Communication Options for IoT

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Parameters

When considering communications options, parameters to be taken into account are:

Range
Multihop capabilities
Battery consumption
Security
Cost (device)
Cost (service)
Availability
Regulation

IoT specific case

IoT nodes can accept:

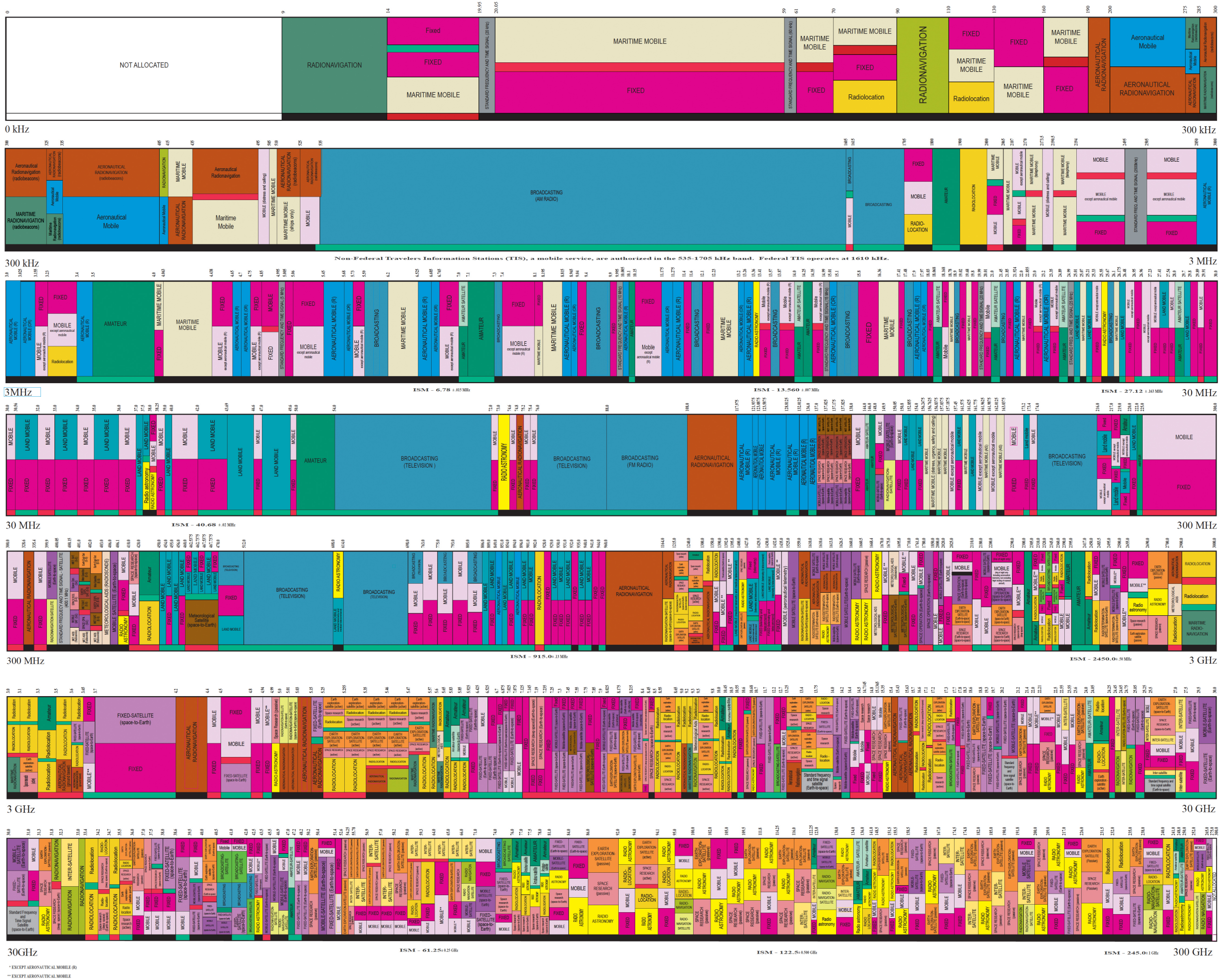
Low throughput, for many applications

Delays

Long Sleeping times

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- INTER-SATELLITE
- RADIO ASTRONOMY
- AERONAUTICAL MOBILE SATELLITE
- LAND MOBILE
- RADIODETERMINATION SATELLITE
- AERONAUTICAL RADIONAVIGATION
- LAND MOBILE SATELLITE
- RADIOLOCATION
- AMATEUR
- MARITIME MOBILE
- RADIOLOCATION SATELLITE
- AMATEUR SATELLITE
- MARITIME MOBILE SATELLITE
- RADIONAVIGATION
- BROADCASTING
- MARITIME RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- BROADCASTING SATELLITE
- METEOROLOGICAL
- SPACE OPERATION
- EARTH EXPLORATION SATELLITE
- METEOROLOGICAL SATELLITE
- SPACE RESEARCH
- FIXED
- MOBILE
- STANDARD FREQUENCY AND TIME SIGNAL
- FIXED SATELLITE
- MOBILE SATELLITE
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- FEDERAL EXCLUSIVE
- FEDERAL/NON-FEDERAL SHARED
- NON-FEDERAL EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

JANUARY 2016

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PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

ISM bands

Industrial, **S**cientific and **M**edical Radio Bands

ISM Band Frequencies
6.765 - 6.795 MHz
13.553 - 13.567 MHz
26.957 - 27.283 MHz
40.66 - 40.70 MHz
83.996 - 84.004 MHz
167.992 - 168.008 MHz
433.05 - 434.79 MHz
886 - 906 MHz
2.400 - 2.500 MHz
5.725 - 5.875 MHz
24.0 - 24.25 GHz
61.0 - 61.5 GHz
122 - 123 GHz
244 - 246 GHz

Options

We will consider the following options for IoT communications:

- Zigbee
- RFID
- Bluetooth and BLE (Bluetooth Low Energy)
- WiFi
- Cellular based
- Satellite
- LPWAN

Zigbee

This standard defines a communication layer at **level 3** and upper in the OSI model. Its main purpose is to create a **network topology** (hierarchy) to let a number of devices communicate among them and to set extra communication features such as authentication, encryption, association and in the upper layer application services.

It was created by a set of companies which form the ZigBee Alliance.

Zigbee

Channels:

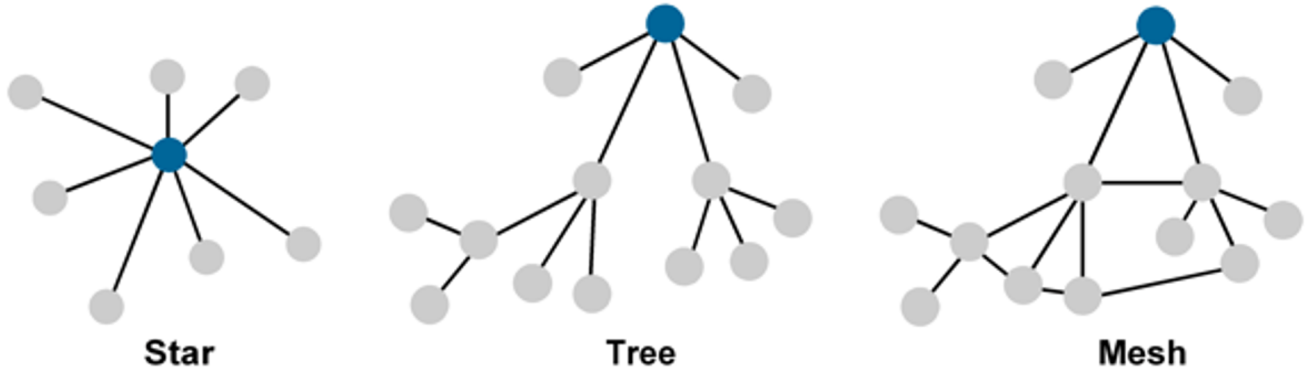
868.0 - 868.6MHz -> 1 channel (Europe, India)
902.0-928.0MHz -> 10 channels (USA)
2.40-2.48GHz -> 16 channels (Worldwide)

