Internet of Things Networks: standards for short and long range

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IoT Networks: standards

(slides credits: Prof. Sami Tabbane - ITU)

IoT Networks: Standards

Sami TABBANE

December 2017

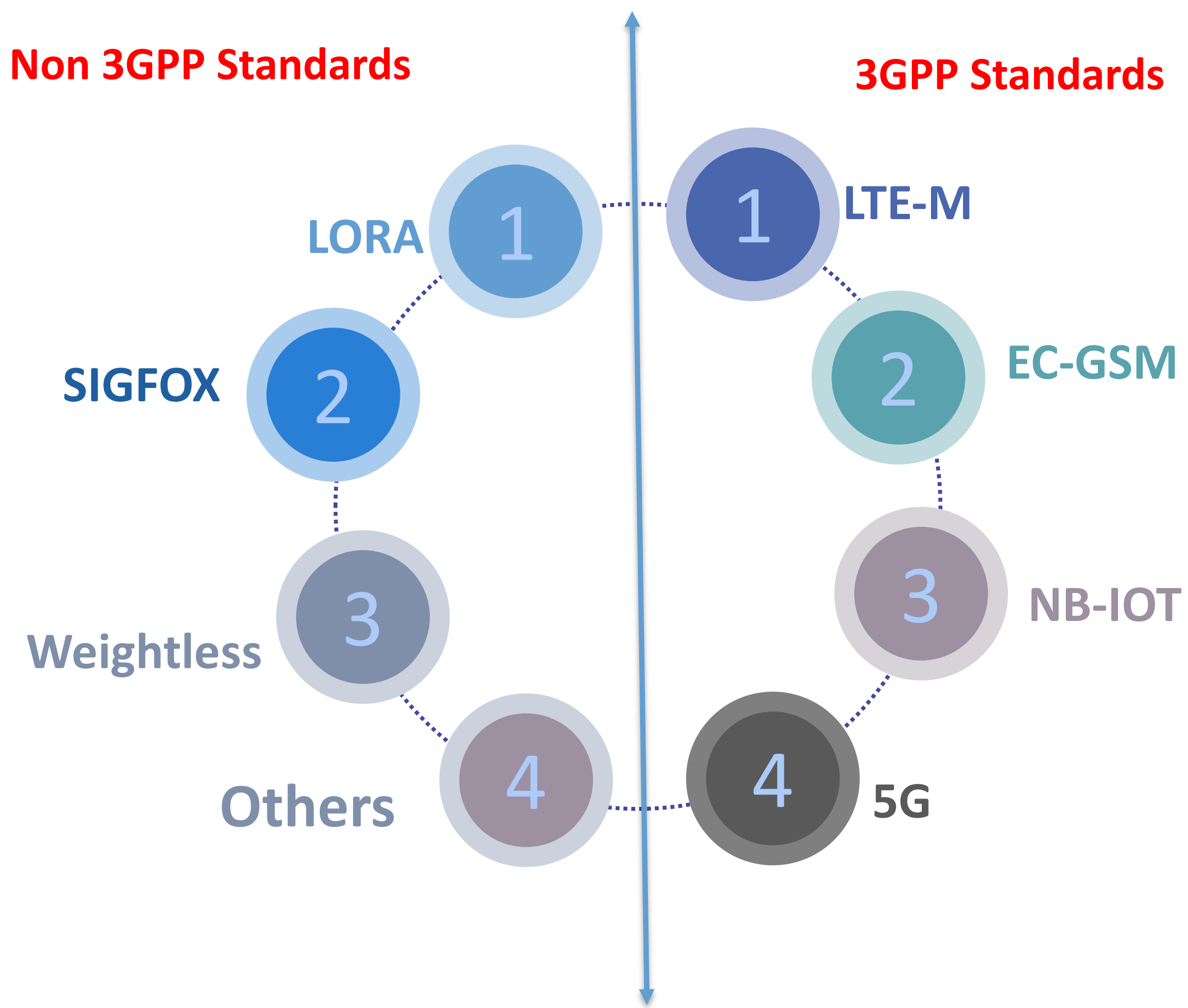
Summary

A. **Fixed & Short Range**

B. **Long Range technologies**

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

LONG RANGE TECHNOLOGIES



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

H. S. Dhillon et al., "*Wide-Area Wireless Communication Challenges for the Internet of Things*," IEEE Communications Magazine, February 2017

B. Non 3GPP Standards (LPWAN)

i. LoRaWAN

ii. Sigfox

iii. RPMA

iv. Others

LPWAN REQUIREMENTS

LPWAN

Long battery life

Low device cost

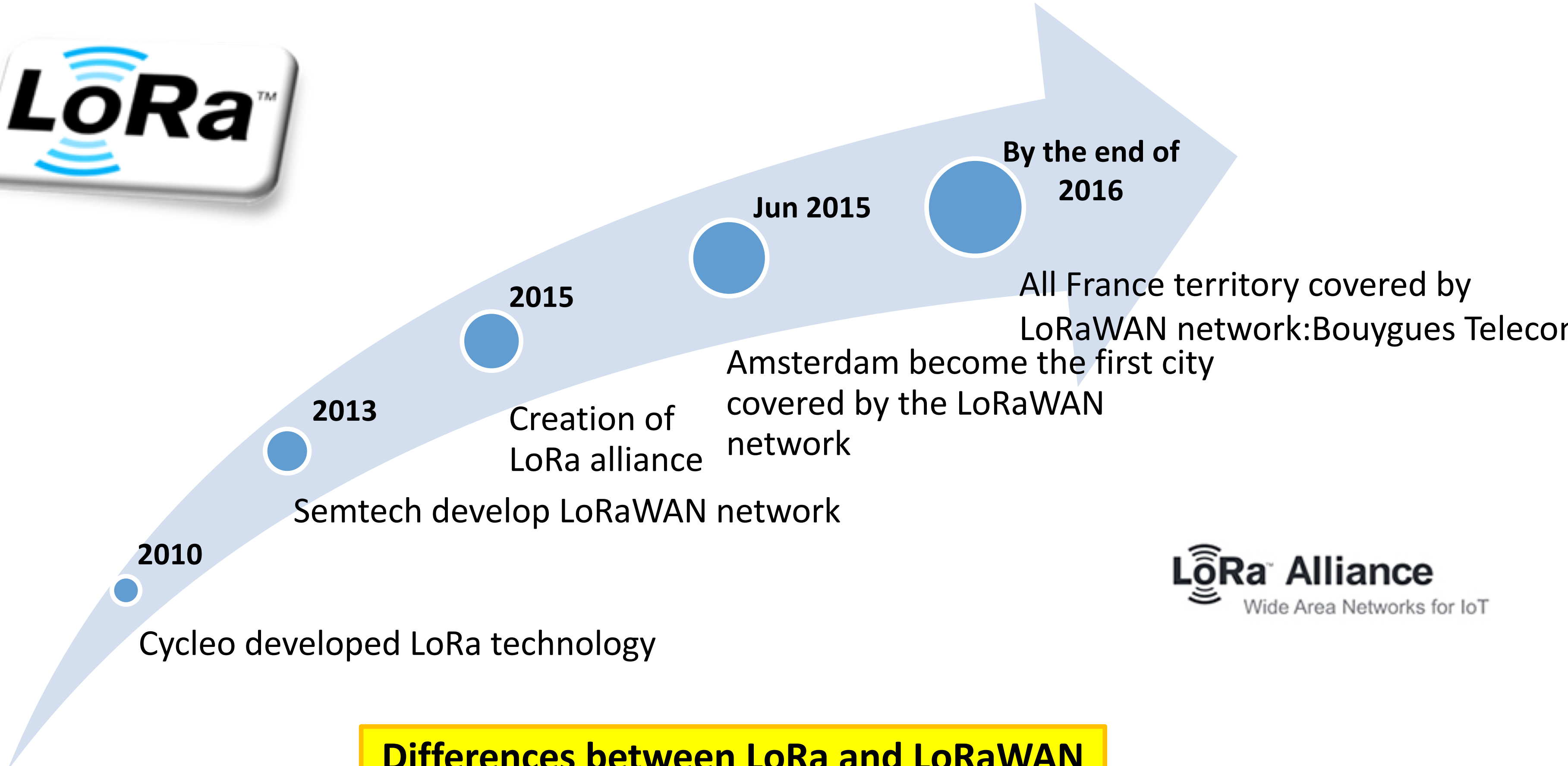
Support for a **massive number of devices**

Extended coverage (**10-15 km** in rural areas, **2-5 km** in urban areas)

Low cost and **easy deployment**

i. LoRaWAN

Roadmap



LoRa Alliance
Wide Area Networks for IoT

Differences between LoRa and LoRaWAN

- **LoRa** contains only the link layer protocol. LoRa modules are a little cheaper that 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.

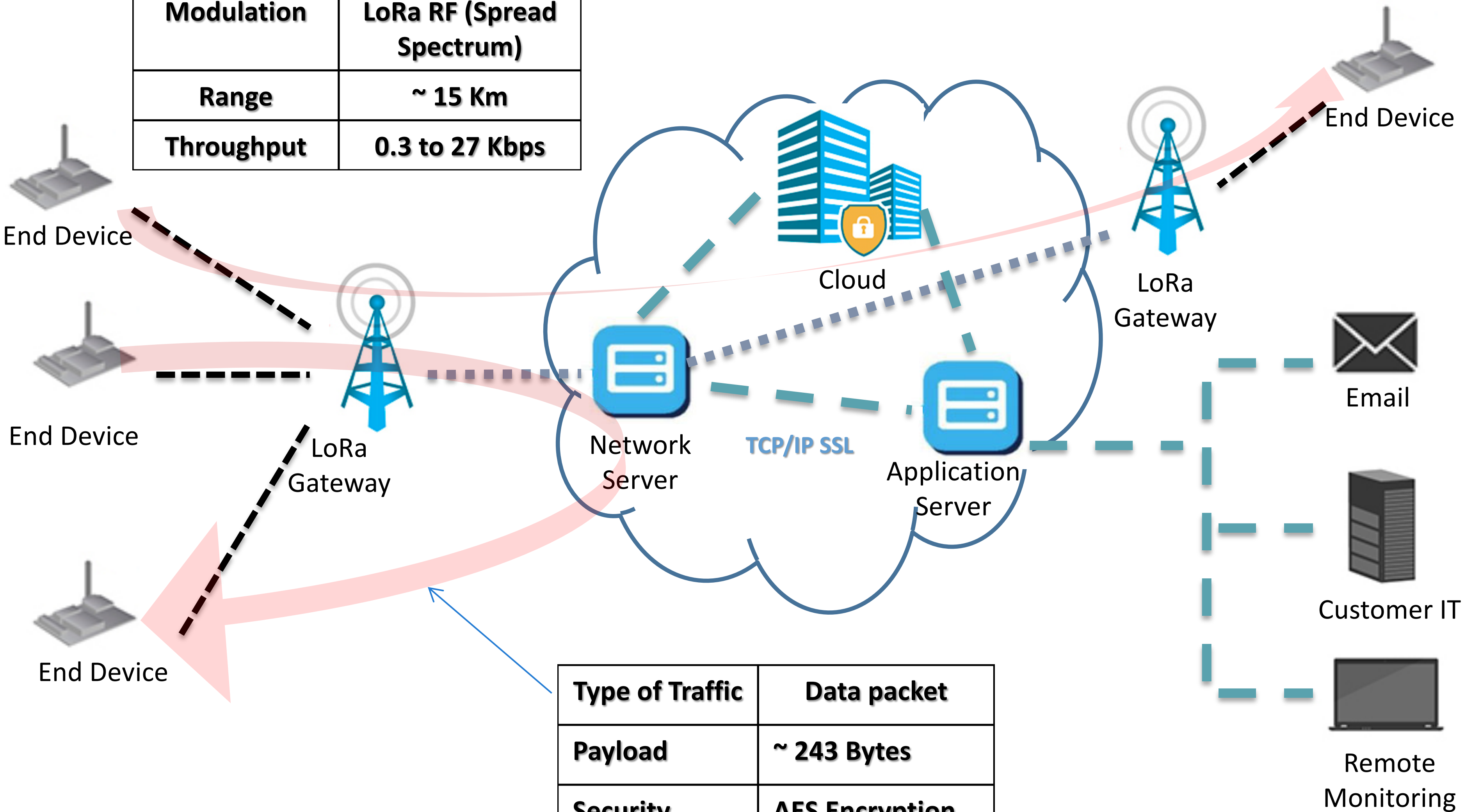
LoRa Alliance

International Operators	International development of the solution
Integrators and industrialists	Appropriate technology and maintain it over time
Manufacturers of End-points	Broadcast end devices
Manufacturers of Semiconductors	Integrate LoRa technology

- 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.

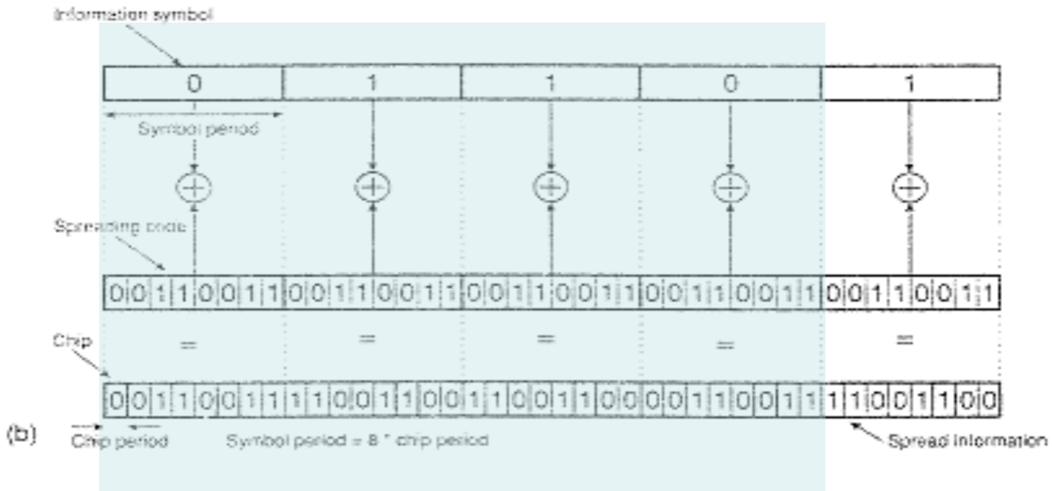
Architecture

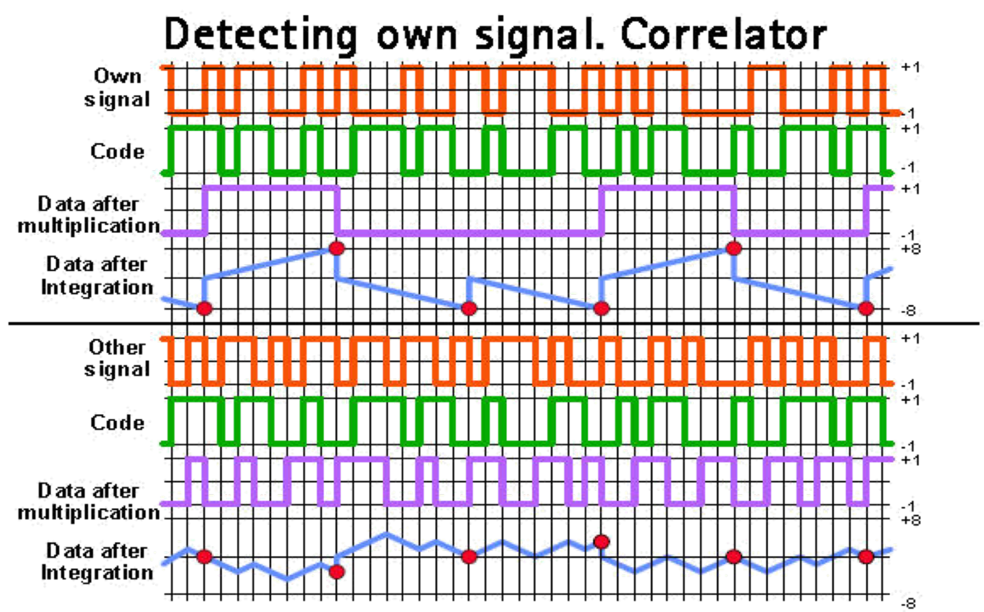
Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	0.3 to 27 Kbps



Type of Traffic	Data packet
Payload	~ 243 Bytes
Security	AES Encryption

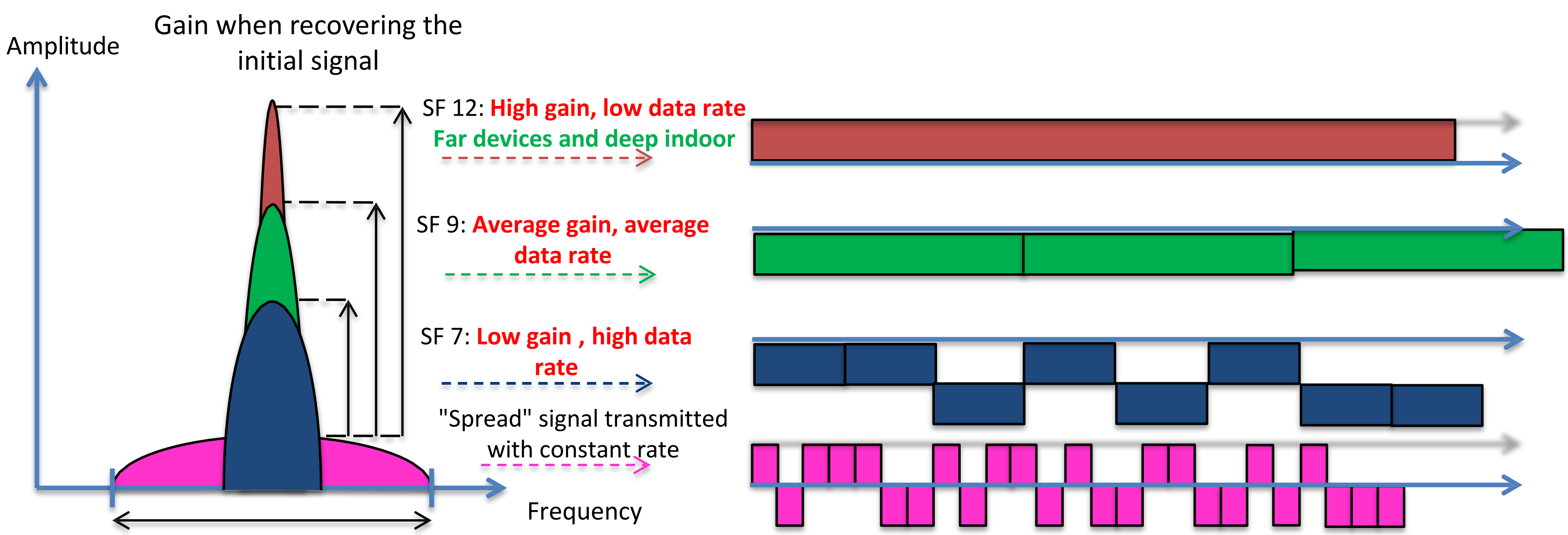
Spread spectrum basics





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

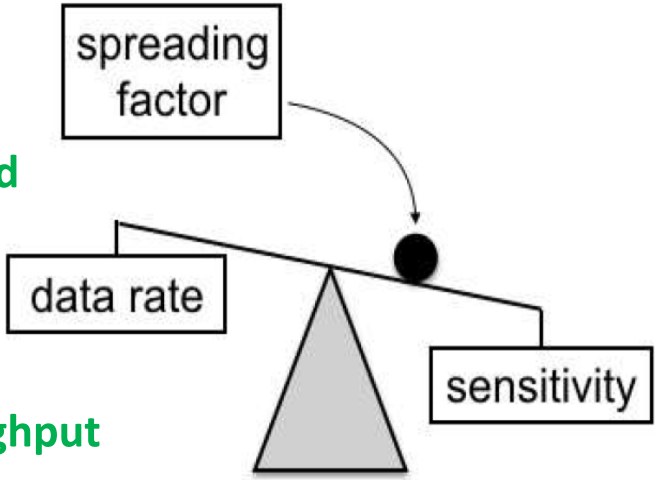
➔ The network **increases** the SF (*Spreading Factor*) ➔

