Tecnologías de Comunicación para IoT

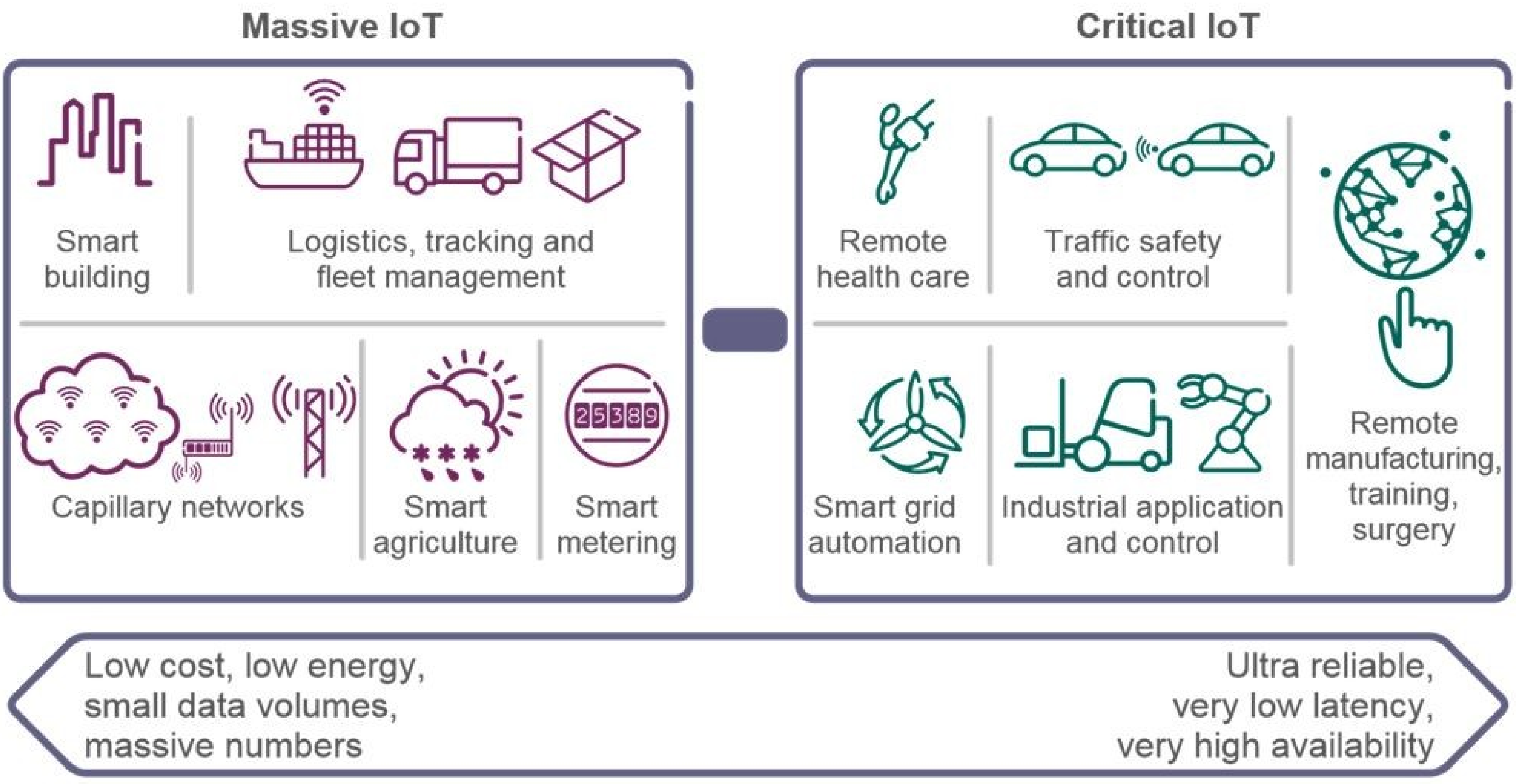
Federico La Rocca

Tecnologías para la Internet de las Cosas

Agenda

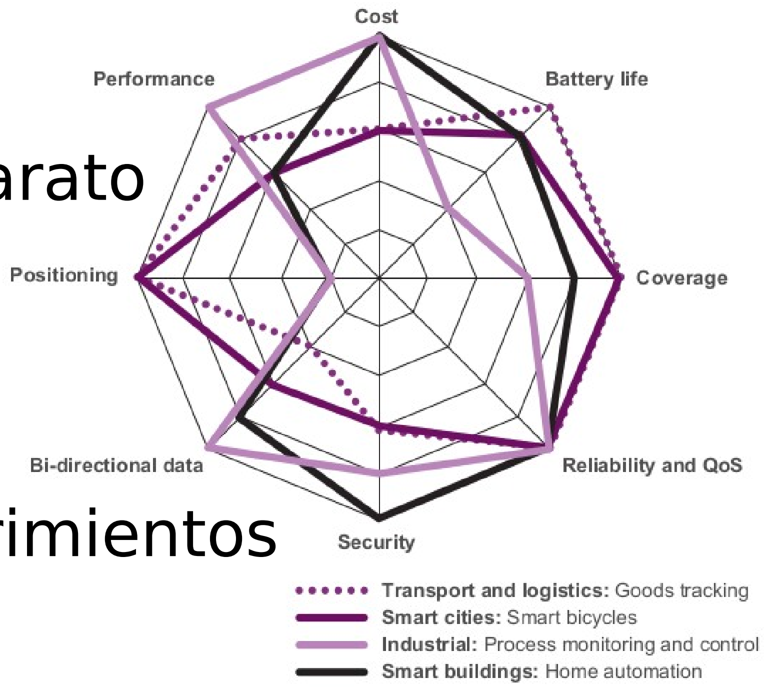
- Introducción
- Tecnologías LPWAN
  - SigFox
  - LoRa
  - Weightless/Telensa
  - RPMA/Ingenu
- Tecnologías “Celulares”
  - NB-IoT
  - LTE-M
- Tecnologías WPAN
  - 802.15.4/Zigbee

Requerimientos



Requerimientos

- Costo
  - Cada terminal debe ser barato
- Duración de batería
  - En escala de años
- Diversidad
  - Las aplicaciones (y requerimientos específicos) son muchas
- Cobertura
  - Extenso e incluso indoor
- Escalabilidad
  - Pasar de algunos terminales a una cantidad masiva



Perspectiva histórica

- Hasta no hace mucho
  - Comunicación con sensores via GPRS

Por otro lado, la Parte II del proyecto surge a partir del contacto con el Dr. Néstor Mazzeo y MSc. Guillermo Goyenola del Departamento de Ecología Teórica y Aplicada del Centro Universitario Regional Este (CURE), para estudiar la factibilidad de implementar un sistema de medida de parámetros en tiempo real *in situ* que permita conocer la calidad del agua. El sistema que implementamos consiste en una serie de nodos independientes que toman medidas sobre la calidad del agua y las reportan a un servidor. Estas se obtienen con los siguientes sensores: pH, oxígeno disuelto, temperatura e intensidad de luz. El nodo se compone de este conjunto de sensores, un microcontrolador Arduino Uno, una batería como fuente de energía, un módem GPRS y un sensor de presión para medir profundidad. Todo el conjunto se monta sobre una boya, en el agua. El sistema opera de forma automática, tomando medidas y transmitiéndolas a través de la red celular. El ser-

Universidad de la República
Facultad de Ingeniería

GALATEA: Grupo de Análisis Local y Alerta TEmprana de calidad de Agua

Memoria de proyecto presentada a la Facultad de Ingeniería de la Universidad de la República por

Federico Nin, Paola Romero

en cumplimiento parcial de los requerimientos para la obtención del título de Ingeniero Electricista.

Tutor

Dr. Ing. Leonardo Steinfeld .... Universidad de la República
Dr. Ing. Federico Lecumberry .... Universidad de la República

Tribunal

Dr. Ing. Federico La Rocca .... Universidad de la República
MSc. Ing. Sebastián Fernández .... Universidad de la República
Ing. Gonzalo Gutiérrez .... Universidad de la República

Montevideo
miércoles 28 diciembre, 2016

Perspectiva histórica

- Pero la red 2G se dará de baja en 2023
- Usar modems 3G/4G?
  - Costo
  - Batería
- Varias empresas vieron el hueco y así surgió LPWAN (Low-Power Wide Area Networks)

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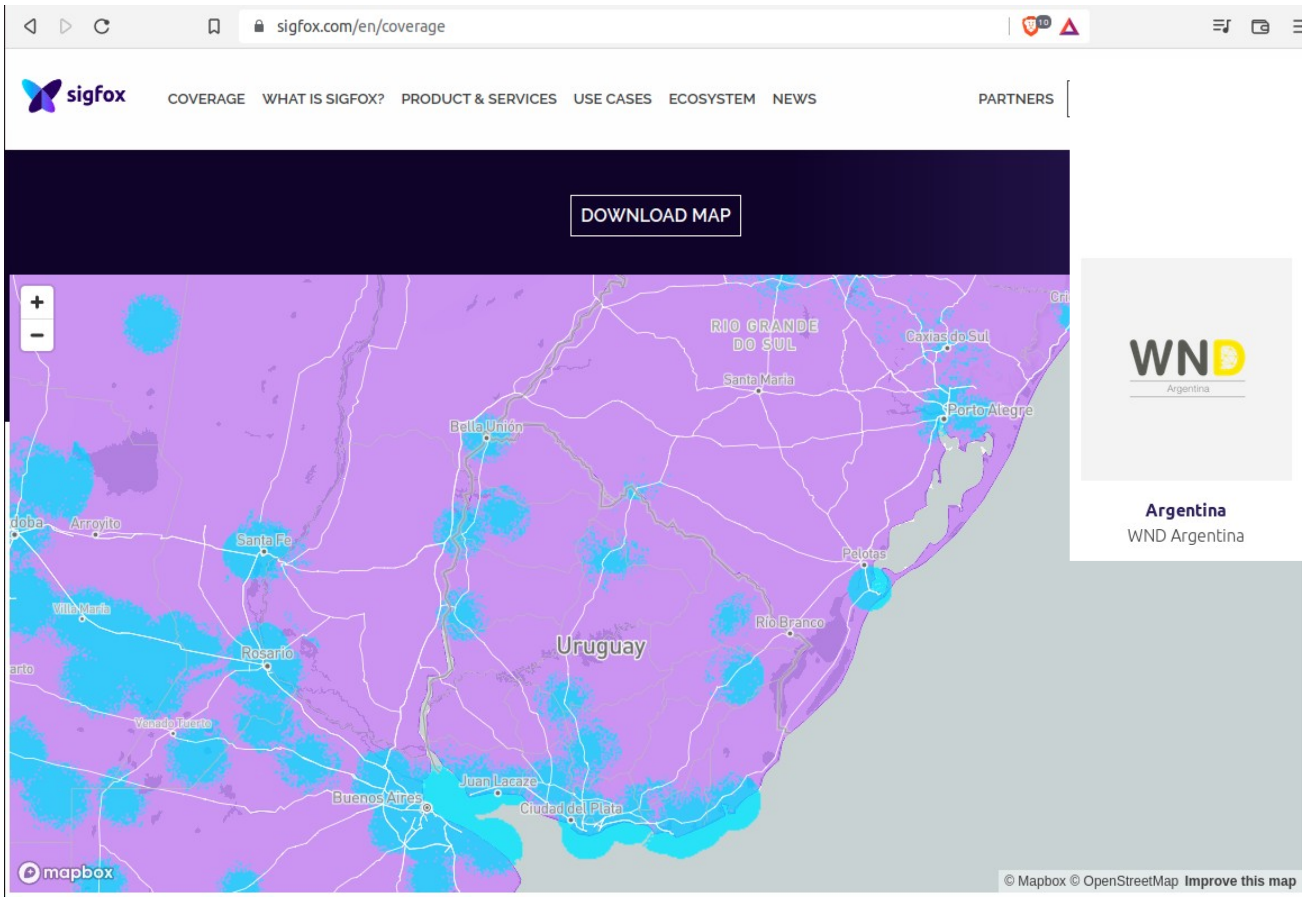
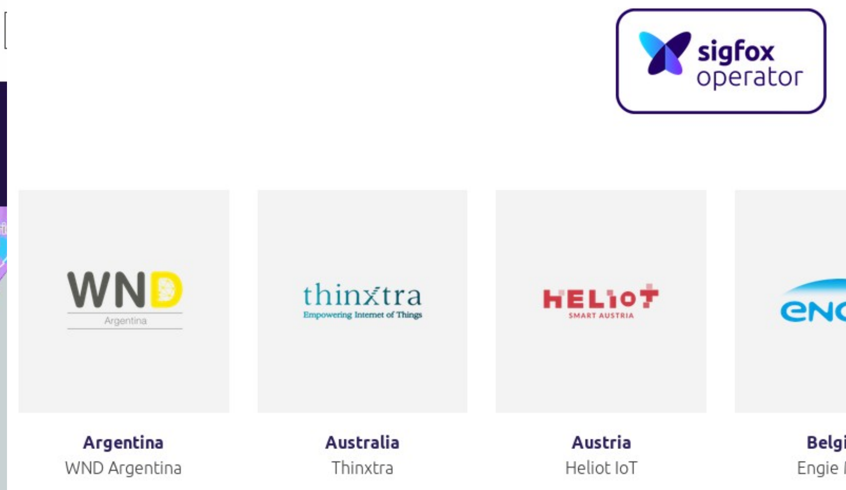
  - NB-IoT
  - LTE-M
- Tecnologías WPAN
  - 802.15.4/Zigbee

Sigfox

- Modelo de negocios:
  - *Sigfox operators* se instalan en los distintos países
    - Las “radiobases” y el backend son propietarios





Uruguay:
0G Uruguay

Sigfox

- Modelo de negocios:
  - *Sigfox operators* se instalan en los distintos países
  - Se paga por el uso de la red

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engie m2m
Sigfox operator

THE SIGFOX NETWORK SOLUTIONS SUBSCRIPTIONS & PRICES

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Subscriptions & prices

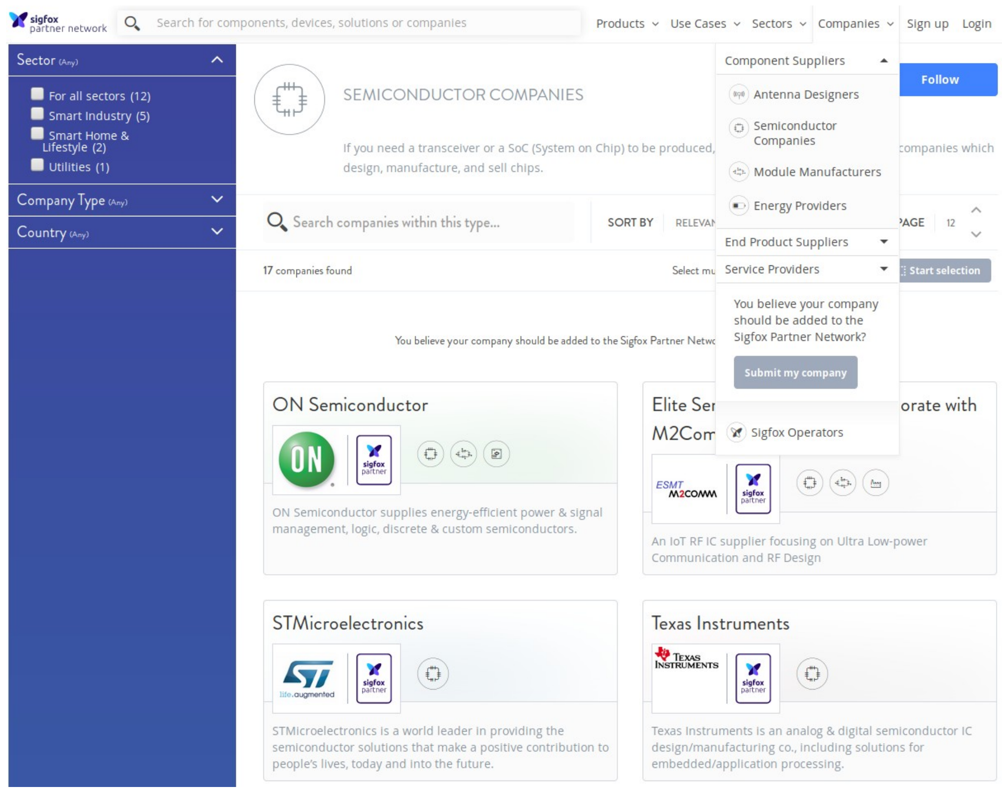
We offer different plans for your Sigfox subscription. Simply fill in the form below and discover which plan is perfect for your Sigfox-enabled project.