Bit Rates:

868.0 - 868.6MHz -> 20/100/250 Kb/s
902.0-928.0MHz -> 40/250 Kb/s
2.40-2.48GHz -> 250 Kb/s

Zigbee – node types

Co-ordinator: all ZigBee networks must have one (and only one) Co-ordinator



Zigbee

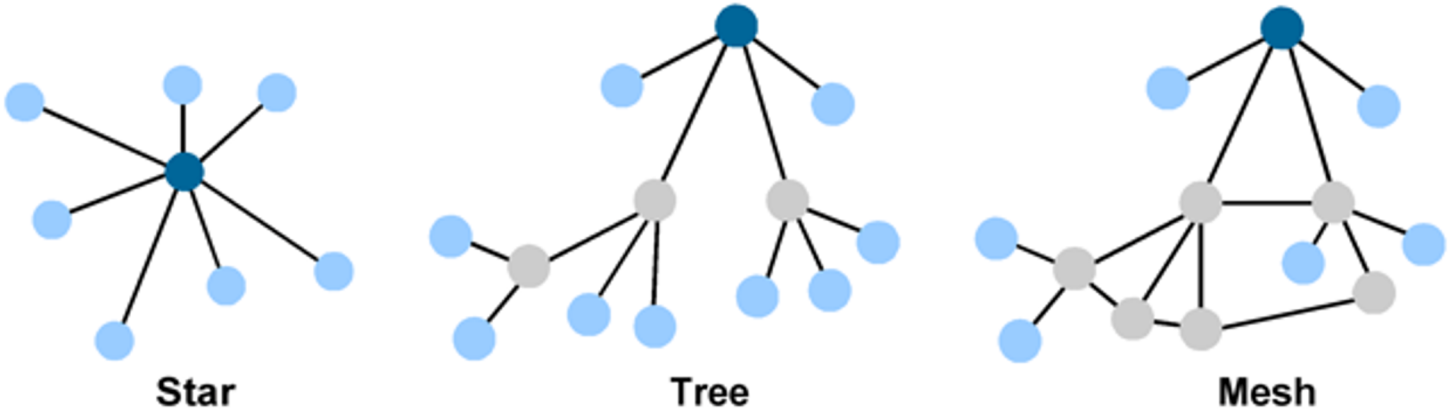
The **tasks of the Co-ordinator** at the network layer are:

1. Selects the **frequency** channel to be used by the network (usually the one with the least detected activity)
2. Starts the network
3. Allows other devices to connect to it (that is, to join the network.

The Co-ordinator can also provide message routing (for example, in a Star network), security management and other services.

Zigbee – node types

End Devices are always located at the extremities of a network:



Zigbee

The main **tasks of an End Device** at the network level are sending and receiving messages. Note that End Devices cannot relay messages and cannot allow other nodes to connect to the network through them.

An End Device can often be battery-powered and, when not transmitting or receiving, can sleep in order to conserve power.

Zigbee – node types

Networks with Tree or Mesh topologies need at least one **Router.**

Zigbee – characteristics

Range	10m
Multihop capabilities	yes
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

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

RFID

Used in shops to expedite check out, automate inventory control and for theft prevention.

Embedded in passports and in even in animals.

May be read only, like for inventory control applications, or writeable for more advanced ones.

Have been implanted in humans.

RFID

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

RDIF – characteristics

Range	1m
Multihop capabilities	no
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

Bluetooth

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.

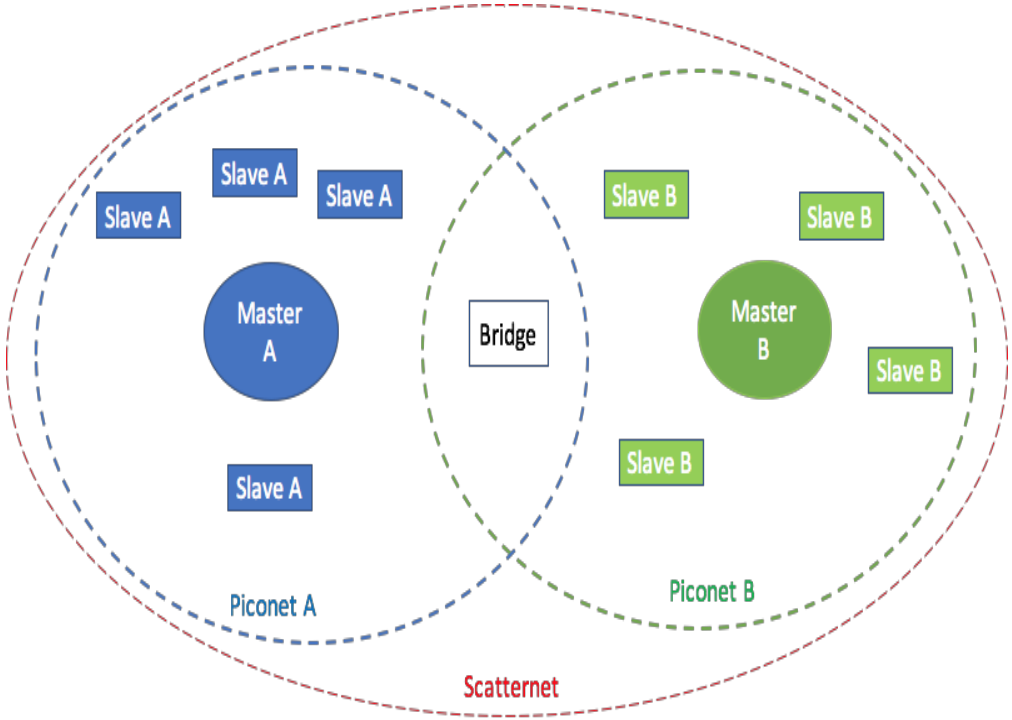
Bluetooth architecture

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 architecture



Bluetooth Low Energy (BLE)

Subset of Bluetooth 4.0, but stemming from an independent Nokia solution.

Smart Mesh.