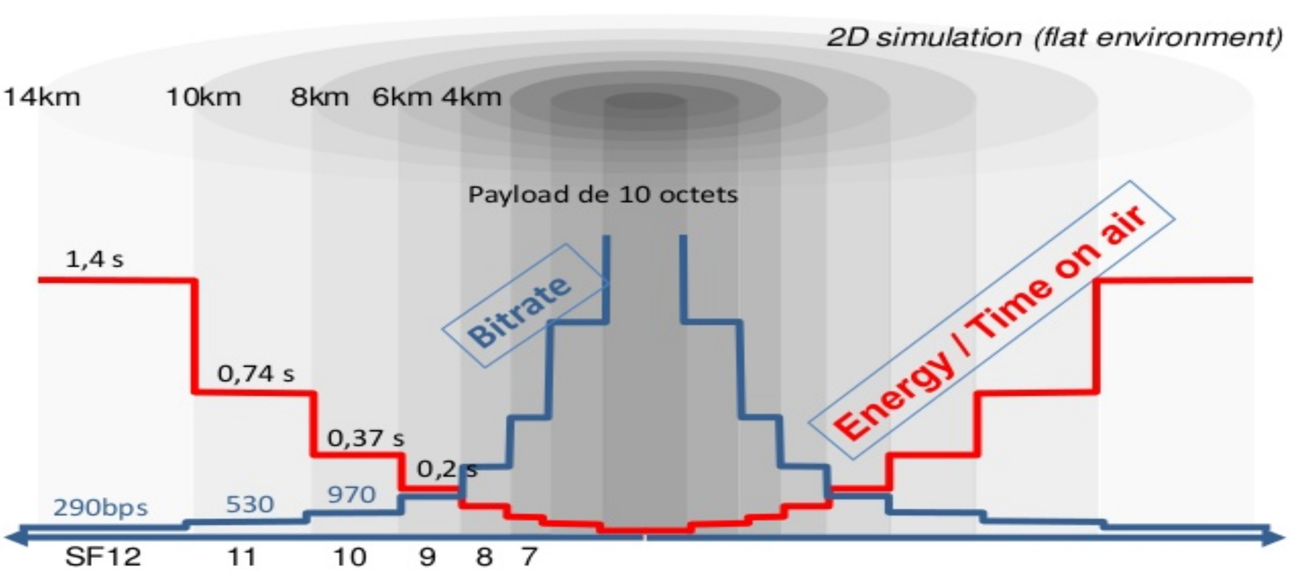
Throughput decreases but **the connection is maintained**

Close:

➔ **Low sensitivity** sufficient

➔ **Decrease** of SF (SPREADING FACTOR), **increase of throughput**



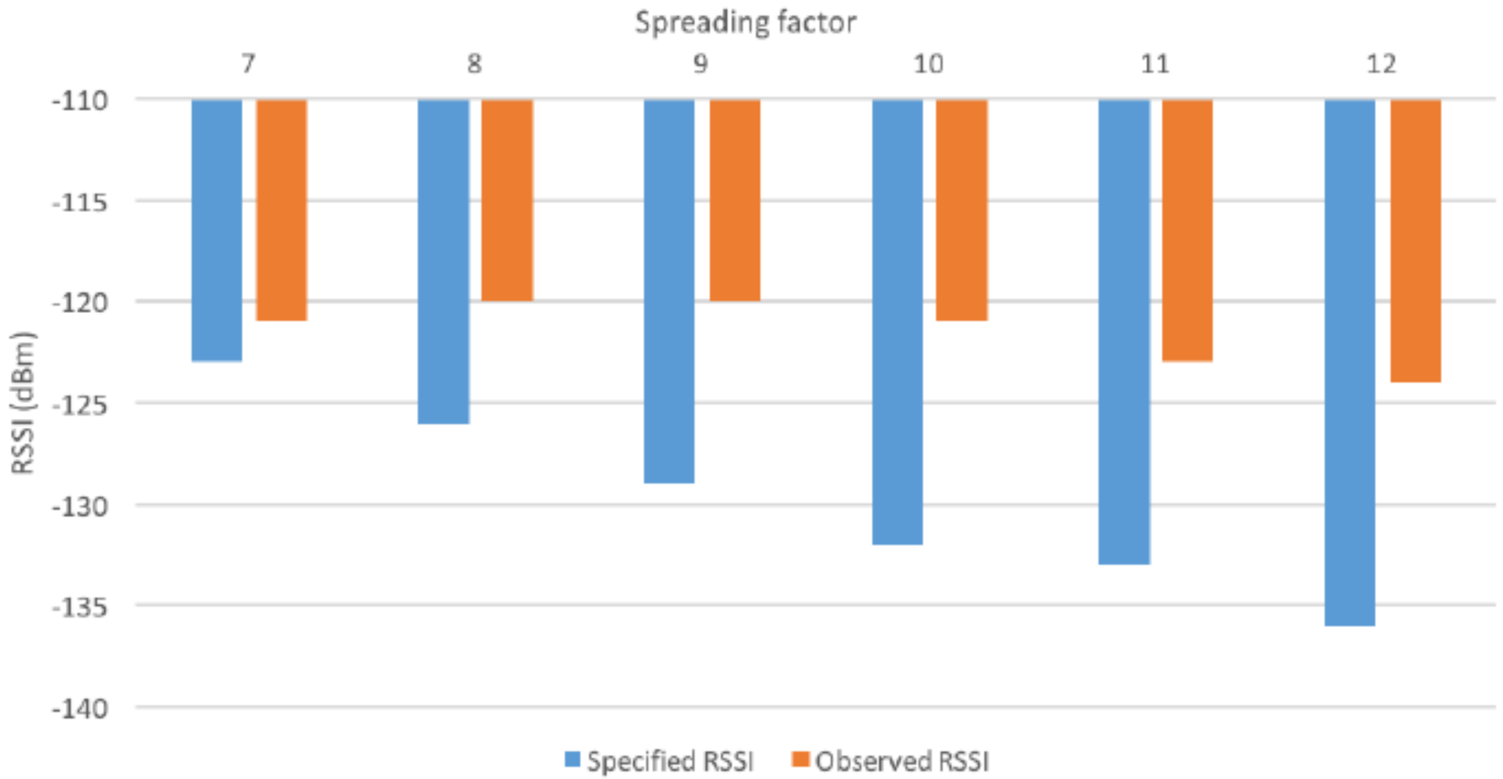


Adaptive throughput

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

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)

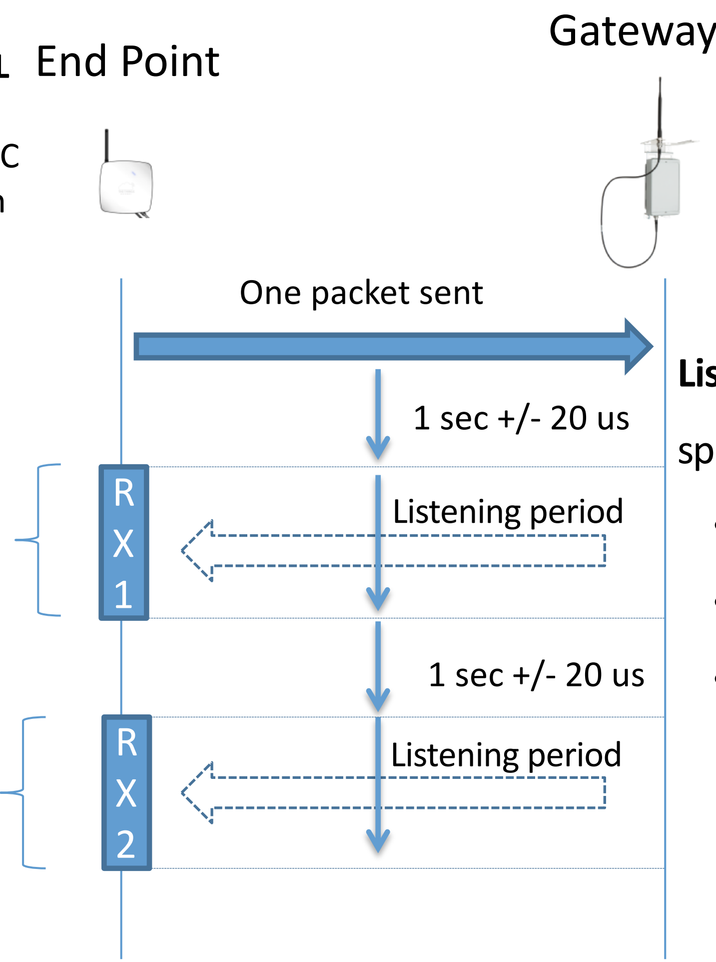
LoRaWAN: device classes

Classes	Description	Intended Use	Consumption	Examples of Services
A (« **a**ll »)	**Listens only after end device transmission**	Modules with **no latency constraint**	The **most economic** communication Class energetically.. **Supported by all modules. Adapted to battery powered modules**	• **Fire Detection** • **Earthquake Early Detection**
B (« **b**eacon »)	The module listens at a **regularly adjustable frequency**	Modules with **latency constraints** for the **reception of messages of a few seconds**	**Consumption optimized. Adapted to battery powered modules**	• **Smart metering** • **Temperature rise**
C (« **c**ontinuous »)	Module **always listening**	Modules with a ***strong reception latency constraint*** (less than one second)	Adapted to **modules on the grid** or with **no power constraints**	• **Fleet management** • **Real Time Traffic Management**

➔ Any LoRa object can transmit and receive data

Class A

Open **2 windows for DL reception** (acknowledgments, MAC commands, application commands...) **after sending a packet**



1st receive window

2nd receive window

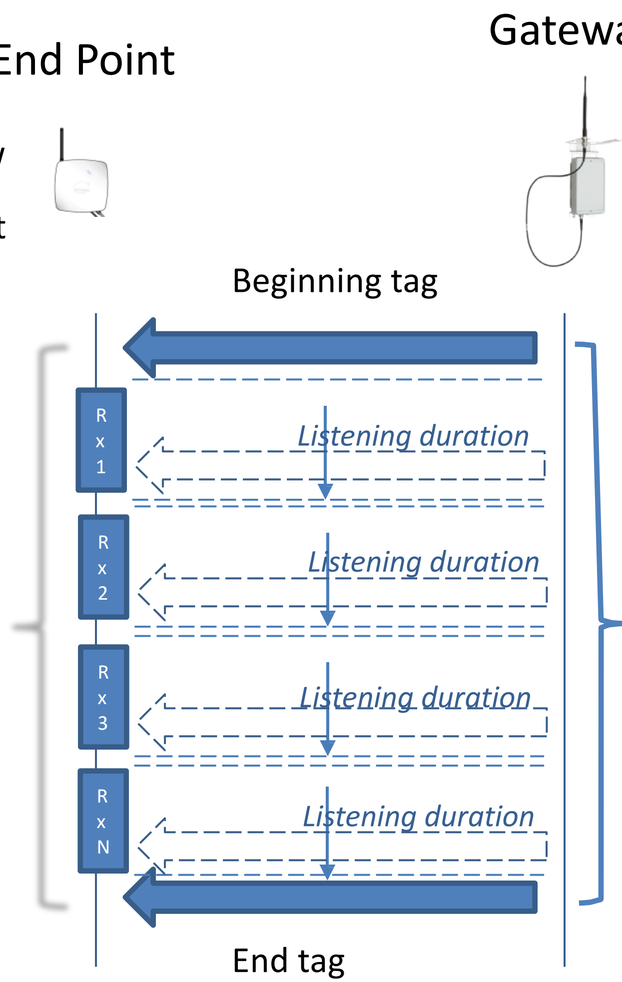
Listening period: varies according to the spreading factor SF

- 5.1 ms at SF7 (outdoor and close devices)
- 10.2 ms at *SF8 …*
- 164 ms at SF12 (deep-indoor or far devices)

- Very economic energetically
- Communication triggered by the end device

Class B (Synchronized mode)

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



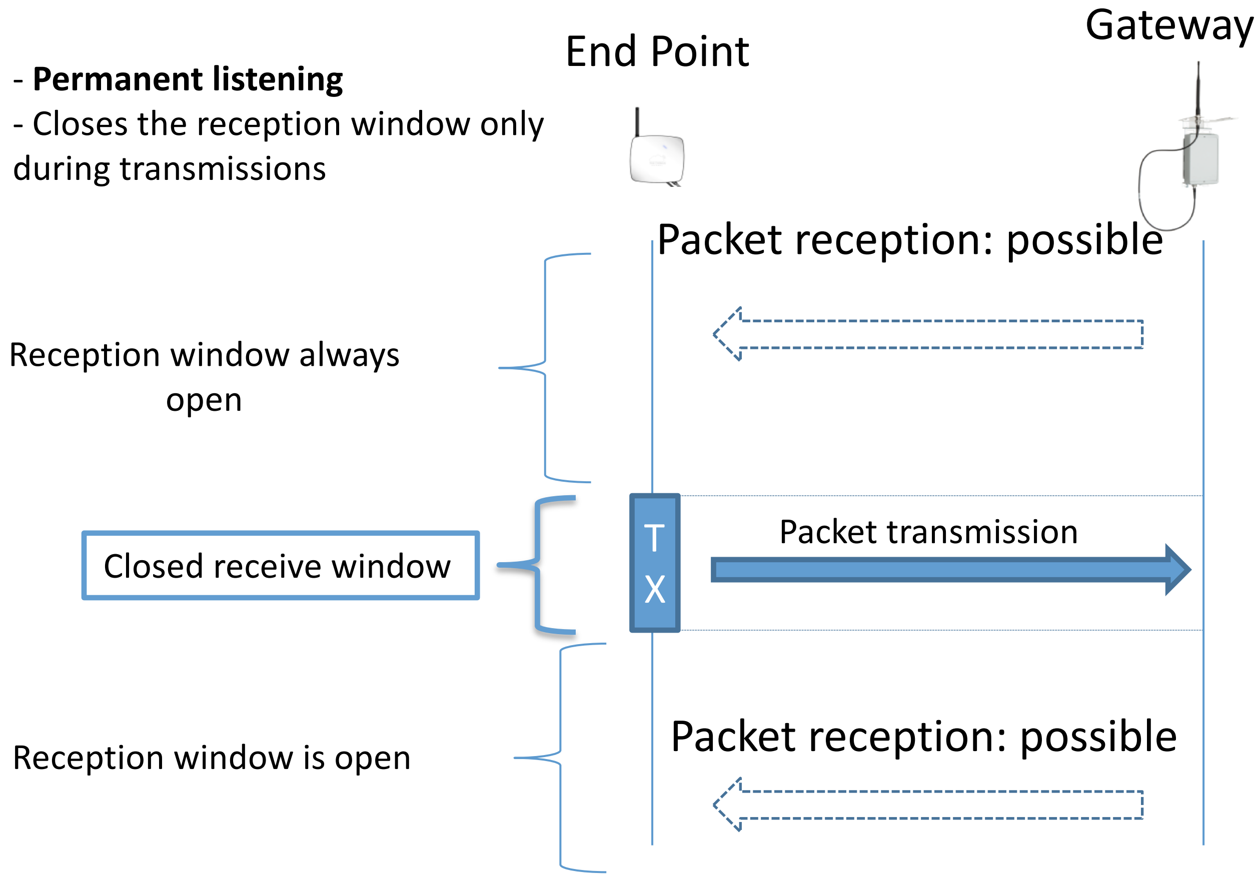
Opens N reception windows between the two tags

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

- **End-device address (*DevAddr*):**

Network identifier	network address of the end-device
7 bits	**25 bits**

- **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

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

ii. Sigfox

Roadmap

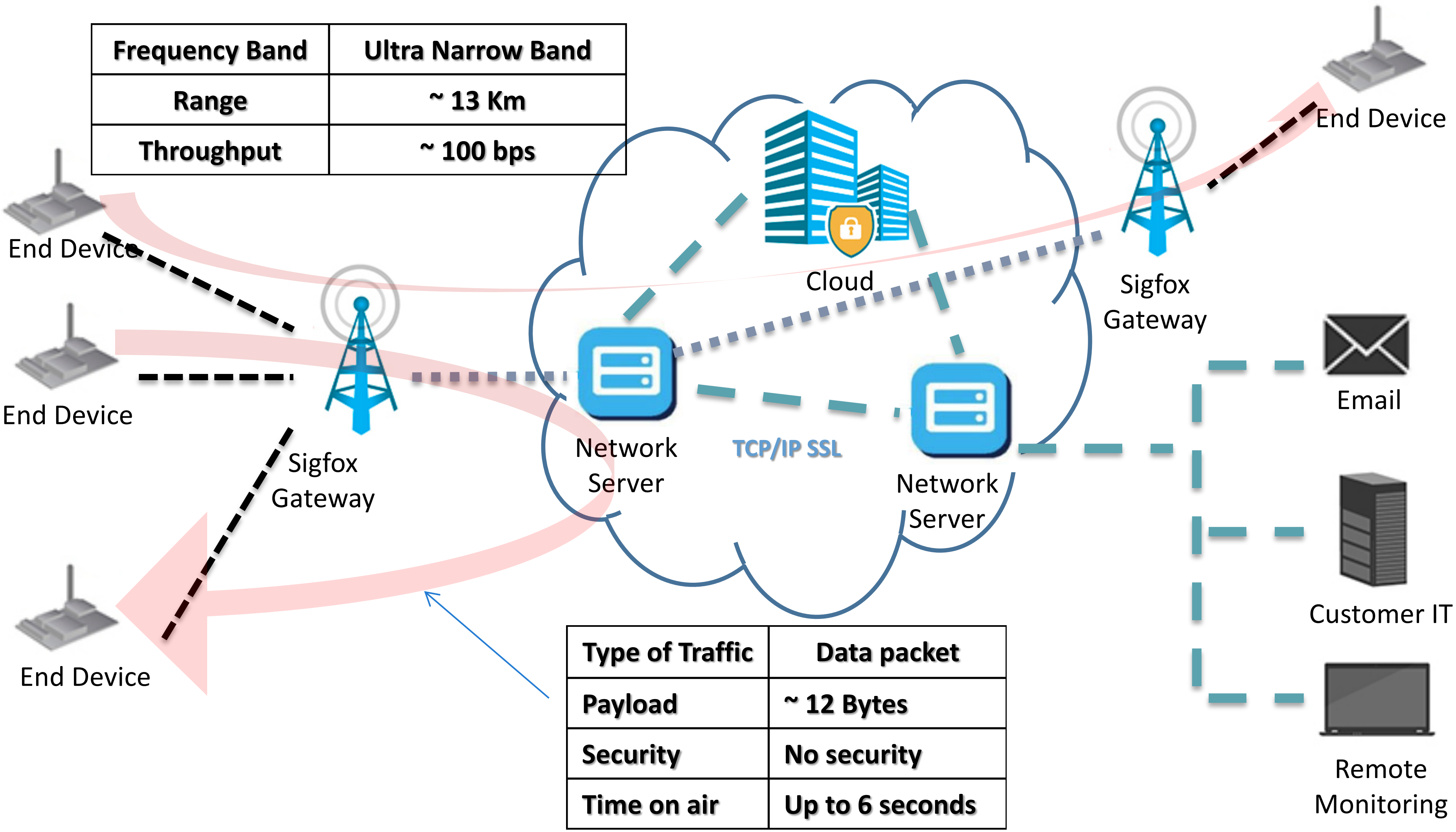
sigfox
Make Things Come Alive

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



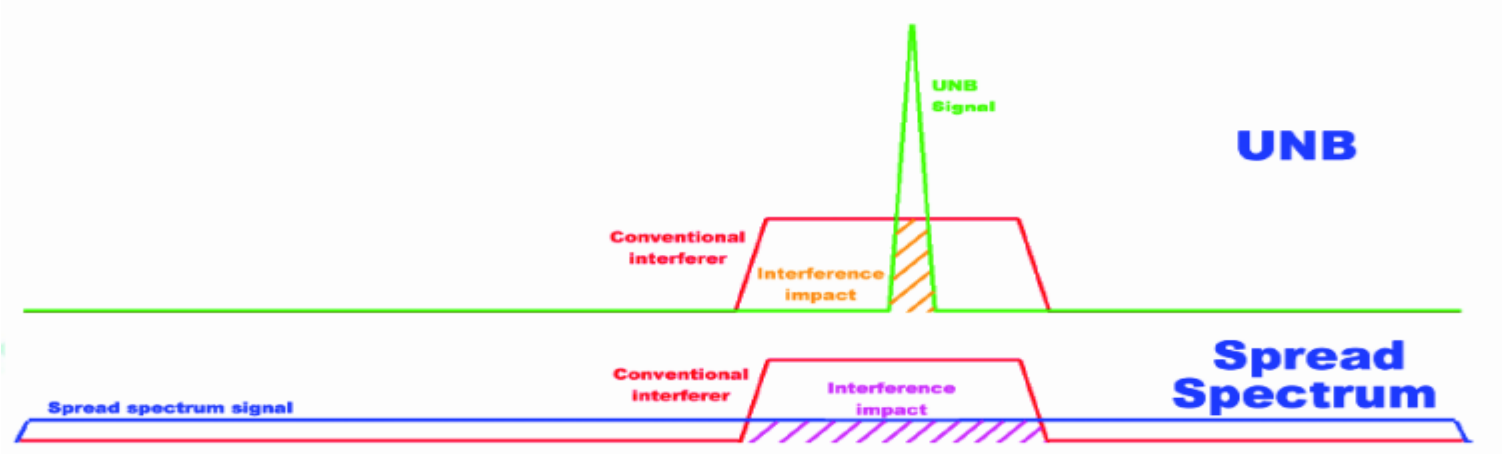
Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps

Type of Traffic	Data packet
Payload	~ 12 Bytes
Security	No security
Time on air	Up to 6 seconds

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

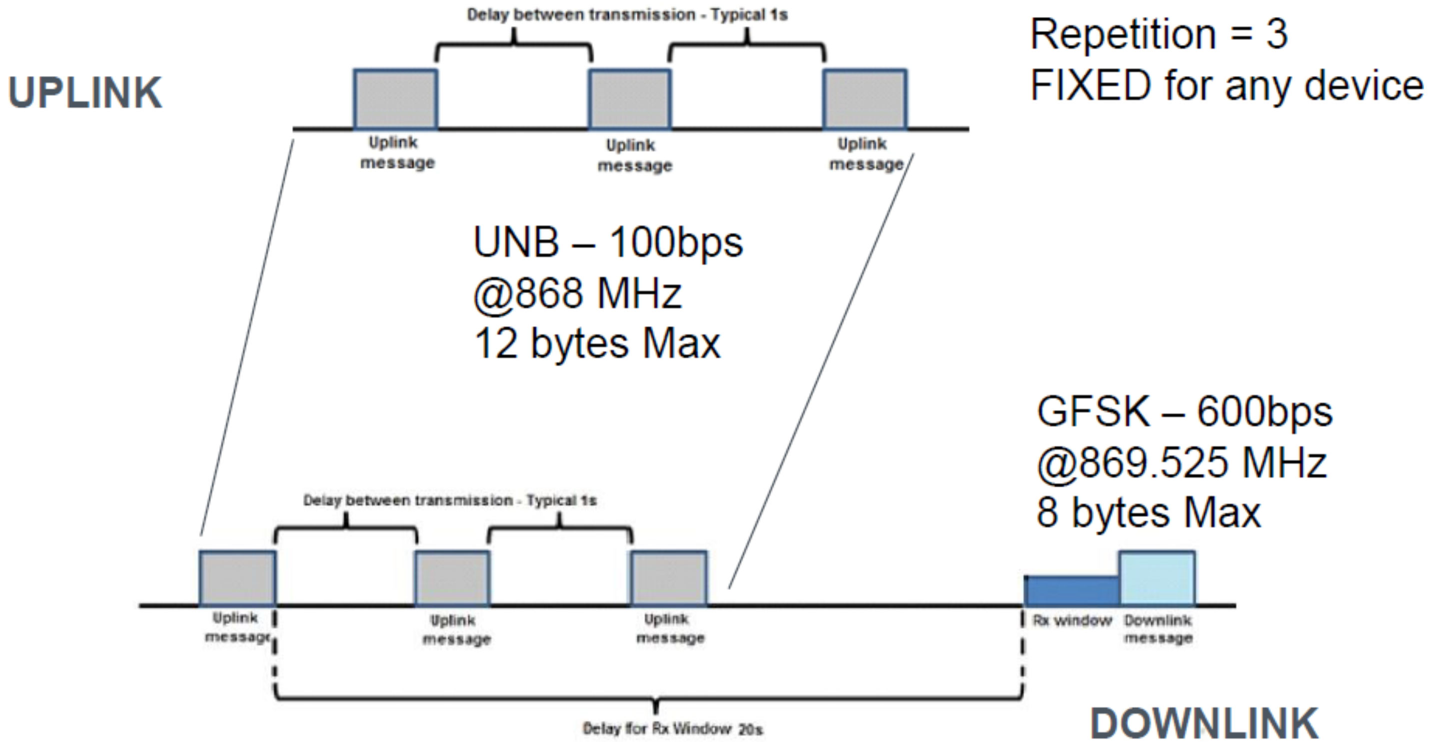
- **Narrowband** technology
- Standard radio transmission method: binary phase-shift keying (**BPSK**)
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data



Frequency spectrum:

- 868 MHz in Europe
- 915 MHz in USA

- 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

26 Countries

Covered countries

1.6 million Km^2

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

SIGFOX One network A billion dreams

iii. RPMA

Roadmap

INGENU

2008

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

September 2015

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

2016

RPMA was implemented in many places Austin, Dallas/Ft. worth, Hostton,TX,Phenix,AZ, ….

2017

RPMA will be invaded in many others countries: Los Angeles, San Franscisco-West Bay,CA,Washington,DC, Baltimore,MD, Kanasas City

INGENU RPMA overview

- *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

- 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

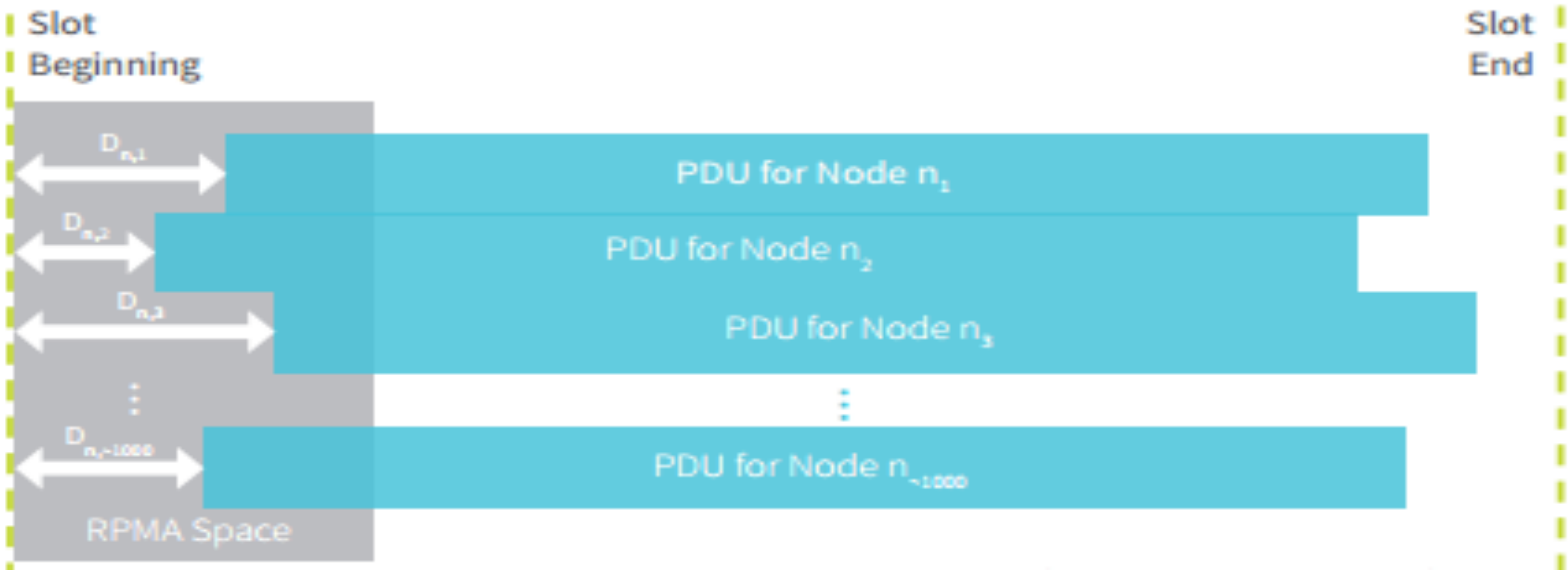
Specifications of RPMA Solution

- ❑ **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

- **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.

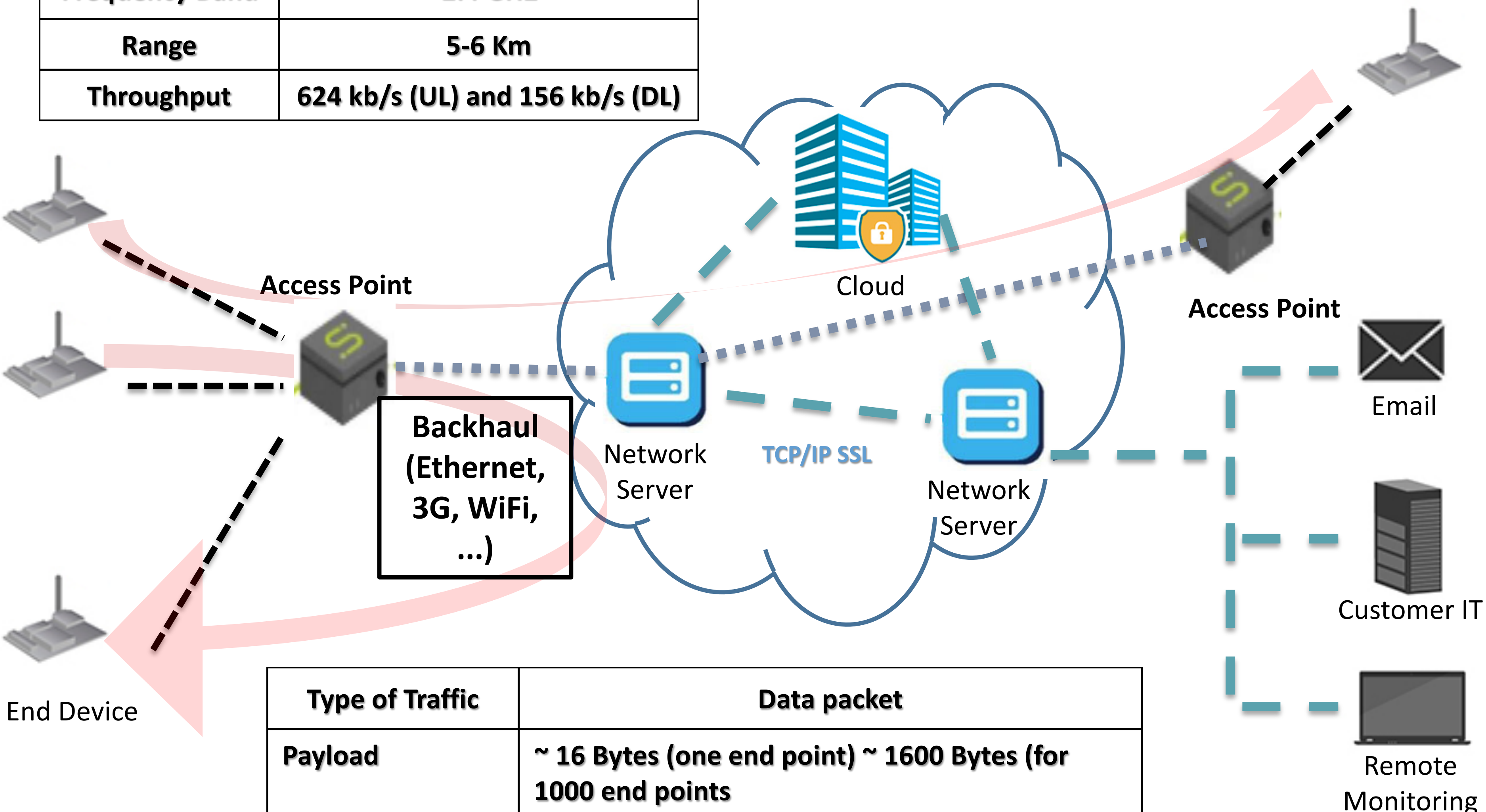
RPMA a Random multiple access Network



- 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

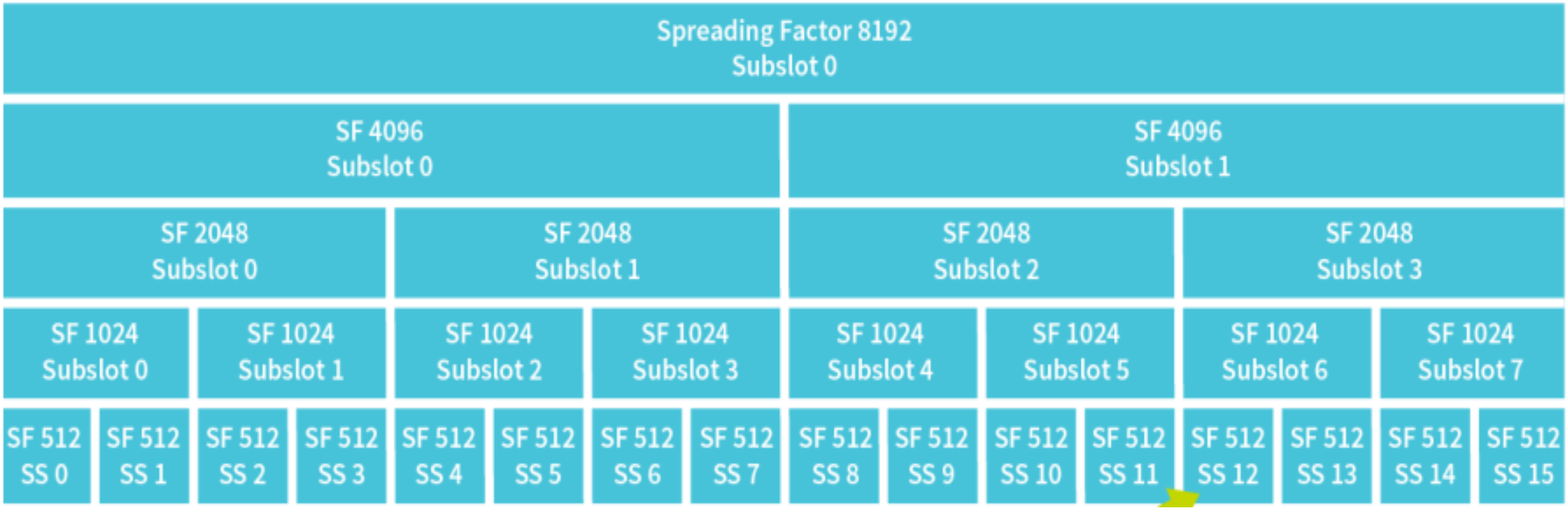
Frequency Band	2.4 GHZ
Range	5-6 Km
Throughput	624 kb/s (UL) and 156 kb/s (DL)



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

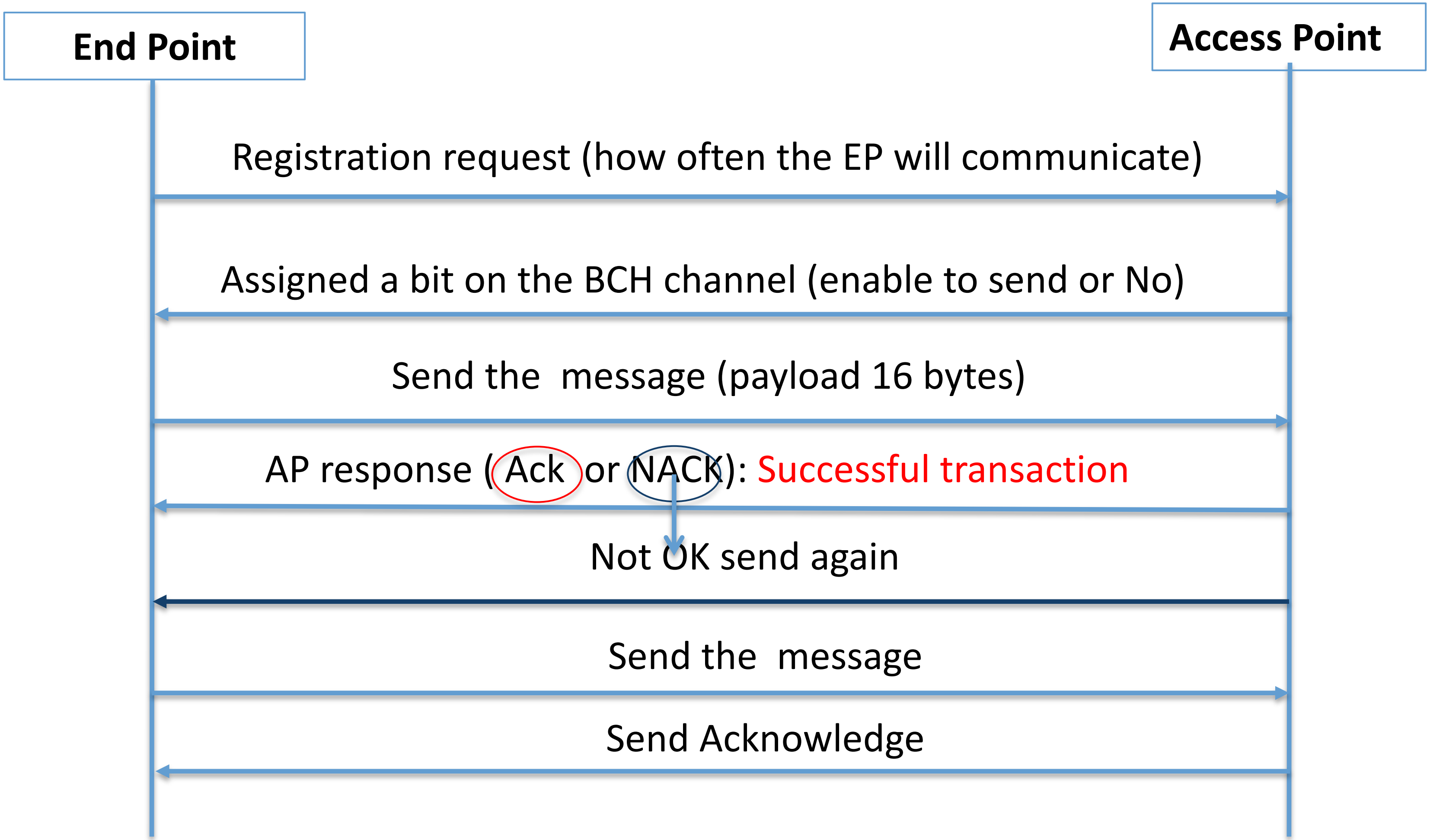
Uplink Subslot Structure

❖Uplink Subslot Structure Supporting Flexible Data Rate



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?



