Session 5: NB-IoT Networks

ITU Asia-Pacific Centre of Excellence Training
On
"Traffic engineering and advanced wireless network planning"

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Objectives

- Present the evolution of LTE towards LTE-M and NB-IoT for IoT services introduction

I. Introduction

II. LTE-M

III. NB-IoT

IV. State of Art

I. Introduction

LPWA could account 70% of Cellular IoT Connections in 2020

Market Segment	Connections in 2020 (Billion)	Requirements	Technology
• CCTV(Camera) • In-vehicle Entertainment…	**0.2B**	• >10Mbps	3G/4G
• IoT Gateway Backhaul • Wearable • …	**0.8B**	• ~1Mbps • Low power consumption	2G/3G/Cat-1 Cat-M1
• Sensors, Meters • Asset Tracking • Smart Parking • Smart agriculture …	**2B**	• Low Throughput (<100kbps) • Deep Coverage (20dB) • Low power (10 Years) • Low cost (<$5)	Short Range Tech. Sigfox, LoRa NB-IoT

LPWA: Low Power Wide Area

C-IoT provides wide WAN coverage

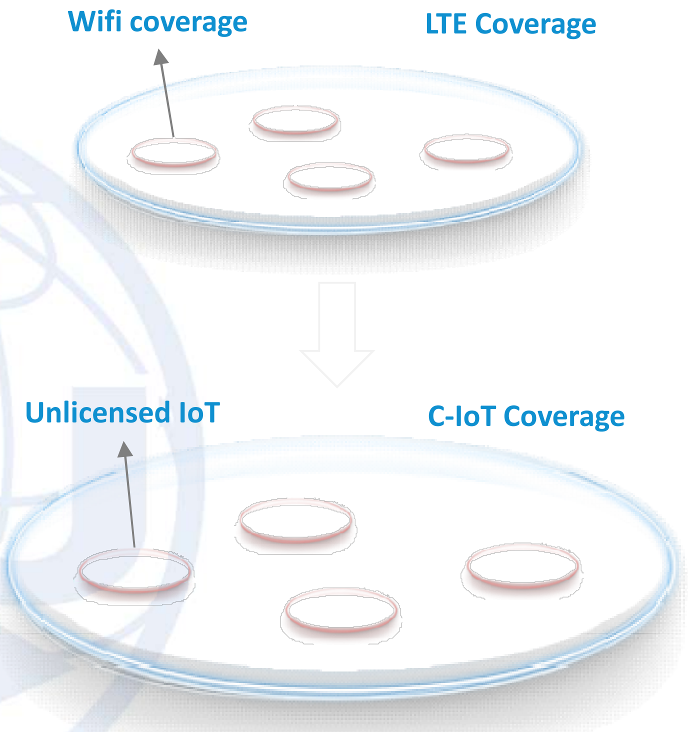
C-IoT

Re-use existing Cellular network

Carrier-grade Reliability

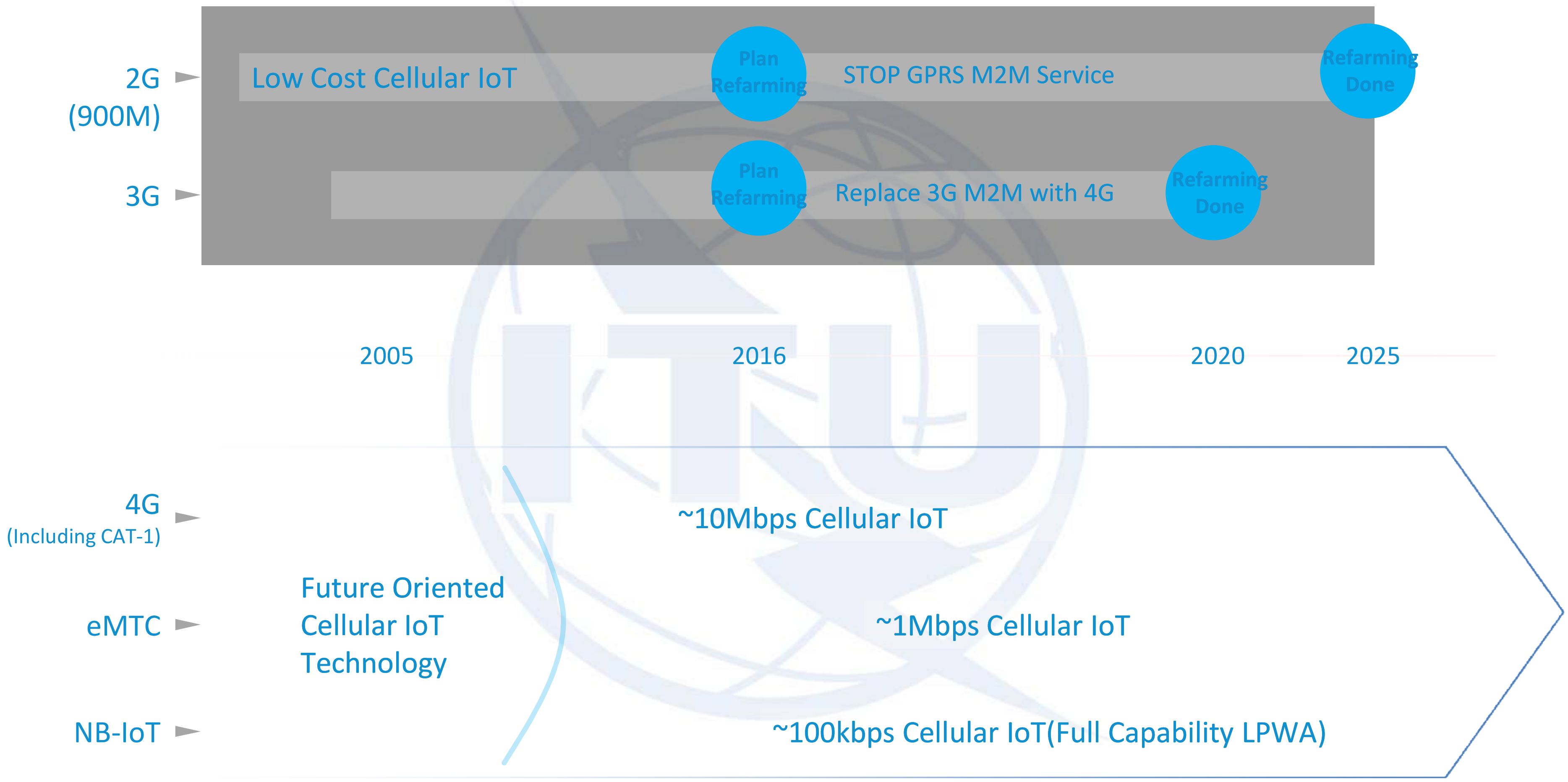
4G-Like Security

Roaming

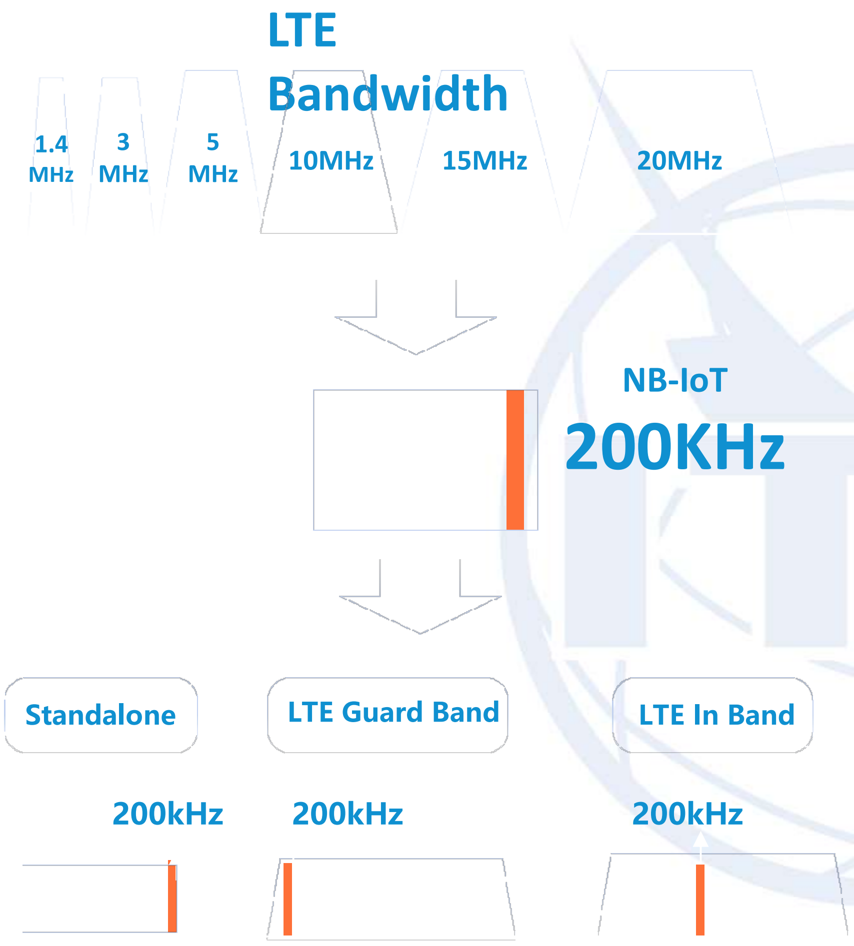


- Unlicensed technology is for local coverage
- C-IoT is for wide coverage

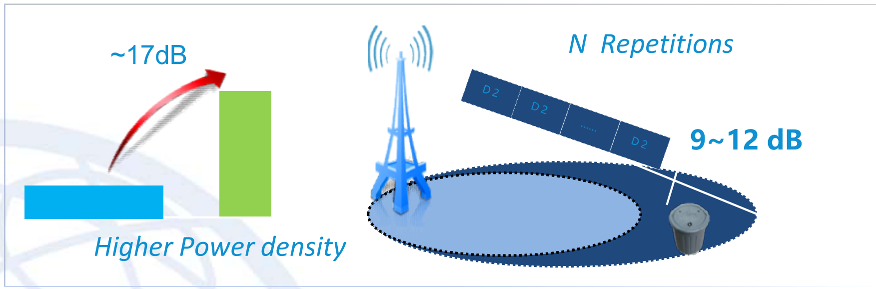
Future Oriented Cellular IoT Network: NB-IoT+eMTC+4G