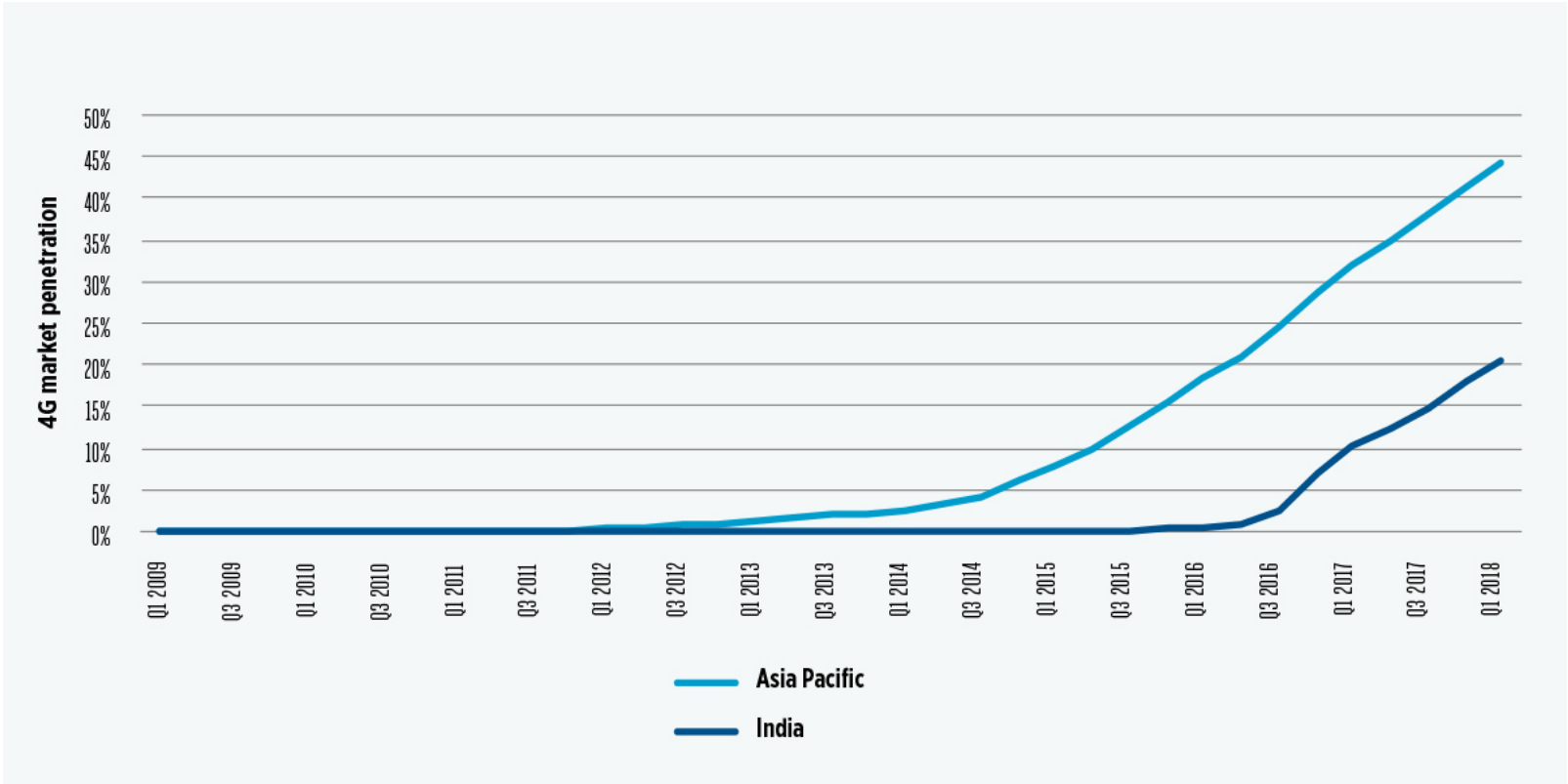
40 channels 2 MHz wide and frequency hopping to combat interference.

Used in smartphones, tablets, smart watches, health and fitness monitoring devices.

Bluetooth – characteristics

Range	10m
Multihop capabilities	no
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

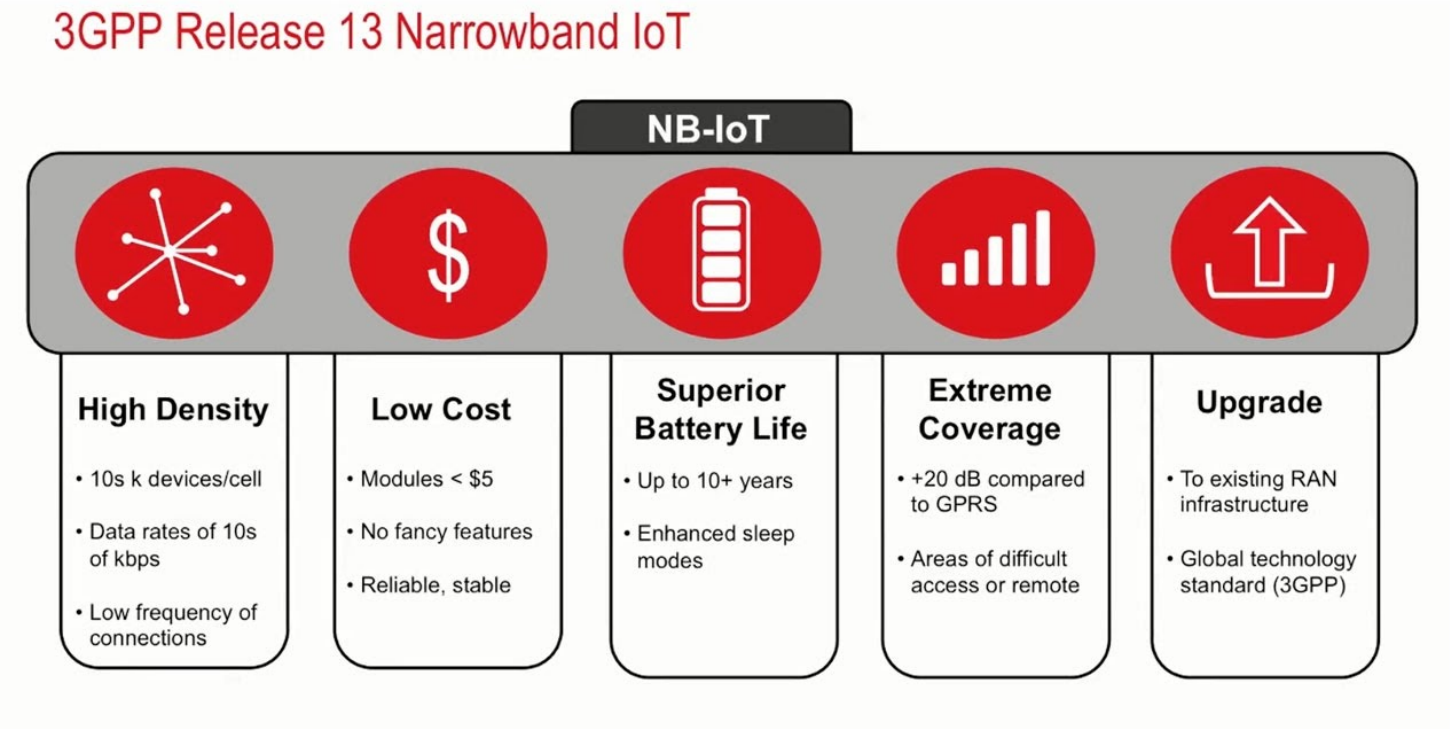
GSM in India


4G market penetration
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Q1 2009
Q3 2009
Q1 2010
Q3 2010
Q1 2011
Q3 2011
Q1 2012
Q3 2012
Q1 2013
Q3 2013
Q1 2014
Q3 2014
Q1 2015
Q3 2015
Q1 2016
Q3 2016
Q1 2017
Q3 2017
Q1 2018
Asia Pacific
India

