



# **IoT Long Range Technologies: Standards**

**Sami TABBANE**

**December 2017**

# Summary

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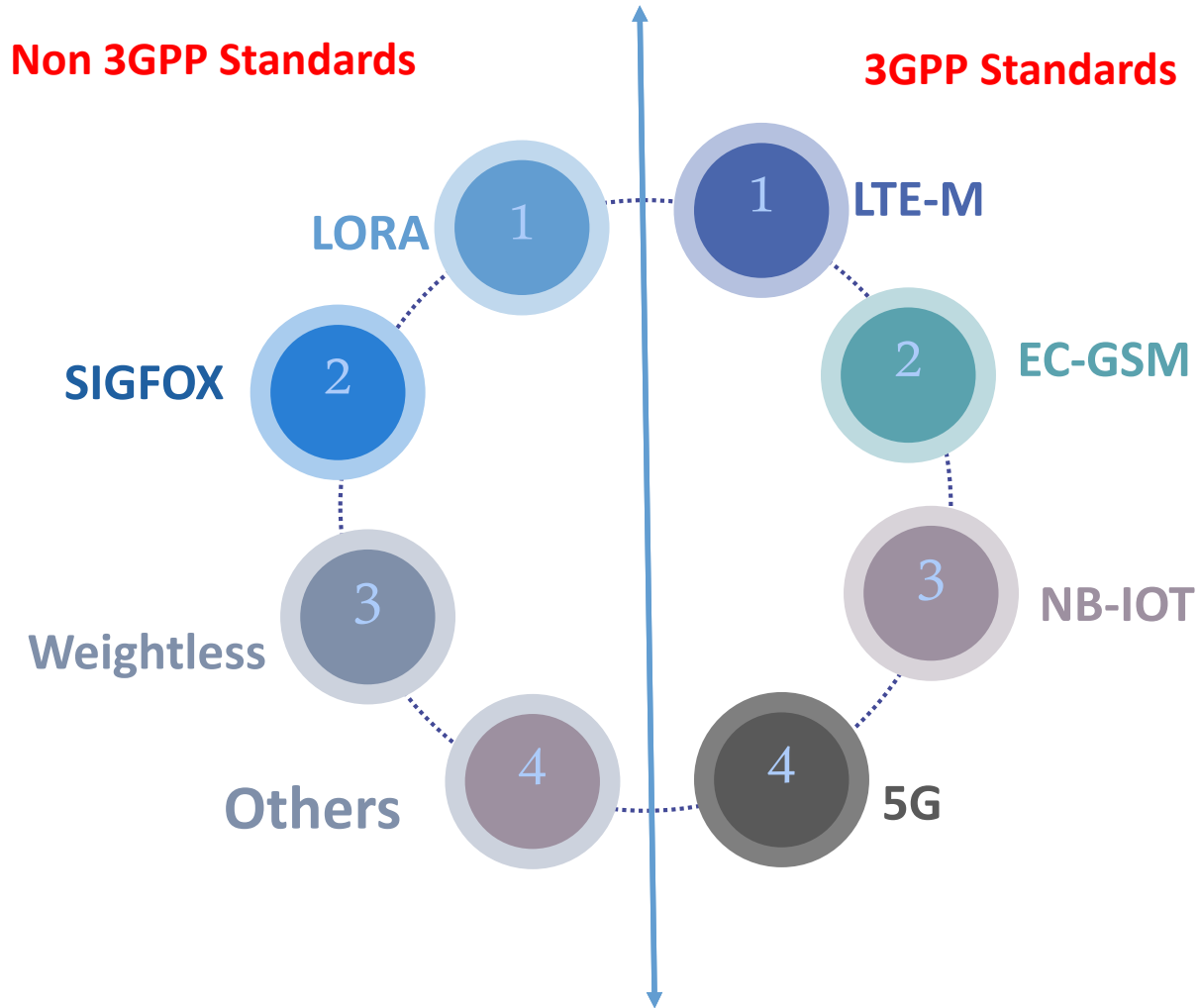
## **A. Fixed & Short Range**

## **B. Long Range technologies**

- 1. Non 3GPP Standards (LPWAN)**
- 2. 3GPP Standards**

# LONG RANGE TECHNOLOGIES

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## Wide-area M2M technologies and IoT

Carrier frequency	Technology	Channel bandwidth	Representative data rate	Link budget target or max. range	
Licensed cellular	LTE Cat. 0	20 MHz	DL: 1 Mb/s UL: 1 Mb/s	140 dB	
	LTE Cat. M	1.4 MHz	DL: 1 Mb/s UL: 1 Mb/s	155 dB	
	NB-IoT	200 kHz	DL: 128 kb/s UL: 64 kb/s	164 dB	
	EC-GSM	200 kHz	DL: 74 kb/s UL: 74 kb/s	164 dB	
Unlicensed	2.4 GHz	Ingenu RPMA	1 MHz	UL: 624 kb/s DL: 156 kb/s	500 km line of sight
	Sub-1 GHz	LoRa chirp spread spectrum	125 kHz	UL: 100 kb/s DL: 100 kb/s	15 km rural 5 km urban
	Sub-1 GHz	Weightless-N	200 Hz	UL: 100 b/s	3 km urban
	Sub-1 GHz	Sigfox	160 Hz	UL: 100 b/s	50 km rural 10 km urban

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## **B. Non 3GPP Standards (LPWAN)**

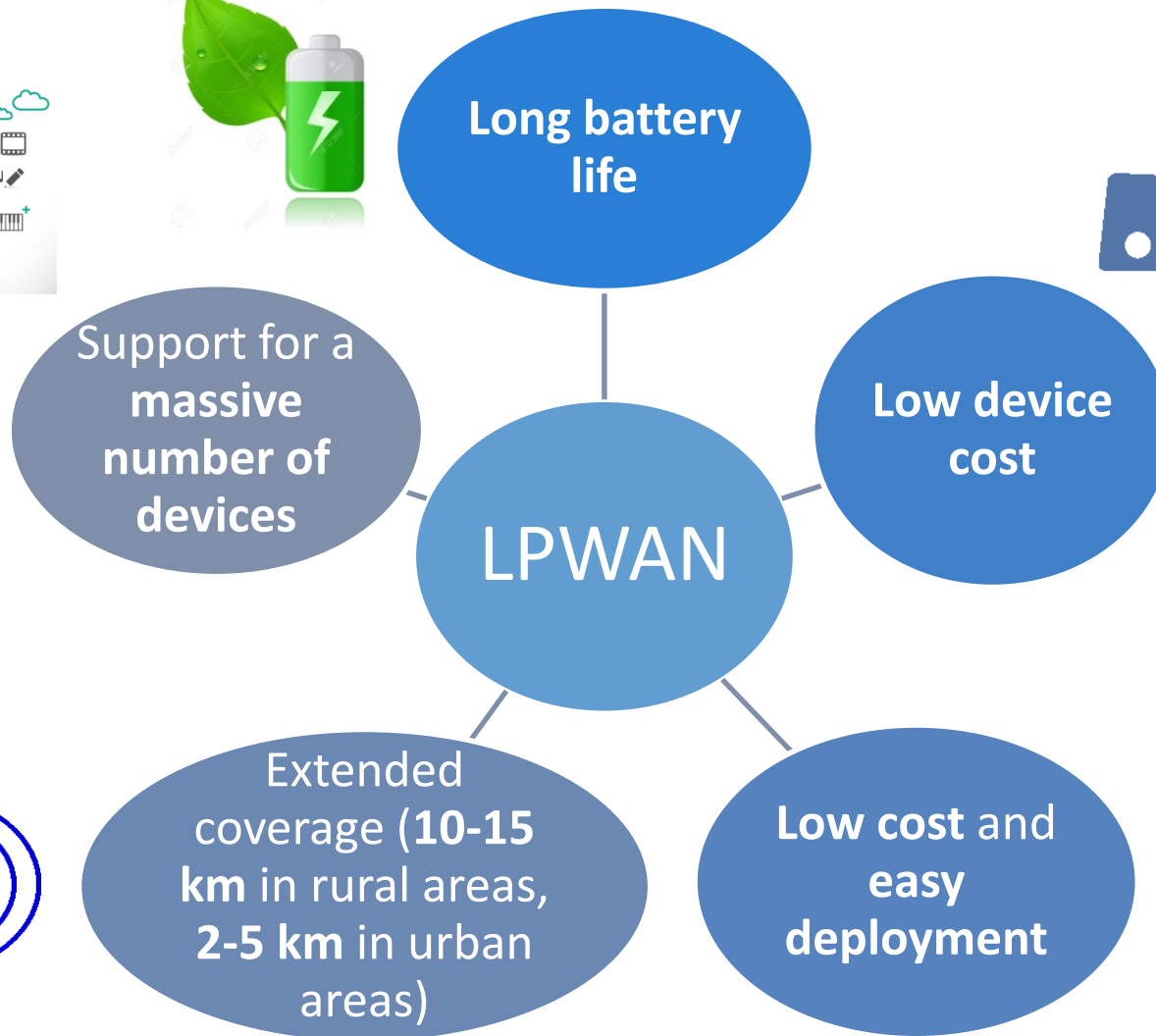
**i. LoRaWAN**

**ii. Sigfox**

**iii. RPMA**

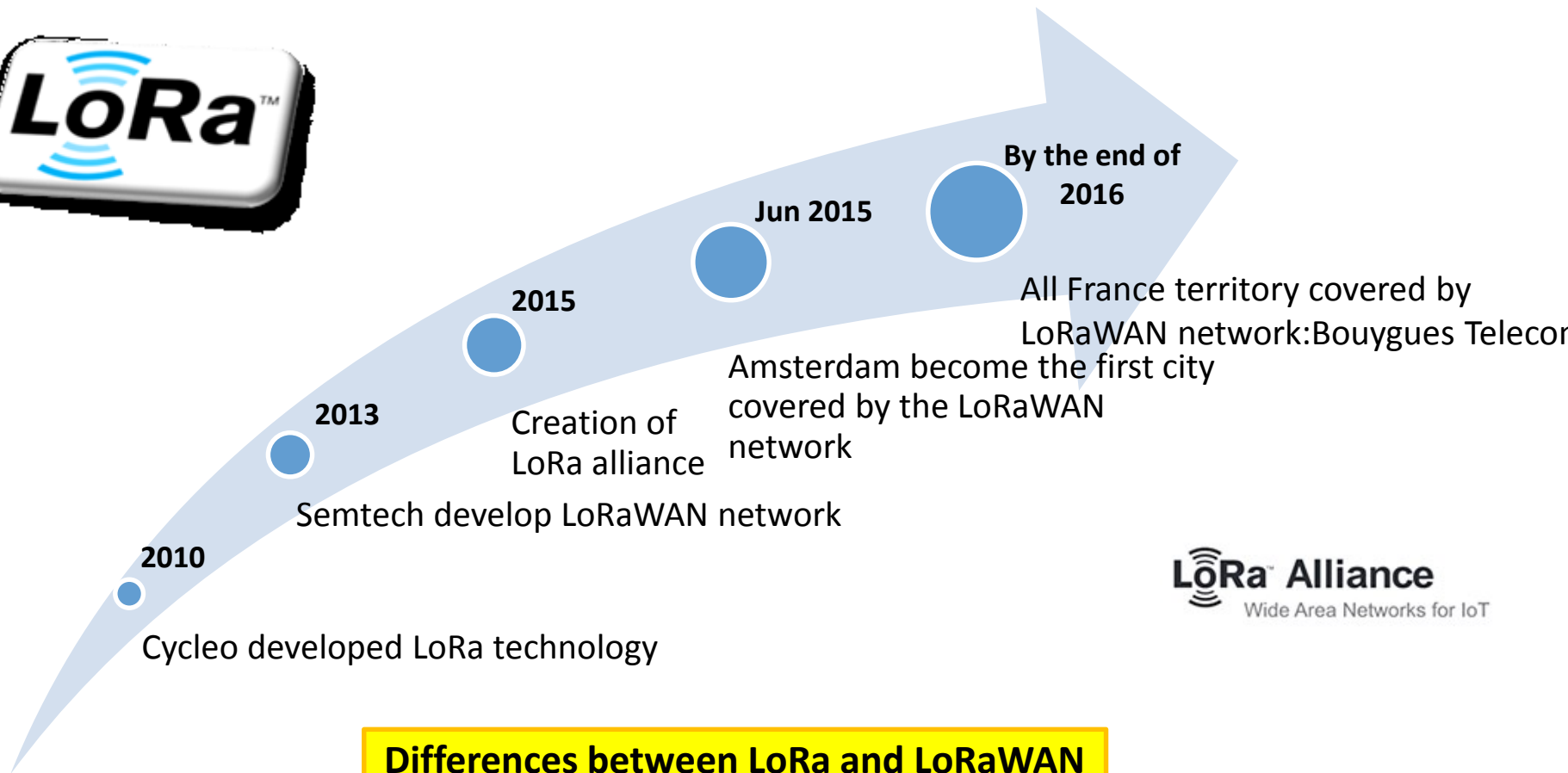
**iv. Others**

# LPWAN REQUIREMENTS



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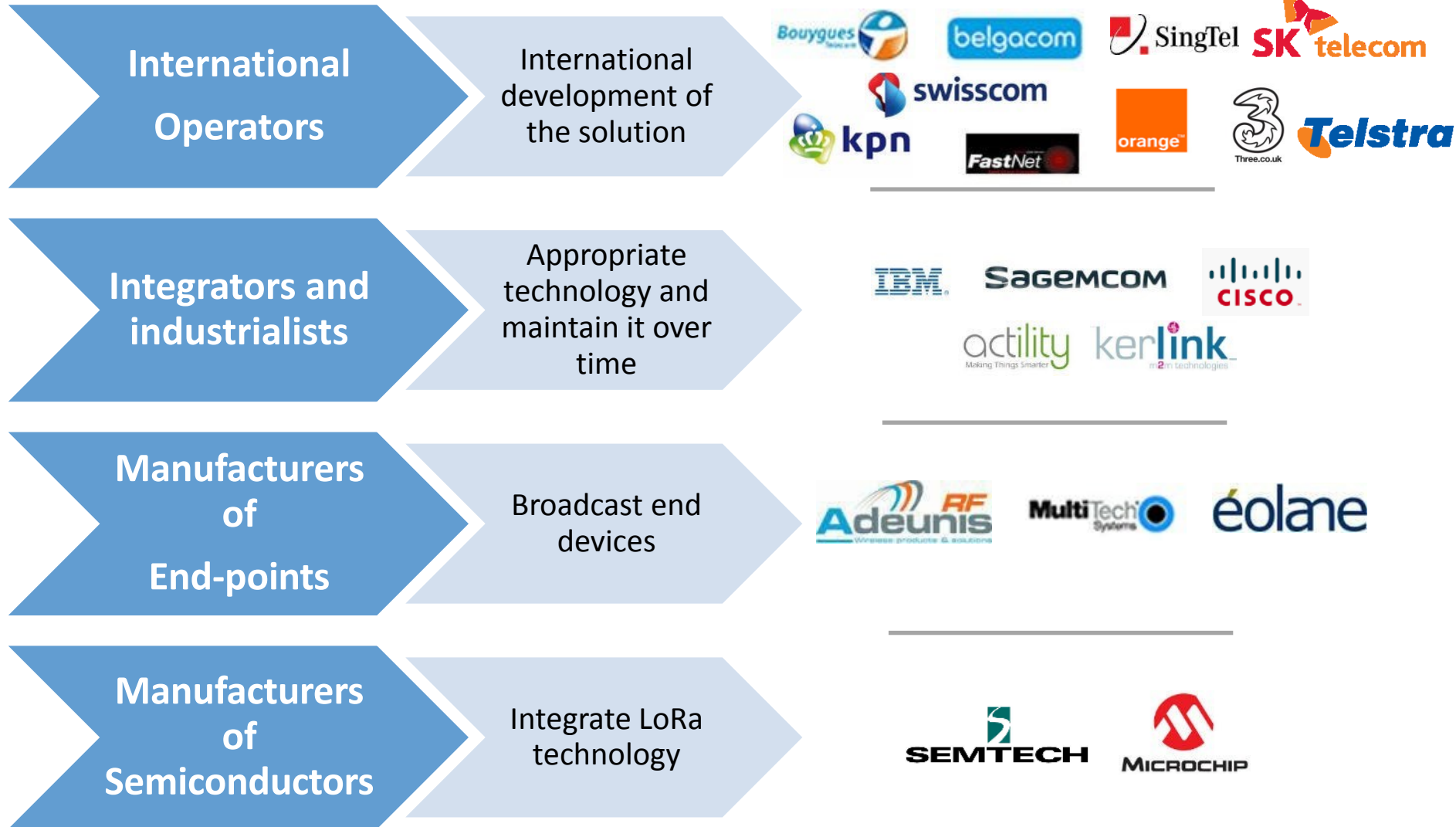
**i. LoRaWAN**



### Differences between LoRa and LoRaWAN

- **LoRa** contains only the link layer protocol. LoRa modules are a little cheaper than the LoRaWAN ones.
- **LoRaWAN** includes the network layer too so it is possible to send the information to any Base Station already connected to a Cloud platform. LoRaWAN modules may work in different frequencies by just connecting the right antenna to its socket.

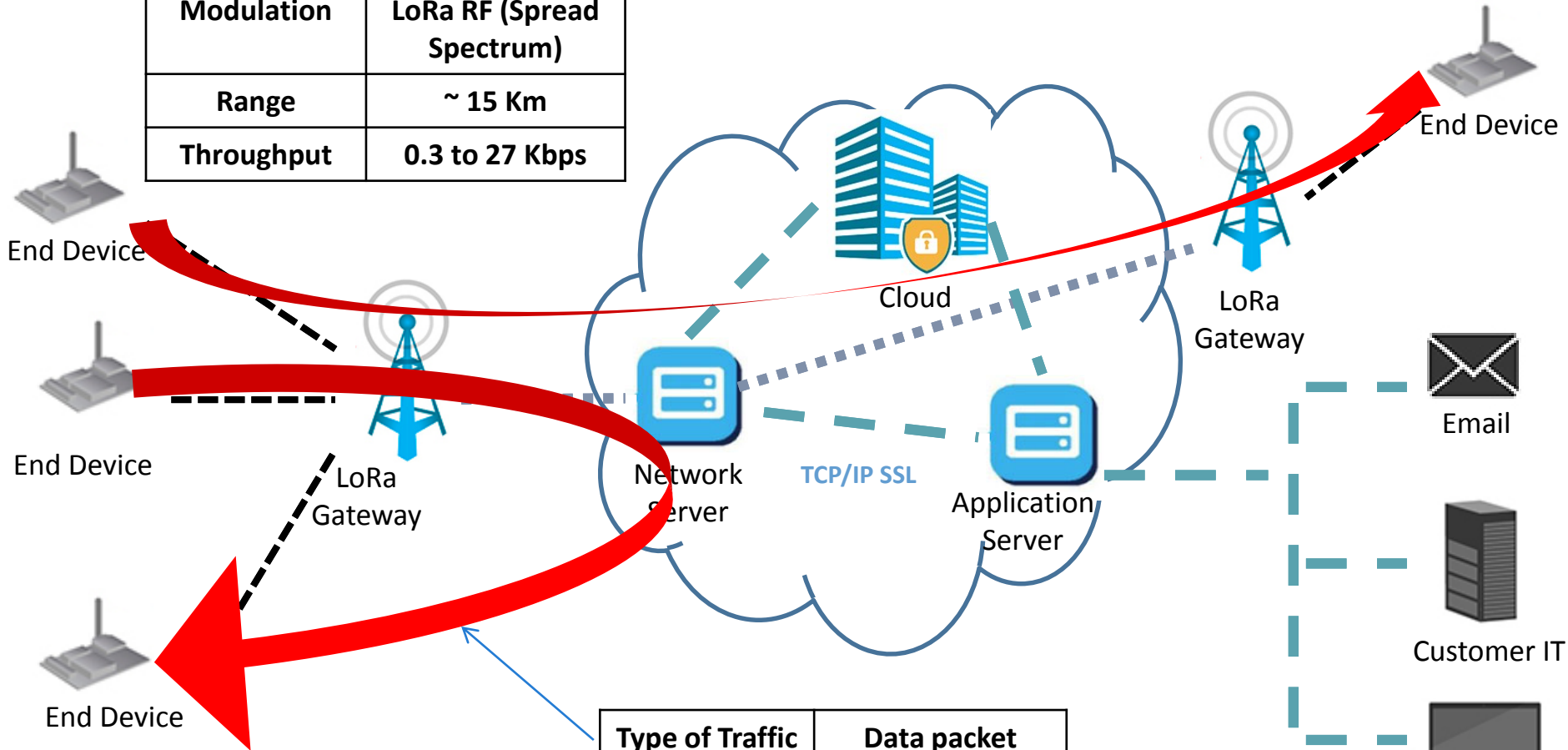




- LoRaWAN is a *Low Power Wide Area Network*
- LoRa modulation: a version of Chirp **Spread Spectrum (CSS)** with a typical channel **bandwidth of 125KHz**
- High **Sensitivity** (End Nodes: Up to **-137 dBm**, Gateways: up to **-142 dBm**)
- Long range communication (up to **15 Km**)
- Strong indoor penetration: With High Spreading Factor, Up to **20dB** penetration (**deep indoor**)
- Occupies the entire bandwidth of the channel to broadcast a signal, making it **robust** to channel noise.
- **Resistant** to Doppler effect, multi-path and signal weakening.

