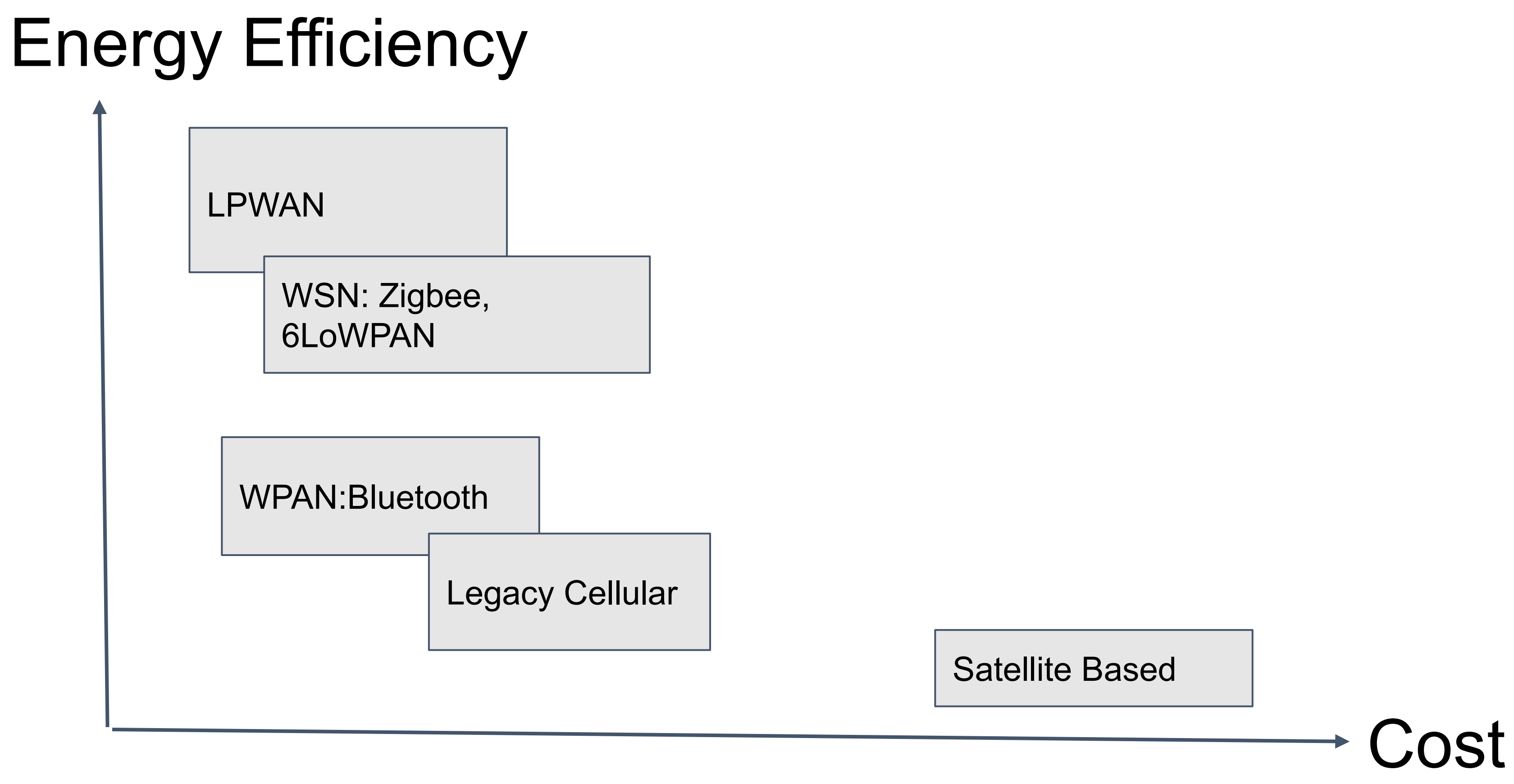
- Rs is the amount of signal power required at the receiver to detect the signal with a specific packet reception rate (PRR)

$$Rs\ [dBm] = N[dBm] + S/N\ [dB] + NF[dB]$$

Where NF is the noise factor, the amount of noise power introduced by the receiver circuitry, on top of the thermal noise, which depends on the quality of the receiver construction

Technology	Sensitivity	Data rate	Spectrum
WiFi (802.11 b, g, n)	-95 dBm	1-54 Mb/s	Wide Band
Bluetooth	-97 dBm	1-2 Mb/s	Wide Band
BLE	-95 dBm	1 Mb/s	Wide Band
ZigBee	-100 dBm	250 kb/s	Wide Band
SigFox	-136 dBm	100 b/s	Ultra Narrow Band
LoRa	-136 dBm	18 b/s - 37.5 kb/s	Narrow Band
Cellular data (2G,3G)	-104 dBm	Up to 1.4 Mb/s	Narrow Band

Energy efficiency Vs. cost



Some solutions

- RFID
- WiFi (based on IEE 802.11 standard)
- Bluetooth and BLE (Bluetooth Low Energy)
- Personal Area Networks (PAN)
  - 802.15.4 based
    - ZigBee, 6LoWPAN, Thread
- Cellular based

  extended coverage GSM (EC-GSM)

  enhanced machine type communication (eMTC) also called LTE-M and NB-IoT

RFID

RFID is a very successful application of short distance radio technology. It uses an object (typically referred to as an RFID tag) applied to a product, animal, or person for the purpose of identification and tracking.

The tag maybe passive, in which case it will just modify the signal transmitted to it by a short distance reader, or active in which case the reader might be at several meters of distance and beyond LOS.

RFID TAGS

- Used in shops to expedite check out, automate inventory control and for theft prevention.
- Embedded in passports and in even in animals.
- Maybe read only, like for inventory control applications, or writeable for more advanced ones.
- Have been implanted in humans.

RFID frequencies of operation

Band	Regulation	Range	Data speed
120-150 kHz	Unregulated	10 cm	low
13.56 MHz	ISM	10 cm-1 m	low to moderate
433 MHz	SRD (Europe)	1-100m	moderate
865-868 MHz	SRD (Europe)	1-12 m	moderate
902-928 MHz	ISM (US)	1-12 m	moderate to high
2400/5825 MHz	ISM	1-2 m	High

ISM bands are also used for other technologies like WiFi , Bluetooth, ZigBee, etc. since they do not require a license in most countries
For details:
ISO/IEC 18000-1:2008 **Radio frequency identification for item management** https://www.iso.org/standard/46145.html

IEEE 802.11 Amendments

Standard	a	b	g	n	ac	ad	af	ah
Year approved	1999	1999	2003	2009	2012	2014	2014	2016
Max data	54 Mb/s	11 Mb/s	54 Mb/s	600 Mb/s	3.2 Gb/s	6.76 Gb/s	426 Mb/s	from 150 kb/s to 347 Mb/s
Frequency band	5 GHz	2.4 GHz	2.4 GHz	2.4/ 5 GHz	5 GHz	60 GHz	54 to 790 MHz	below 1 GHz
Channel width	20 MHz	20 MHz	20 MHz	20/40 MHz	20 to 160 MHz	2160 MHz	6 - 8 MHz	1-2 MHz
RF chains	1X1 SISO	1X1 SISO	1X1 SISO	up to 4X4 MIMO	Up to 8X8 MIMO, MU	1X1 SISO	up to 4X4 MIMO	1X1 SISO

802.11ah (WiFi HaLow)

- Sub 1 GHz, most commonly 900 MHz
- Low power, long range WiFi, less attenuated by walls and vegetation.
- Up to 1 km range.
- Lower power consumption thanks to sleep mode capabilities.
- 1, 2, 4, 8 and 16 MHz channels.
- Competes with Bluetooth, speed from 100 kb/s to 40 Mb/s.
- Support of Relay AP to further extend coverage.

802.11ah (WiFi HaLow)

- Down sampled 802.11a/g specification to provide 26 channels, each of them with 100 kbit/s throughput.
- More efficient modulation and coding schemes borrowed from 802.11 ac.
- Relay (AP) capability, an entity that logically consists of a Relay and a client station (STA) which extends the coverage and also allows stations to use higher MCSs (Modulation and Coding Schemes) while reducing the time stations stay in Active mode, therefore improving battery life.
- To limit overhead, the relaying function is bi-directional and limited to two hops only.

Bluetooth

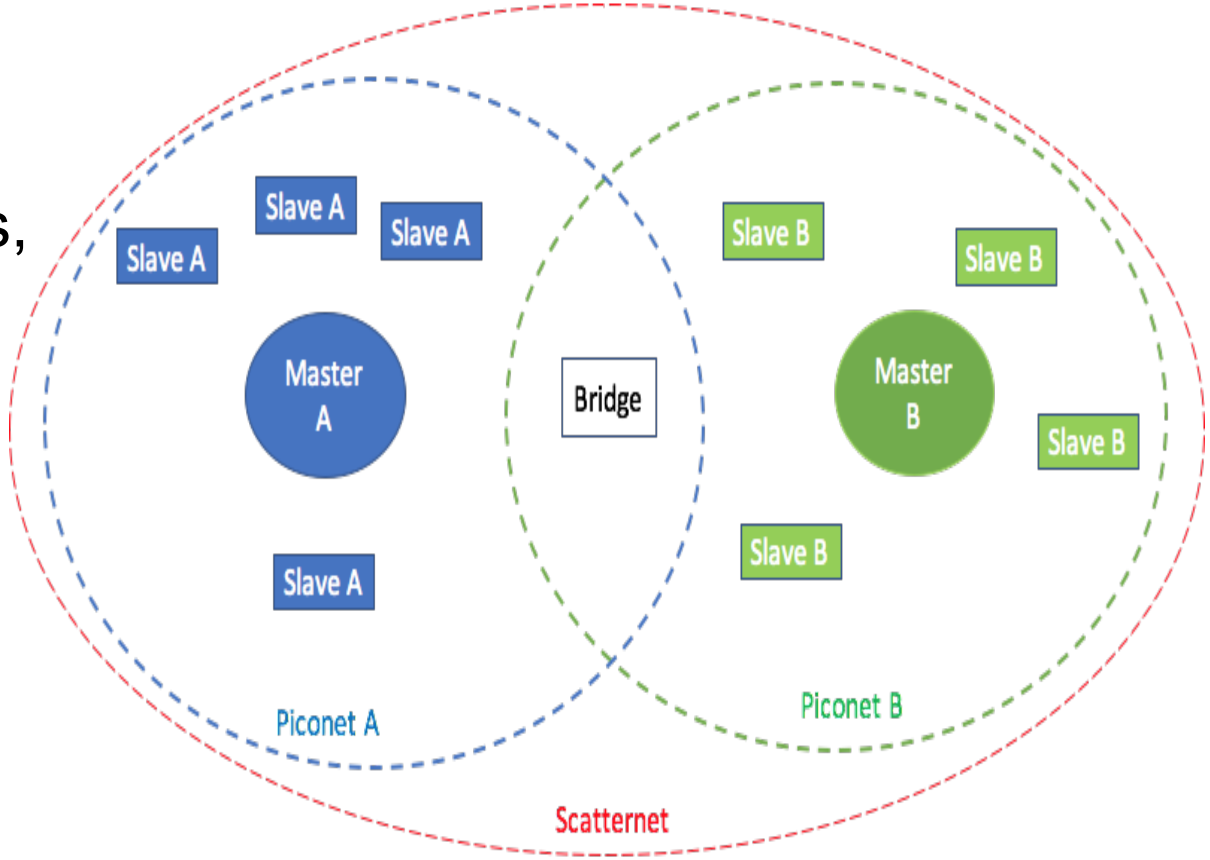
- Based on IEEE 802.15.1
- Smart Mesh.
- 79 channels 1 MHz wide and frequency hopping to combat interference in the crowded 2.4 GHz band.
- Used mainly for speakers, health monitors and other short range applications.
- Proximity and indoors location services capabilities.