RPMA security

Message confidentiality: use of powerful encryption

Message integrity1 Replay protection

Mutual Authentication

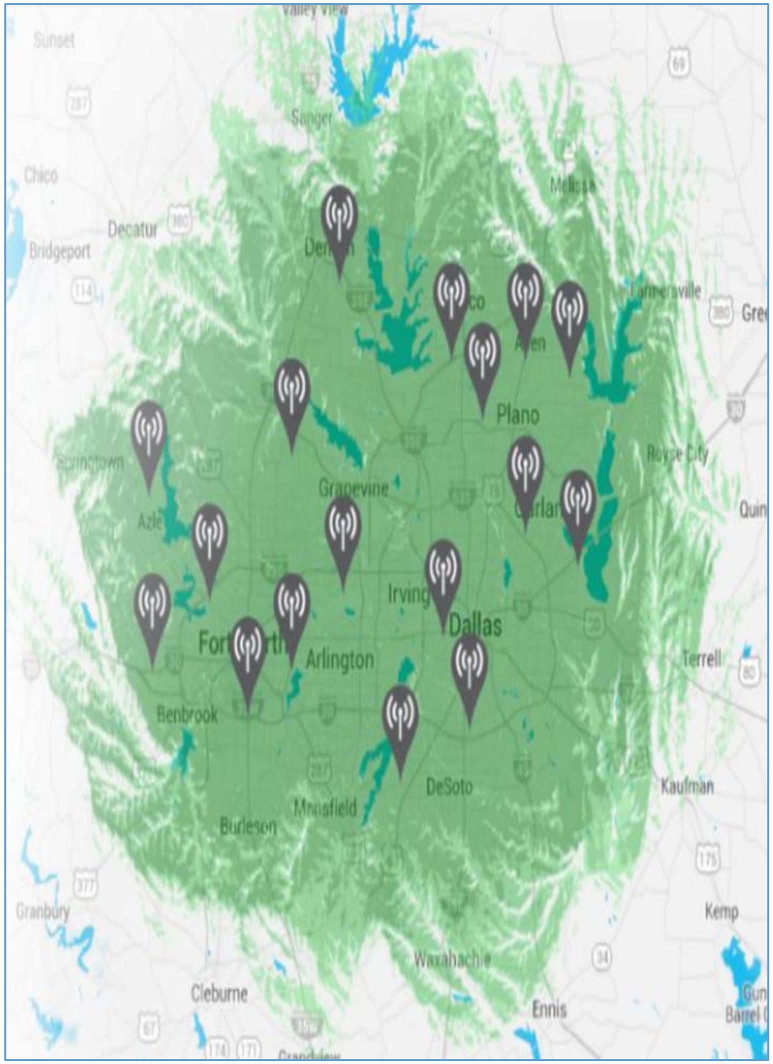
Device Anonymity

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
• Austin,TX • Dallas/Ft.worth, TX • Hostton,TX • Phenix,AZ • Riverside,CA • San Antonio,TX • San Diego,CA	• Columbus, OH • Indianapolis,IN	• Atlanta,GA • Jacksonville,FL • Miami,FL • Oriando,FL • New Orleans,LA • Charlotte,NC • Albuquerque • Memphis,TN • Nashville,TN EL paso,TX • Salt Lake City,UT • Richmound, • Virginia beach,VA	• Los Angeles,CA • San Franscisco-West Bay,CA • Washington,DC • Baltimore,MD • Kanasas City • Greeensboro,NC • Las Vegas,NV • Oklahorma City, OK • And many more cities

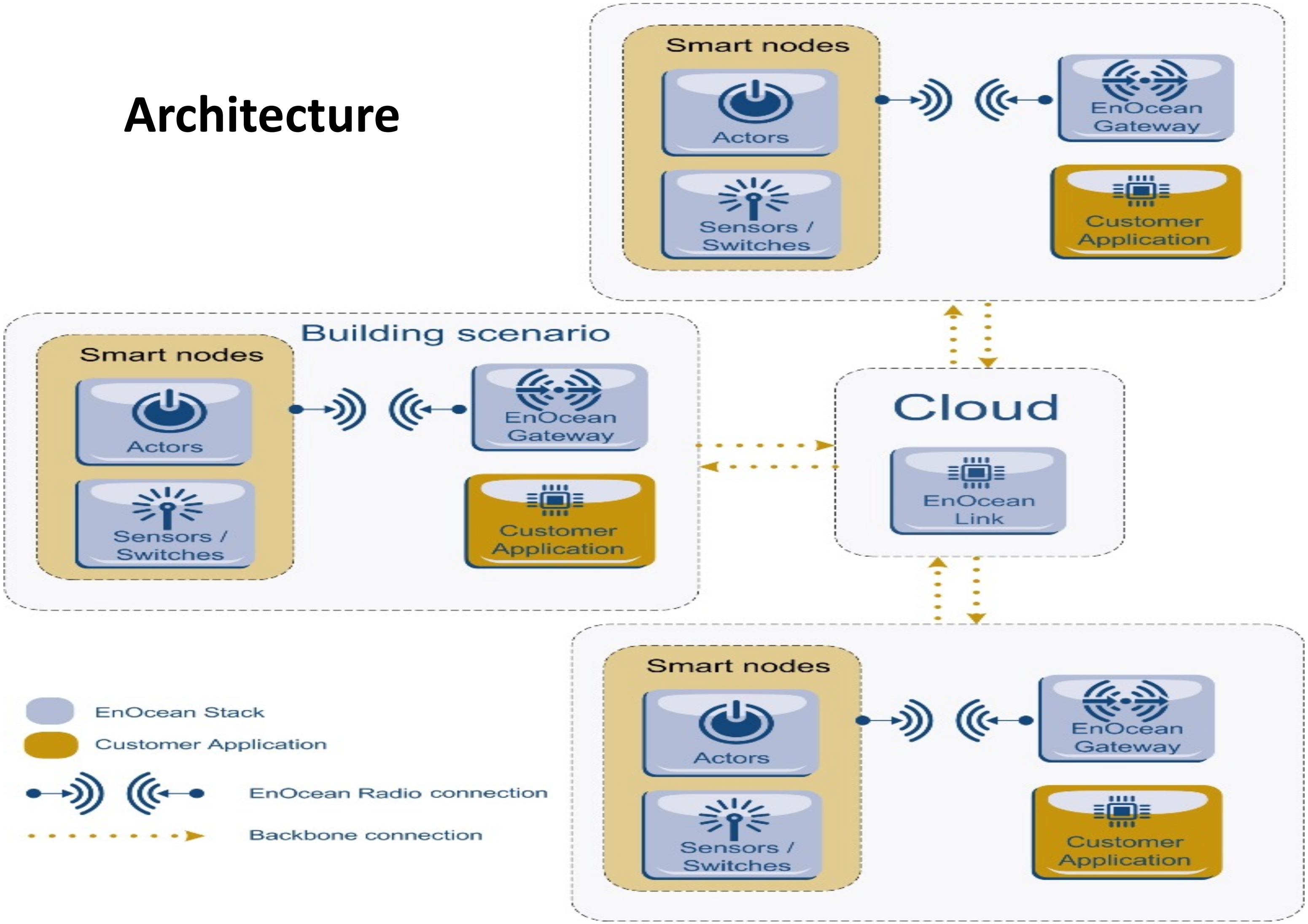
v. Others

EnOcean

- 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 ...)

Green.Smart.Wireless.
enocean®

Architecture



ZWave

- 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


Home Control
Remote Home Management and Monitoring
Energy Conservation
ZWAVE®
Home Entertainment Control
Safety & Security
Comfort and Convenience

Summary

A. Fixed & Short Range

B. Long Range technologies

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

2. 3GPP Standards

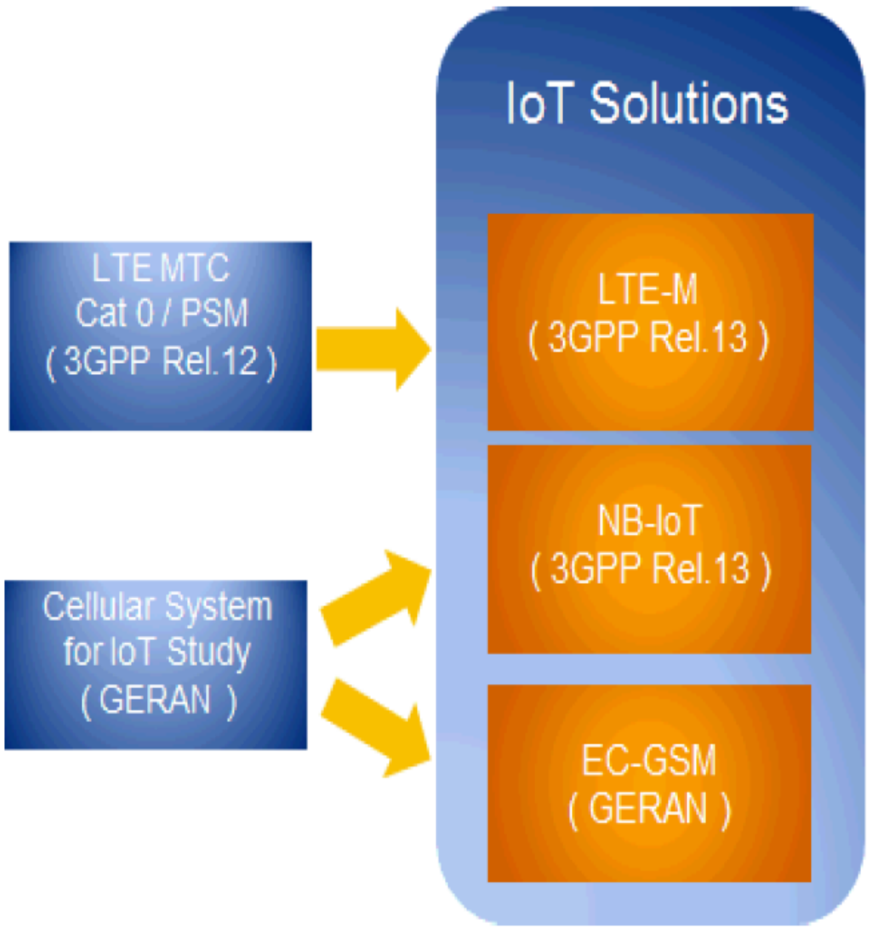
i. LTE-M

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

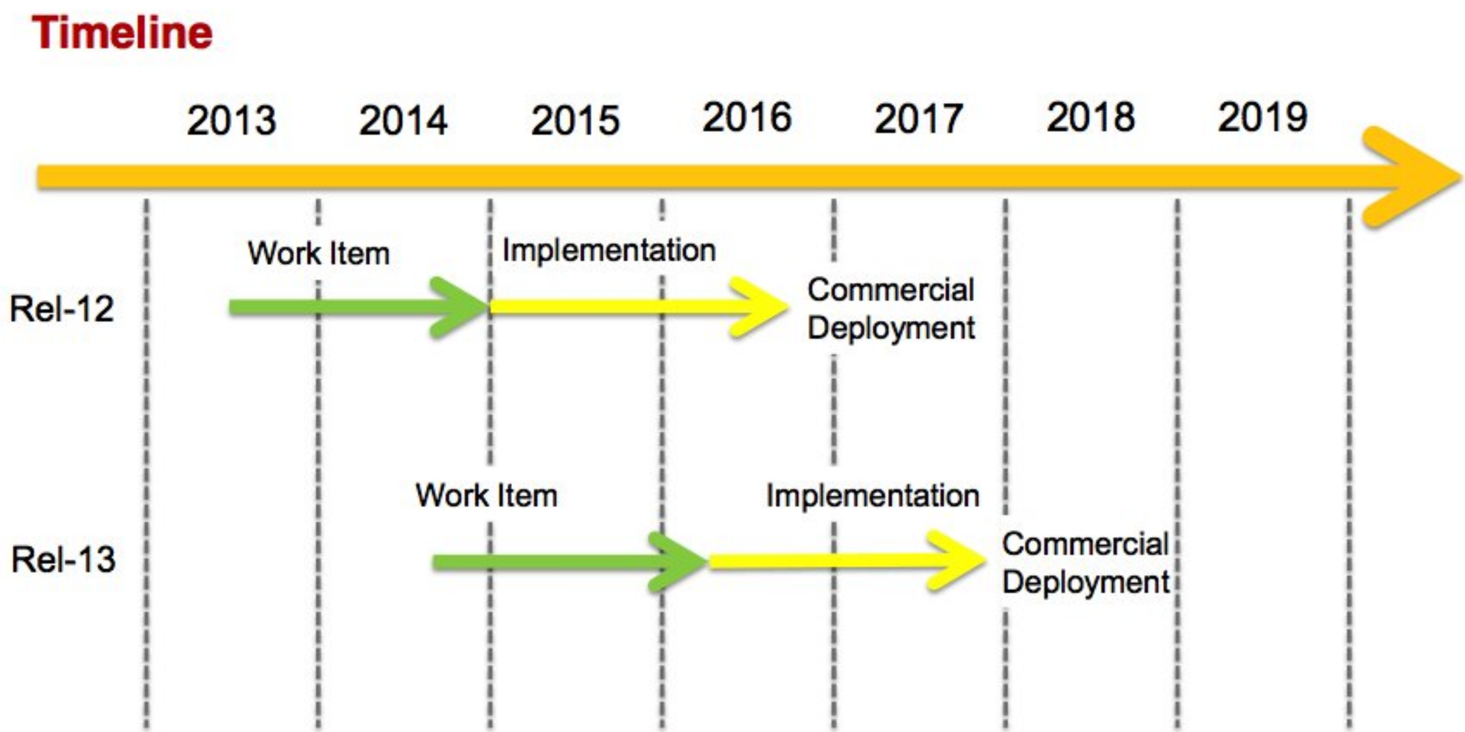
Criterion	Cat. 1 (Rel. 8+)	Cat. M1 (Rel. 13)	Cat. NB1 (Rel. 13)	FeMTC (Rel. 14)	eNB-IOT (Rel. 14)
Bandwidth	20 MHz	1.4 MHz	180 kHz	Up to 5 MHz (CE Mode A and B for PDSCH and A only for PUSCH)	180 kHz
Deployments/ HD-FDD	LTE channel / No HD-FDD	Standalone, in LTE channel / HD-FDD preferred	Standalone, 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%]

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: ≤ **1 Mbps**

LTE-M

Roadmap



- First released in Rel.1in 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	**1**	**1**
Uplink peak rate (Mbps)	50	5	**1**	**1**
Number of antennas (MIMO)	2	2	**1**	**1**
Duplex Mode	Full	Full	**Half**	**Half**
UE receive bandwidth (MHz)	**20**	**20**	**20**	**1.4**
UE Transmit power (dBm)	**23**	**23**	**23**	**20**

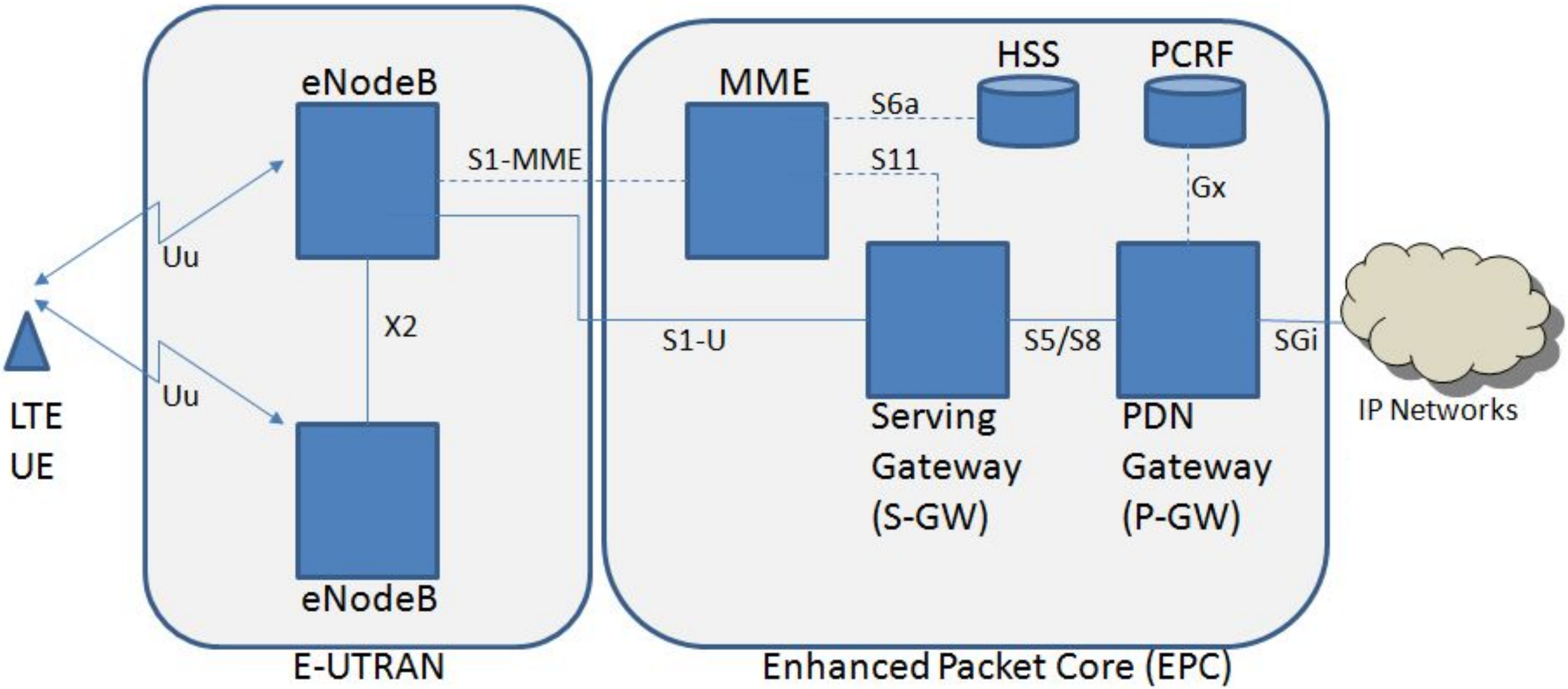
Release 12

- 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

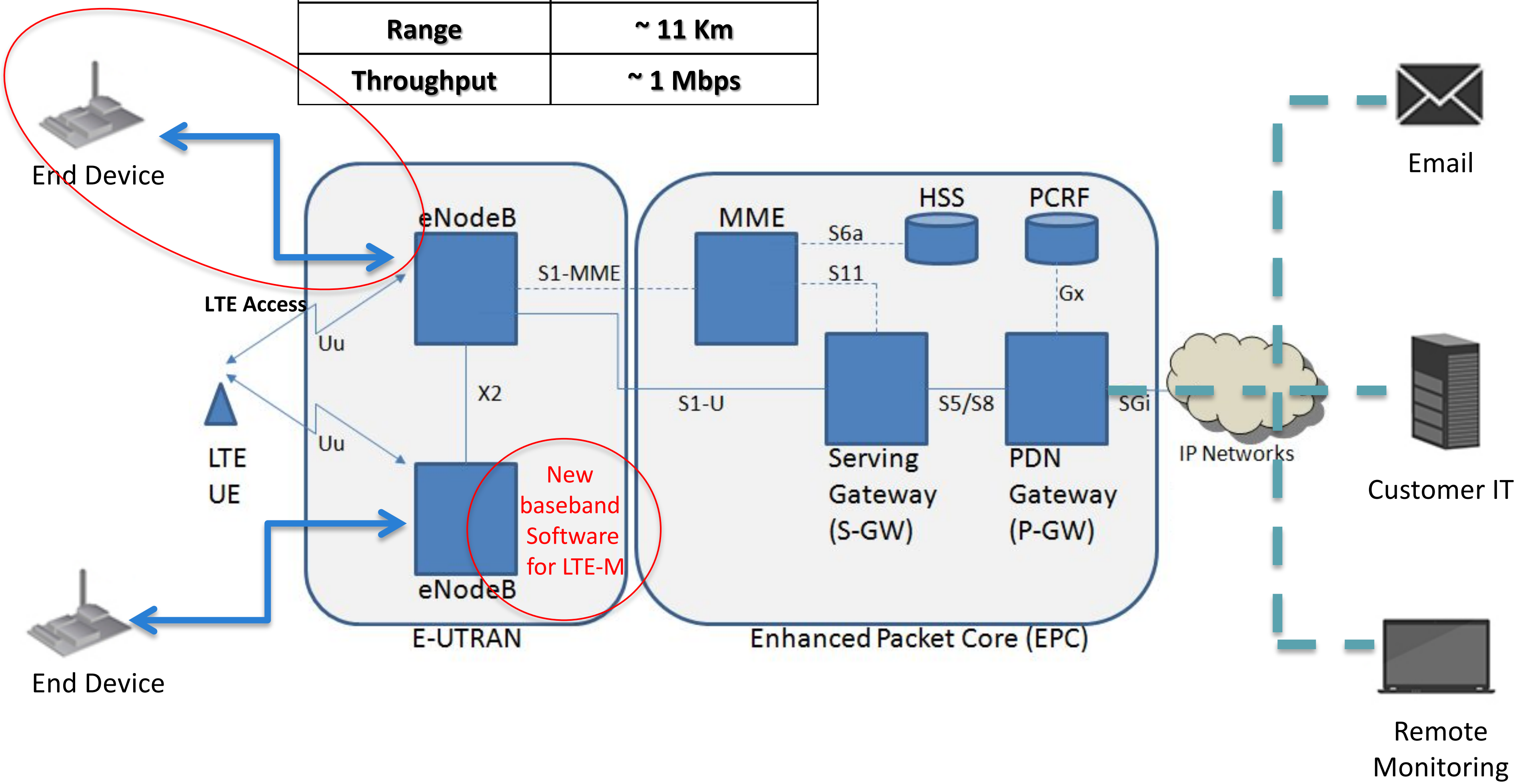
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