Platinum	Gold	Silver	One
140 uplink & 4 downlink messages/day	100 uplink & 2 downlink messages/day	50 uplink & 1 downlink messages/day	2 uplink & 0 downlink messages/day
€7/year	**€6/year**	**€5/year**	**€3/year**
For the first year, a one-time activation fee of €7 per device will be added.	For the first year, a one-time activation fee of €6 per device will be added.	For the first year, a one-time activation fee of €5 per device will be added.	For the first year, a one-time activation fee of €3 per device will be added.

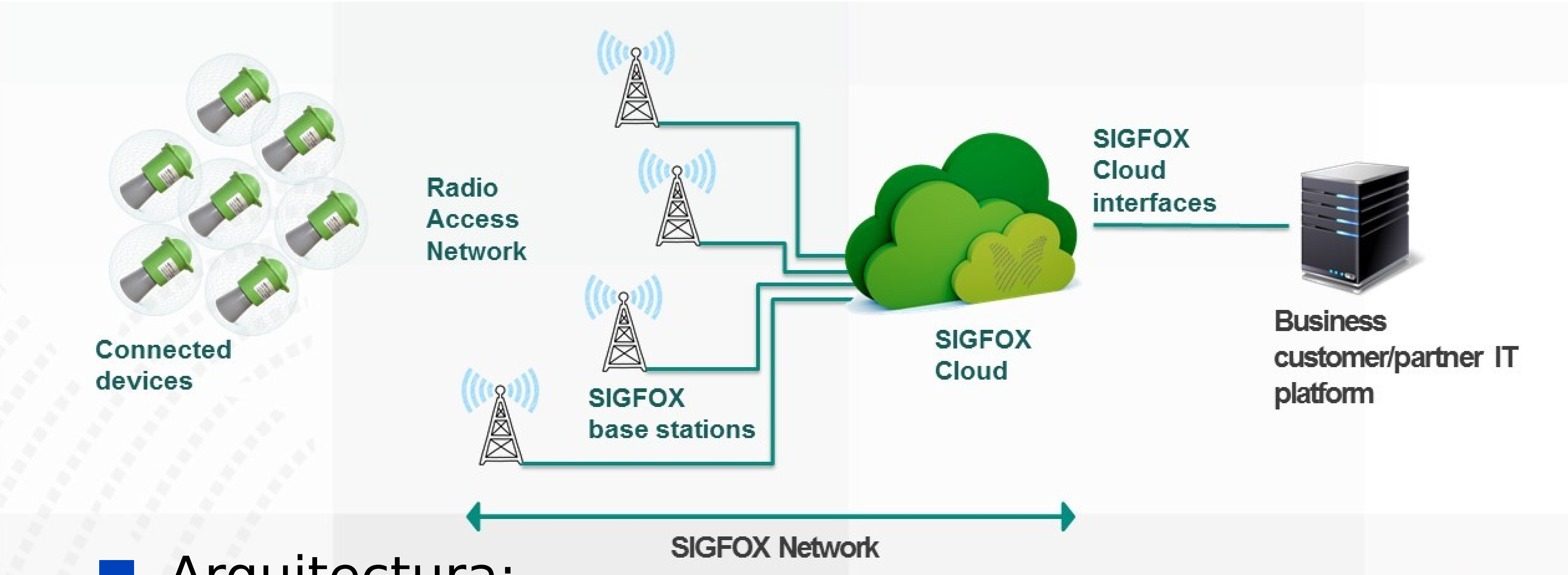
Mensaje uplink = 12 Bytes
Mensaje downlink = 8 Bytes

Sigfox

- Modelo de negocios:
  - *Sigfox operators* se instalan en los distintos países
  - Se paga por el uso de la red
  - Varias empresas proveen chips, módulos, o productos completos



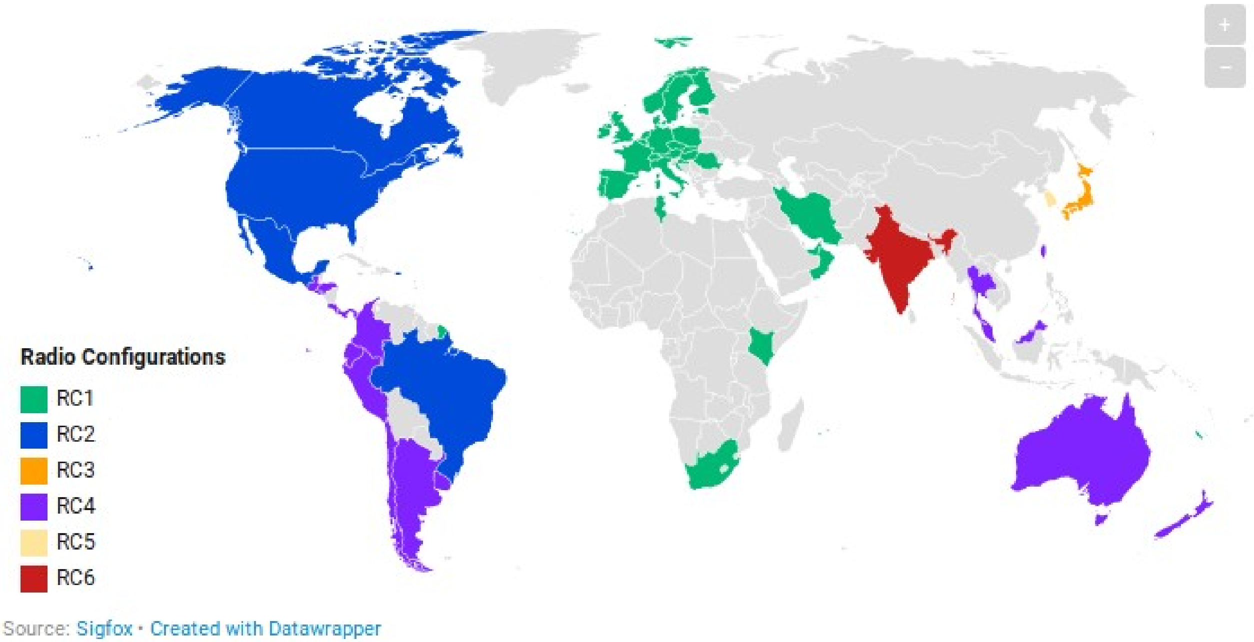
Sigfox - Arquitectura



- Arquitectura:
  - Aloha no-ranurado: el nodo envía por triplicado en tres frecuencias distintas
- Todo mensaje recibido por las estaciones base es re-enviado a la nube Sigfox
- La nube Sigfox se encarga de autenticar y eliminar duplicados, y luego los envía al cliente correspondiente

Sigfox - Tecnología

- Modulación:
  - Señal modulada en DBPSK a 100/600 Hz (i.e. 100/600 bps) en el **uplink**: UNB (Ultra Narrow Band)
  - Modulación GFSK a 1.5 kHz (600 bps) en el **downlink**
- Banda:



Sigfox - Tecnología

- Banda:

	RC1	RC2	RC3	RC4	RC5	RC6
Uplink center frequency (MHz)	868.130	902.200	923.200	920.800	923.300	865.200
Downlink center frequency (MHz)	869.525	905.200	922.200	922.300	922.300	866,300
Uplink data rate (bit/s)	100	600	100	600	100	100
Downlink data rate (bit/s)	600	600	600	600	600	600
Sigfox recommended EIRP (dBm)	16	24	16	24	14	16
Specifics	Duty cycle 1% *	Frequency hopping **	Listen Before Talk ***	Frequency hopping **	Listen Before Talk ***	

- * **Duty cycle** is 1% of the time per hour (36 seconds). For an 8 to 12 bytes payload, this means 6 messages per hour, 140 per day.
- ** **Frequency hopping**: The device broadcasts each message 3 times on 3 different frequencies. Maximum On time 400 ms per channel. No new emission before 20 s.
- *** **Listen Before Talk**: Devices must verify that the Sigfox-operated 200 kHz channel is free of any signal stronger than −80 dBm before transmitting.

Sigfox - Tecnología

- Modulación: UNB
- Capa MAC
  - Aloha no-ranurado: el nodo envía por triplicado en tres frecuencias elegidas al azar
  - No hay conexión con la estación base (y por lo tanto no hay handover) ni ACKs
- Link budget: 155 dB
  - Alcance de hasta 10km en medios urbanos

The main reasons for the choice of UNB signals were not dictated by budget link gains (ie: range) - similar performance being achievable with the other mentioned techniques- but by a better resilience to unexpected or largely unpredictable interferences under “shared spectrums” (typically license exempt bands), and by higher capacity of short messages per MHz, with a low if not inexistent synchronization protocol and the reception of more than 300 simultaneous messages.

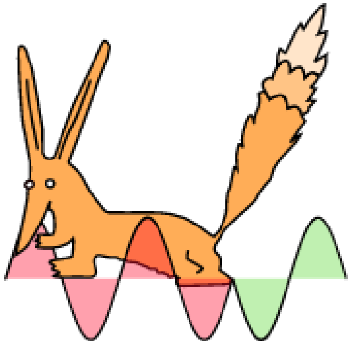
Sigfox - Tecnología

■ Implementaciones abiertas: renard-phy

README.md

`renard-phy` - Sigfox Protocol Physical Layer

`renard-phy` is an open source physical layer implementation of the Sigfox protocol's uplink and downlink written in Python for use with software defined radios (SDRs). It supports demodulating received Sigfox uplinks and downlinks recorded as WAV files (e.g. with gqrx and any SDR hardware that supports Sigfox's frequency range). Modulating uplink and downlink frames is supported for the *HackRF One* SDR.



`renard-phy` is built on top of `renard`, the CLI interface to the open source Sigfox protocol library `librenard`.

`renard-phy` has only been tested in regulatory zone "RCZ1" (Europe / ETSI).

LoRa

- Modelo de negocios: SemTech tiene las patentes de la capa física
  - Fabrica los chips

Semtech SX1272

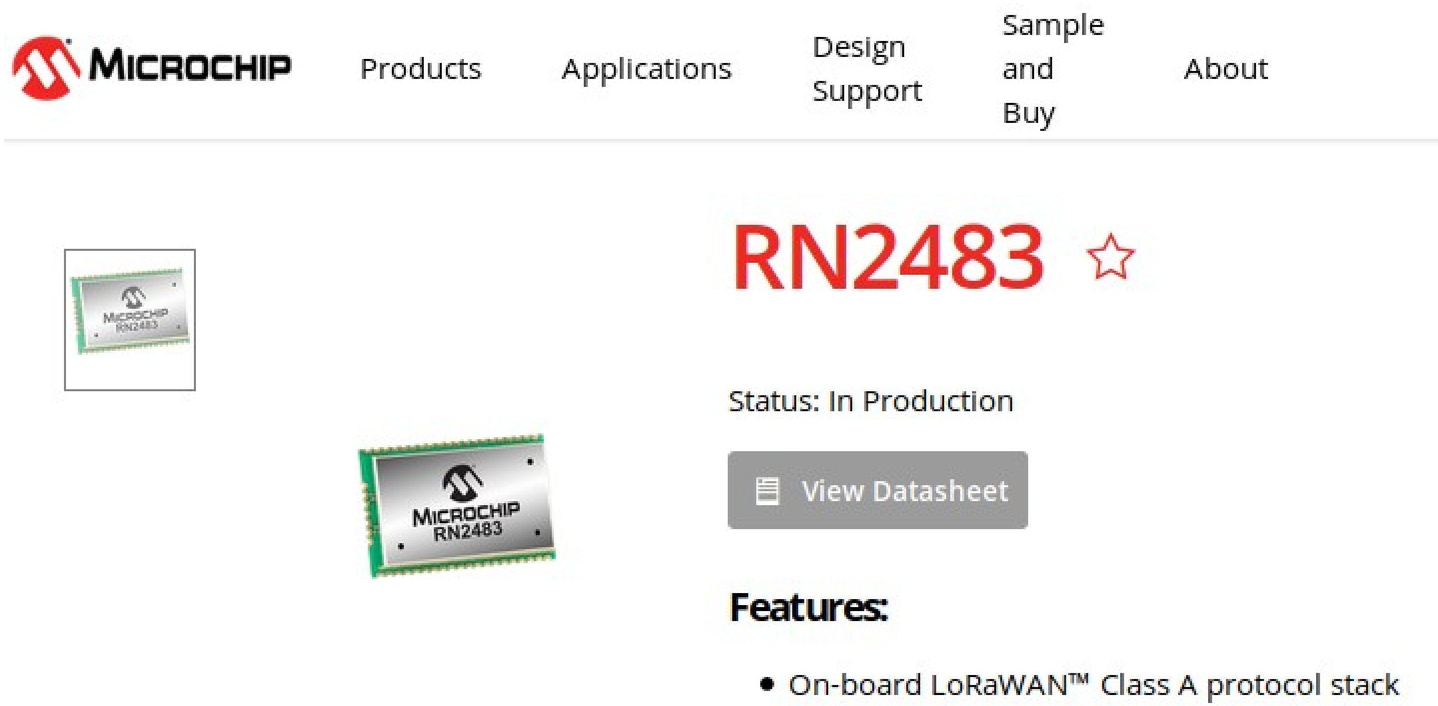
Long Range, Low Power RF Transceiver 860-1000 MHz with LoRa® Technology

The SX1272/73 transceivers feature the LoRa® long range modem that provides ultra-long range spread spectrum communication and high interference immunity whilst minimising current consumption.