Bluetooth architecture

Master node controls up to 7 active

slave nodes and up 255 inactive nodes, forming a *piconet*.

- Several piconets can form a *scatternet* by leveraging bridging nodes associated to more than one *master.*
- *Slaves* must communicate through the master node.



Bluetooth Low Energy (BLE) or Smart Bluetooth

- Based on IEEE 802.15.1
- Subset of Bluetooth 4.0, but stemming from an independent Nokia solution.
- Smart Mesh.
- Support for IOS, Android, Windows and GNU/Linux.
- 40 channels 2 MHz wide and frequency hopping to combat interference.
- Used in smartphones, tablets, smart watches, health and fitness monitoring devices.

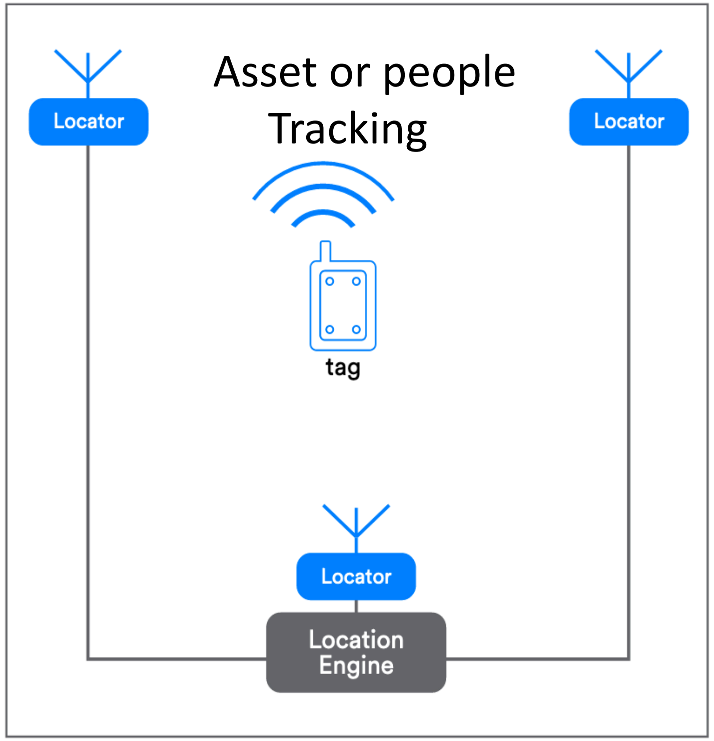
Bluetooth 5.X

Options that can:

- Double the speed (2 Mbit/s burst) at the expense of range.
- Increase the range up to fourfold at the expense of data rate.
- Increase up to 8 times the data broadcasting capacity of transmissions by increasing the packet lengths.
- Bluetooth 5.1 adds advanced location features.

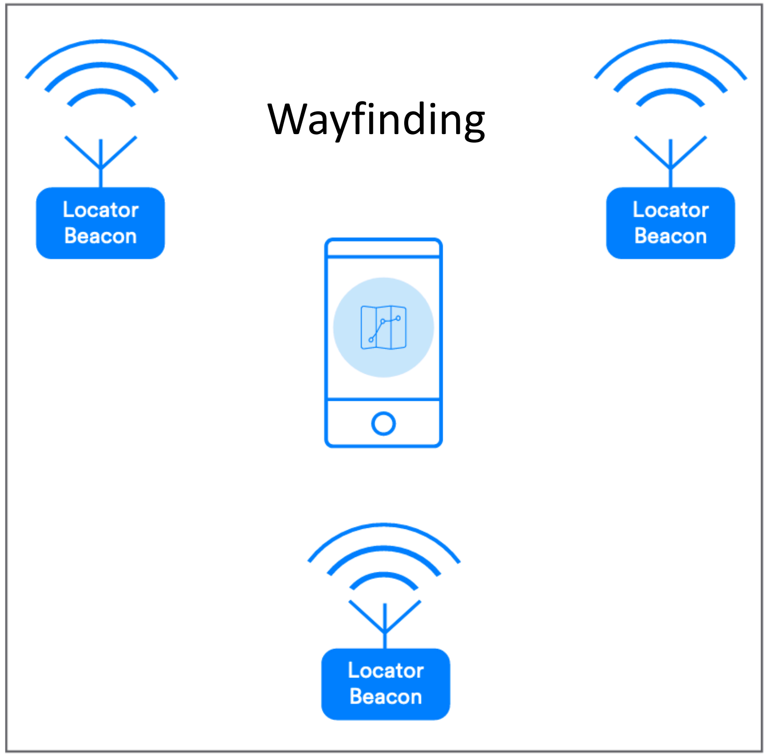
Location Determination: RTLS and IPS

Real Time Location System



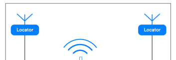
Bluetooth asset tracking system based on RSSI and trilateration.

Indoor Position System



Bluetooth IPS system based on RSSI and trilateration.

https://www.bluetooth.com/bluetooth-resources/enhancing-bluetooth-location-services-with-direction-finding/?utm_campaign=location-services&utm_source=internal&utm_medium=blog&utm_content=4-essentials-of-enhanced-location-services



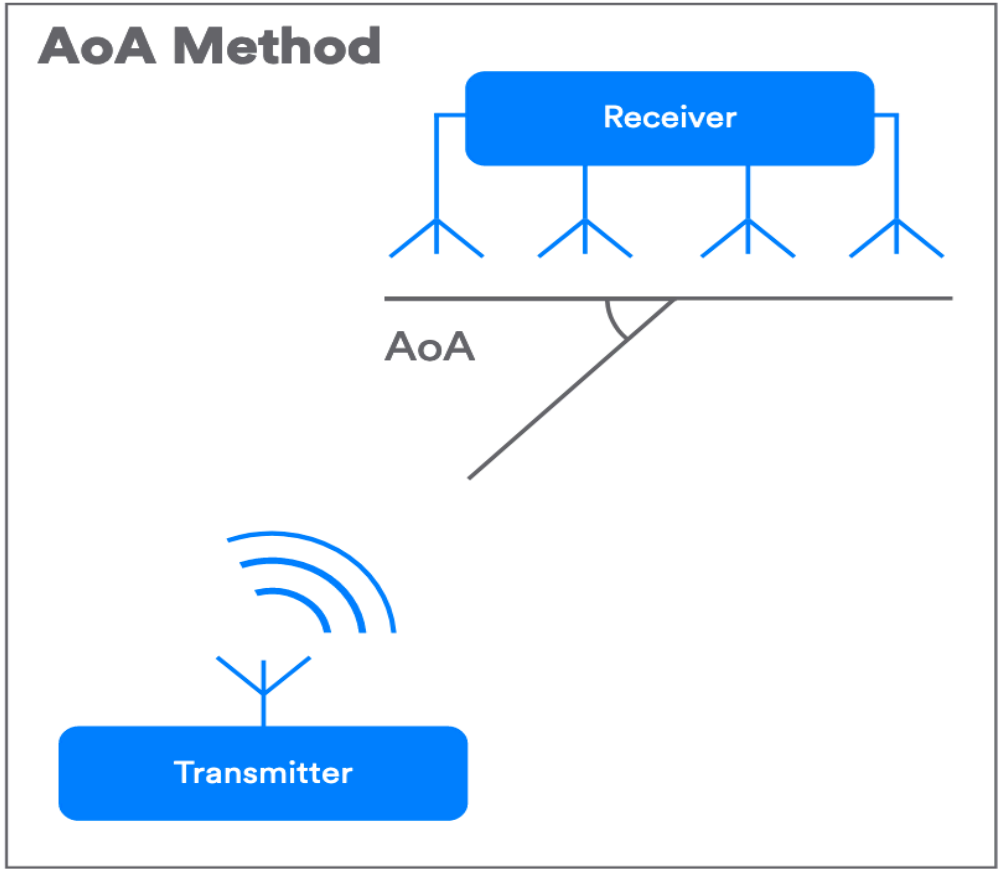
Location Determination

Coordinates of device are determined by calculating distances to several antennas

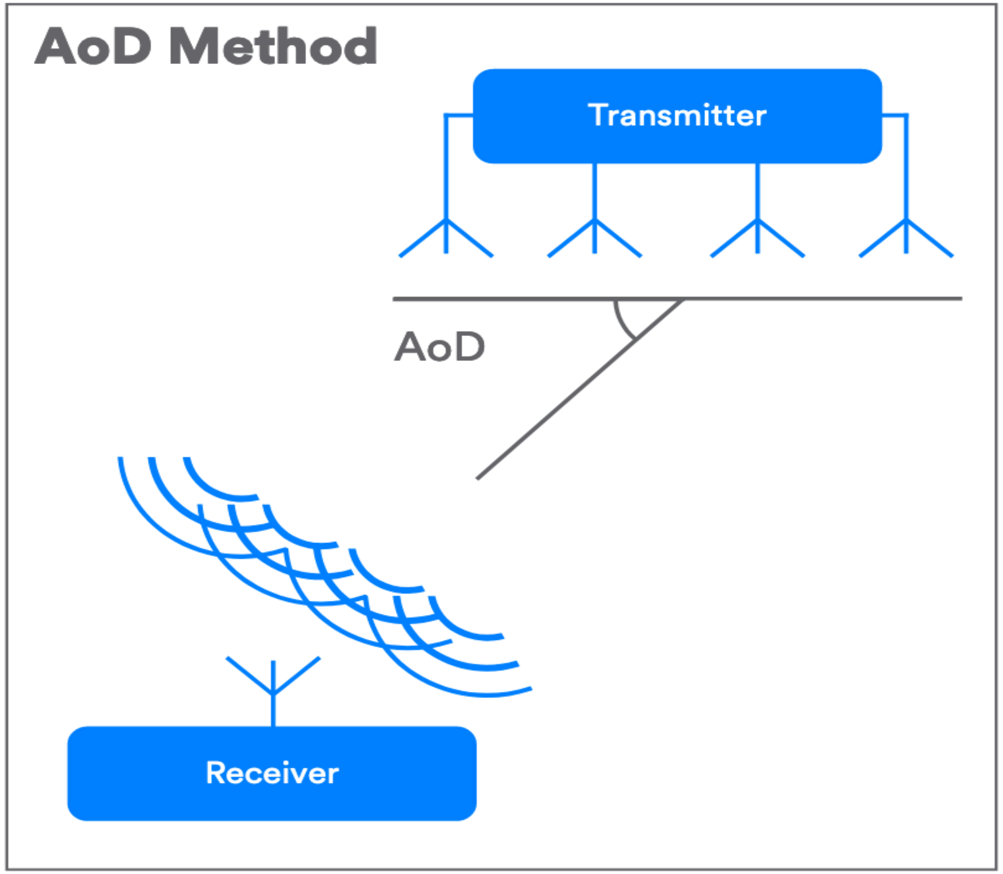
- RTLS and IPS (Real Time Location System and Indoor Position System)
- Trilateration (3 fixed receivers measure the transmitted signal)
  - Measuring RSSI (Received Signal Strength Indicator)
  - Measuring flight time (accurate clocks required)
- Triangulation, antenna array determines the direction of signals
  - Measuring angle of signal received at several fixed antennas
  - Measuring angle of signal transmitted from several fixed antennas

Bluetooth 5.1 Triangulation

Angle of Arrival



Angle of Departure



https://www.bluetooth.com/bluetooth-resources/enhancing-bluetooth-location-services-with-direction-finding/?utm_campaign=location-services&utm_source=internal&utm_medium=blog&utm_content=4-essentials-of-enhanced-location-services

Bluetooth 5.1 Angle of Arrival (AoA)

- The device transmits a special direction finding signal using a single antenna. The receiving device has multiple antennas arranged in an array
- As the signal crosses the array, the receiving device sees a signal phase difference due to the difference in distance from each of the antenna to the transmitting antenna
- AoA is intended for RTLS

Bluetooth 5.1 Angle of Departure (AoD)

- The device to which direction is being determined transmits a special signal using multiple antenna arranged in an array. The receiving device, such as a mobile phone, has a single antenna
- As the multiple signals from the transmitting device cross the antenna in the receiving device, the receiving device calculates the the relative signal direction based on the phase differences
- AoD method is intended for use in IPS solutions

Quiz

1. Which of the technologies described so far allows for a longer lasting battery?
2. Which one offers the longest range?
3. Which one offers the highest throughput?
4. Which one uses less bandwidth?