Present LTE Architecture

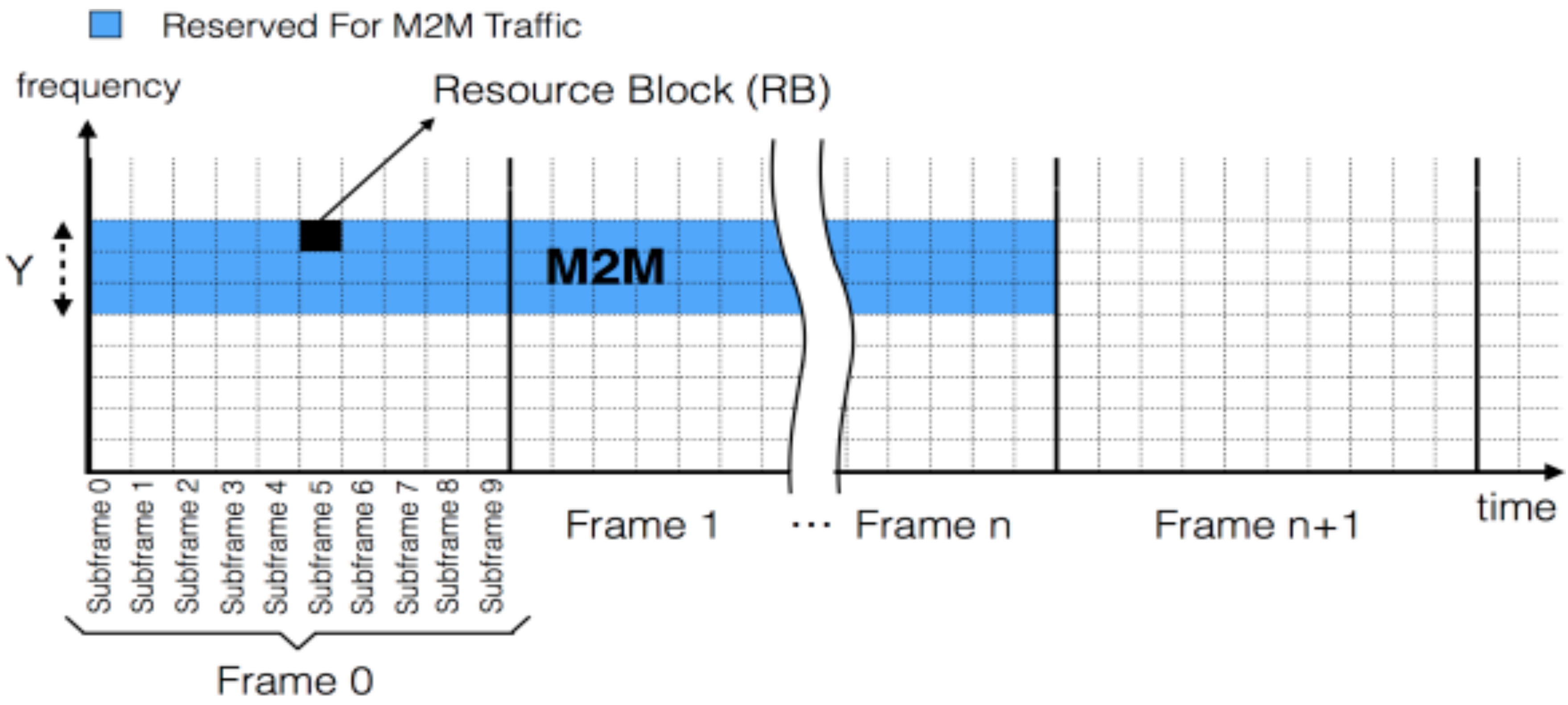


Architecture

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

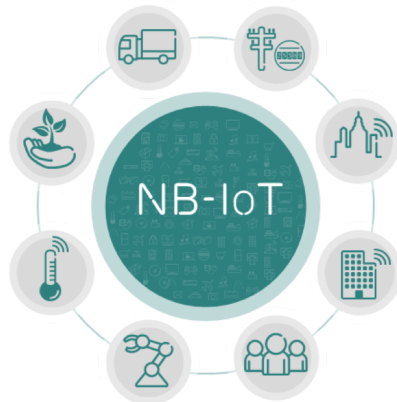


- **Licensed Spectrum**
- **Bandwidth: 700-900 MHz for LTE**
- **Some resource blocks allocated for IoT on LTE bands**



ii. NB-IOT

Current status



April 2014	Narrowband proposal to Connected Living
May 2014	3GPP ‘Cellular IoT’ Study Item
Mars 2015	GSMA Mobile IoT created
August 2015	3GPP alignment on single standard
November 2015	1st live pre-standard NB-IoT message
Jun 2015	Full NB-IoT 3GPP Standard Released
2017+	Commercial rollout

Evolution of LTE-M

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

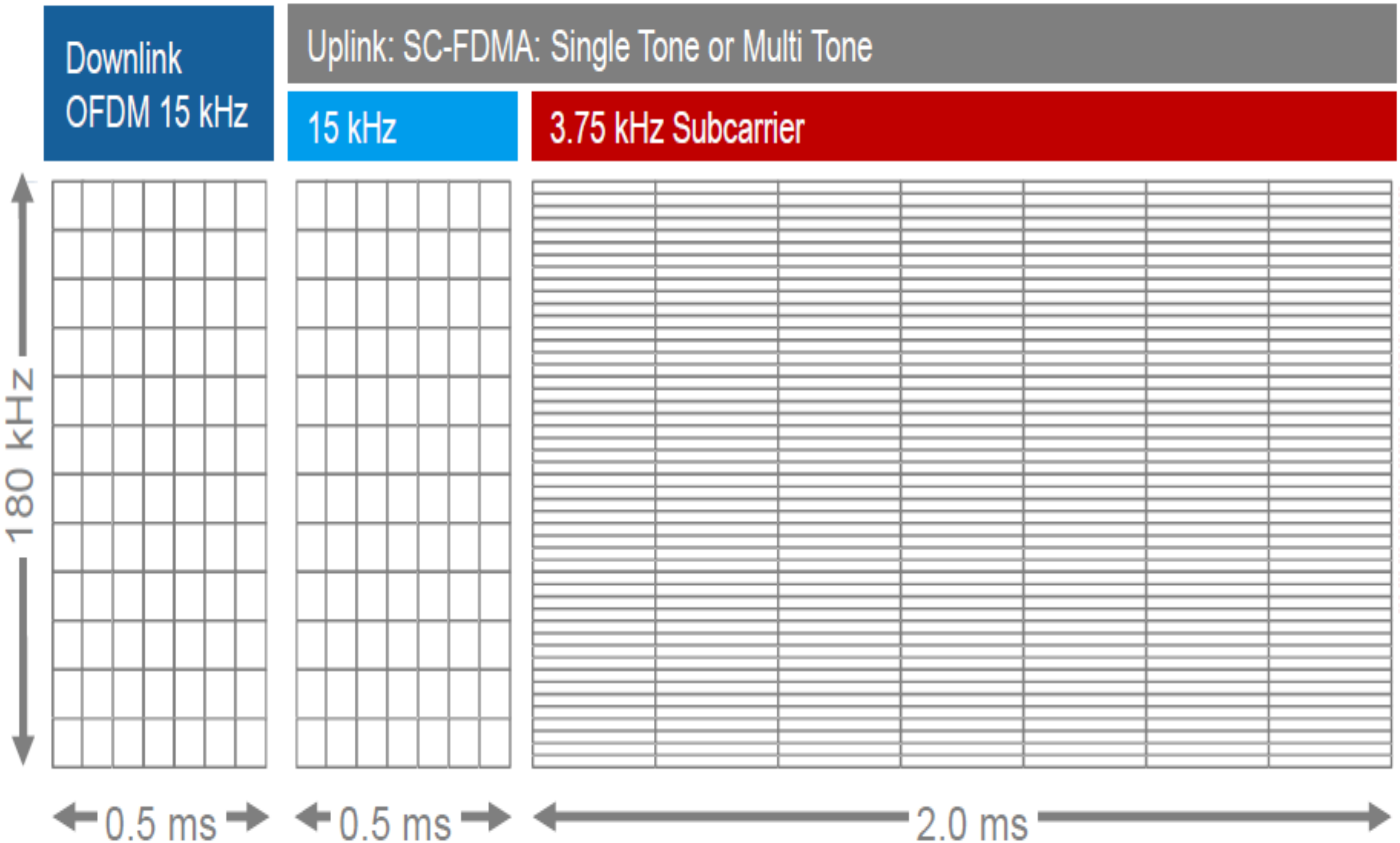
↳ ***Reduced time*** to develop:

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

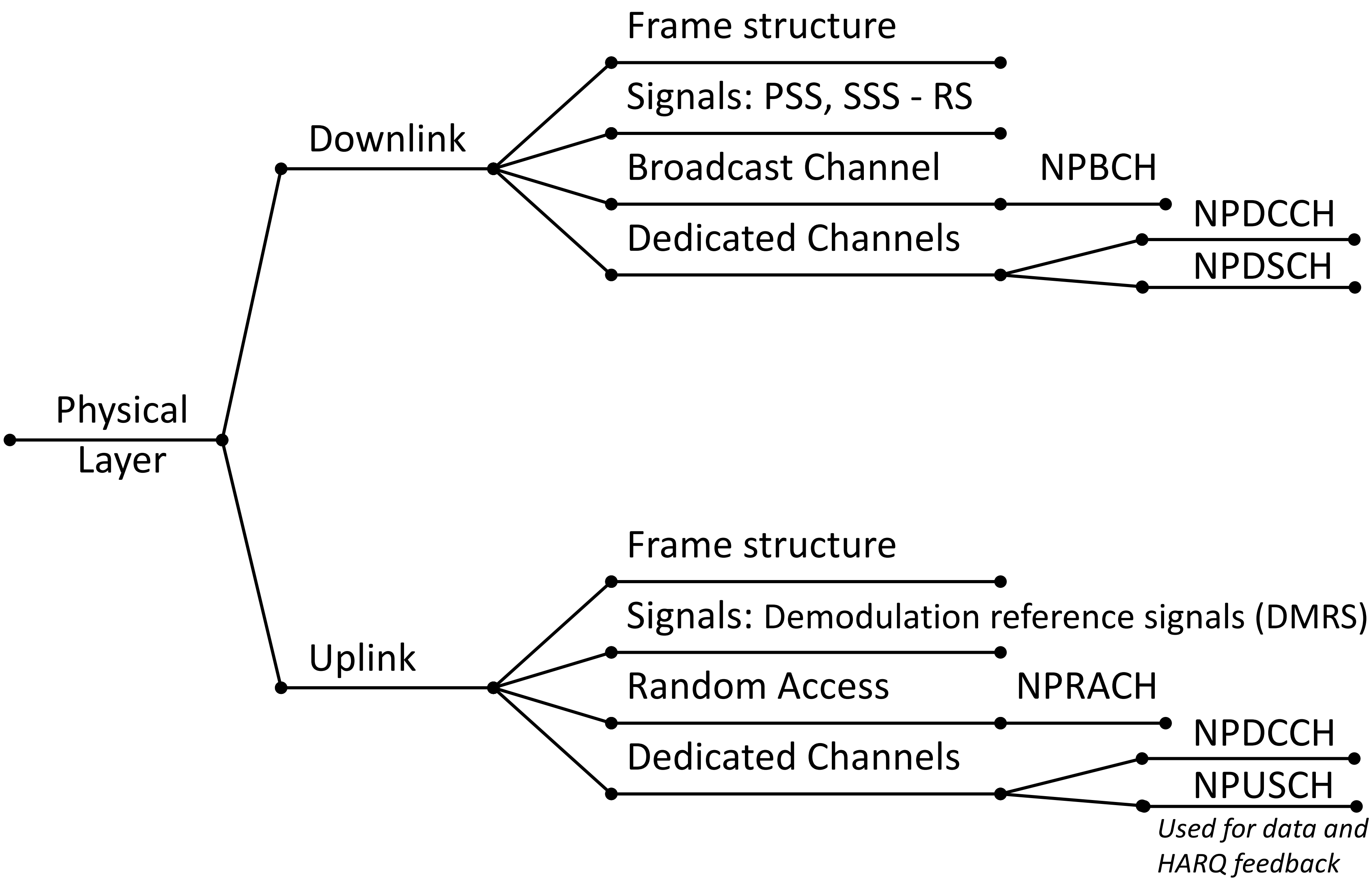
June 2016: core specifications completed.

Beginning of 2017: commercial launch of products and services.

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

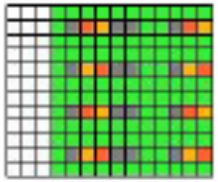


NB-IoT Channels



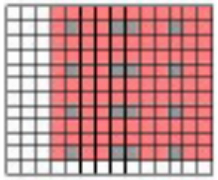
Physical downlink channels

NB-PBCH



- 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*8 = 1600 bits.

NB-PSS

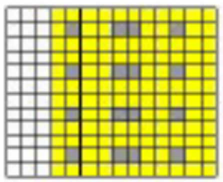


- Transmitted on subframe 5
- Length-11 ZC sequence is generated for each OFDM symbol.
- Punctured by LTE CRS locations

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

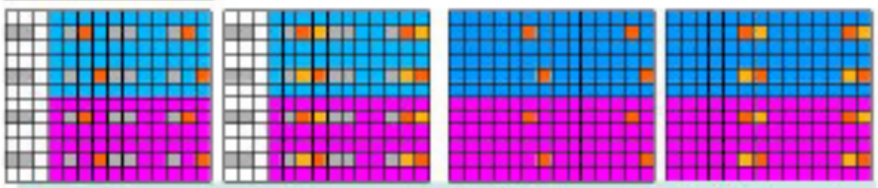
- Size of LTE control region and number of NB-RS ports is indicated by NB-MIB.

NB-SSS



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

NB-PDCCH

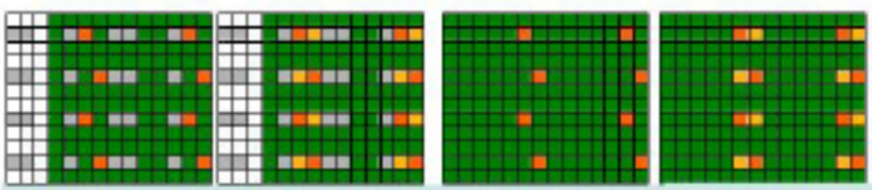


Single NB Antenna port | Two NB Antenna ports | Single NB Antenna port | Two NB Antenna ports

Inband Mode | Standalone / Guard band Mode

- 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

NB-PDSCH



Single NB Antenna port | Two NB Antenna ports | Single NB Antenna port | Two NB Antenna ports

Inband Mode | Standalone / Guard band Mode

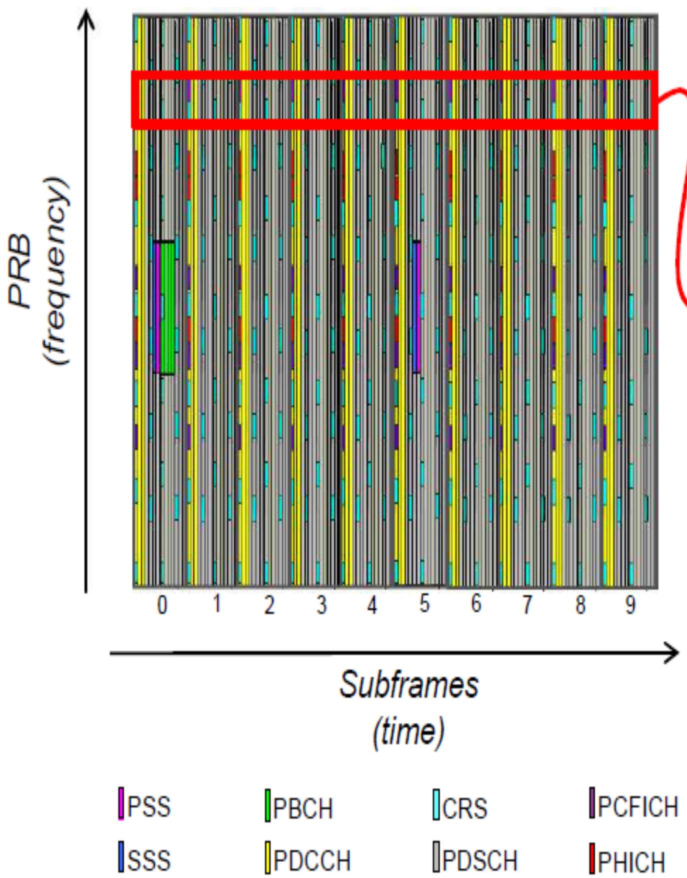
- Error detection through 24-bit CRC for NB-PDSCH
- 16QAM is not supported for NB-PDSCH
- The maximum TBS for NB-PDSCH is 680 bits
- Redundancy versions (RVs) for NB-PDSCH are not supported
- NB-SIB1 is transmitted in one subframe of every other frame in 16 continuous frames. The subframes which are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

