Wireless options for IoT

Workshop on LPWAN Solutions for the Internet of Things

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Goals

- Expose the specific requirements of IoT and why traditional wireless technologies fail to meet them.
- Describe the technologies that can be used to build IoT networks.
- Describe LPWAN solutions currently with more traction and those poised to attain it.

Many IoT nodes can accept:

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

Capacity of a communications channel

$$C = B * \log_2\{1 + [S/(N_o * B)]\}$$

Noise power density, W/Hz

Received signal power, W

Bandwidth, Hz

Capacity (maximum throughput), bit-per-second

The maximum range is determined by the energy per bit received, and depends on the effective transmitted power, receiver sensitivity, interference and data rate.

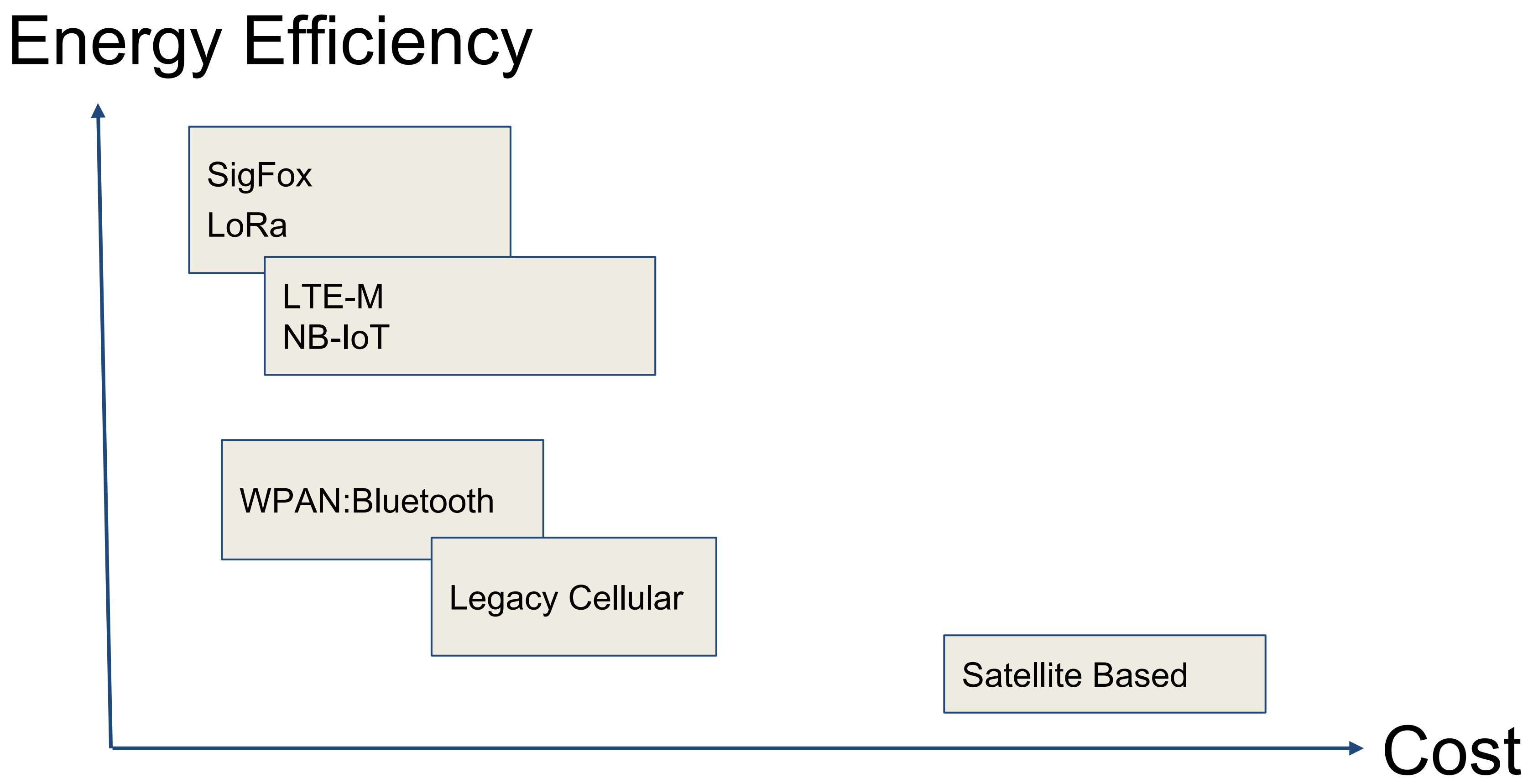
LoRa and Sigfox represent different strategies to achieve long range.

