Introduction to IoT communication

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Ermanno Pietrosemoli

ICTP 1964–2024

Science, Technology and Innovation unit

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.

Goals

- Describe the fundamentals variables that determine the maximum range attainable in wireless communications.
-
- Explain the IoT communication solutions based in licensed and unlicensed frequencies that currently show more traction and those poised to attain it.

- Describe the LoRaWAN technologies particularly suited for remote areas, including satellite solutions.

IoT requirements and tolerances

Require:

- Low cost
- Energy efficiency
- Ubiquitous coverage
- Massive deployments
- Extended coverage
- Security
- Confidentiality
- Geolocation capability*

May tolerate:

- Low throughput
- Very sparse datagrams
- Delays
- Long sleeping times
- Packet losses
- Lack of mobility
- Planned retransmissions

Important IoT System Qualities

Security, to keep devices, network & backend secure.

Privacy, to keep people in control of their own data.

Interoperability, to become part of an ecosystem.

Openness, standards & open source to build trust.

Scalability, to manage the ever growing number of devices.

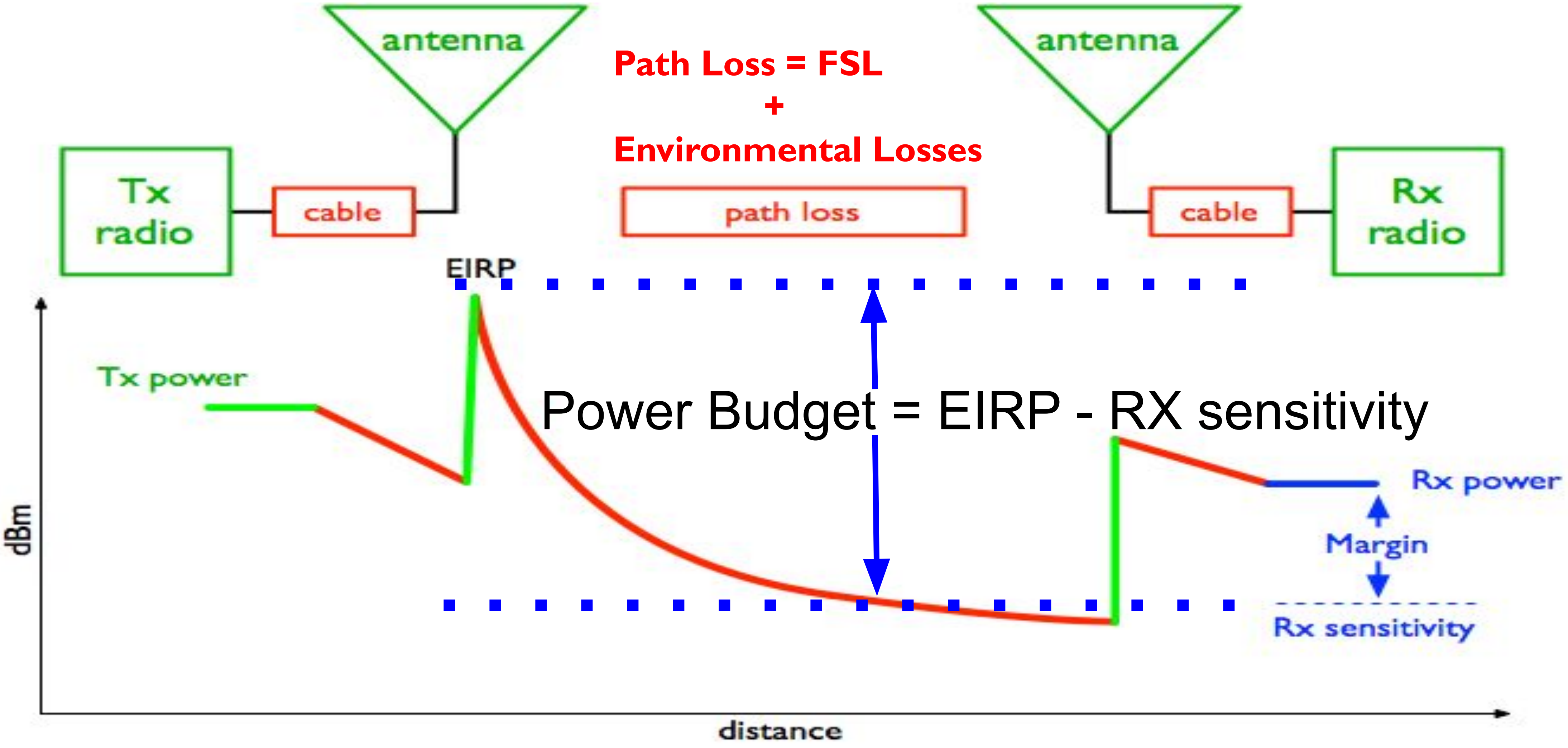
Environmental data in remote locations

- Monitoring environmental parameters and effects in remote locations is of increasing interest due to the rapidly changing global climate and the world in general.

- Parameters like temperature, pressure, water levels, snow levels and seismic activity have significant effects on applications such as green energy (wind and hydro power), agriculture, weather forecasting and tsunami warnings.

LoRaWAN Meteo station with rain gage
in Kampala, Uganda

Power in a wireless system



Link budget

Link budget, also known as maximum coupling loss (MCL), is a way of quantifying the link performance, calculated as the difference in dB between the EIRP and the sensitivity of the receiver.

- The transmitter power is limited by the regulations of each country, and depends on the type of service.
- In the 868 MHz unlicensed band the maximum allowed EIRP is **14 dBm** in Africa and in Europe (ITU Region 1).
- The allowed transmit power is higher in licensed bands, broadcasters can even transmit at thousand of watts.
- When using a high gain transmitter antenna the conducted power of the transmitter might have to be reduced to comply with the allowed EIRP.

EIRP: Equivalent Isotropic Radiated Power

Link budget

- The received power in a wireless link is determined by the following factors:
  - transmitter power, loss of the cable between transmitter and antenna, transmitting antenna gain, *transmission path loss*, receiving antenna gain, and loss of the cable between the antenna and the receiver.
- If that power is greater than the ***sensitivity* (S)** of the receiving radio, then the link is feasible.
- The sensitivity decreases with the bandwidth, transmission speed, the noise figure of the receiver and the required S/N to achieve a given bit error ratio (BER).

$$S\ (dBm) = KTB\ (dBm) + NF\ (dB) + S/N\ (dB)$$

NF is the noise figure and S/N depends on the transmission rate and modulation used

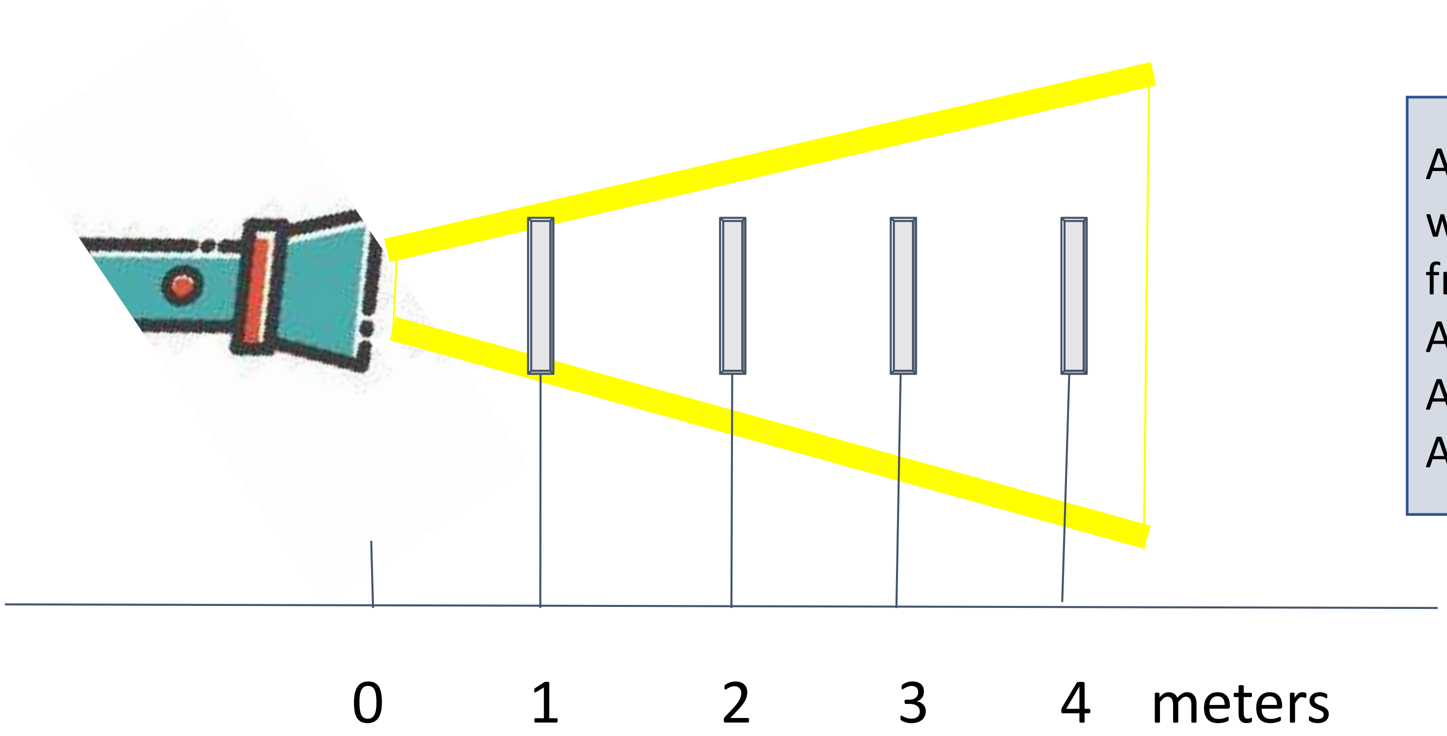
at room temperature, $S = -174\ dBm + 10Log_{10}(B) + NF + S/N$