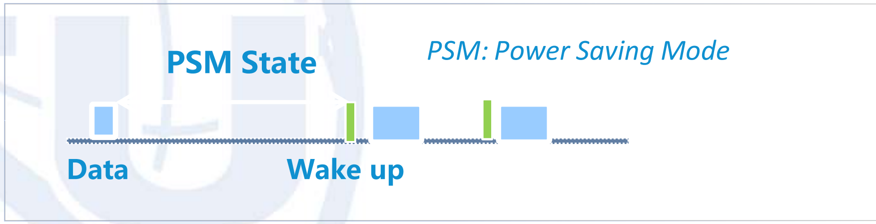
NB-IoT Network Performance



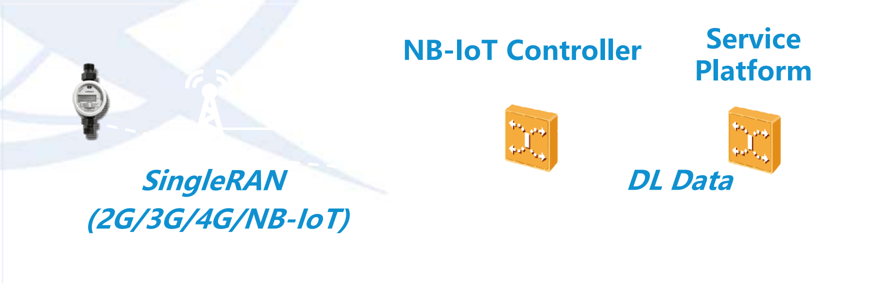
20+dB Gain Over 2G Coverage



10-year Battery Life



SingleRAN Based Network



NB-IoT/eMTC Standard's evolution path to 5G

NB-IoT

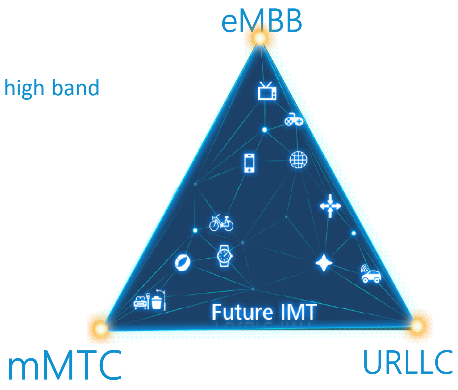
Rel-14	Rel-15
• Positioning：E-CID，OTDOA • SC-PTM • 14dBm output power • Peak throughput improvement (DL 114kbps/UL 142.5kbps)	• TDD NB-IoT • RRM measurement, latency improvement • **NPRACH enhancement** • **Differ group QoS**

eMTC

Rel-14	Rel-15
• Positioning：OTDOA • SC-PTM • VoLTE coverage improvement (5dB) • 5MHz/20MHz bandwidth (UL 3Mbps/7Mbps；DL 4Mbps/27Mbps)	• Capacity improvement: Sub-PRB eMTC (45KHz) • **64QAM** • Low UE output power

Technology:

NR、LTE to cover high band and low band



Technology:

NB-IoT,

- mMTC NR will not be considered until R17;
- NB-IoT will be used to cover 5G mMTC use case before R17

R14: Positioning to simplify device requirement

NB-IoT Tracking Technologies Overview:

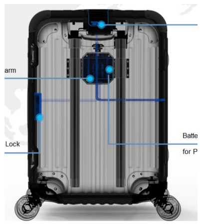
- Device cost: ~50USD
- Accuracy: 10m
- Latency:30s
- Power consumption:

0.3mAh/Report

- Device cost: ~40USD
- OTDOA: 30~50m
- Latency:10s
- Power consumption:

0.2mAh/Report

NB-IoT Tracker



BaaS Business Model:

Kids tracking (GizmoPal)

verizon

Monthly service fee: 5USD

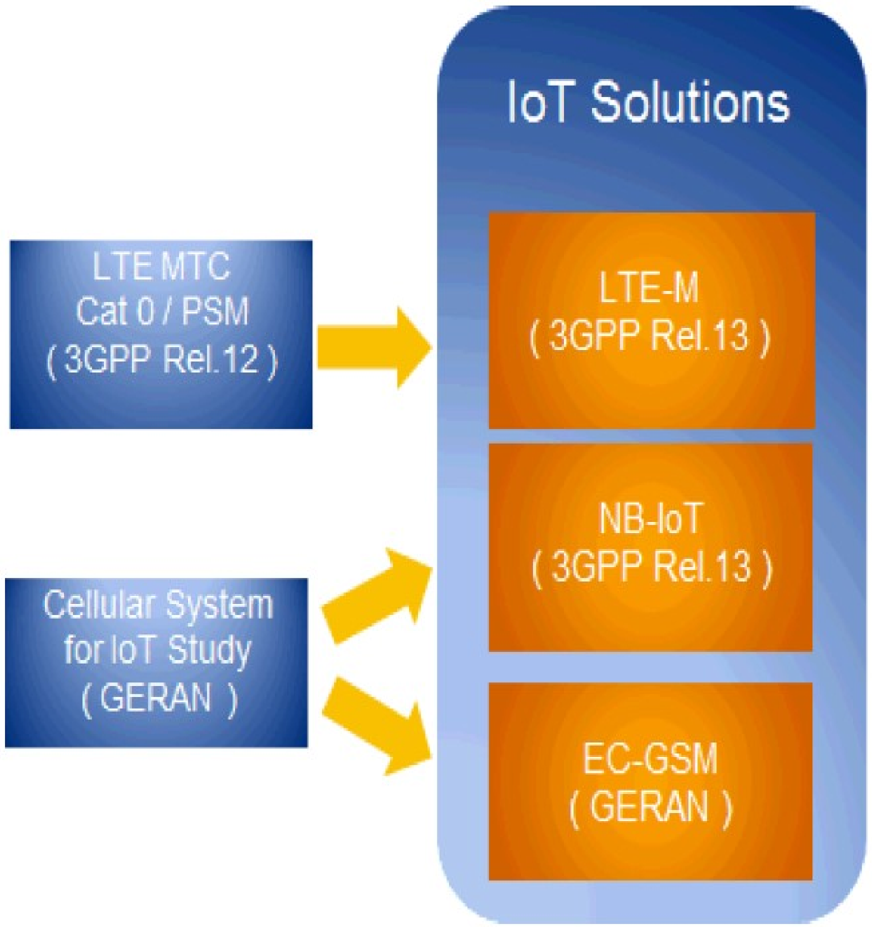
Kids tracking (Filip2 Tracker)

at&t

Monthly fee:

USD10 for voice and data

- **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 eMTC, NB-IoT and EC-GSM-IoT features

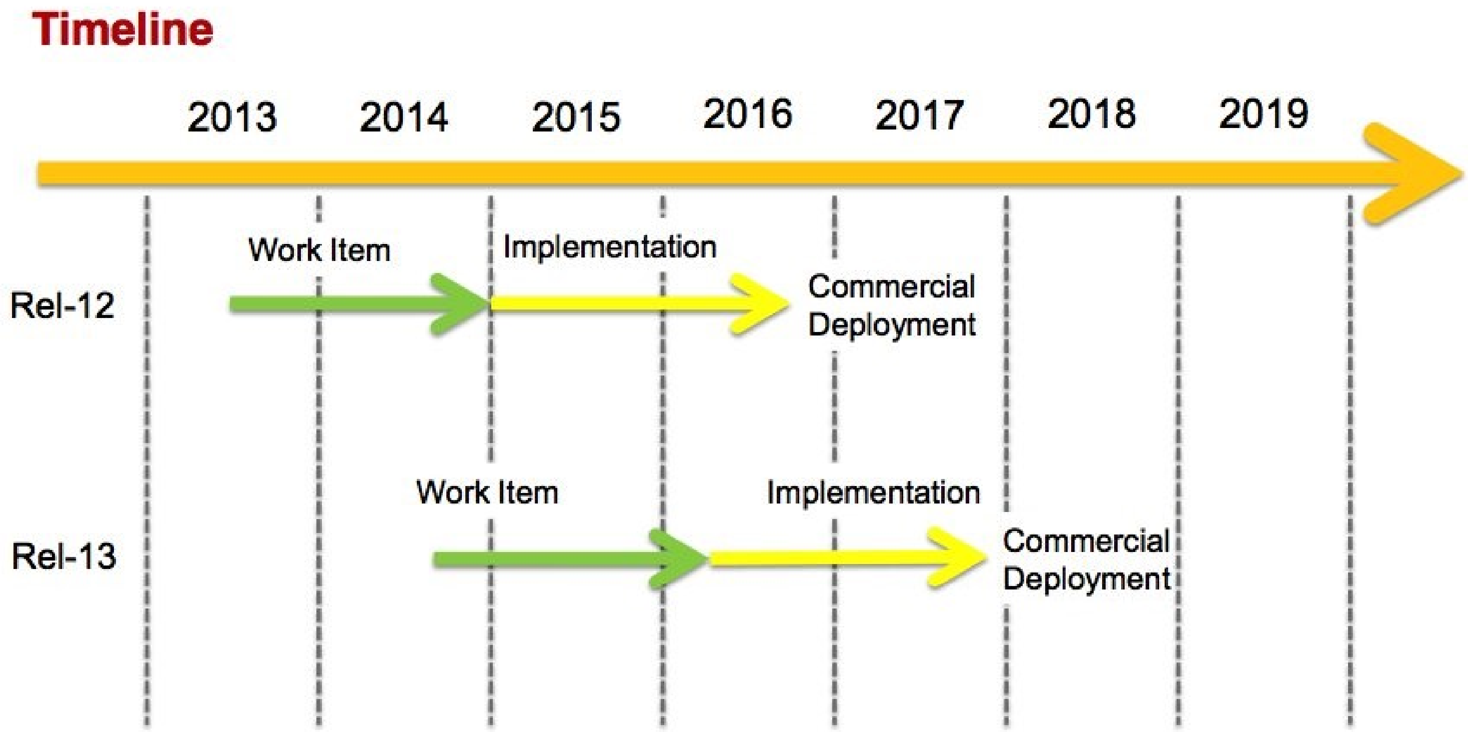
	eMTC (LTE Cat M1)	NB-IOT	EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone	In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others	164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone 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