Using Semtech's patented LoRa modulation technique SX1272/73 can achieve a sensitivity of over -137 dBm using a low cost crystal and bill of materials. The high sensitivity combined with the

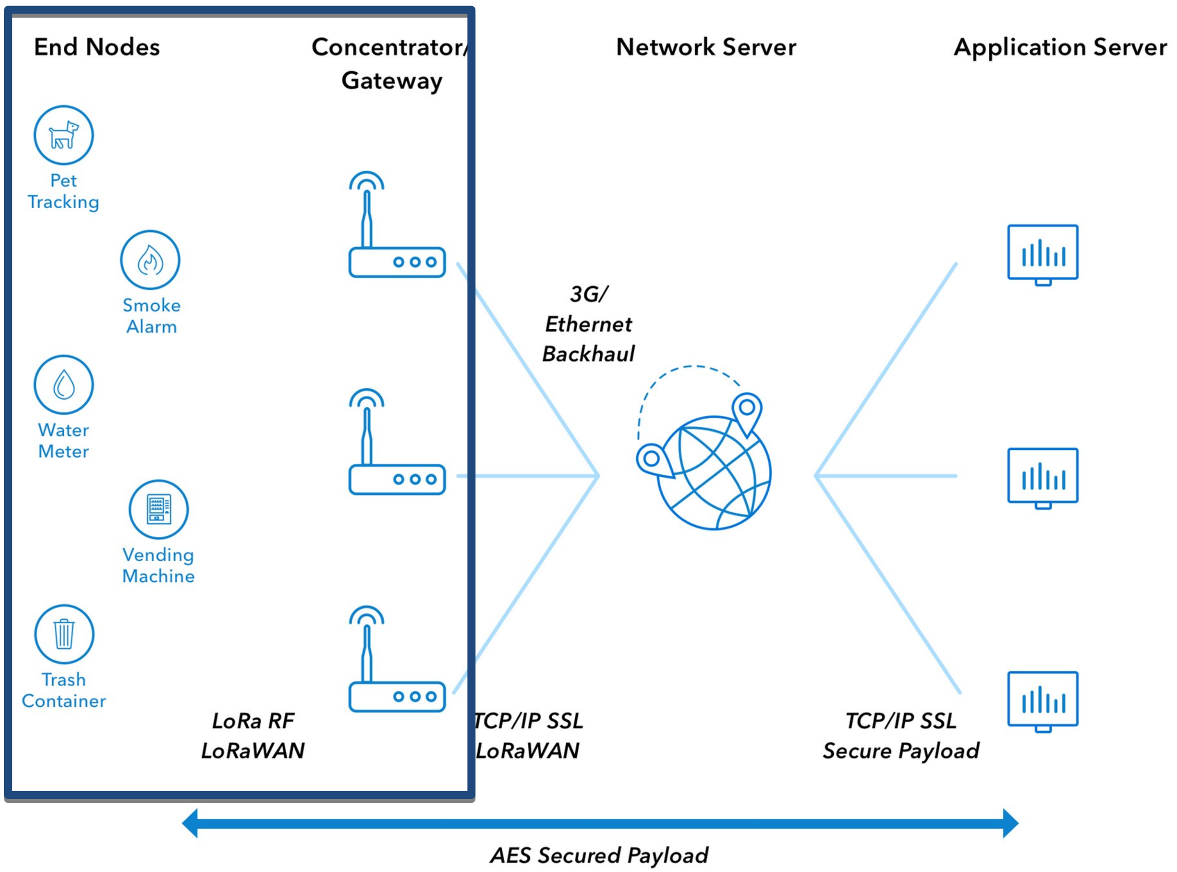
LoRa

- Modelo de negocios: SemTech tiene las patentes de la capa física
  - Fabrica los chips
  - O cobra las regalías



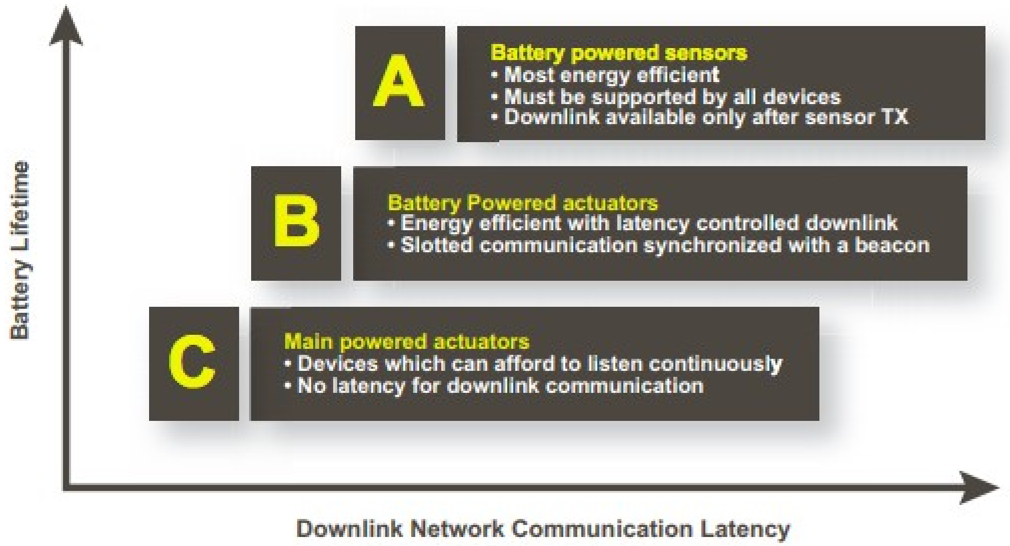
LoRa - Arquitectura

- A diferencia de Sigfox, es “abierta”
  - Hoy vamos a hablar del último salto



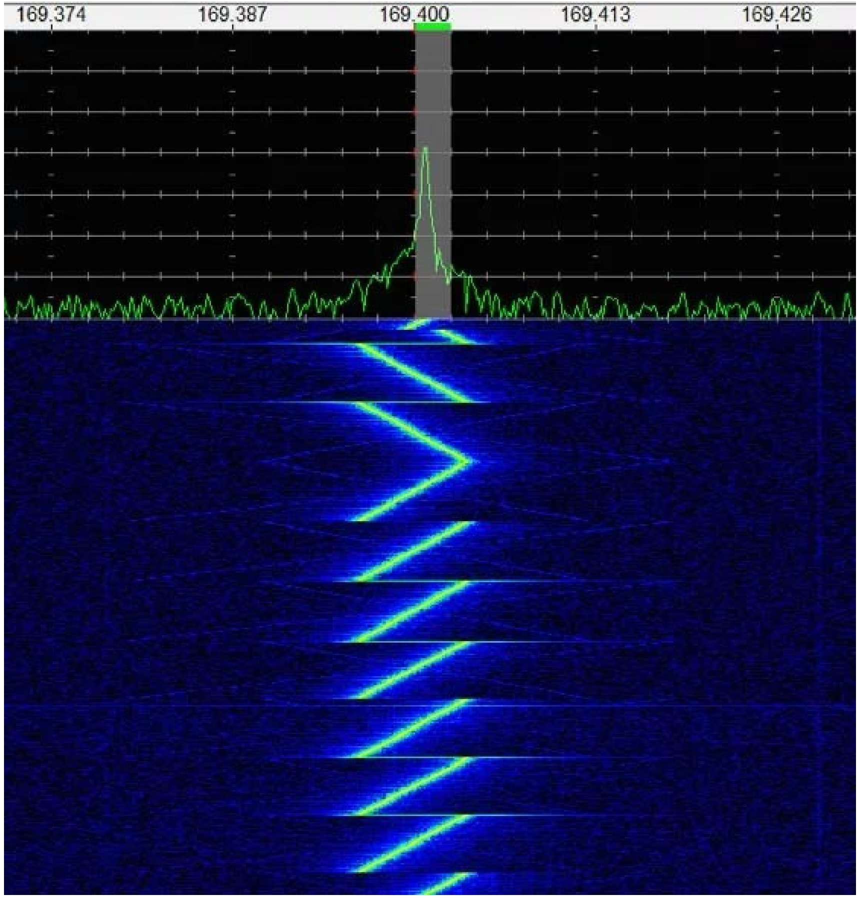
LoRa

- Tipos de "end nodes"
  - Clase A (all): abre una ventana de recepción sólo luego de cada transmisión
  - Clase B (Beacon): abre una ventana de recepción periódicamente
  - Clase C (Continuous): todo el tiempo escucha



LoRa - Modulación

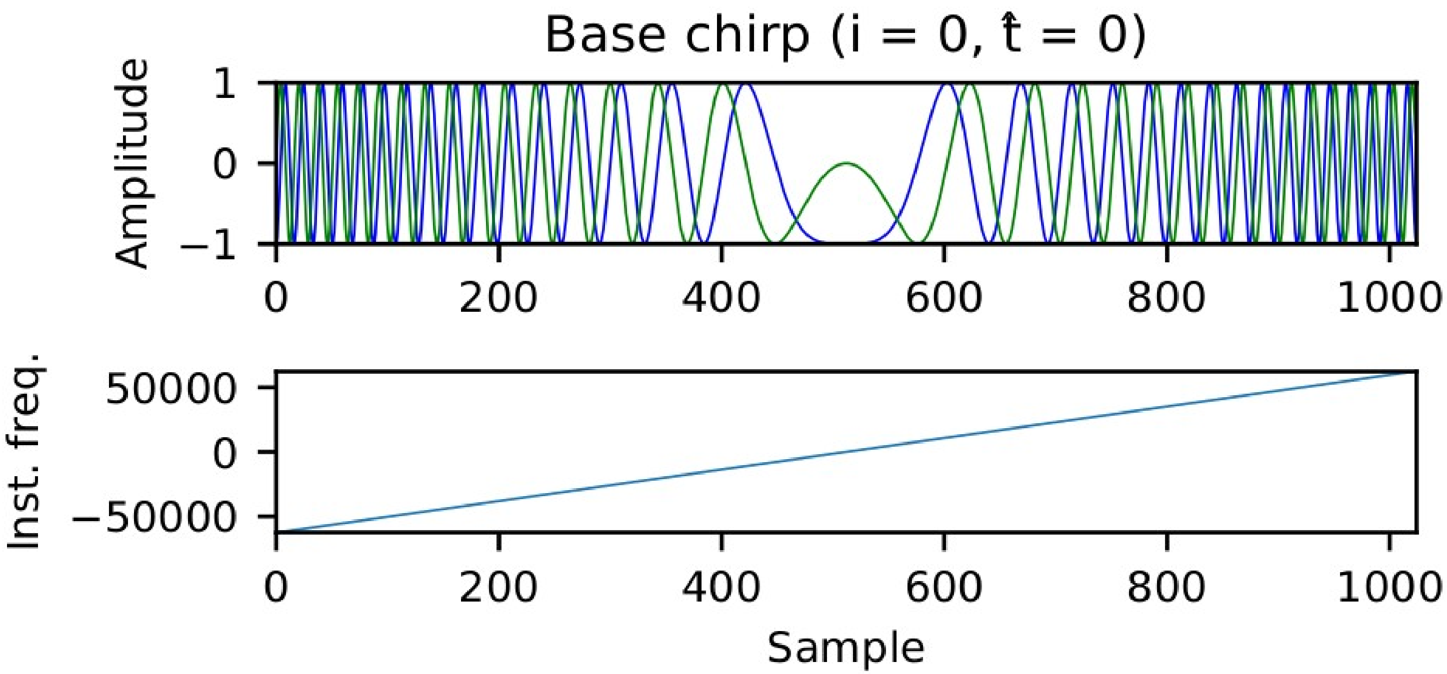
- LoRa es también el nombre de la modulación
  - Patentada, así que mucho reverse-engineering
  - Fuente y detalles: “A Multi-Channel Software Decoder for the LoRa Modulation Scheme”, P. Robyns et al., IoTBDS 2018
- Base: Chirp Spread Spectrum (CSS)



LoRa - Modulación

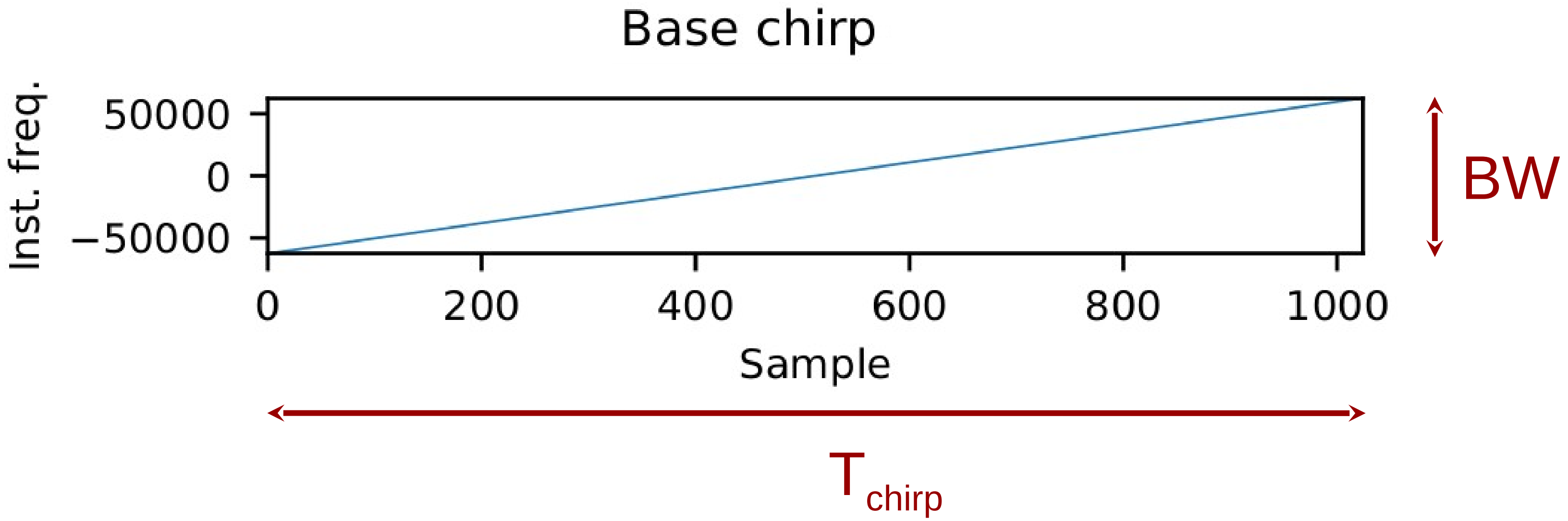
- Base (Up-)chirp: aumento lineal de la frecuencia durante T_{chirp} segundos