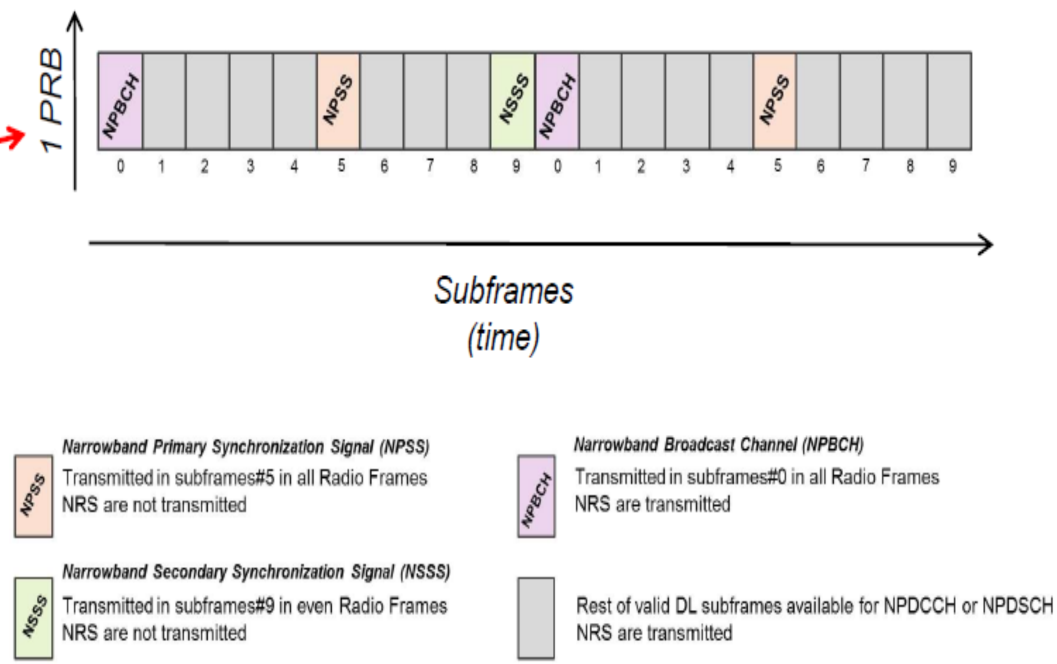
LTE

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

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

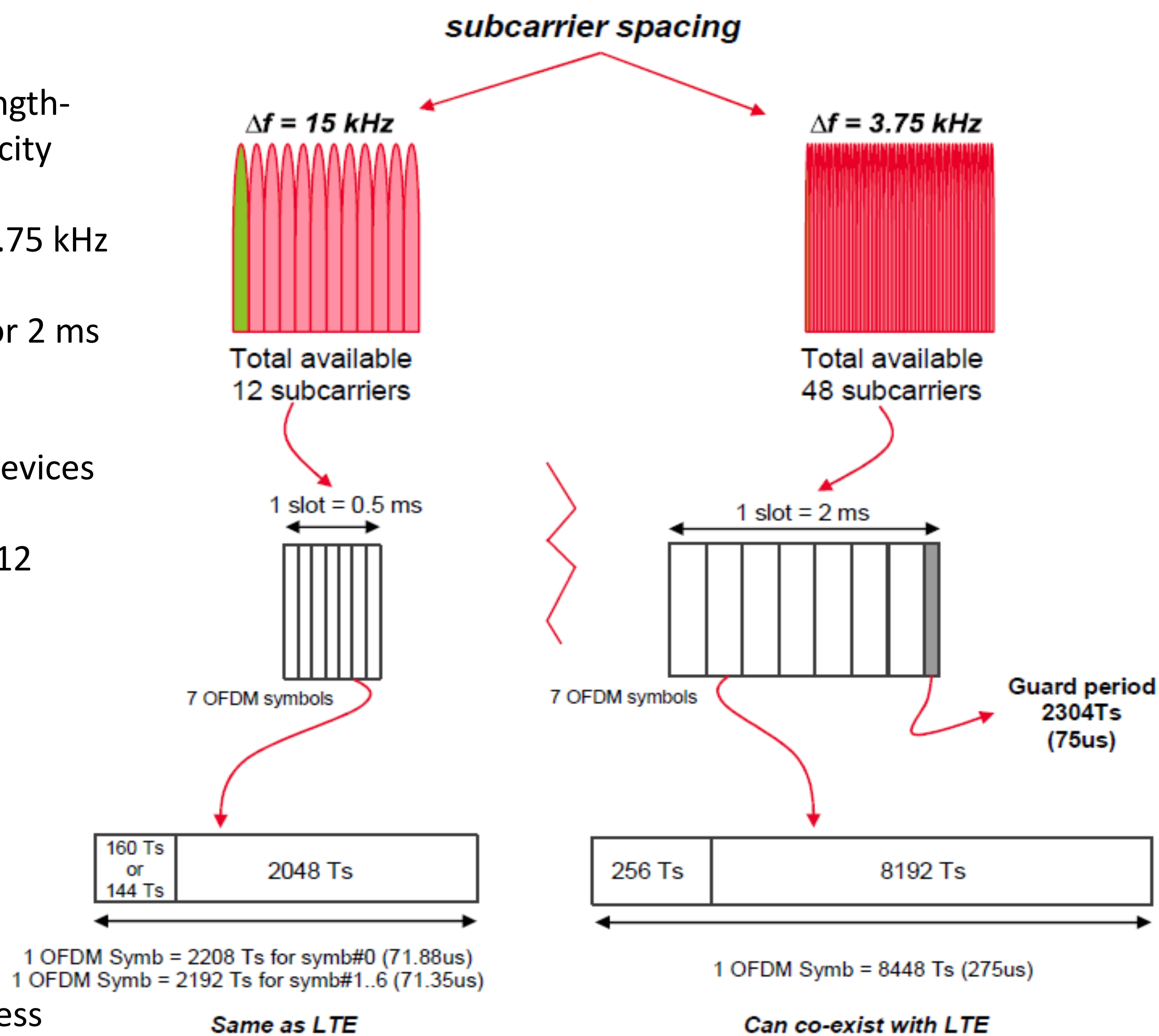
- Number of subcarriers: 3, 6 or 12 signaled via DCI
- Subcarrier spacing: 15 kHz
- Slot duration = 0.5 ms

New UL signals

DMRS (demodulation reference signals)

New UL channels

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



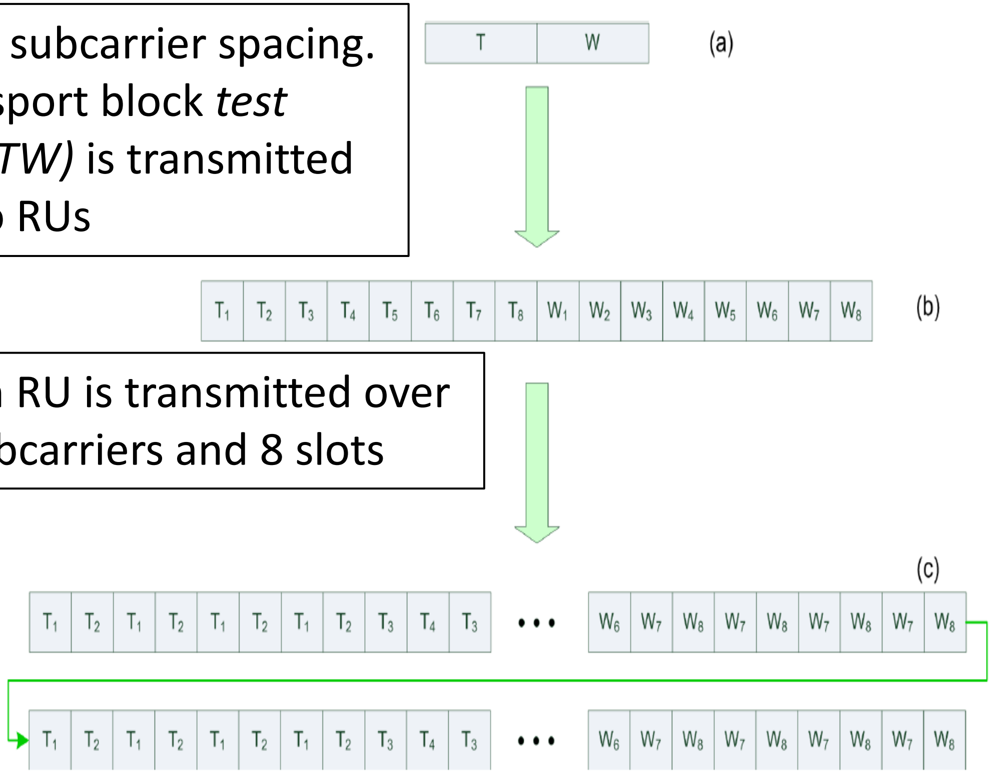
NB-IoT Repetitions

Consists on repeating the same transmission several times:

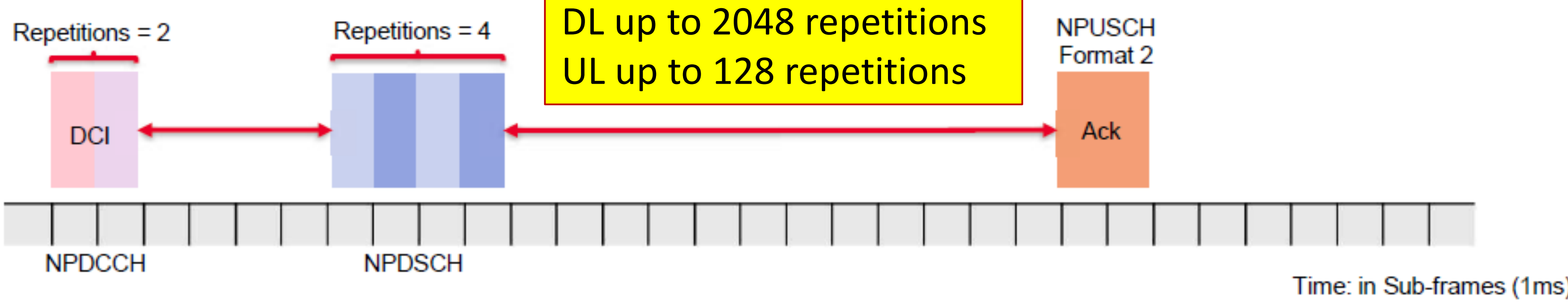
- Achieve extra coverage (up to 20 dB compared to GPRS)
- Each repetition is self-decodable
- SC is changed for each transmission to help combination
- Repetitions are ACK-ed just once
- All channels can use Repetitions to extend coverage

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

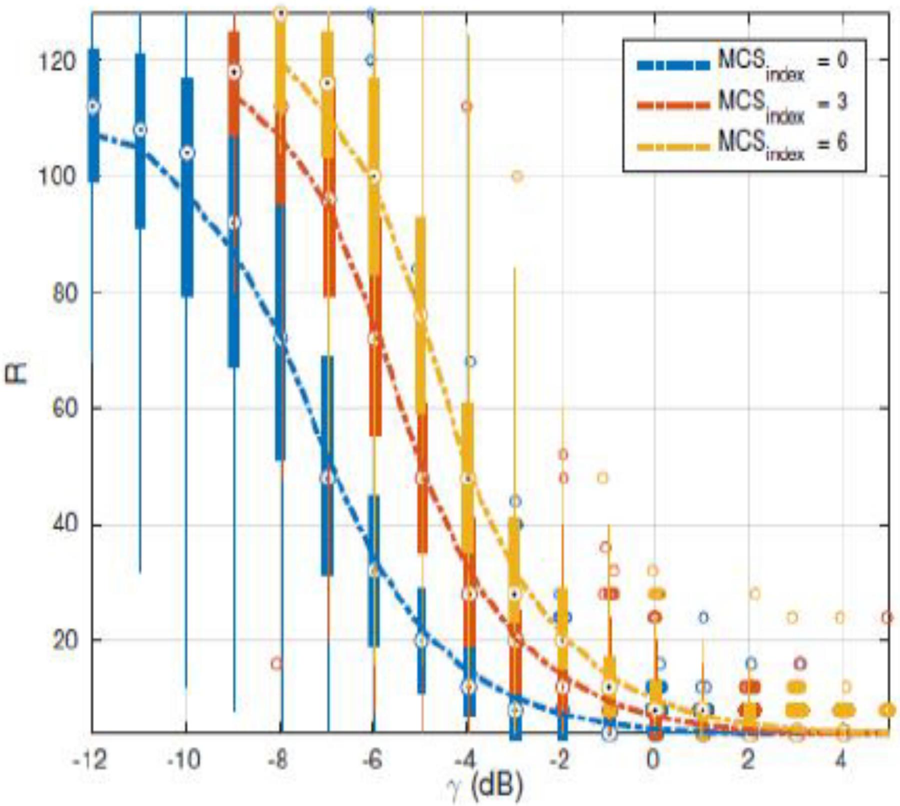


DL up to 2048 repetitions
UL up to 128 repetitions

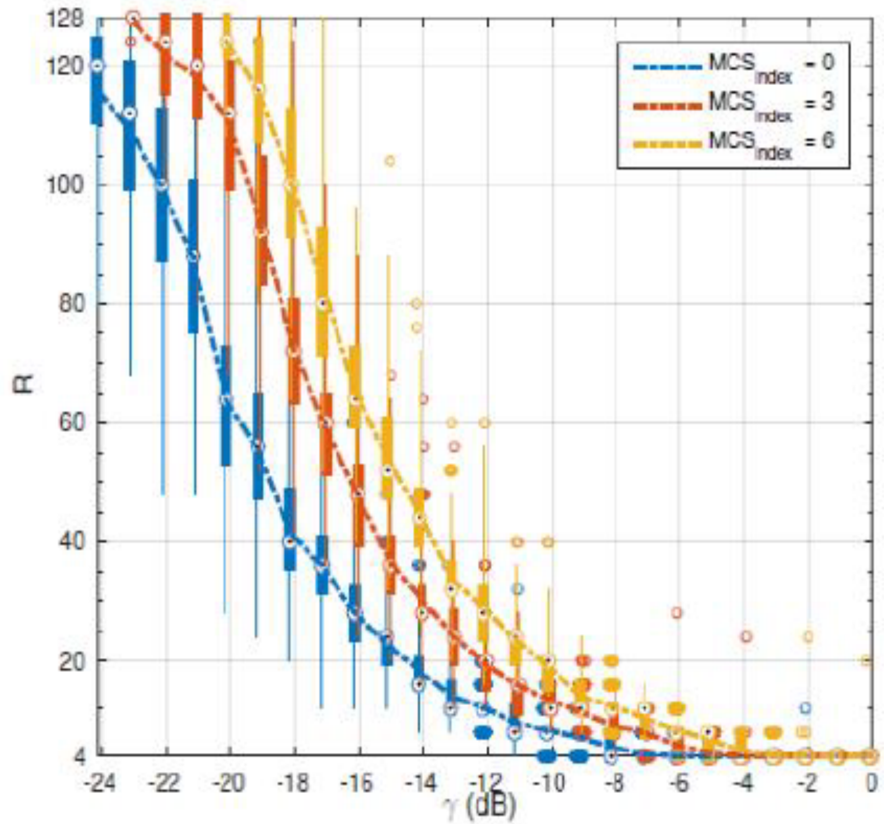


Example: *Repetitions used in NB-IoT in NPDCCH and NPDSCH channels*

Repetitions number to decode a NPUSCH

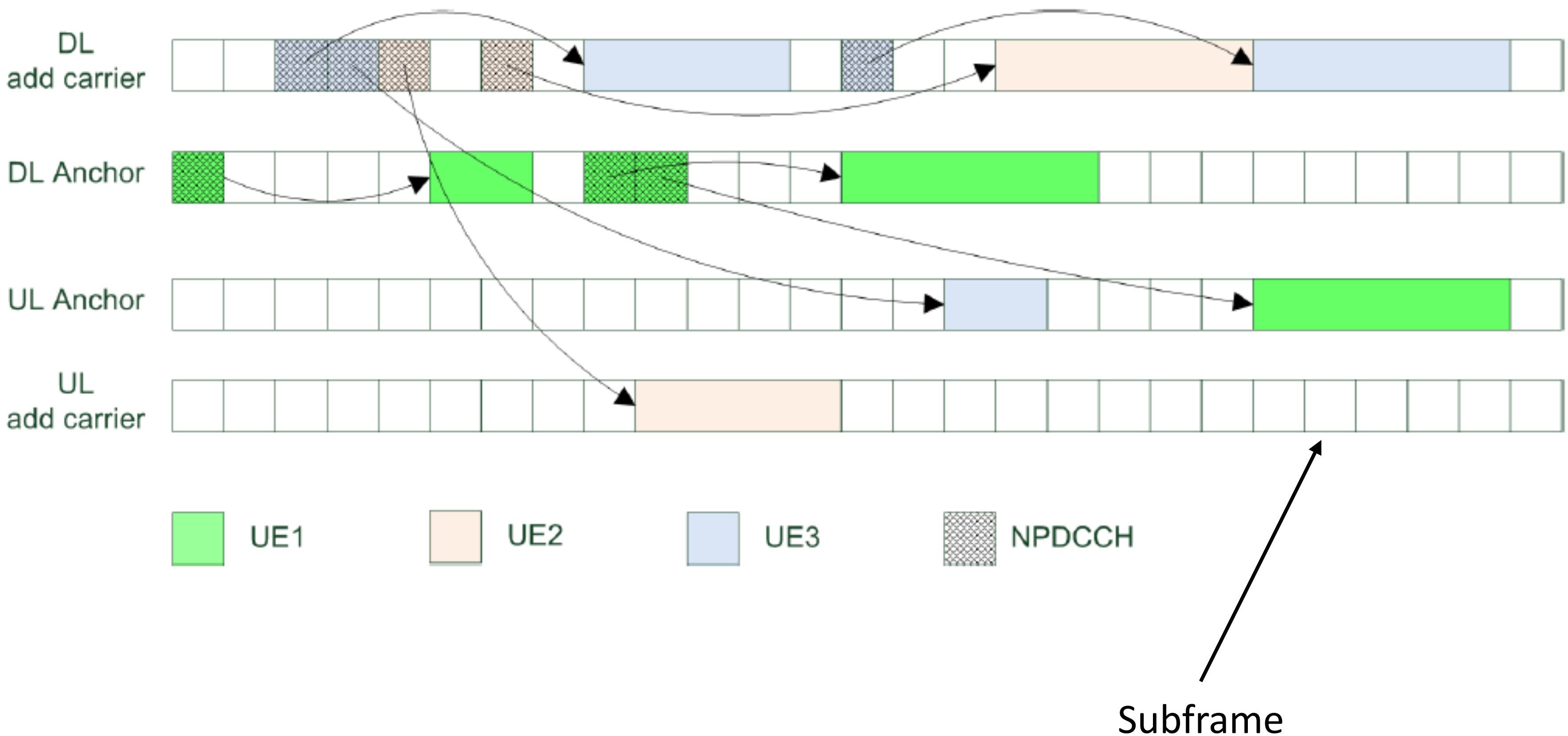


$f_D = 0 \quad Hz$



$f_D = 80 \quad Hz$

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-IoTPRB)
- 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