for B = 125 kHz, NF = 5 dB and S/N = - 20 dB, S= -174 + 51 + 5 - 20 = -138 dBm

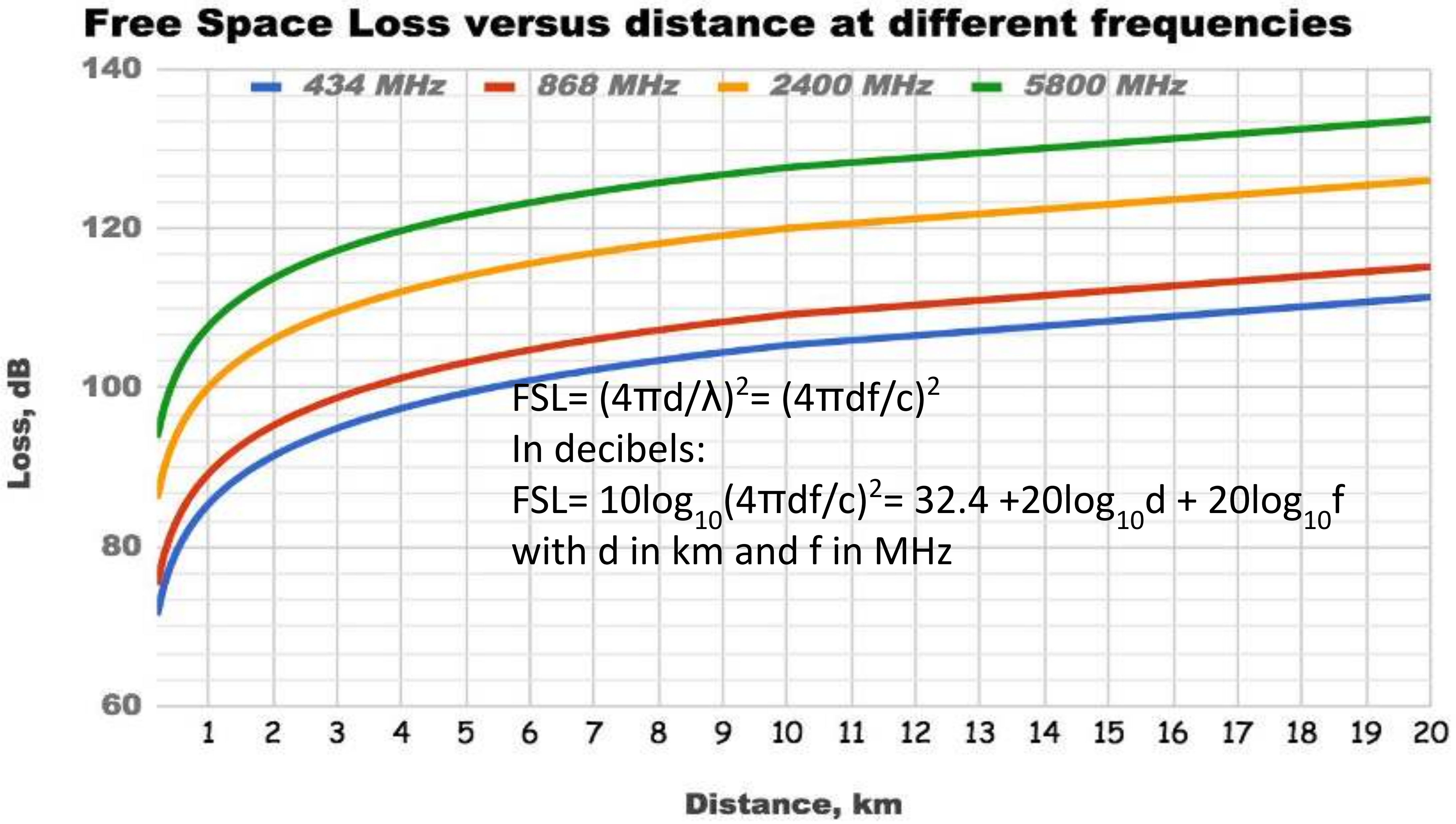
K = Boltzmann's constant = 1.381×10^{-23}, T is temperature in kelvins, B bandwidth in Hz, NF depends on the quality of the receiver circuit

Free Space Loss (FSL)

As the wave propagate from the source it spreads over an ever increasing area, so an antenna of a fixed size would be able to capture a fraction of the wavefront's power that decreases with the square of the distance.



A screen at 1 m distance would capture all the light from the torch.
At 2 m would capture 1/4
At 3 m would capture 1/9
At 4 m would capture 1/16



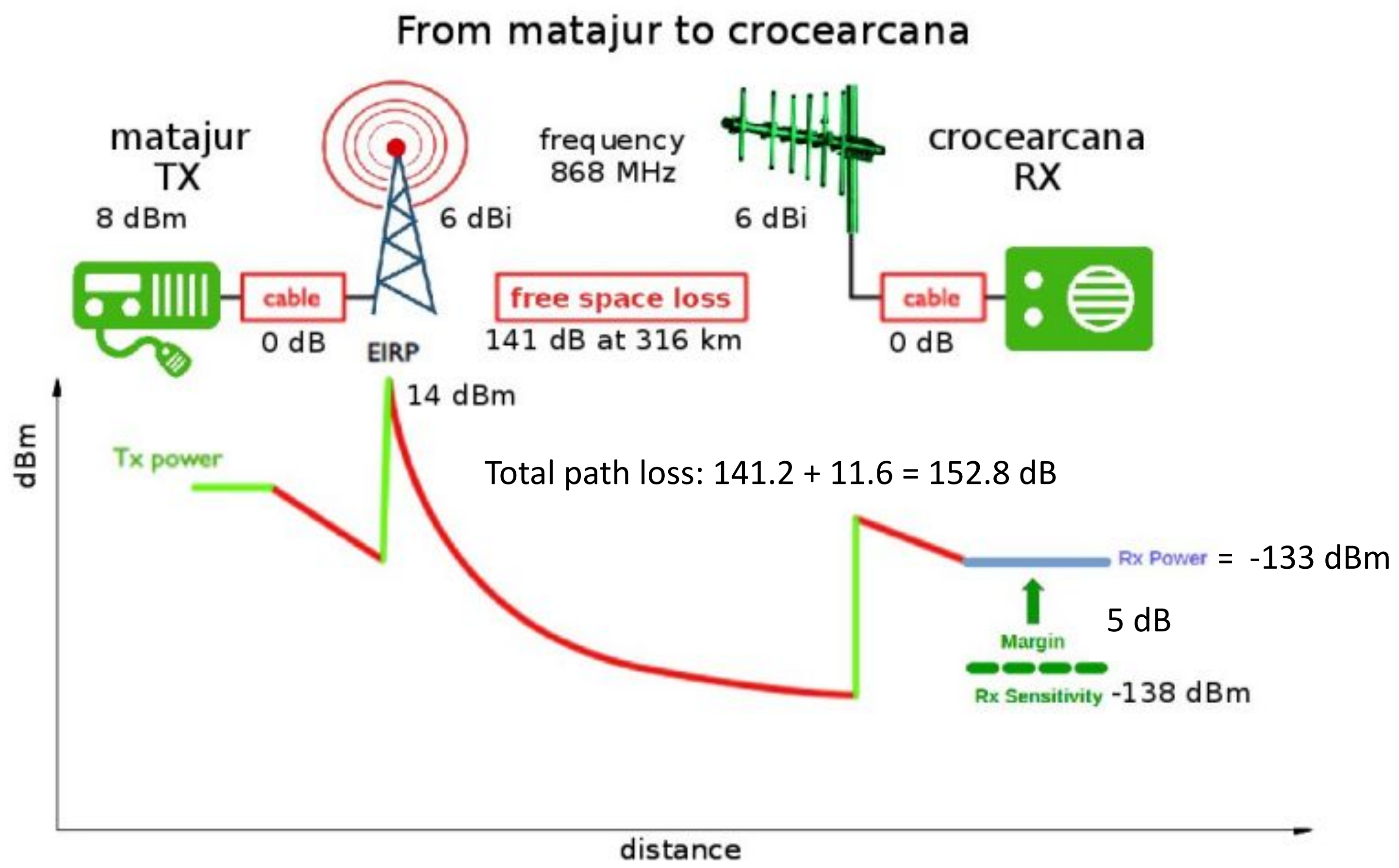
FSL= $(4\pi d/\lambda)^2 = (4\pi df/c)^2$

In decibels:

FSL= $10\log_{10}(4\pi df/c)^2 = 32.4 + 20\log_{10}d + 20\log_{10}f$

with d in km and f in MHz

Example of an extreme IoT power budget



The earth's curvature was cleared thanks to the height at both ends.

Short and midrange wireless networks

RFID
Bluetooth and Bluetooth Low Energy (BLE)
IEEE 15.4 based: Zigbee, Thread, Wireless HART, 6LowPAN
WiFi, WiFi HaLow
Z-Wave
Dash-7
Wi SUN
EnOcean

Long Distance: Two categories of LPWAN

Cellular IoT

(3GPP standardized)

- LTE-M
- NB-IoT

Unlicensed Spectrum

- SigFox
- LoRa
- MIOTY
- RPM (Ingenu)
- NB-Fi
- WiFi HaLow

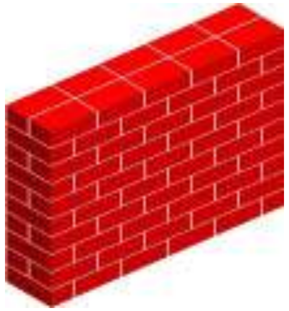
Cellular success

- Traditional Cellular technologies promoted by 3GPP have had an enormous success.
- They have focused on providing ever greater speeds to meet the demand of the booming data consumption, but had to reduce the range as a compromise.
- 4G and 5G user devices have complex and power hungry circuitry that are not suited to the needs of IoT.
- A cellular device must keep frequent communication with the base station, thus consuming energy even when there is no traffic.

Unlicensed Spectrum LPWAN

Limitations of cellular were addressed by non-cellular LPWANs:

- IoT connectivity requires low cost devices that consume little power to allow their deployment in large numbers and possibly in places that make battery changing impractical.
- Most of these devices do not need a high throughput.
- Many do not have stringent latency requirements.



- Some might be in basements or beyond several walls that absorb significant amount of RF signals, requiring a high power budget (Maximum Coupling Loss).

Cellular IoT (CIoT)

The 3GPP response to the threat of unlicensed LPWAN was addressed starting from Release 13 of the 3GPP standard, with 2 variants:

- LTE-M
- NB-IoT

They are both officially 5G technologies and 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.

NB-IoT has been widely deployed in China, while LTE-M is more popular in US.