$$x(t) = e^{j(\phi_0 + 2\pi(kt^2/2 + f_0 t))}$$



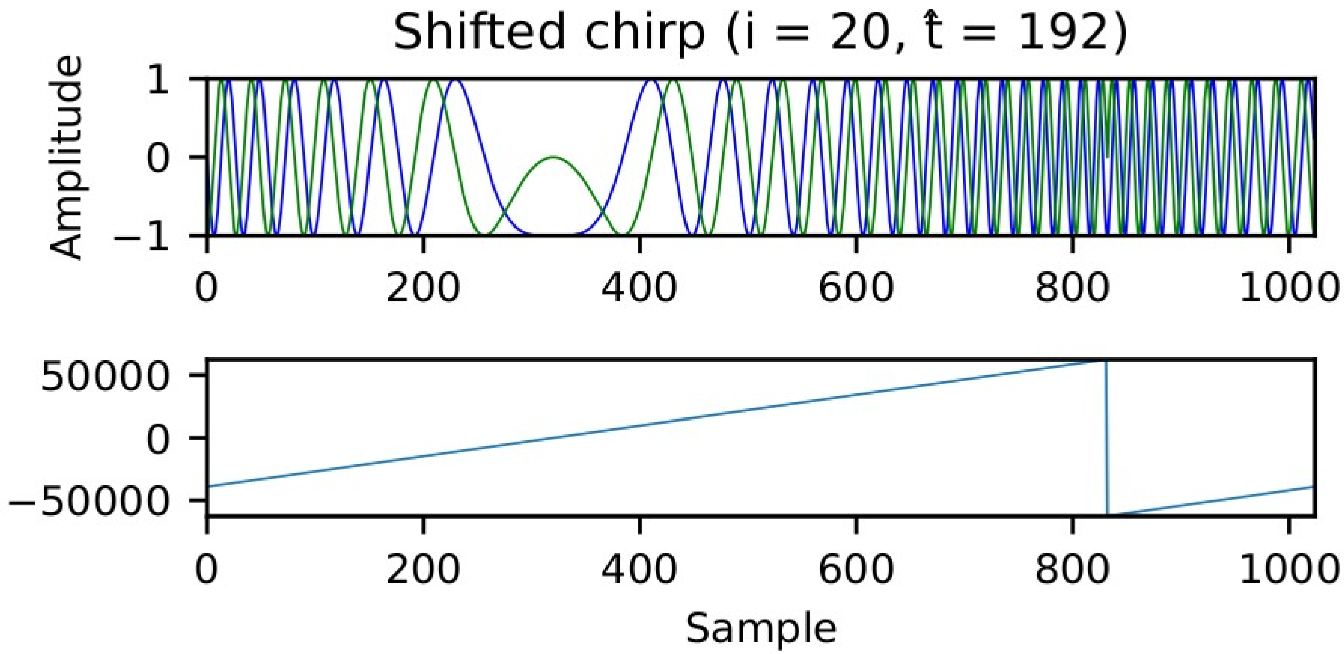
LoRa - Modulación

- Parámetros:
  - BW: ancho de banda ocupado por el chirp
  - Duración del chirp: $T_{chirp} = 2^{SF}/BW$
  - Spreading Factor (SF): entero entre 7 y 12



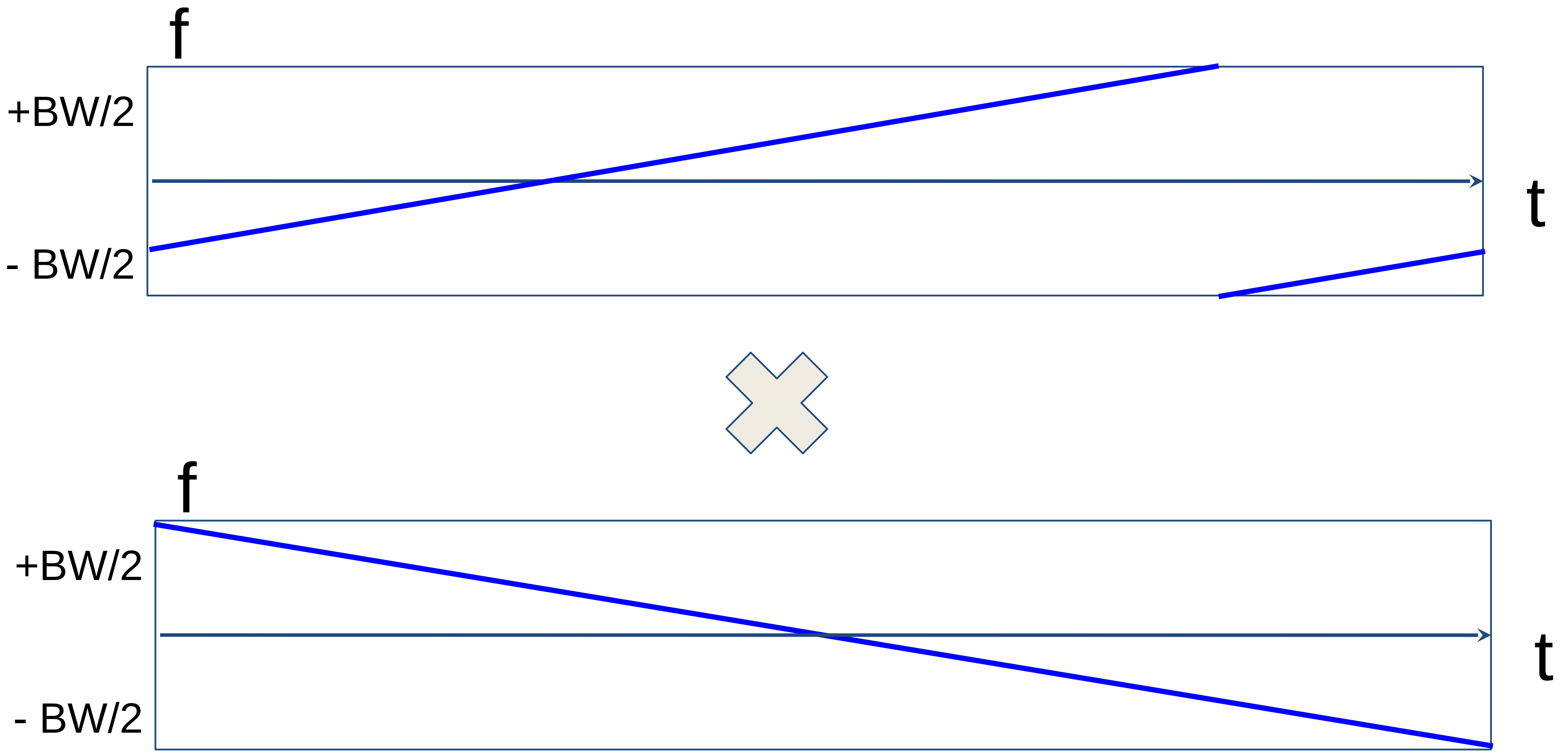
LoRa - Modulación

- Símbolo:
  - Cada chirp envía *SF* bits
  - ¿Cómo se generan los 2^{SF} símbolos posibles?
    - T_{chirp} se parte en 2^{SF} sub-intervalos: el punto de quiebre en la pendiente marca el símbolo

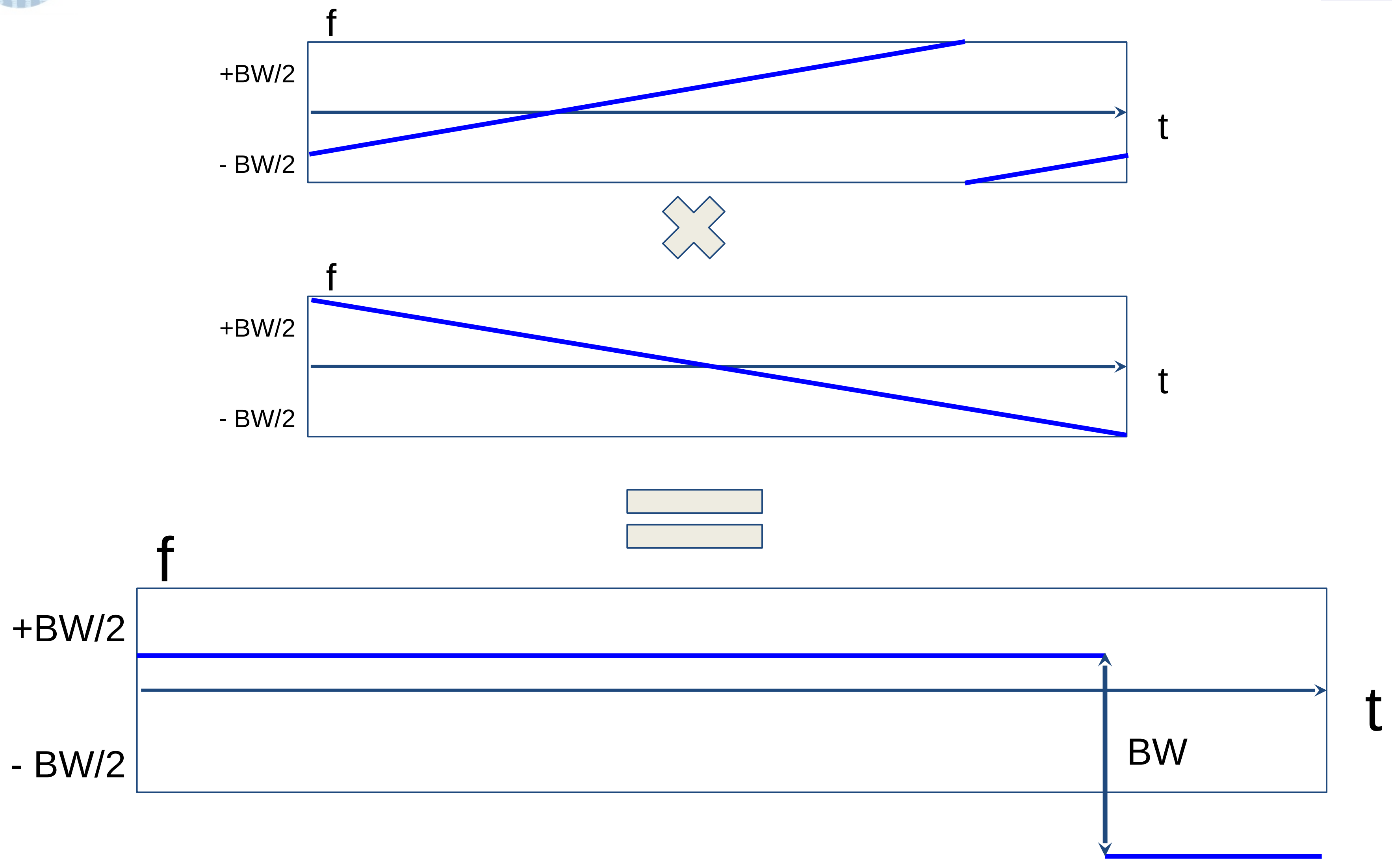


LoRa - Modulación

- Recepción: ¿Si multiplico el símbolo recibido por un base down-chirp en qué resulta?

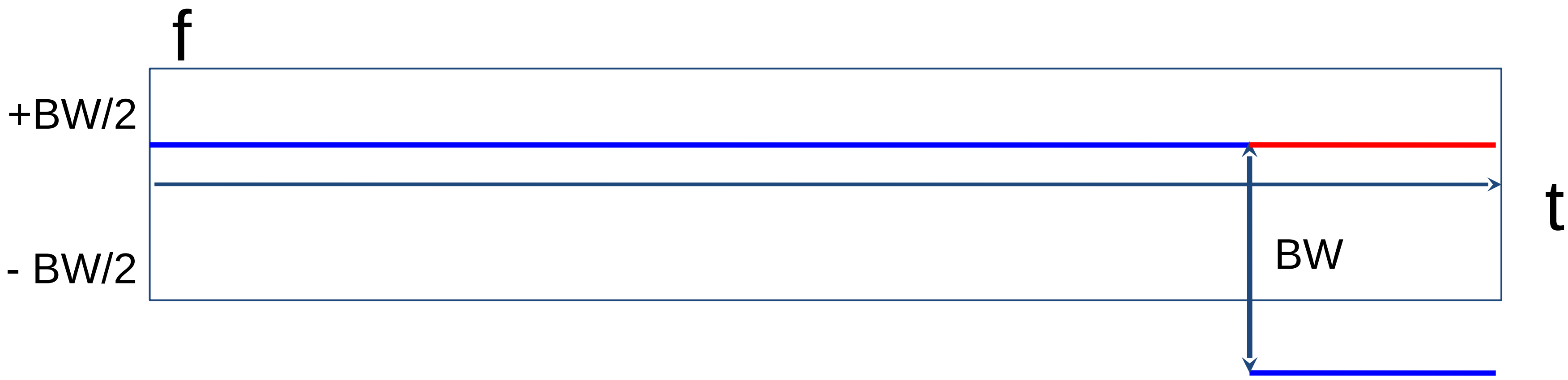


LoRa - Modulación



LoRa - Modulación

- Tomo muestras a tasa BW y aliasing mediante...
  - Observación: tomo 2^{SF} muestras ($T_{chirp}=2^{SF}/BW$)