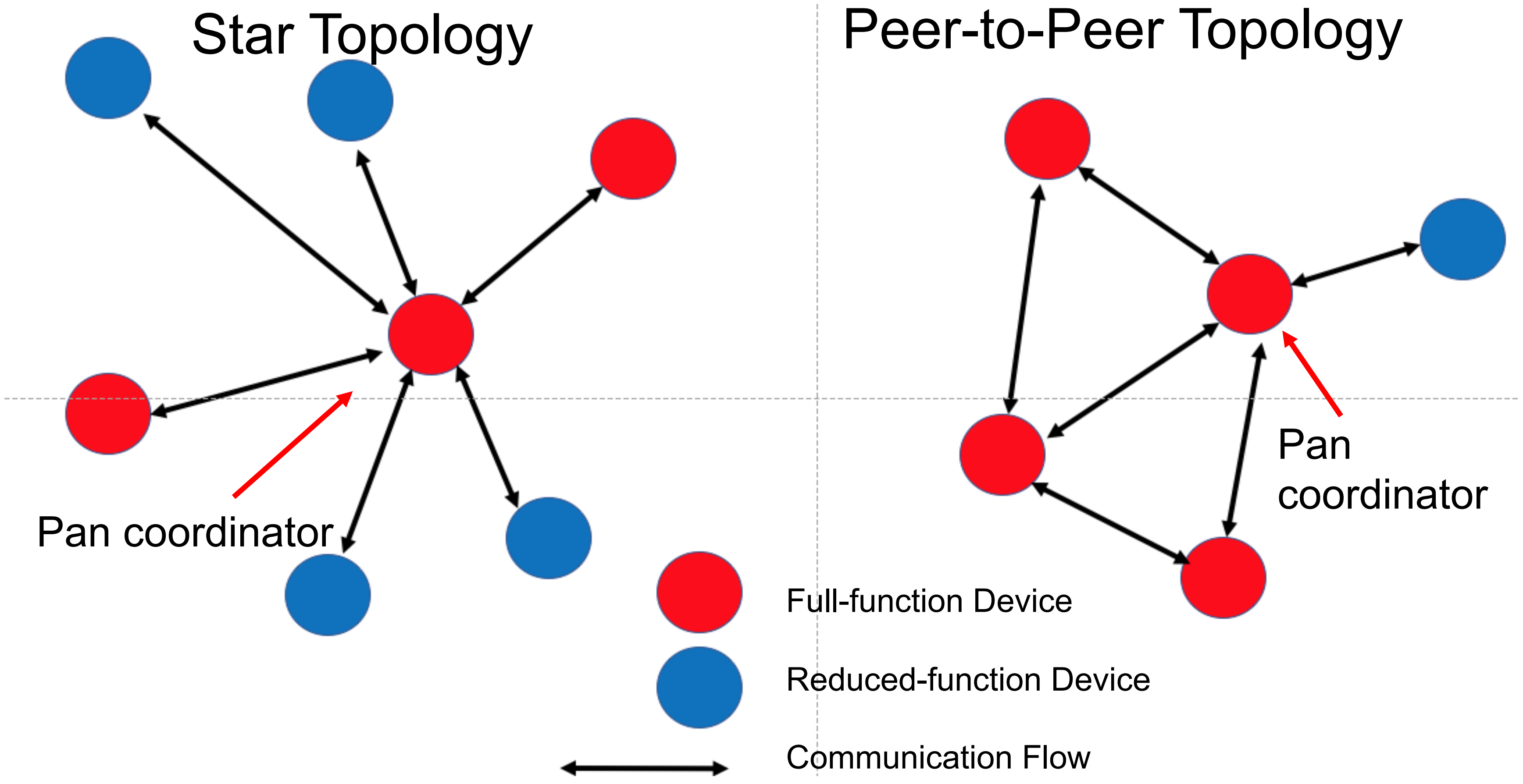
IEEE 802.15.4

Standard for Low-Rate Wireless Personal Area Networks (LR-WPANs)

- Little or no Infrastructure, low power.
- Defines the physical (PHY) and the medium access control (MAC) sublayer.
- Targets small, power-efficient, inexpensive solutions for a variety of devices.
- It is used by many upper layer protocols like Zigbee, Thread, Wireless HART, 6LowPAN.

http://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=68

IEEE 802.15.4 Topology



Zigbee

- Based on IEEE 802.15.4, provides the higher functions up to the application layer for WPAN
- Mesh topology
- Short range, 20 to 250 kbps
- 2.4 GHz, 915 MHz or 868 MHz
- Channels 2 MHz wide with Direct Sequence Spread Spectrum media access
- Zigbee alliance supported by many vendors
- Latest standard Zigbee 3.0 issued Dec 2015

Zigbee

Three specifications targeting different applications

- Zigbee Pro for reliable device to device communication supporting thousands of devices. Green Power feature for energy saving.
- Zigbee RF4CE for simpler, two-way control applications, lower memory requirements, lower cost.
- Zigbee IP for Internet Protocol v6 wireless mesh connecting dozens of different devices.

Emerging Technologies

SIGFOX
One network A billion dreams

LoRa™

nwave

LTE-M

NB-LTE

INGENU

WEIGHTLESS

IEEE 802.11ah

DASH7™ ALLIANCE

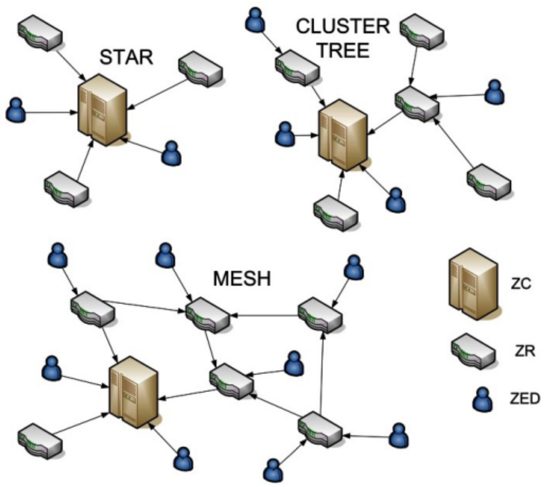
EC-GSM

ZigBee 3.0

Bluetooth® 4.0

Low Power Wide Area Network (LPWAN)

- Optimized for **IoT** and **Machine to Machine** (M2M) applications
- Trade **throughput** for **coverage** (up to several kilometers)
- **Star** or **star-of-stars** topology
- **Low power consumption**
- **Low** on board processing **power capabilities**



Battery duration

- LoRa, SigFox: up to years

  Devices sleep most of the time, low rate and limited messages per day

- 2G, a few days
- 802.15.4, months
- WiFi, a few days
- Energy scavenging schemes are being pursued
- Inductive powering
- Photovoltaic

Spectrum Usage

- Frequencies allocation country dependent
- Cellular uses costly exclusive licensed spectrum
- Alternatives use ISM bands, without fee payment, but subject to interference

Interference addressed by limiting power and:

- Listen Before Talk (LBT)
- Duty Cycle limitations
- Spatial confinement
    - Use high directivity antennas
    - Frequencies subjected to high attenuation (60GHz)
    - Light communication blocked by walls

6LoWPAN

IPv6 over low power wireless personal area networks, concluded working group of IETF

- Defines encapsulation and header compression to send and receive IPv6 packets over IEEE 802.15.4 networks.
- Defines mechanisms for fragmentation and reassembly of IPv6 packets to meet constraints of IoT networks.
- Thread is a royalty-free protocol using 6LoWPAN for IoT.

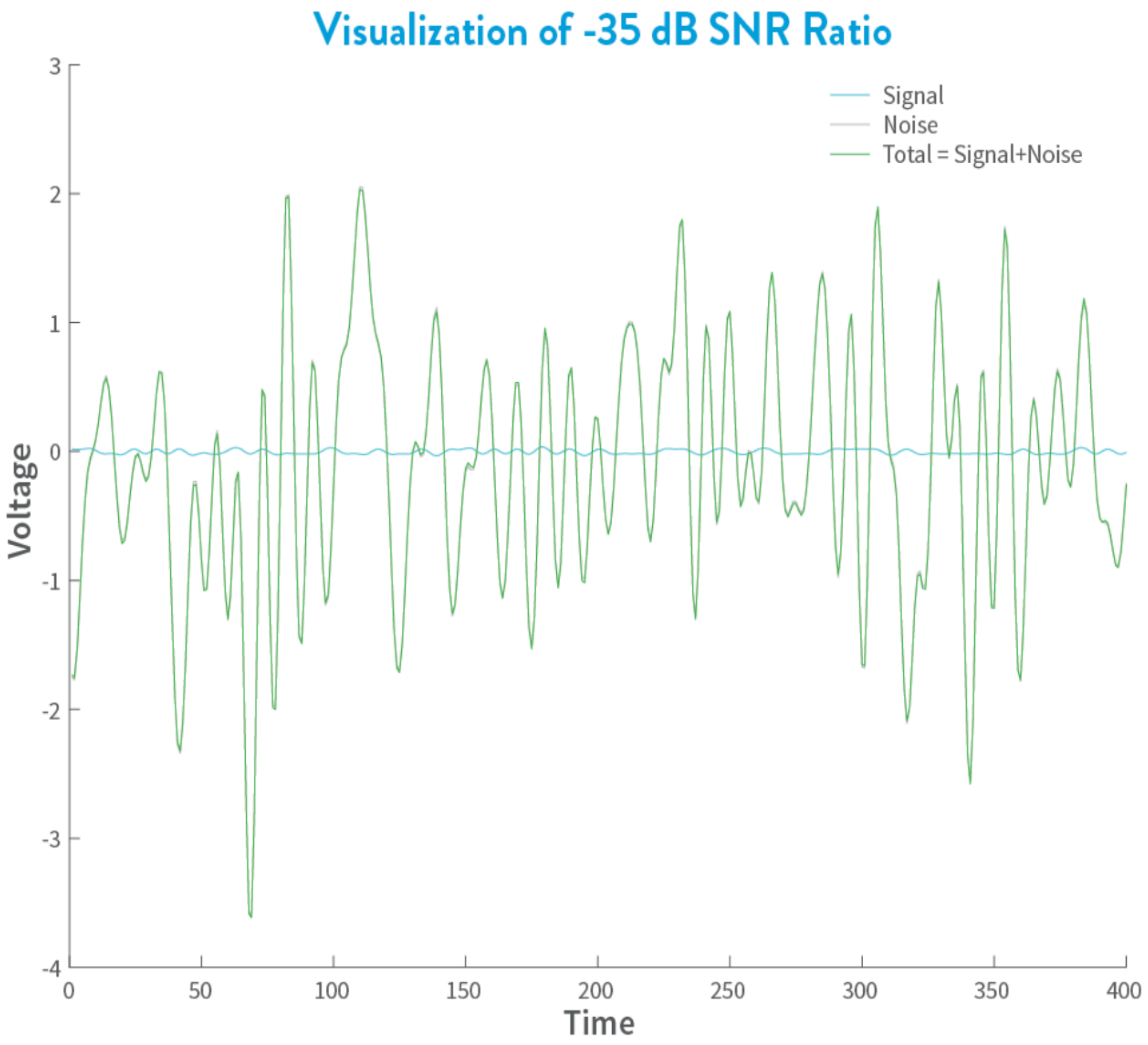
RPMA

Random Phase Multiple Access, backed by Ingenu

- Spread Spectrum technology based on CDMA.
- 172 dB link budget offers the longest range.
- 2.4 GHz band, 1 MHz channel bandwidth.
- Up to 624 kbps UL and 156 kbps DL, slower in mobile applications.
- Reliable message through ACK and 128 bit AES.
- Robust to interference and Doppler effects.
- Supports background firmware updates.
- Can tolerate up to -35 dB SNR

RPMA

- Coverage area of up to 200 square miles in US, 36 in Europe.
- 2 downlink channels: one broadcast channel for firmware upgrades and a second for data downlink.
- The endpoint will determine the minimum spreading factor required to close the link.
- Sensors that support RPMA are more expensive.