Technology	Sensitivity	Data rate	Spectrum
WiFi (802.11 b,g,h)	-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
SigFox	-126 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

Constraints of legacy cellular in IoT

- 3G and 4G have focused on increasing transmission speed at the price of high energy consumption
- The handset must be in constant connection with the cellular B.S.
- 2G is being discontinued in many countries
- Charging a monthly fee for each SIM card is too expensive for IoT applications in which there is a big number of devices that generate little traffic

Energy efficiency Vs. cost



Some solutions

- WiFi (legacy, af, ah and WiFi 6)
- Bluetooth and BLE (Bluetooth Low Energy)
- New Cellular based (3GPP Release 13 and up)
  - Extended coverage GSM (EC-GSM)
  - LTE-M
  - NB-IoT

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 up to 26 channels.
- 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

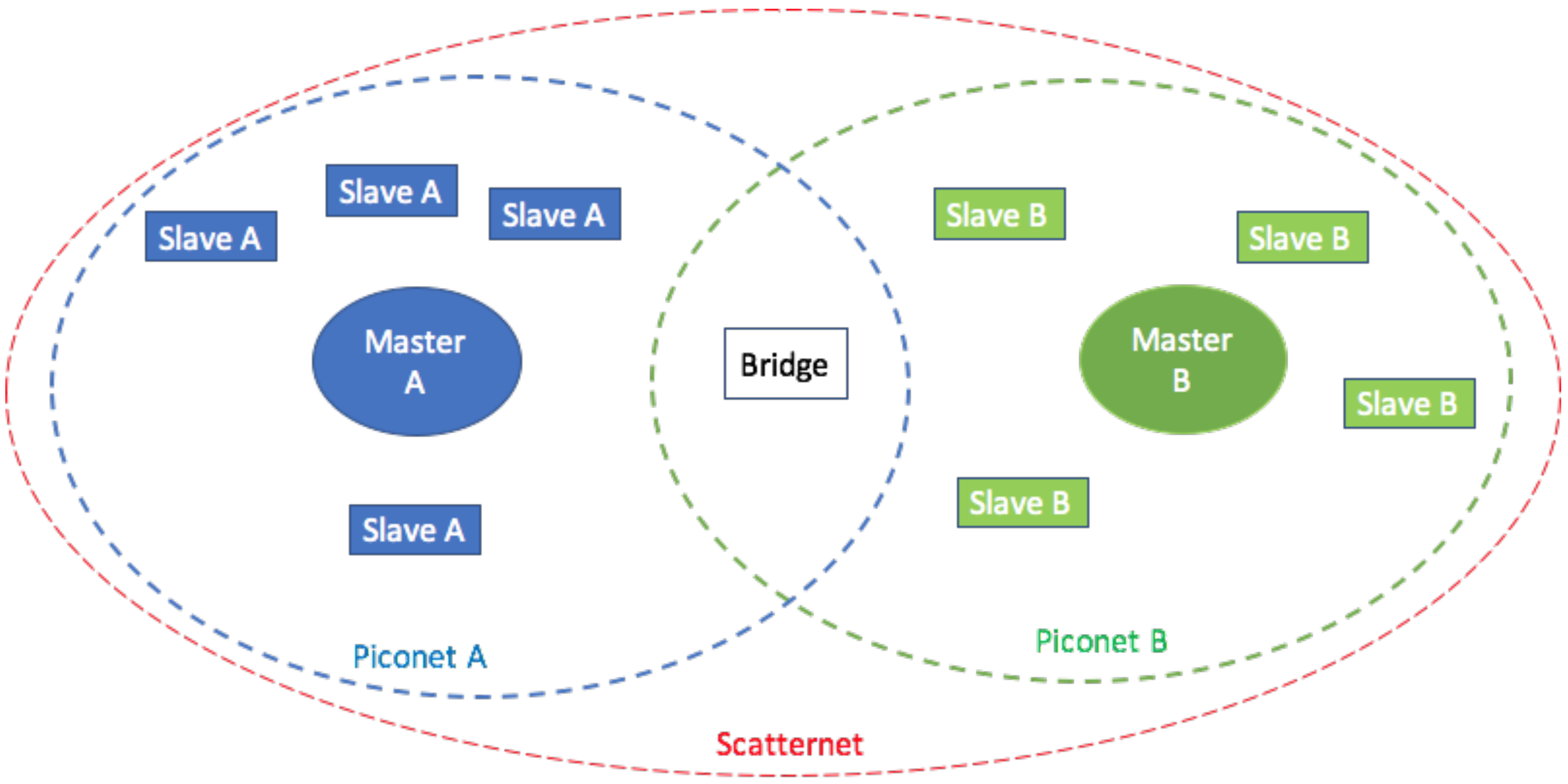
- Based on IEEE 802.15.1
- Smart Mesh.
- 79 channels 1 MHz wide and frequency hopping to combat interference in the crowded 2.4 GHz band.
- Used mainly for speakers, health monitors and other short range applications.

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) 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 Low Energy (BLE) or Smart Bluetooth

- Data channels used for bidirectional traffic.
- Beacon mode, where low power, transmit-only sensors periodically transmit in one of three dedicated “advertising channels”.
- BLE compatible receiving devices must periodically listen in each of the tree advertising channels
- Transmitter consumption is 2.9 mW and receiver's is 2.3 mW.