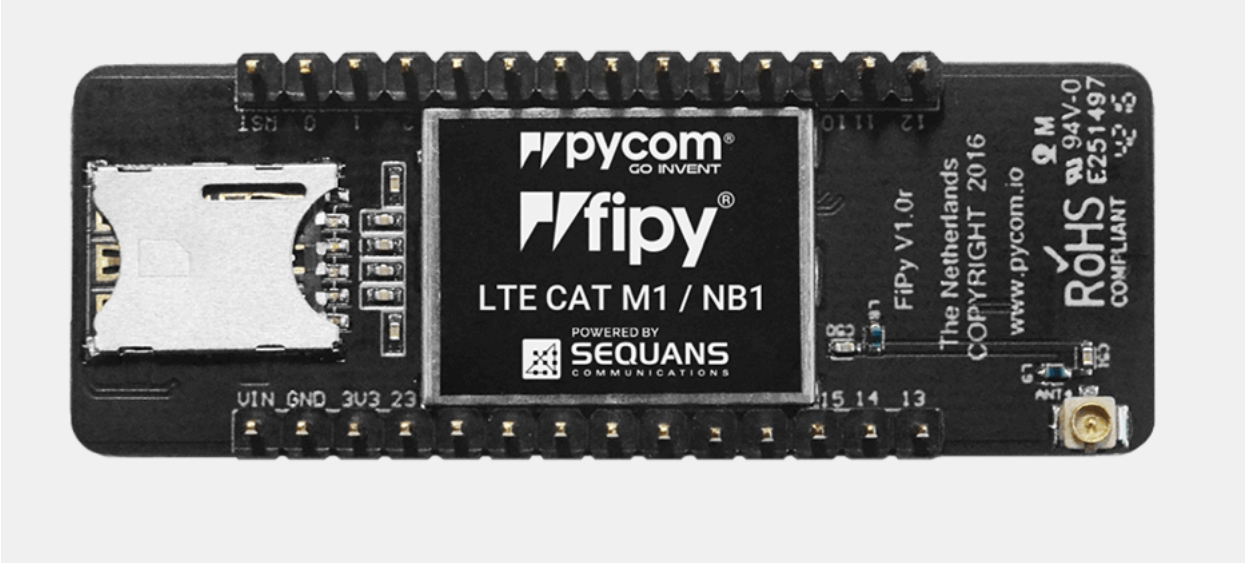
3GPP

	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

3GPP


3GPP Release 13 Narrowband IoT
NB-IoT
High Density
• 10s k devices/cell
• Data rates of 10s of kbps
• Low frequency of connections
Low Cost
• Modules < $5
• No fancy features
• Reliable, stable
Superior Battery Life
• Up to 10+ years
• Enhanced sleep modes
Extreme Coverage
• +20 dB compared to GPRS
• Areas of difficult access or remote
Upgrade
• To existing RAN infrastructure
• Global technology standard (3GPP)

FiPy


pycom
GO INVENT
fipy
LTE CAT M1 / NB1
POWERED BY
SEQUANS
COMMUNICATIONS
FiPy V1.0r
The Netherlands
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RoHS
COMPLIANT
E251497
94V-0
VIN_GND_3V3_23
15_14_13

GSM – characteristics

Range	infinite
Multihop capabilities	no
Battery consumption	medium
Security	yes
Cost (device)	medium
Cost (service)	high
Availability	good
Regulation	good

WiFi

Credit: WiFi Aliance

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
Frequenc y 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.

WiFi – characteristics

Range	1km
Multihop capabilities	no
Battery consumption	mid
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

Satellite

Iridium 9603

Power

- Supply input voltage range: 5.0V +/- .5V DC
- Supply input voltage ripple: <40mV pp
- Idle Current (peak): 156mA
- Idle Current (average): 34mA
- Transmit Current (peak): 1.3A
- Transmit Current (average): 145mA
- Receive Current (peak): 156mA
- Receive Current (average): 39mA
- SBD message transfer – average current: 158mA
- SBD message transfer – average power: <= 0.8 W

Satellite

Bundle	per Credit	Bundle Price
100 Credits	£0.11	£11.00
200 Credits	£0.10	£20.00
500 Credits	£0.09	£45.00
1000 Credits	£0.08	£80.00

Satellite – characteristics

Range	infinite
Multihop capabilities	no
Battery consumption	high
Security	no
Cost (device)	medium
Cost (service)	medium
Availability	low
Regulation	poor

LPWAN

LPWAN

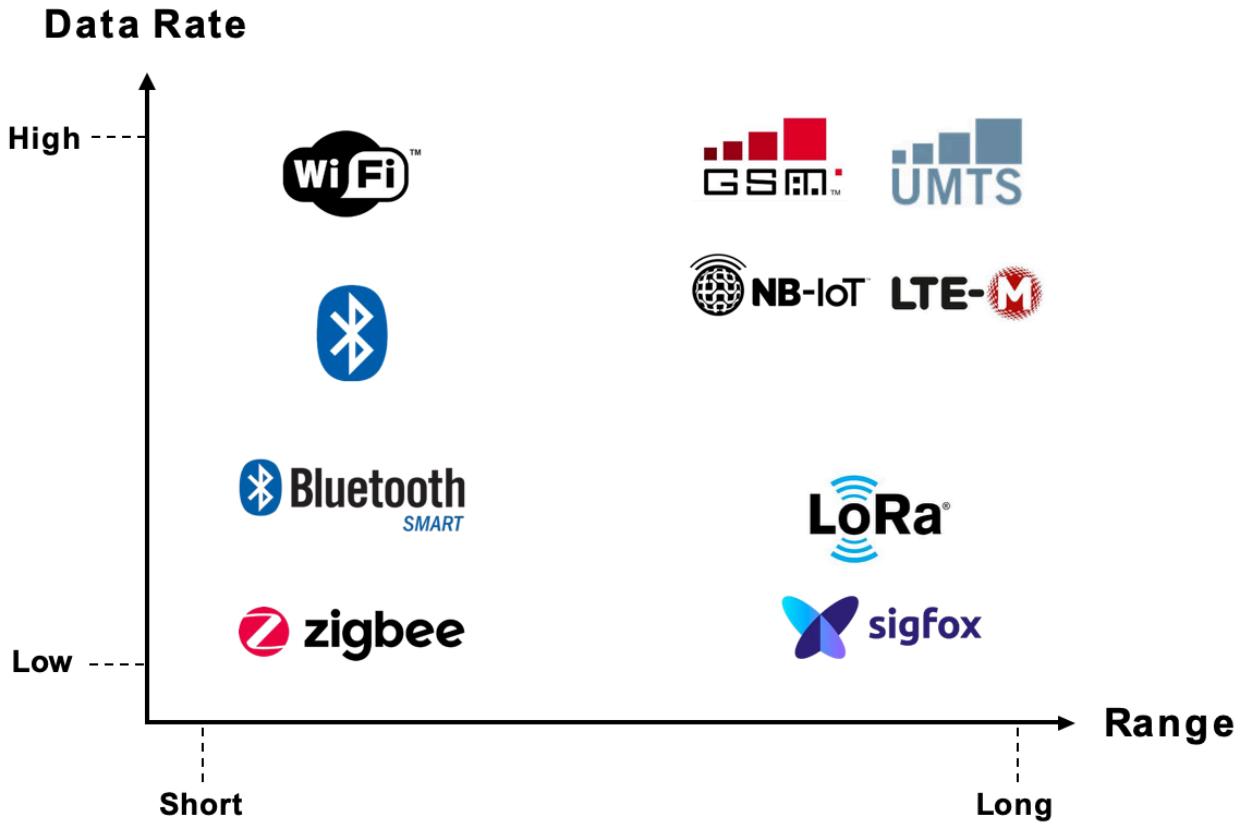
Low Power, Wide Area Networks

Connectivity designed specifically for IoT
Low data throughput = High sensitivity = Long range