II. 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**

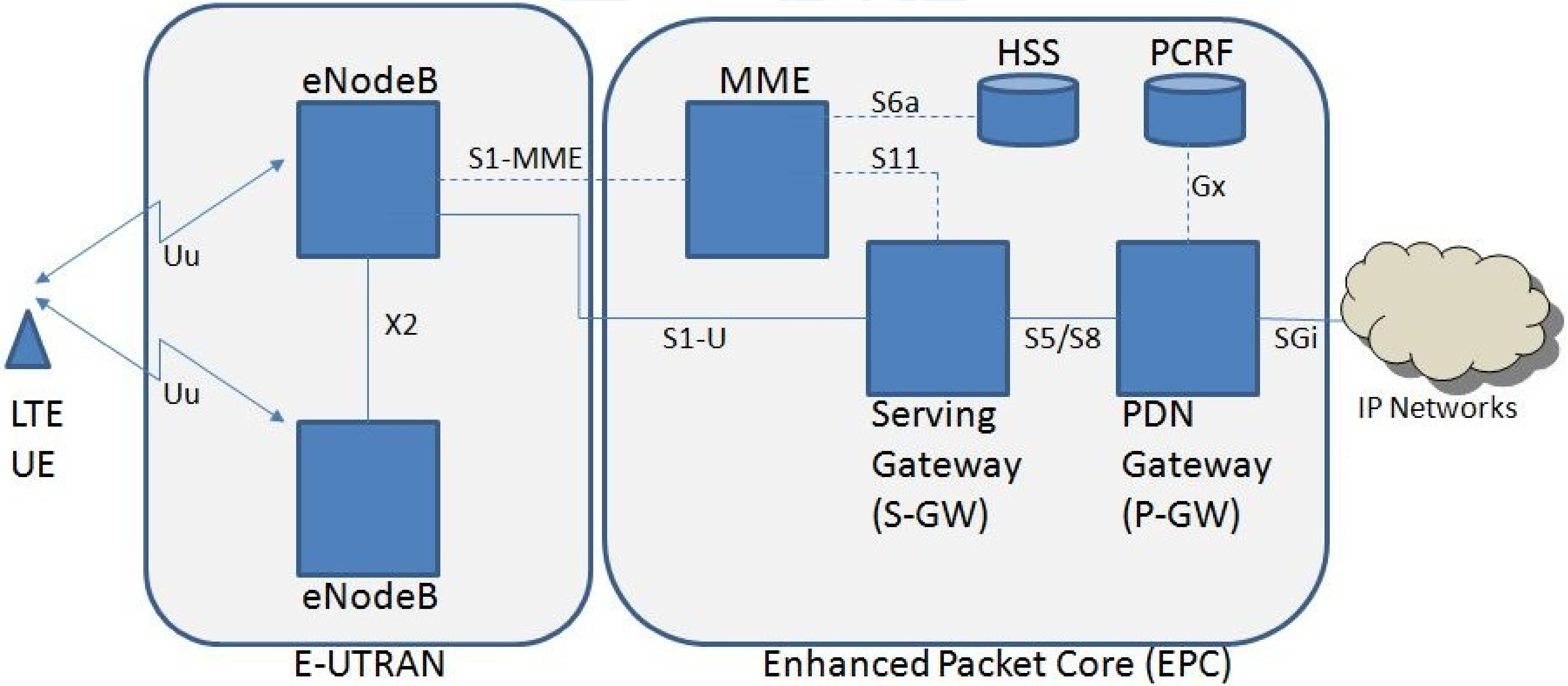
Release 12

- 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

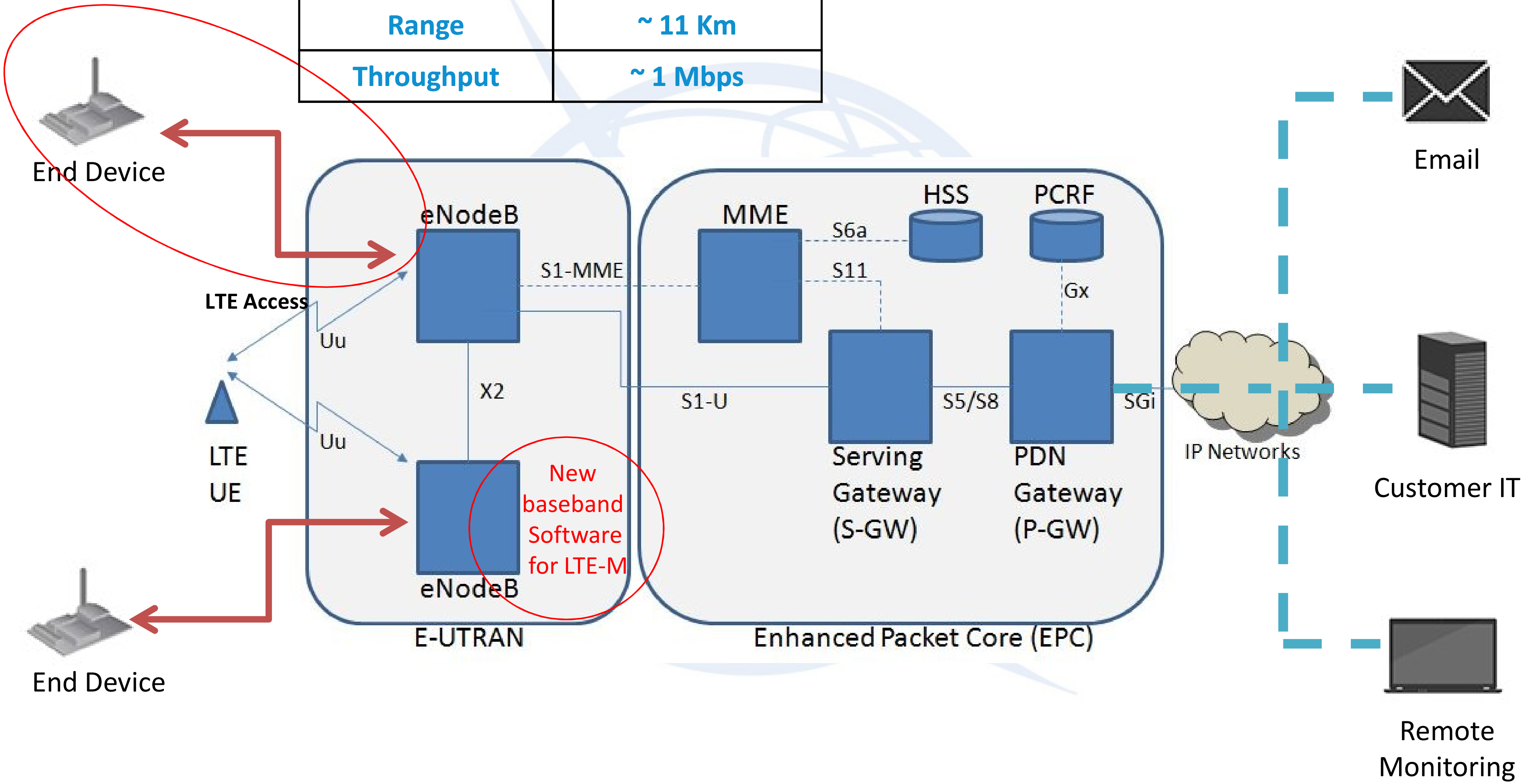
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

Present LTE Architecture

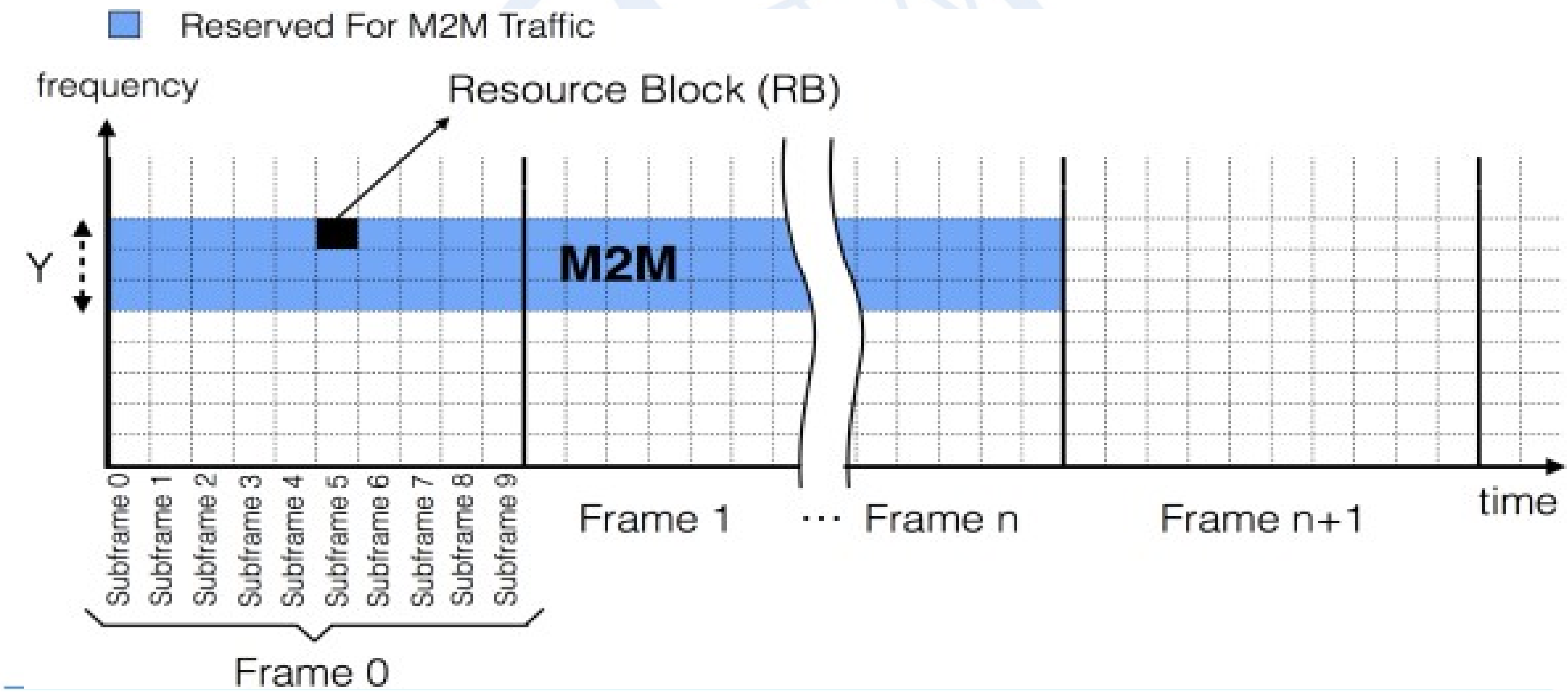


Architecture

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**



III. NB-IOT

Current status

April 2014	May 2014	March 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	1st live pre-standard NB-IoT message	Full NB-IoT 3GPP Standard Released	Commercial rollout

Evolution of LTE-M

Comparison with LTE-M

Attribute	CAT-1	LTE-M		NB-IOT	
		Rel 13	Rel 14	Rel 13	Rel 14
Spectrum	LTE bands	LTE bands Stand Alone (1.4MHz)		LTE Bands Stand Alone (200KHz)	
Typical MNO	LTE Coverage	Good LTE Coverage		Mix LTE and 2G	
Bandwidth	20 MHz	1.08MHz (CAT-M1)	5 MHz (CAT-M2)	180kHz	
Number of DL Antennas	2	1		1	
Duplex Modes	FD-FDD/TDD	HD-FDD, FD-FDD,TDD		HD-FDD	
UL Modulation	QPSK, 16QAM	QPSK, 16QAM		Pi/2 BPSK, Pi/4 QPSK	
DL Modulation	QPSK, 16QAM	QPSK, 16QAM		QPSK	
Spectral Efficiency	V.Good	Good		OK	
Power Class	Class 3 (23dBm)	Class 3 (23 dBm) Class 5 (20 dBm)		Class 3 and 5	* 14 dBm
UL Multple Access	LTE SC-FDMA	LTE SC-FDMA		LTE SC-FDMA + Single tone transmission with 3.75kHz and 15kHz bandwidths	

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.

NB-IoT is non backwards compatible version of LTE targeted for cellular based IoT applications.