Two main categories of solutions

- Cellular based (3GPP standardized)
  - Legacy
  - LTE-M
  - NB-IoT
- Proprietary or based on de facto standards LPWAN
  - SigFox
  - LoRa

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

Low Power Wide Area Network (LPWAN)

Optimized for IoT and Machine to Machine (M2) applications

Trade throughput for coverage (up to several kilometers)

Star or star of stars topology

Low power consumption

Low on board processing power

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

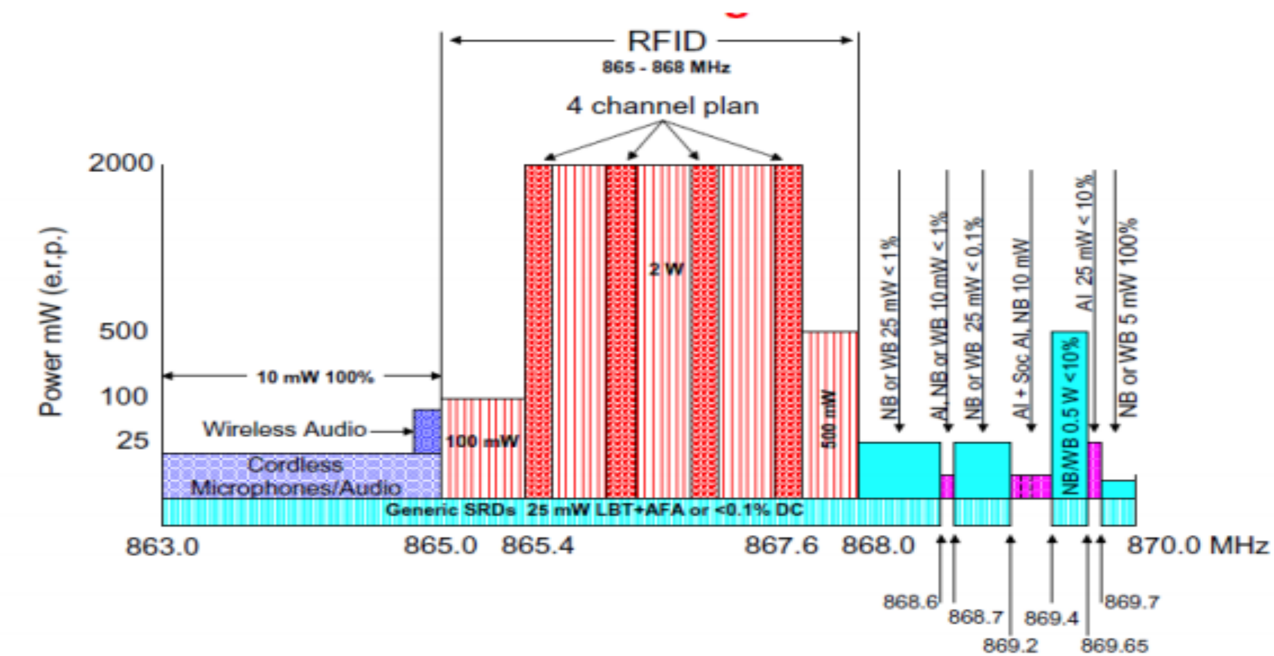
Spectrum Usage

- 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

Short Range Devices spectrum access (applies to LoRa and SigFox)



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

LPWAN spectrum usage

Africa and 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: 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

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 Africa and 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.

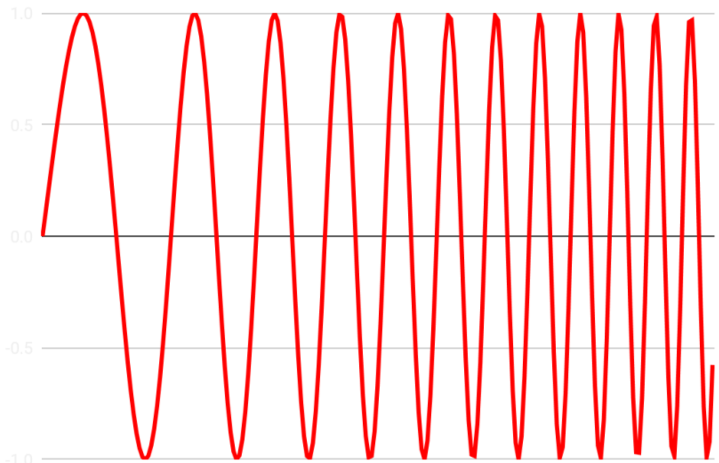
Sigfox

- 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.