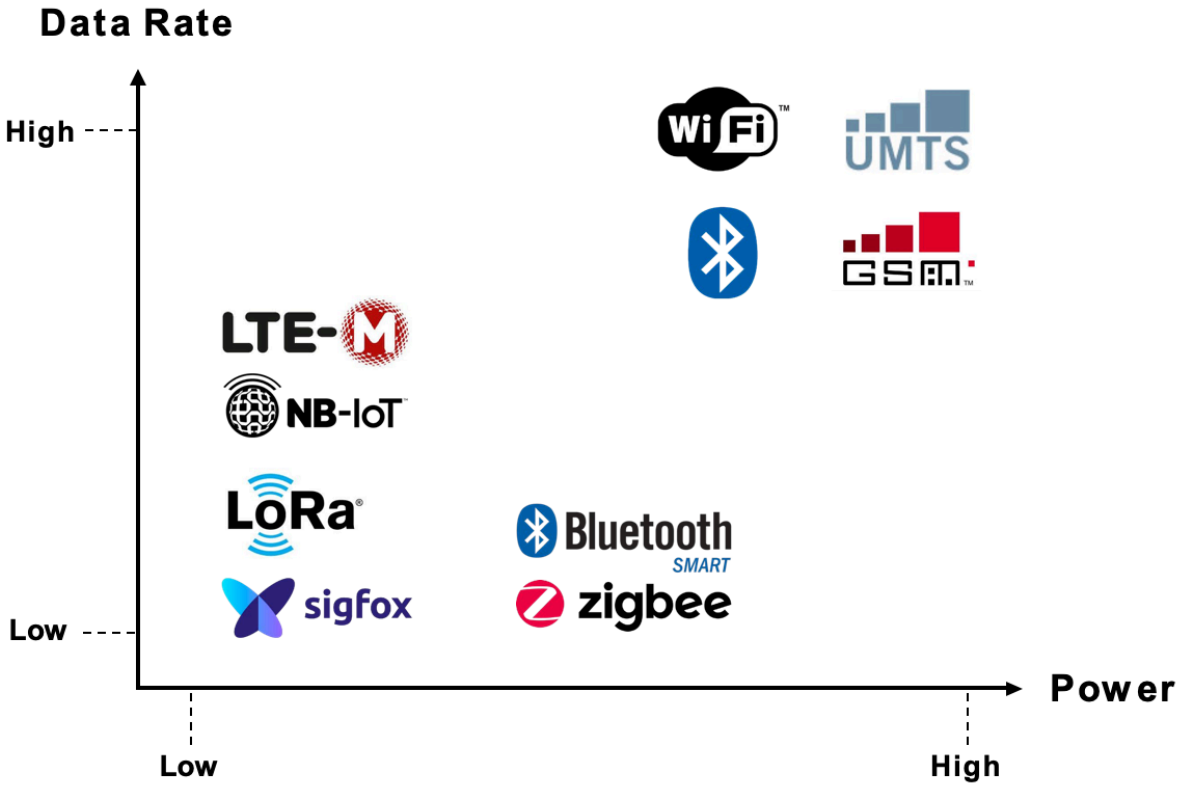
(Relatively) low cost

Using licensed or unlicensed spectrum

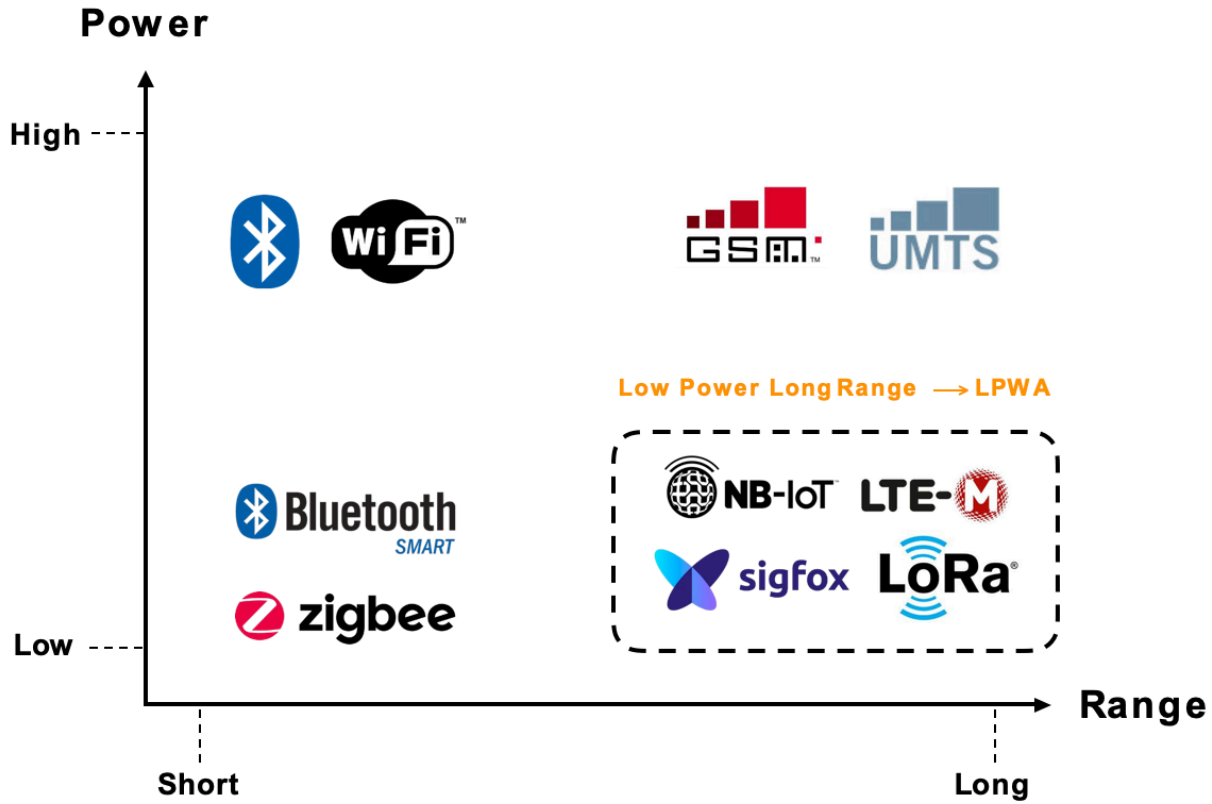
LPWAN


Data Rate
High
Low
Short
Long
Range
Wi Fi
GSM
UMTS
NB-IoT
LTE-M
Bluetooth
SMART
LoRa
zigbee
sigfox

LPWAN


Data Rate
High
Low
Low
High
Power
Wi Fi
UMTS
GSM
LTE-M
NB-IoT
LoRa
sigfox
Bluetooth
SMART
zigbee

LPWAN


Power
High
Low
Short
Long
Range
Low Power Long Range ⟶ LPWA
Bluetooth SMART
zigbee
NB-IoT
LTE-M
sigfox
LoRa
GSM
UMTS

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.

Mobility restricted to 6 km/h.