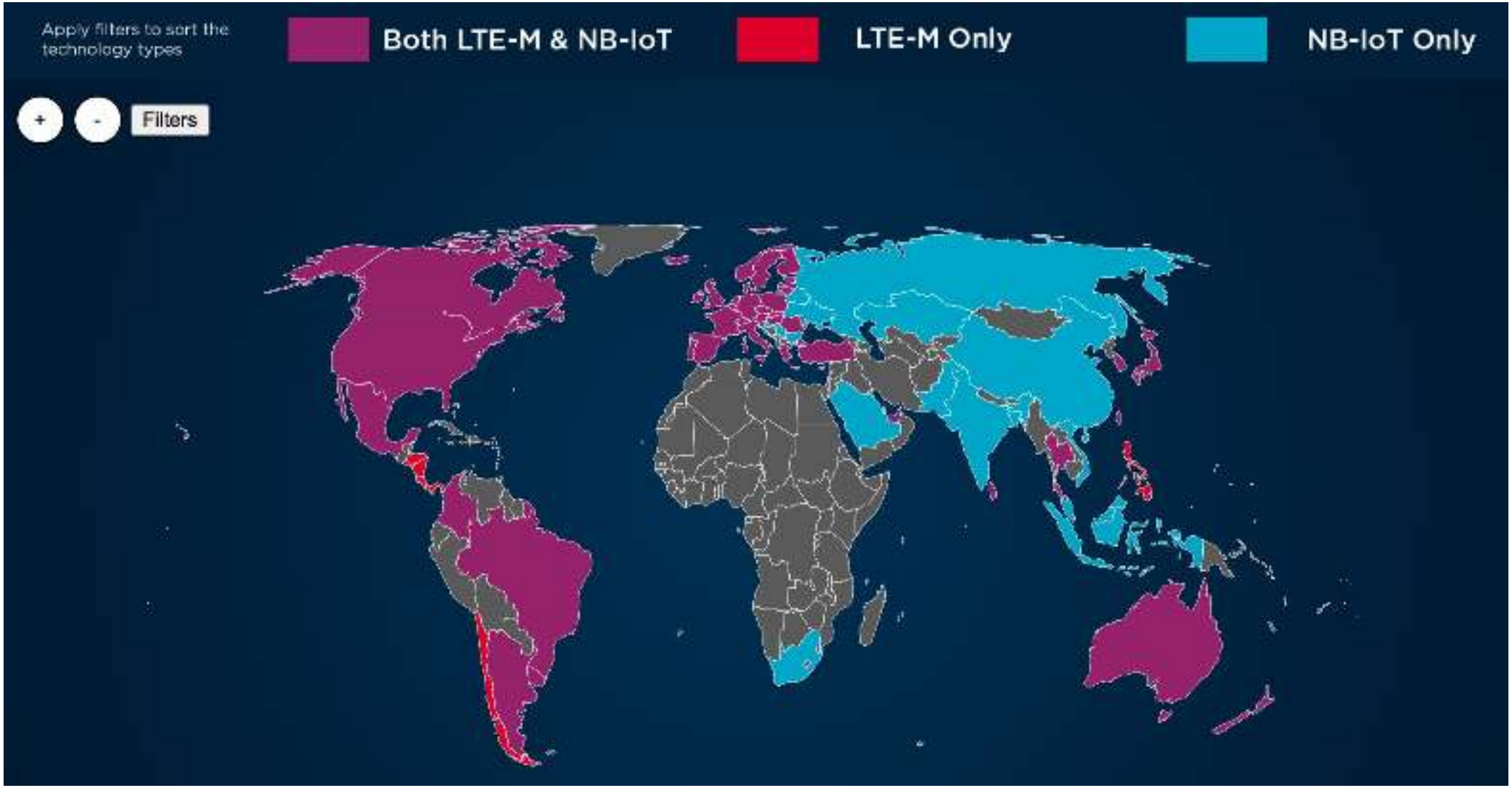
LTE-M (eMTC)

- High System capacity and reliability
- Low Latency
- Full or half duplex
- Supports both TDD and FDD
- Supports Voice/IP and positioning
- Limited or full mobility
- Power saving mode (PSM)
- Extended discontinuous reception (eDRx) up to 44 minutes (amount of sleeping between paging cycles)

Narrowband for IoT (NB-IoT)

- Messages can be repeated up to 128 times in UL and 2048 in DL, to provide processing gain at the receiver.
- Bandwidth is 180 kHz, half duplex, does not support voice or mobility.
- Support for time-division duplexing (TDD), over-the-air (OTA) firmware updates, unlicensed frequencies, small cells and Wake-up Signal (WUS) for groups.
- 164 dB power budget, improved wall penetration.
- Long battery life and lower device complexity.

IoT Cellular Networks Deployments



https://www.gsma.com/solutions-and-impact/technologies/internet-of-things/deployment-map/

Spectrum allocation

- 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 which is blocked by walls

Most used Unlicensed bands LPWAN

- SigFox
- LoRa, LoRaWAN
- Telegram Splitting based:
  - MIOTY
  - LoRa-FHSS

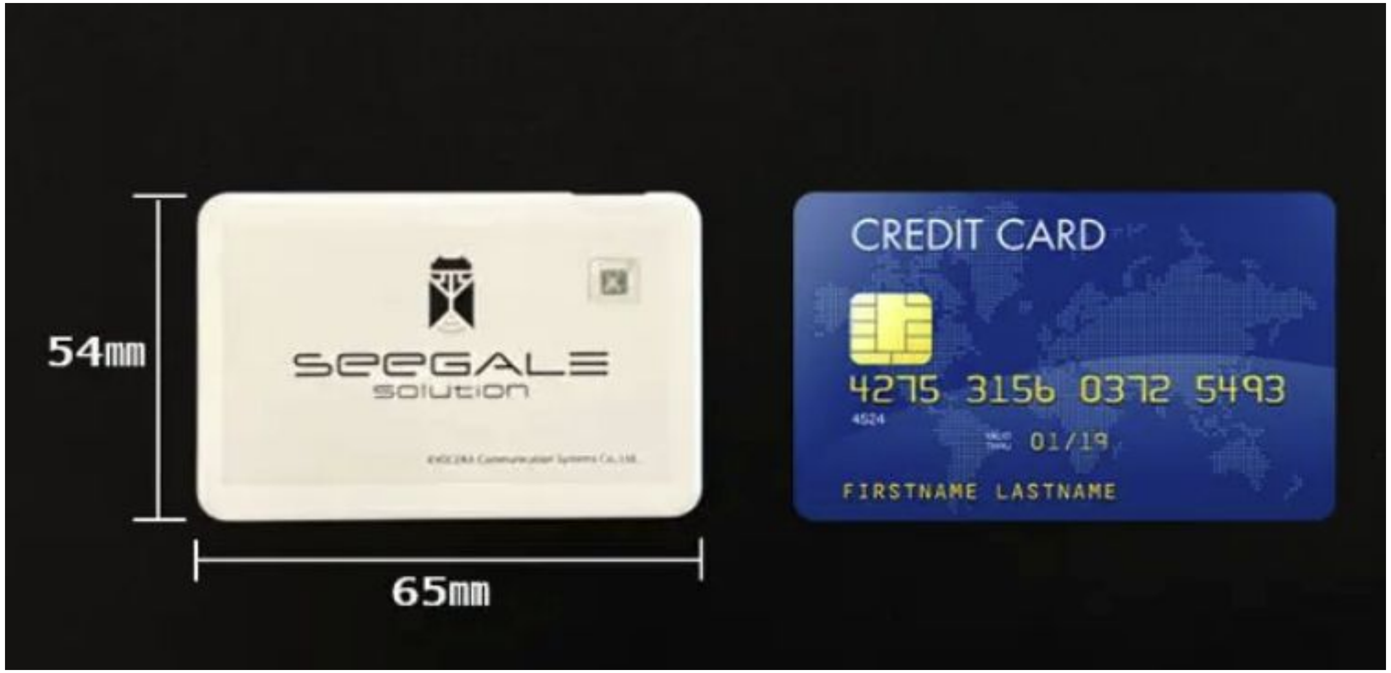
Sigfox

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 tracker for premium goods

Detects the opening and closing of parcels during transportation, to ensure their integrity and security.
The device lasts for approximately two years, based on one message per day



In April 2022, Sigfox's assets were acquired by UnaBiz, a Singapore-based IoT solutions company, after going through receivership.

https://www.rcrwireless.com/20231024/internet-of-things-4/unabiz-eyes-euro-supply-chain-with-sigfox-tracker-for-premium-goods-auto-parts?_hsmi=279622402

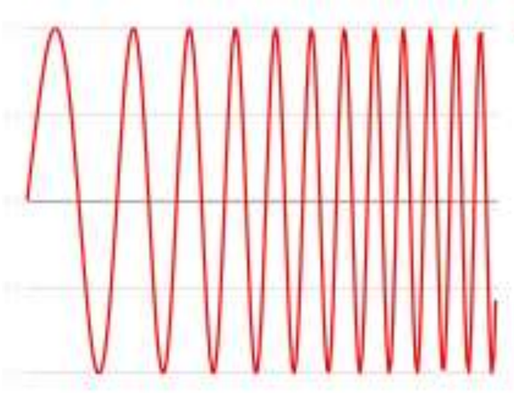
LoRa and LoRaWAN

LoRa is a physical layer proprietary scheme for LPWAN based on spread spectrum, trading bandwidth for Signal to Noise ratio (S /N).

Accordingly with Shannon's $C = B * \log_2(1 + S/N)$ equation for channel capacity in bit/s.

It achieves long range and deep indoor penetration while consuming little power.

Uses linearly varying frequency pulses called “chirps”.



LoRaWAN is an ITU standard, Rec. ITU-T Y.4480 (11/2021), controlled by the LoRa Alliance, that adds the MAC, networking and application layers to provide the functionalities required for a complete networking solution.

Parameters of LoRa physical layer

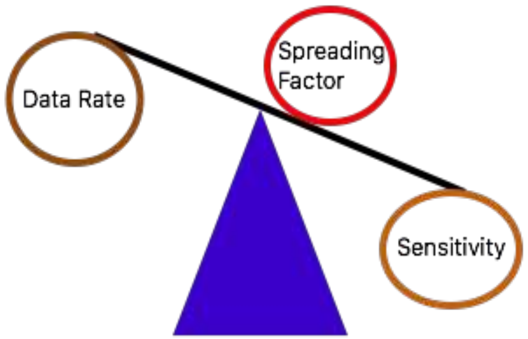
- Bandwidth (BW): 125 KHz, 250 kHz or 500 kHz
- Spreading Factor (SF): 7, 8, 9, 10, 11, 12
- Coding Rate (CR): 5/4, 6/4, 7/4/ 8/4
- payload size (PL): maximum 255 octets

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.