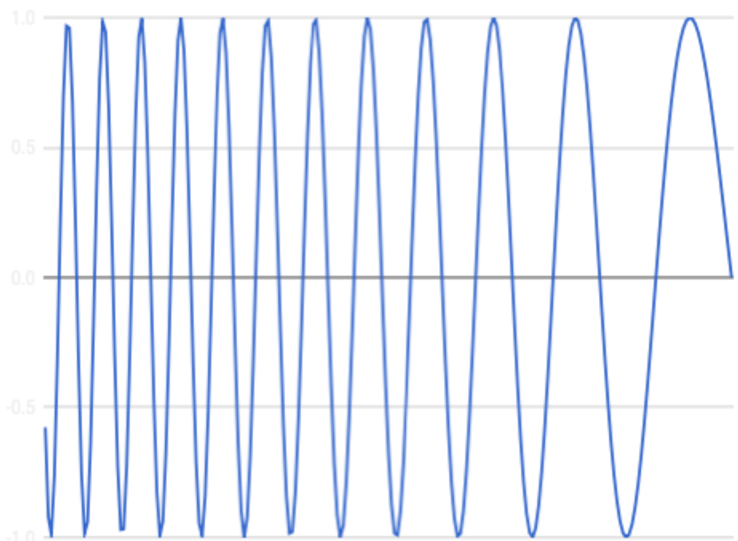
LoRa

- 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

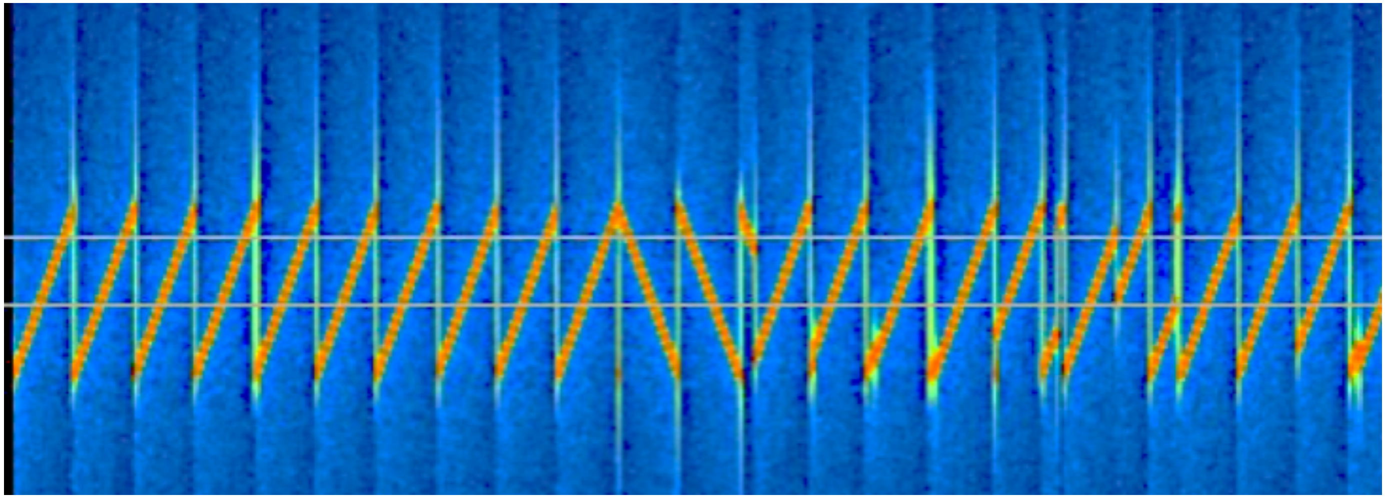


Up-chirp:
sinusoidal signal of linearly increasing frequency



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 frequency transitions

Beginning of data

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.