Sigfox

- Ultra narrowband technology designed for low throughput and few messages/day.
- Low consumption, low cost
- High receiver sensitivity: -134 dBm at 600 b/s or -142 dBm at 100 b/s on a 100 Hz channel, allows 146 to 162 dB of link budget.
- Each message transmitted 3 times in 3 different frequencies offering resilience to interference.

Sigfox

- Unlicensed frequencies: 868 MHz in Europe, 915 MHz in US.
- Maximum of 140 uplink messages/day with 12 octets payload, 26 octets total with overhead.
- Maximum of 4 downlink messages/day with 8 octets payload.
- Robust modulation: BPSK Uplink, GFSK Downlink.
- Mobility restricted to 6 km/h.
- One hop star topology.

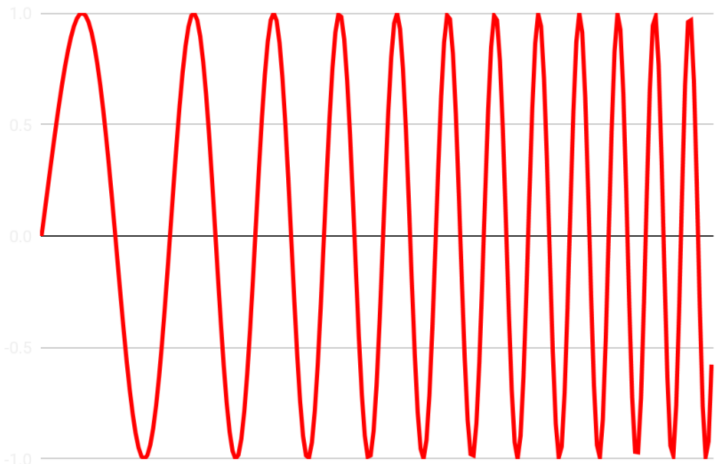
Sigfox

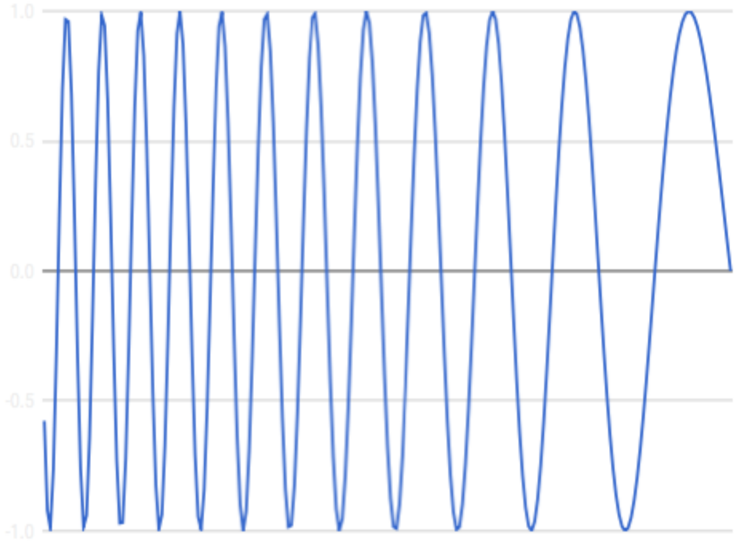
- Partnerships with cellular providers with an aim to worldwide penetration.
- Many network operators worldwide offer Sigfox services on a subscription basis.
- Cloud managed leveraging SDR to offer many services.
- Coarse geolocation capability without GPS.
- Roaming capability.

LoRa

- LoRA is a physical layer proprietary scheme for LPWAN based on spread spectrum, trading bandwidth for S/N.
- It achieves long range and deep indoor penetration.
- Uses linearly varying frequency pulses called “chirps” inspired in radar signals.
- Several vendors offer devices built on the chip owned by Semtech.

LoRa modulation

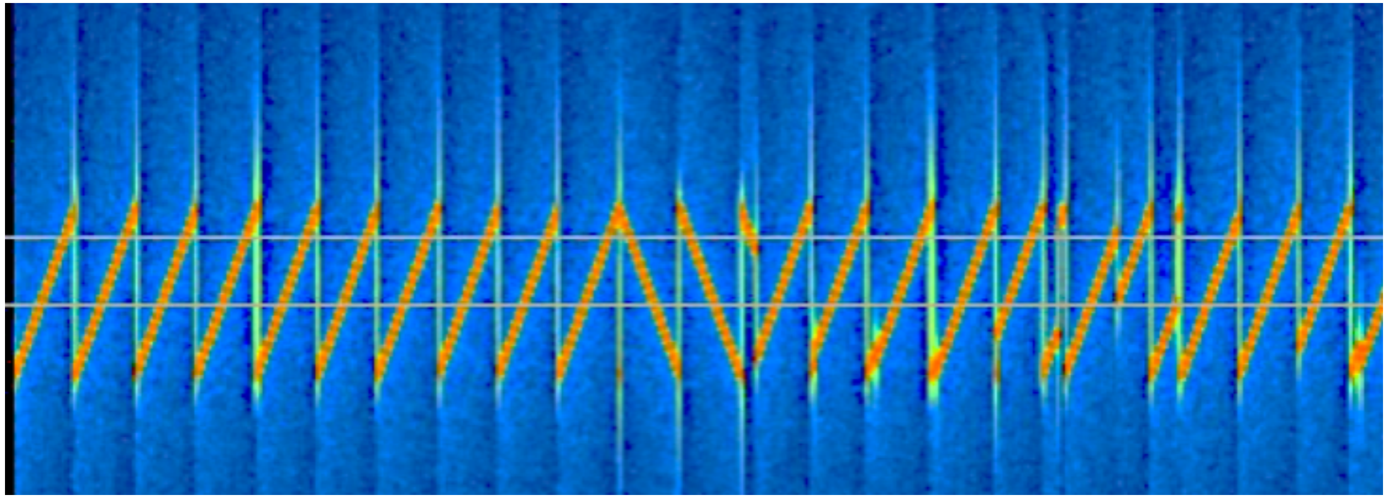




Up-chirp:
sinusoidal signal of linearly
increasing frequency

Down-chirp:
sinusoidal of linearly
decreasing frequency

LoRa physical layer



Preamble: at least 10 up-chirps followed by 2.25 down-chirps

Data: Information transmitted by the Instantaneous up-chirp frequency transitions

Beginning of data

LoRa physical layer

An optional header can be inserted between the preamble and the data.

Data can be followed by an optional cyclic redundancy check (CRC) if this is specified in the header.

BW and SF are constant in a given LoRa frame, but the SF can be changed to accommodate different channel conditions on subsequent

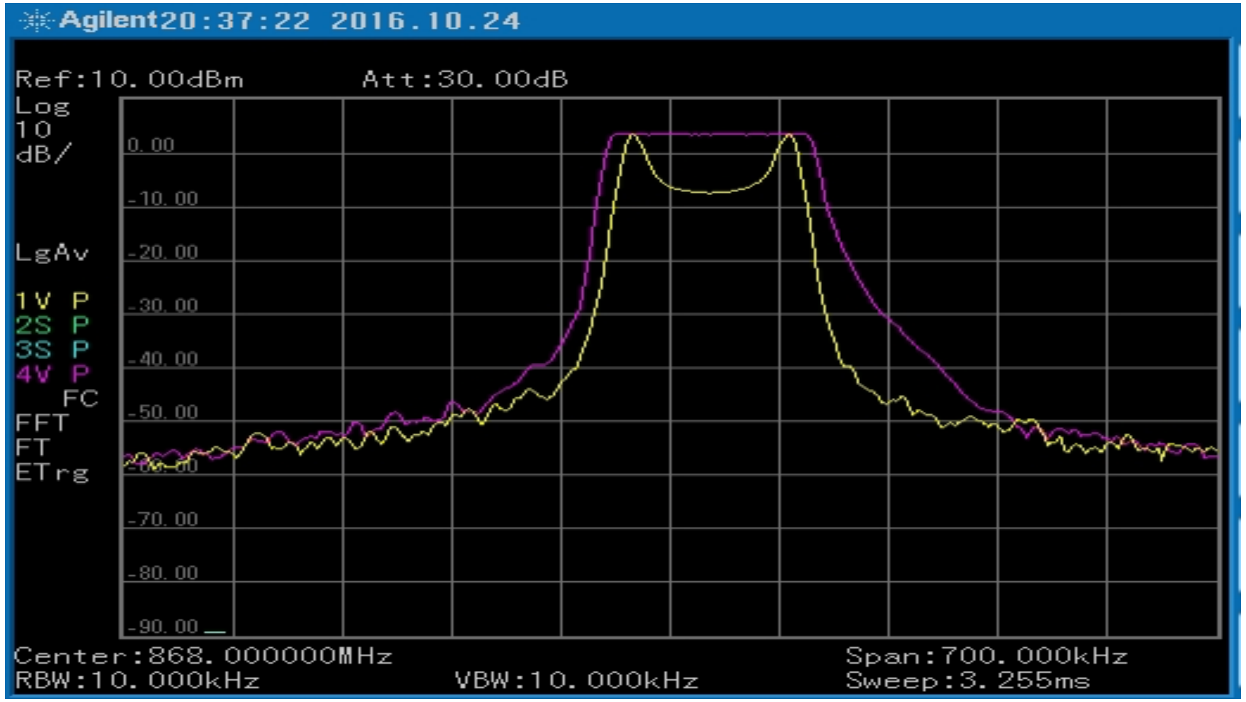
Parameters of LoRa physical layer

- Bandwidth (BW): 125 KHz, 250 kHz or 500 kHz
- Spreading Factor (SF): 6, 7,8,9,10,11,12
- Coding Rate (CR): 5/4, 6/4, 7/4/ 8/4
- payload size (PL): maximum 255 octets