# Architecture

<b>Modulation</b>	<b>LoRa RF (Spread Spectrum)</b>
<b>Range</b>	<b>~ 15 Km</b>
<b>Throughput</b>	<b>0.3 to 27 Kbps</b>

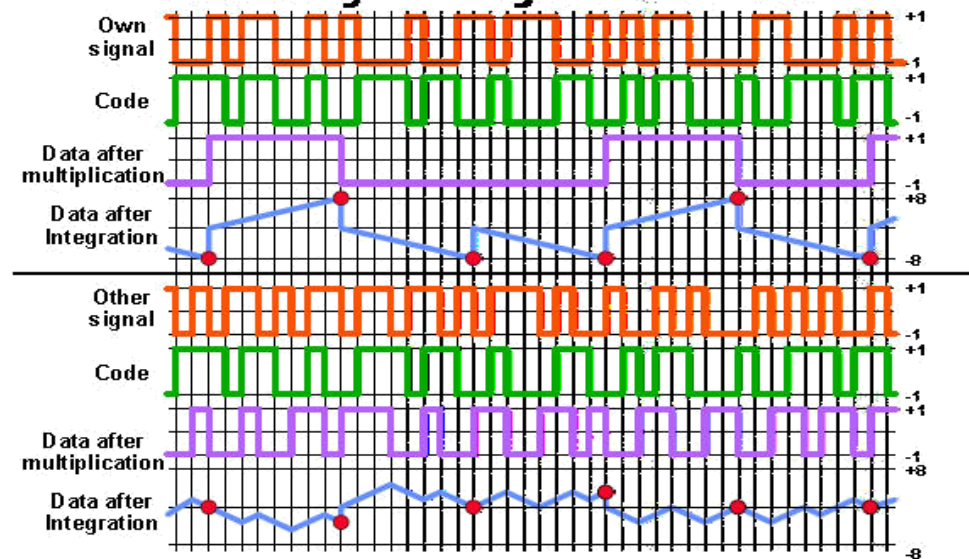


<b>Type of Traffic</b>	<b>Data packet</b>
<b>Payload</b>	<b>~ 243 Bytes</b>
<b>Security</b>	<b>AES Encryption</b>

# Spread spectrum basics

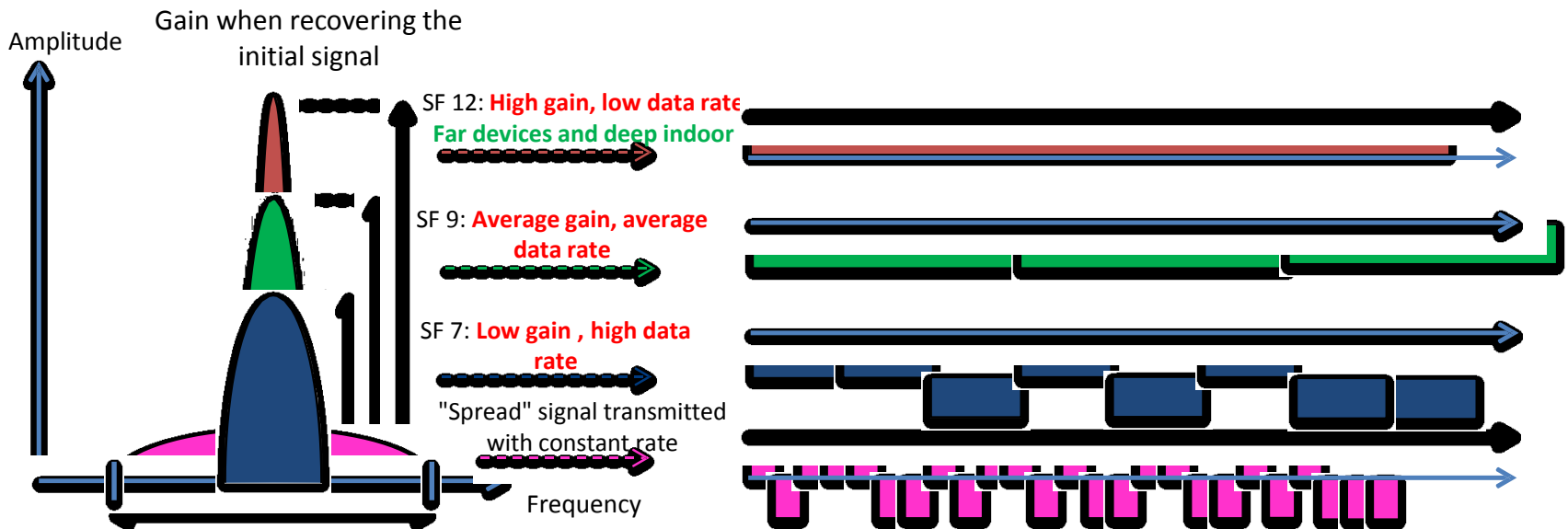


## Detecting own signal. Correlator



# Spectrum

- Orthogonal sequences: 2 messages, transmitted by 2 different objects, arriving simultaneously on a GW without interference between them (*Code Division Multiple Access* technique: CDMA , used also in 3G).
- **Spread Spectrum**: Make the signal more robust , the more the signal is spread the more robust. Less sensitive to *interference* and *selective frequency fadings* .



**Spectrum:** unlicensed, i.e. the 915 MHz ISM band in the US, 868 MHz in Europe

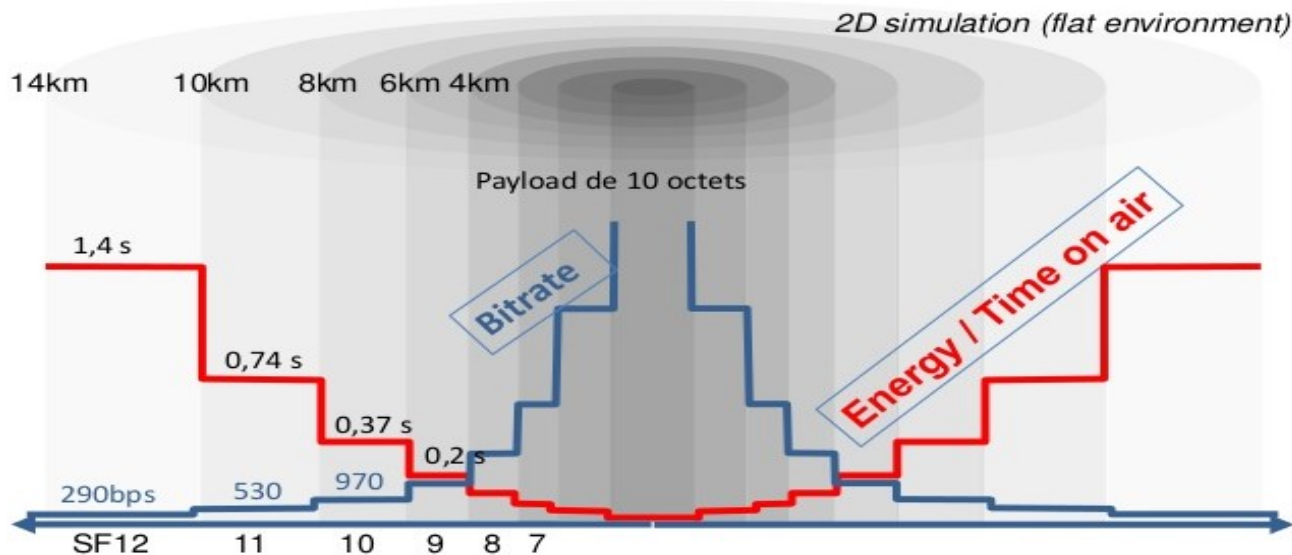
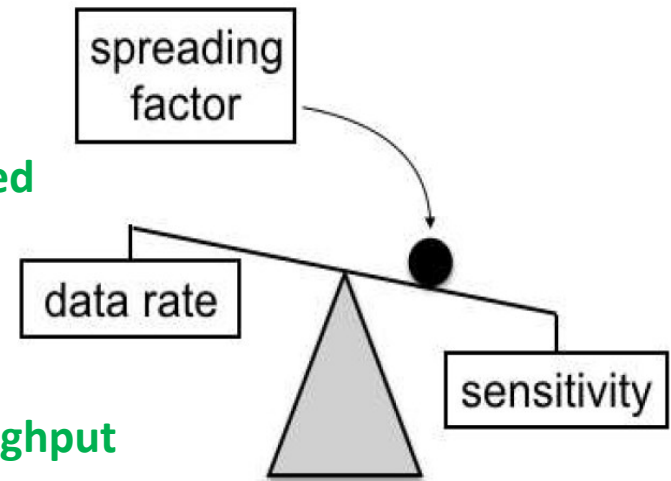
# Spectrum (Influence of the Spreading Factor)

Far with obstacles:

- ➔ **High sensitivity** required
- ➔ The network **increases** the SF (*Spreading Factor*) ➔  
Throughput decreases but **the connection is maintained**

Close:

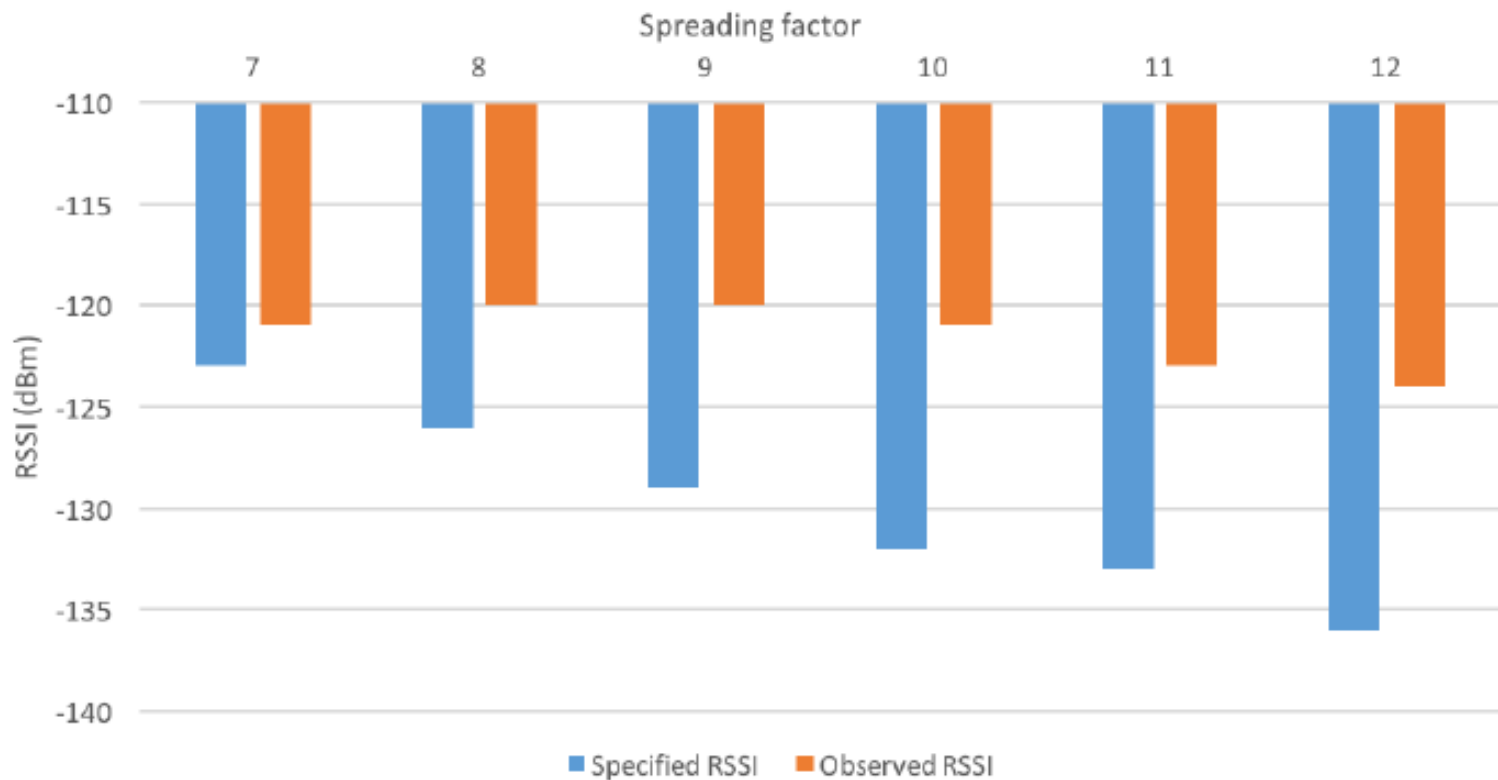
- ➔ **Low sensitivity** sufficient
- ➔ **Decrease of SF (SPREADING FACTOR), increase of throughput**



**Adaptive throughput**  
**ADR: Adaptive Data Rate**

## RSSI and SF versus BW

BW \ SF	7	8	9	10	11	12
125 kHz	-123	-126	-129	-132	-133	-136
250 kHz	-120	-123	-125	-128	-130	-133
500 kHz	-116	-119	-122	-125	-128	-130



## SF, bitrate, sensitivity and SNR for a 125 kHz channel

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Spreading factor	Bitrate (bit/sec)	Sensitivity (dBm)	LoRa demodulator SNR
7 (128)	5 469	-124 dBm	-7.5 dB
8 (256)	3 125	-127 dBm	-10 dB
9 (512)	1 758	-130 dBm	-12.5 dB
10 (1024)	977	-133 dBm	-15 dB
11 (2048)	537	-135 dBm	-17.5 dB
12 (4096)	293	-137 dBm	-20 dB

SF and repetition can be either **manual** (i.e., determined by the end-device) or **automatic** (i.e., managed by the network)

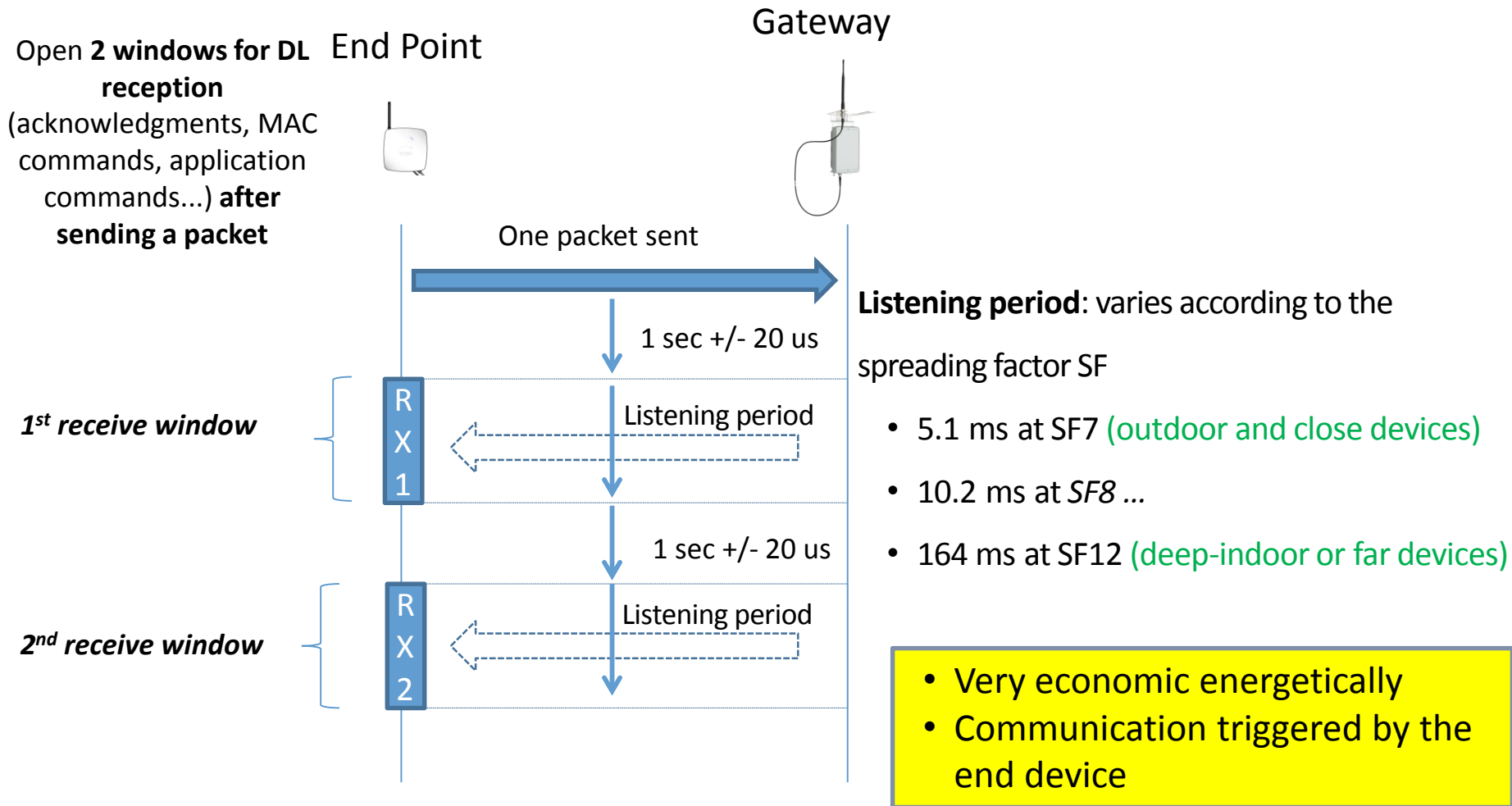


## LoRaWAN: device classes

Classes	Description	Intended Use	Consumption	Examples of Services
<b>A</b> (« all »)	Listens only after end device transmission	Modules with <b>no latency constraint</b>	The <b>most economic</b> communication Class energetically.. <b>Supported by all modules.</b> <b>Adapted to battery powered modules</b>	<ul style="list-style-type: none"> <li>• <b>Fire Detection</b></li> <li>• <b>Earthquake Early Detection</b></li> </ul>
<b>B</b> (« beacon »)	The module listens at a <b>regularly adjustable frequency</b>	Modules with <b>latency constraints</b> for the reception of messages of a few seconds	<b>Consumption optimized.</b> <b>Adapted to battery powered modules</b>	<ul style="list-style-type: none"> <li>• <b>Smart metering</b></li> <li>• <b>Temperature rise</b></li> </ul>
<b>C</b> (« continuous »)	Module <b>always listening</b>	Modules with a <b>strong reception latency constraint</b> (less than one second)	Adapted to <b>modules on the grid</b> or with <b>no power constraints</b>	<ul style="list-style-type: none"> <li>• <b>Fleet management</b></li> <li>• <b>Real Time Traffic Management</b></li> </ul>

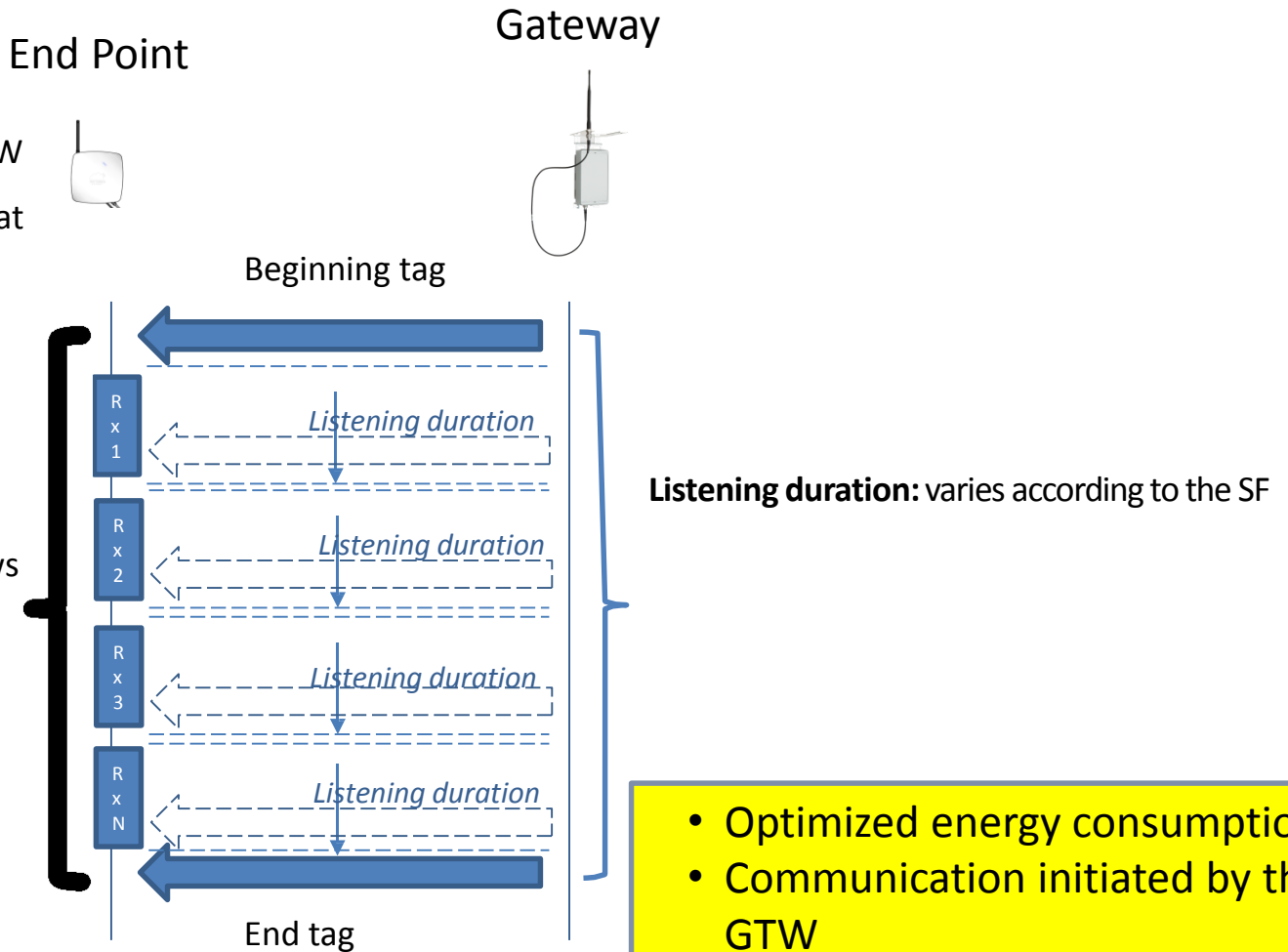
→ Any LoRa object can transmit and receive data

# Class A



# Class B (Synchronized mode)

- **Synchronized** with the GTW
- **Opens listening windows** at regular intervals.



Opens N reception windows between the two tags

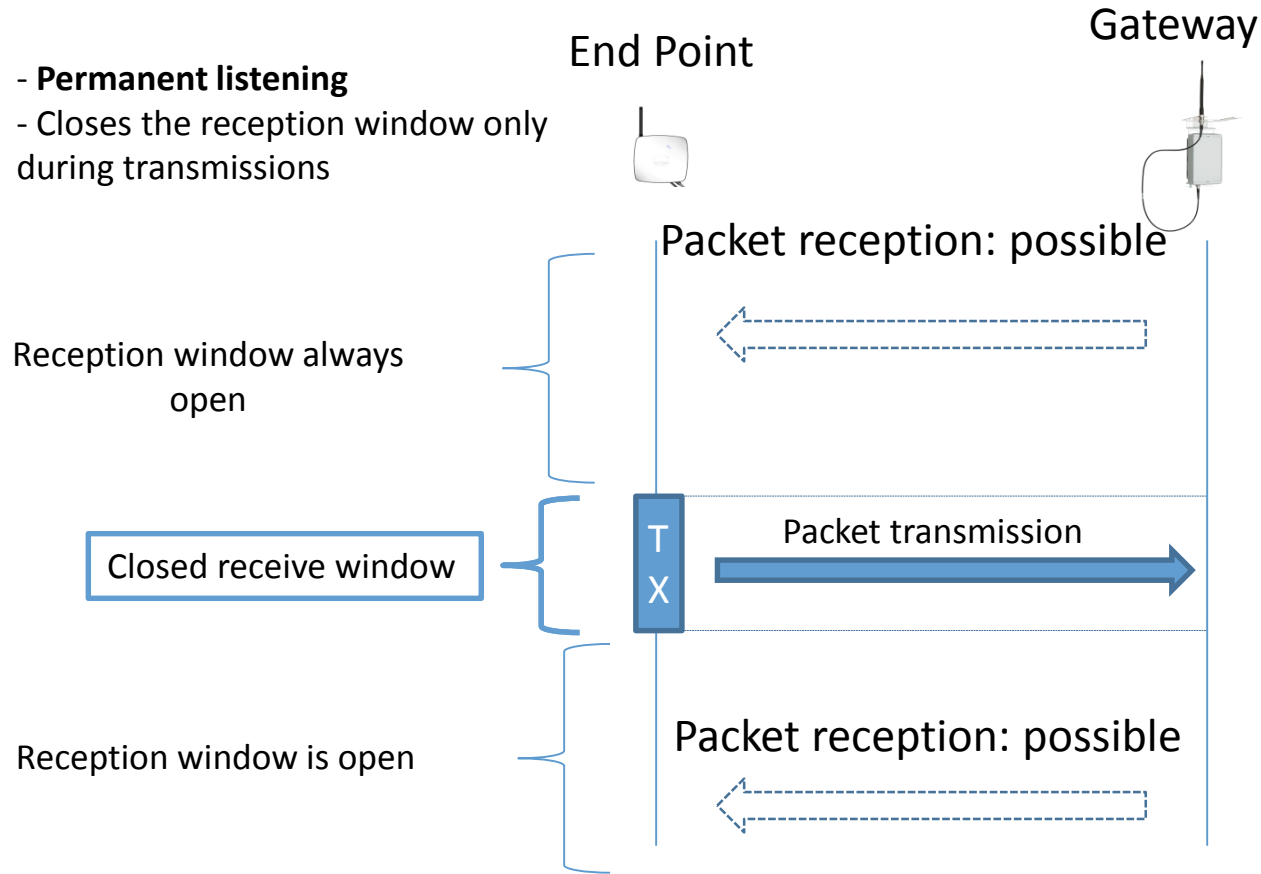
Listening duration: varies according to the SF

- Optimized energy consumption
- Communication initiated by the GTW

# Class C

- **Permanent listening**

- Closes the reception window only during transmissions

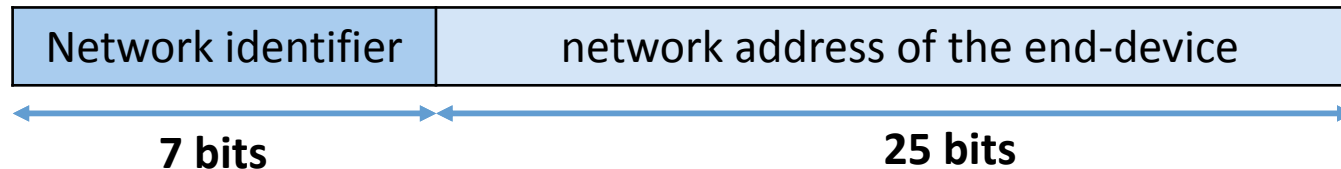


Adapted to devices on the power grid

## Identification of an end device in LORA

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- ❑ End-device address (*DevAddr*):



- ❑ **Application identifier (*AppEUI*):** A global application ID in the IEEE EUI64 address space that uniquely identifies the owner of the end-device.
- ❑ **Network session key (*NwkSKey*):** A key used by the network server and the end-device to calculate and verify the message integrity code of all data messages to ensure data integrity.
- ❑ **Application session key (*AppSKey*):** A key used by the network server and end-device to encrypt and decrypt the payload field of data messages.