Parameters of LoRa physical layer

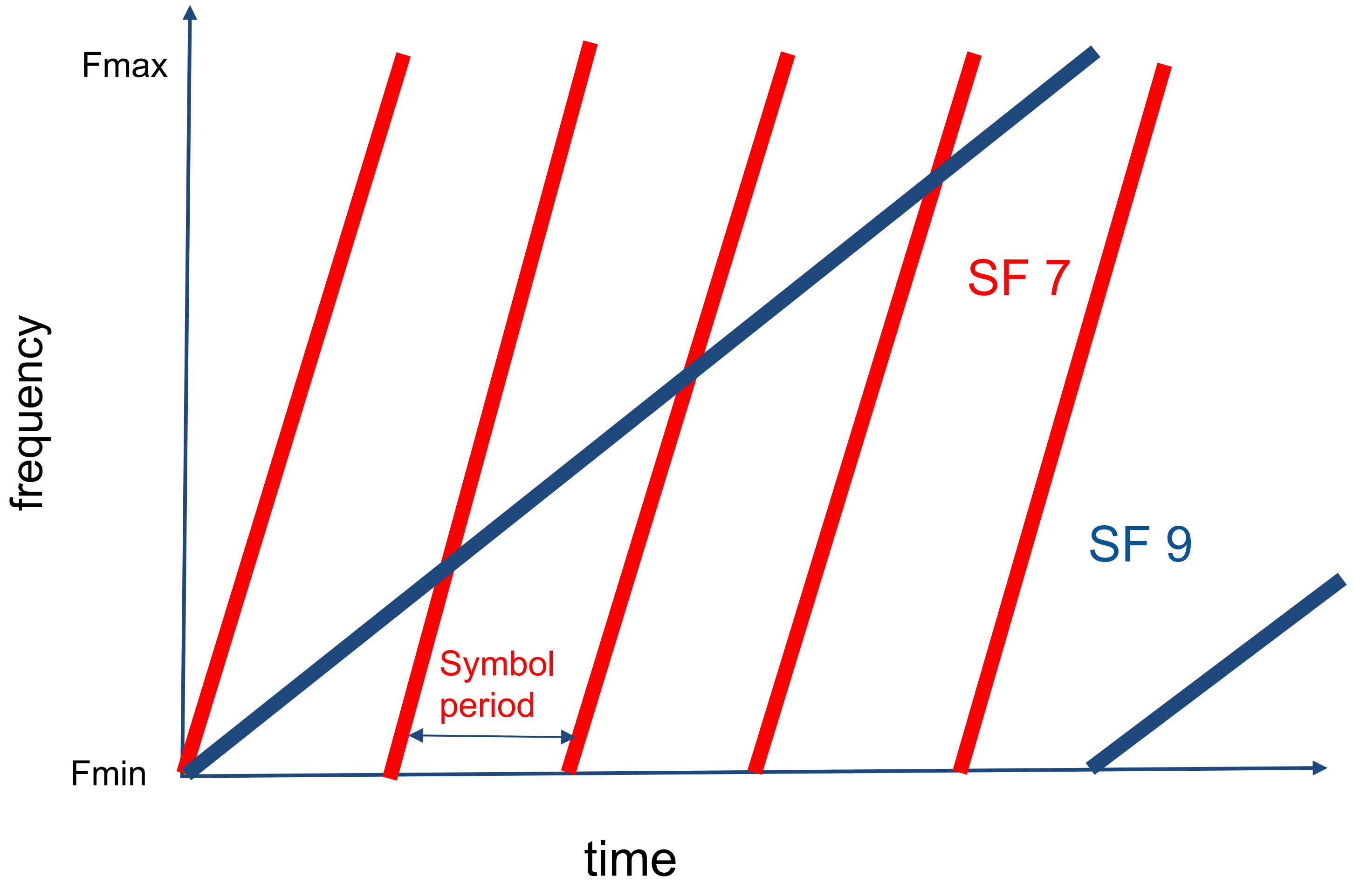
- Coding Rate (CR): 5/4, 6/4, 7/4/ 8/4

The coding rate (CR) is the fraction of transmitted bits that actually carry information. So if CR is 4/8 we are transmitting twice as many bits as the ones containing information.

A symbol can encode SF bits of information.

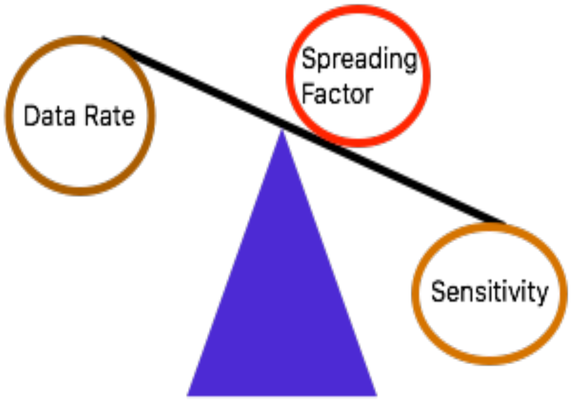
The duration of a symbol is Ts=(2^SF)/BW, so the useful bit rate is Rb=SF*CR/Ts.