A LoRa symbol is composed of 2^{SF} chirps

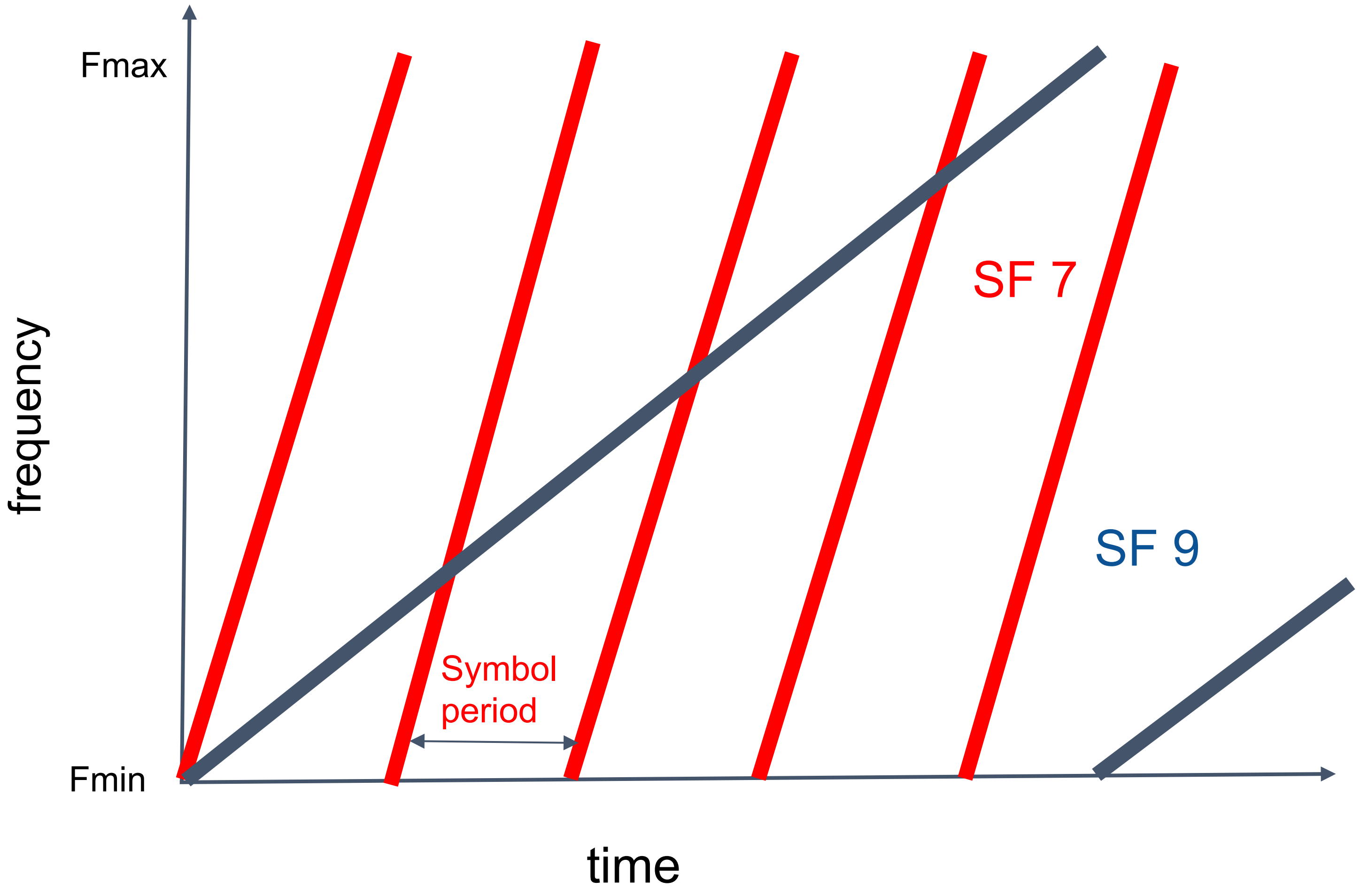
- The number of symbols transmitted depends also on the number of symbols in the preamble and whether a header and CRC are present.

LoRa and FSK spectra



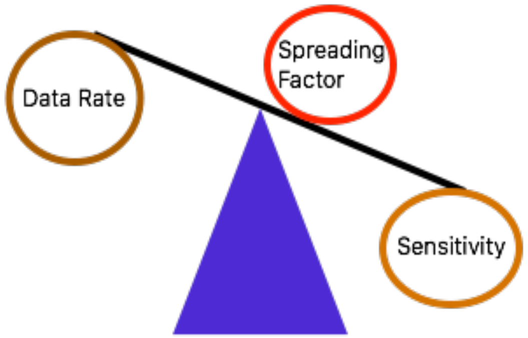
Flat top LoRa spectrum implies a more efficient spectrum usage as compared with the two peaked FSK.
Output power is the same, bandwidth is 125 kHz

Spreading Factors and duration



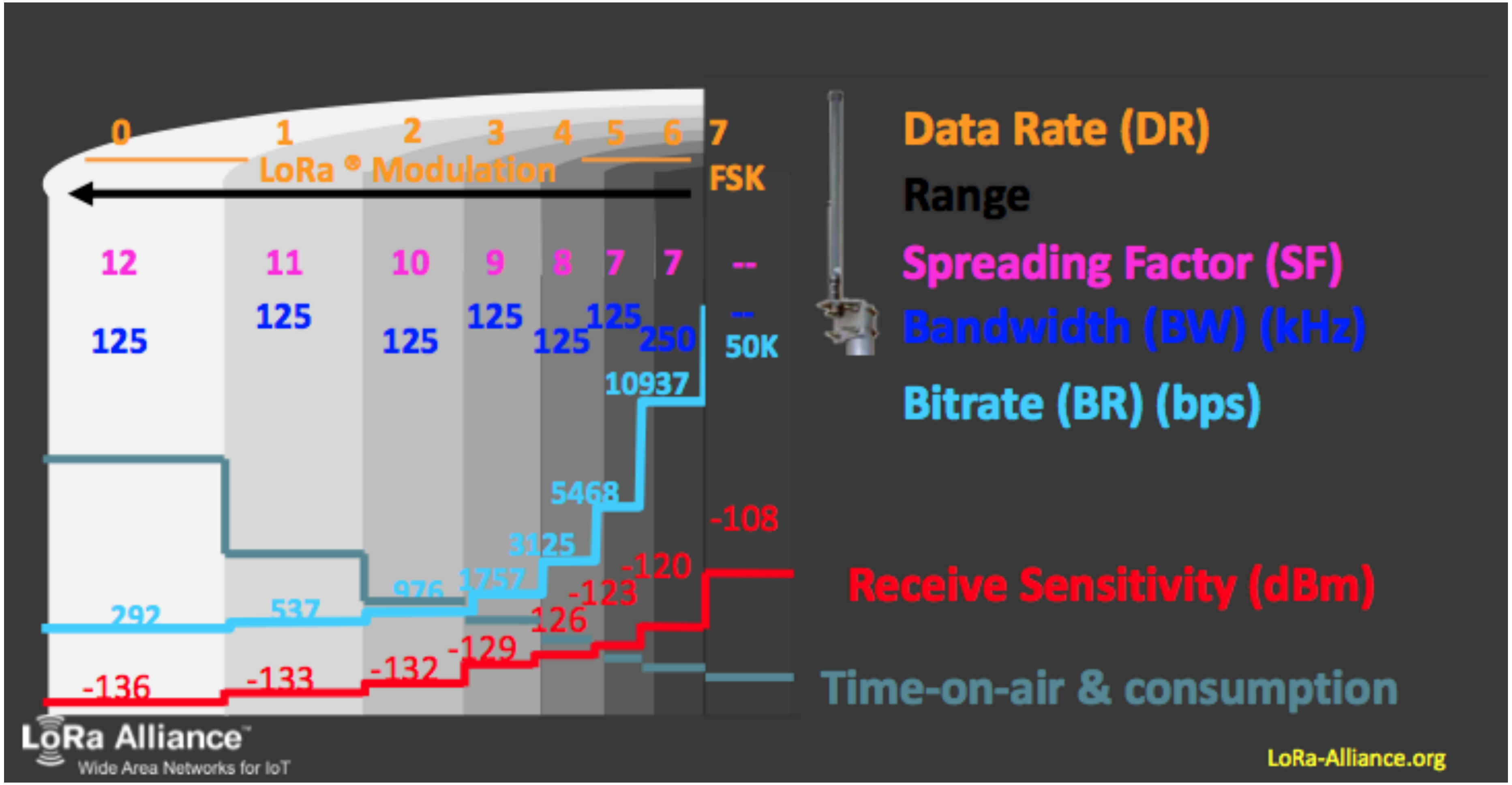
Adaptive Data Rate (ADR) at 125 kHz BW

Sprd. Factor	S/N dB	bit rate bit/s	ms per ten byte packet
7	-7.5	5469	56
8	-10	3125	103
9	-12.5	1758	205
10	-15	977	371
11	-17.5	537	741
12	-20	292	1483

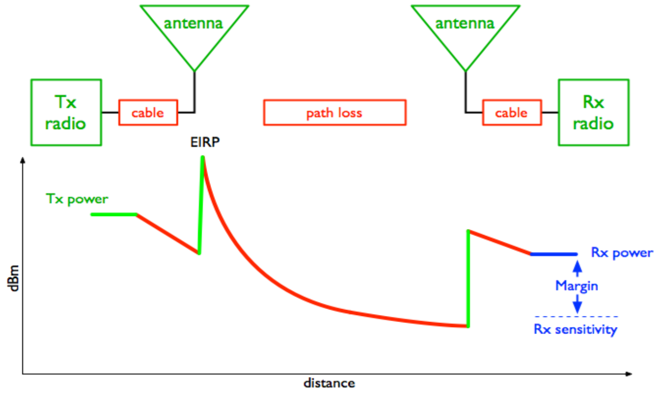


Sensitivity increases with spreading factor

LoRa parameters interaction



LoRa link budget



Tx=14 dBm

BW = 125 kHz, S/N = -20 (for SF 12)