## Current state

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Amsterdam: was the first city covered by LoRaWAN with only 10 Gateways for the whole city at \$ 1200 per unit. Since then, several cities have followed the trend:



By the end of 2016 , France will all be covered by LoRa

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## **ii. Sigfox**

# Roadmap

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2012

2013

2014

Mars  
2016

By the end of  
2016



Launch of the  
Sigfox  
network

First fundraising  
of Sigfox  
company to  
cover France

All France  
territory is  
covered by  
Sigfox network

San-Francisco  
become the first  
US. State covered  
by Sigfox

Sigfox in  
America in  
100 U.S.  
cities

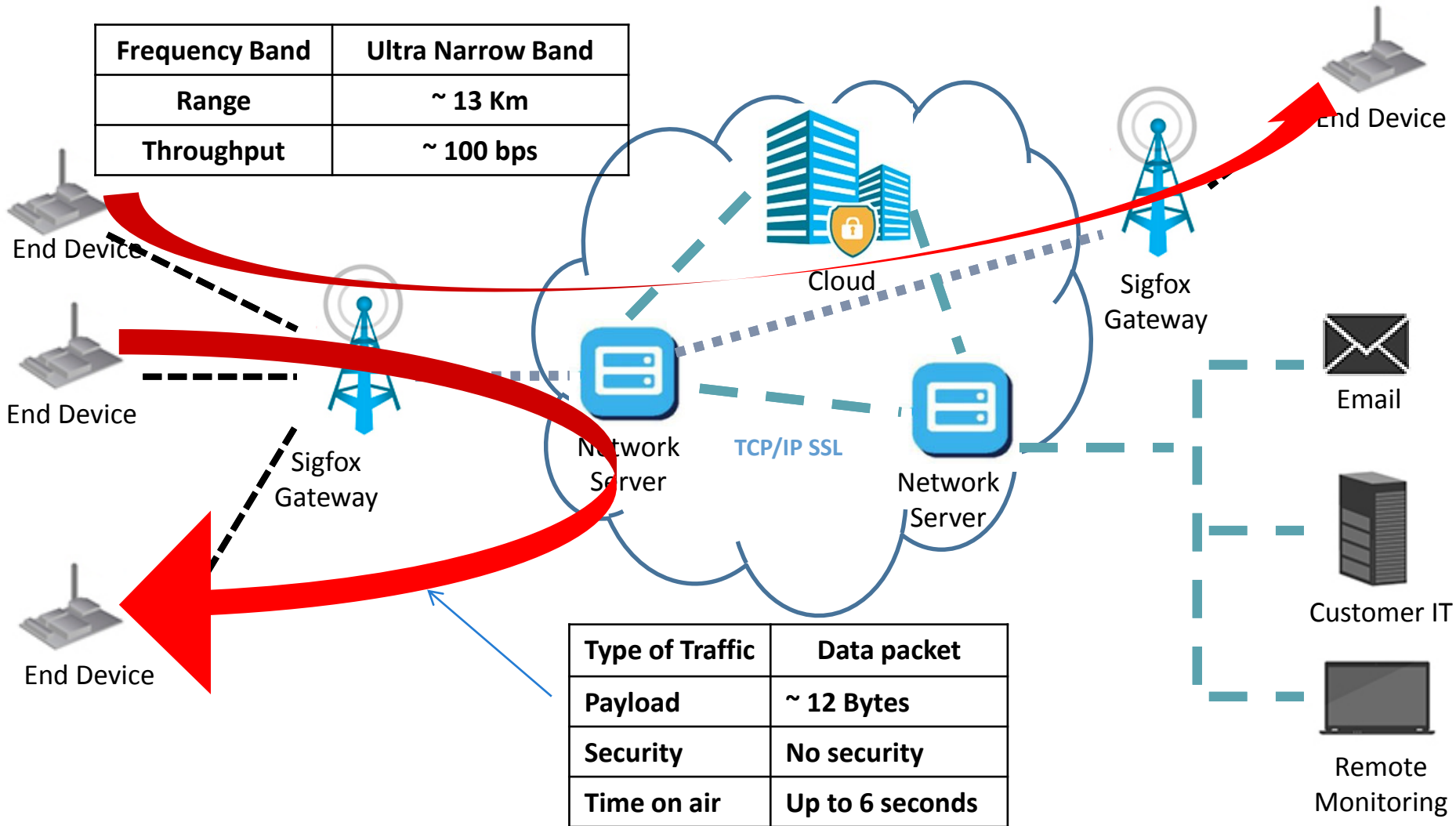


## Sigfox Overview

- **First LPWAN** Technology
- The physical layer based on an **Ultra-Narrow band wireless** modulation
- **Proprietary** system
- Low throughput ( **~100 bps**)
- Low power
- Extended range (**up to 50 km**)
- **140 messages/day/device**
- Subscription-based model
- **Cloud platform** with Sigfox –defined API for server access
- **Roaming capability**



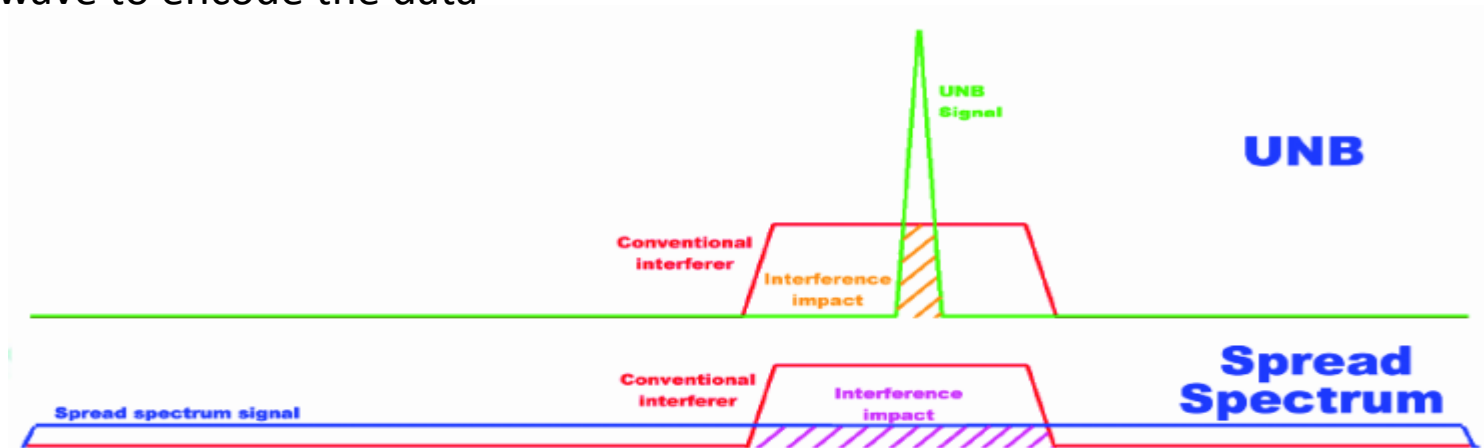
# Architecture



By default, data is conveyed over the air interface without any encryption. Sigfox gives customers the option to either implement their own end-to-end encryption solutions.

## Spectrum and access

- **Narrowband** technology
- Standard radio transmission method: binary phase-shift keying (**BPSK**)
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data

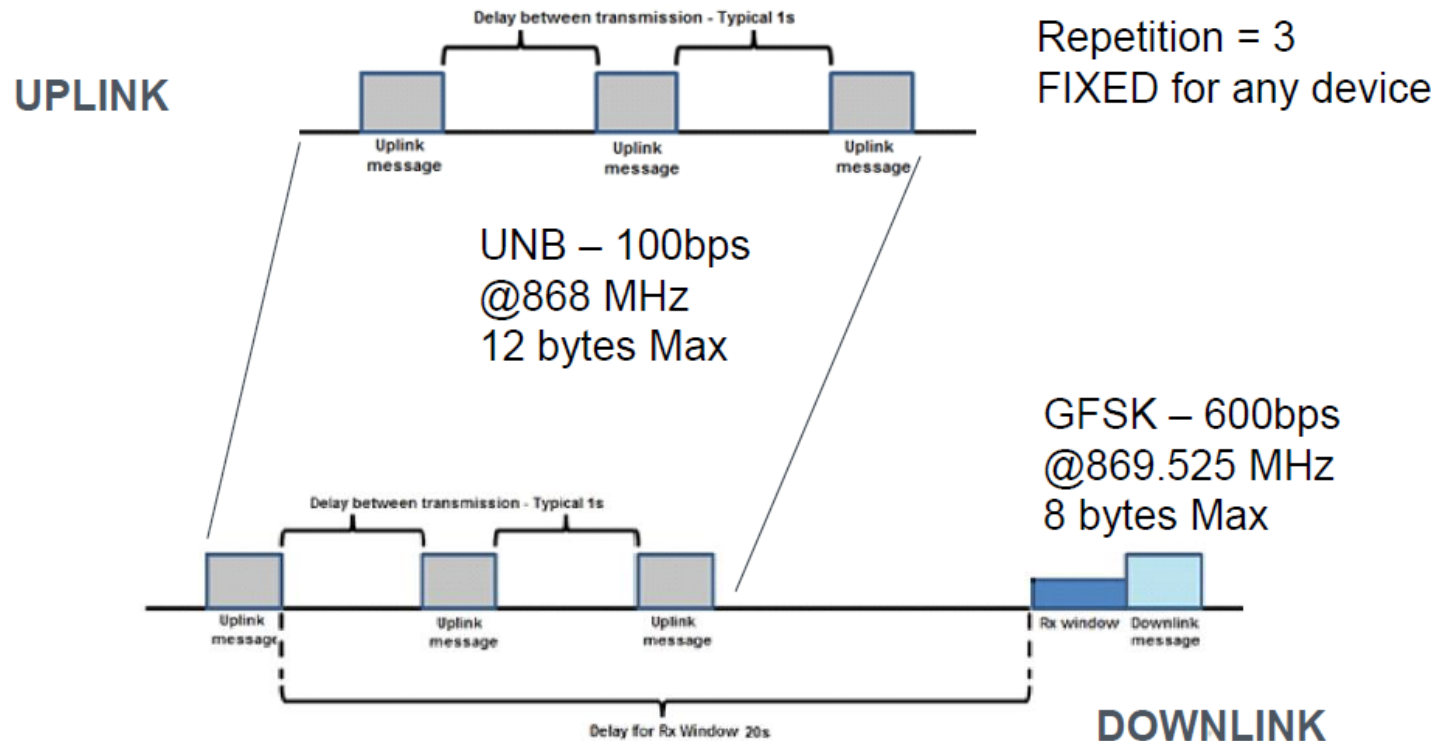


### Frequency spectrum:

- 868 MHz in Europe
- 915 MHz in USA

## Sigfox transmission

- Starts by an **UL transmission**
- Each message is transmitted 3 times
- A **DL message** can be sent (option)
- Maximum payload of **UL messages** = 12 data bytes
- Maximum payload of **DL messages** = 8 bytes



## Current state

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26  
Countries

**Covered countries**

1.6  
million  
Km<sup>2</sup>

**Covered areas**

424  
million

**End devices**

- SIGFOX LPWAN deployed in France, Spain, Portugal, Netherlands, Luxembourg, and Ireland , Germany, UK, Belgium, Denmark, Czech Republic, Italy, Mauritius Island, Australia, New Zealand, Oman, Brazil, Finland, Malta, Mexico, Singapore and U.S.

### **Sigfox company objectives:**

- ✓ Cover **China** in 2017
- ✓ 60 countries covered by the end of 2018

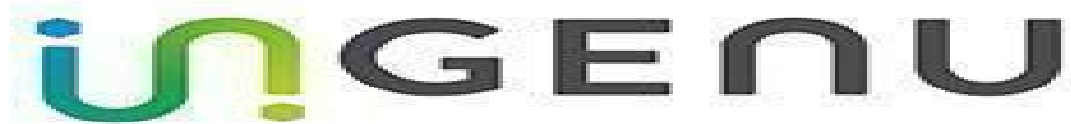


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## **iii. RPMA**

# Roadmap

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2008

September  
2015

2016

2017

RPMA was developed by On-Ramp Wireless to provide connectivity to oil and gas actors

it was renamed Ingenu, and targets to extend its technology to the IoT and M2M market

RPMA was implemented in many places  
Austin, Dallas/Ft. worth,  
Houston, TX, Phoenix, AZ,  
....

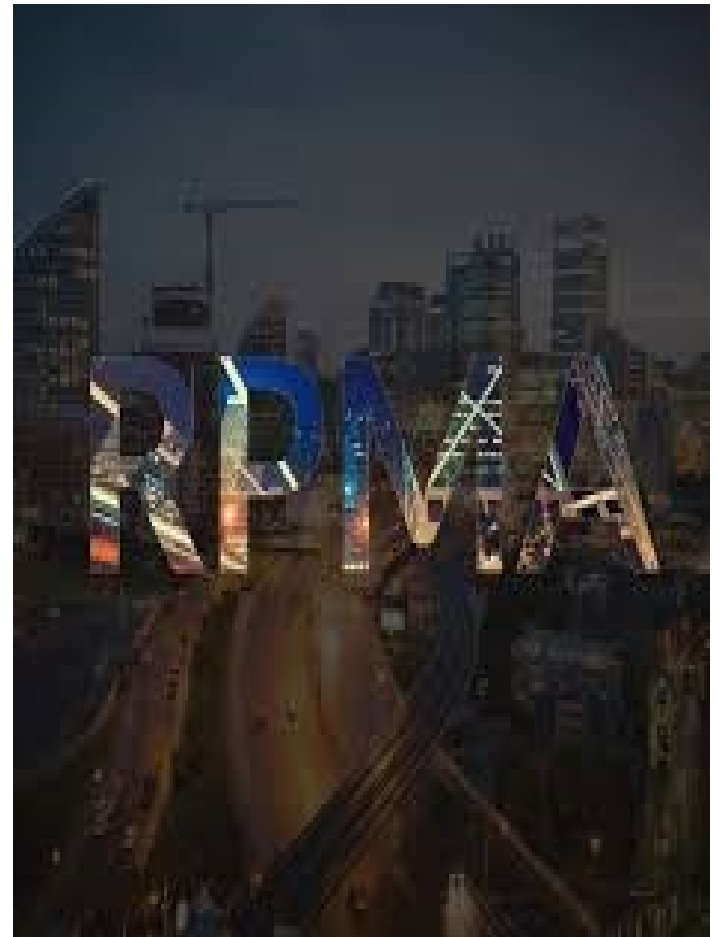
RPMA will be invaded in many others countries: Los Angeles, San Francisco-West Bay, CA, Washington, D C, Baltimore, MD, Kansas City

### ❑ *Random Phase Multiple Access (RPMA)*

technology is a low-power, wide-area channel access method used exclusively for machine-to-machine (M2M)

communication

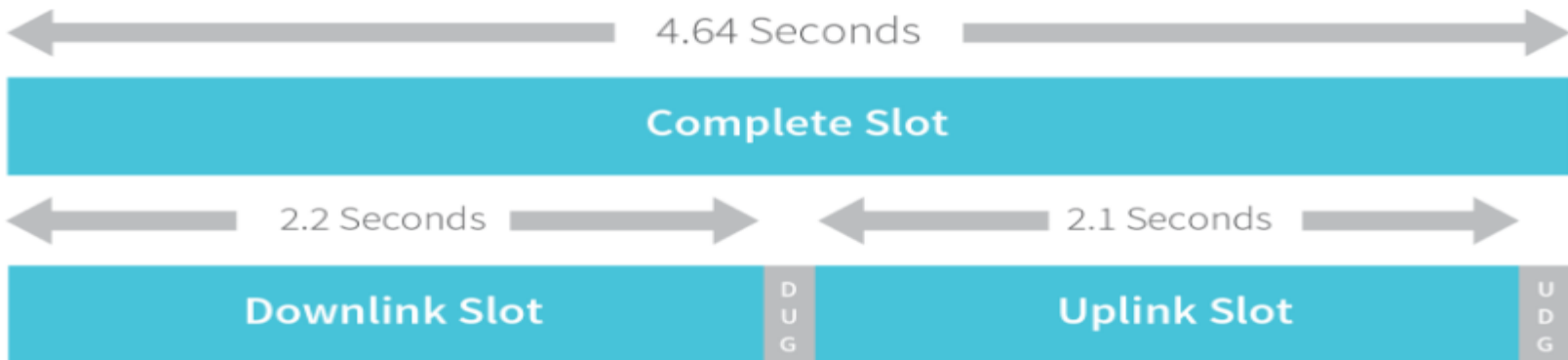
- ❑ RPMA uses the 2.4 GHz band
- ❑ Offer extreme coverage
- ❑ High capacity
- ❑ Allow handover (channel change)
- ❑ Excellent link capacity





## INGENU RPMA Overview

- ❑ RPMA is a Direct Sequence Spread Spectrum (DSSS) using:
  - ❖ Convolutional channel coding, gold codes for spreading
  - ❖ 1 MHz bandwidth
  - ❖ Using **TDD frame** with power control:
    - **Closed Loop Power Control:** the access point/base station measures the uplink received power and periodically sends a one bit indication for the endpoint to turn up transmit power (1) or turn down power (0).
    - **Open Loop Power Control:** the endpoint measures the downlink received power and uses that to determine the uplink transmit power without any explicit signaling from the access point/base station.



TDD frame

## Specifications of RPMA Solution

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### ❑ Time/Frequency Synchronization

### ❑ Uplink Power Control

- ✓ Creating a very tightly power controlled system in free-spectrum and presence of interference which **reduces** the amount of **required endpoint transmit power** by a factor of >50,000 and mitigates the **near-far effect**.
- ✓ Frame structure to allow continuous channel tracking.
- ✓ Adaptive spreading factor on uplink to optimize battery consumption.

### ❑ Handover

- ✓ Configurable gold codes per access point to eliminate ambiguity of link communication.
- ✓ Frequency reuse of 3 to eliminate any inter-cell interference degradation.
- ✓ Background scan with handover to allow continuous selection of the best access point

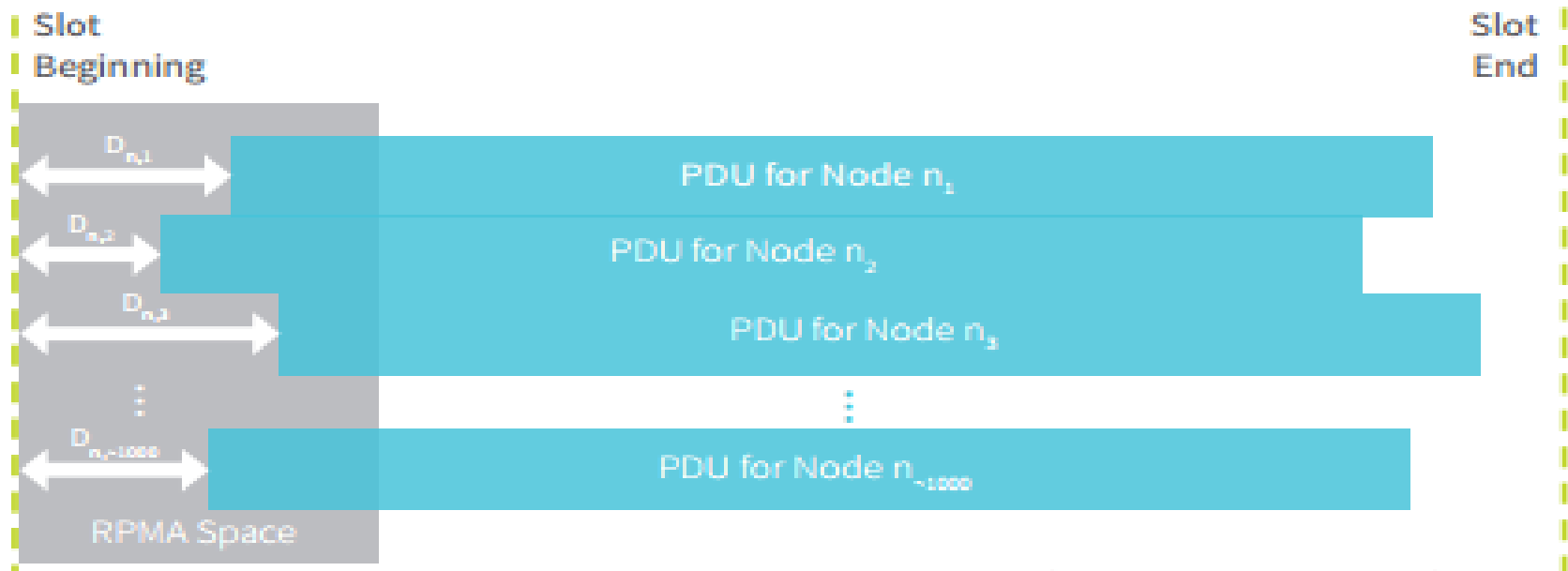
## Specifications of RPMA Solution

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### ❑ Downlink Data Rate Optimization

- ✓ Very high downlink capacity by use of adaptive downlink spreading factors.
- ✓ Open loop forward error correction for extremely reliable firmware download.
- ✓ Open loop forward error correction to optimize ARQ signaling. Signaling only needs to indicate completion, not which particular PDUs are lost.