Adaptive Data Rate (ADR) at 125 kHz

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

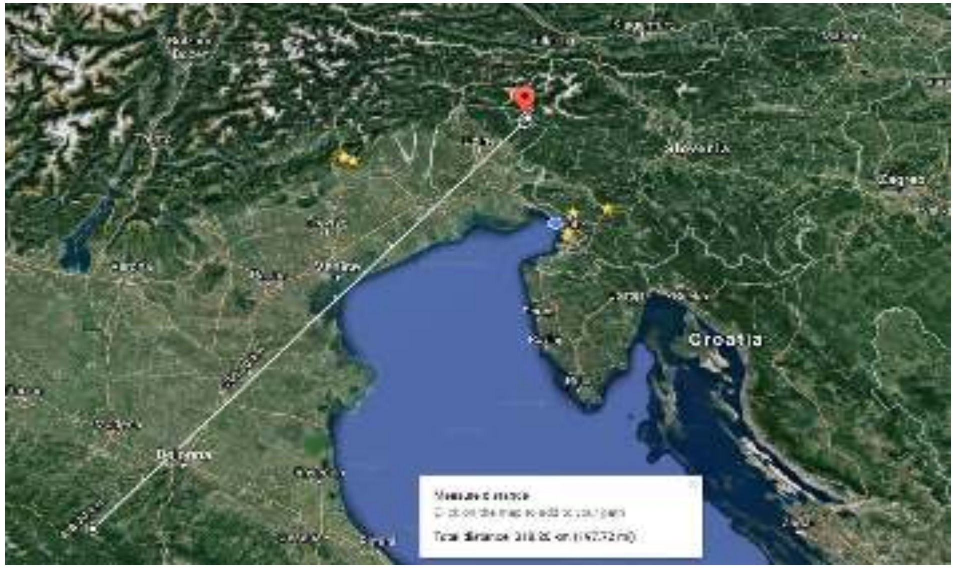


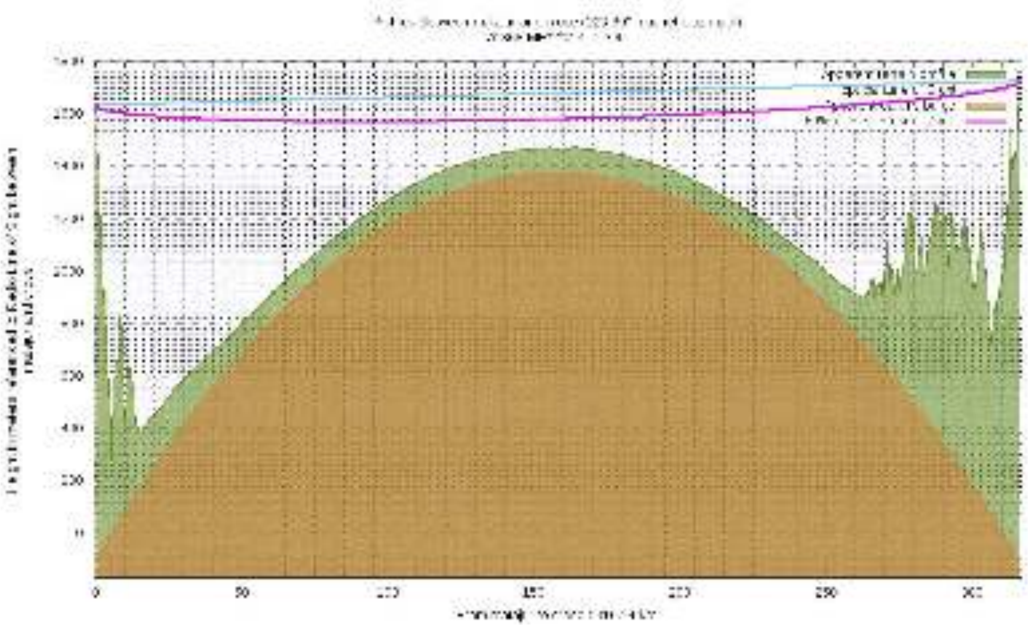
Sensitivity increases with spreading factor, but so does time on air and therefore consumption.

Calculation for time on air: https://loratools.nl/#/airtime

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





Battery duration

Devices sleep most of the time, with low data rate and limited number of messages per day.

- LoRa, SigFox: up to years
- NB-IoT, up to years
- LTE-M, a few days
- 802.15.4, months
- WiFi, a few days

Energy scavenging schemes are being pursued: Photovoltaic, piezoelectric, thermoelectric, vibration, air or water flow, inductive powering, radiofrequency energy.

LoRa spectrum usage

Africa and Europe: 863 to 868 MHz and 434 MHz

Duty cycle limitations: 1%

Max ERP: 14 dBm

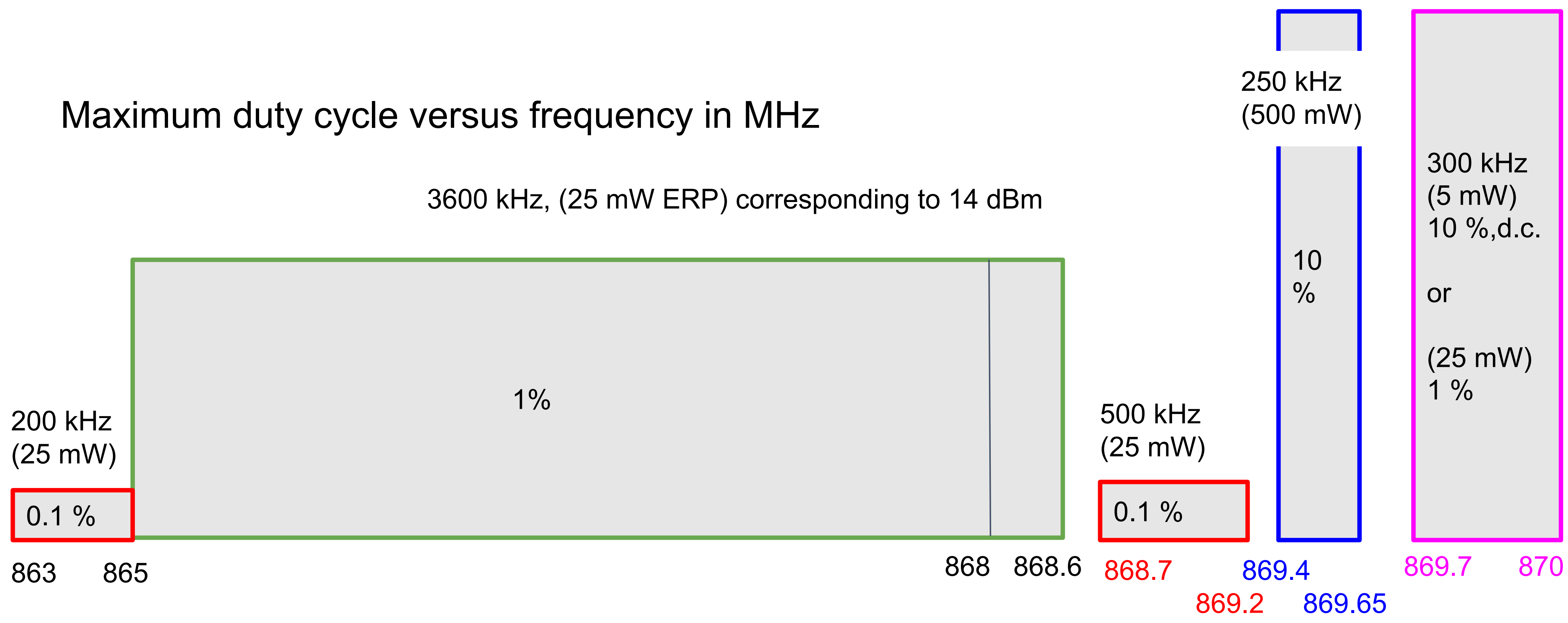
US: 902 to 928 MHz

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

Russia: EU863 to 870 MHz and EU 433 MHz

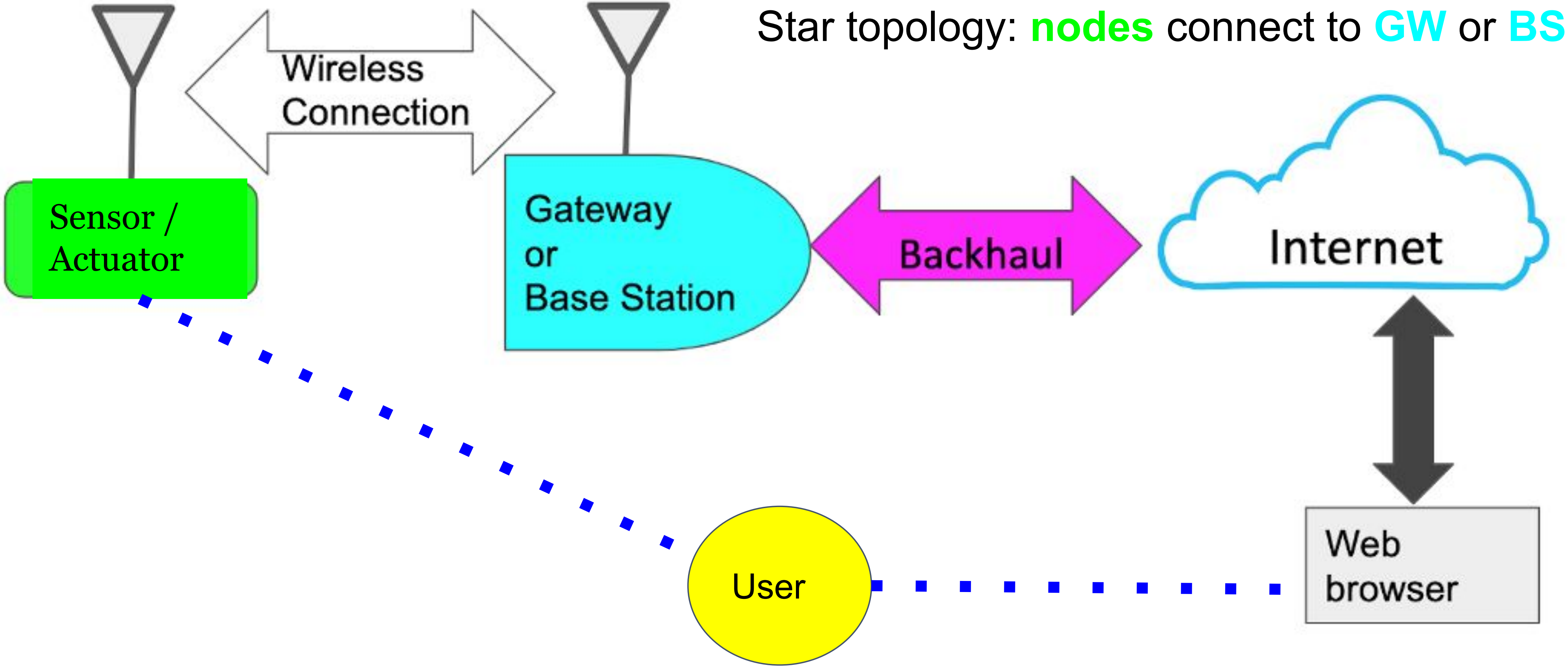
EU SDR spectrum regulation, applicable in Africa