Assume Noise Figure = 6 dB

Sensitivity = $-174 + 10 \log_{10}(BW) + NF + S/N =$

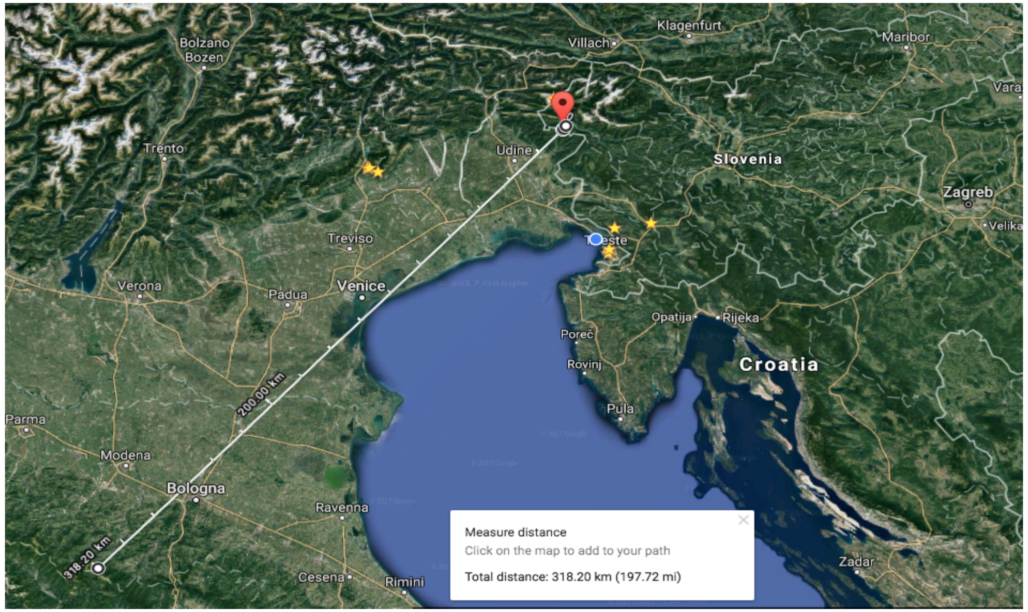
$-174+51+6-20= -137$ dBm

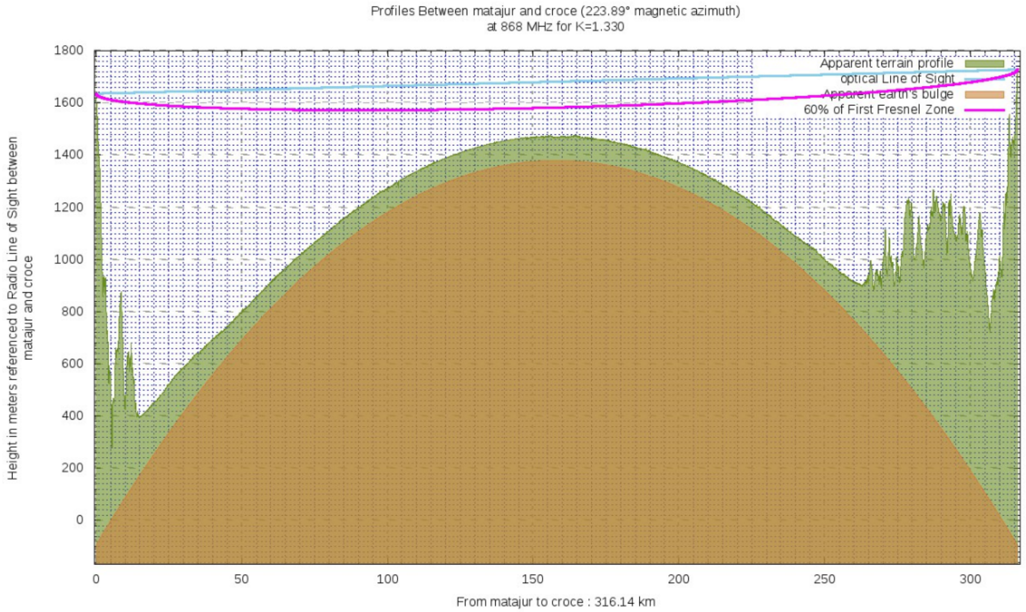
Link budget for Europe: 14+137 = 151 dB

In US, up to -157 dB in the 900 MHz band

Range

- **LoRa and SigFox**: many kilometers
- **WiFi**, typically 100 m, much higher values attainable with high gain antennas
- LoRa has reached 316 km with clear line of sight





LoRa spectrum usage

Europe: 863 to 868 MHz and 434 MHz

Duty cycle limitations: 0.1%, 1% and 10%

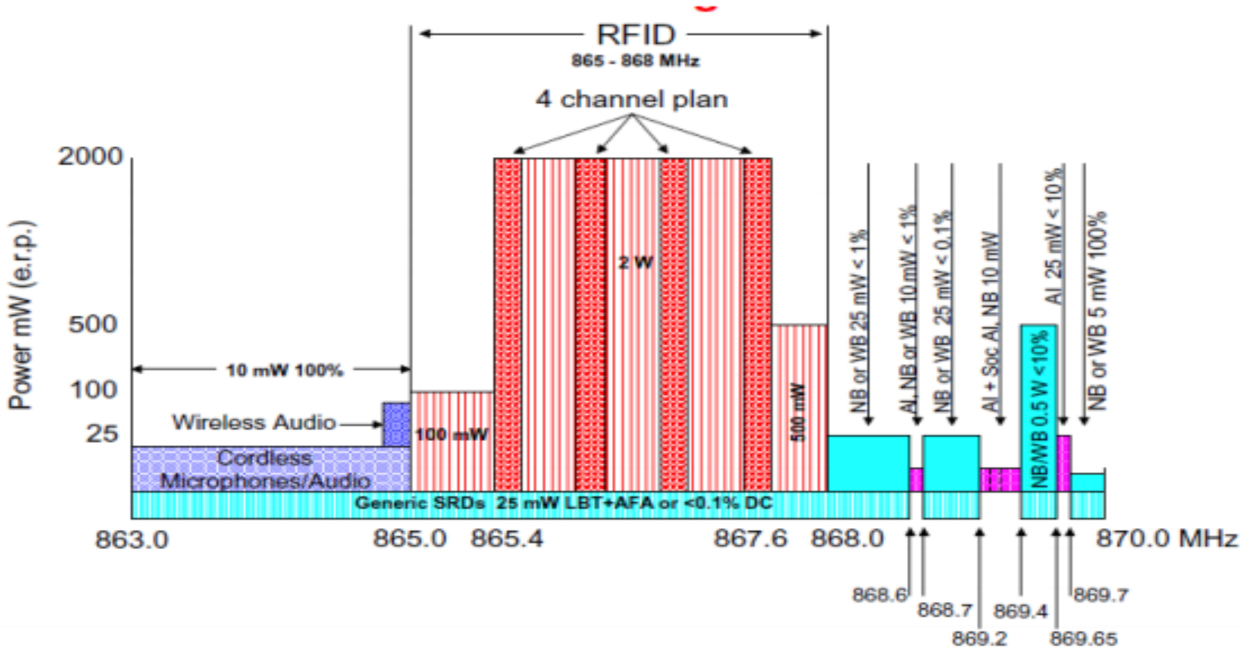
Max EIRP: 14 dBm, 27 dBM in G3 sub-band

US and Latin America: 902 to 928 MHz

400 ms max. dwell time per channel (SF 7 to SF 10 at 125 kHz)

Max EIRP: 21 dBm on 125 kHz, 26 dBm on 500 kHz channel

Short Range Devices and LoRa spectrum access in Europe



G1: 868,000 MHz to 868,600 MHz with 25 mW EIRP (14 dBm) and 1 % duty cycle.
G2: 868,700 MHz to 869,200 MHz with 25 mW EIRP (14 dBm) and 0,1 % duty cycle.
G3: 869,400 MHz to 869,650 MHz with 500 mW EIRP (27 dBm) and 10 % duty cycle.

http://www.etsi.org/deliver/etsi_tr/103000_103099/103055/01.01.01_60/tr_103055v010101p.pdf

LoRa duty cycle example

A device in Europe transmits a 0.75 s long frame at 868.3 MHz in the G1 (868 to 868.6 MHz) sub-band.

The whole sub-band (868 – 868.6) will be unavailable for 73.25 seconds, but the same device can hop to another sub-band meanwhile.

In US, the device would be violating the 400 ms maximum dwell time.

Effect of LoRa SF on consumption

You can change the values in columns A, B, C, D and H to suit your particular case.

	SF 7	SF 7	SF 7	SF 7	SF 7	SF 7	SF 12	SF12	SF 12
	Active T, ms	#of times/h	current, mA	mA/h	mA/year	battery %	Active T, ms	mA/year	battery %
Transmit	70	12	38	0.0088666	77.67	18	1650	1,800.83	83.99
Receive	10	12	15	0.0005	4.38	1	165	71.09	3.32
Receive 2	70	12	15	0.0035	30.66	6	70	30.16	1.41
Temperature	20	12	15	0.001	8.76	2	20	8.62	0.40
Humidity	20	12	15	0.001	8.76	2	20	8.62	0.40
CO2	60	12	130	0.026	227.76	48	60	224.03	10.45
sleep	1000	3600	0.004	0.004	35.04	8	10	0.34	0.02
battery	1000	3600	0.004	0.004	35.04	8	10	0.34	0.02
			Sum	0.0488666	428.07		2005	2,144.02	
Years of duration with a 3.6 V		800	mA.h battery =		1.87				0.37

Quiz

A LPWAN device is allowed to hop over 3 different frequencies while obeying the 1% duty cycle limitation.
If each frame carries a maximum of 100 octets,
a) What would be the maximum throughput given a frame duration of 400 ms?
b) How many octets could be transferred in 24 hours?

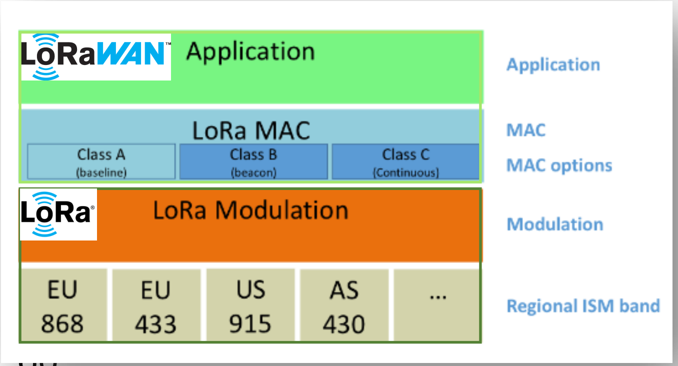
Chirp Spread Spectrum advantages

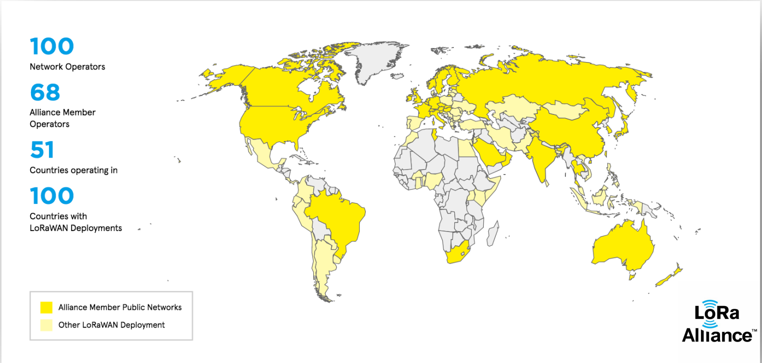
- Great link budget, low power transmission
- Resistant to multipath and other interference
- Orthogonality of spreading factors
- Simplified electronic for receiver synchronization
- Robust against Doppler shift (apt for mobile applications)

LoRa and LoRaWAN

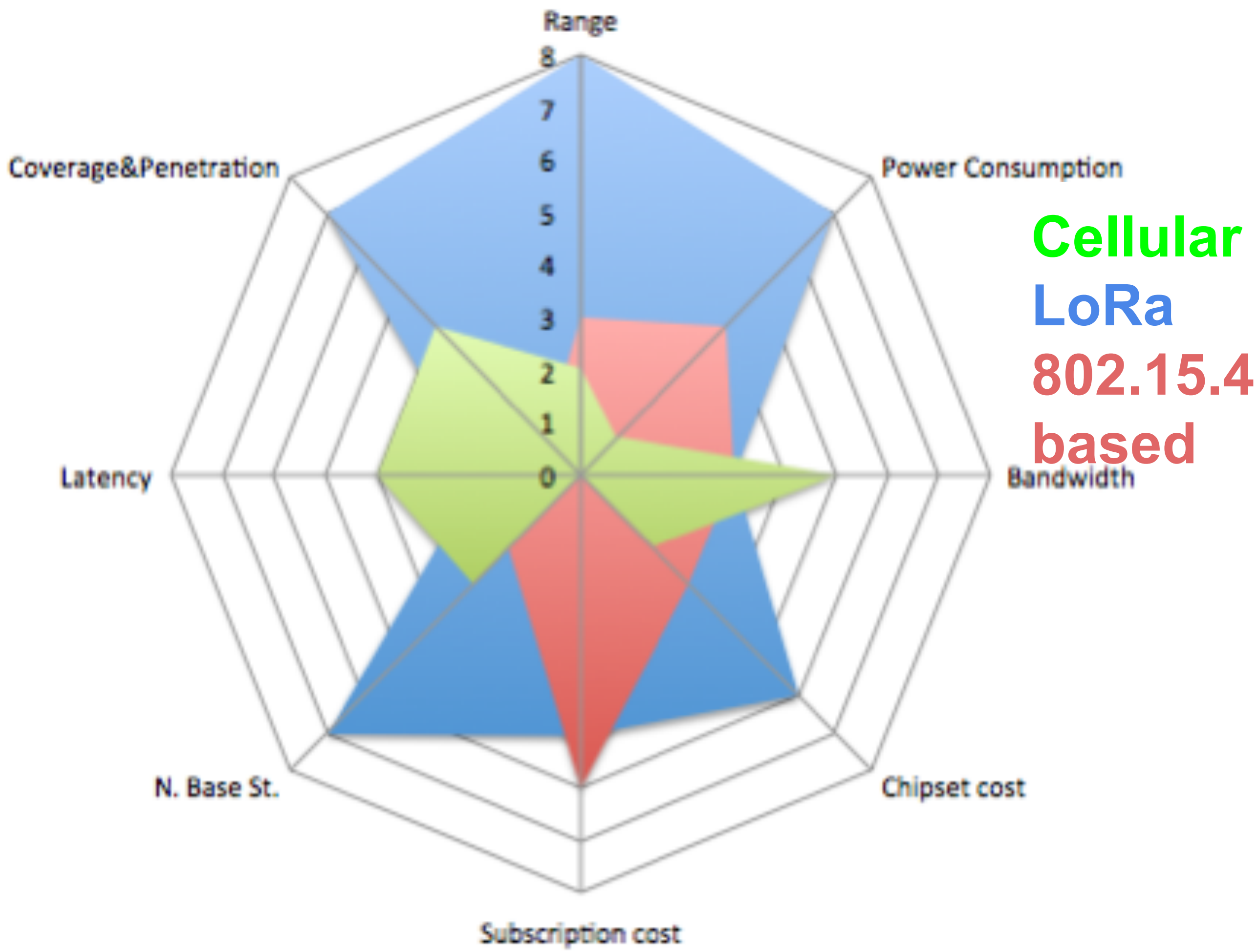
LoRa is strictly a physical layer, and is proprietary. Chip manufacturers include Semtech, Microchip and Hope RF.