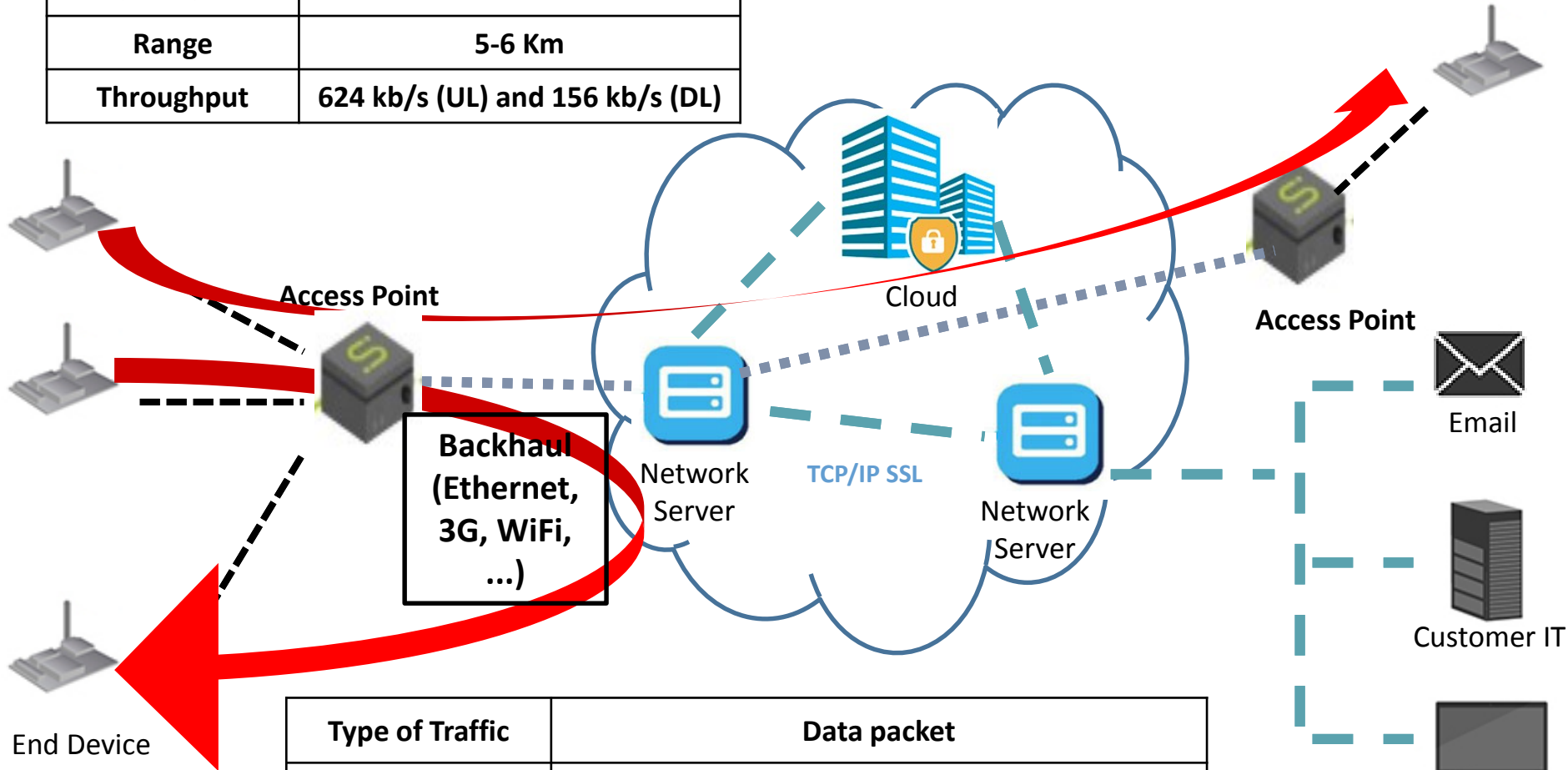
## RPMA a Random multiple access Network



- ❑ Random multiple access is performed by delaying the signal to transmit at each end-device
- ❑ Support up to **1000 end devices** simultaneously
- ❑ For the uplink, or the downlink broadcast transmission, a unique Gold code is used.
- ❑ For unicast downlink transmission, the **Gold code** is built with the **end-device ID**, such that **no other end-device is able to decode the data**.

# INGENU RPMA architecture

Frequency Band	2.4 GHZ
Range	5-6 Km
Throughput	624 kb/s (UL) and 156 kb/s (DL)



Type of Traffic	Data packet
Payload	~ 16 Bytes (one end point) ~ 1600 Bytes (for 1000 end points)
Security	AES Encryption

# Uplink Subslot Structure

## ❖ Uplink Subslot Structure Supporting Flexible Data Rate

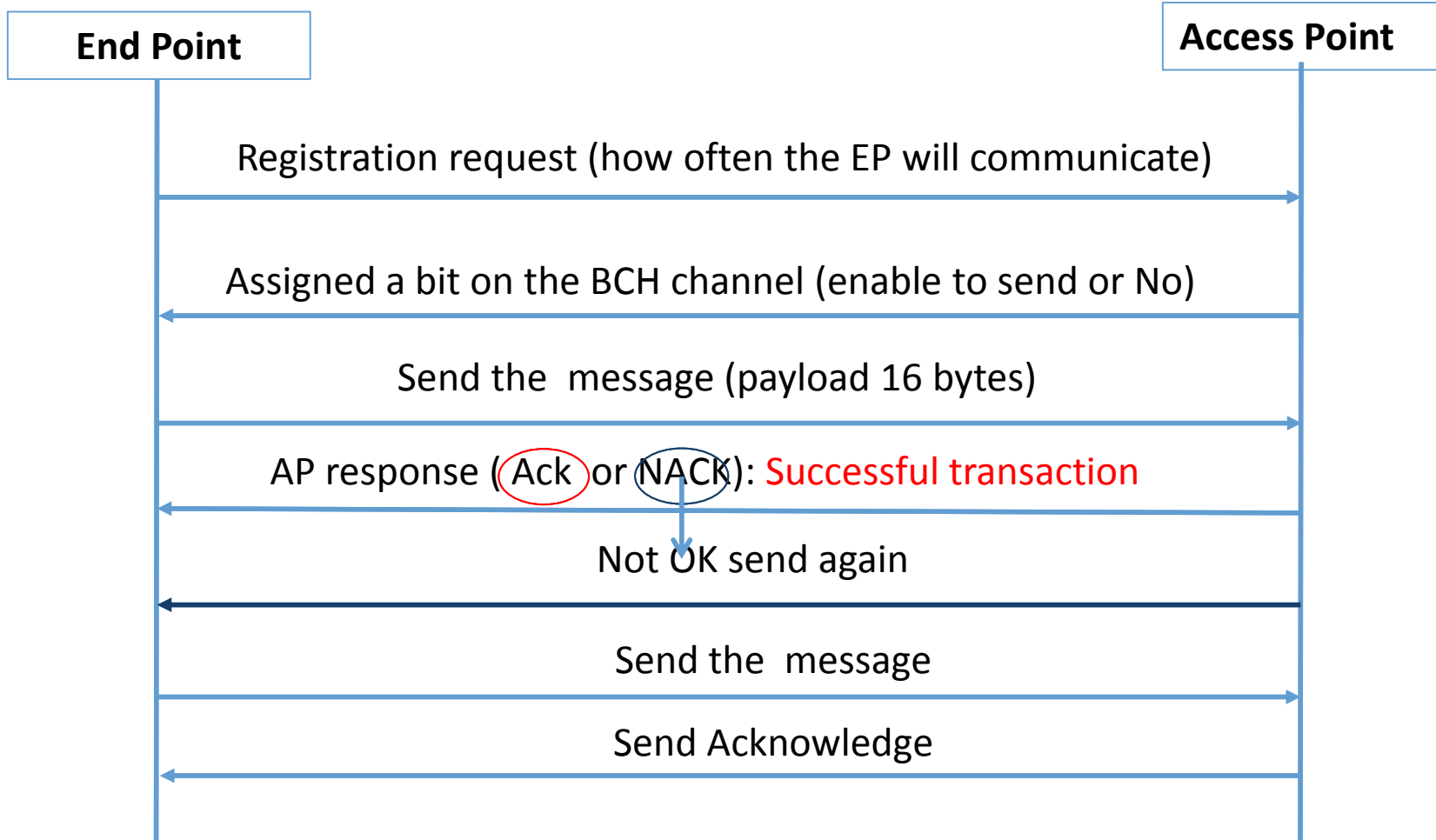
Spreading Factor 8192 Subslot 0															
SF 4096 Subslot 0								SF 4096 Subslot 1							
SF 2048 Subslot 0				SF 2048 Subslot 1				SF 2048 Subslot 2				SF 2048 Subslot 3			
SF 1024 Subslot 0		SF 1024 Subslot 1		SF 1024 Subslot 2		SF 1024 Subslot 3		SF 1024 Subslot 4		SF 1024 Subslot 5		SF 1024 Subslot 6		SF 1024 Subslot 7	
SF 512 SS 0	SF 512 SS 1	SF 512 SS 2	SF 512 SS 3	SF 512 SS 4	SF 512 SS 5	SF 512 SS 6	SF 512 SS 7	SF 512 SS 8	SF 512 SS 9	SF 512 SS 10	SF 512 SS 11	SF 512 SS 12	SF 512 SS 13	SF 512 SS 14	SF 512 SS 15

**Step 1:** Choose Spreading factor from 512 to 8192

**Step 2:** randomly select subslot

**Step 3:** Randomly select delay to add to subslot start from 0 to 2048 chips

## How end point can transfer a data?



**Message confidentiality: use of powerful encryption**

**Message integrity<sup>1</sup>  
Replay protection**

**Mutual Authentication**

**Device Anonymity**

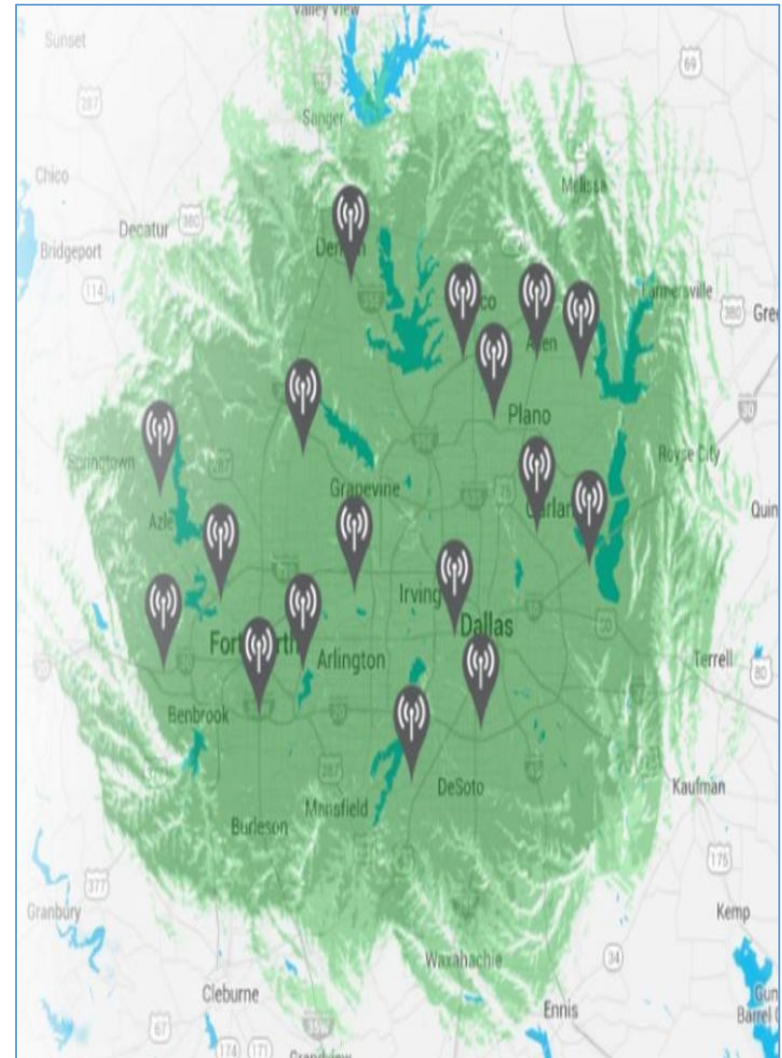
**Authentic firmware  
Upgrades**

**Secure Multicasts**



## RPMA's current and future presence

- ❑ heavy presence in Texas, with networks in Dallas, Austin, San Antonio, Houston, and large white space areas.
- ❑ Ingenu offer the connectivity to more **50% of the Texas state population**.
- ❑ Three densely populated Texas markets are served by only **27 RPMA access points**
- ❑ RPMA currently provides **more than 100,000 square miles** of wireless coverage for a host of IoT applications.
- ❑ Ingenu will be expanding its coverage to dozens of cities in the next few years.



## RPMA's current and future presence

Currently live	Coverage Rollout Q3	Coverage ROLLOUT Q4 2016	Coverage planned 2017
<ul style="list-style-type: none"> <li>• Austin, TX</li> <li>• Dallas/Ft. worth, TX</li> <li>• Houston, TX</li> <li>• Phoenix, AZ</li> <li>• Riverside, CA</li> <li>• San Antonio, TX</li> <li>• San Diego, CA</li> </ul>	<ul style="list-style-type: none"> <li>• Columbus, OH</li> <li>• Indianapolis, IN</li> </ul>	<ul style="list-style-type: none"> <li>• Atlanta, GA</li> <li>• Jacksonville, FL</li> <li>• Miami, FL</li> <li>• Orlando, FL</li> <li>• New Orleans, LA</li> <li>• Charlotte, NC</li> <li>• Albuquerque</li> <li>• Memphis, TN</li> <li>• Nashville, TN</li> <li>• El Paso, TX</li> <li>• Salt Lake City, UT</li> <li>• Richmond, Virginia</li> <li>• Virginia beach, VA</li> </ul>	<ul style="list-style-type: none"> <li>• Los Angeles, CA</li> <li>• San Francisco-West Bay, CA</li> <li>• Washington, DC</li> <li>• Baltimore, MD</li> <li>• Kansas City</li> <li>• Greensboro, NC</li> <li>• Las Vegas, NV</li> <li>• Oklahoma City, OK</li> <li>• And many more cities</li> </ul>

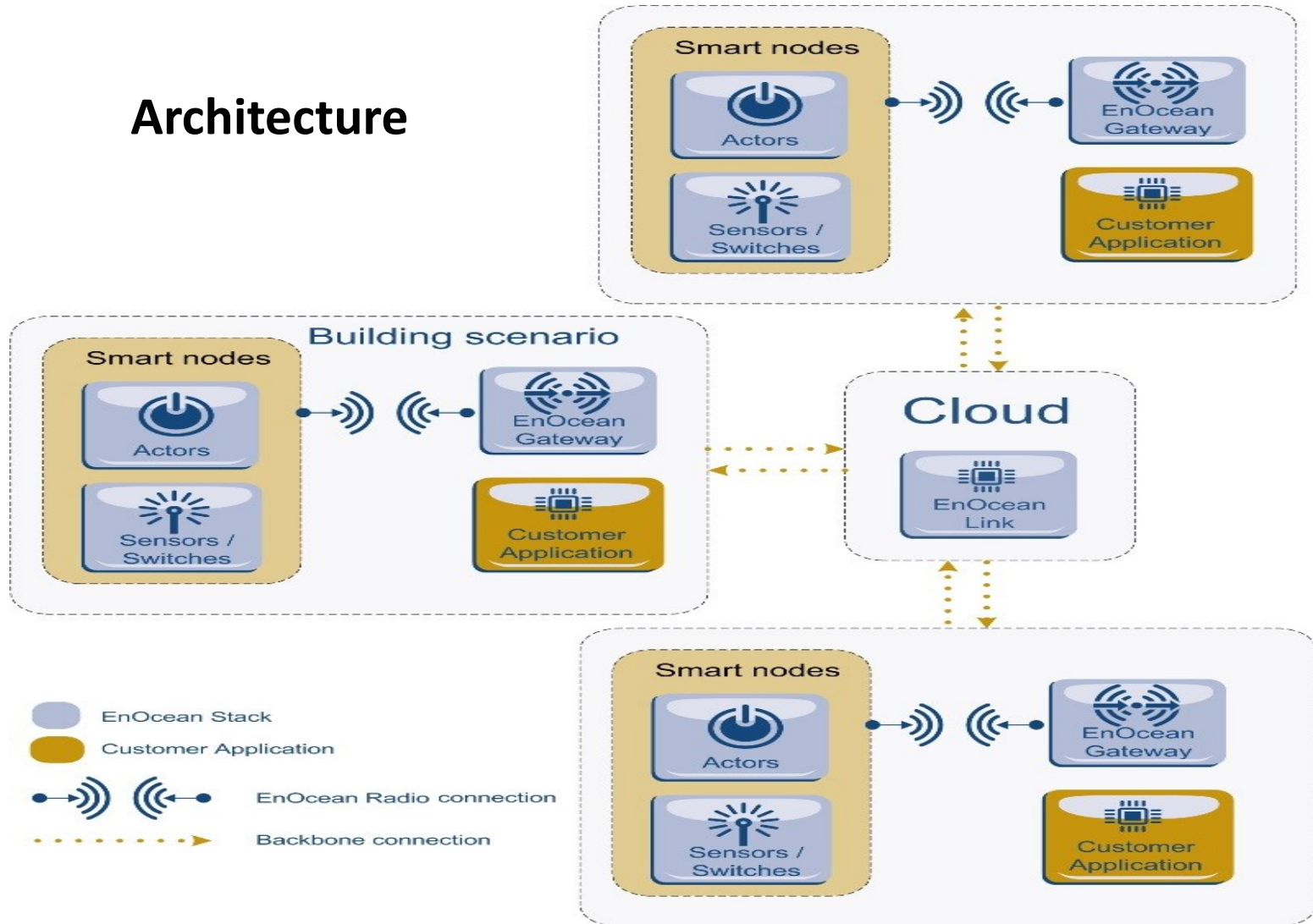
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**v. Others**

- ❑ Based on **miniaturized power converters**
- ❑ **Ultra low power** radio technology
- ❑ Frequencies: 868 MHz for Europe and 315 MHz for the USA
- ❑ Power from pressure on a switch or by photovoltaic cell
- ❑ These power sources are sufficient to power each module to transmit wireless and battery-free information.
- ❑ EnOcean Alliance in 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)



# Architecture





- Low power radio protocol
- Home automation (lighting, heating, ...) applications
- Low-throughput: 9 and 40 kbps
- Battery-operated or electrically powered
- Frequency range: 868 MHz in Europe, 908 MHz in the US
- Range: about 50 m (more **outdoor**, less indoor)
- Mesh architecture possible to increase the coverage
- Access method type CSMA / CA
- Z-Wave Alliance: more than 100 manufacturers in

# Services



# Summary

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## **A. Fixed & Short Range**

## **B. Long Range technologies**

- 1. Non 3GPP Standards (LPWAN)**
- 2. 3GPP Standards**

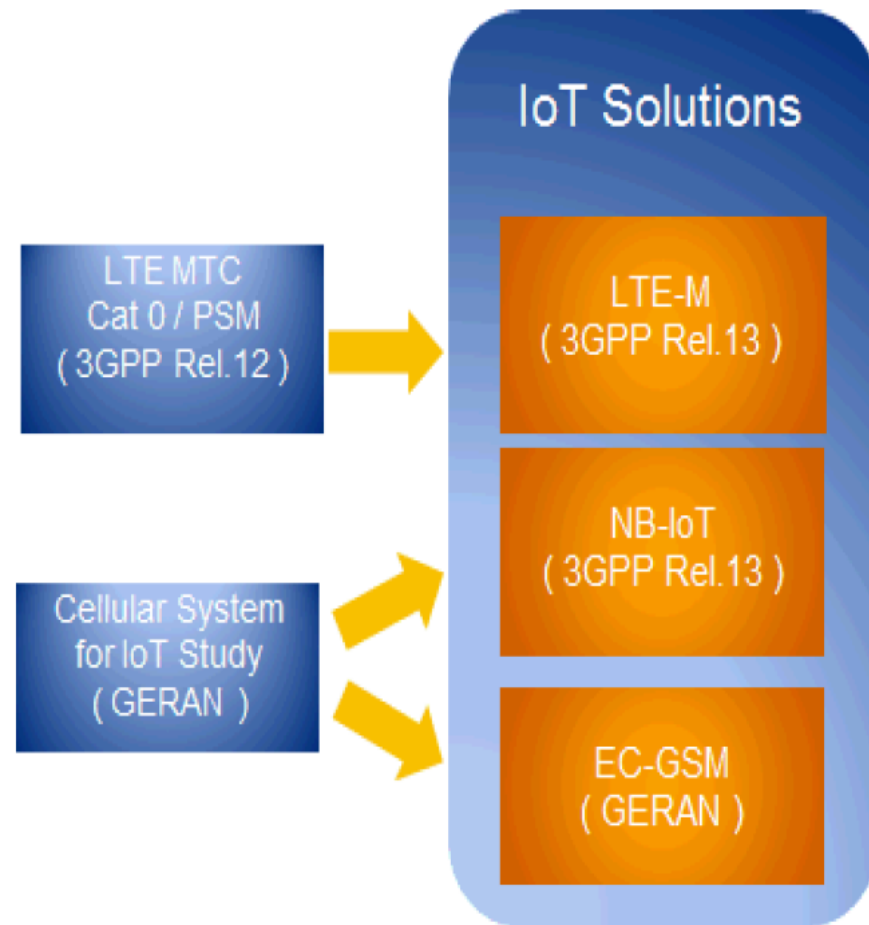


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## **2. 3GPP Standards**

- i. LTE-M**
- ii. NB-IOT**
- iii. EC-GSM**
- iv. 5G and IoT**

- **eMTC:** LTE enhancements for MTC, based on Release-12 (UE Cat 0, new PSM, power saving mode)
- **NB-IOT:** New radio added to the LTE platform optimized for the low end of the market
- **EC-GSM-IoT:** EGPRS enhancements in combination with PSM to make GSM/EDGE markets prepared for IoT



### Main feature enhancements

- Support for positioning (E-CID and OTDOA)
- Support for Multicast (SC-PTM)
- Mobility for inter-frequency measurements
- Higher data rates
- Specify HARQ-ACK bundling in CE mode A in HD-FDD
- Larger maximum TBS
- Larger max. PDSCH/PUSCH channel bandwidth in connected mode at least in CE mode A in order to enhance support e.g. voice and audio streaming or other applications and scenarios
- Up to 10 DL HARQ processes in CE mode A in FD-FDD
- Support for VoLTE (techniques to reduce DL repetitions, new repetition factors, and adjusted scheduling delays)

## Main eMTC, NB-IoT and EC-GSM-IoT features

	eMTC (LTE Cat M1)	NB-IOT	EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone	In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others	164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, 1 Rx	TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code	TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz	200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]
Peak rate (DL/UL)	1 Mbps for DL and UL	DL: ~50 kbps UL: ~50 for multi-tone, ~20 kbps for single tone	For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD	HD, FDD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, others TBD	33 dBm, 23 dBm