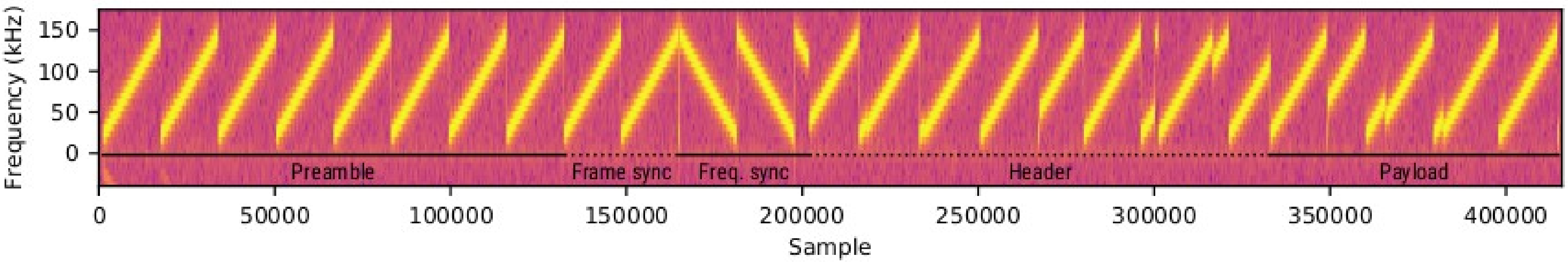
- Otra forma de pensarlo: categorizar *f* (de entre las 2^{SF} posibilidades) de la señal discreta

$$x_r[n] = e^{2\pi f n BW} x_{chirp}(nBW)$$

LoRa - Modulación

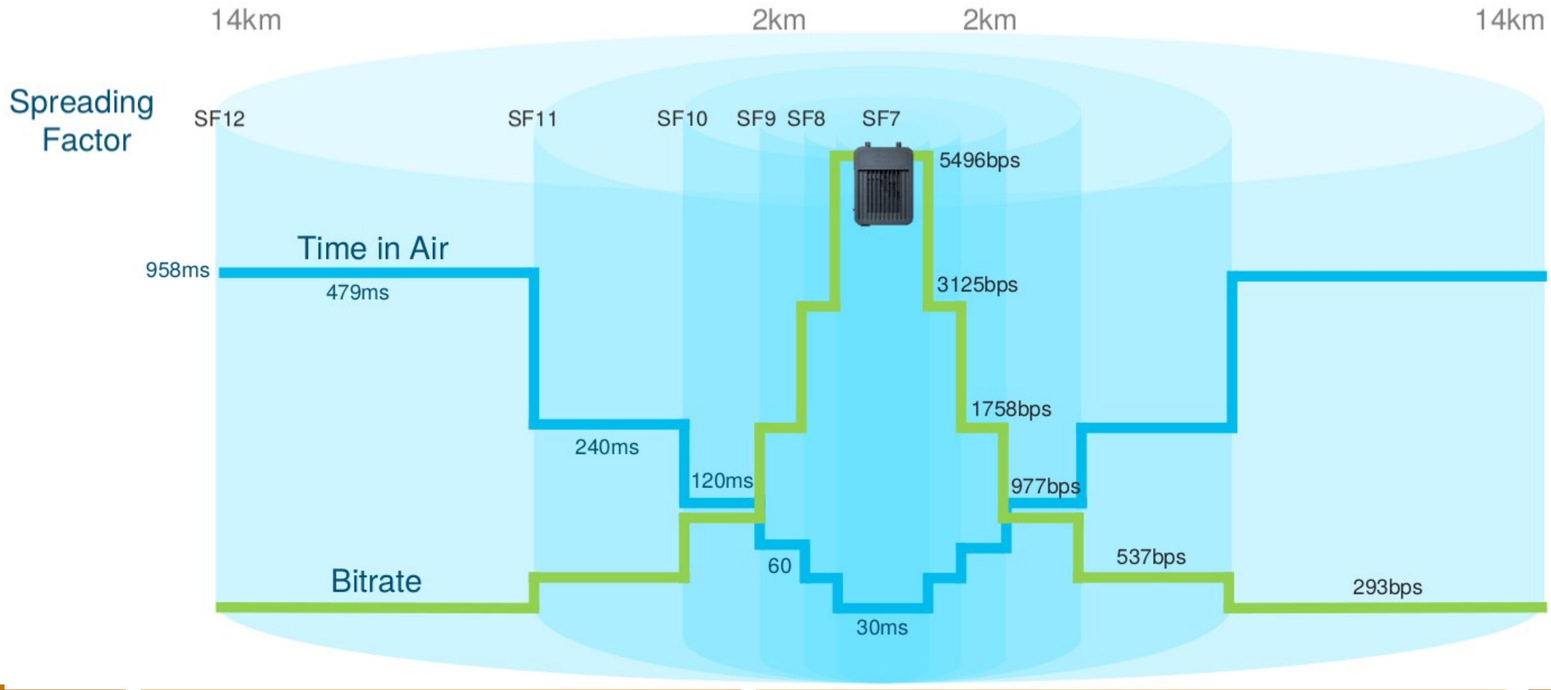
- Otra forma de pensarlo: categorizar *f* (de entre las 2^{SF} posibilidades) de la señal discreta

$$x_r[n] = e^{2\pi f n BW} x_{chirp}(nBW)$$



LoRa - Modulación

- Tasa de bits:
  - Tiempo de chirp: $T_{chirp} = 2^{SF}/BW$
  - Tiempo de símbolo: $r_s = 1/T_{chirp} = BW/2^{SF}$
  - Tasa de bits: $r_b = (\text{bits/símbolo})r_s = SF x BW/2^{SF}$



LoRa - Canales

THE THINGS NETWORK

AU915-928

Uplink:

1. **916.8** - SF7BW125 to SF10BW125
2. **917.0** - SF7BW125 to SF10BW125
3. **917.2** - SF7BW125 to SF10BW125
4. **917.4** - SF7BW125 to SF10BW125
5. **917.6** - SF7BW125 to SF10BW125
6. **917.8** - SF7BW125 to SF10BW125
7. **918.0** - SF7BW125 to SF10BW125
8. **918.2** - SF7BW125 to SF10BW125
9. **917.5** SF8BW500

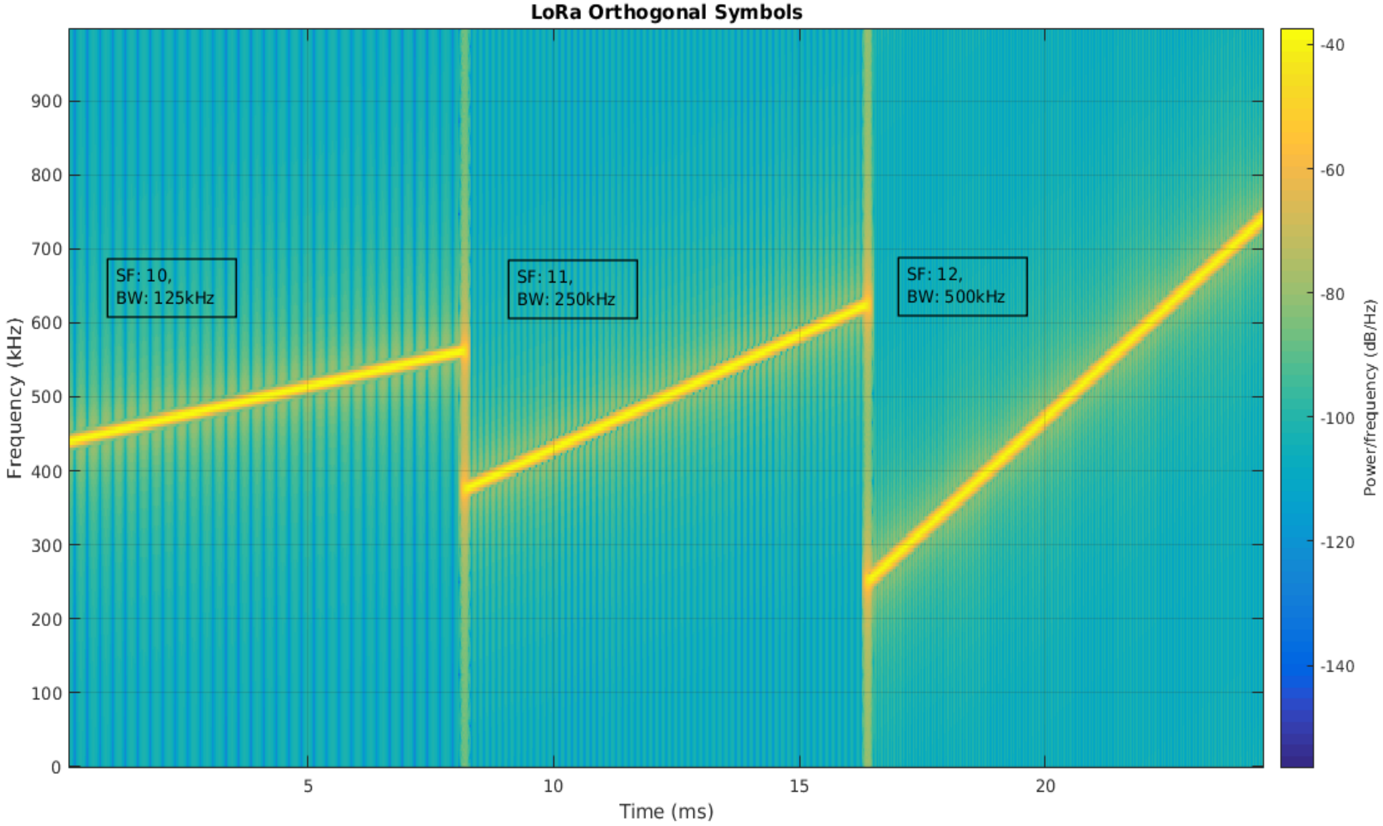
Downlink:

1. **923.3** - SF7BW500 to SF12BW500
2. **923.9** - SF7BW500 to SF12BW500
3. **924.5** - SF7BW500 to SF12BW500
4. **925.1** - SF7BW500 to SF12BW500
5. **925.7** - SF7BW500 to SF12BW500
6. **926.3** - SF7BW500 to SF12BW500
7. **926.9** - SF7BW500 to SF12BW500
8. **927.5** - SF7BW500 to SF12BW500

- Comunicaciones con distintos *SF* son “ortogonales“

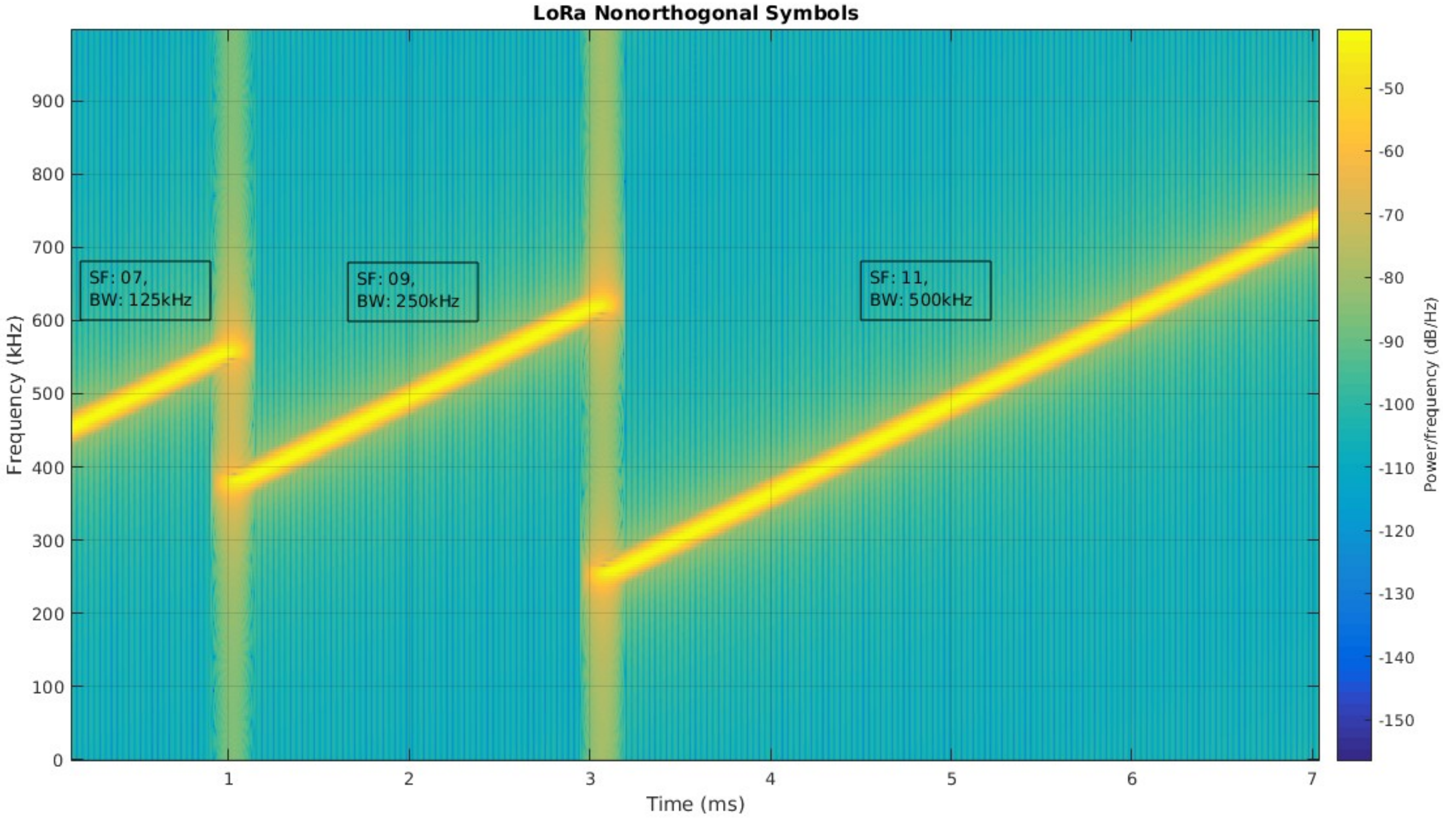
LoRa - Canales

- Comunicaciones con distintos *SF* son "ortogonales"
- Pero con distintos anchos de banda?



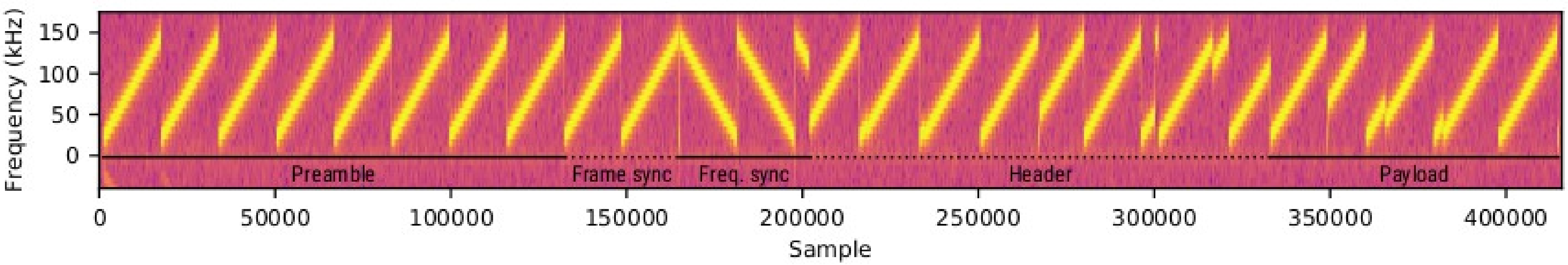
LoRa - Canales

- Comunicaciones con distintos *SF* son "ortogonales"
- Pero con distintos anchos de banda?