Spreading Factors and duration

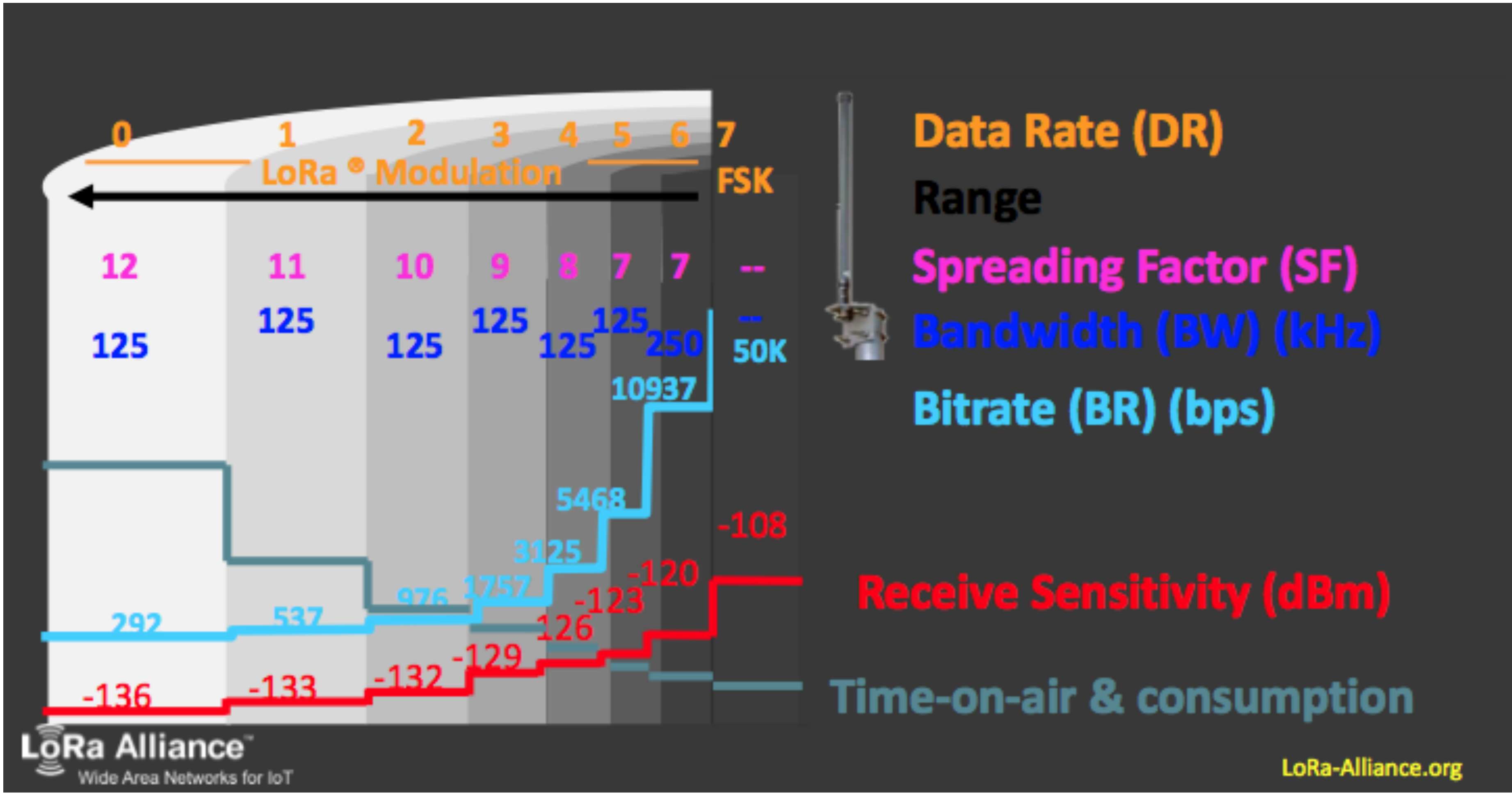


Adaptive Data Rate (ADR) at 125 kHz BW

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



LoRa parameters interaction



Range

- LoRa and SigFox: many kilometers
- 2G, typically 3 km, maximum 30 km
- 802.15.4 less than 100 m
- WiFi, typically 100 m, much higher values attainable with high gain antennas

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

LoRa and LoRaWAN

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

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

Satellites

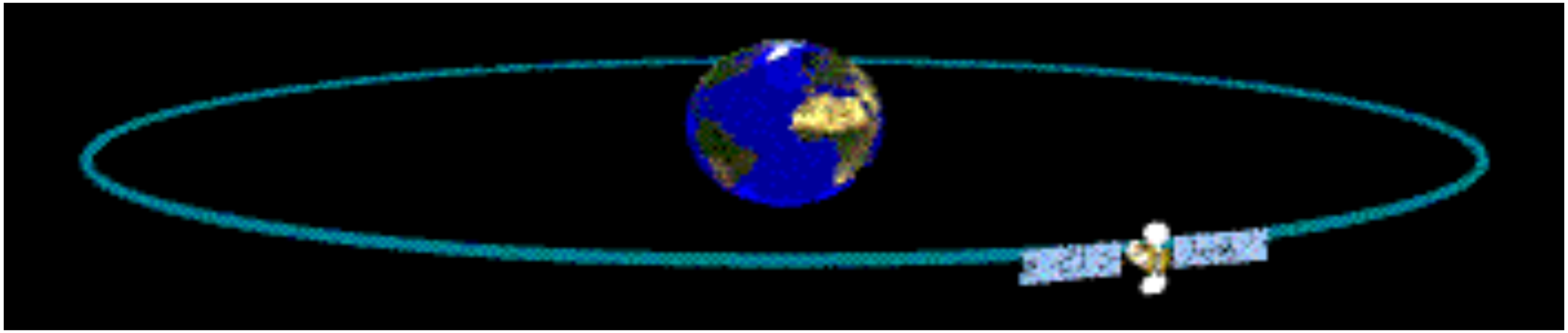
- Satellite communications have been very successful for broadcasting applications and also for two way communications, but the associated costs have precluded them to find extensive usage in IoT.
- The situation is beginning to change, so it is worth to briefly describe the technology involved.

Satellites

There are three mayor categories for communications satellites:

- Geostationary (GEO), orbiting the Earth in an Equatorial plane at 36000 km.
- Medium Earth Orbit (MEO), with different orbits at around 20000 km.
- Low Earth Orbit (LEO), at altitudes between 600 and 800 km.

We can also consider High Altitude Platforms (HAPS) at much less distance from the earth, but they are not yet commercially available.



Period of any satellite is given by:

$$T = SQRT(4\pi^2 a^3/\mu)$$

Where T is orbital period in seconds, a is distance to the center of earth in km and μ = Kepler's constant ($\mu = 3.9861352 \times 10^5\ km^3/s^2$)

For geostationary satellites, T=23 hours 56 minutes (82856 s) and a=42164 km above the equator