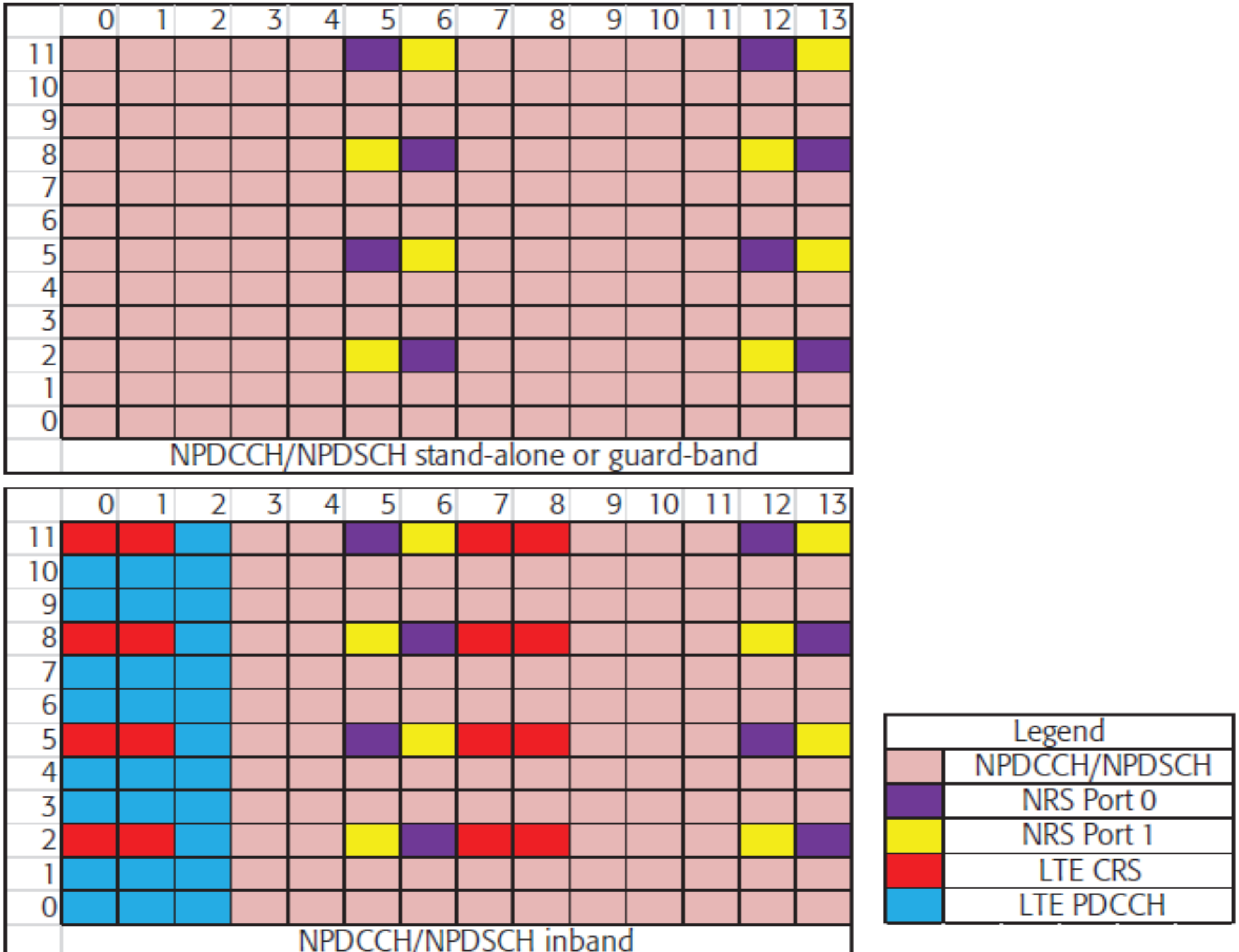
Physical signals and channels in the downlink:

- **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)

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



Physical signals and channels and relationship with LTE

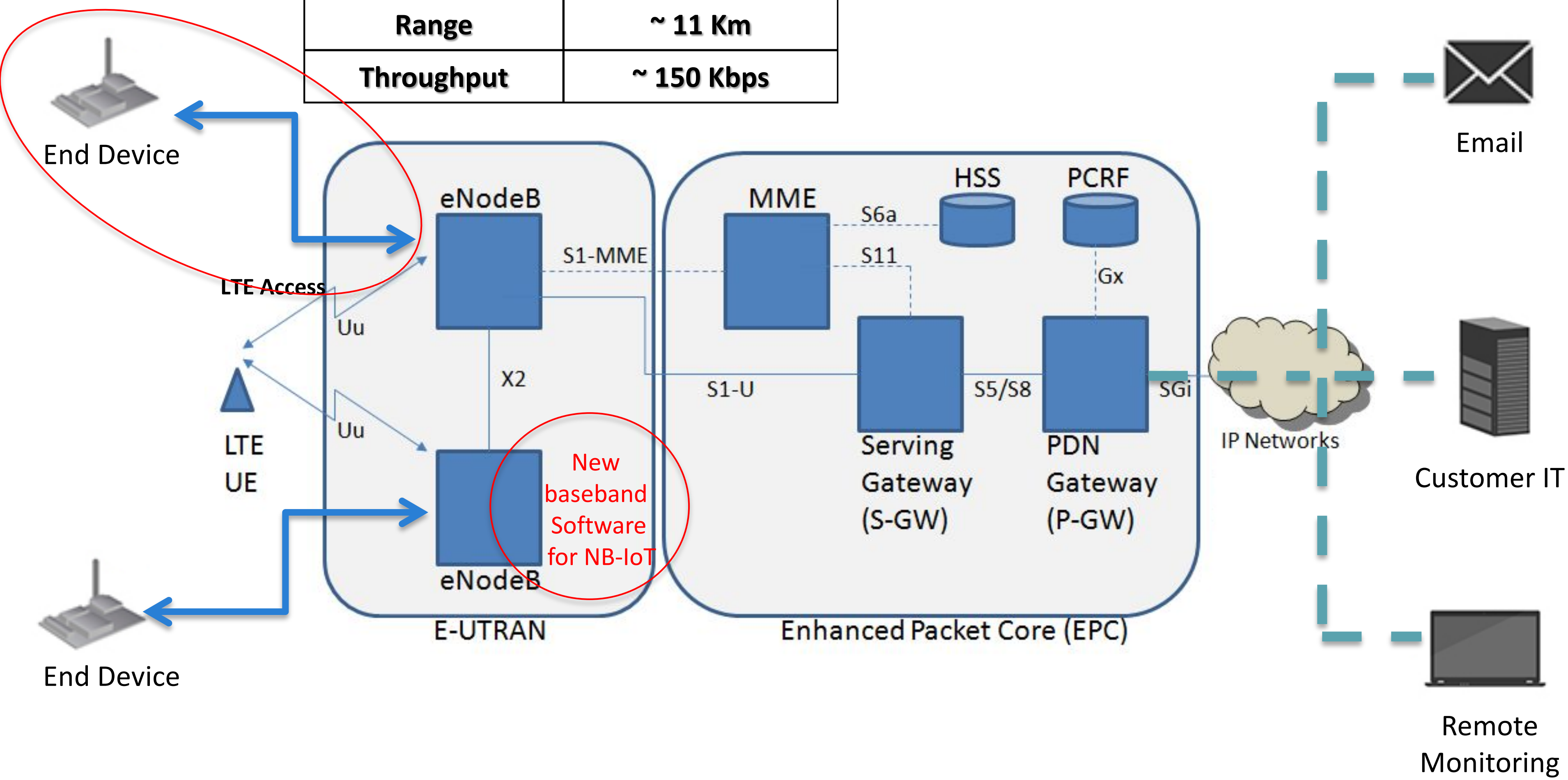
	Physical channel	Relationship with LTE
Downlink	NPSS	• New sequence for fitting into one PRB (LTE PSS overlaps with middle six PRBs) • All cells share one NPSS (LTE uses 3 PSSs)
	NSSS	• New sequence for fitting into one PRB (LTE SSS overlaps with middle six PRBs) • NSSS provides the lowest 3 least significant bits of system frame number (LTE SSS does not)
	NPBCH	• 640 ms TTI (LTE uses 40 ms TTI)
	NPDCCH	• May use multiple PRBs in time, i.e. multiple subframes (LTE PDCCH uses multiple PRBs in frequency and 1 subframe in time)
	NPDSCH	• Use TBCC and only one redundancy version (LTE uses Turbo Code with multiple redundancy versions) • Use only QPSK (LTE also uses higher order modulations) • Maximum transport block size (TBS) is 680 bits. (LTE without spatial multiplexing has maximum TBS greater than 70000 bits, see [9]) • Supports only single-layer transmission (LTE can support multiple spatial-multiplexing layers)
Uplink	NPRACH	• 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)
	NPUSCH Format 1	• Support UE bandwidth allocation smaller than one PRB (LTE has minimum bandwidth allocation of 1 PRB) • Support both 15 kHz and 3.75 kHz numerology for single-tone transmission (LTE only uses 15 kHz numerology) • Use $\pi/2$-BPSK or $\pi/4$-QPSK for single-tone transmission (LTE uses regular QPSK and higher order modulations) • Maximum TBS is 1000 bits. (LTE without spatial multiplexing has maximum TBS greater than 70000 bits, see [9]) • Supports only single-layer transmission (LTE can support multiple spatial-multiplexing layers)
	NPUSCH Format 2	• New coding scheme (repetition code) • Uses only single-tone transmission

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

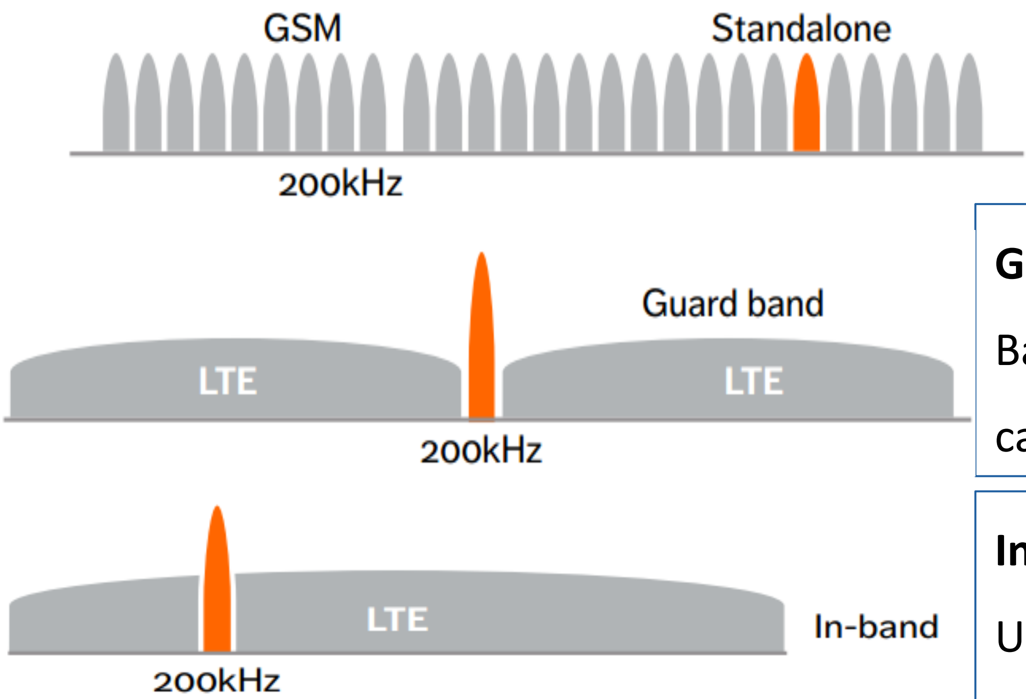
Architecture

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.

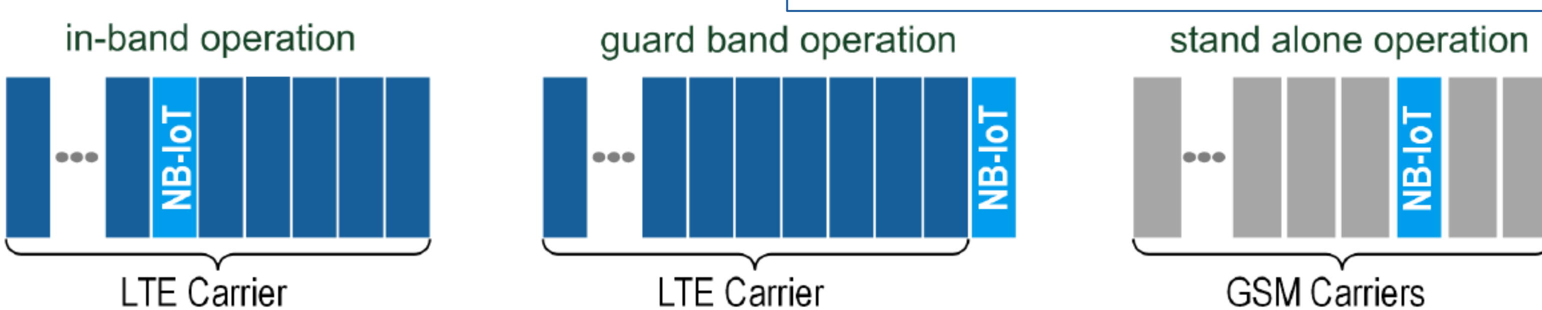
Ex.: By **re-farming GSM channels**

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

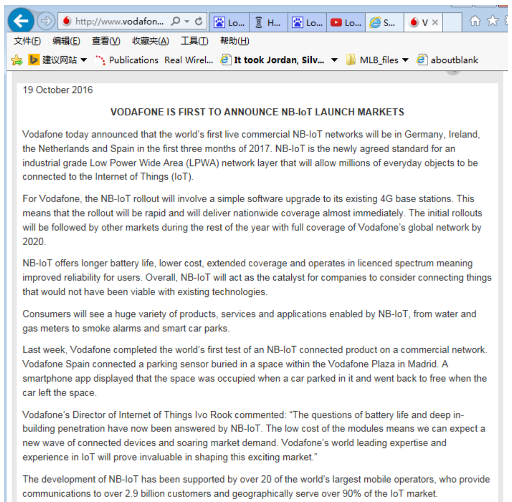


LTE-M to NB-IoT

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	**300 bps to 200 kbps**
Uplink peak rate	1 Mbps	1 Mbps	**144 kbps**
Number of antennas	1	1	1
Duplex Mode	Half	Half	Half
UE receive bandwidth	20 MHz	1.4 MHz	**200 kHz**
UE Transmit power (dBm)	23	20	**23**

- **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



19 October 2016

VODAFONE IS FIRST TO ANNOUNCE NB-IoT LAUNCH MARKETS

Vodafone today announced that the world's first live commercial NB-IoT networks will be in Germany, Ireland, the Netherlands and Spain in the first three months of 2017. NB-IoT is the newly agreed standard for an industrial grade Low Power Wide Area (LPWA) network layer that will allow millions of everyday objects to be connected to the Internet of Things (IoT).

For Vodafone, the NB-IoT rollout will involve a simple software upgrade to its existing 4G base stations. This means that the rollout will be rapid and will deliver nationwide coverage almost immediately. The initial rollouts will be followed by other markets during the rest of the year with full coverage of Vodafone's global network by 2020.

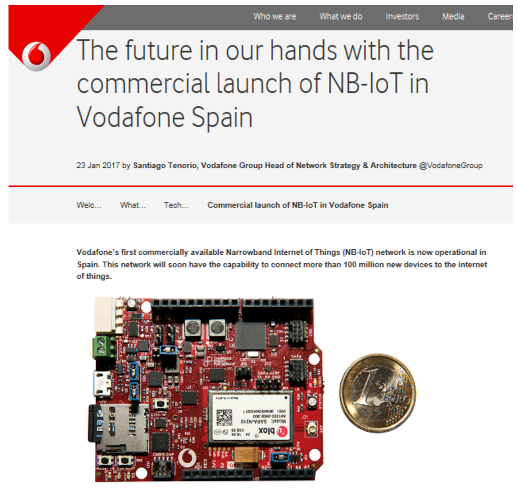
NB-IoT offers longer battery life, lower cost, extended coverage and operates in licenced spectrum meaning improved reliability for users. Overall, NB-IoT will act as the catalyst for companies to consider connecting things that would not have been viable with existing technologies.

Consumers will see a huge variety of products, services and applications enabled by NB-IoT, from water and gas meters to smoke alarms and smart car parks.

Last week, Vodafone completed the world's first test of an NB-IoT connected product on a commercial network. Vodafone Spain connected a parking sensor buried in a space within the Vodafone Plaza in Madrid. A smartphone app displayed that the space was occupied when a car parked in it and went back to free when the car left the space.

Vodafone's Director of Internet of Things Ivo Rook commented: "The questions of battery life and deep in-building penetration have now been answered by NB-IoT. The low cost of the modules means we can expect a new wave of connected devices and soaring market demand. Vodafone's world leading expertise and experience in IoT will prove invaluable in shaping this exciting market."

The development of NB-IoT has been supported by over 20 of the world's largest mobile operators, who provide communications to over 2.9 billion customers and geographically serve over 90% of the IoT market.



Who we are What we do Investors Media Careers

The future in our hands with the commercial launch of NB-IoT in Vodafone Spain

23 Jan 2017 by **Santiago Tenorio, Vodafone Group Head of Network Strategy & Architecture** @VodafoneGroup

Welc... What... Tech... **Commercial launch of NB-IoT in Vodafone Spain**

Vodafone's first commercially available Narrowband Internet of Things (NB-IoT) network is now operational in Spain. This network will soon have the capability to connect more than 100 million new devices to the internet of things.