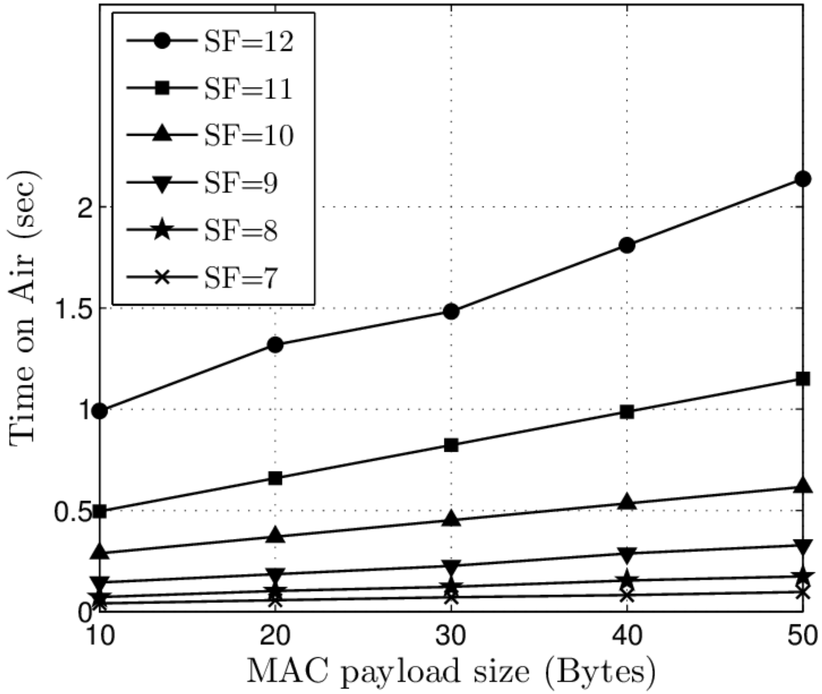
LoRa

- Estructura de trama
  - Preámbulo (largo variable): sincronismo en tiempo y frecuencia
  - Frame synchronization: una suerte de identificación de red
  - Símbolos de sincronismo en frecuencia
  - Cabecera (opcional): largo de la trama, data rate, etc.



LoRa

- Otros features:
  - Código corrector de errores de tasa 4/(4+CR)
    - Con CR configurable entre 1 y 4
    - Código de Hamming
    - Tasa de datos r_b = 4/(4+CR) x SFxBW/2^{SF}



CR = 1
BW = 125 kHz

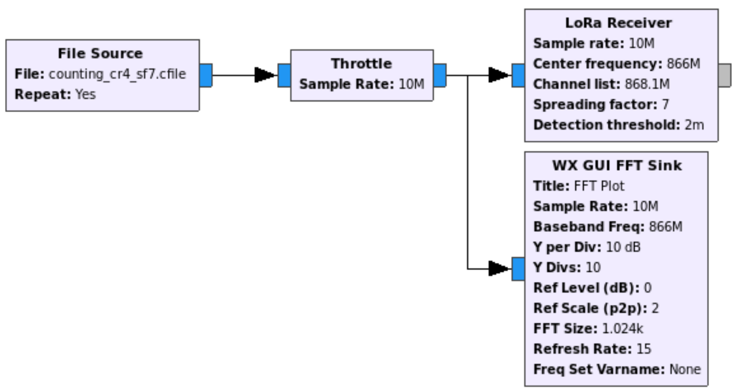
- Implementaciones abiertas: gr-lora

README.md

gr-lora

build error DOI 10.5281/zenodo.853201

The gr-lora project aims to provide a collection of GNU Radio blocks for receiving LoRa modulated radio messages using a Software Defined Radio (SDR). More information about LoRa itself can be found on the website of the LoRa Alliance.



Features

All features of the LoRa physical-layer modulation scheme are described in various patents and blog posts (for a good resource, see this RevSpace page). `gr-lora` supports most of these features, except for:

- CRC checks of the payload and header
- Decoding multiple channels simultaneously

This library was primarily tested with a USRP B201 as receiver and Microchip RN2483 as transmitter. If you encounter an issue with your particular setup, feel free to let me know in the 'Issues' section of this repository.

LoRa

■ Implementaciones abiertas: gr-lora_sdr

README.md

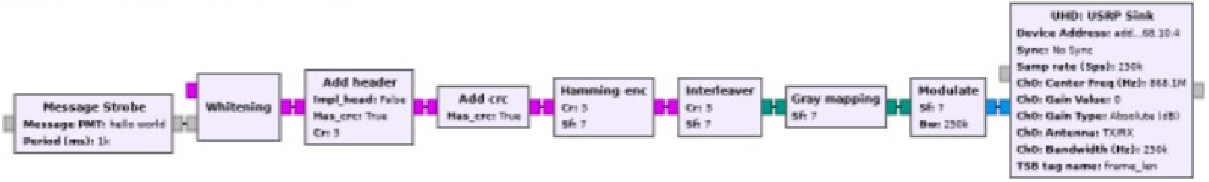
last commit july 2021 | arXiv 2002.08208 | License GPLv3 | hits 16 / 7578

Summary

This is the fully-functional GNU Radio software-defined radio (SDR) implementation of a LoRa transceiver with all the necessary receiver components to operate correctly even at very low SNRs. The transceiver is available as a module for GNU Radio 3.8. This work has been conducted at the Telecommunication Circuits Laboratory, EPFL.

In the GNU Radio implementation of the LoRa Tx and Rx chains the user can choose all the parameters of the transmission, such as the spreading factor, the coding rate, the bandwidth, the sync word, the presence of an explicit header and CRC.

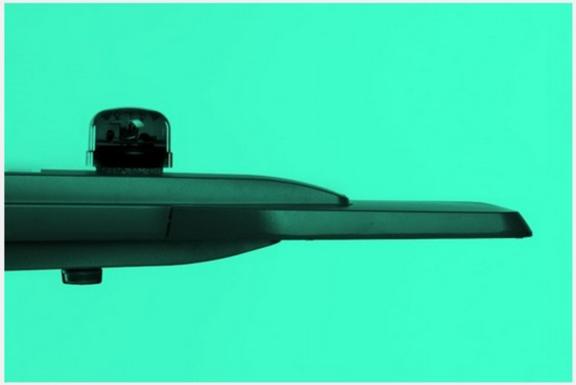
- In the Tx chain, the implementation contains all the main blocks of the LoRa transceiver: the header- and the CRC-insertion blocks, the whitening block, the Hamming encoder block, the interleaver block, the Gray mapping block, and the modulation block.



- On the receiver side there is the packet synchronization block, which performs all the necessary tasks needed for the synchronization, such as the necessary STO and CFO estimation and correction. The demodulation block follows, along with the Gray demapping block, the deinterleaving block, the Hamming decoder block and the dewhitening block, as well as a CRC block.

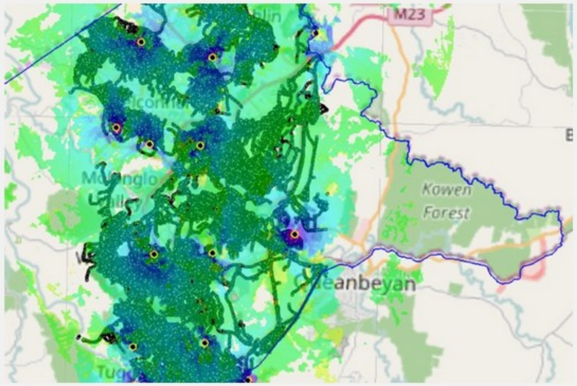
Telensa

- **Modelo de negocios:**
  - Empresa “pionera” en sistemas de Smart Cities (fundada en 2005)
  - Proporciona soluciones completas (y cerradas) particularmente para luminarias inteligentes



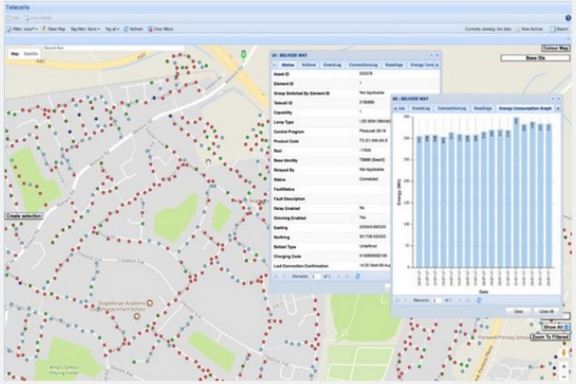
Telecell control nodes

– 5,000 per base station
– Very low power (0.7W)
– Works without network
– Fixture independent
– Metering and GPS



Ultra Narrow Band (UNB) Network

– Range up to 10 miles/16 km
– Minimal data costs
– ETSI standards path
– Simple light pole install



Central Management System

– Map-based control programs
– Scales to millions of lights
– Integration options for asset management, metering and billing systems

Telensa - Tecnología

- Modulación:
  - Señal modulada en 2-FSK resultando en 62.5 bps en el uplink y 500 bps en el downlink
- Poco más se sabe al ser cerrado y propietario
- Estrategia: Participar en cuerpos de estandarización
  - En 2012 se une a TALQ

OUR VISION

Setting an intelligent standard for Smart Cities

The TALQ Consortium aims to establish a globally accepted standard for management software interfaces to configure, command, control and monitor heterogeneous outdoor device networks including street lighting.

This way interoperability between Central Management Software (CMS) and Outdoor Device Networks (ODN) for several Smart City Applications from different vendors will be enabled, such that a single CMS can control different ODNs in different parts of a city or region.

Telensa - Tecnología

- Modulación:
  - Señal modulada en 2-FSK resultando en 62.5 bps en el uplink y 500 bps en el downlink
- Poco más se sabe al ser cerrado y propietario
- Estrategia: Participar en cuerpos de estandarización
  - En 2012 se une a TALQ
  - En 2016 se une al Weigthless-SIG

Weightless

- Weightless-SIG: Consorcio industrial cuyo objetivo es

The Weightless SIG is a non-profit global standards organisation formed to coordinate the activities needed to deliver the world's best IoT connectivity technology. These activities include:

- Developing the definitive open standard LPWAN technology for IoT connectivity
- Managing ongoing evolution, innovation and upgrades to the Standard
- Administering the IPR policy
- Managing legal disputes
- Communicating and evangelising the technology
- Managing test, certification and licensing of the technology

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- En principio propuso tres estándares:
  - Weightless-W: TV Whitespaces
  - Weightless-N: solo uplink
  - Weightless-P: el definitivo (lo que hoy se conoce como Weightless a secas)

Weightless

- Weightless:
  - Modulación GMSK y O-QPSK en canales de 12.5 kHz
  - Tasas adaptativas entre 200 bps y 100 kbps
  - En la banda sub-GHz ISM o incluso licenciadas
  - Otras features:
    - Arquitectura en estrella con estaciones base sincronizadas
    - FEC
    - ARQ
    - etc
  - Peeeeero: no conozco implementaciones del estándar
- Los esfuerzo de estandarización más fuertes quizá los está llevando adelante la ETSI y su Low Throughput Network (LTN)

RPMA/Ingenu

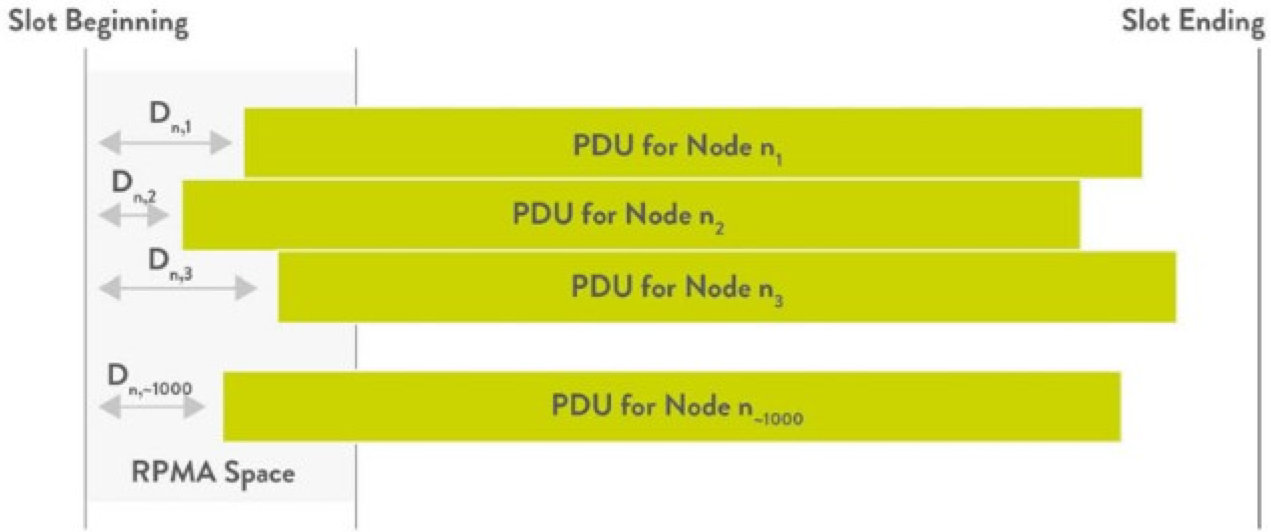
- Ingenu (antes conocida como On-Ramp Wireless) ofrece un modelo similar a Telensa, pero usando RPMA (patentado)

END-TO-END. TURNKEY SOLUTION.

The Smarter City by RPMA is a turnkey end-to-end smart city solution. Because RPMA is the wireless backbone that connects the city's leaders and managers to its assets and people, it is uniquely positioned to provide an all-in-one solution for the simplest deployment of smart parking, street lighting, water and electricity metering and management, proactive infrastructure management, and environmental monitoring.