Closer orbits require higher satellite speeds

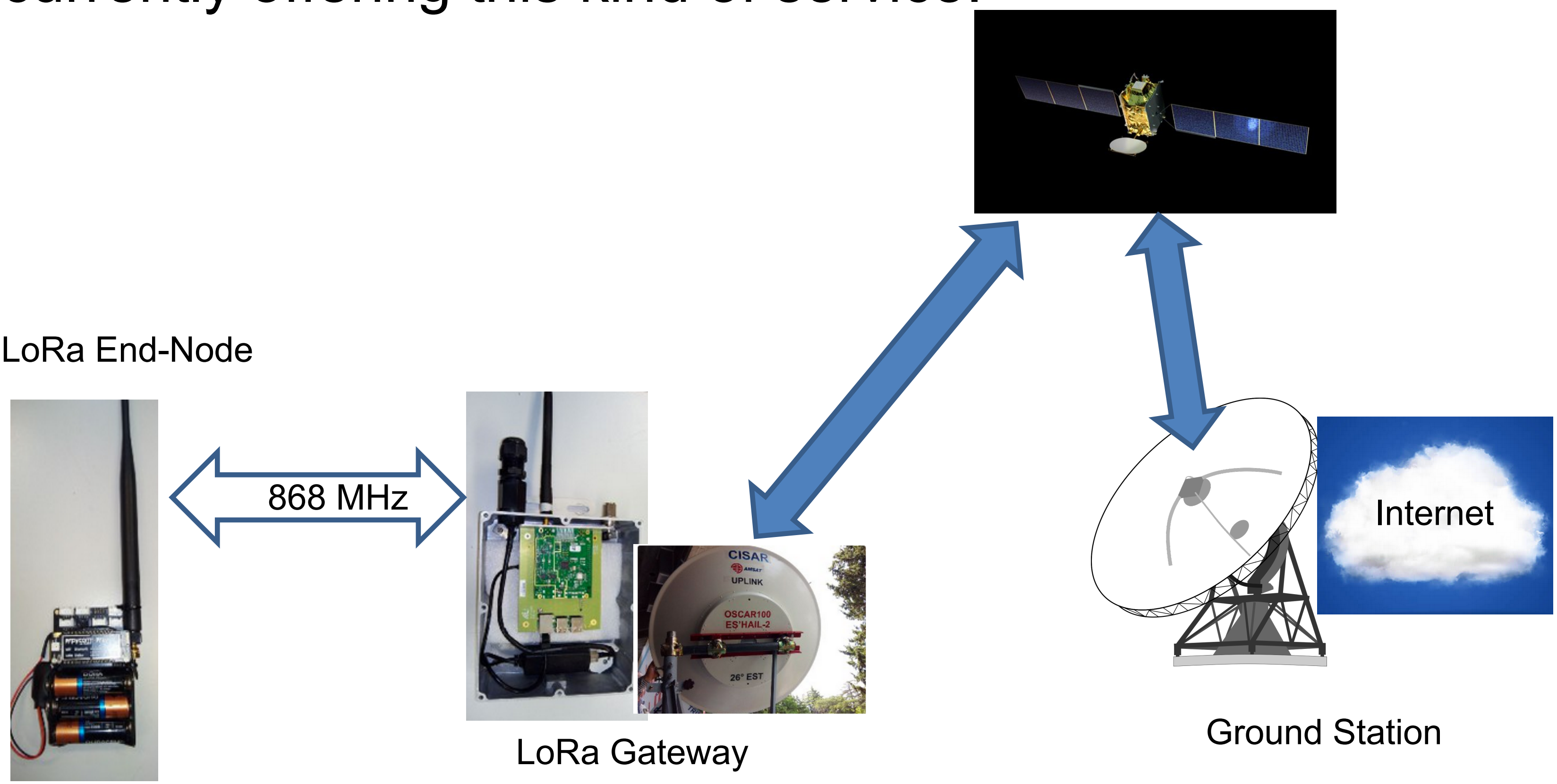
Satellites

The satellite is essentially a repeater up in the sky, so an Earth station connected to the terrestrial network normally by fiber optic will function as the gateway for all the traffic.

- Gateways communicate with the satellite using the uplink RF channel.
- The satellite can detect this signal, amplify, change frequency and beam it back to earth, in what is known as the “bent-pipe” technology, or:
- It can regenerate the signal thus emulating a gateway in the sky.