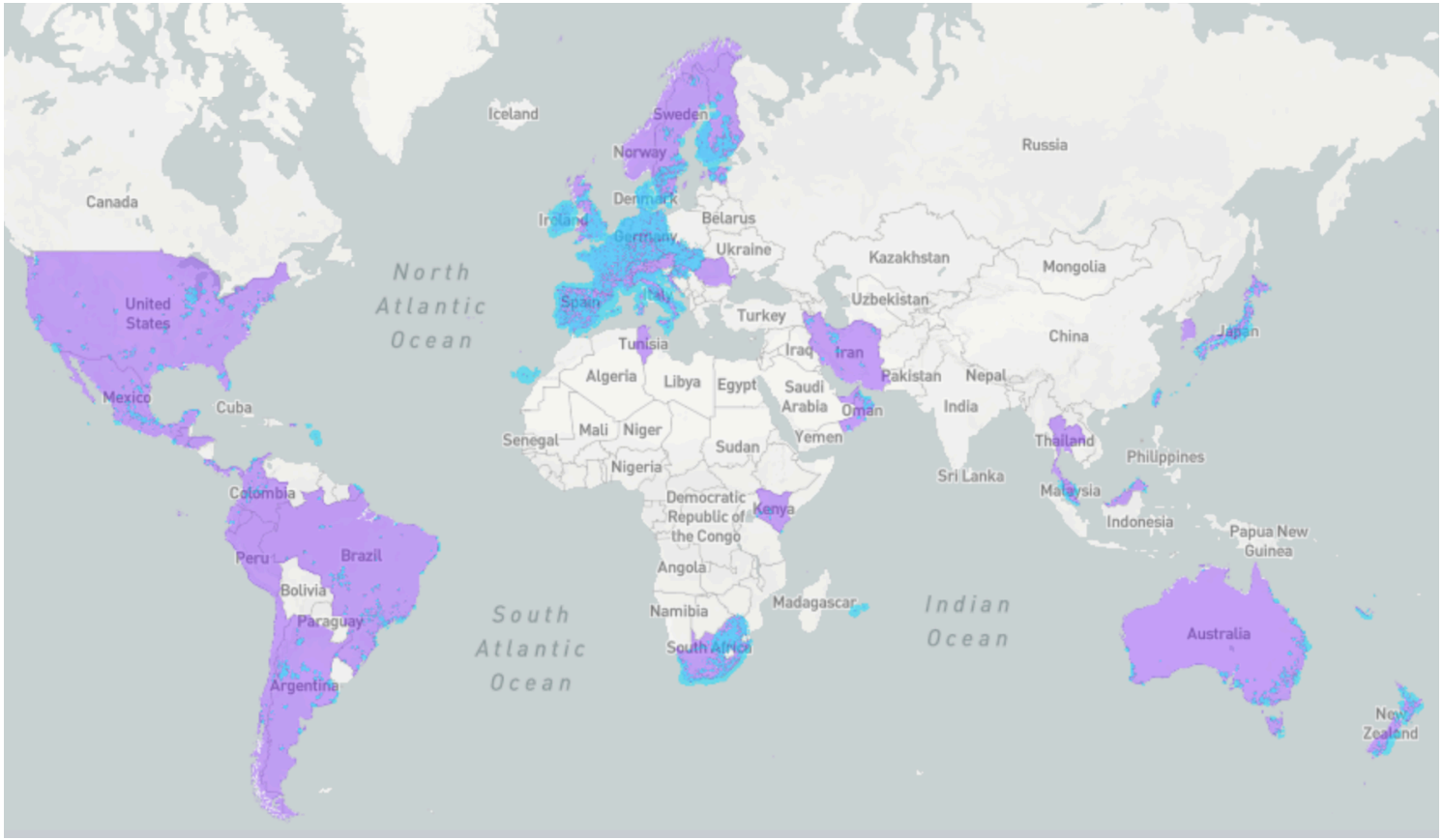
Sigfox

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.

Sigfox coverage



Sigfox – characteristics

Range	10km
Multihop capabilities	no
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	low
Availability	low
Regulation	good

What is LoRa

Wireless modulation technology, based on Semtech's proprietary Chirp Spread Spectrum (CSS)

Physical (PHY) layer for long range wireless communications
Operates in the license-free Industrial Scientific Medical (ISM) bands all around the world

Based on spread spectrum, trading bandwidth for S/N.

What is LoRa

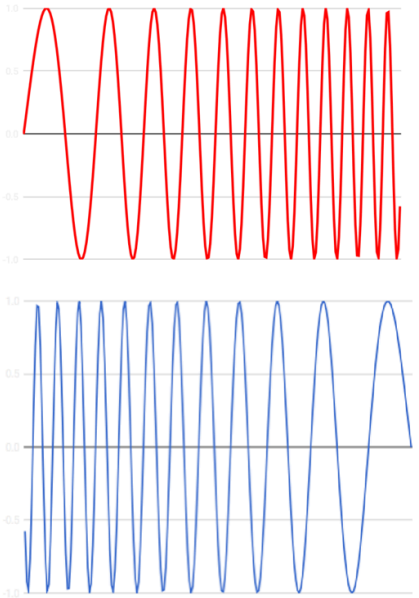
Sub-GHz frequency, e.g: 433, 868, 915 MHz, depends on the country's regulation

Regulated power, duty-cycle, and bandwidth.

E.g: in EU, **1%** per sub-band duty-cycle limitation (per hour, meaning transmission is allowed for 36 sec in each 1 hour)

LoRa modulation

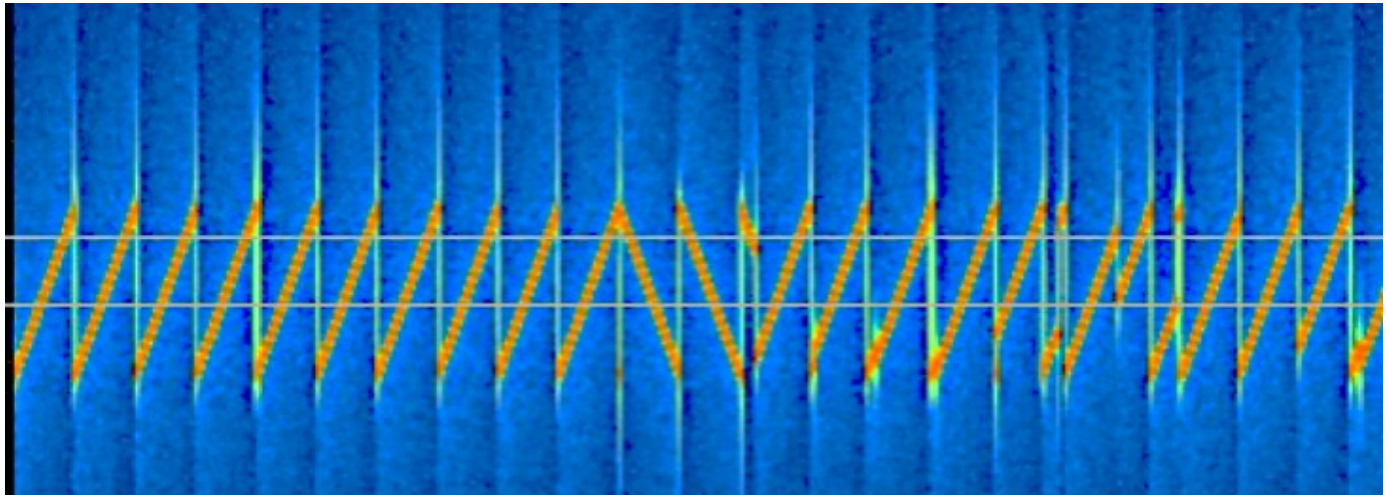
Uses linearly varying frequency pulses called "**chirps**" inspired in radar signals.