Objectives

- Lower cost than eMTC
- Extended coverage: **164 dB maximum coupling loss** or link budget (at least for standalone) to be compared to GPRS link budget of 144dB and LTE of 142.7 dB
- Receiver sensitivity = -141 dBm
- Long battery life: 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- Support for massive number of devices: at least 50.000 per cell

Main simplification

- Reduced data rate/bandwidth, mobility support and further protocol optimizations

3 modes of operation:

- **Stand-alone:** stand-alone carrier, e.g. spectrum currently used by GERAN systems as a replacement of one or more GSM carriers
- **Guard band:** unused resource blocks within a LTE carrier's guard-band
- **In-band**: resource blocks within a normal LTE carrier

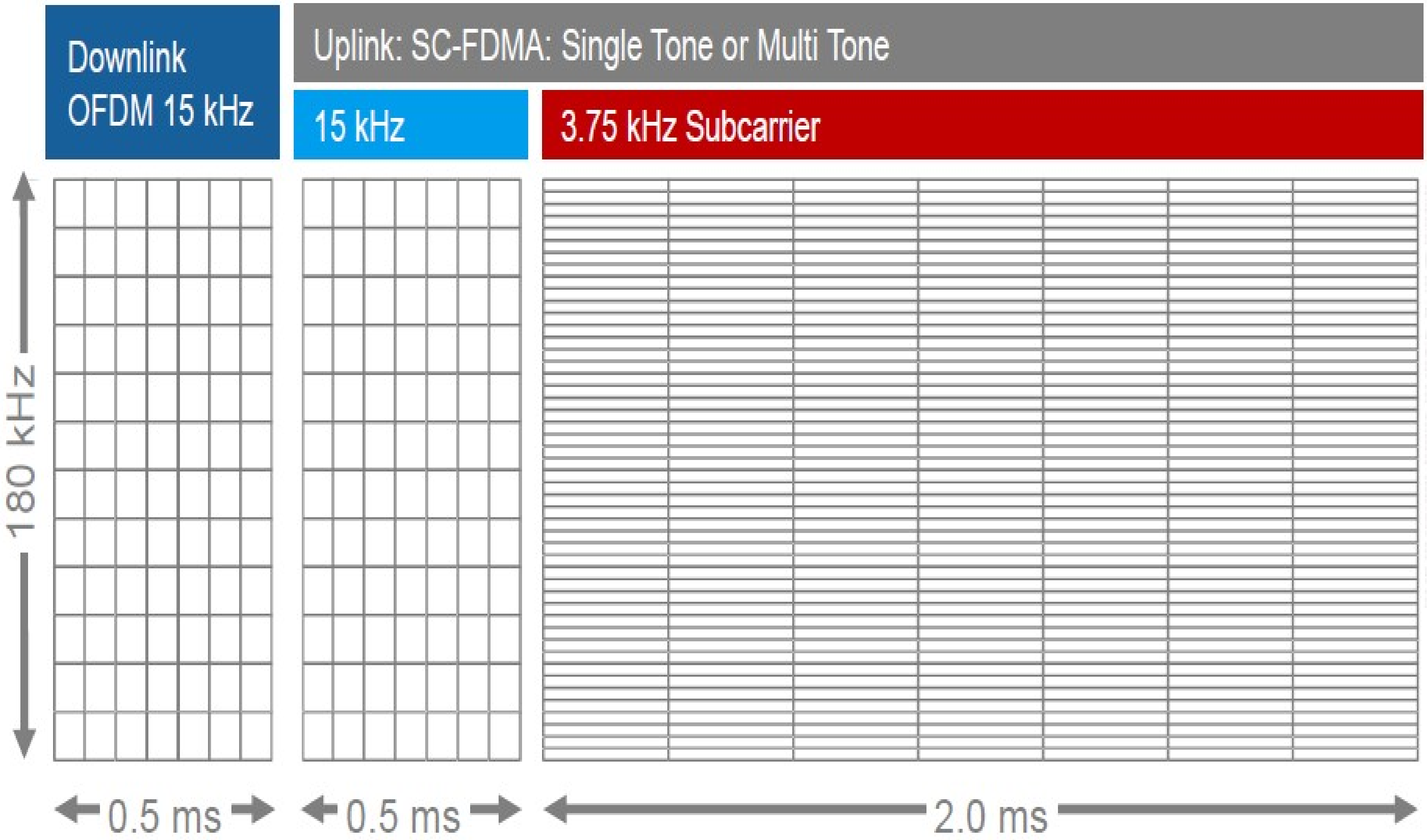
Main **PHY features**:

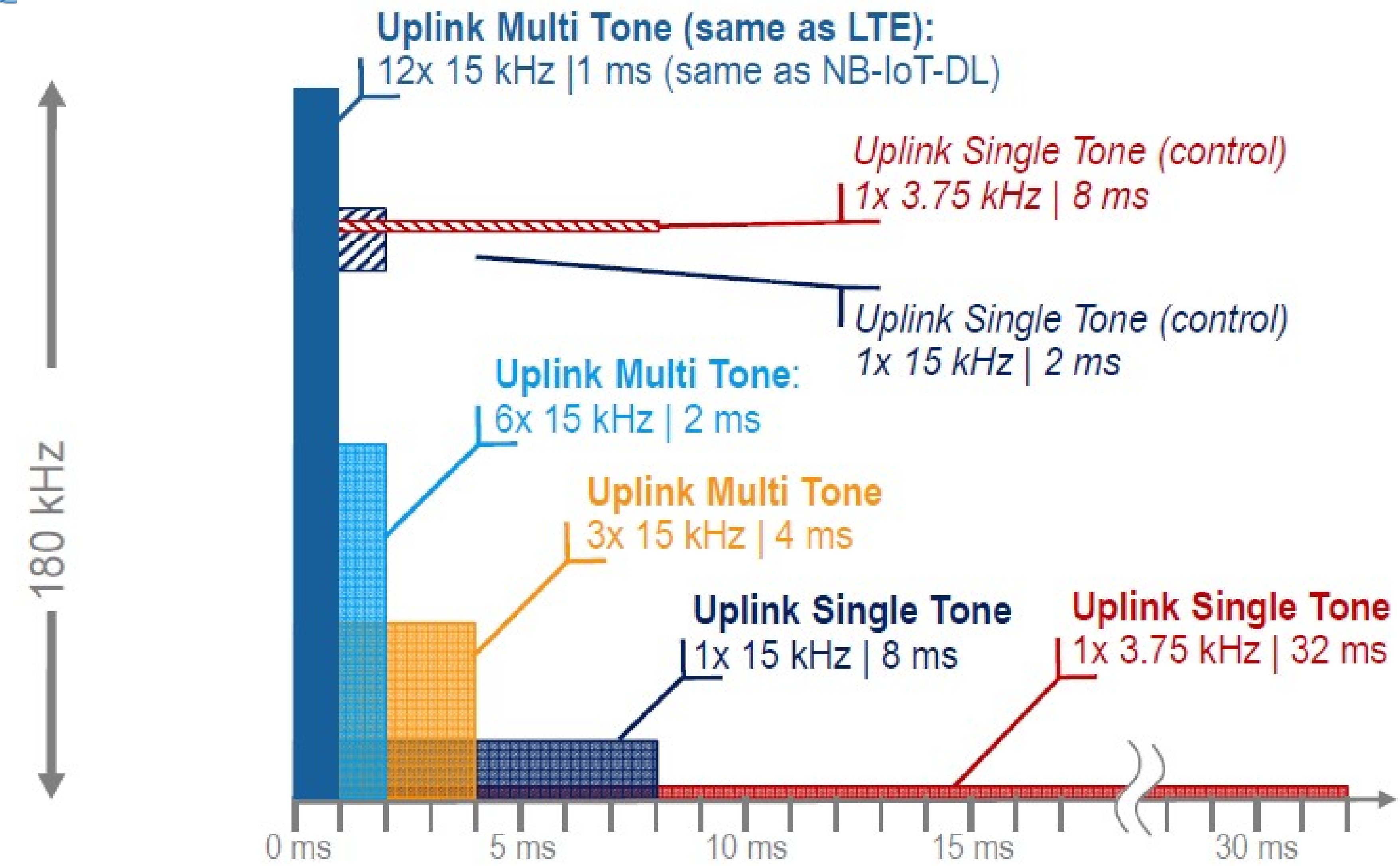
- Narrow band support of 180 kHz
- Supports **two modes** for uplink
  - ***Single tone*** with 15 kHz and/or 3.75 kHz tone spacing
  - ***Multiple tone*** transmissions with 15 kHz tone spacing
- No support of Turbo code for the downlink
- Single transmission mode of SFBC for PBCH, PDSCH, PDCCH
- New narrowband channels: NPSS, NSSS, NPBCH, NPDCCH, NPDSCH, NPUSCH, NPRACH

Main **radio protocol features**:

- Single HARQ process
- Only RLC AM mode with simplified status reporting
- Two PDCP options:
  - SRB 0 and 1 only. No AS security (NAS security is used instead). PDCP operating in TM.
  - SRB 0, 1, 2 and one DRB. AS security, which is cached upon RRC connection release. RRC connection suspend/resume procedures to maintain AS security context
- Reduced broadcast system information

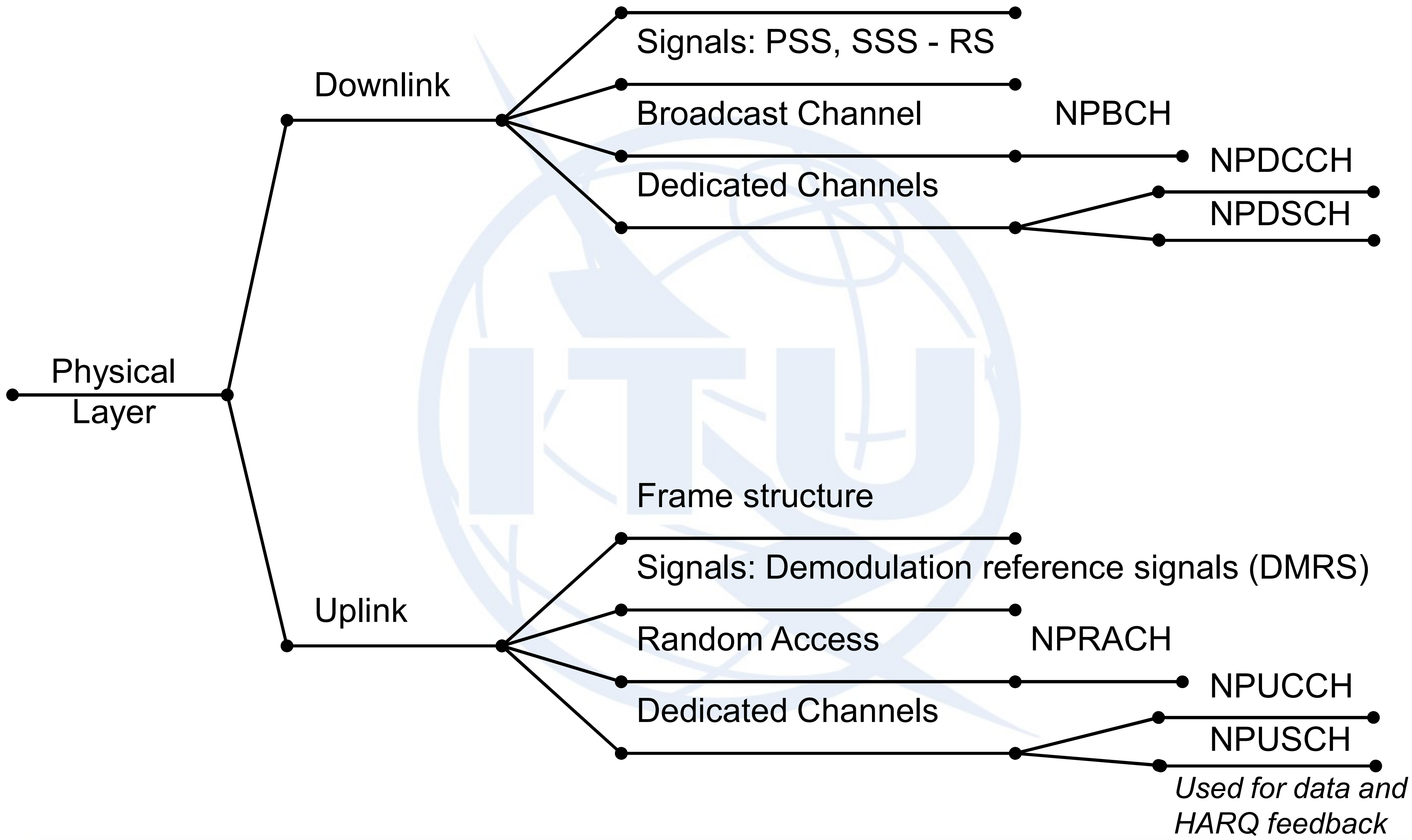
Frame and Slot Structure – NB-IoT – 7 symbols per slot