RPMA/Ingenu

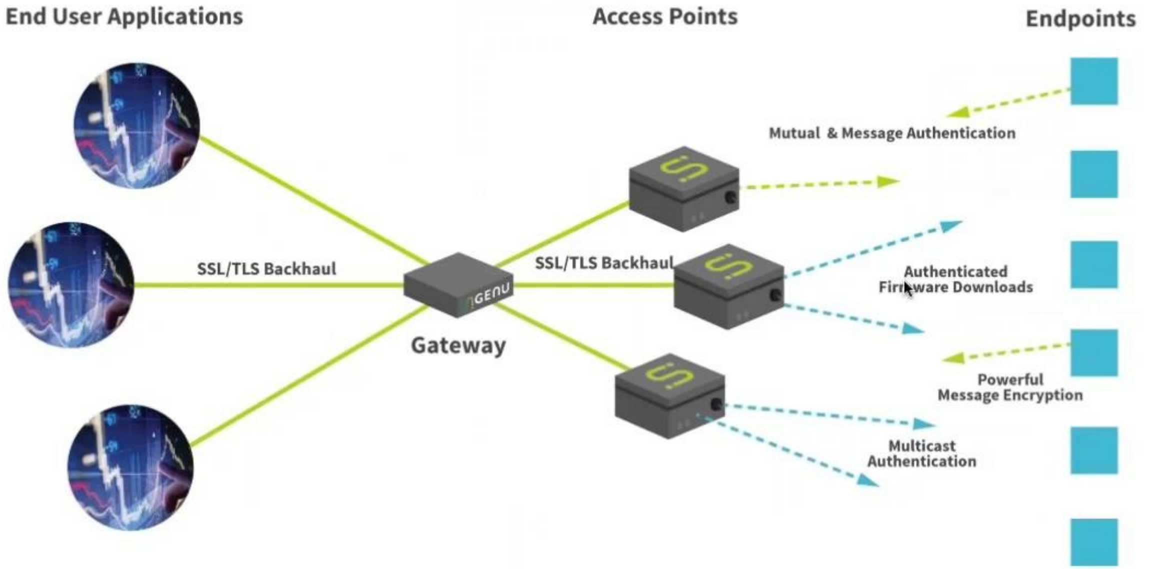
- RPMA: Random Phase Multiple Access
  - El clásico DSSS donde cada nodo transmite con un retraso aleatorio



- En el canal de bajada se usa CDMA

RPMA/Ingenu

- Banda: 2.4 GHz (!)
  - Menos restricciones de potencia y por lo tanto mayores alcances y capacidad
- 40 Canales de 1 MHz (con hasta 1200 transmisiones simultáneas) resultando en hasta 78 kbps (UL) y 19.5 kbps (DL)
- Alcance de 15 km en entornos urbanos



Agenda

- Introducción
- Tecnologías LPWAN
  - SigFox
  - LoRa
  - Weightless/Telensa
  - RPMA/Ingenu
- Tecnologías “Celulares”
  - NB-IoT
  - LTE-M
- Tecnologías WPAN
  - 802.15.4/Zigbee

3GPP

- El release 13 de 2016 incluye

LTE enhancements for Machine-Type Communications (MTC)

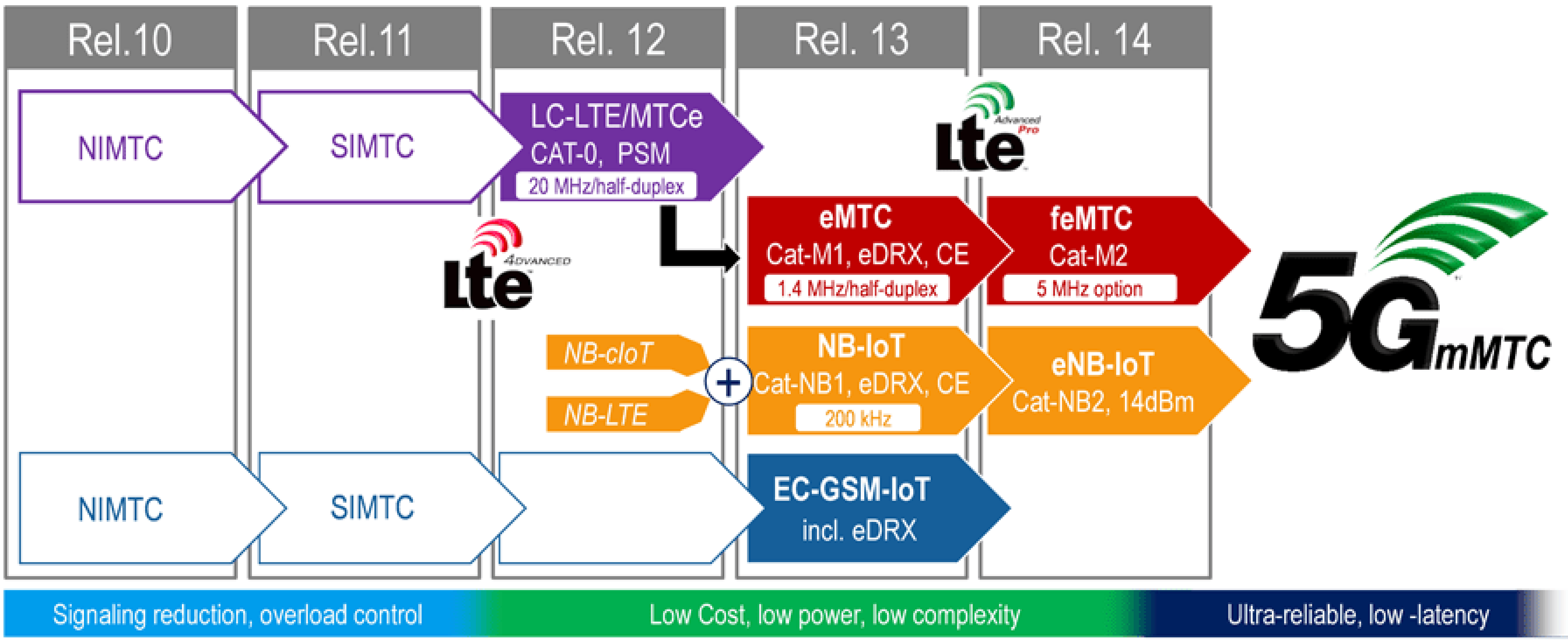
Continuing the normative work started in Release 12 to specify key physical layer and RF enablers to enhance LTE's suitability for the promising IoT market, the key focus for Release 13 is to define a new low complexity UE category type that supports reduced bandwidth, reduced transmit power, reduced support for downlink transmission modes, ultra-long battery life via power consumption reduction techniques and extended coverage operation.

In terms of reduced bandwidth the goal is to specify 1.4 MHz operation at the terminal within any LTE system bandwidth, allowing operators to multiplex reduced bandwidth MTC devices and regular devices in their existing LTE deployments. For coverage, the goal is to improve by 15dB the coverage of delay-tolerant MTC devices, allowing operators to reach MTC devices in poor coverage conditions – such as meters located in basements.

- Hay básicamente tres estándares:
  - eMTC (LTE Cat M1)
  - NB-IoT
  - EC-GSM-IoT

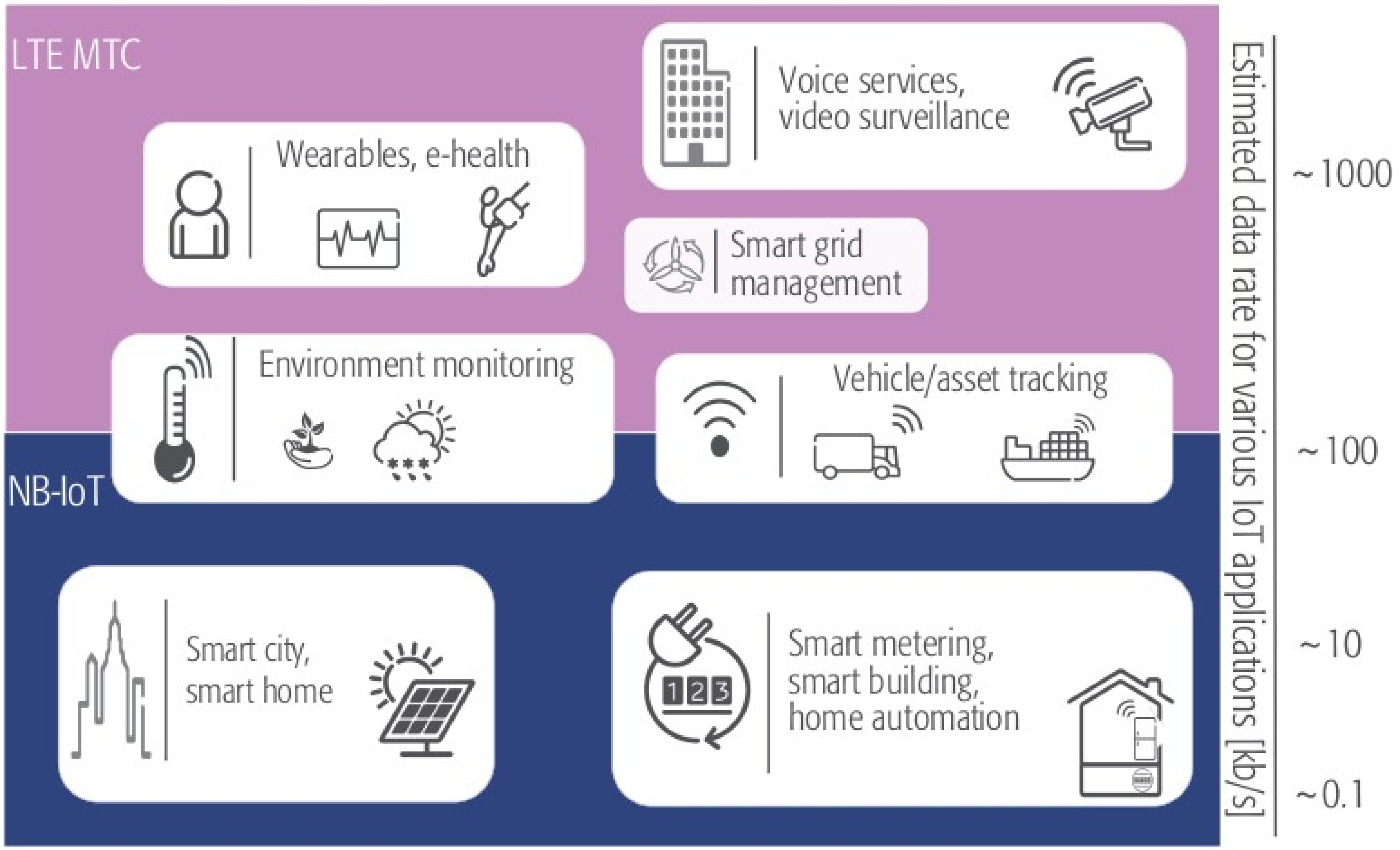
3GPP

- **Básicamente** tres estándares



3GPP

- Nos vamos a enfocar en NB-IoT

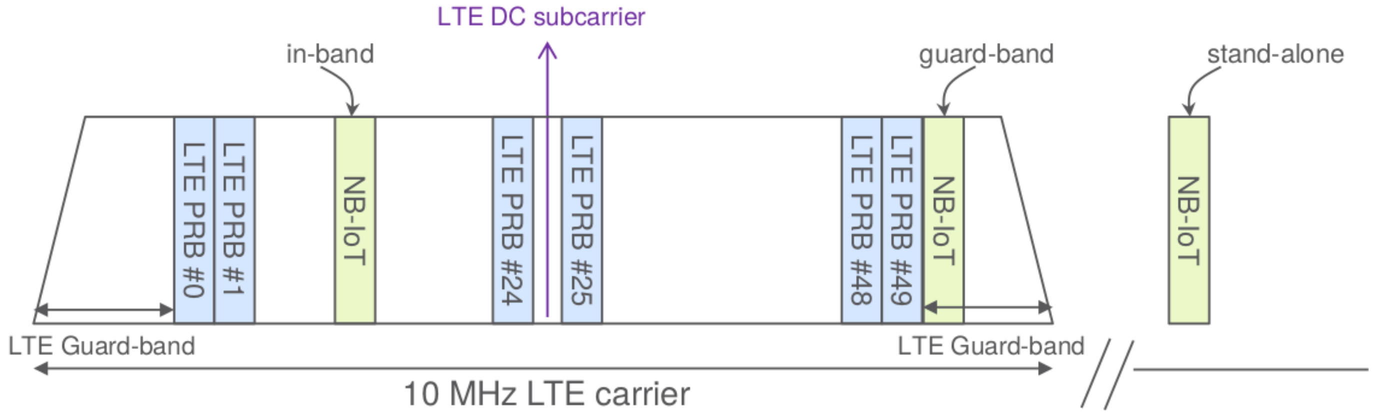


3GPP

- **Gran diferencia**: el uso de bandas licenciadas al operador local
  - Regulaciones más “permisivas”
  - Operador “dueño” de la red (simil Sigfox)

3GPP - NB-IoT

- Tres escenarios de despliegue (software update):
  - In-Band:
    - Ocupa un PRB (Physical Resource Unit) de LTE (180 kHz)
  - Standalone:
    - Sustituye un despliegue GSM (200 kHz)
  - Guard-band:
    - Ocupa bandas de guarda

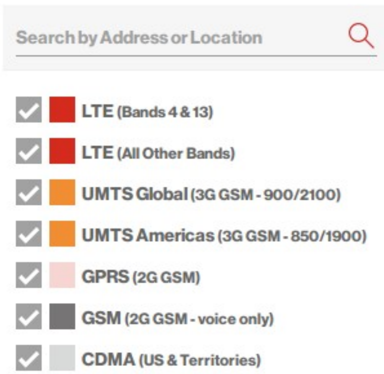


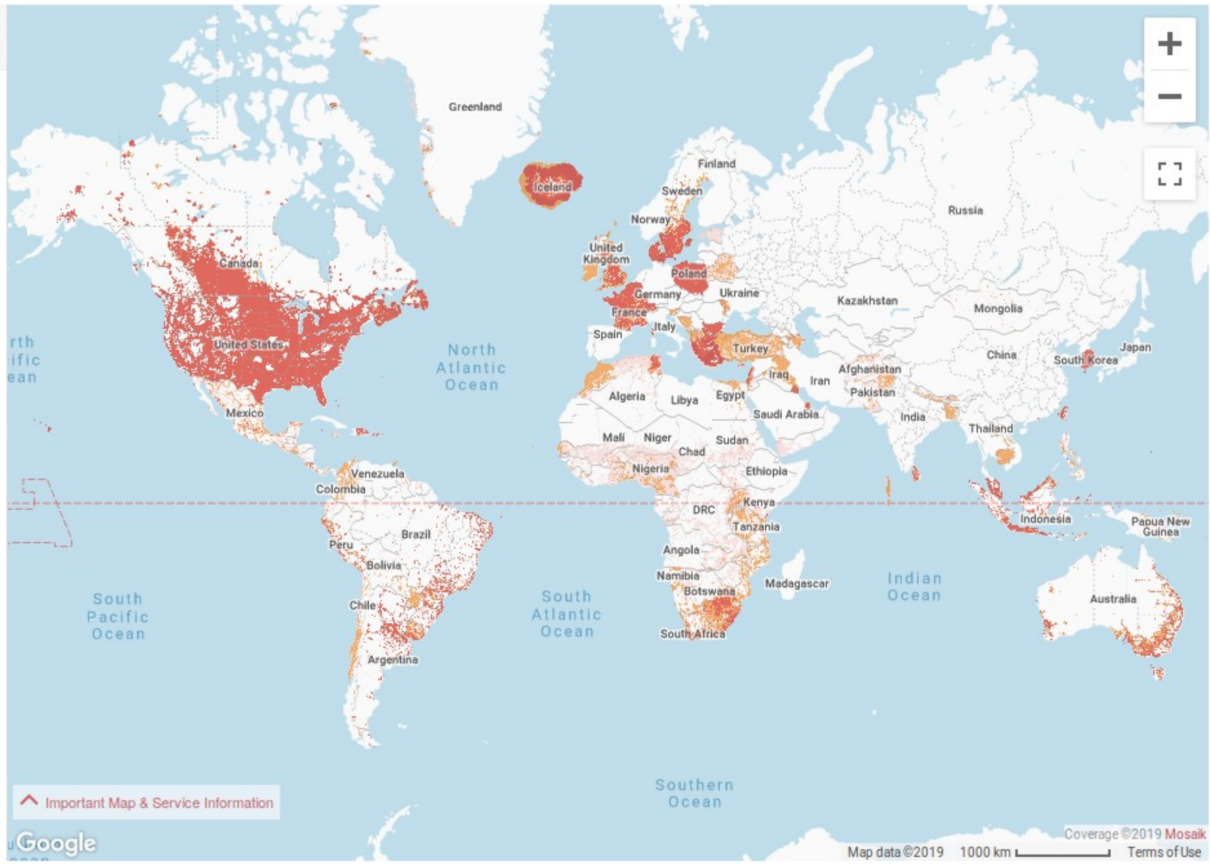
3GPP - NB-IoT

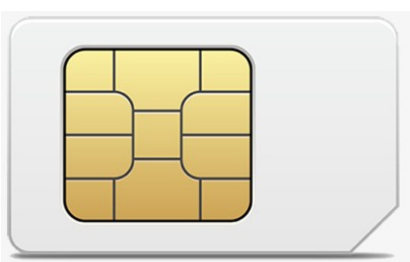
- Por lo tanto se trata básicamente de un LTE simplificado:
  - Menor ancho de banda (180 kHz)
  - Modulación QPSK o BPSK y una única antena
  - El canal de bajada sigue siendo OFDMA y el de subida SC-OFDM
  - Acceso al canal simplificado
- La idea es simplificar el despliegue

3GPP - NB-IoT

- Avance lento pero seguro







3GPP - NB-IoT

- Avance lento pero seguro

Activate SIM Card »

Note: this will take you to an external payment site powered by RevX Systems.