## Comparison of cellular IoT-LPWA

Criterion	Cat. 1 (Rel. 8+)	Cat. M1 (Rel. 13)	Cat. NB1 (Rel. 13)	FeMTC (Rel. 14)	eNB-IOT (Rel. 14)
Bandwidth	20 MHz	1.4 MHz	180 kHz	Up to 5 MHz (CE Mode A and B for PDSCH and A only for PUSCH)	180 kHz
Deployments/ HD-FDD	LTE channel / No HD-FDD	Standalone, in LTE channel / HD-FDD preferred	Standalone, in LTE channel, LTE guard bands, HD-FDD	Standalone, in LTE channel / HD-FDD, FD-FDD, TDD	Standalone, in LTE channel, LTE guard bands, HD-FDD preferred
MOP	23dBm	23dBm/ 20dBm	23dBm/ 20dBm	23dBm / 20dBm	23dBm/ 20dBm/ 14dBm
Rx ant / layers	2/1/	1/1	1/1	1/1	1/1
Coverage, MCL	145.4dB DL, 140.7dB UL (20 Kbps, FDD)	155.7dB	Deep coverage: 164dB +3	155.7dB (at 23dBm)	Deep coverage: 164dB
Data rates (peak)	DL: 10 Mbps, UL: 5 Mbps	~800 Kbps (FD-FDD) 300/375 Kbps DL/UL (HD-FDD)	30kbps (HD-FDD)	DL/ UL: 4 Mbps FD-FDD@5MHz	TBS in 80/ 105Kbps 1352/ 1800 peak rates t.b.d.
Latency	Legacy LTE: < 1s	~ 5s at 155dB	<10s at 164 dB	At least the same as Cat. M1 Legacy LTE (normal MCL)	At least the same as Cat. NB1, some improvements are FFS
Mobility	Legacy support	Legacy support	Cell selection, re-selection only	Legacy support	More mobility compared to Cat. NB1
Positioning	Legacy support	Partial support	Partial support	OTDA with legacy PRS and Frequency hopping	50m H target, new PRS introduced. details FSS. UTDOA under study
Voice	Yes (possible)	No	No	Yes	No
Optimizations	n/a	MPDCCH structure, Frequency hopping, repetitions	NPDCCH, NPSS/NSSS, NPDSCH, NPUSCH, NPRACH etc., frequency hopping, repetitions, MCO	Higher bandwidth will be DCI or RRC configured, Multi-cast e.g. SC-PTM	Multi-cast e.g. SC-PTM
Power saving	DRX	eDRX, PSM	eDRX, PSM	eDRX, PSM	[eDRX, PSM]
UE complexity BB	100%	~45%	< 25%	[~55%]	[~25%]

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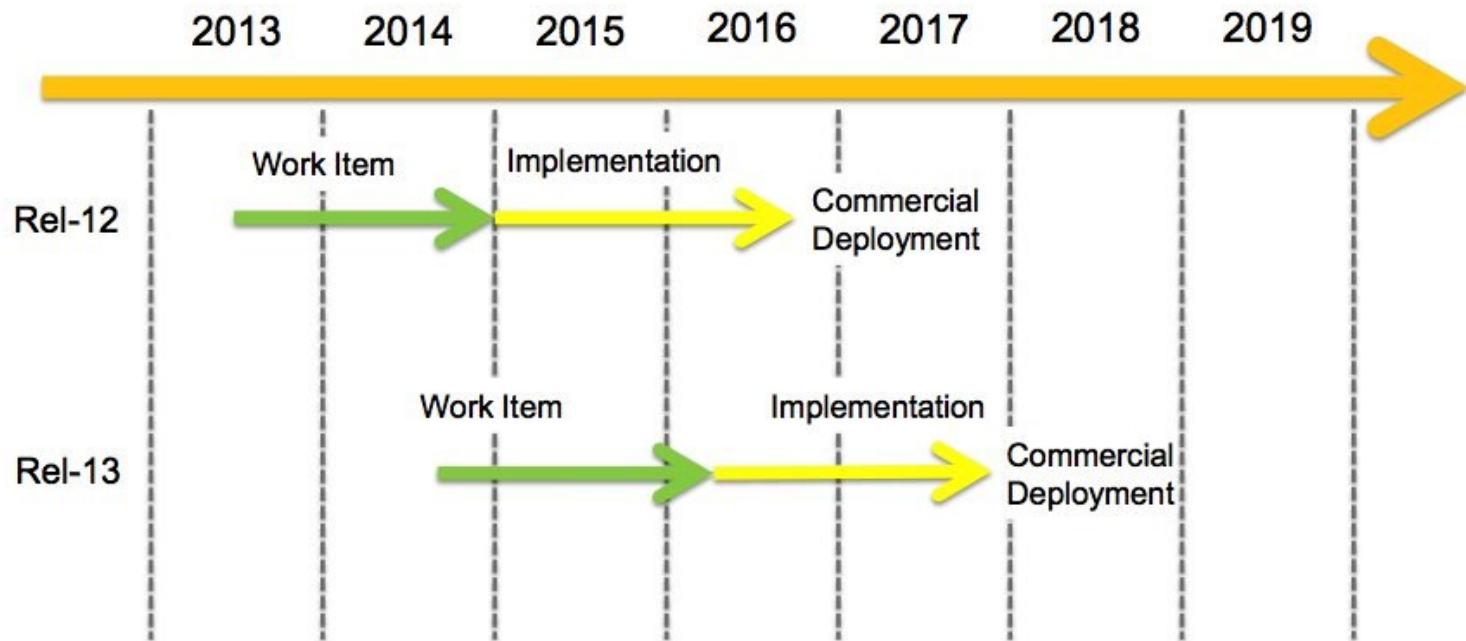
**i. LTE-M**

- **Evolution of LTE optimized for IoT**
- **Low power consumption and extended autonomy**
- **Easy deployment**
- **Interoperability** with LTE networks
- **Low overall cost**
- **Excellent coverage: up to 11 Km**
- **Maximum throughput:  $\leq 1$  Mbps**



**LTE-M**

## Timeline



- First released in Rel.1 in 2 Q4 2014
- Optimization in Rel.13
- Specifications completed in Q1 2016
- Available in 2017 (?)



## LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	<b>1</b>	<b>1</b>
Uplink peak rate (Mbps)	50	5	<b>1</b>	<b>1</b>
Number of antennas (MIMO)	2	2	<b>1</b>	<b>1</b>
Duplex Mode	Full	Full	<b>Half</b>	<b>Half</b>
UE receive bandwidth (MHz)	<b>20</b>	<b>20</b>	<b>20</b>	<b>1.4</b>
UE Transmit power (dBm)	<b>23</b>	<b>23</b>	<b>23</b>	<b>20</b>

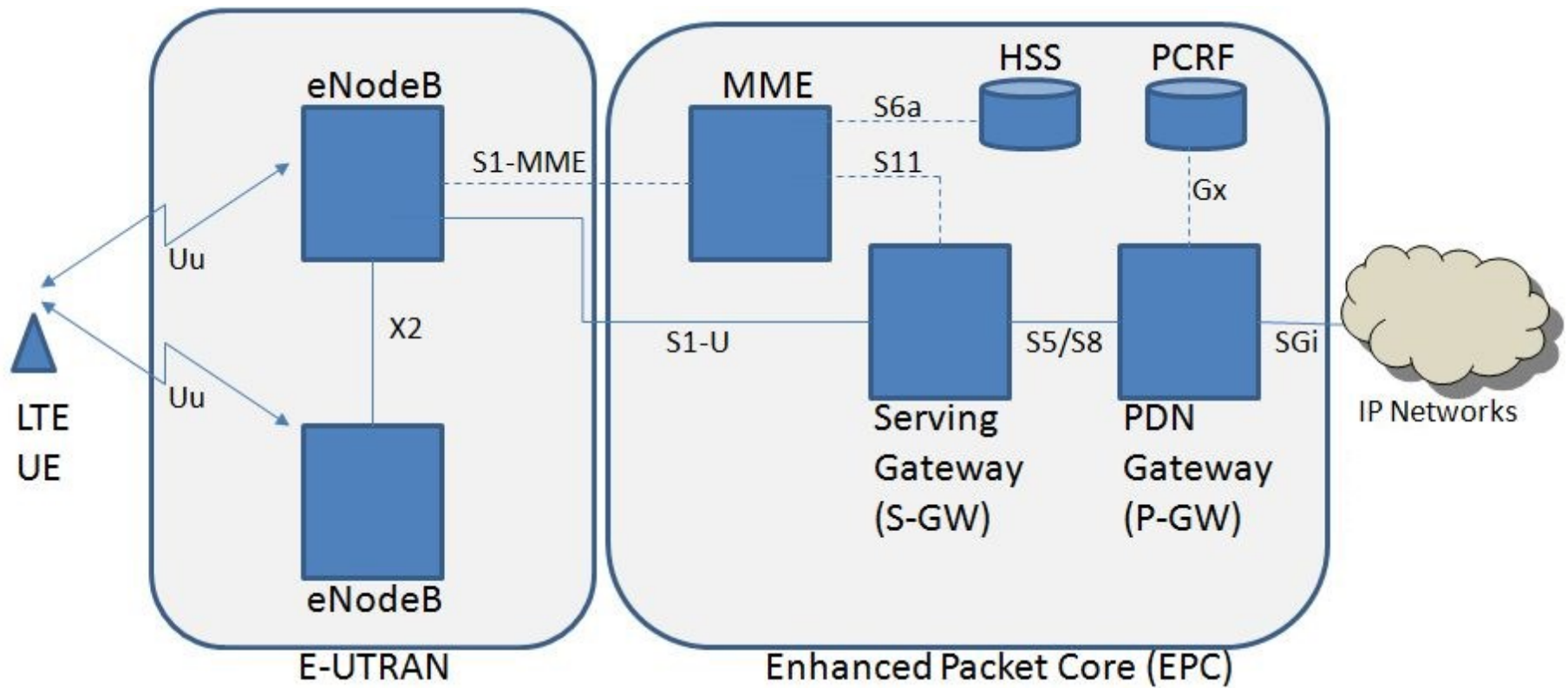
### Release 12

- New category of UE (“Cat-0”): **lower complexity** and low cost devices
- **Half duplex FDD** operation allowed
- **Single receiver**
- Lower data rate requirement (Max: 1 Mbps)

### Release 13

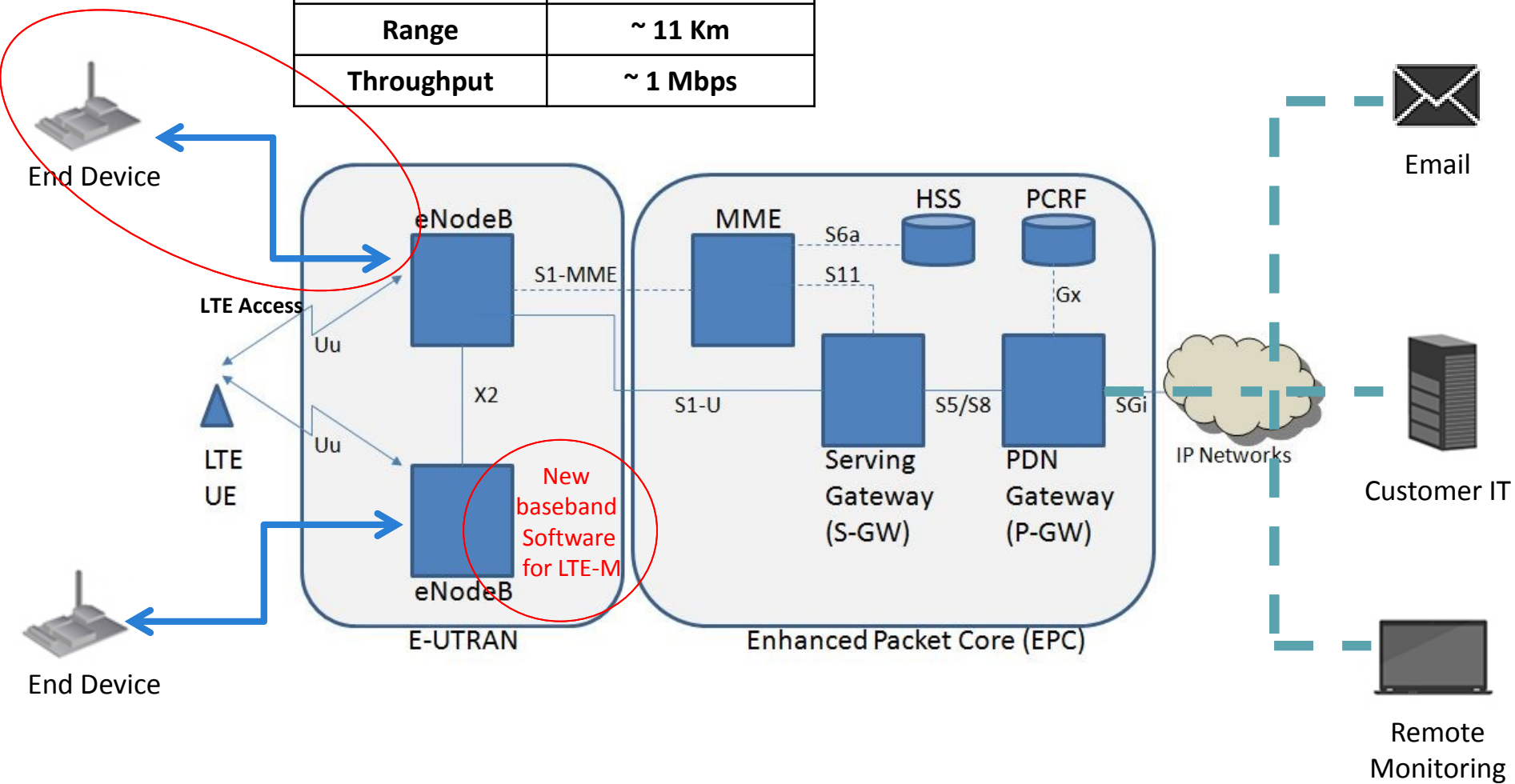
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

## Present LTE Architecture



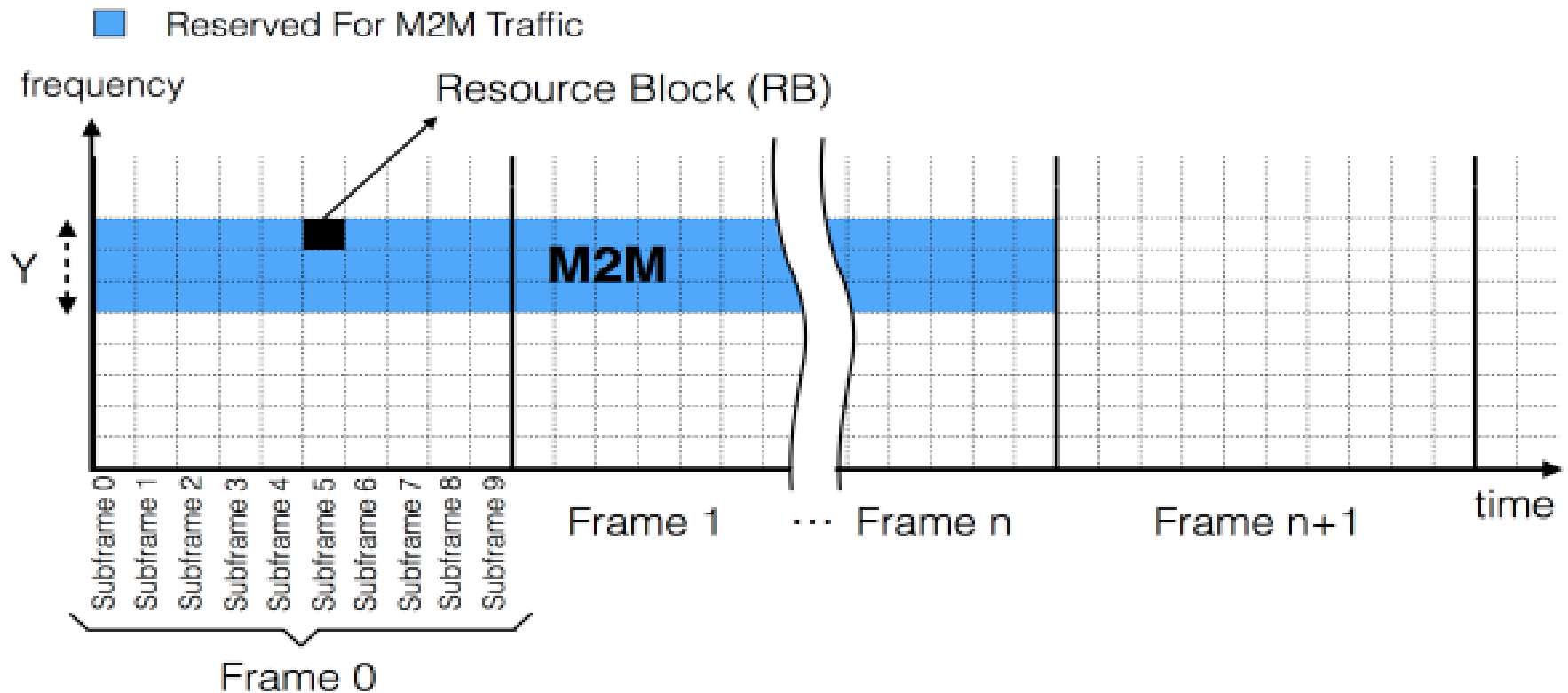
# Architecture

Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps



## Spectrum and access

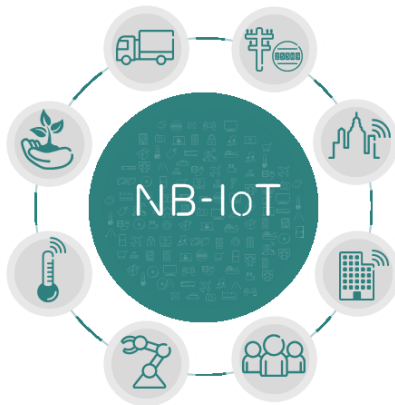
- Licensed Spectrum
- Bandwidth: 700-900 MHz for LTE
- Some resource blocks allocated for IoT on LTE bands



---

## **ii. NB-IOT**

## Current status



April  
2014

May  
2014

Mars  
2015

August  
2015

November  
2015

Jun  
2015

2017+

Narrowband  
proposal to  
Connected  
Living

3GPP  
'Cellular IoT'  
Study Item

GSMA  
Mobile IoT  
created

3GPP  
alignment on  
single  
standard

1<sup>st</sup> live pre-  
standard  
NB-IoT  
message

Full NB-IoT  
3GPP  
Standard  
Released

Commercial  
rollout

**Evolution of LTE-M**

**Reuses the LTE design extensively:** numerologies, DL OFDMA, UL SC-FDMA, channel coding, rate matching, interleaving, etc.

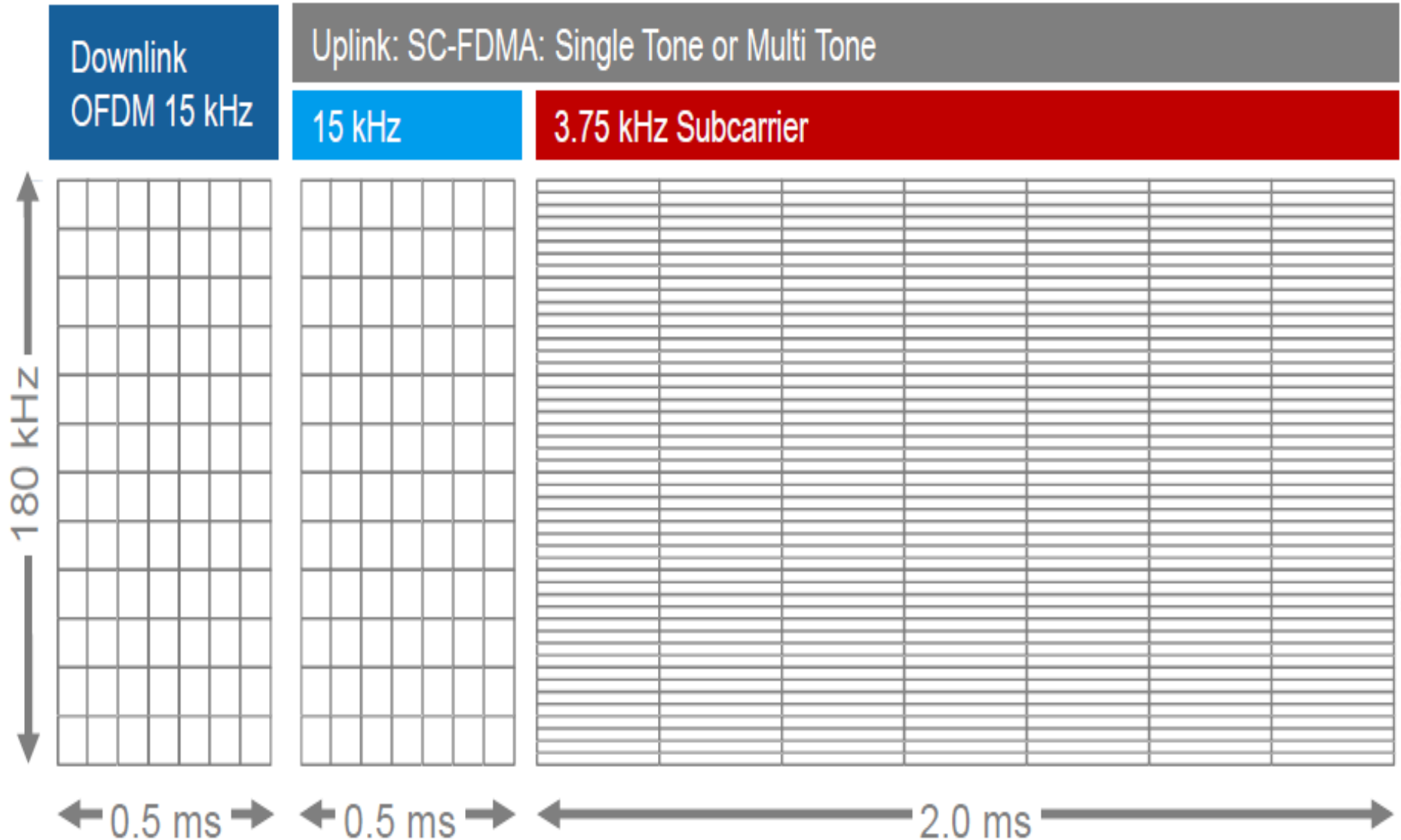
↳ ***Reduced time*** to develop:

- Full specifications.
- NB-IoT products for existing LTE equipment and software vendors.