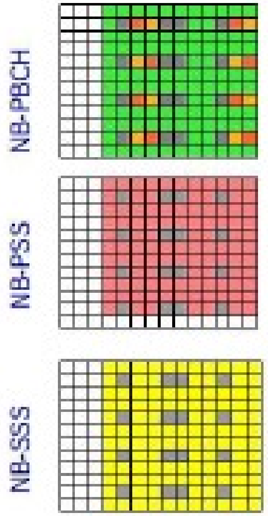

Uplink Multi Tone (same as LTE):
12x 15 kHz |1 ms (same as NB-IoT-DL)
Uplink Single Tone (control)
1x 3.75 kHz | 8 ms
Uplink Single Tone (control)
1x 15 kHz | 2 ms
Uplink Multi Tone:
6x 15 kHz | 2 ms
Uplink Multi Tone
3x 15 kHz | 4 ms
Uplink Single Tone
1x 15 kHz | 8 ms
Uplink Single Tone
1x 3.75 kHz | 32 ms
180 kHz
0 ms
5 ms
10 ms
15 ms
30 ms

NB-IoT Channels

Frame structure



Physical downlink channels



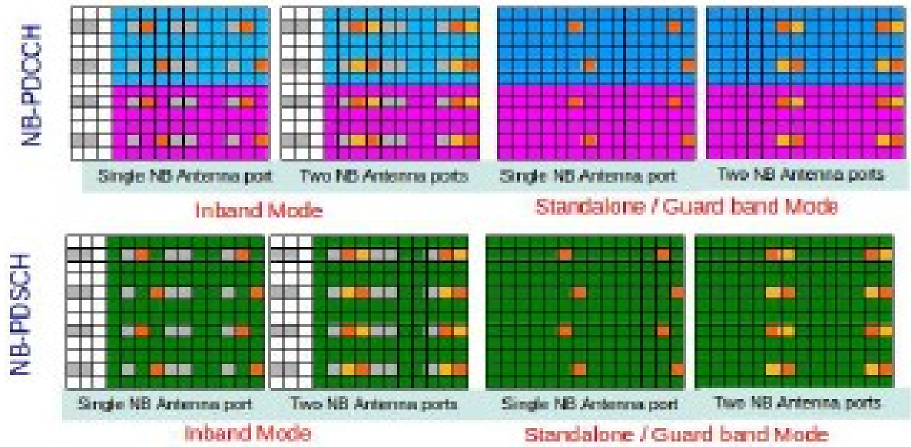
- NB-MIB (34-bit payload + 16 CRC bit) is channel-coded and rate-matched into 1600 bits.
- Transmitted on Subframe 0
- One subframe carries 200 bits which are repeated on 8 consecutive radio frames. One block is made up of 8 radio frames. Each subframe is independently decodable
- 8 blocks (64 frames)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

- 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**

Smallest unit to map a transport block: *resource unit (RU).*

NPUSCH format 1

- 3.75 kHz subcarrier spacing, an RU = 1 subcarrier in the frequency range, and 16 slots in the time range (length of 32 ms).
- 15 kHz subcarrier spacing 4 options:

Number of subcarriers	Number of slots	RU Duration
1	16	8 ms
3	8	4 ms
6	4	2 ms
12	2	1 ms

- RUs with one subcarrier, *BPSK* or *QPSK*,
- Other RUs: *QPSK*.

NPUSCH format 2

RU always composed of one subcarrier with a length of 4 slots.

- 3.75 kHz subcarrier spacing the RU has an 8 ms duration,
- 15 kHz subcarrier spacing has an 2 ms duration.

Modulation scheme: *BPSK*.

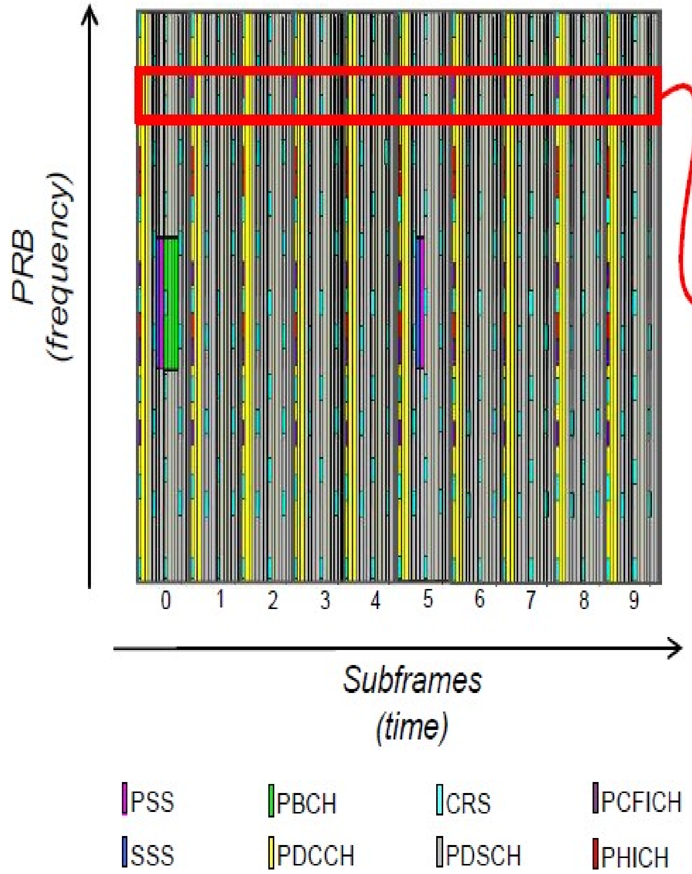
UCI: *Uplink Control Information*

Physical channel	Transport channel	Number of carri-ers	Modulation scheme	Channel coding
NPUSCH format 1	UL-SCH	1 (single-tone)	π/2-BPSK π/4-QPSK	Turbo 1/3
		> 1 (multitone)	QPSK	
NPUSCH format 2	UCI	1 (single-tone)	π/2-BPSK	Block 1/16

Downlink Frame Structure

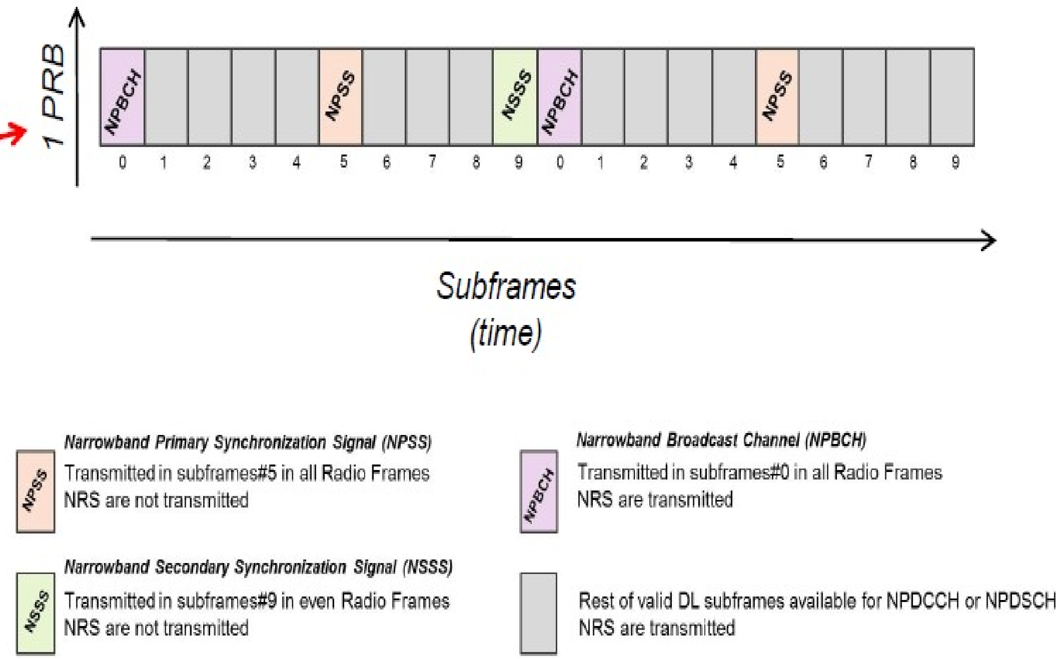
LTE

Channels are time and frequency multiplexed;
Multiple channels per subframe



NB-IoT

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



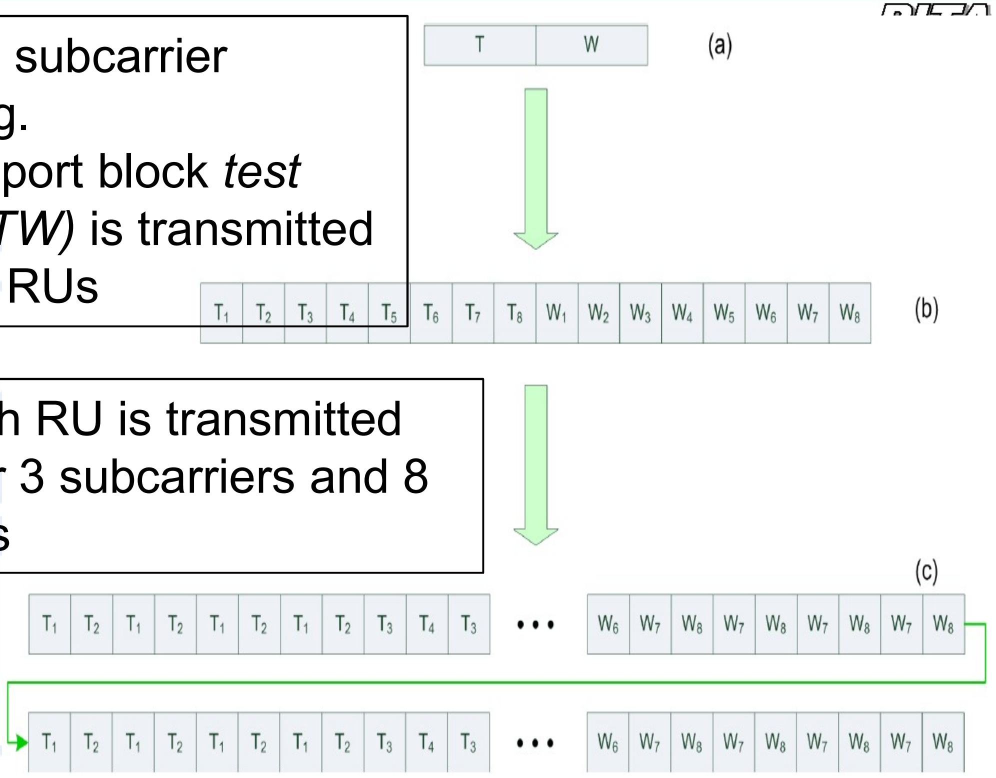
NB-IoT Repetitions

Consists on repeating the same transmission several times:

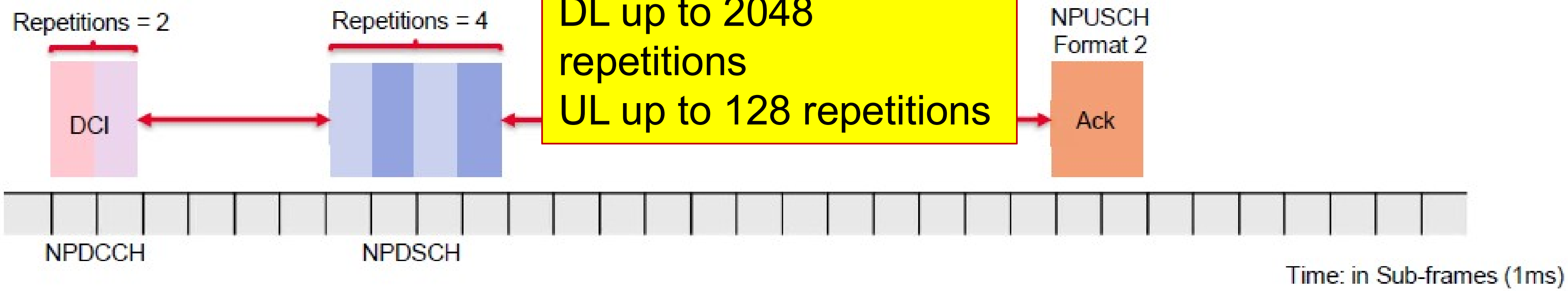
- Achieve extra coverage (up to 20 dB compared to GPRS)
- Each repetition is self-decodable
- SC is changed for each transmission to help combination
- Repetitions are ACK-ed just once
- All channels can use Repetitions to extend coverage

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

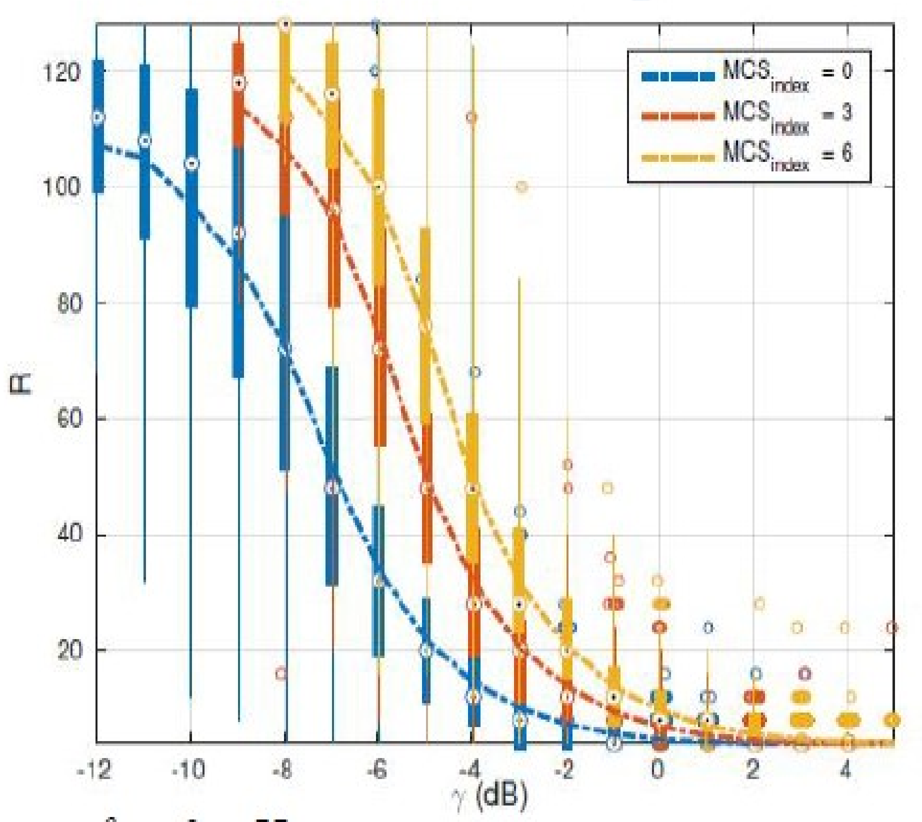
Each RU is transmitted over 3 subcarriers and 8 slots



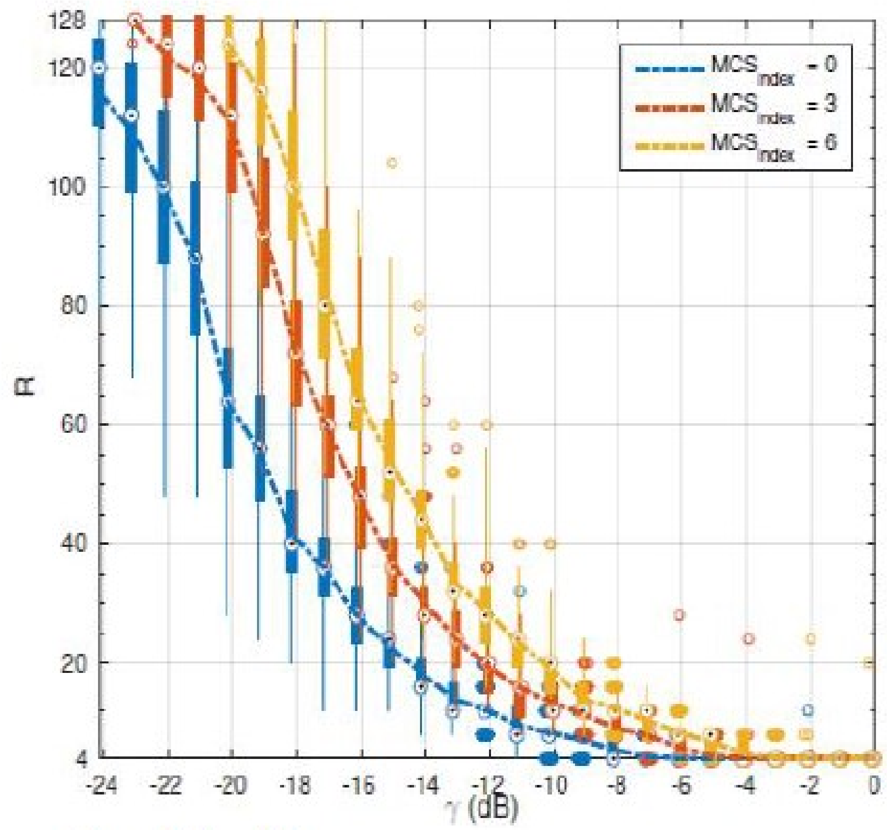
DL up to 2048 repetitions
UL up to 128 repetitions



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



$f_D = 0 \quad Hz$



$f_D = 80 \quad Hz$

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

NDSCH peak data rate achieved with the largest TBS of 680 bits transmitted over 3 ms.

➯ ***226.7 kb/s peak layer 1 data rate (multitone configuration)***.

NPUSCH peak data rate achieved with the largest TBS of 1000 bits transmitted over 4 ms.

➯ ***250 kb/s peak layer 1 data rate (multitone configuration) and 20 kb/s (single tone configuration)***.

Peak throughputs of both DL and UL are lower than these figures when the time offsets between DCI, NPDSCH/NPUSCH, and HARQ acknowledgment are taken into account.

Coverage

- **Maximum coupling loss** 20 dB higher than LTE Rel-12.
- **Coverage extension** is achieved by trading off data rate through ***increasing the number of repetitions***.
- **Coverage enhancement** is also ensured by introducing ***single subcarrier NPUSCH transmission and π/2-BPSK modulation*** to maintain close to 0 dB PAPR ➲ Reduces the coverage potential issues due to power amplifier backoff.
- **NPUSCH** with 15 kHz single-tone gives a layer 1 data rate of approximately **20 b/s** when the highest repetition factor (i.e., 128) and the most robust MCS are applied,
- **NPDSCH** gives a layer 1 data rate of **35 b/s** with a repetition factor 512 and the most robust MCS.
- These configurations support close to **170 dB coupling loss** (compared to Rel-12 LTE designed for up to approximately 142 dB coupling loss).

Link Budget	15kHz	3.75 kHz
(a) Transmit power (dBm)	23	23
(b) Thermal noise (dBm/Hz)	-174	-174
(c) Receiver noise figure (dB)	3	3
(d) Occupied channel bandwidth (Hz)	15 000	3 750
(f) Effective noise power (b)+(c)+10log_10(d) (dBm)		
(g) Required SINR (dB)	-11.8	-5.7
(h) Receiver sensitivity (c)+(g) (dBm)	-141	-141
(i) Maximum coupling loss (a)-(h)	164	164

23 dB improvement over LTE
Urban: Deep in-building penetration
Rural: Long rage (10 – 15 km)

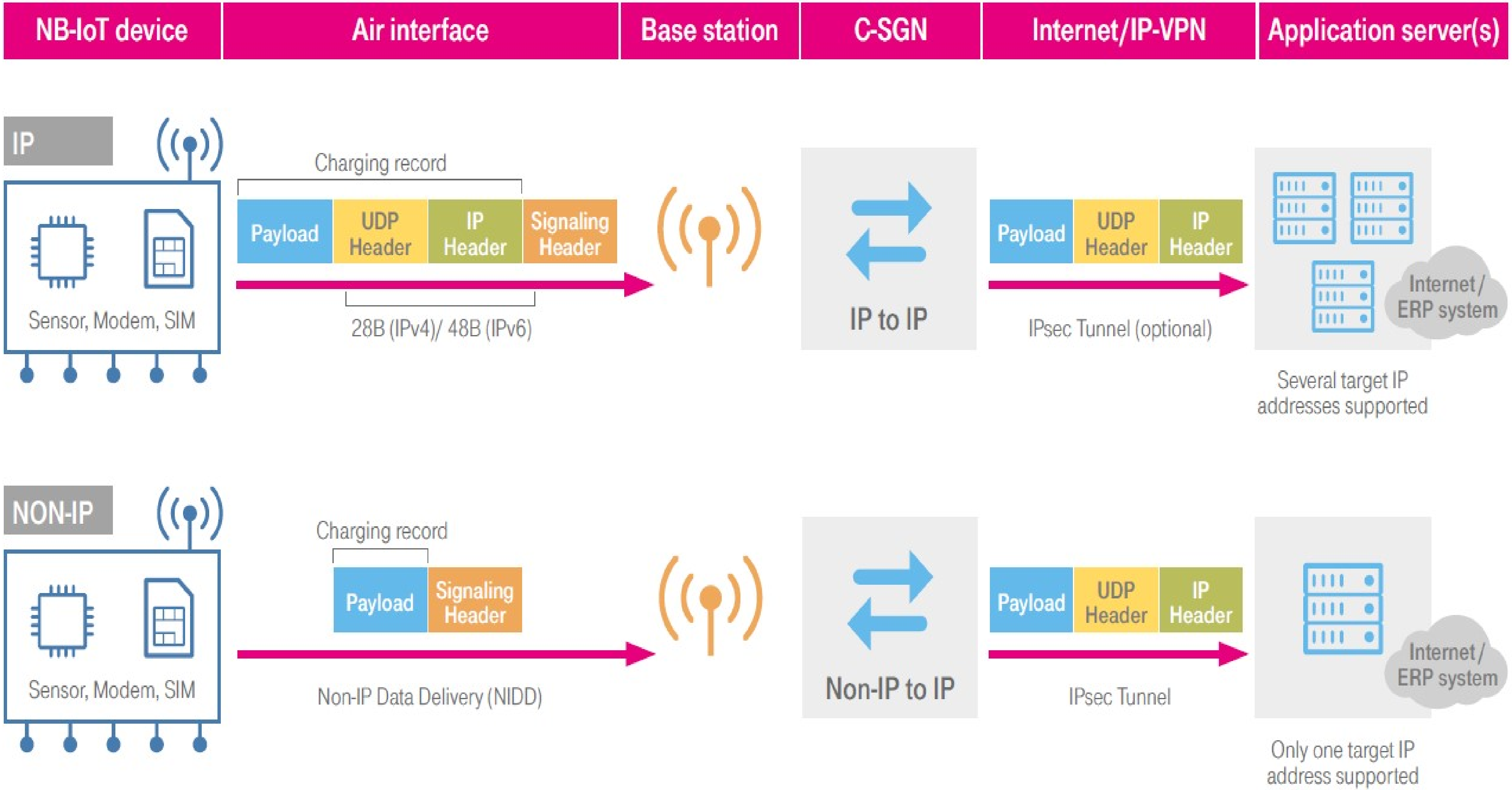
Data transmission options

2 possibilities for data transmission between NB-IoT devices and the AS:

1. **IP**: Depending on the capabilities of the radio module and the operator, *IPv4* and *IPv6* are supported. UDP is the common and recommended transport protocol. On the air interface, TCP is in supported for NB-IoT (and specified in the 3GPP standard), but not recommended due to the resulting higher data volume. HTTP and HTTPS over the air interface cannot be implemented, because they rely on TCP and require additional data volume for their overhead.
2. **Non-IP**: If possible, a non-IP based data transmission is recommended for NB-IoT because it reduces the transmitted data volume. The is forwarded by the network to the application via IP. Data can only be sent to one target IP address (server).

Application protocols like MQTT, MQTT-SN, COAP and oneM2M can be used.

Data transmission options



NB-IoT bands

Supporting bands: Band 1, 3, 5, 8, 12, 13, 17, 19, 20, 26, 28

NB-IOT Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	HD-FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	HD-FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	HD-FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	HD-FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	HD-FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	HD-FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	HD-FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	HD-FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	HD-FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	HD-FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	HD-FDD

- NB-IoT supports massive IoT capacity with **only one PRB in both UL and DL**.
- NB-IoT can support multiple carrier operation to get more IoT capacity.
- Sub-PRB UE scheduled bandwidth is introduced in the uplink, including single-subcarrier NPUSCH.
- Based on a traffic model with a split of devices is:
  - 80%: MAR (Mobile Autonomous Reporting) periodic
  - 20%: Network Command is MAR periodic.

➲ NB-IoT with one PRB supports more than 52,500 UEs per cell.

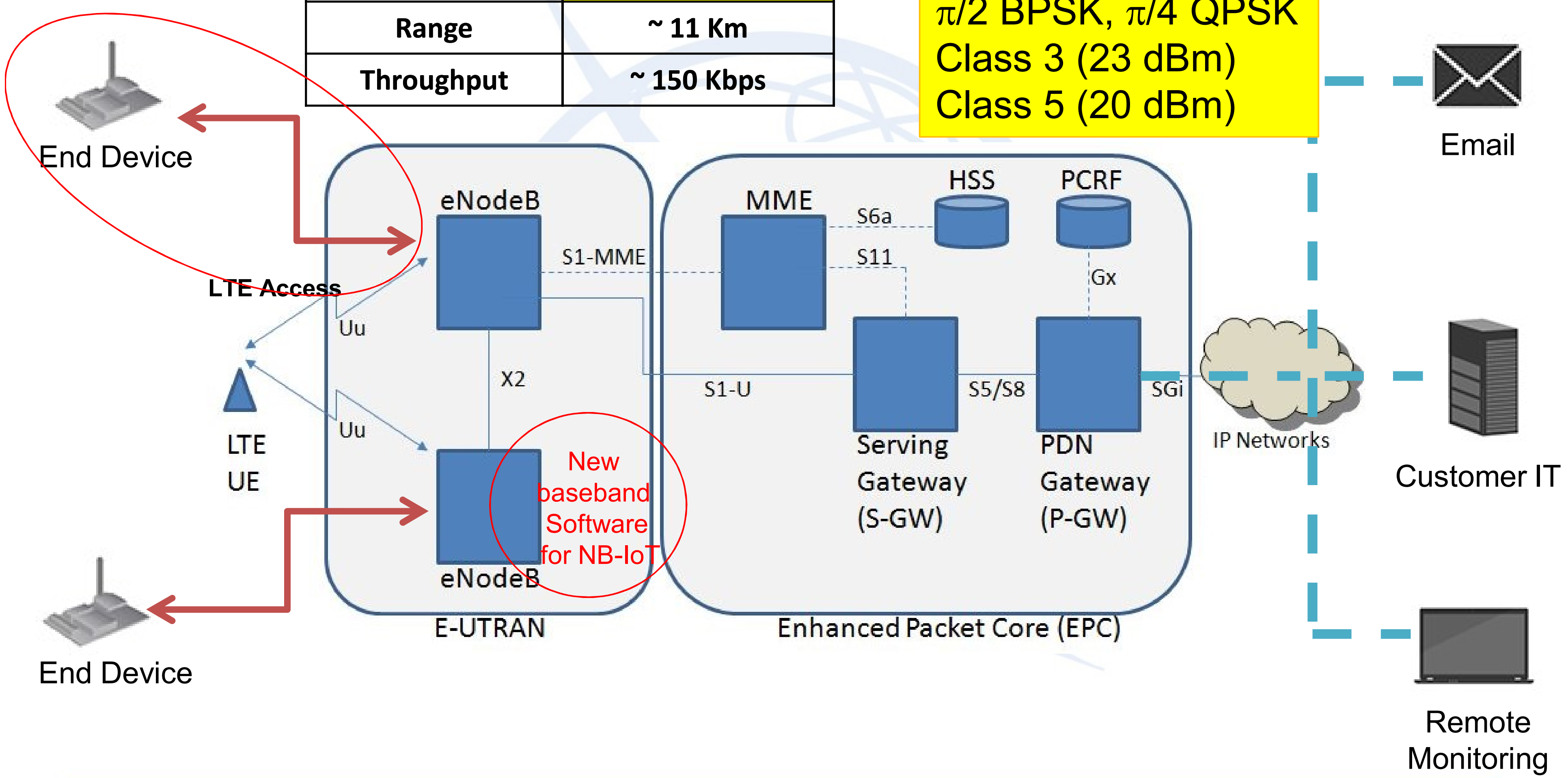
Extended C-DRX and I-DRX operation

- 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

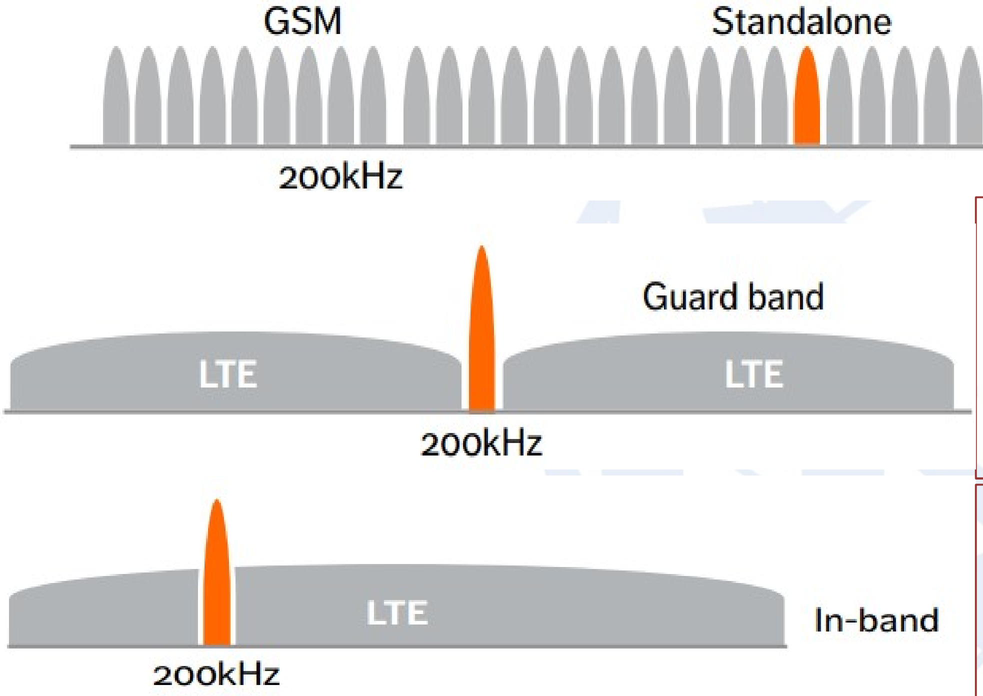
Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps

HD-FDD
π/2 BPSK, π/4 QPSK
Class 3 (23 dBm)
Class 5 (20 dBm)



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.