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

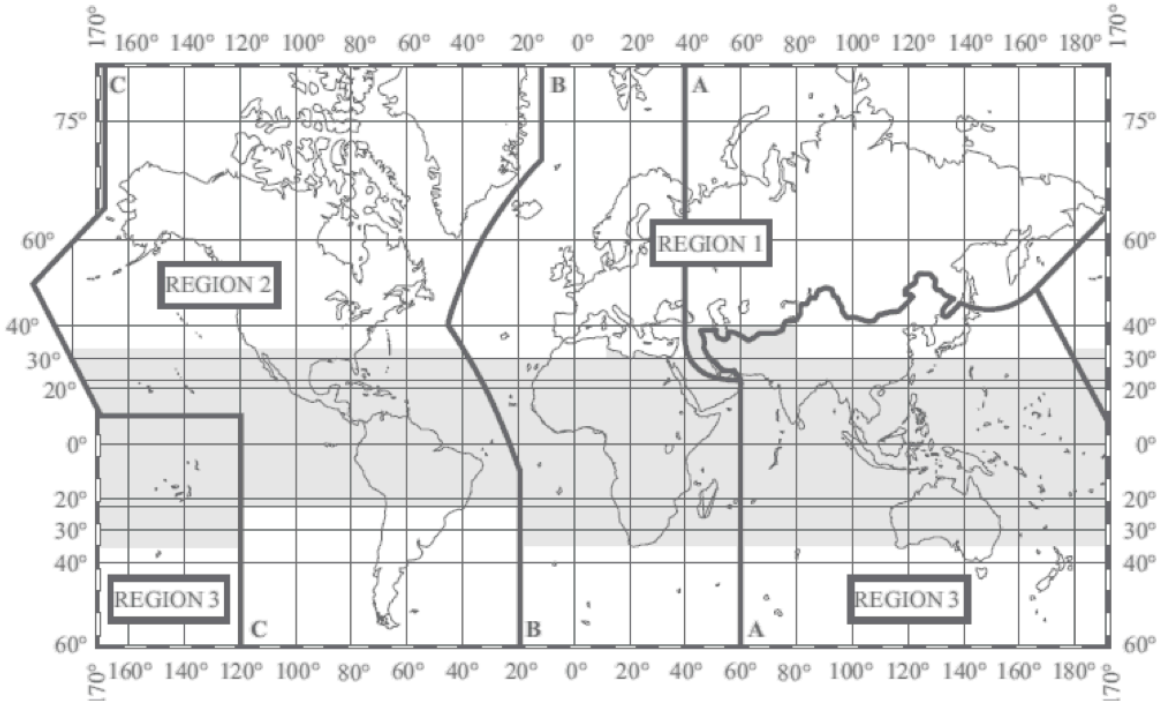
Data: information transmitted by the instantaneous frequency transitions

LoRa physical layer consists of many parameters which can be configured into 6720 different settings!

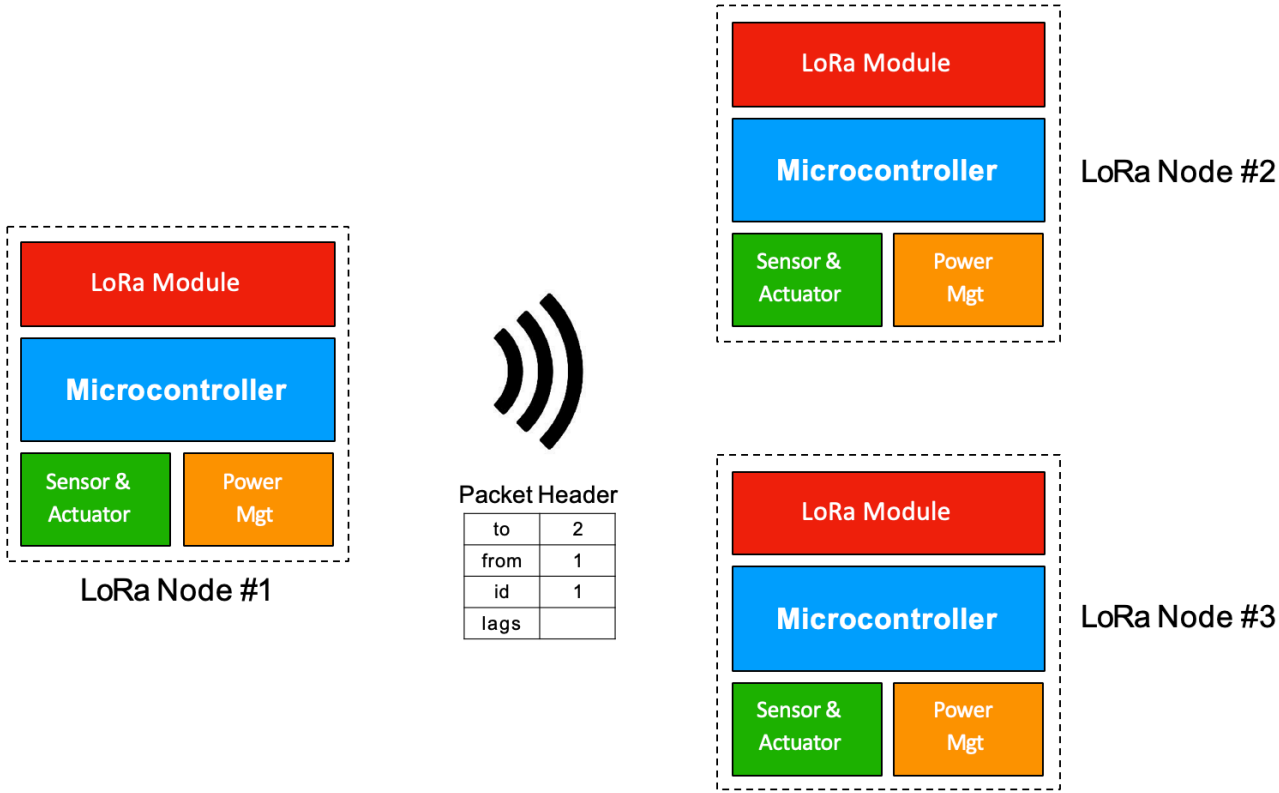
SeRing	Values	DeSnition	ETects
Bandwidth	125, …„500 kHz	Width of spectrum occupied by chirp	A higher bandwidth is required for transmiRing data at high rates (1 kHz = 1kcps). However, increasing this parameter decreases the communication range and sensitivity.
Spreading Factor	2^6, …„2^{12} chips/ symbol	Number of bits encoded per symbol. Symbol is RF state representing some quantity of information. SF12 means 2^{12} chips/symbol, 12 bits of data	A higher spreading factor (*SF*) increases the communication range, radio sensitivity, and the signal-to-noise ratio (SNR). However, energy consumption consequently increases.
Coding Rate	1,…„4 or 4/5, …„4/8	Propoaion of transmiRed bits that caries actual data, as opposed to error correction bits. CR1 · 4/(4+1) = 4/5	Bigger coding rates increase the protection against decoding errors and intecerence bursts at the expense of longer packets, longer air time, and higher power consumption.
Transmission Power	−4, …„20 dBm	Transmission power can be adjusted from −4 to 20 dBm, in 1dB steps. Because of hardware implementation limits, the range is o<en limited to 2 to 20 dBm.	The signal-to-noise ratio is increased by increasing the transmission power at the cost of energy expenditure.
Carrier Frequency	137,…„1020 MHz	CF represents the central transmission frequency used in a band, can be programmed between 137 MHz to 1020 MHz, in steps of 61 Hz.	Lower frequency enables to achieve higher communication ranges for the same transmission power. However, selected CF needs to comply with country's regulation.