LoRaWAN is an open standard promoted by the LoRa Alliance that adds the MAC and application layers that provide additional functionalities for managing medium access, security and so on.





Comparison of LPWAN solutions



Commercial solutions based on IoT LoRaWAN-buoys network to monitor the coral reefs

Connected buoys developed by Bioceanor in collaboration with EGM now make it possible to monitor the environment of coral reefs using data collected in real time.
Monitored parameters include temperature, salinity, turbidity and even certain pollutants.

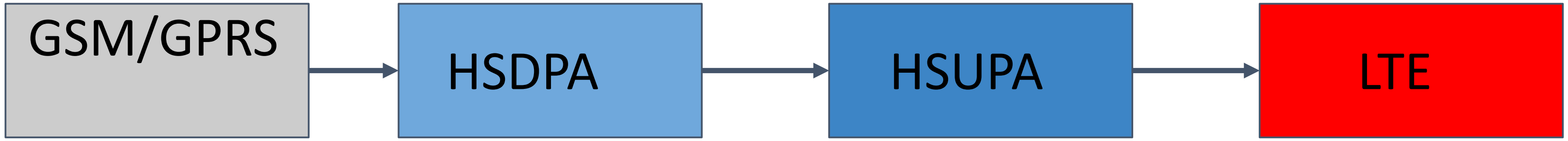
A box PC developed by Kontron acts as both a LoRaWAN-compatible IoT gateway and a network server. It converts the status information sent by these sensors into MQTT streams and enables continuous secure retrieval and remote analysis of this data. Assystem Pacifique and Easy Global Market teams integrated this networked LoRa system.

Cellular 3GPP

2G

3G

4G



Voice
14.4 kb/s

Voice
14.4 Mb/s
Packet
Switching

OFDM
VoIP
PTT
Backward compatibility

LTE: Long Term Evolution

Features:

- OFDM (Orthogonal Frequency Diversity Multiplex), improves spectrum efficiency and resistance to multipath impairments and interference.
- Completely IP (Internet Protocol) based, better integration with the dominant paradigm.
- First truly worldwide cellular standard.

Cellular revisited

The 3GPP response to the threat of LPWAN was addressed in Release 13 of the LTE standard, with 3 variants:

- EC-GSM (formerly EC-EGPRS)
- LTE-M
- NB-IoT

They differentiate in terms of bandwidth, data rate, latency and consumption to cover different needs and present a strong competition to the LPWAN vendors.

3GPP can benefit of existing direct ties with consumers and a well known, mature ecosystem.

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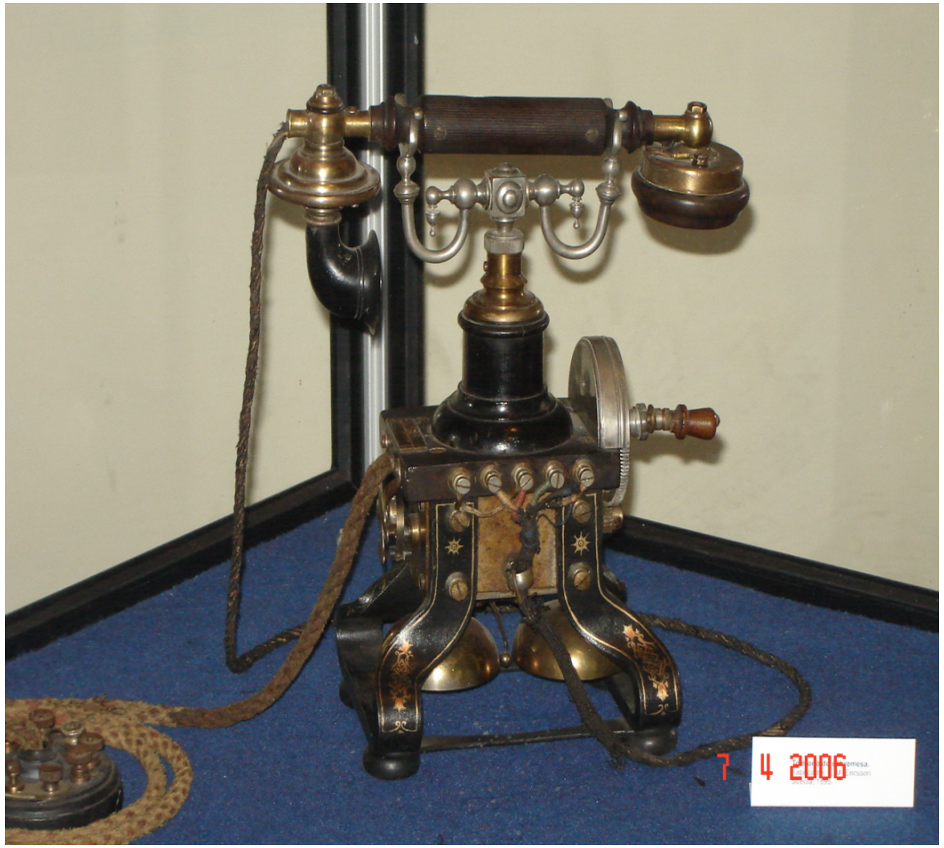
Power saving mode (PSM)

- Device stays registered with the network, thus avoiding having to reestablish its network connection.
- Uses the smallest possible amount of energy to run the Real Time Clock for keeping track of time and scheduled events.
- Negotiation of idle time between wake up, and then device stays available for a specified time (up to 1 year) before sleeping again.

A manually powered telephone



EC-GSM Release 13

- 20 dB increase in power budget compared with EGPRS
- Better power efficiency
- Reduced device complexity
- 200 kHz bandwidth

LTE-M (eMTC) Release 13

- High System capacity and reliability
- Low Latency
- Full or half duplex
- Supports both TDD and FDD
- Supports Voice/IP
- Limited or full mobility
- Power saving mode (PSM)
- Extended discontinuous receive (eDRx)

LTE-M (eMTC) Release 13

- Half duplex mode reduce the cost and complexity of the device because a duplexer filter is not needed
- Lower data rate of 1400 kb/s, 300 kbit/s downlink
- Extended discontinuous receive (eDRx) increases from seconds to minutes the amount of sleeping between paging cycles (periodic check in with the network).
- Compatible with existing LTE networks

Duplexer is a filter used to separate transmission from reception in FDD.

NB-IoT Release 13

Link budget of 164 dB is 20 dB better than that of GSM, offering improved penetration in buildings and basements while still conserving battery lifetime.

NB-IoT Release 13

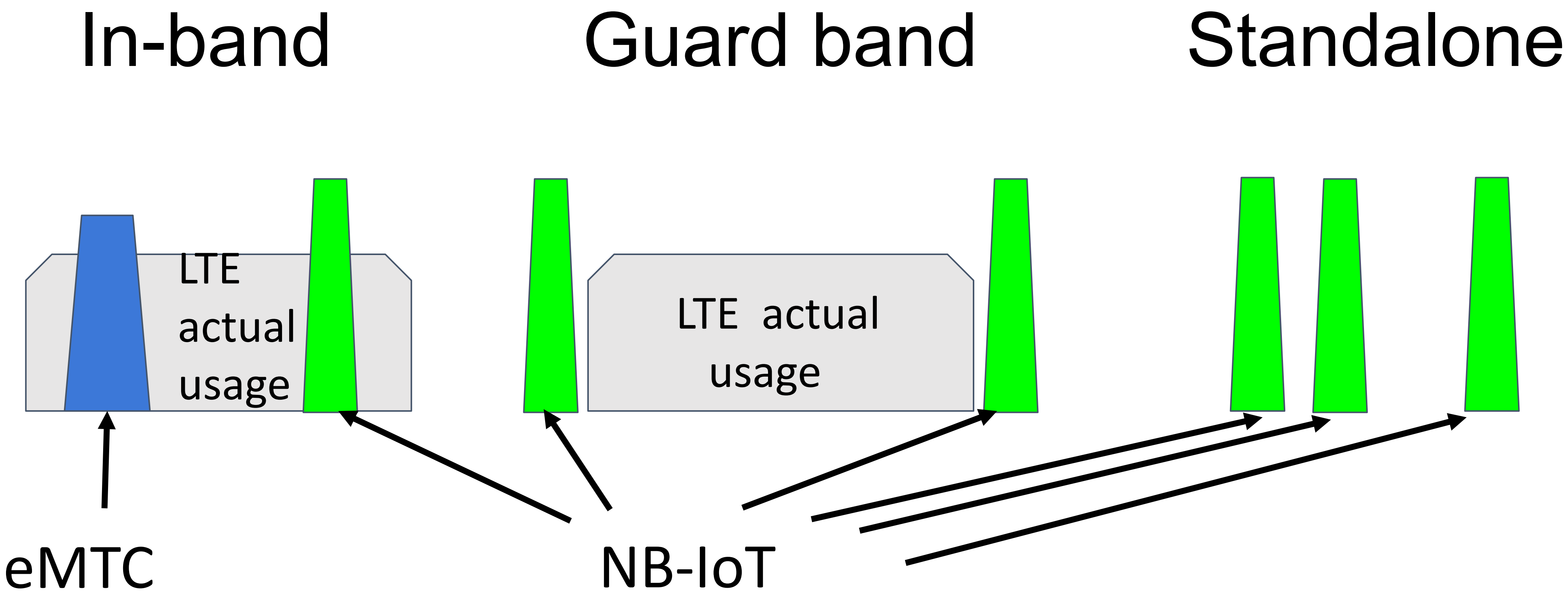
Meant for high system capacity that can accept delay and low throughput.

- Narrow band system, 200 kHz wide, can fit in the guard band of existing LTE systems.
- Higher power budget
- Long battery life and lower device complexity.
- No support for voice or mobility
- Cell reselection only
- Half duplex

NB-IoT Release 13

- Extended DRX (Discontinuous Reception Mode) cycles
- Downlink peak rate 300 bps to 200 kb/s with OFDMA
- Uplink peak rate 144 kb/s with SC-FDMA transmission, either single or multiple tone
- 164 dB power budget for greater range and building penetration achieved by:
  - Bandwidth reduction to 200 kHz
  - Redundant transmissions by frame repetition
  - Usage of robust modulation schemes (QPSK instead of 16-QAM)

Spectrum flexibility (Release 13)



Quiz

Use Shannon's channel capacity formula:

$C=B\log_2(1+S/N)$

to explain each of the three mechanisms employed to achieve a power budget increase of 20 dB with respect to former releases of the standard.