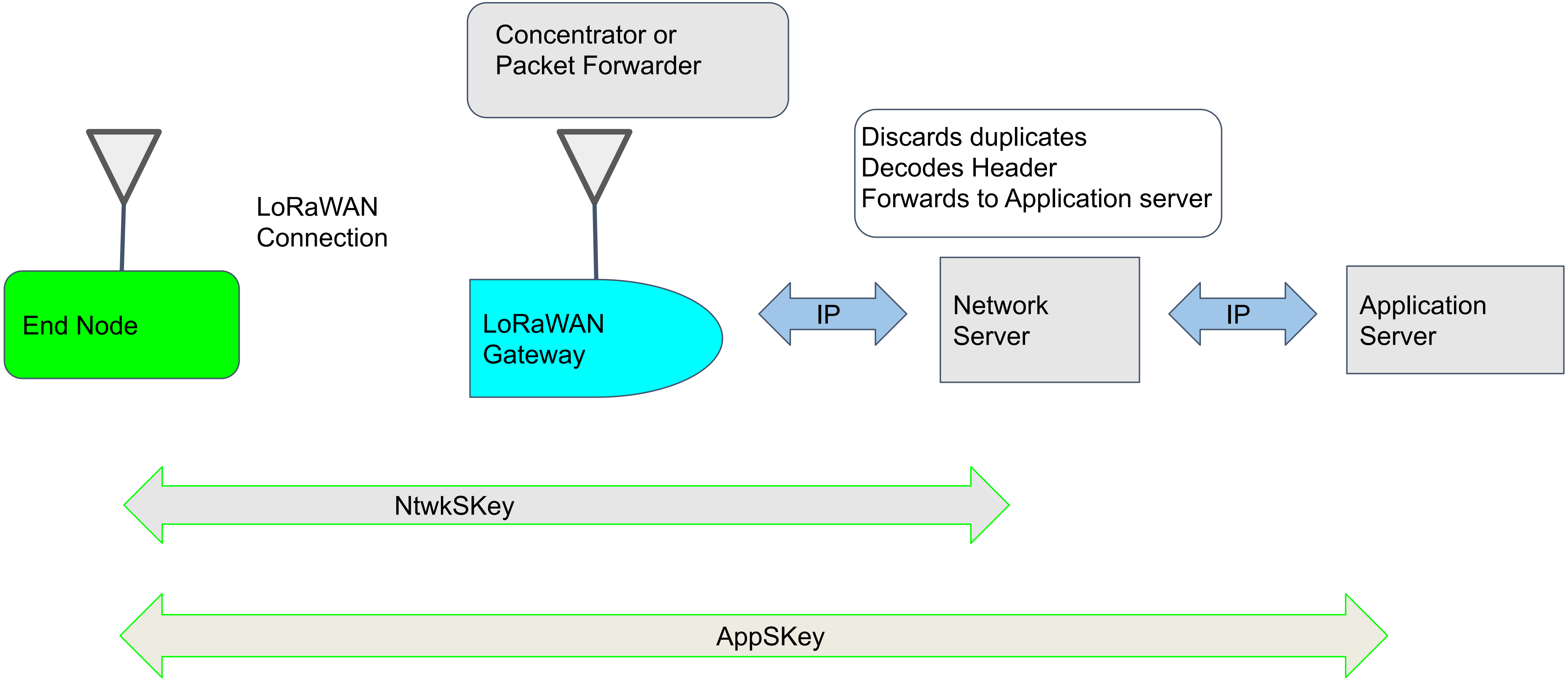
Effective Radiated Power (ERP) in dBm = EIRP + 2.15
EIRP = Equivalent Isotropic Radiated Power

Generic IoT Connection

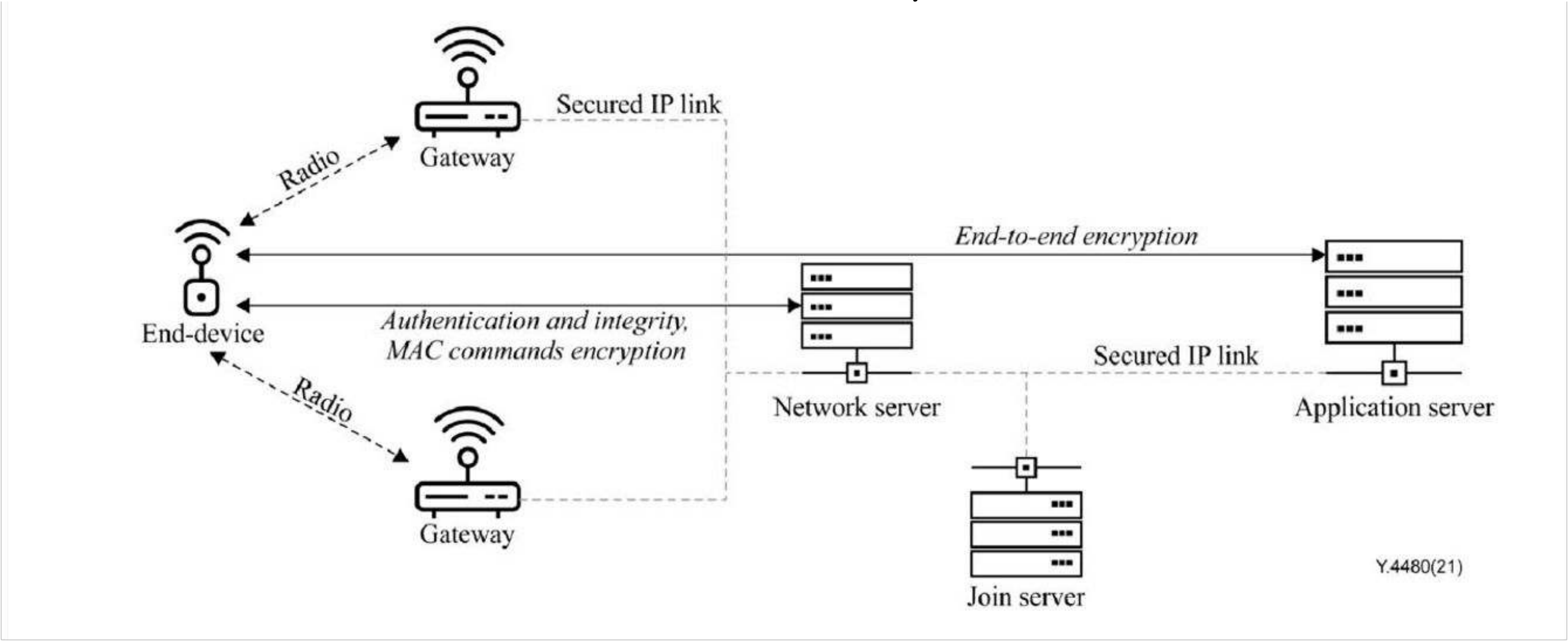
Star topology: nodes connect to GW or BS



LoRaWAN with end to end encryption



ITU-T Y4480 Recommendation, November 2021



LoRaWAN

All of the gateways in a network communicate to the same server, and it decides which gateway should respond to a given transmission.

Any end device transmission can be heard by multiple gateways, but the server chooses one gateway to respond, instructing the others to ignore the transmission.

This process helps to avoid downlink and uplink collisions, because only a single gateway is transmitting, but other end points might nevertheless overlap

LoRaWAN

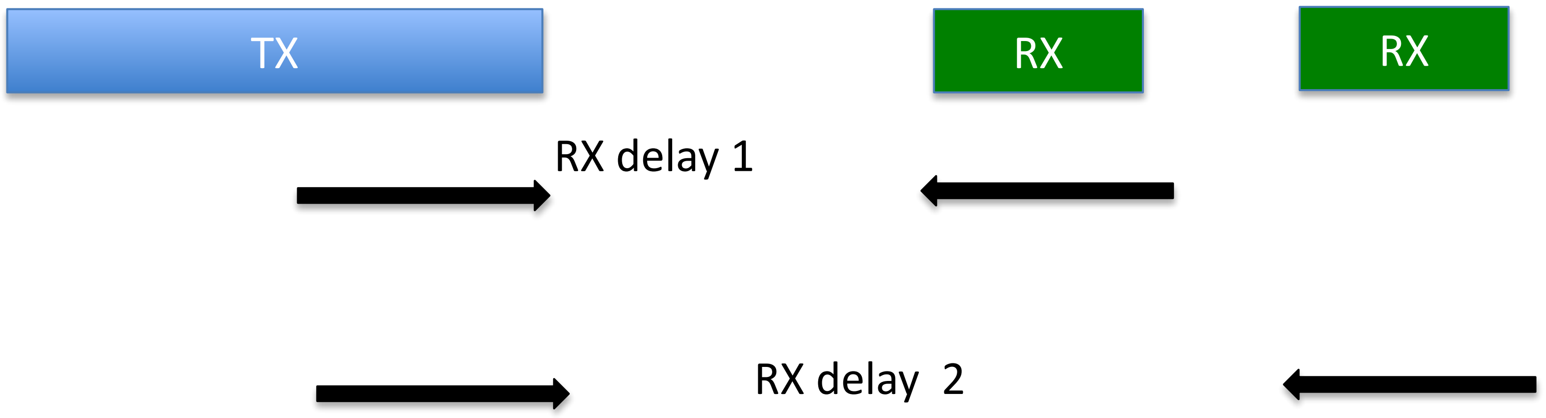
- Supports
  - Secure bidirectional traffic
  - Mobility
  - Localization
- Star of stars topology
- Collisions prevented by maximum duty cycle limitations per frequency
- If nevertheless, there is a collision, the strongest packet prevails

LoRaWAN EU863-870

Data Rate	Configuration	Indicative physical bit rate, bit/s	Max payload size, bytes
0	SF 2/125 kHz	250	51
1	SF11/125 kHz	440	51
2	SF10/125 kHz	980	51
3	SF9/125 kHz	1760	115
4	SF8/125 kHz	3125	242
5	SF7/125 kHz	5470	242
6	SF7/250 kHz	1100	242
7	FSK	50000	242

https://lora-alliance.org/sites/default/files/2018-04/lorawantm_regional_parameters_v1.1rb_-_final.pdf

Down-stream transmission modes



Class A : Following upstream transmission two receive windows are opened after the delay to account for the transmission times.
Gateway must transmit in one of these windows.
Mandatory mode, saves energy but introduces latency.
Class B uses beacons to elicit End Nodes reception.
In Class C, the End Nodes are always listening.