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

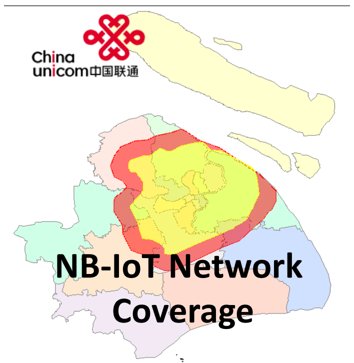
- Announced the commercialization of NB-IoT on 23rd Jan 17
- **1000** sites activated NB-IoT in Spain by the end of march 2017
- Took just a few hours to deploy NB-IoT with software upgrade in Valencia

- 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:



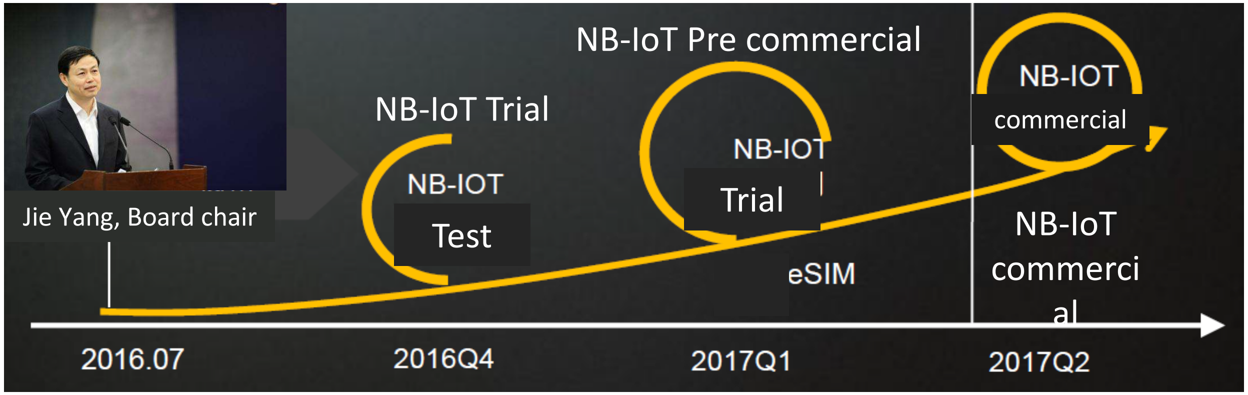
- **800+** base stations covered Shanghai in 2016Q4

Network readiness accelerates the development of vertical customers

Parking operator	Gas Utility	Fire center
		
Smart Parking	Smart Gas Meter	Smart Fire Protection

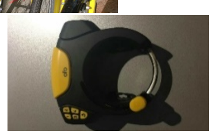
Source: *Huawei*

China Telecom: NB-IoT Nationwide Coverage in 2017H1



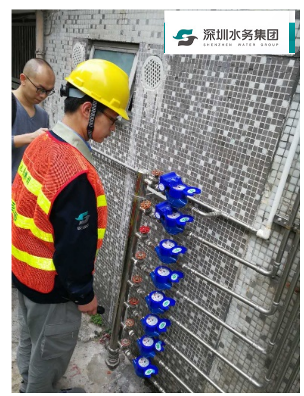
- 2017H1, NB-IoT enabled in L850 to achieve national wide coverage

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

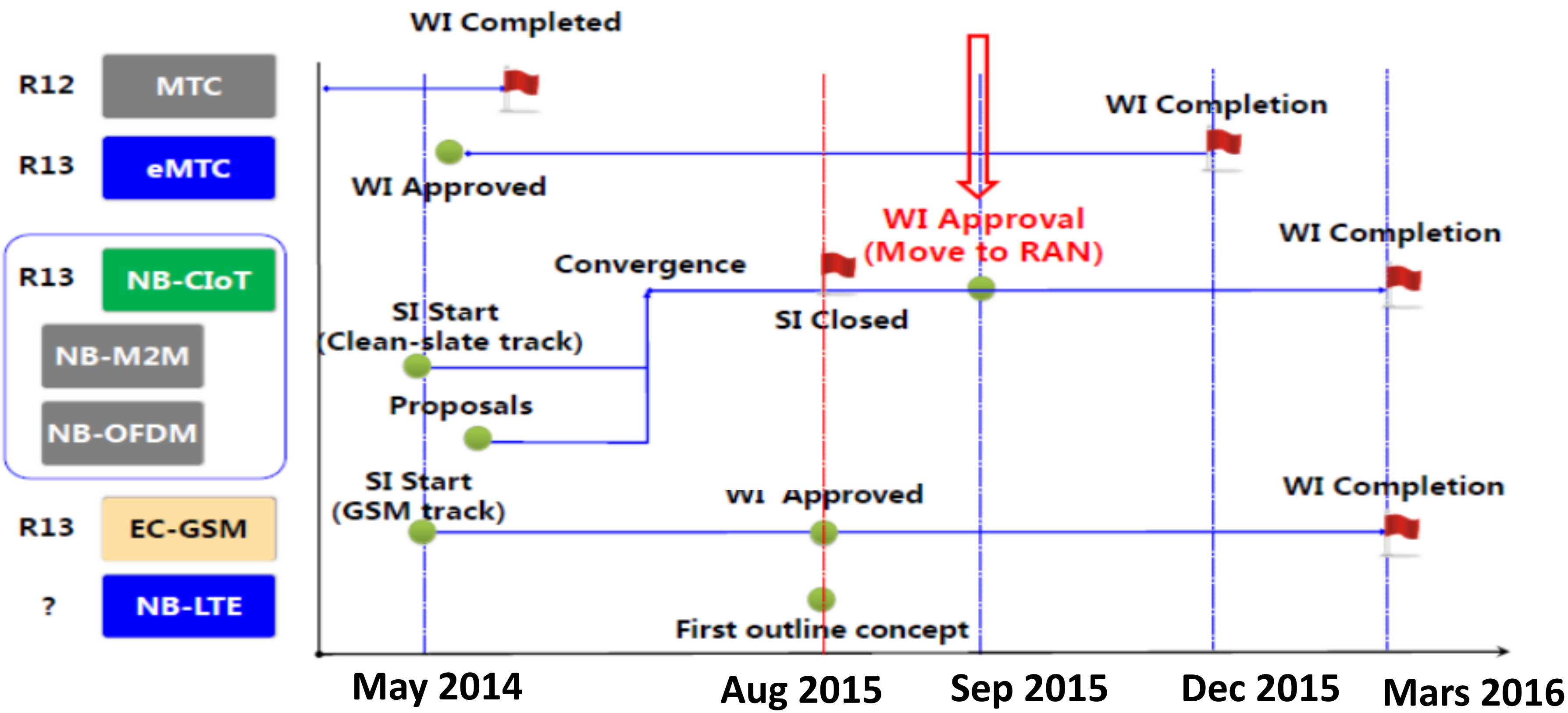


- Mar 22 2017, Shenzhen water utility announced commercialization;
- 1200 meters (phase 1) running in live network;

Source: *Huawei*

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 Whbattery (depending on traffic pattern and coverage needs)
- Low device cost compared to GPRS/GSM devices

Extended coverage:

- 164 dB MCL for 33 dBmUE,
- 154 dB MCL for 23 dBmUE

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)

	GSM900		LoRa
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)	139	dB	161

- **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

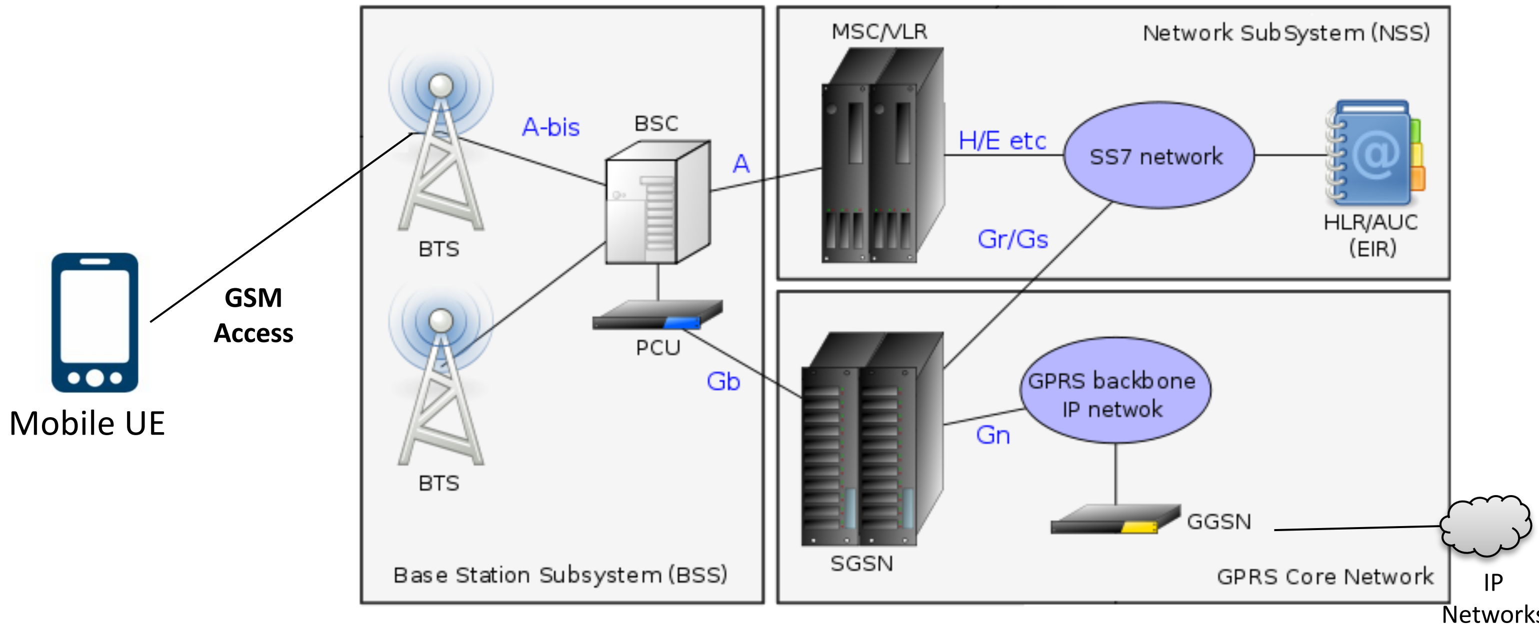
- Beacon and Synchronization channel don't use coverage class
  - EC-BCCH: always repeated 16 times
  - EC-SCH: always repeated 28 times
  - FCCH: legacy FCCH is used.

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

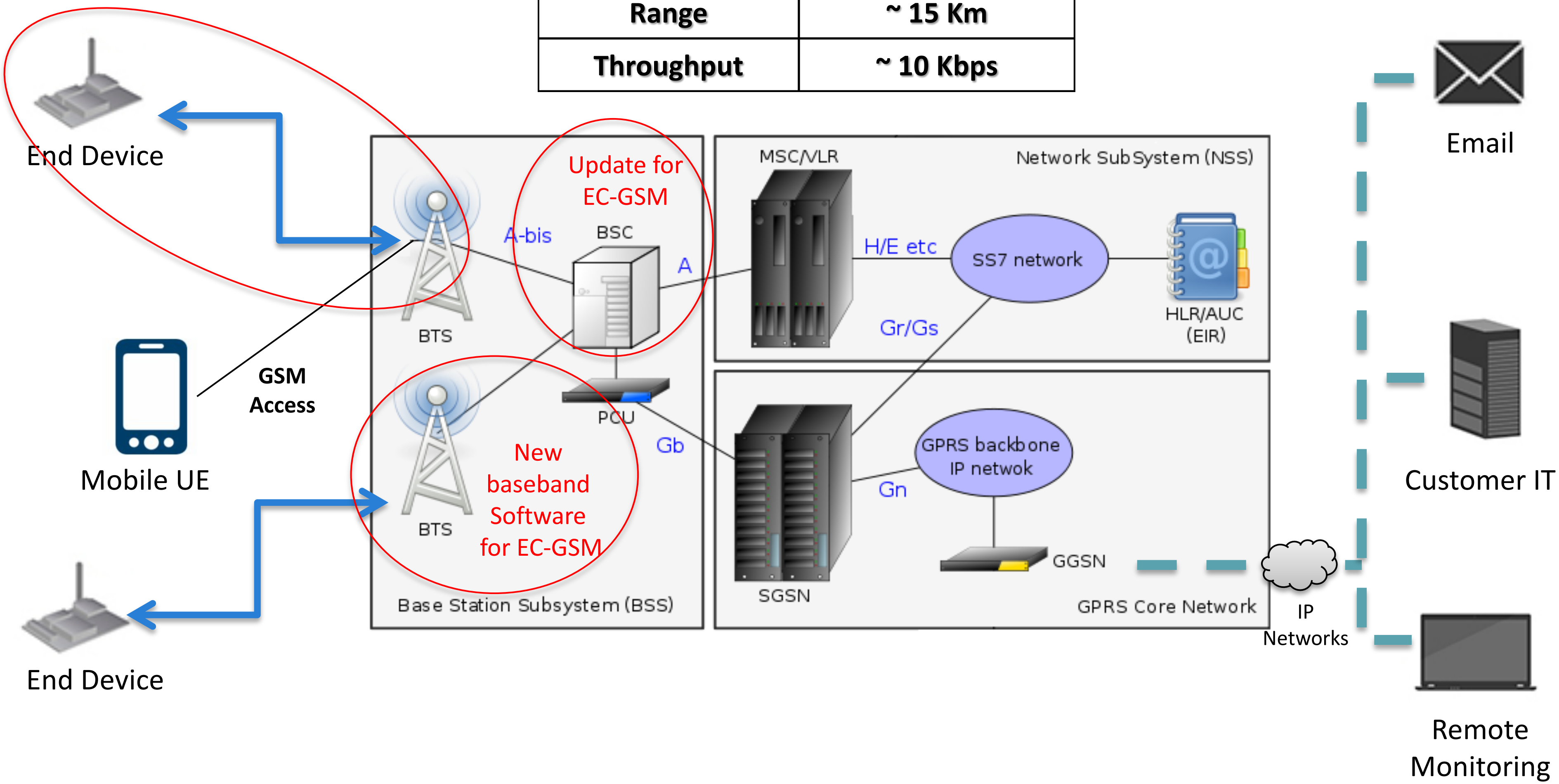
Actual GSM/GPRS Architecture



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

Architecture

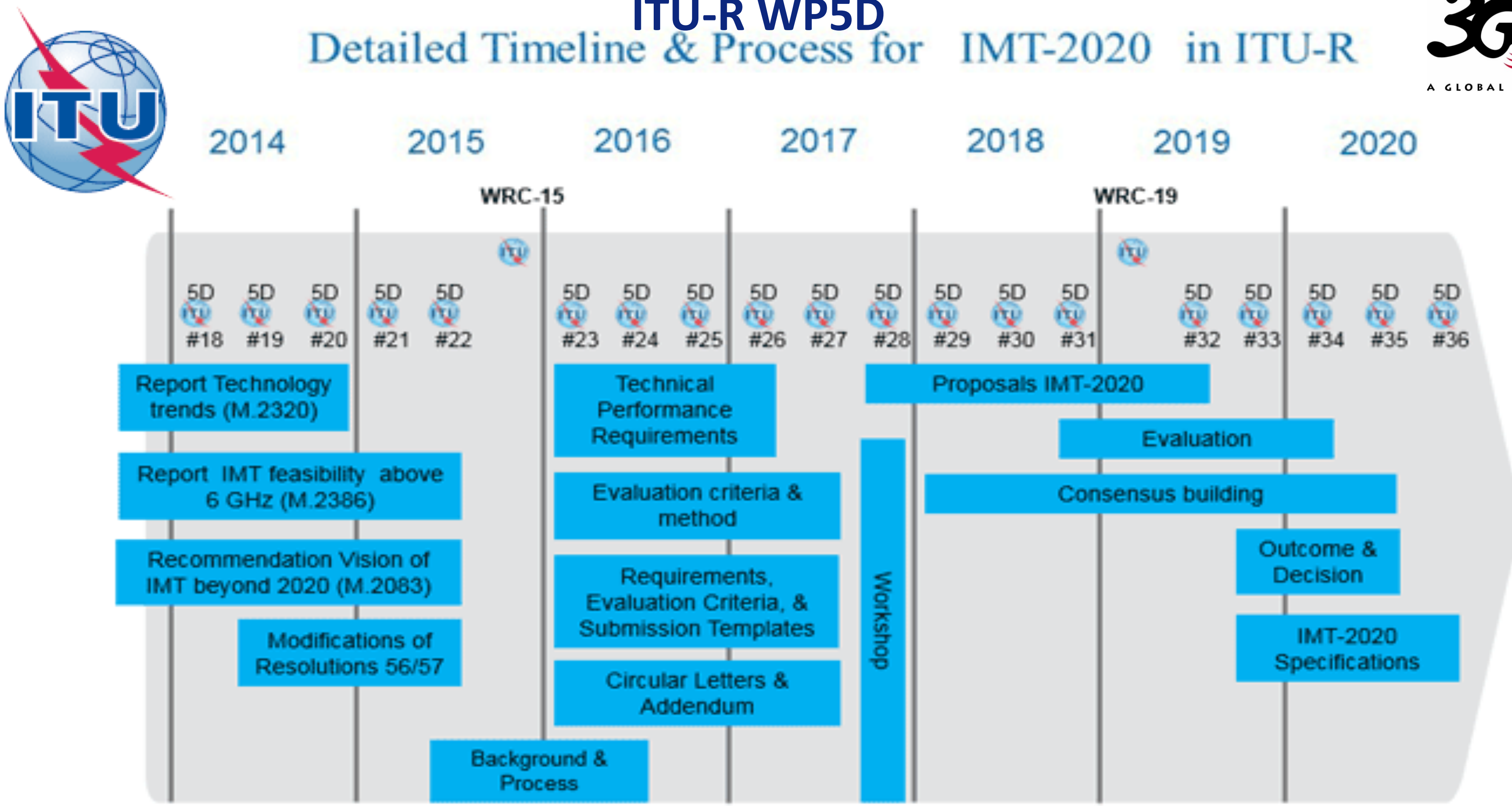
Access	EC-GSM
Frequency Band	Narrow Band
Range	~ 15 Km
Throughput	~ 10 Kbps



iv. 5G and IoT

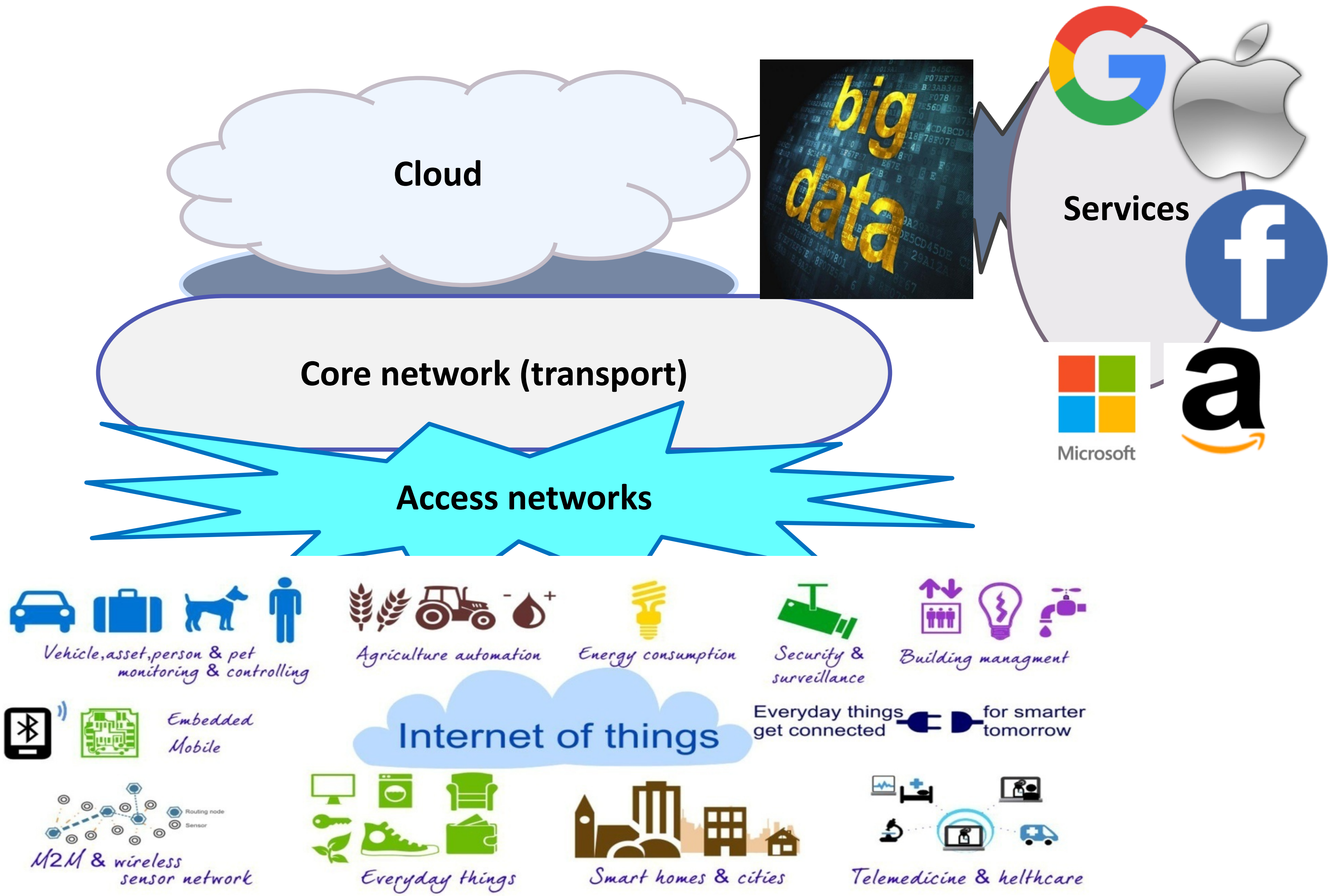
Roadmap

ITU-R WP5D



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

Vision of 5G


Cloud
big data
Services
Microsoft
Core network (transport)
Access networks
Vehicle,asset,person & pet
monitoring & controlling
Agriculture automation
Energy consumption
Security &
surveillance
Building managment
Embedded
Mobile
Internet of things
Everyday things
get connected
for smarter
tomorrow
Routing node
Sensor
M2M & wireless
sensor network
Everyday things
Smart homes & cities
Telemedicine & helthcare