LoRa frequency bands

Countries	Frequency band review	Max. output power
EU	868 MHz	14 dBm
USA	915 MHz	20 dBm
Korea	900 MHz	14 dBm
Japan	920 MHz	
Malaysia	862 to 875 MHz	20 dBm
Philippines	868 MHz	
Vietnam	920 to 925 MHz	
India	865 to 867 MHz	
Singapore	922 MHz	
Thailand	920 to 925 MHz	
Indonesia		
ANZ	915 to 928 MHz	
Taiwan	920 to 925 MHz	
China	470 to 510 MHz	17 dBm



LoRa nodes


LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #1
Packet Header
to 2
from 1
id 1
lags
LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #2
LoRa Module
Microcontroller
Sensor & Actuator
Power Mgt
LoRa Node #3

What is LoRaWAN

Communications protocol and architecture utilizing the LoRa physical layer

Open Source and freely available, specified by LoRa Alliance

Star of Starts Topology. **Nodes connect to multiple gateways**

What is LoRaWAN

Adaptive Data Rate (ADR) to improve performance

Built-in multiple levels of security: network or application level encryption, frame counter, etc

LoRaWAN end device/mote

Communicates with LoRaWAN gateways, never directly with other motes.

Has 64 bit globally unique identifier: **DevEUI**.

When joining a network, it receives a 32 bit unique identifier: DevAddr.

Defined 3 device classes: A, B, and C

LoRaWAN device classes

Class A

Device-initiated communication; lowest power

Devices are typically in deep sleep and send messages on intervals and/or events

After uplink transmission, device opens two receive windows at specified times for downlink messages

Best fit for most battery-powered sensor applications

Class B

Time-synchronized communication, deterministic downlink

Extend Class A by adding scheduled receive windows for downlink messages from backend

Using time-synchronized beacons transmitted by the gateway, the devices periodically open receive windows

Best for most downlink intensive applications

Class C

Network-initiated communication; lowest latency

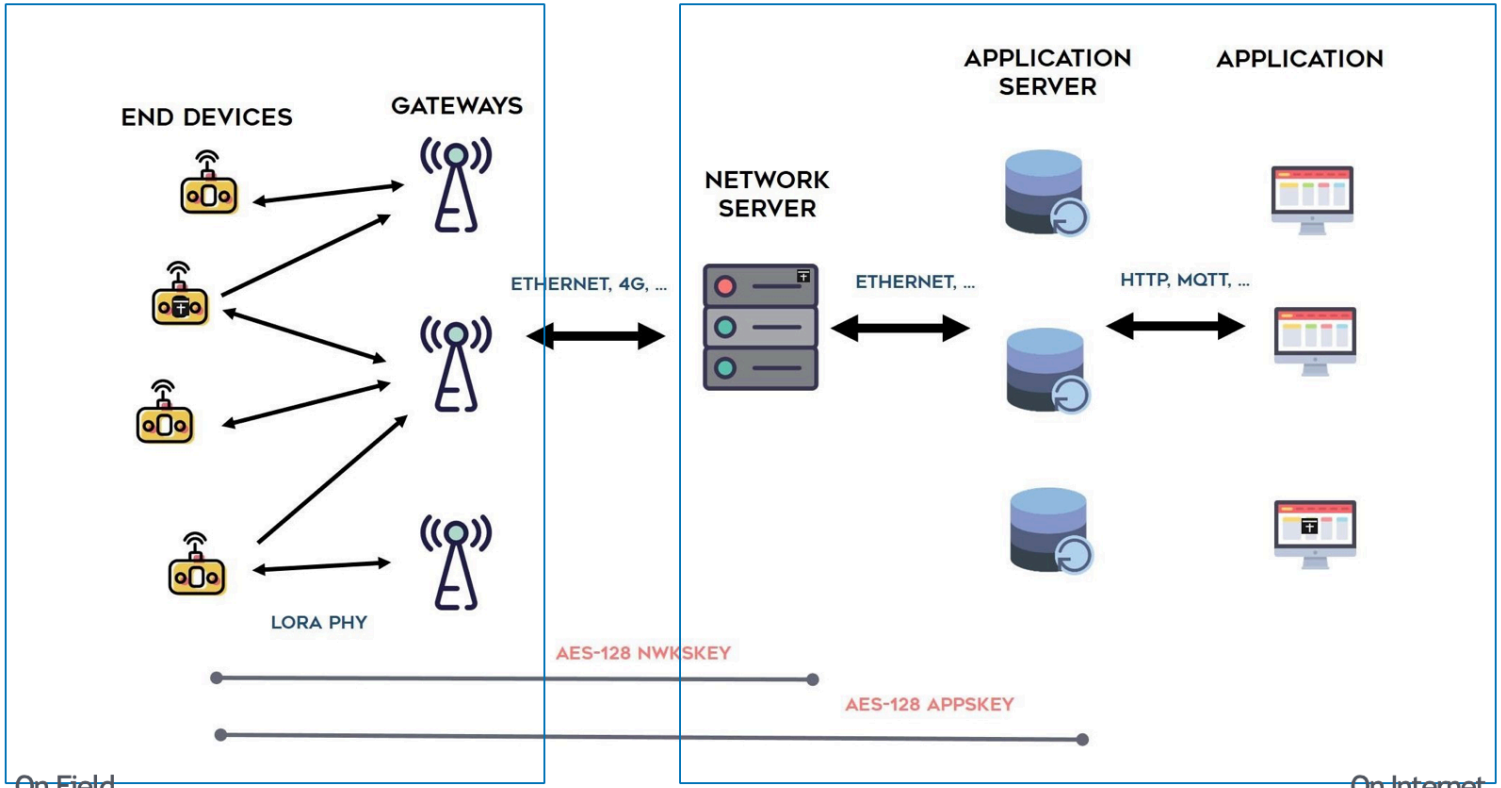
Extend Class A by keeping the receive windows open unless uplink-transmitting

The backend can send downlink message at any given time

Best for downlink intensive applications that require low latencies, non battery-powered

ICTP

LoRaWAN architecture



Source: http://www.frugalprototype.com/technologie-lora-reseau-lorawan/

LoRaWAN products

LoRaWAN Certified℠ Products

A huge array of certified products available now to fulfill the wide-ranging spectrum of IoT use cases served by LoRaWAN™.

Soon this will be extended to include LoRa Alliance™ member services, software and full solutions in addition to these certified devices. This will be a comprehensive directory of all our Members' products and services with tools to find the right solution for every LPWAN requirement.

ED1608

1M2M

1M2M's ED1608 is an out of the box, ready to use universal Low Power WAN Smart Sensor/GPS Tracker. It has on board 3D accelerometer,

ED1608 Rail Temperature Sensor

1M2M

The ED1608RTS is a rail temperature sensor that can be used to measure the temperature

LoRaWAN – characteristics

Range	10km
Multihop capabilities	no
Battery consumption	low
Security	yes
Cost (device)	low
Cost (service)	free
Availability	good
Regulation	good

Summary

We analyzed different communication options for IoT.

We looked into details of LPWAN.

We've seen why LoRaWAN is a good candidate for applications.

Feedback?

Email me mzennaro@ictp.it