The Thing Network (Community)

Open source LoRaWAN server with end-to-end encryption.

Anyone can:

- Connect devices to The Things Network (TTN).
- Extend TTN by installing a Gateway.
- Build a GW using low cost hardware.
- Manage your own applications and devices or build new applications.

Free trial subscription can be used to assess the technology.

https://www.thethingsnetwork.org/

Build your own Servers

Chipstack (https://www.chirpstack.io) offers all the functionalities required for a complete LoRaWAN network:

- Join and Authentication Server
- Network Server
- Application Server

These servers can be physically located in different places, communicating over the Internet protocol, or can be integrated in the same box.

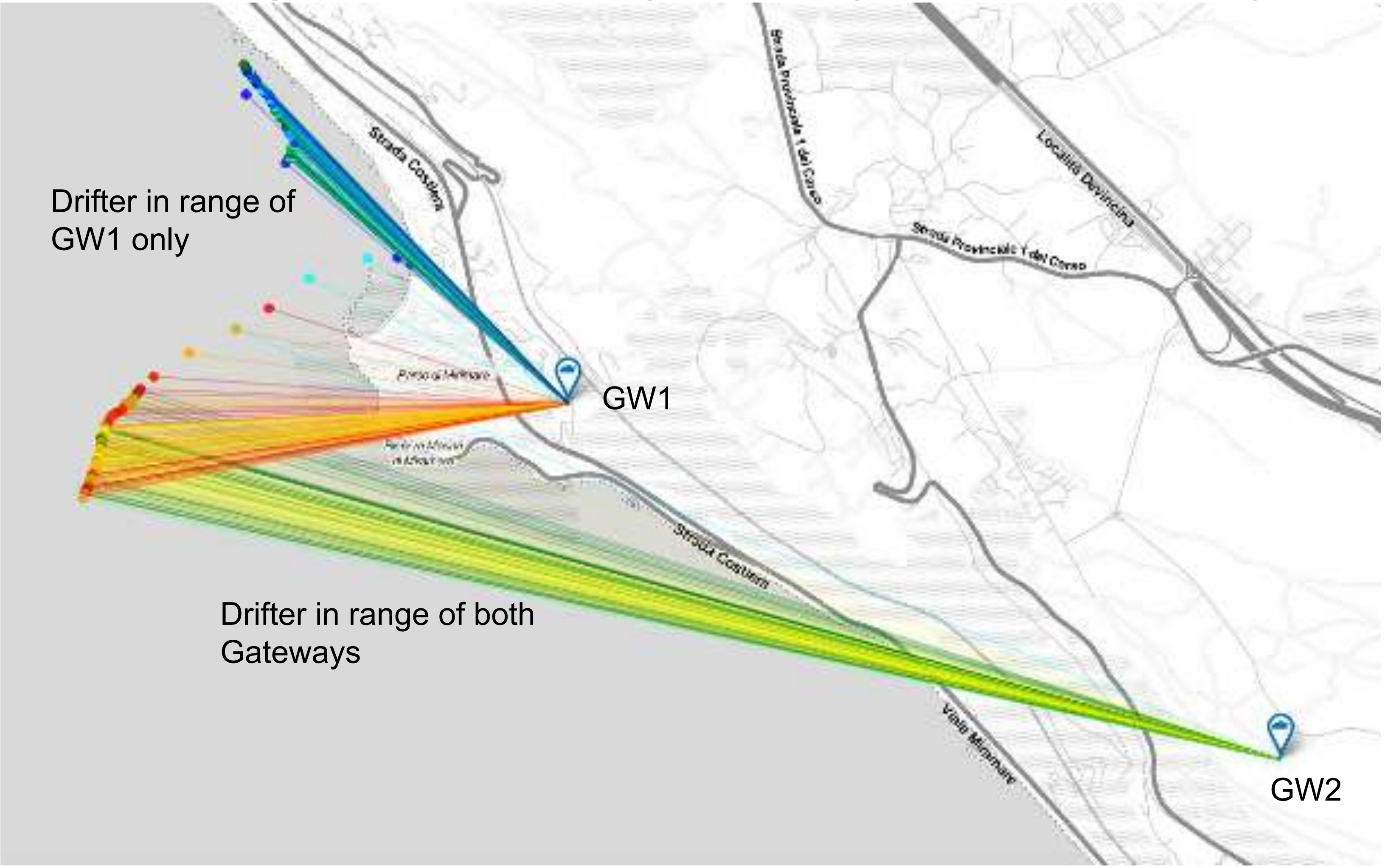
Gateway manufacturers like Milesight and RAK offer easily configurable LoRaWAN servers in their products.

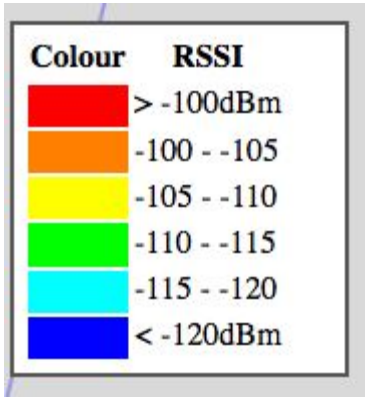
Commercial providers of LoRaWAN services

The Things Industries https://www.thethingsindustries.com
Loriot https://www.loriot.io/professional-public-server.html
Senet https://senetco.com
Actillity https://www.actility.com
Helium https://www.helium.com/lorawan
AWS IoT https://aws.amazon.com/iot/
Loriot and Actillity also offer free trial versions of their services
An updated list of providers is at:
https://www.semtech.com/lora/ecosystem/networks

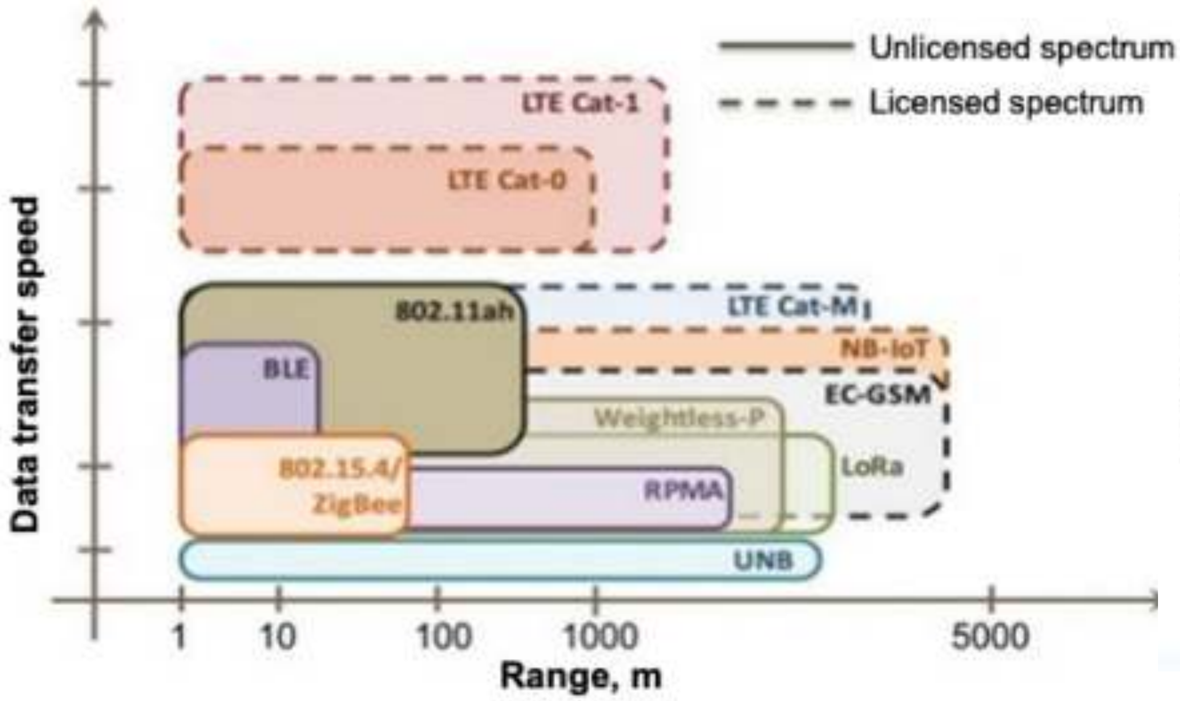
Factor	Public LoRaWAN Networks	Private LoRaWAN Networks
Ownership	Managed by network providers	Under user's control
Coverage	Available in specific regions	Free to cover the area you care
Security	Shared infrastructure	Enhanced control and security
Steup cost	Relatively low cost of entry	Significant infrastructure costs at launch
Data transmission cost	High subscription fees for end devices data transmission	No subscription