**June 2016:** core specifications completed.

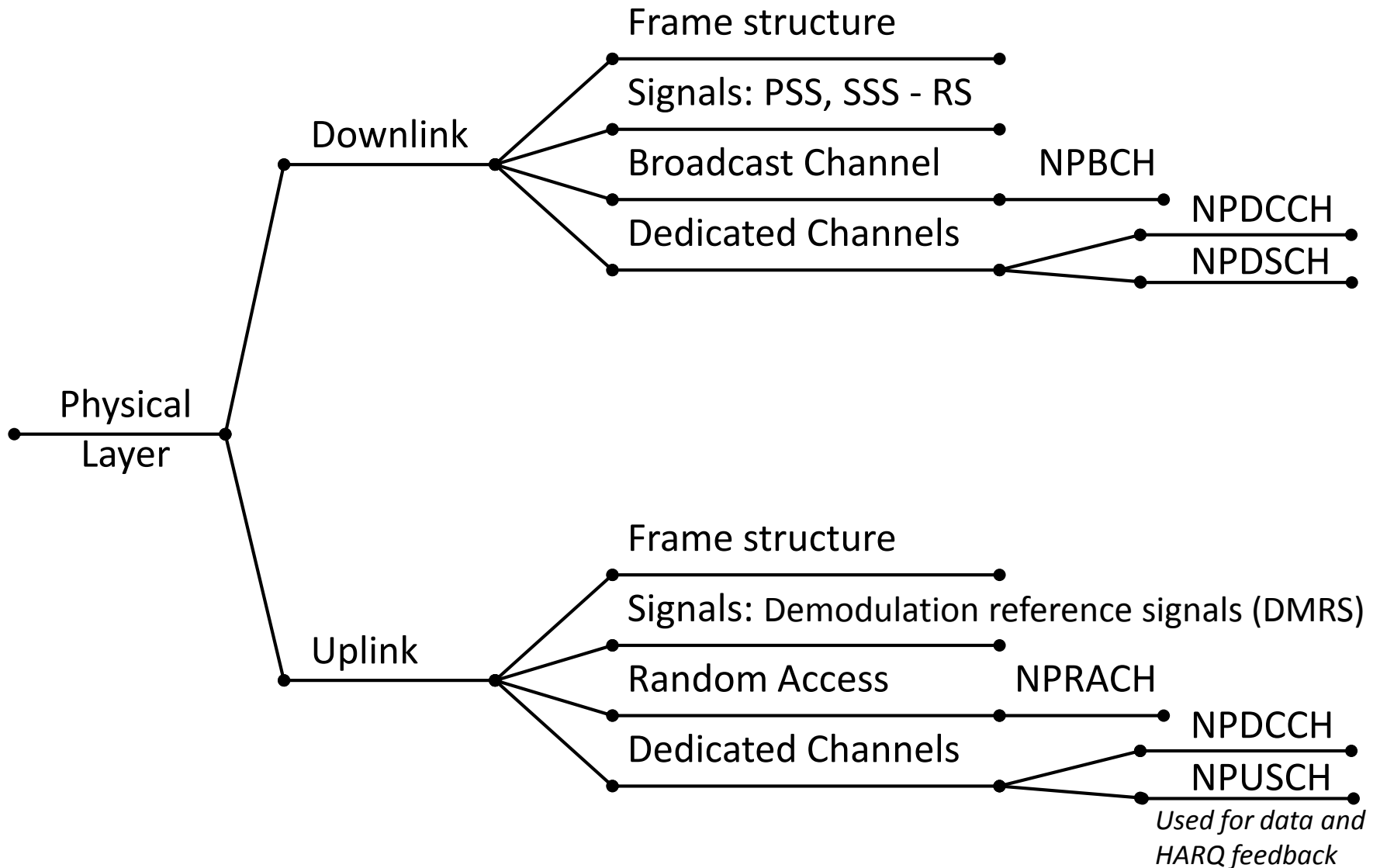
**Beginning of 2017:** commercial launch of products and services.

# Frame and Slot Structure – NB-IoT – 7 symbols per slot

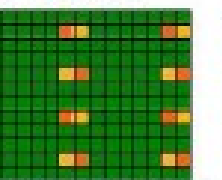
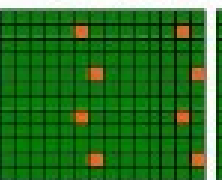
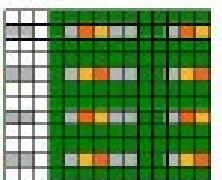
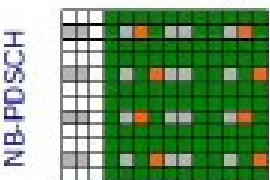
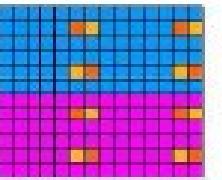
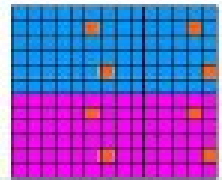
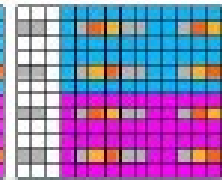
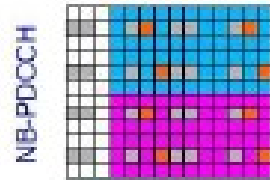
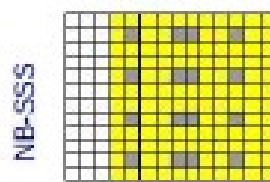
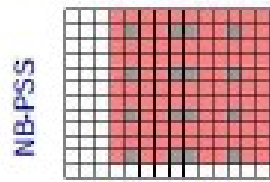
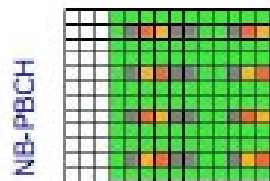




# NB-IoT Channels



# Physical downlink channels



- NB-MIB (34-bit payload + 16 CRC bit) is channel-coded and rate-matched into 1600 bits.
- Transmitted on Subframe 0
- One subframe carries 200 bits which are repeated on 8 consecutive radio frames. One block is made up of 8 radio frames. **Each subframe is independently decodable**
- 8 blocks (64 frames) carry  $200 \times 8 = 1600$  bits.

- Transmitted on subframe 5
- Length-11 ZC sequence is generated for each OFDM symbol.
- Punctured by LTE CRS locations

**NB-PDCCH and NB-PDSCH mapping in inband mode:**

- Size of LTE control region and number of NB-RS ports is indicated by NB-MIB.

- Transmitted on subframe 9
- Punctured by LTE CRS locations
- Occupies 12 subcarriers

- Two CCEs (upper 6 REs, and lower 6 REs) defined.
- NB-PDCCH is punctured on REs used for CSI-RS in the in-band case
- Max aggregation level for NB-PDCCH: 2
  - Repetition is only applied in case AL=2
- When AL = 2 is used, two NB-CCEs of the same UE are in the same subframe
- Different NB-PDCCHs:
  - TDM at subframe level for extended and extreme coverage.
  - Can be multiplexed in one subframe for normal coverage

Inband Mode

Standalone / Guard band Mode

Inband Mode

Standalone / Guard band Mode

- Error detection through 24-bit CRC for NB-PDSCH
- 16QAM is not supported for NB-PDSCH
- The maximum TBS for NB-PDSCH is 680 bits
- Redundancy versions (RVs) for NB-PDSCH are not supported
- NB-SIB1 is transmitted in one subframe of every other frame in 16 continuous frames. The subframes which are used are fixed.

Maximum Transmission Block Size = **680 bits**

**Inband mode: 100 to 108 symbols – Standalone/Guard band mode: 152 to 160 symbols**

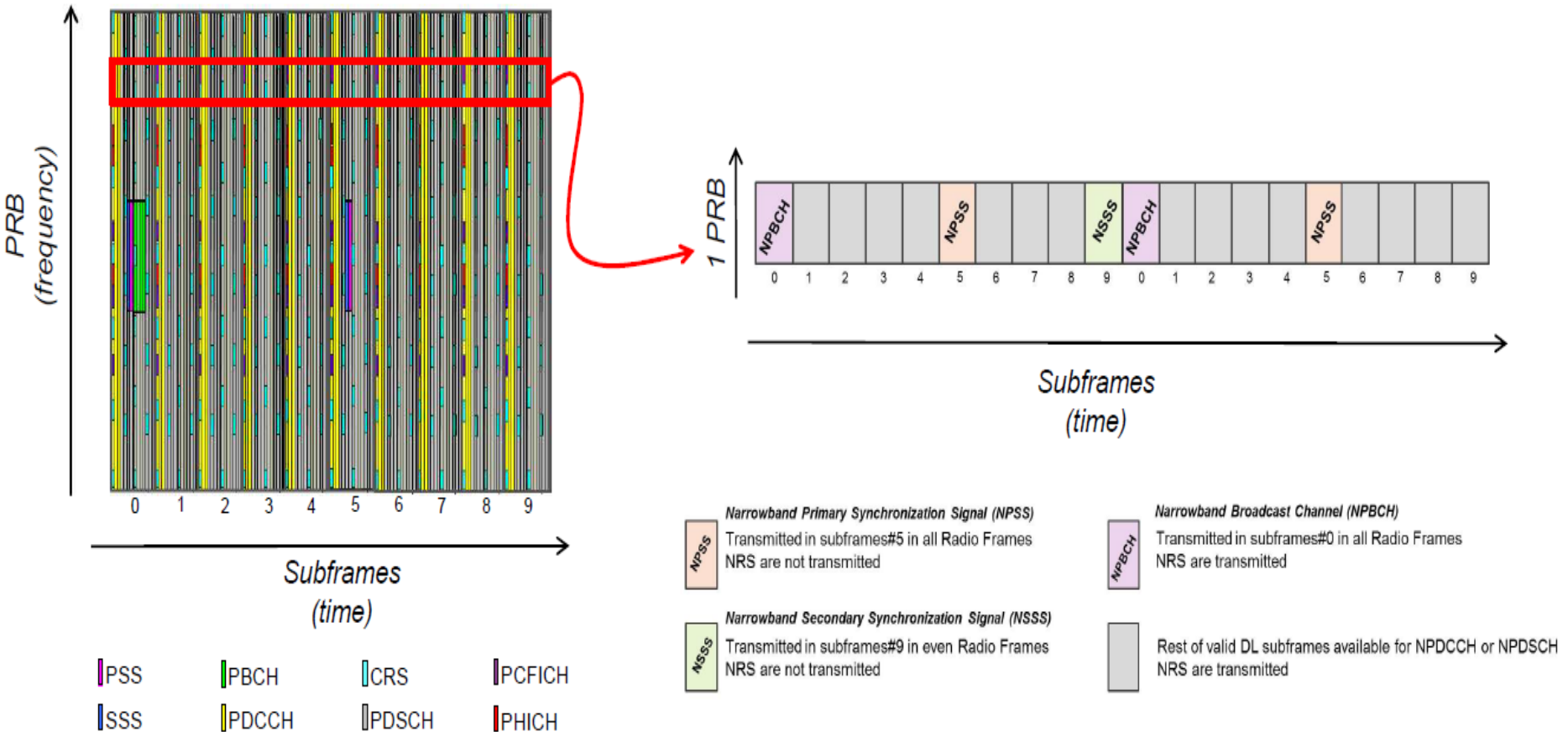
# Downlink Frame Structure

## LTE

Channels are time and frequency multiplexed;  
Multiple channels per subframe

## NB-IoT

Each physical channel occupies the whole PRB;  
Only one channel per subframe



# UL frame structure

## UL frame structure

### Single-Tone (mandatory):

To provide capacity in signal-strength-limited scenarios and dense capacity

- Number of subcarriers: 1
- Subcarrier spacing: 15 kHz or 3.75 kHz (via Random access)
- Slot duration: 0.5 ms (15 kHz) or 2 ms (3.75 kHz)

### Multi-tone (optional):

To provide higher data rates for devices in normal coverage

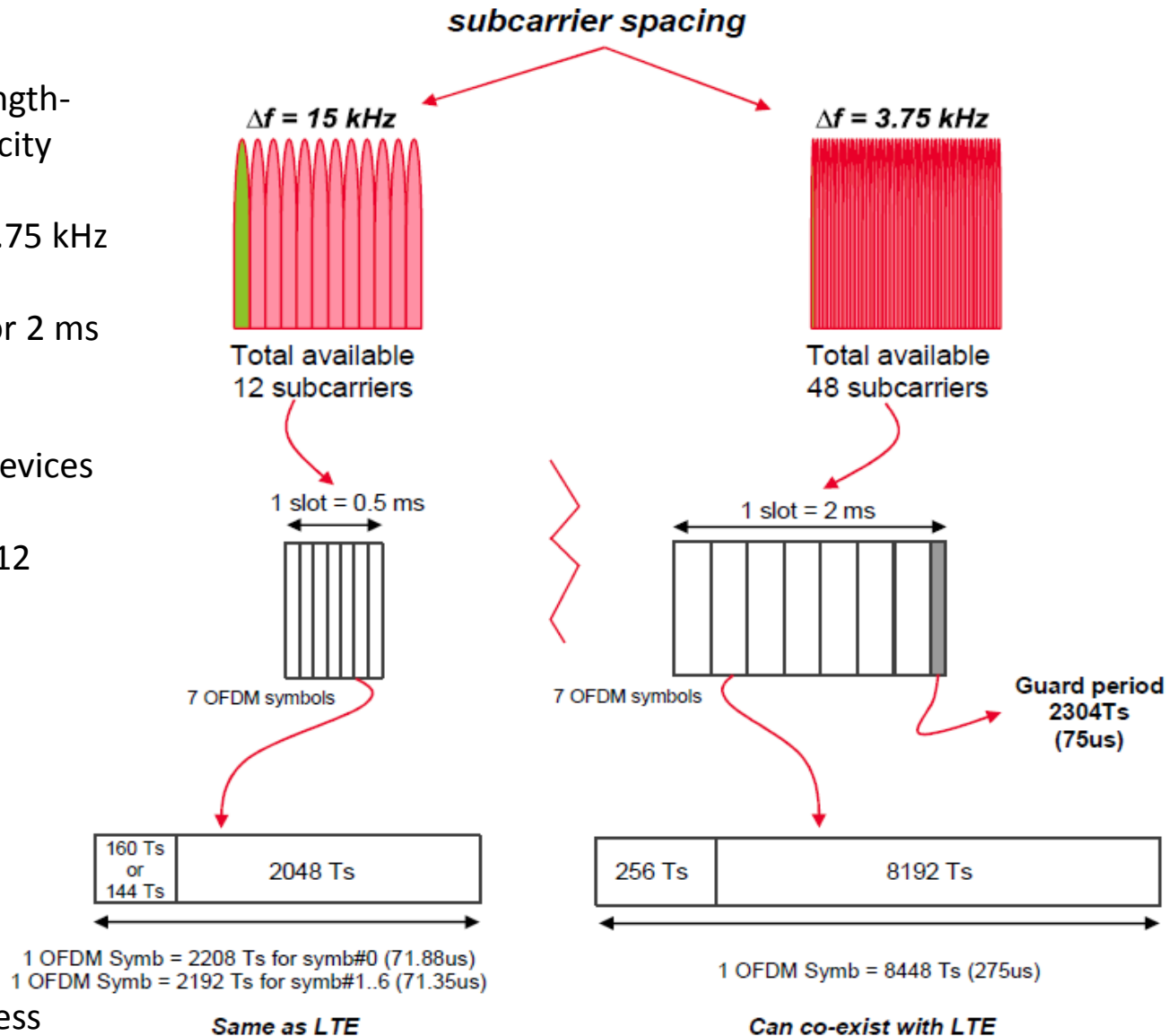
- Number of subcarriers: 3, 6 or 12 signaled via DCI
- Subcarrier spacing: 15 kHz
- Slot duration = 0.5 ms

### New UL signals

DMRS (demodulation reference signals)

### New UL channels

- NPUSCH (Physical UL Shared Channel)
- Channel)
- NPRACH (Physical Random Access Channel)

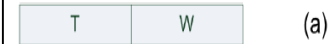


# NB-IoT Repetitions

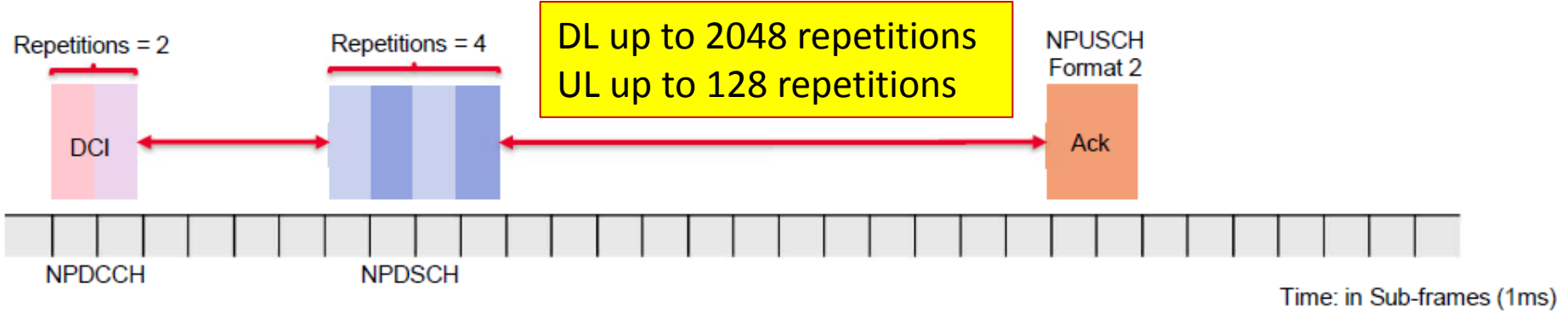
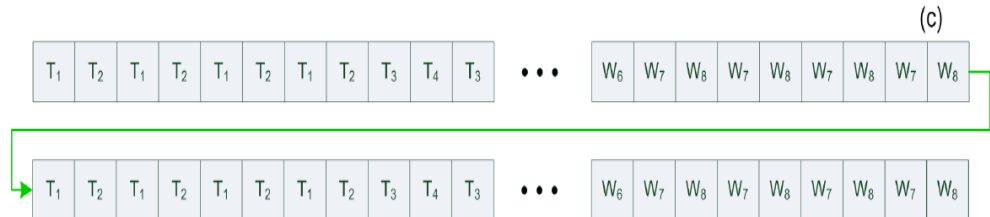
Consists on repeating the same transmission several times:

- Achieve extra coverage (up to 20 dB compared to GPRS)
- Each repetition is self-decodable
- SC is changed for each transmission to help combination
- Repetitions are ACK-ed just once
- All channels can use Repetitions to extend coverage

15 kHz subcarrier spacing.  
A transport block *test word (TW)* is transmitted on two RUs

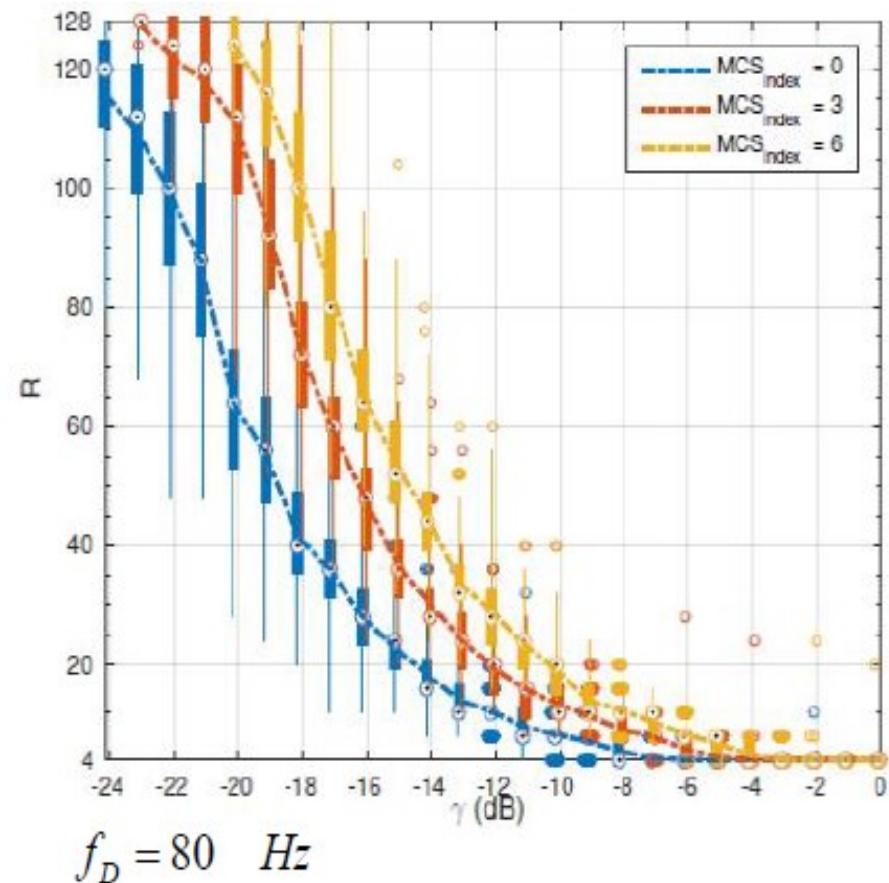
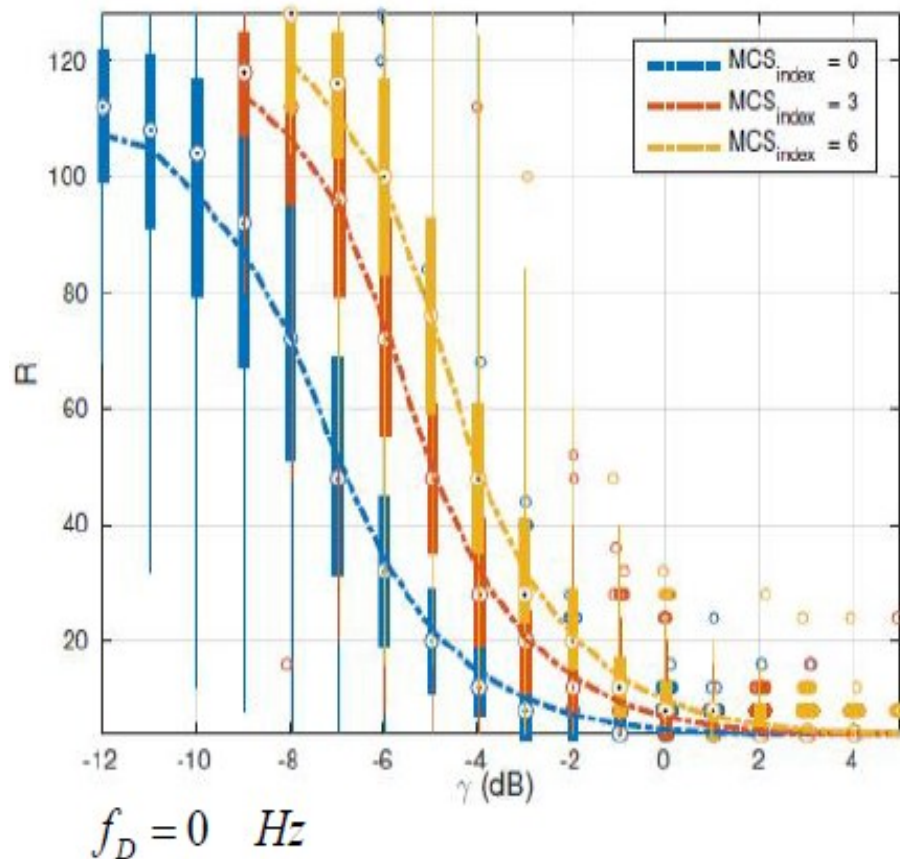