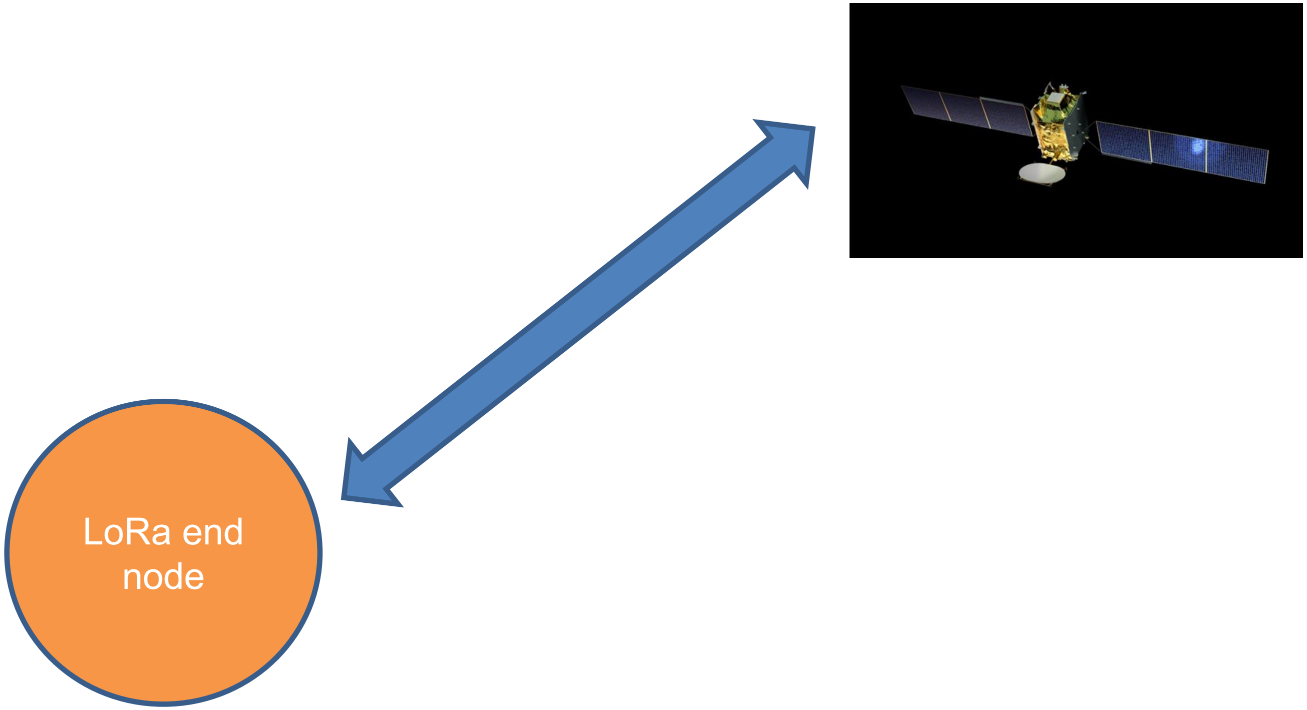
Satellites for IoT

Satellites can be used to communicate the IoT gateway to the respective server, and a number of vendors are currently offering this kind of service.



Satellites for IoT

- The novelty lies in the possibility of a direct link from an end-device to a Gateway up in the sky.
- Both SigFox and LoRa solutions have been proposed and trials made but no commercial service is yet available.

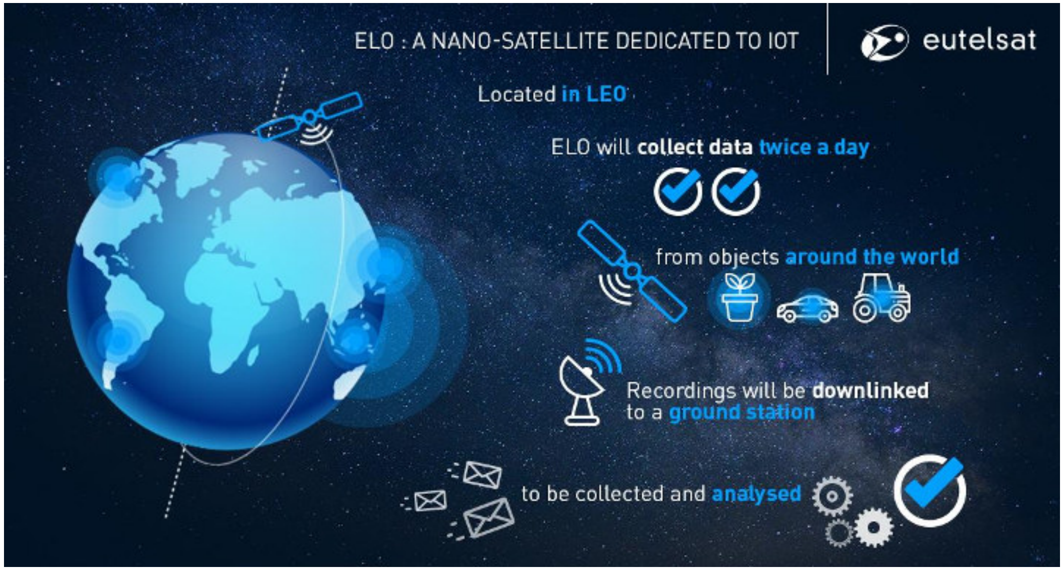


Lacuna Satellites for LoRa

from:
https://www.semtech.com/company/press/semtech-and-lacuna-receiving-messages-from-space

- Lacuna Space uses a constellation of polar low-earth orbiting satellites to receive messages from sensors integrated with LoRa radios.
- At about 500 km above the ground, the satellites circle over the poles every 100 minutes and as the earth revolves below them, they cover the globe.
- The satellites store the messages for a short period of time until they pass over the network of ground stations.

SigFox Satellite Service with Eutelsat



Located on a sun-synchronous orbit at about 600 km in altitude, the satellite will collect data from connected objects equipped with the same omnidirectional antennas used by terrestrial IoT networks. Data will then be transmitted daily to a ground station located on Svalbard, a Norwegian archipelago in the Arctic Ocean

https://www.connectedbaltics.com/ecosystem/sigfox-iot-satellite/

Link calculations

Upnlink from the LoRa end-device to the LEO:

$$L_{fs} = 92.4 + 20*\log(D) + 20*\log(f)$$

$L_{fs} = 92.4 + 20*\log(500) + 20*\log(0.868) = 145.9$ dB

Assuming a 14 dBm EIRP for the TX, the satellite antenna will receive a signal of 14 -145.9 = -131.9 dBm

The sensitivity with SF 12 is -136 dBm, so the signal can be detected even with a 0 dBi antenna.

Note that this is a delay tolerant network (DTN), and the number of ground stations needed will depend on the application's latency requirements.

Conclusions

- IoT requires specific standards.
- 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 but with limited data rate.
- Satellites for IoT will offer services in areas that do not have Internet connectivity.