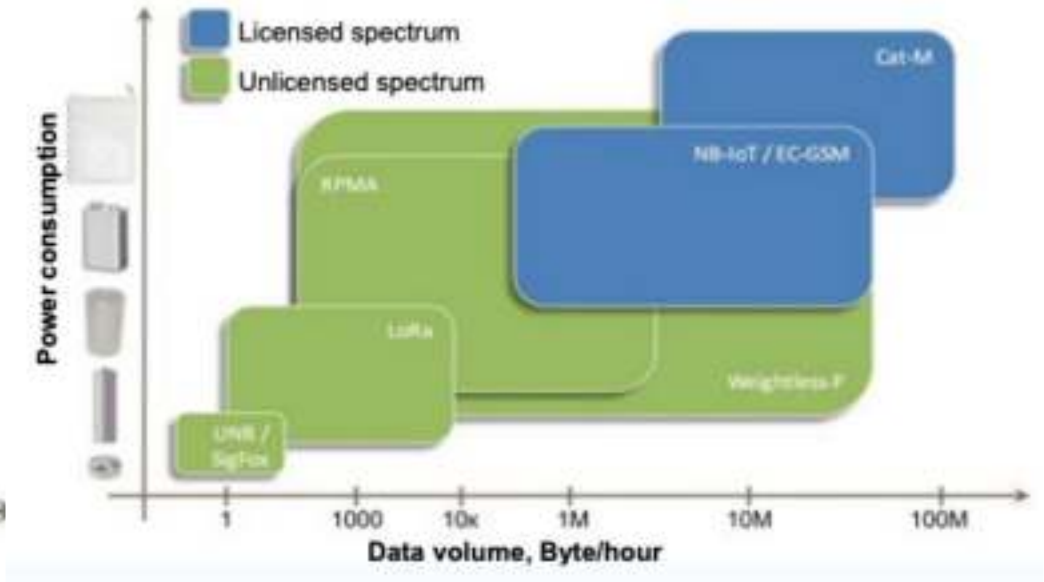
Floating drifter trajectory tracked by two gateways



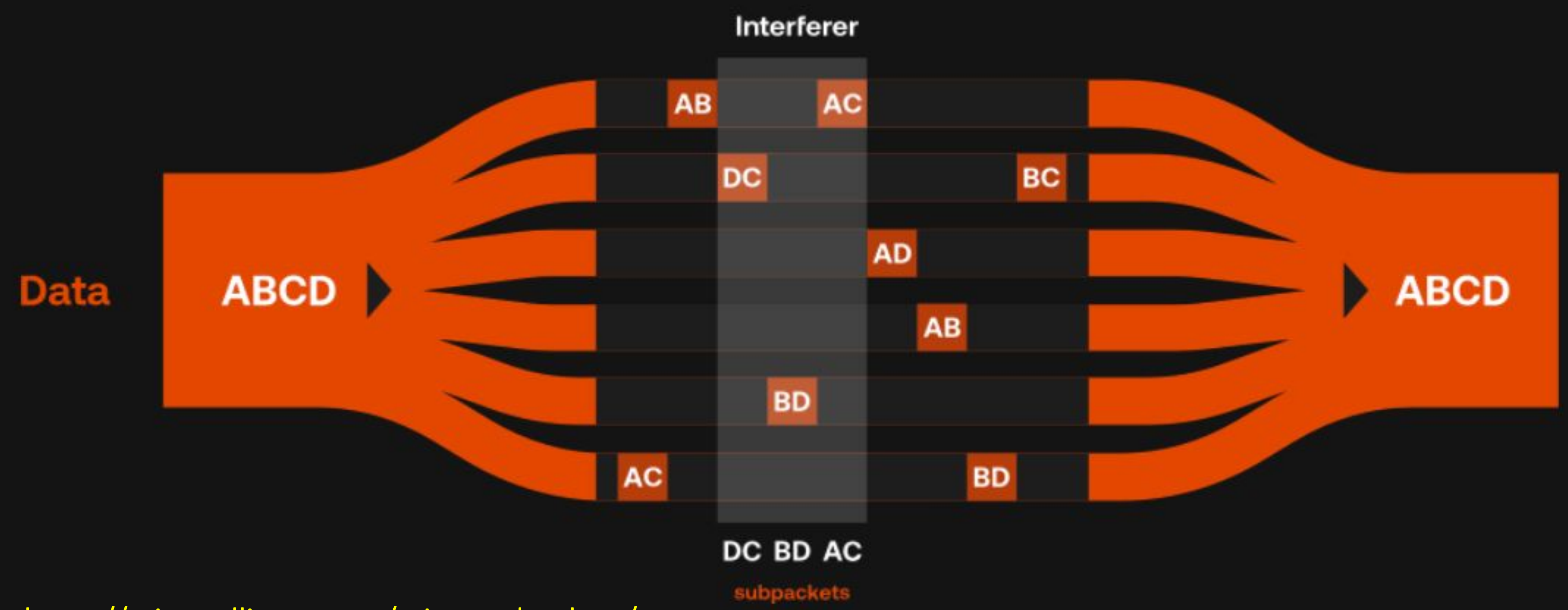


Comparison of IoT technologies





Telegram Splitting concept, for massive deployments



https://mioty-alliance.com/miotytechnology/

MIOTY

ETSI defined telegram-splitting ultra-narrowband (TS-UNB) in ETSI TS 103 357, co-developed by the Fraunhofer IIS in Germany, the promoters of MIOTY, now handled by an international alliance.

- Data is transferred through multiple packets transmitted at varying times and frequencies, providing high immunity to interference and low power consumption.
- Can support up to one million devices per gateway.
- Bandwidth is 200 kHz for two channels (e.g. ,up- and downlink)
- Supports devices that are moving at up to 120 km/h.
- MIOTY can achieve ranges of up to 1.5 km in urban environments and up to 20 km in rural environments.

LoRa-FHSS, another LoRaWAN standard

LoRa-FHSS is another telegram splitting technology that uses frequency hopping like MIOTY.

Classical LoRa transceivers cannot decode LoRa-FHSS, which relies on a software-defined radio approach, making it suitable only for uplink due to its high decoding complexity which allows many more users than classical LoRa .

But LoRa-FHSS has drawbacks:

- Energy consumption is 40% higher than LoRa SF12 (making it 6 times more power hungry than mioty!).
- Sensitivity goes down 3dB in comparison with LoRa SF12.
- Transmission and on-air time goes up.

https://mioty-alliance.com/2024/06/11/new-study-report-mioty-vs-lora-fhss/

RPMA, EC-GSM-IoT, DASH7 and MIOTY adoption

RPMA, EC-GSM-IoT, DASH7, and MIOTY have seen varied levels of adoption, often focused on specific regions or industries.

RPMA targets utility and smart city applications with deployments in parts of the United States and internationally.

EC-GSM-IoT, an enhanced version of GSM for IoT, is being deployed in regions with existing GSM networks but has faced competition from NB-IoT and LTE-M.

DASH7 offers unique capabilities for asset tracking and logistics, with adoption in specific military and commercial applications.

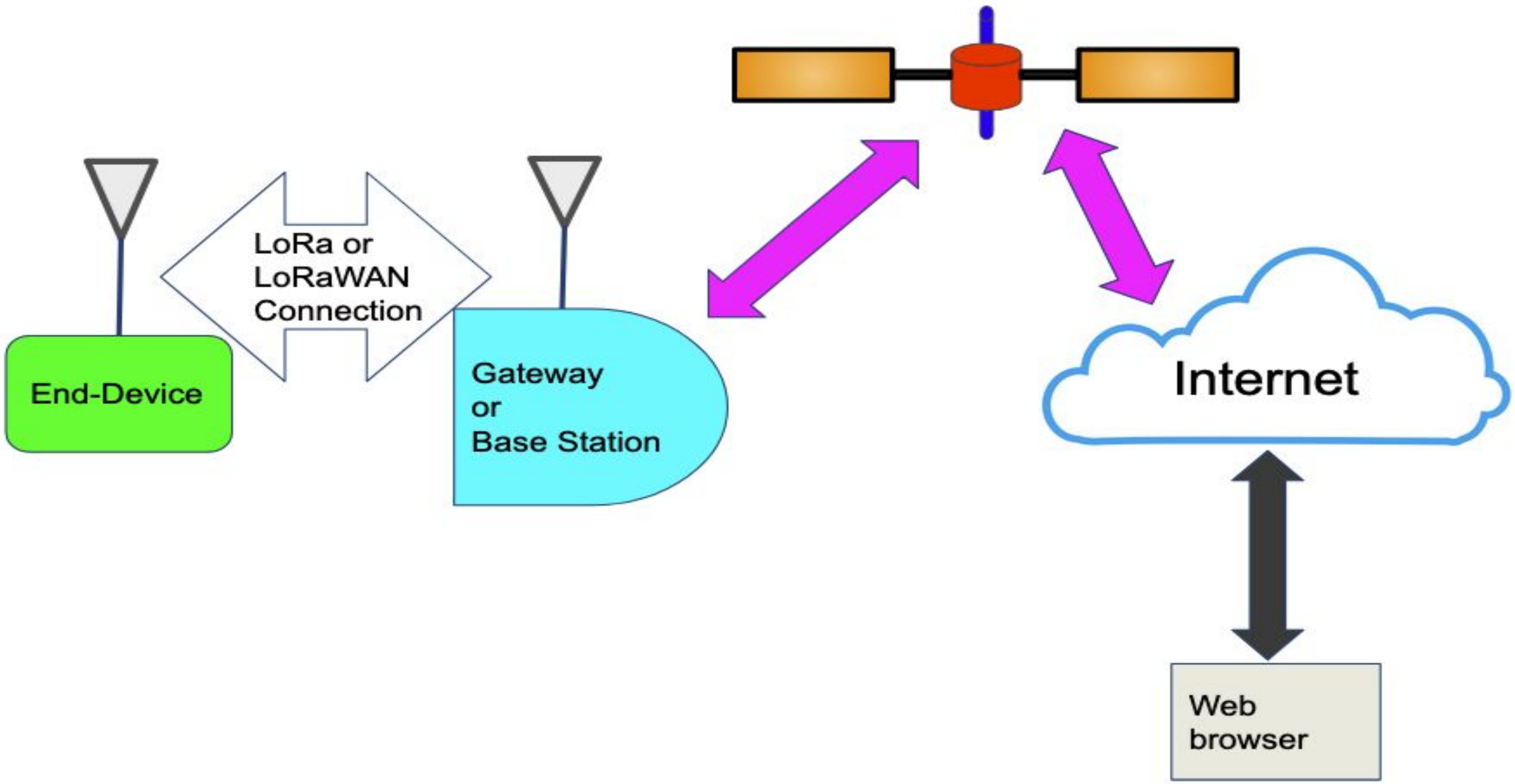
MIOTY is emerging as a strong contender for massive IoT deployments, offering high reliability and scalability, particularly in industrial IoT settings.

https://iotmktg.com/empowering-the-internet-of-things-a-comprehensive-guide-to-lpwan-technologies/

Satellites for IoT

- 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.
- Currently, satellites in both geostationary and LEO orbits are being used to connect gateways or base stations to their core networks.
  - Starlink has over 6000 on LEO providing broadband services in many countries and others entrants are catering to direct IoT services.
- Several constellations of satellites are being launched to provide direct connectivity to the users, and commercial trials are underway.