Each RU is transmitted over 3 subcarriers and 8 slots

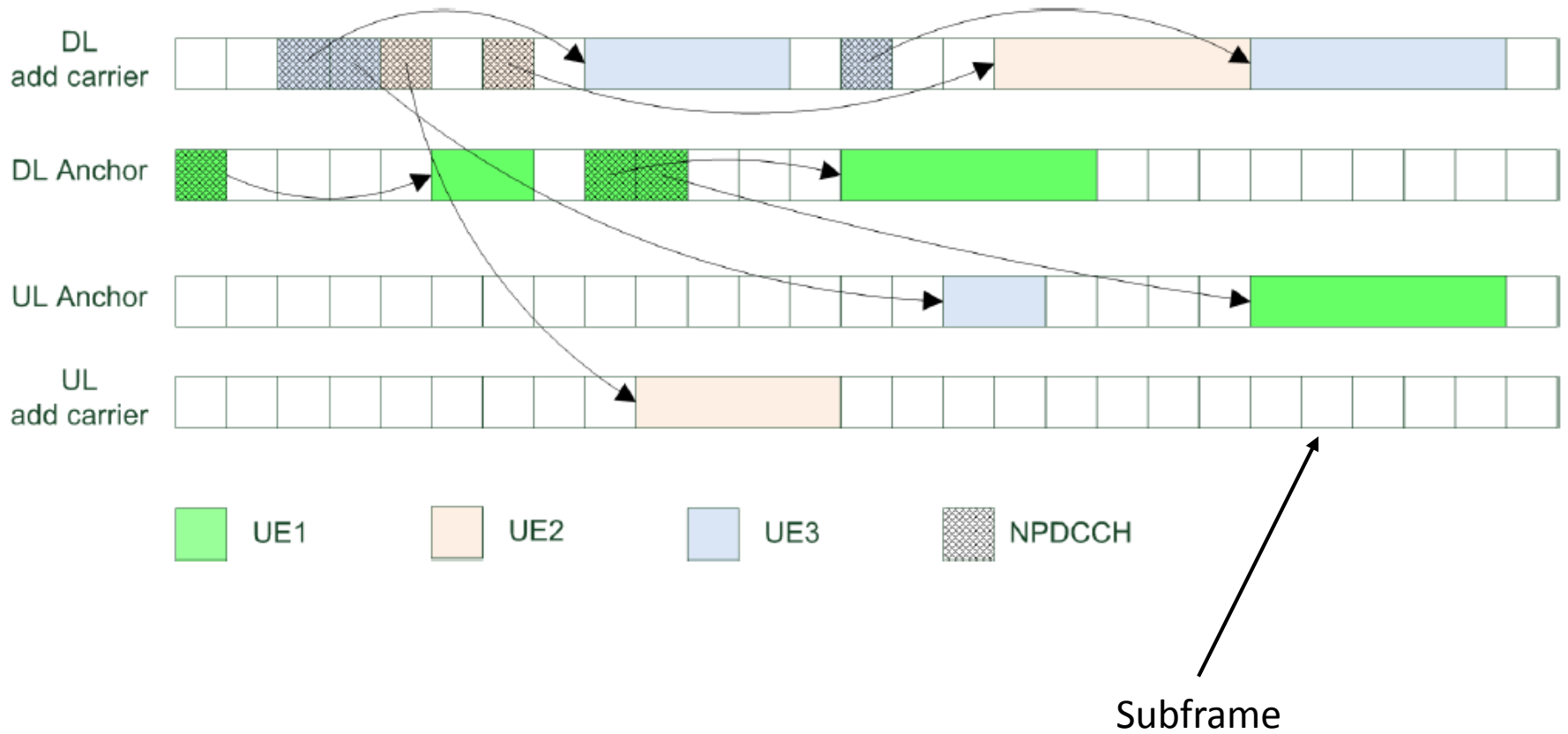


**Example:** Repetitions used in NB-IoT in NPDCCH and NPDSCH channels

# Repetitions number to decode a NPUSCH



# Transmissions scheduling



## Release 14 enhancements

---

- OTDOA
- UTDOA positioning is supported under the following conditions:
- It uses an existing NB-IoT transmission
  - It can be used by Rel-13 UEs
  - Any signal used for positioning needs to have its accuracy, complexity, UE power consumption performance confirmed

### Main feature enhancements:

- Support for Multicast (SC-PTM)
- Power consumption and latency reduction (DL and UL for 2 HARQ processes and larger maximum TBS)
- Non-Anchor PRB enhancements (transmission of NPRACH/Paging on a non-anchor NB-IoT PRB)
- Mobility and service continuity enhancements (without the increasing of UE power consumption)
- New Power Class(es) (if appropriate, specify new UE power class(es), e.g. 14dBm)



## Physical Channels in Downlink

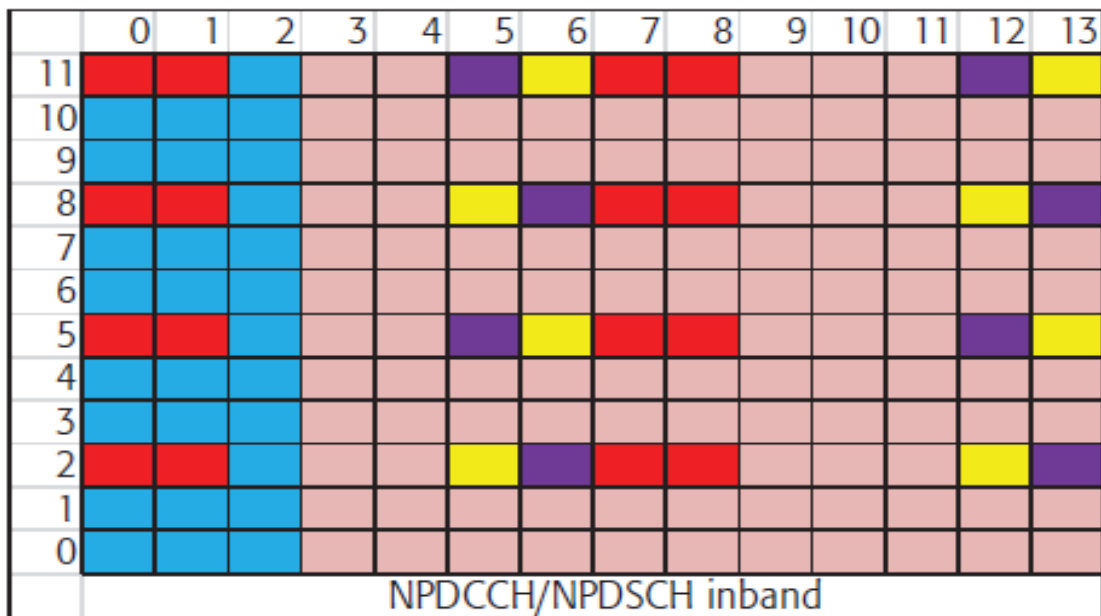
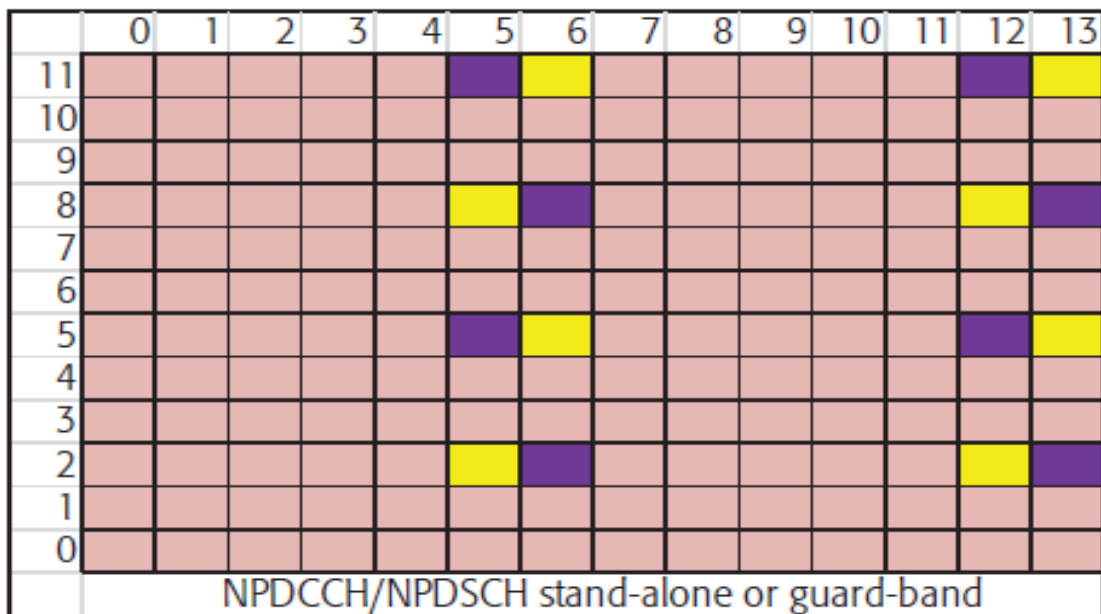
Physical signals and channels in the downlink:






- **Narrowband primary synchronization signal (NPSS)** and **Narrowband secondary synchronization signal (NSSS)**: cell search, which includes time and frequency synchronization, and cell identity detection
- Narrowband physical broadcast channel (NPBCH)
- Narrowband reference signal (NRS)
- Narrowband physical downlink control channel (NPDCCH)
- Narrowband physical downlink shared channel (NPDSCH)

Even numbered frame	Subframe number									
	0	1	2	3	4	5	6	7	8	9
	NPBCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPSS	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NSSS
Odd numbered frame	Subframe number									
	0	1	2	3	4	5	6	7	8	9
	NPBCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPSS	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH	NPDCCH or NPDSCH

- Narrowband physical random access channel (**NPRACH**): new channel since the legacy LTE physical random access channel (PRACH) uses a bandwidth of 1.08 MHz, more than NB-IoT uplink bandwidth
- Narrowband physical uplink shared channel (**NPUSCH**)

# NPDCCH/NPDSCH resource mapping example



Legend	
	NPDCCH/NPDSCH
	NRS Port 0
	NRS Port 1
	LTE CRS
	LTE PDCCH

## Physical signals and channels and relationship with LTE

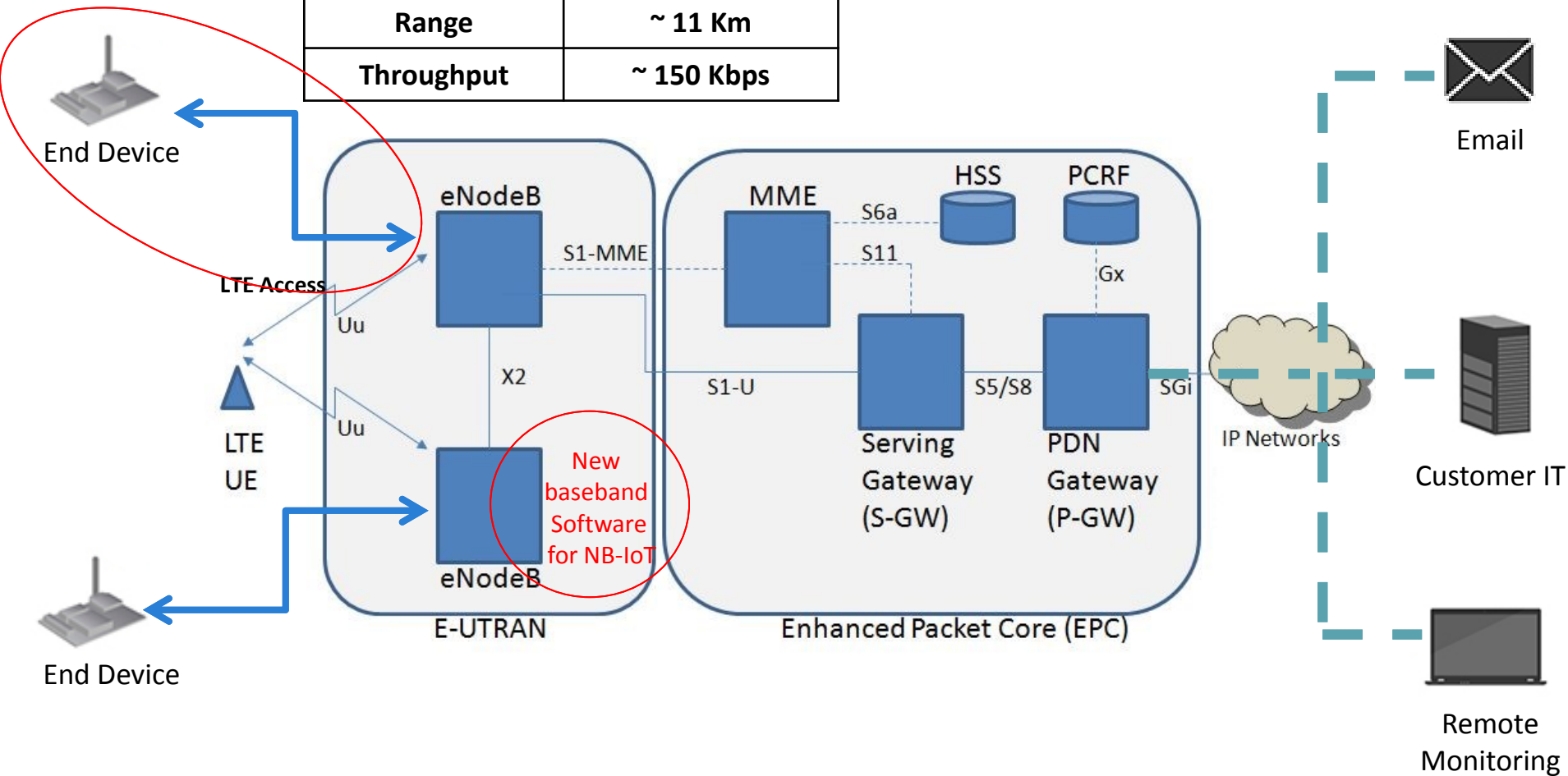
	Physical channel	Relationship with LTE
Downlink	NPSS	<ul style="list-style-type: none"> <li>• New sequence for fitting into one PRB (LTE PSS overlaps with middle six PRBs)</li> <li>• All cells share one NPSS (LTE uses 3 PSSs)</li> </ul>
	NSSS	<ul style="list-style-type: none"> <li>• New sequence for fitting into one PRB (LTE SSS overlaps with middle six PRBs)</li> <li>• NSSS provides the lowest 3 least significant bits of system frame number (LTE SSS does not)</li> </ul>
	NPBCH	<ul style="list-style-type: none"> <li>• 640 ms TTI (LTE uses 40 ms TTI)</li> </ul>
	NPDCCH	<ul style="list-style-type: none"> <li>• May use multiple PRBs in time, i.e. multiple subframes (LTE PDCCH uses multiple PRBs in frequency and 1 subframe in time)</li> </ul>
	NPDSCH	<ul style="list-style-type: none"> <li>• Use TBCC and only one redundancy version (LTE uses Turbo Code with multiple redundancy versions)</li> <li>• Use only QPSK (LTE also uses higher order modulations)</li> <li>• Maximum transport block size (TBS) is 680 bits. (LTE without spatial multiplexing has maximum TBS greater than 70000 bits, see [9])</li> <li>• Supports only single-layer transmission (LTE can support multiple spatial-multiplexing layers)</li> </ul>
Uplink	NPRACH	<ul style="list-style-type: none"> <li>• New preamble format based on single-tone frequency hopping using 3.75 kHz tone spacing (LTE PRACH occupies 6 PRBs and uses multi-tone transmission format with 1.25 kHz subcarrier spacing)</li> </ul>
	NPUSCH Format 1	<ul style="list-style-type: none"> <li>• Support UE bandwidth allocation smaller than one PRB (LTE has minimum bandwidth allocation of 1 PRB)</li> <li>• Support both 15 kHz and 3.75 kHz numerology for single-tone transmission (LTE only uses 15 kHz numerology)</li> <li>• Use <math>\pi/2</math>-BPSK or <math>\pi/4</math>-QPSK for single-tone transmission (LTE uses regular QPSK and higher order modulations)</li> <li>• Maximum TBS is 1000 bits. (LTE without spatial multiplexing has maximum TBS greater than 70000 bits, see [9])</li> <li>• Supports only single-layer transmission (LTE can support multiple spatial-multiplexing layers)</li> </ul>
	NPUSCH Format 2	<ul style="list-style-type: none"> <li>• New coding scheme (repetition code)</li> <li>• Uses only single-tone transmission</li> </ul>

### Extended C-DRX and I-DRX operation

- Connected Mode (C-eDRX):
- Extended DRX cycles of 5.12s and 10.24s are supported
- Idle mode (I-eDRX):
- Extended DRX cycles up to ~44min for eMTC
- Extended DRX cycles up to ~3hr for NB-IOT

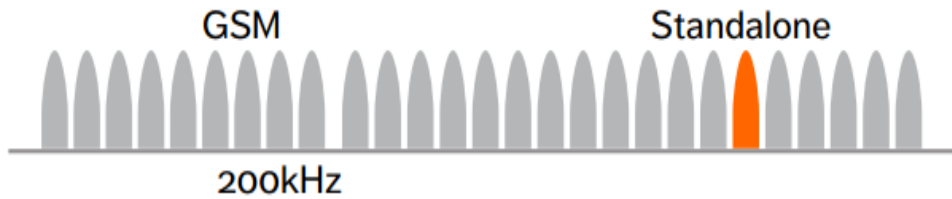
# Architecture

Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps



## Spectrum and access

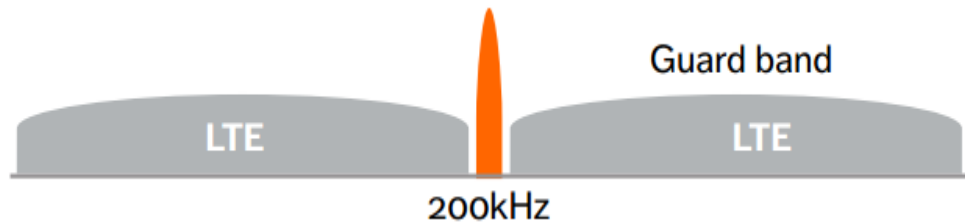
- Designed with a number of deployment options for **GSM** , **WCDMA** or **LTE** spectrum to achieve spectrum efficiency.
- Use **licensed spectrum**.



### Stand-alone operation

Dedicated spectrum.

Ex.: By **re-farming GSM channels**



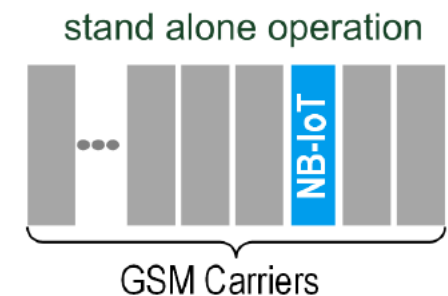
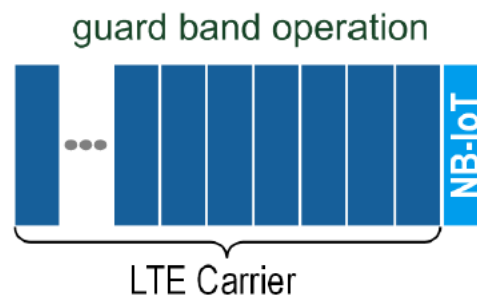
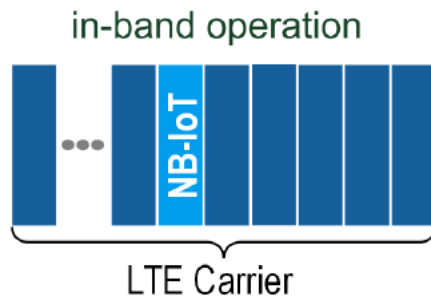
### Guard band operation

Based on the unused RB within a LTE carrier's **guard-band**



### In-band operation

Using **resource blocks** within a normal LTE carrier



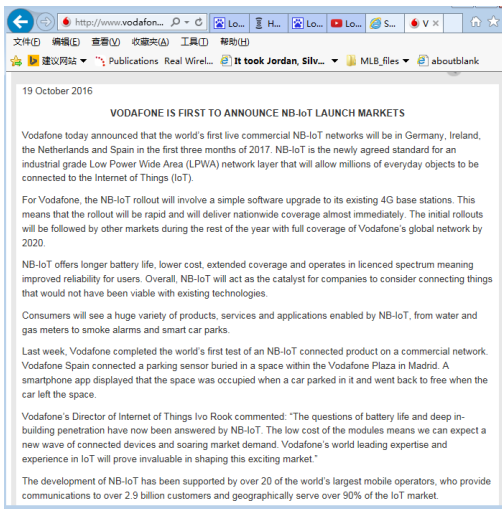
## LTE-M to NB-IoT

3GPP Release	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M	13 (Cat. 200 KHz) NB-IoT
Downlink peak rate	1 Mbps	1 Mbps	<b>300 bps to 200 kbps</b>
Uplink peak rate	1 Mbps	1 Mbps	<b>144 kbps</b>
Number of antennas	1	1	1
Duplex Mode	Half	Half	Half
UE receive bandwidth	20 MHz	1.4 MHz	<b>200 kHz</b>
UE Transmit power (dBm)	23	20	<b>23</b>

- **Reduced throughput** based on single PRB operation
- Enables **lower processing and less memory** on the modules
- 20dB additional link budget → **better area coverage**



# Vodafone announced the commercialization of NB-IoT



- 4 countries in Europe (Germany, Ireland, the Netherlands and Spain) will commercially launch NB-IoT in 2017.