3GPP data

	LTE cat 0	LTE cat M1 (eMTC)	LTE cat NB1 (NB IoT)	EC-GPRS	LTE cat 1	GSM 900
DL BW	20 MHz	1.4 MHz	180 kHz	200 kHz	20 MHz	200 kHz
UL BW	20 MHz	1.4 MHz	180 kHz	200 kHz	20 MHz	200 kHz
DL Peak rate	1 Mb/s	1 Mb/s	250 kb/s	10 kb/s	10 Mb/s	22.8 kb/s
UL Peak rate	1 Mb/s	1 Mb/s	250 kb/s (Multitone) 20 kb/s (Single tone)	10 kb/s	5 Mb/s	22.8 kb/s
Duplex	half or full	half or full	half	half	full	full

Repetitions in NB-IoT

- Every repetition increases the coverage by 3dB assuming ideal channel estimation and TX/RX chain. However, latency experienced by the application is doubled, throughput and spectral efficiency are sliced to half.
- Achieve extra coverage (up to 20 dB compared to GPRS)
- Each repetition is self-decodable
- Repetitions are ACK-ed just once
- DL up to 2048 repetitions
- UL up to 128 repetitions

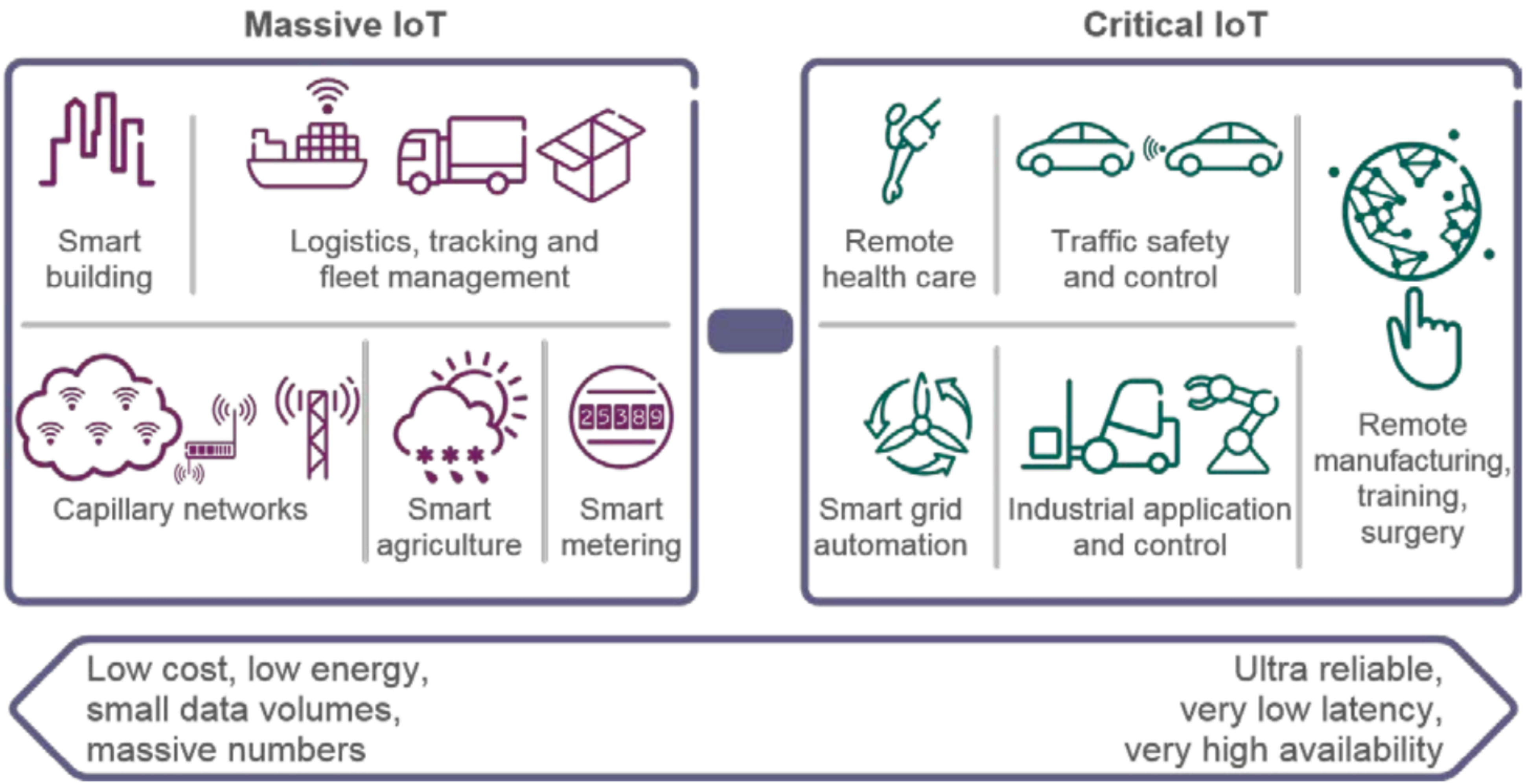
Beyond 4G

Release 14 brings single-cell multicast for easy over-the-air firmware upgrades and device positioning for asset location tracking

•Release 15 introduces Time Division Duplex (TDD) support for NB-IoT, as well as a new wake-up receiver design to allow for even better energy efficiency

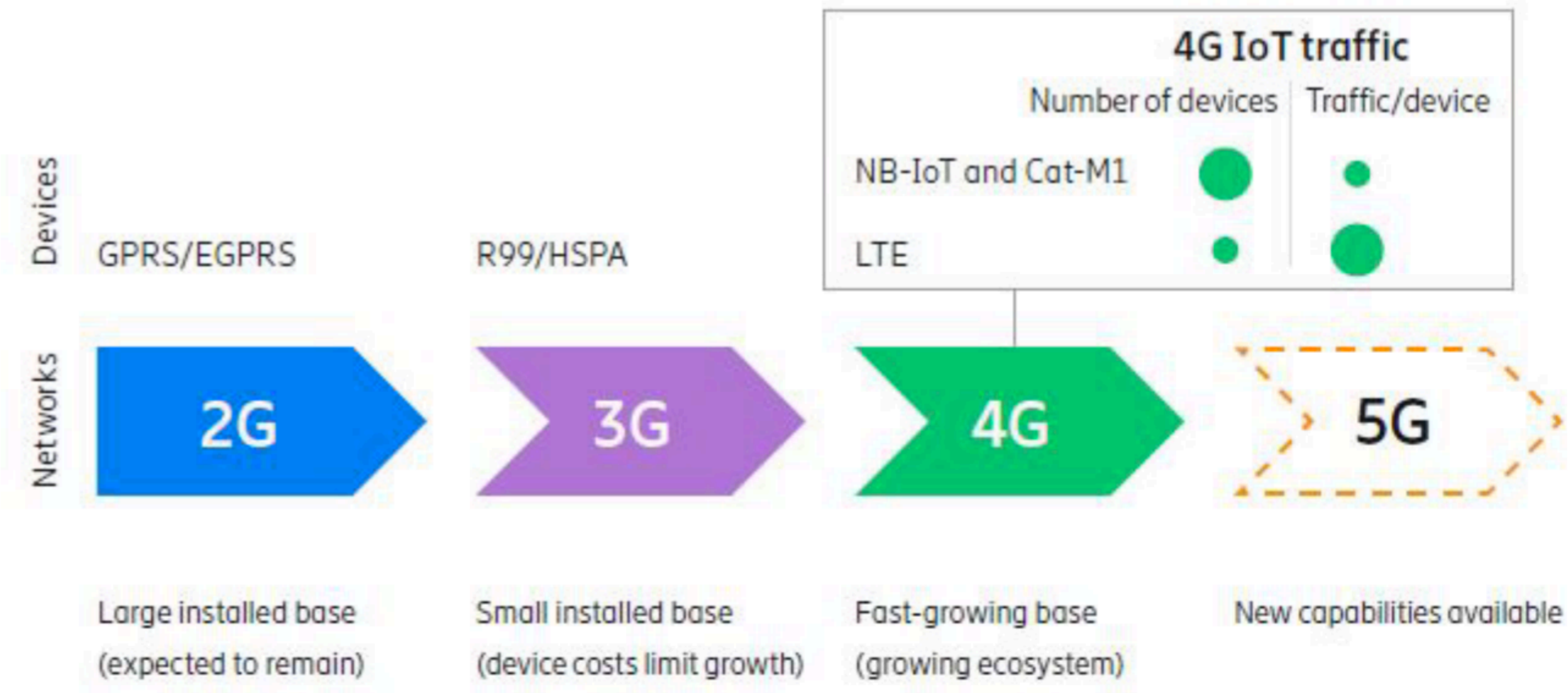
•Release 16 offers enhancements for both LTE IoT and 5G NR IoT such as grant-free uplink that allow IoT devices to send sporadic small data bursts to the network without scheduling, reducing overhead for more efficient handling of IoT communication. Another feature is mesh networking with Wide Area Network (WAN) management, which helps with extending range and optimizing device cost.

Massive or Critical IoT



https://www.5gamericas.org/wp-content/uploads/2019/07/5G_Americas_White_Paper_on_5G_IOT_FINAL_7.16.pdf

Evolution of cellular networks supporting IoT traffic growth



https://www.5gamericas.org/wp-content/uploads/2019/07/5G_Americas_White_Paper_on_5G_IOT_FINAL_7.16.pdf

A rich roadmap of enhancements in 3GPP Rel-14 & 15

eMTC

Enhancing VoLTE[1]
For wearables to more efficiently handle voice in half-duplex mode

Better mobility
Full support for inter-frequency measurements[1] and higher velocity in extended coverage[2]

eMTC and NB-IoT

Single-cell multicast[1]
Efficient OTA firmware update for large number of devices

Lower latency
More HARQ processes[1], faster system acquisition[2], early data transmission[2]

Device positioning[1]
Providing location services for e.g., asset tracking and eCall

Energy reduction
Wake-up radio for low-power channel monitoring[4] and lower transmit power classes[5]

Higher data rate[1]
Supporting wider bandwidth, e.g., 5 MHz, and more[3]

Higher density support[2]
Improved load control with level-based access class barring

NB-IoT

Cell size extension[2]
Additional cyclic prefixes to support cell radius of at least 100km

TDD support[2]
For deployment in higher TDD bands, also further optimizing for small cells

5G

Release 14 and 15 enhancements

https://www.qualcomm.com/media/documents/files/leading-the-lte-iot-evolution-to-connect-the-massive-internet-of-things.pdf

QUIZ

What are the main trade-offs that have been made in low power long range networks in order to improve battery lifetime and extend range?

What are the advantages that cellular based solutions can offer with respect to LPWAN for IoT applications?

Conclusions I

- Both standards and proprietary solutions for IoT will continue to thrive.
- WPAN are dominated by IEEE 802.15.4 based technologies.
- Currently LPWAN have a greater market share of IoT deployments, with LoRa and Sigfox leading.
- 3GPP based networks should become stronger competitors due to the advantages derived from the existing Cellular installations

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Conclusions II

- IoT requires specific solutions.
- Legacy cellular technologies not efficient.
- Cellular based on Release 13 address most of the shortcomings but the cost is high and availability limited.
- WiFi, Zigbee and BLE have limited range.
- Several vendors offer alternatives.
- LoRa and SigFox are widely used worldwide for long distance for limited data rate applications.
- LoRaWAN can be leveraged to build your own LPWAN infrastructure.

Wireless.ictp.it

This is our web site, with plenty of information and downloadable training materials, free to use and customize to your own application