Lora through Satellites: Classical connection

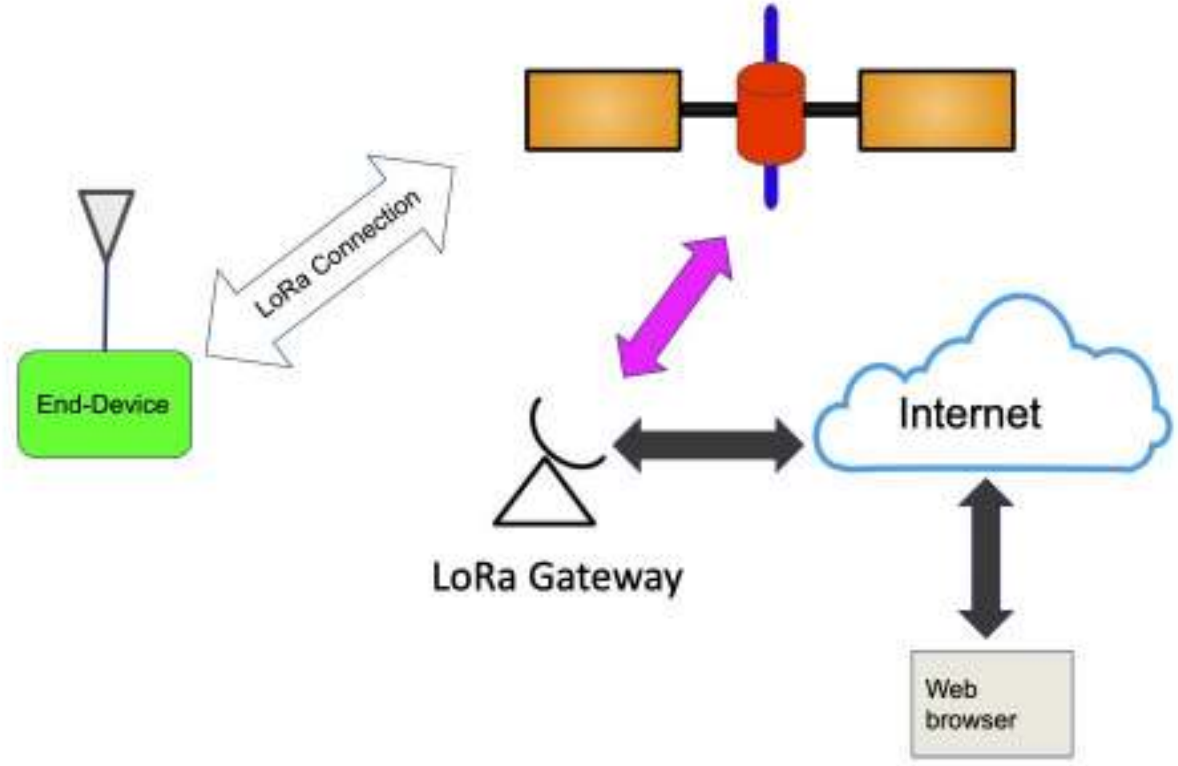


Lora through Satellites: Direct connection

Several vendors WILL offer this service using either GEO or LEO Satellites.

LoRaWAN is not suited for the very long ranges encountered in satellite applications, so different upper layer protocols are employed using LoRa modulation.

LoRa-FHSS can handle the massive number of End Nodes potentially served by a satellite.



Lora through Satellites: Gateway in the sky

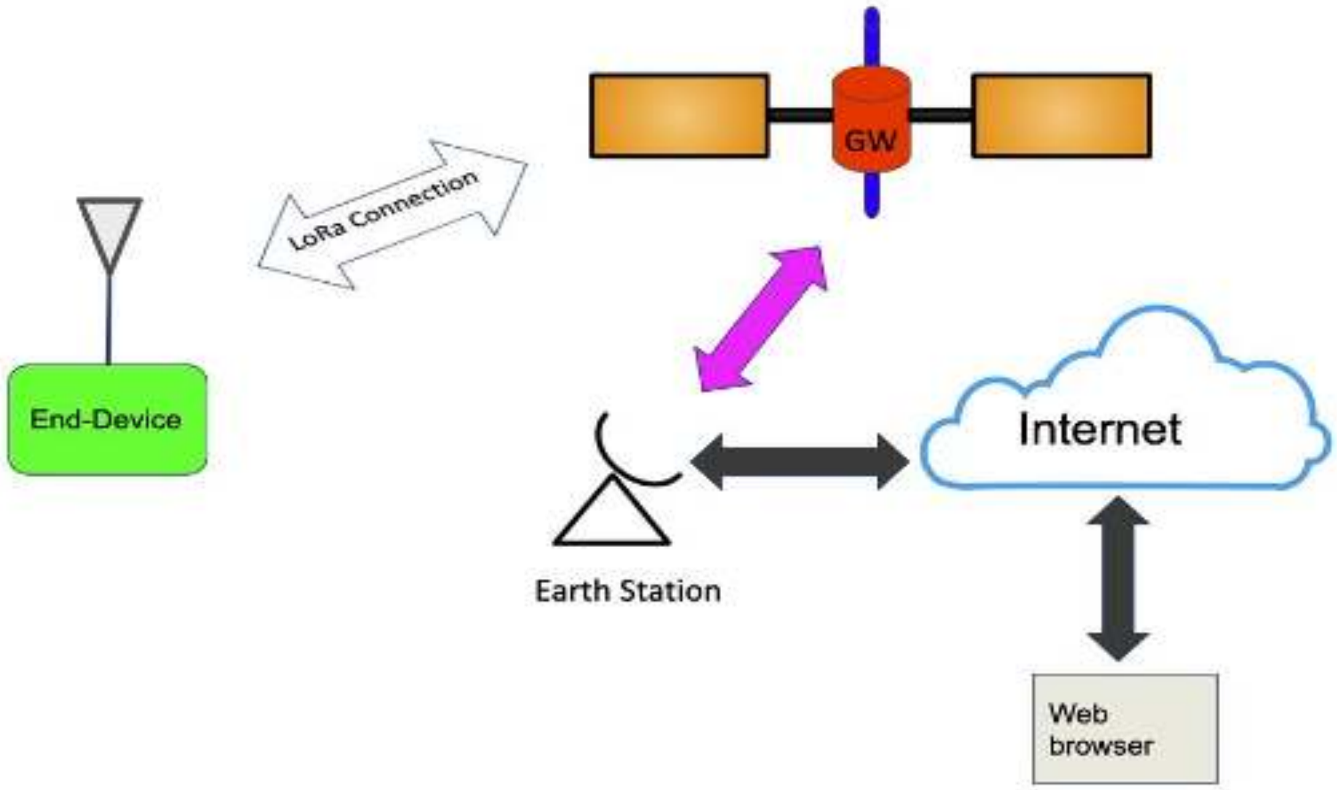
Best solution for IoT.

Several vendors have announced this service using either GEO or LEO Satellites.

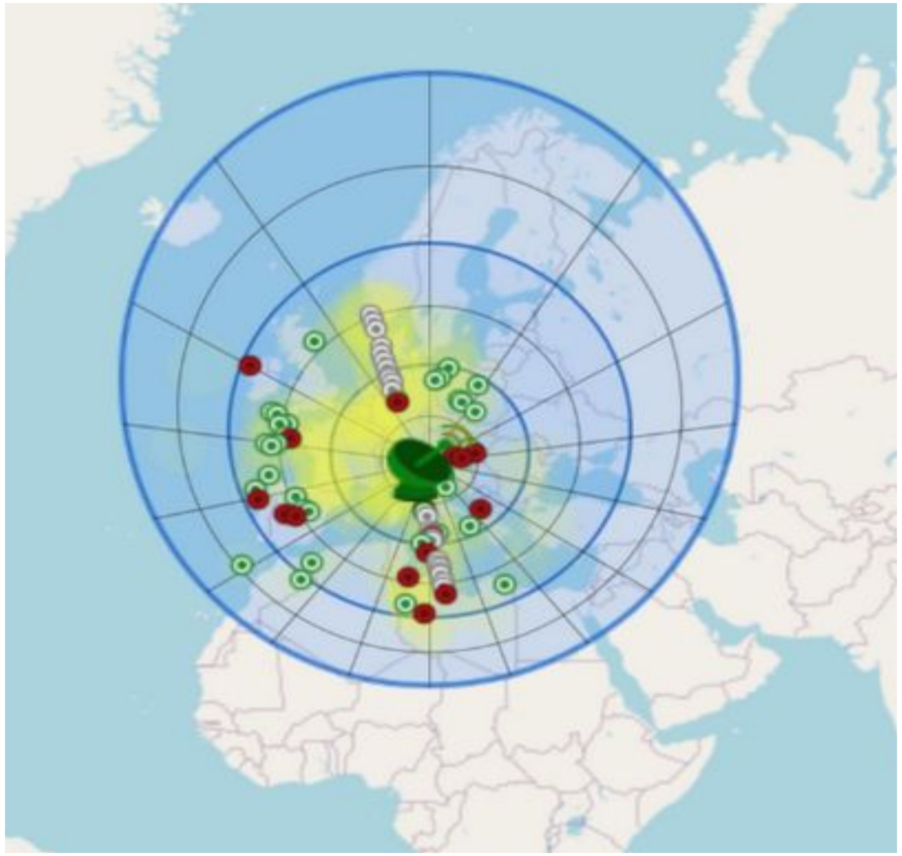
Lacuna is already offering service in Portugal.

The satellites store the messages for a short period of time until they pass over the network of ground stations.

https://lacuna-space.com



TINY GS IoT Open (Source Gateways)



Conclusions

- IoT requires specific solutions.
- Legacy cellular technologies not efficient.
- Cellular IoT address most of the shortcomings but the cost is high and availability limited.
- WiFi , Zigbee and BLE have limited range.
- LoRa and SigFox are widely used worldwide for long distance but with limited data rate.
- LoRaWAN can be leveraged to build your own LPWAN infrastructure.
- Telegram splitting supports a great number of devices per gateway by using software defined radios.
- Machine Learning can alleviate the communication burden of IoT and open up new applications.

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