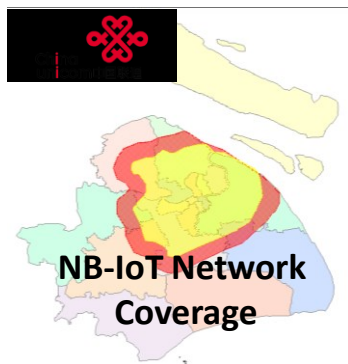
- Announced the commercialization of NB-IoT on 23rd Jan 17
- **1000** sites activated NB-IoT in Spain by the end of march 2017
- Took just a few hours to deploy NB-IoT with software upgrade in Valencia

- Madrid, Valencia, Barcelona is covered, Plan to cover 6 cities in 2017H1

Source: Huawei

# China Unicom: 800+ Sites Activated NB-IoT in Shanghai

Shanghai Unicom:



- **800+** base stations covered Shanghai in 2016Q4

Network readiness accelerates the development of vertical customers

Parking operator



Smart Parking

Gas Utility



Smart Gas Meter

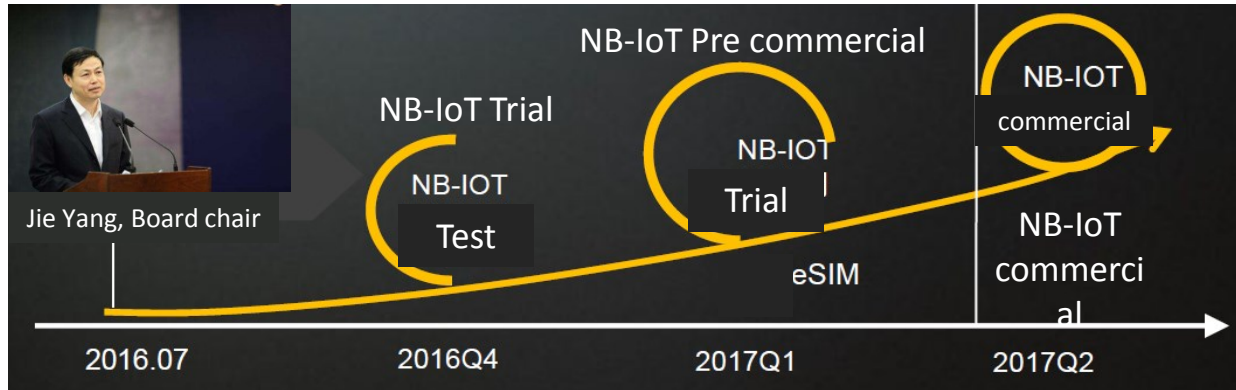
Fire center



Smart Fire Protection

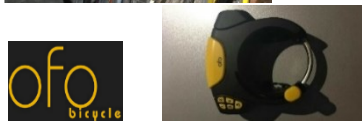
Source: Huawei

# China Telecom: NB-IoT Nationwide Coverage in 2017H1



- 2017H1, NB-IoT enabled in L850 to achieve national wide coverage

## Use cases



Share bicycle

- 100 NB-IoT bicycles test in Beijing University in Q2 2017
- 100K bicycles in Beijing city by September 2017
- China Telecom to provide NB-IoT coverage in whole Beijing by June 2017



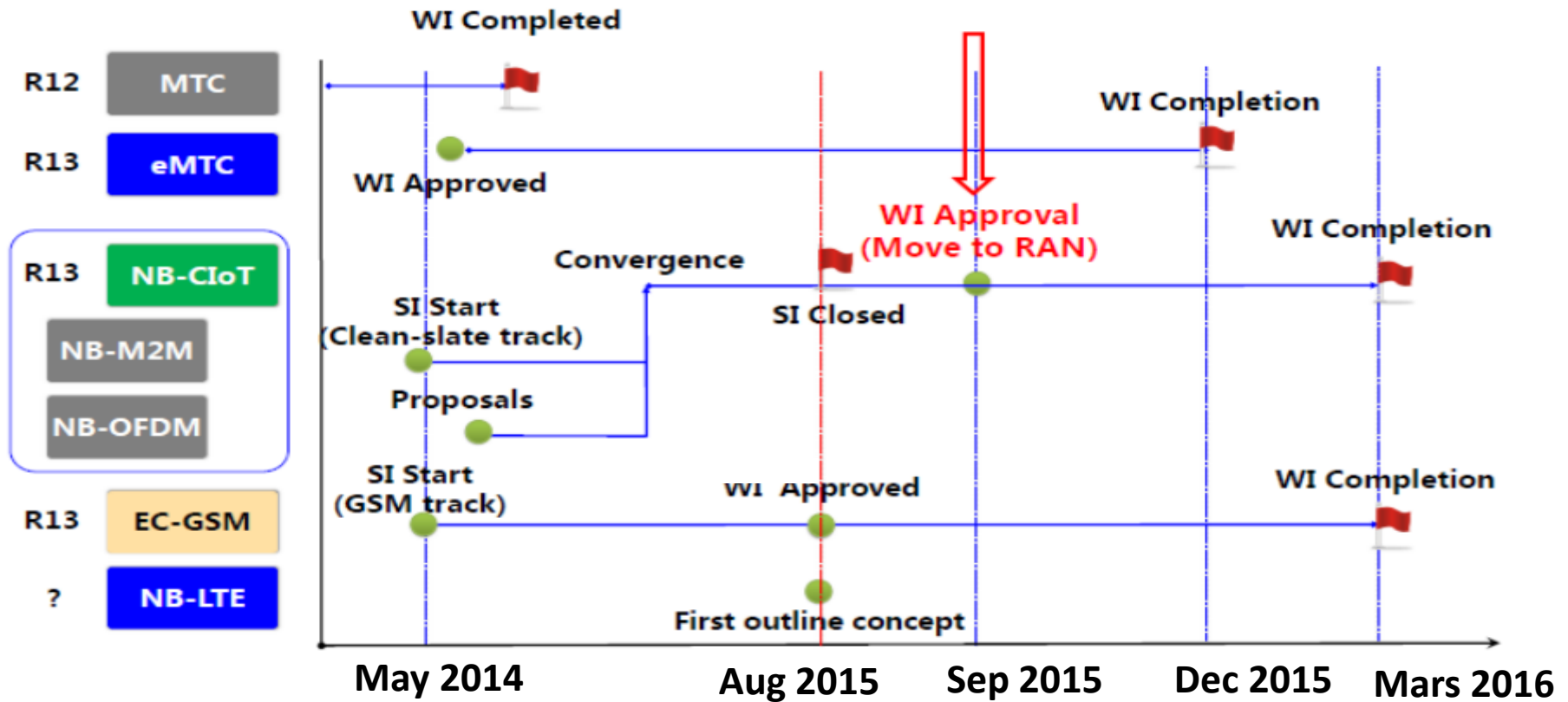
- Mar 22 2017, Shenzhen water utility announced commercialization;
- 1200 meters (phase 1) running in live network;

Source: Huawei

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### **iii. EC-GSM**

# Roadmap



2020: 15% connections excluding cellular IoT will still be on 2G in Europe and 5% in the US (*GSMA predictions*).

GPRS is responsible for most of today's M2M communications

**EC-GSM-IoT Objectives:** Adapt and leverage existing 2G infrastructure to provide efficient and reliable IoT connectivity over an extended GSM Coverage

- **Long battery life:** ~10 years of operation with 5 Wh battery (depending on traffic pattern and coverage extension)
- **Low device cost** compared to GPRS/GSM device
- **Variable data rates:**
  - GMSK: ~350bps to 70kbps depending on coverage extension
  - 8PSK: up to 240 kbps
- Support for massive number of devices: ~50.000 devices per cell
- Improved security adapted to IoT constraint.
- Leverage on the GSM/GPRS maturity to allow fast time to market and low cost

### **Objectives**

- Long battery life: ~10 years of operation with 5 Wh battery (depending on traffic pattern and coverage needs)
- Low device cost compared to GPRS/GSM devices

### **Extended coverage:**

- 164 dB MCL for 33 dBm UE,
- 154 dB MCL for 23 dBm UE

### **Variable rates:**

- GMSK: ~350bps to 70kbps depending on coverage level
- 8PSK: up to 240 kbps
- Support for massive number of devices: at least 50.000 per cell
- Improved security compared to GSM/EDGE

### **Main PHY features**

- New logical channels designed for extended coverage
- Repetitions to provide necessary robustness to support up to 164 dB MCL
- Overlaid CDMA to increase cell capacity (used for EC-PDTCH and EC-PACCH)

### **Other features**

- Extended DRX (up to ~52min)
- Optimized system information (i.e. no inter-RAT support)
- Relaxed idle mode behavior (e.g. reduced monitoring of neighbor cells)
- 2G security enhancements (integrity protection, mutual authentication, mandate stronger ciphering algorithms)
- NAS timer extensions to cater for very low data rate in extended coverage
- Storing and usage of coverage level in SGSN to avoid unnecessary repetitions over the air



➤ **Extended coverage** (~ 20 dB compared to GSM coverage)

	<b>GSM900</b>		<b>LoRa</b>
Sens de la Liaison	Montante	Unités	Montante
Partie Réception	BTS		GW
Sensibilité	-104	dBm	-142
Marge de protection	3	dB	0
Perte totale câble et connecteur	4	dB	4
Gain d'antenne (incluant 5 dB de diversité)	-17	dBi	-6
Marge de masque (90% de la surface)	5	dB	5
Puissance médiane nécessaire	-109	dBm	-141
Partie Emission	MS		Capteur
Puissance d'émission (GSM Classe 2 = 2W) Bilan de liaison	33	dBm	20
Affaiblissement maximal	142	dB	161
Pertes dues au corps humain	-3	dB	0
Affaiblissement de parcours (bilan de liaison)	<b>139</b>	dB	<b>161</b>

### ❑ Deployment

- To be deployed in existing GSM spectrum without any impact on network planning.
- EC-GSM-IoT and legacy GSM/GPRS traffic are dynamically multiplexed.
- Reuse existing GSM/GPRS base stations thanks to software upgrade.

### ❑ Main PHY features:

- New “EC” logical channels designed for extended coverage
- Repetitions to provide necessary robustness to support up to 164 dB MCL
- Fully compatible with existing GSM hardware design (Base station and UE)
- IoT and regular mobile traffic are share GSM time slot.

❑ Coverage Extension: 4 different coverage class

	Channels	CC1	CC2	CC3	CC4
DL	MCL(dB)	149	157	161	164
	EC-CCCH	1	8	16	32
	EC-PACCH	1	4	8	16
	EC-PDTCH	1	4	8	16
UL	MCL(dB)	152	157	161	164
	EC-CCCH	1	4	16	48
	EC-PACCH	1	4	8	16
	EC-PDTCH	1	4	8	16

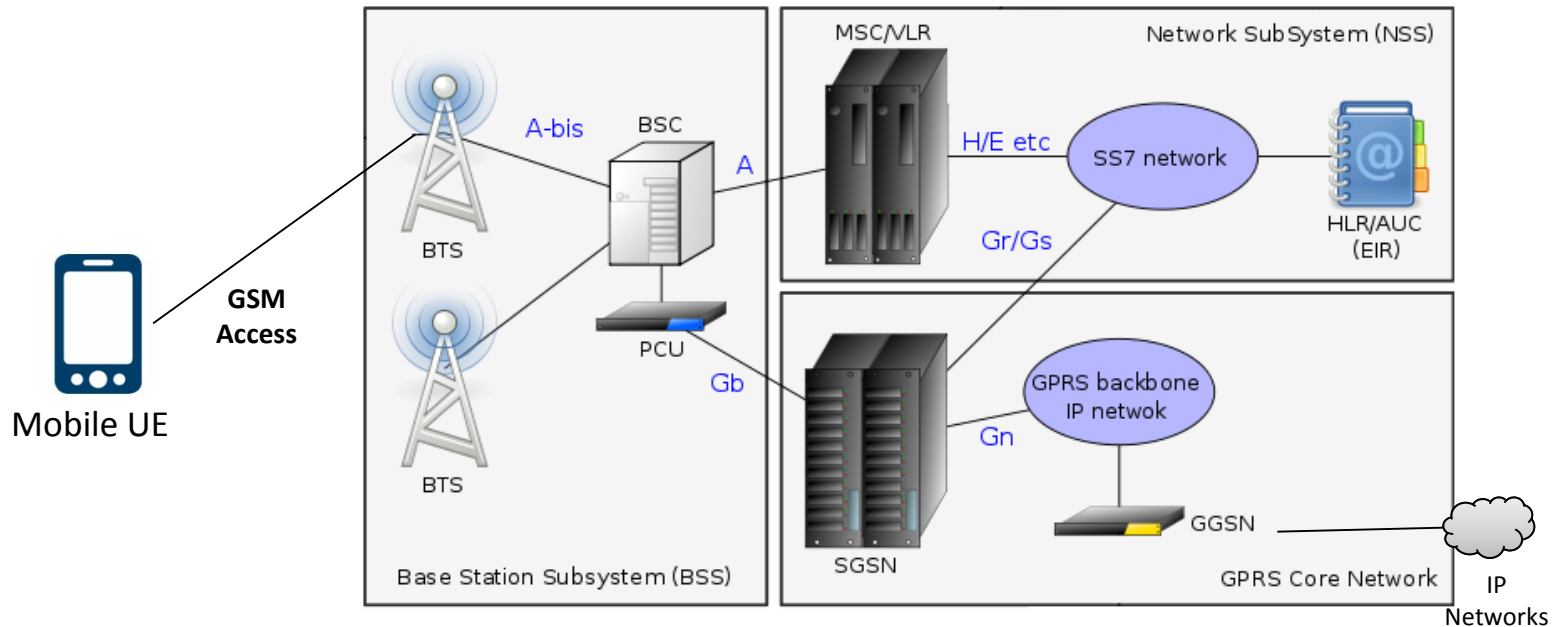
- Beacon and Synchronization channel don't use coverage class
- EC-BCCH: always repeated 16 times
- EC-SCH: always repeated 28 times
- FCCH: legacy FCCH is used.

} Mapped on TS 1

### ❑ Other features:

- Support of SMS and Data, but no voice
- Extended DRX (up to ~52min) [ GSM DRX ~11 min]
- Optimized system information (i.e. no inter-RAT support)
- Relaxed idle mode behavior (e.g. reduced monitoring of neighbor cells)
- 2G security enhancements (integrity protection, mutual authentication, mandate stronger ciphering algorithms)
- NAS timer extensions to cater for very low data rate in extended coverage
- Storing and usage of coverage level in SGSN to avoid unnecessary repetitions over the air
- Optional mobility between GSM and EC-GSM

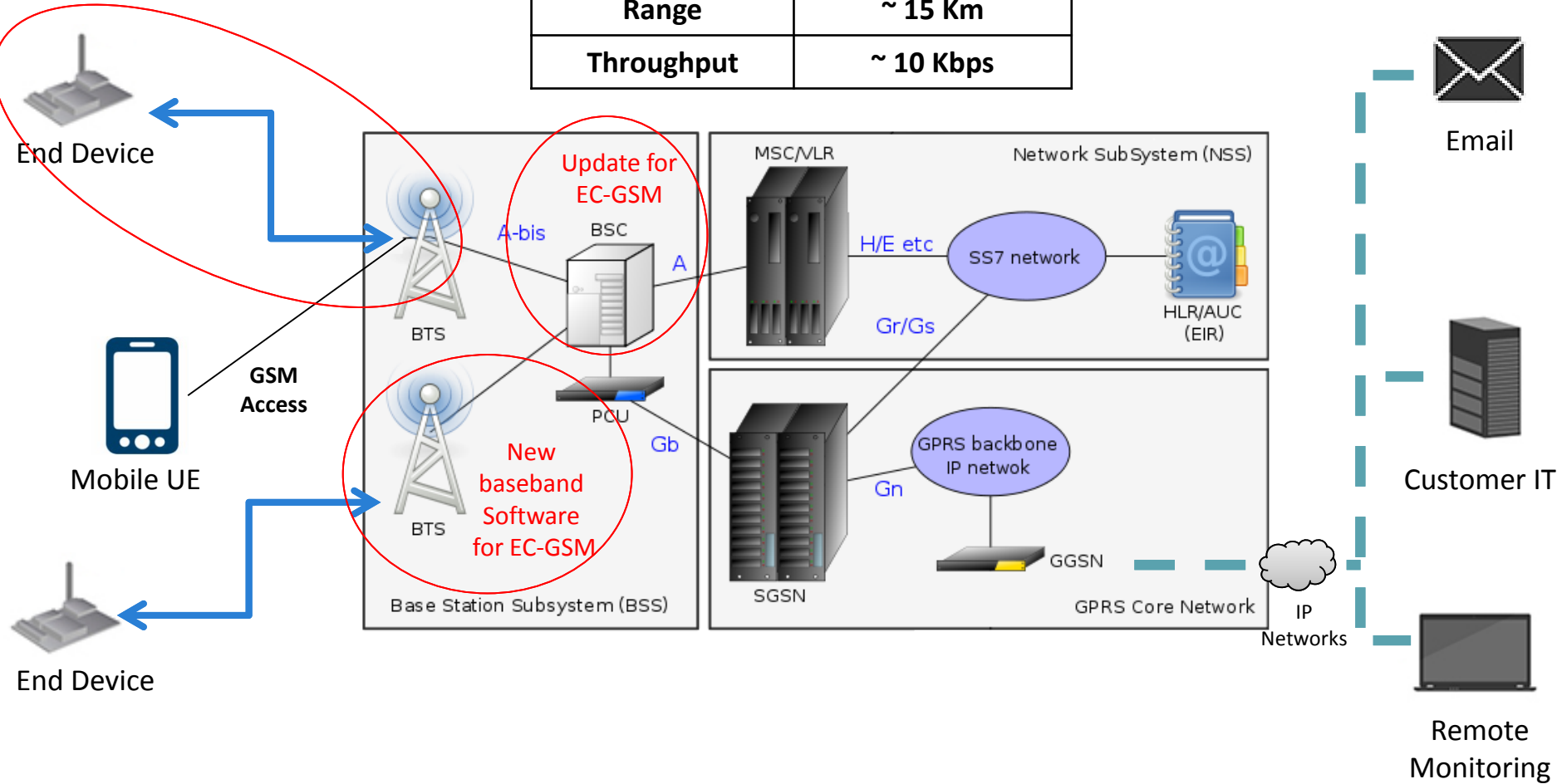
## Actual GSM/GPRS Architecture



2G-based NB-IoT networks should come at the end of 2017, with LTE following around 12 months later

# Architecture

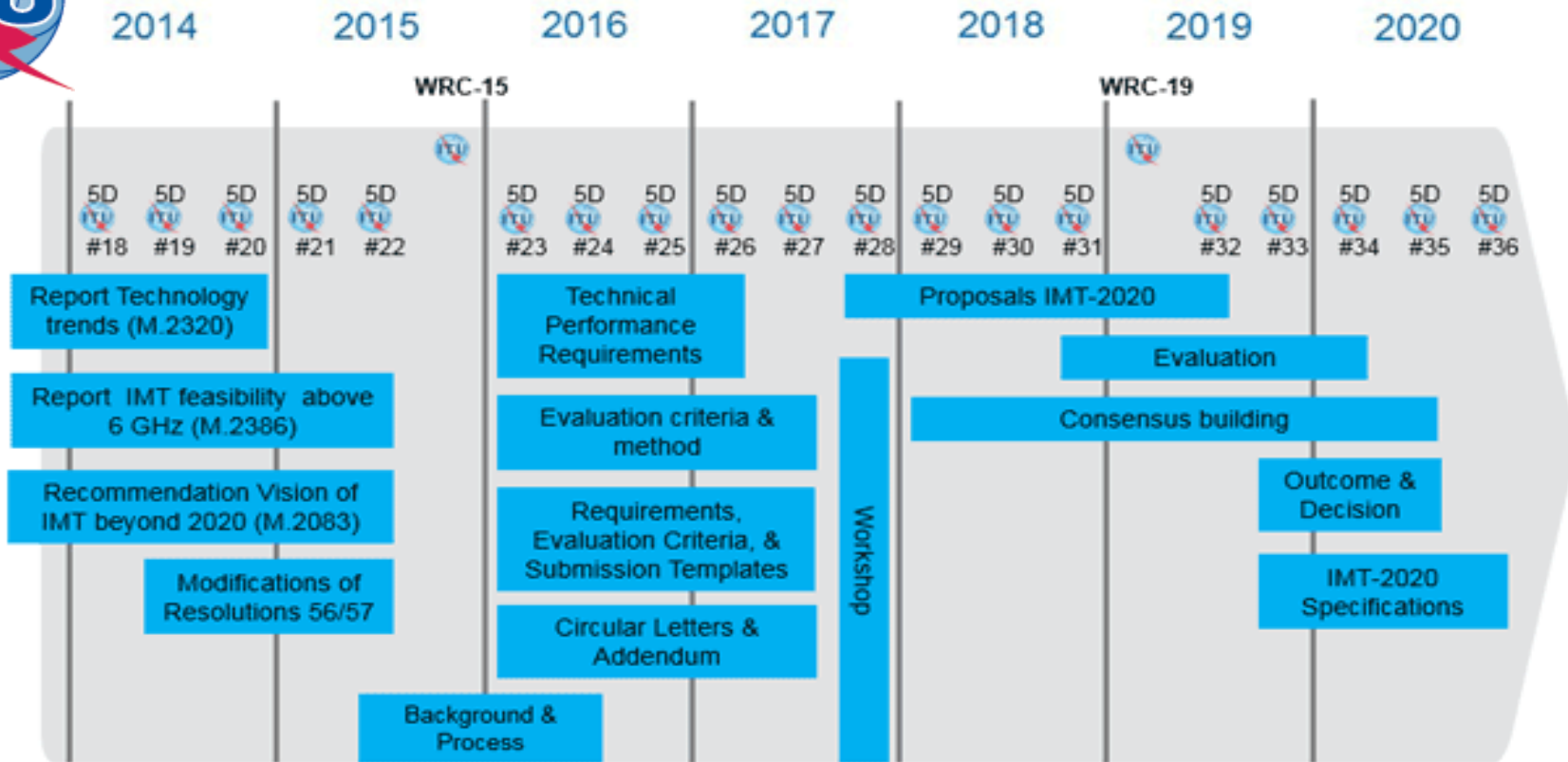
<b>Access</b>	<b>EC-GSM</b>
<b>Frequency Band</b>	<b>Narrow Band</b>
<b>Range</b>	<b>~ 15 Km</b>
<b>Throughput</b>	<b>~ 10 Kbps</b>



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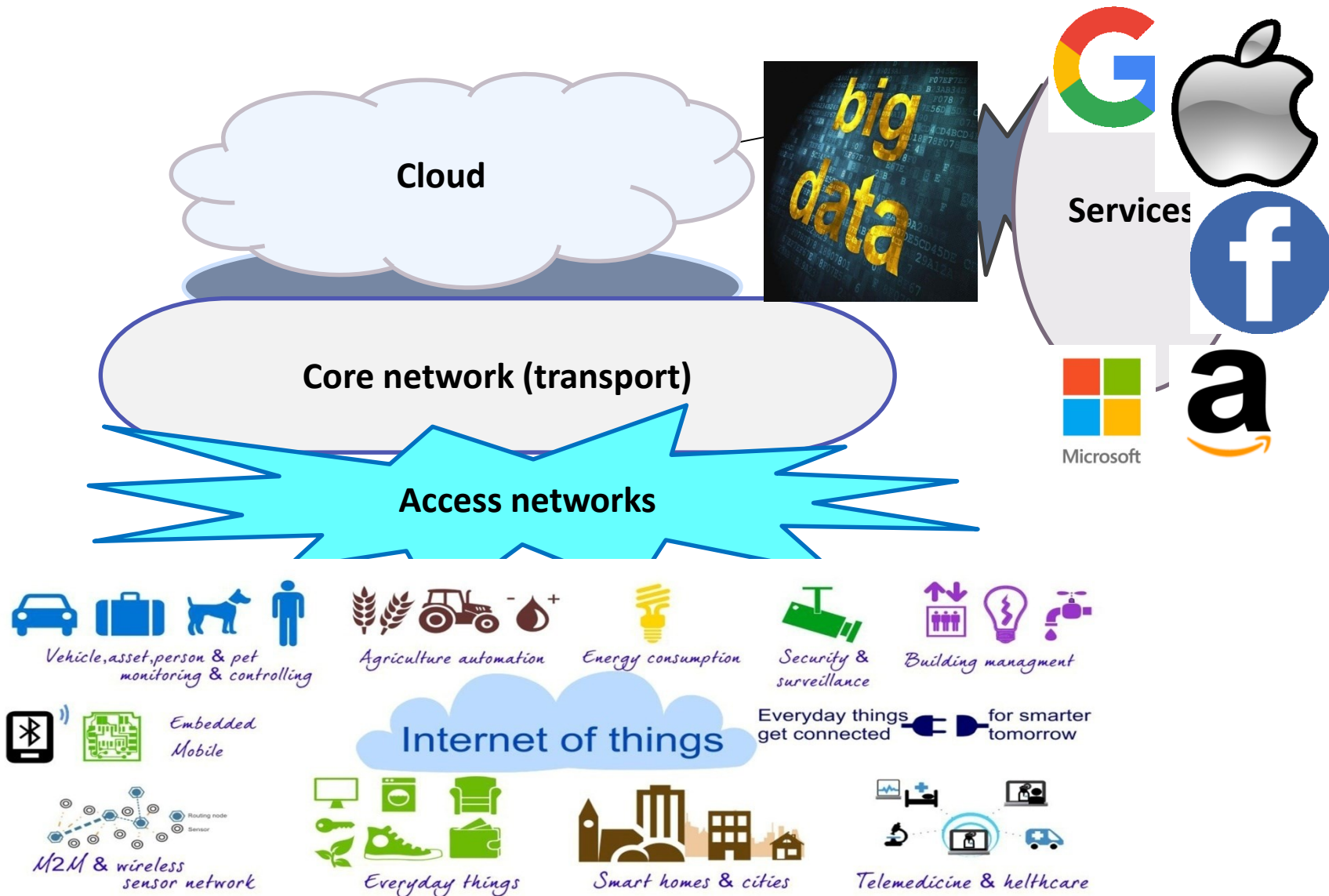
## **iv. 5G and IoT**

## ITU-R WP5D Detailed Timeline & Process for IMT-2020 in ITU-R



- Initial technology submission: Meeting 32 (June 2019)
- Detailed specification submission: Meeting 36 (October 2020)





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Thank you!