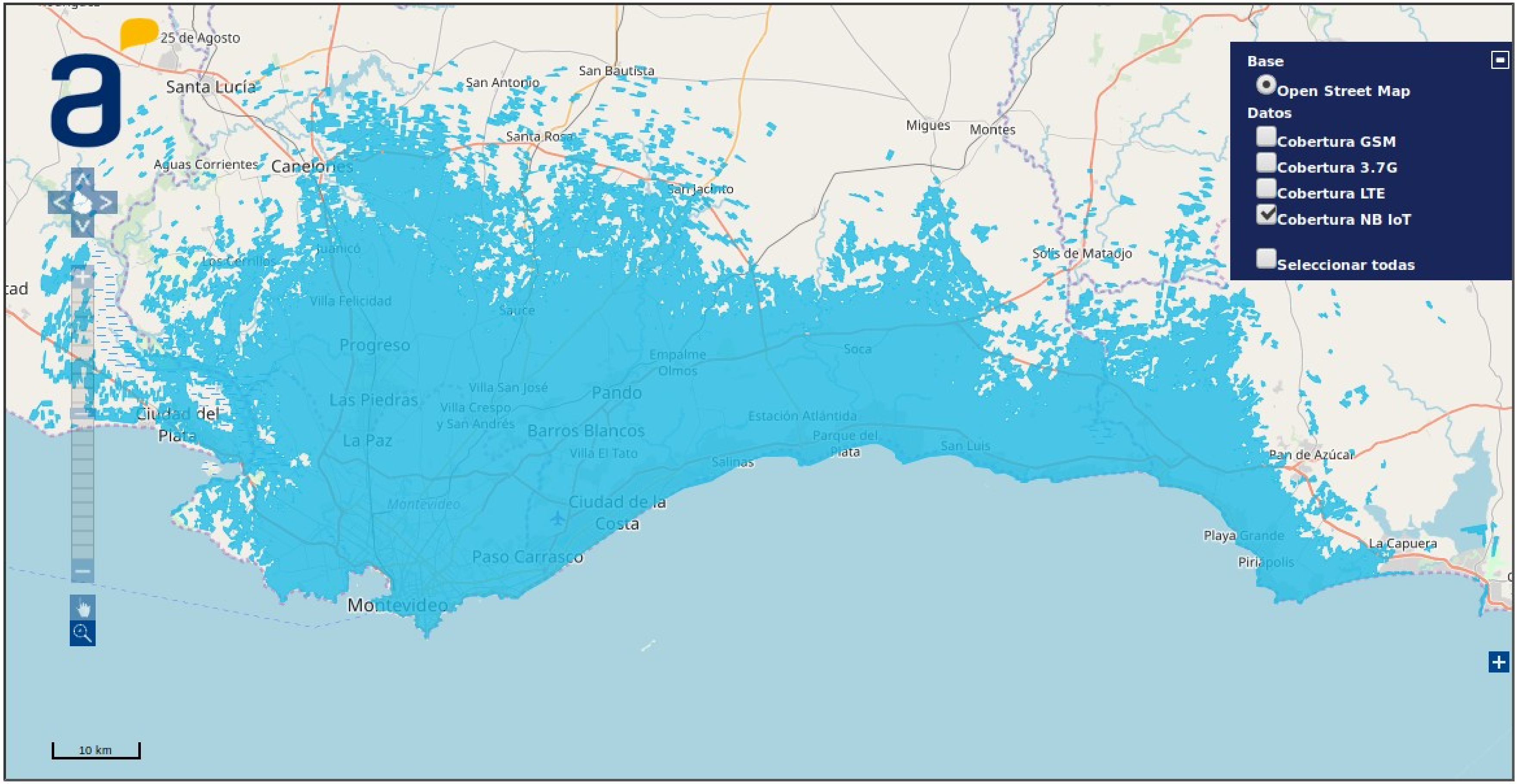
DATA PLANS

U.S. Anywhere - 4G LTE Coverage

	300 KB	1 MB	10 MB	100 MB	500 MB	1 GB	5 GB
Verizon	$3.00	$5.00	$12.00	$16.00	$20.00	$30.00	$60.00
Overage Rate/MB	$2.00	$2.00	$2.00	$1.50	$1.00	$0.03	$0.03
AT&T	$3.00	$4.00	$6.50	$16.00	$20.00	$28.00	$60.00
Overage Rate/MB	$1.50	$1.50	$1.50	$1.50	$0.75	$0.03	$0.03
T-Mobile	$3.00	$4.00	$5.00	$9.00	$15.00	$20.00	$60.00
Overage Rate/MB	$1.50	$1.50	$1.50	$1.50	$0.75	$0.03	$0.03
SMS per msg	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05	$0.05

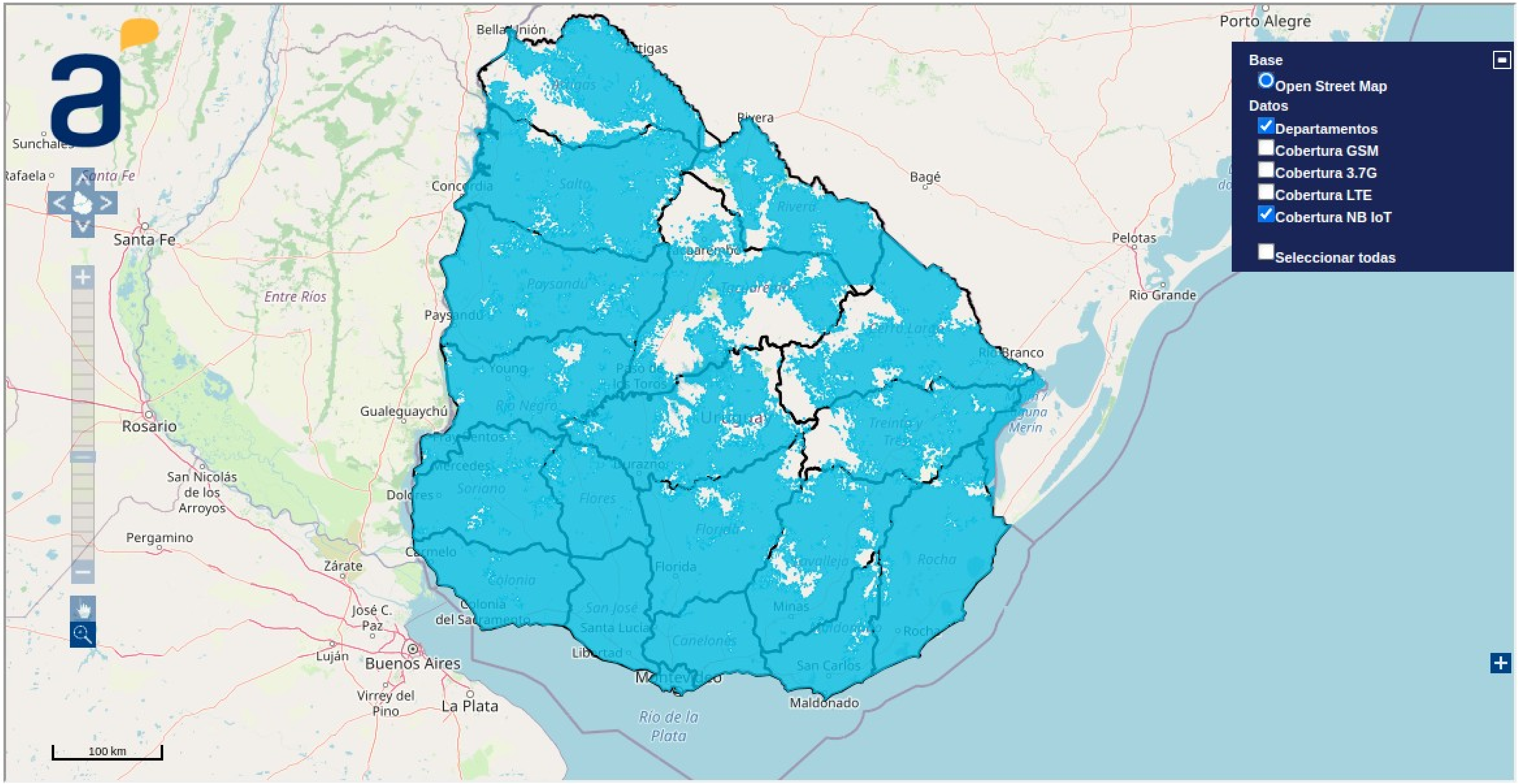
3GPP - NB-IoT

- Avance lento pero seguro: 9/2019



3GPP - NB-IoT

- Avance lento pero seguro: 4/2022



3GPP - NB-IoT

- Implementaciones abiertas

OpenAirInterface

5G software alliance for democratising wireless innovation

Home Members 5G Strategic Areas Community Media OAI Code

Internet of Things (IoT)

Internet of Things (IoT) is an application domain that integrates different technological fields. IoT covers many areas ranging from enabling technologies and components to several mechanisms to effectively integrate low level components. Software that manages IoT platforms is a key factor enabling the success of future IoT platforms. IoT operating systems are designed to run efficiently on small form factor low power devices, while at the same time providing features to simplify and support the IoT system in its objectives. Programmability, middleware and open application programmable interfaces (APIs) are the key factors needed to ensure the success of future IoT platforms. IoT systems are predicted to grow to billions of devices within the next decade which implies sophisticated management systems are necessary large number of these devices. IoT places lot of requirements for the future design of cellular networks due to the large number of such devices. Moreover, such devices generate traffic which is very different from human generated traffic. The power consumption of IoT devices especially ones running on small batteries is also one of the key design requirements.

- Implementaciones no abiertas: srsLTE, nutaq

Comparativa

Technology	***LoRa***	***Sigfox***	***NB-IoT***	***EC-GSM-IoT***
Topologies supported	typically Star, Mesh possible	Star	Star	Star
Max data rate per terminal	50kbps	100bps	60 kbps DL, 50kbps UL	70kbps
Maturity Level	Early stages - some deployments	in use commercially	early stages	early stages
Frequency Band	sub GHz ISM bands	sub GHz ISM bands	LTE and GSM bands	GSM bands
MAC Layer	ALOHA-based	ALOHA-based	LTE-based	GSM-based
Range/Coverage	2-5km urban, 10-15km rural	3-10km urban, 20-50km rural	164dB	154 - 164dB
Founded	2015	2009	2016	2016
Modulation Technique	Spread-Spectrum	Ultra-Narrow Band (UNB)	LTE-based?	GSM-based
Proprietary aspects	Physical layer	Physical and MAC layers	Full stack	Full stack
Nodes per gateway	>1,000,000	>1,000,000	52,000	50,000
Deployment model	Private and Operator-based	Operator-based	Operator-based	Operator-based
Encryption	AES	Not built in	3GPP (128-256bit)	3GPP (128-256bit)

Technology	***Telensa***	***RPMA (Ingenu)***	***Weightless-P***
Topologies supported	Star	Star	Star
Max data rate per terminal	—	8kbps	100kbps
Maturity Level	in use commercially (>9m devices deployed)	in use commercially	early stages
Frequency Band	sub GHz ISM bands	2.4 GHz band	sub GHz ISM bands
MAC Layer	—	RPMA-DSSS	—
Range/Coverage	2-3km urban, 4-10km rural	4km	2km urban
Founded	2005	2008, renamed 2015	2012
Modulation Technique	UNB	Spread-Spectrum	Narrowband
Proprietary aspects	Full stack	Full stack	Open standard
Nodes per gateway	5,000	500,000	—
Deployment model	Private	Private	Private
Encryption	—	AES-128bit	—

Fuente: Finnegan et al. “A Comparative Study of LPWA Networking,” arXiv:1802.04222v1 [cs.NI], Febrero de 2018

Comparativa

	SIGFOX [9]	LORAWAN [15]	WEIGHTLESS-N [16]	INGENU [90]	3GPP Cellular IoT
Deployment model	Nationwide (multiple countries)	Private or nationwide networks	Private networks	Private or nationwide networks	Nationwide networks
Ease of roaming	Seamless roaming across SIGFOX networks in different countries at no extra charges	Roaming agreements required	Not applicable	?	Operator alliances for cross-border roaming
SLA support	✗	✗	✗	✗	✓
Device availability	✓	✓	Focus is on gateway	✓	✗(Still in standardization phase, devices will emerge later)
Over-the-air updates for devices	✗	possible	✗	possible	likely be made available
Supplier ecosystem	Transceivers and modules from many vendors	Limited choice of vendors for transceivers, several module vendors	Limited choice of vendors	Transceivers and modules from many vendors	Availability likely from all the usual vendors once standard is ratified
Licensing	Technology freely available for chip/device vendors. Network operators pay royalty to SIGFOX (revenue sharing basis)	Technology licensed by device vendors. No royalty to be paid by network operators	Technology freely available for chip/device vendors. No royalty thereafter.	Upfront fee + per application & per device fee / year (No revenue sharing)	Standardized technology. Usual cellular model likely to prevail
Deployment status	Network deployed & running in several countries. Several operators have invested in SIGFOX	Early trials & deployments by some operators. Several operators are members of LoRa™ Alliance	Some trials but no major deployments	Several private deployments in over 5 continents	Early days with some in-house trials with pre-standardized technology by handful of operators
Longevity offered by the solution	Deployments in several countries. Not much insight into transition plan should SNOs find it infeasible to run the network. Transitioning will entail replacement of endpoint/communications module in the endpoints.	Some deployments by cellular operators in a few countries. No insight into transition plan should LoRa network be decommissioned. Transitioning will entail replacement of endpoint/communications module in the endpoints.	No deployments so far so longevity is questionable	Deployments in several countries. Not much insight into transition plan should MNOs find it infeasible to run the network. Transitioning will entail replacement of endpoint/communications module in the endpoints.	Promising as this being a solution designed exclusively for IoT, is less likely to be de-commissioned.

Fuente: Raza et al. "Low Power Wide Area Networks: An Overview," IEEE Communications Surveys & Tutorials, vol. 19, no. 2, second quarter 2017

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Gracias!