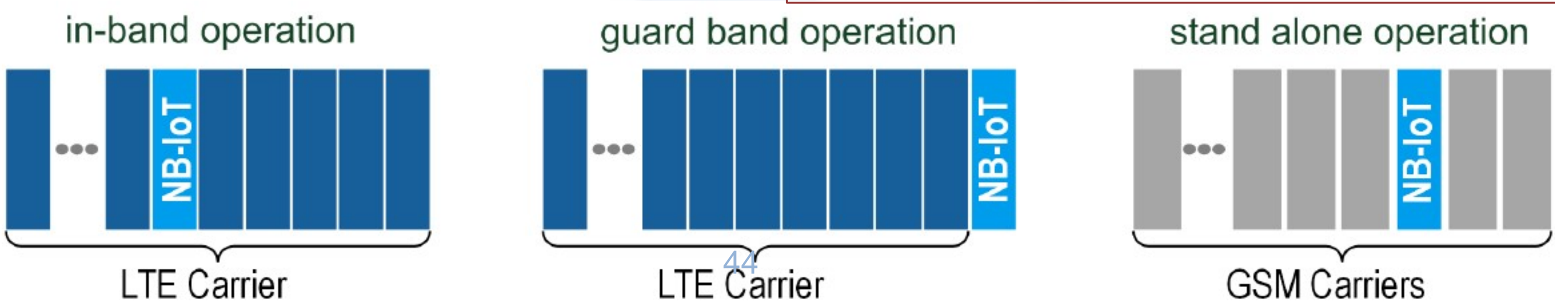
Ex.: By **re-farming GSM channels**

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**

IV. State of Art

A. Regulation

Frequency bands of SRDs

Global
Only in Europe
Only in Americas

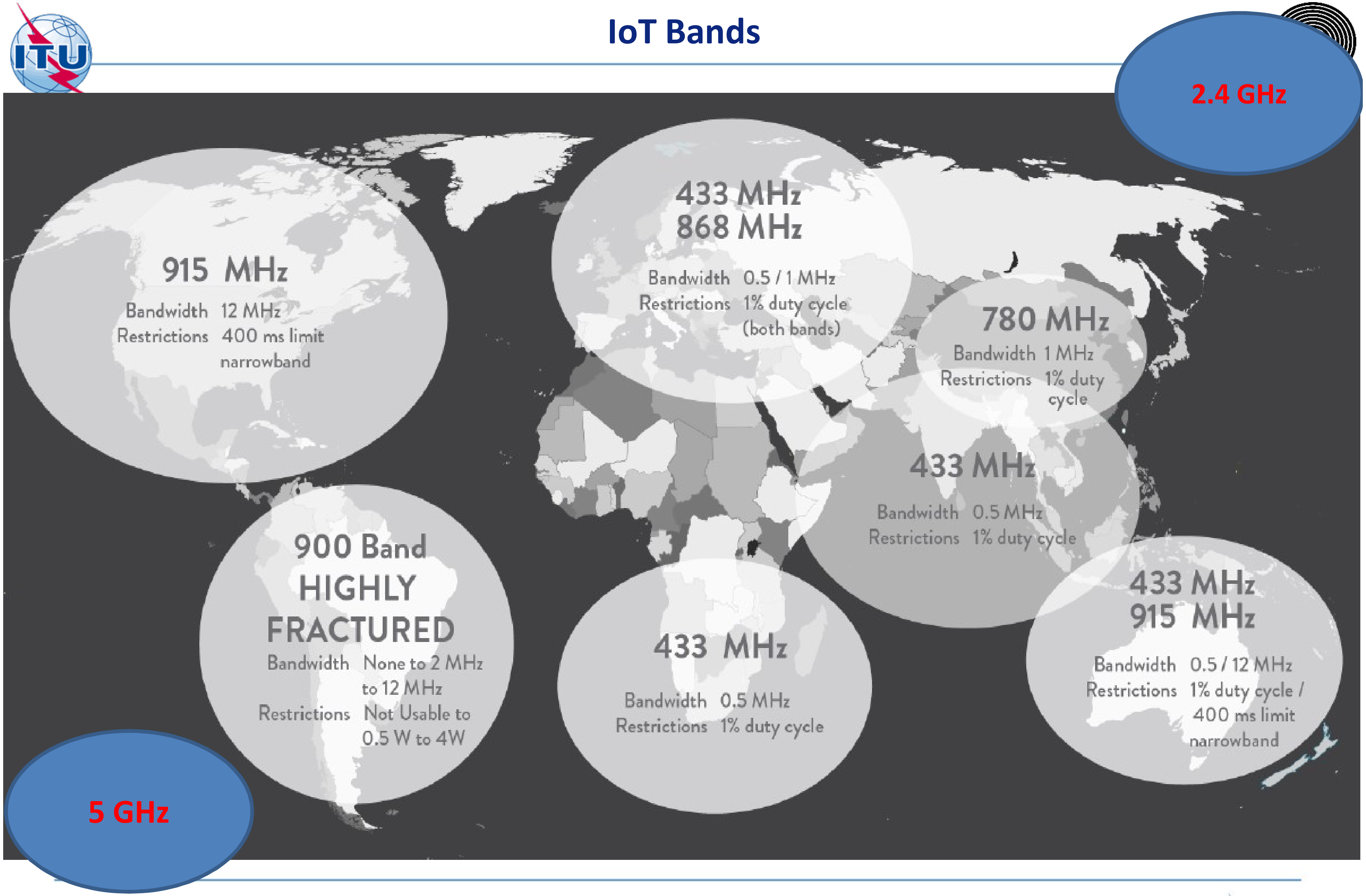
ISM bands

6,780 kHz; 13,560 kHz
27,120 kHz; 40.68 MHz
433.92 MHz
915 MHz
2,450 MHz; 5,800 MHz
24.125 GHz; 61.25 GHz
122.5 GHz; 245 GHz

9-148.5 kHz; 3,155-3,400 kHz
9 kHz- 47 MHz (specific SRDs)
7,400-8,800 kHz
138.20-138.45 MHz
169.4-216 MHz
312-315MHz (non Europe)
402-405 MHz medical devices
470-489 MHz (normally individually licensed)
823-832 MHz and 1,785-1,805 MHz
862-875 MHz in some Asian counties
862-876MHz Non-Specific SRDs
915-921 MHz (in some countries)
5,150-5,350 & 5,470-5,725 MHz
57-64GHz, 76-77GHz, 77-81GHz

non-ISM candidate bands for SRDs

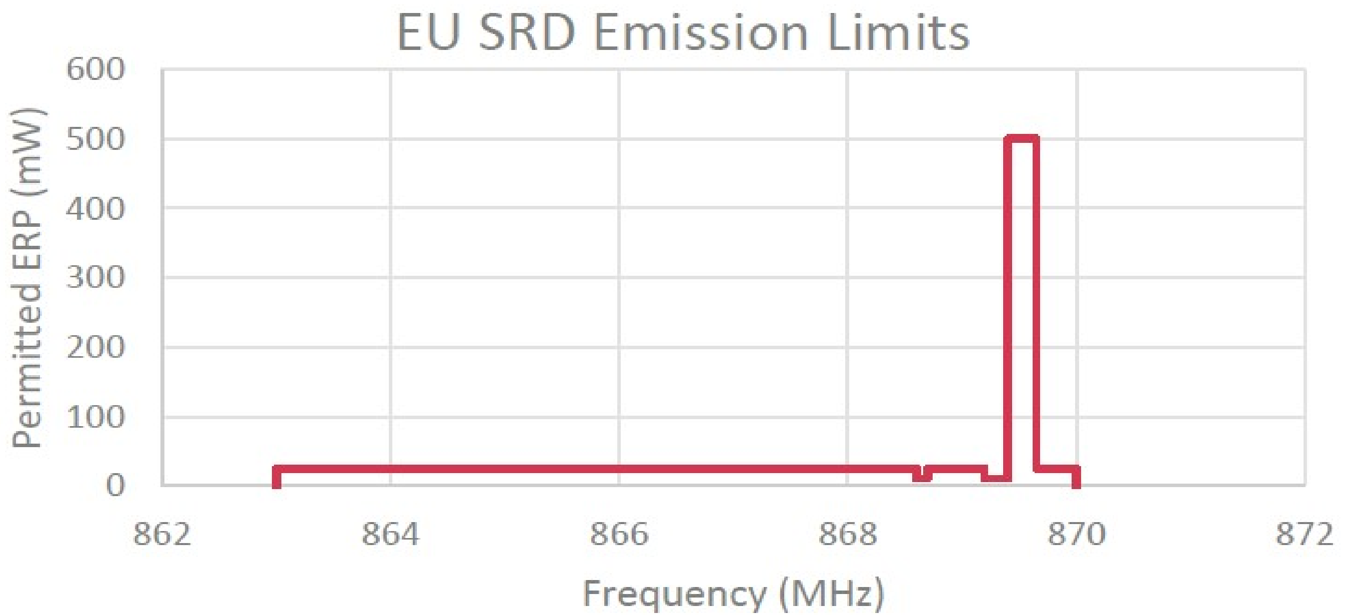
IoT Bands



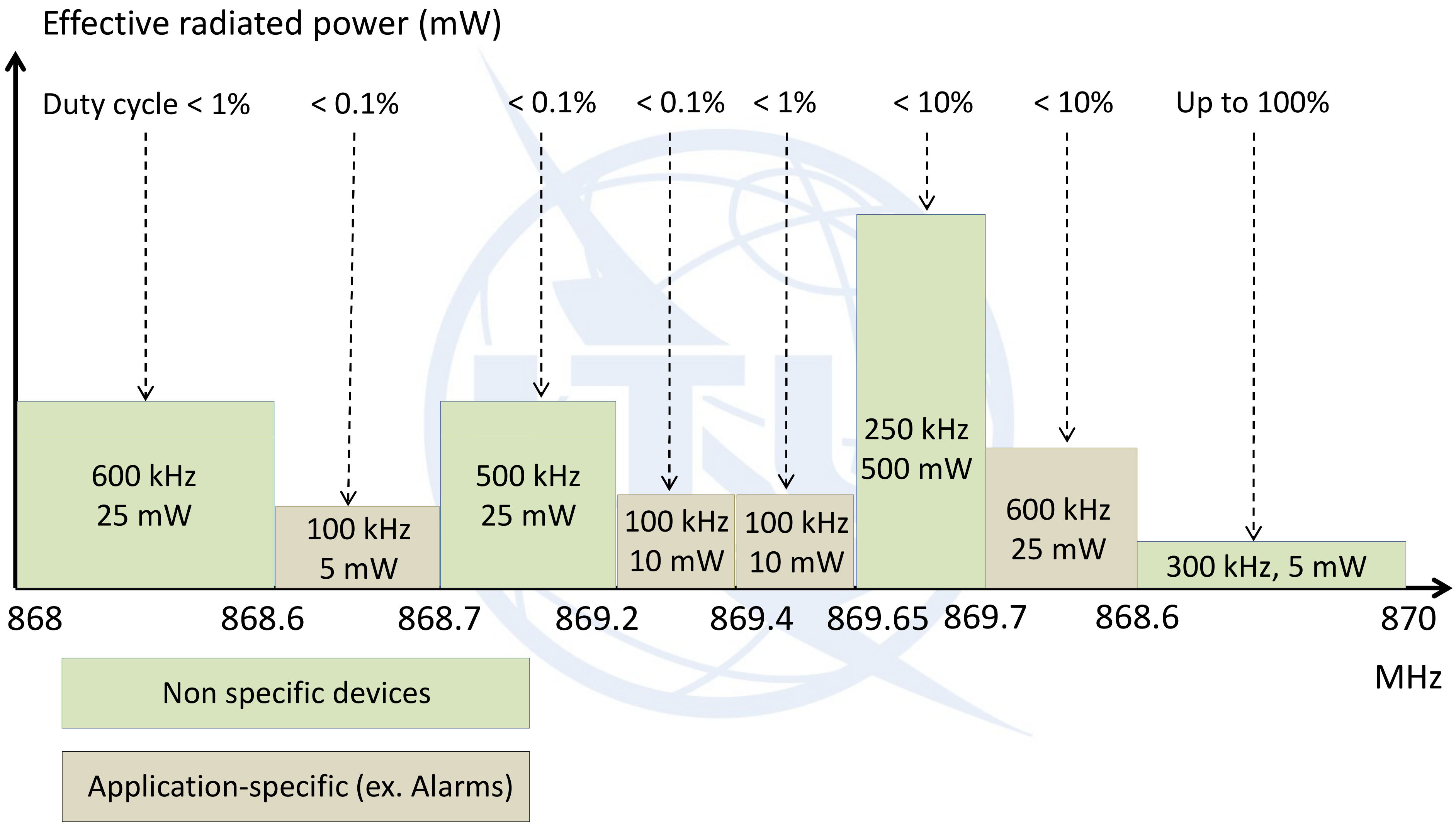
2.4 GHz
915 MHz
Bandwidth 12 MHz
Restrictions 400 ms limit narrowband
433 MHz
868 MHz
Bandwidth 0.5 / 1 MHz
Restrictions 1% duty cycle (both bands)
780 MHz
Bandwidth 1 MHz
Restrictions 1% duty cycle
433 MHz
Bandwidth 0.5 MHz
Restrictions 1% duty cycle
900 Band
HIGHLY
FRACTURED
Bandwidth None to 2 MHz to 12 MHz
Restrictions Not Usable to 0.5 W to 4W
433 MHz
Bandwidth 0.5 MHz
Restrictions 1% duty cycle
433 MHz
915 MHz
Bandwidth 0.5 / 12 MHz
Restrictions 1% duty cycle / 400 ms limit narrowband
5 GHz

Link	Activity rate	Power
DL	10%	25 mW
UL	1%	500 mW

Arcep France



ISM 868MHz Band Plan



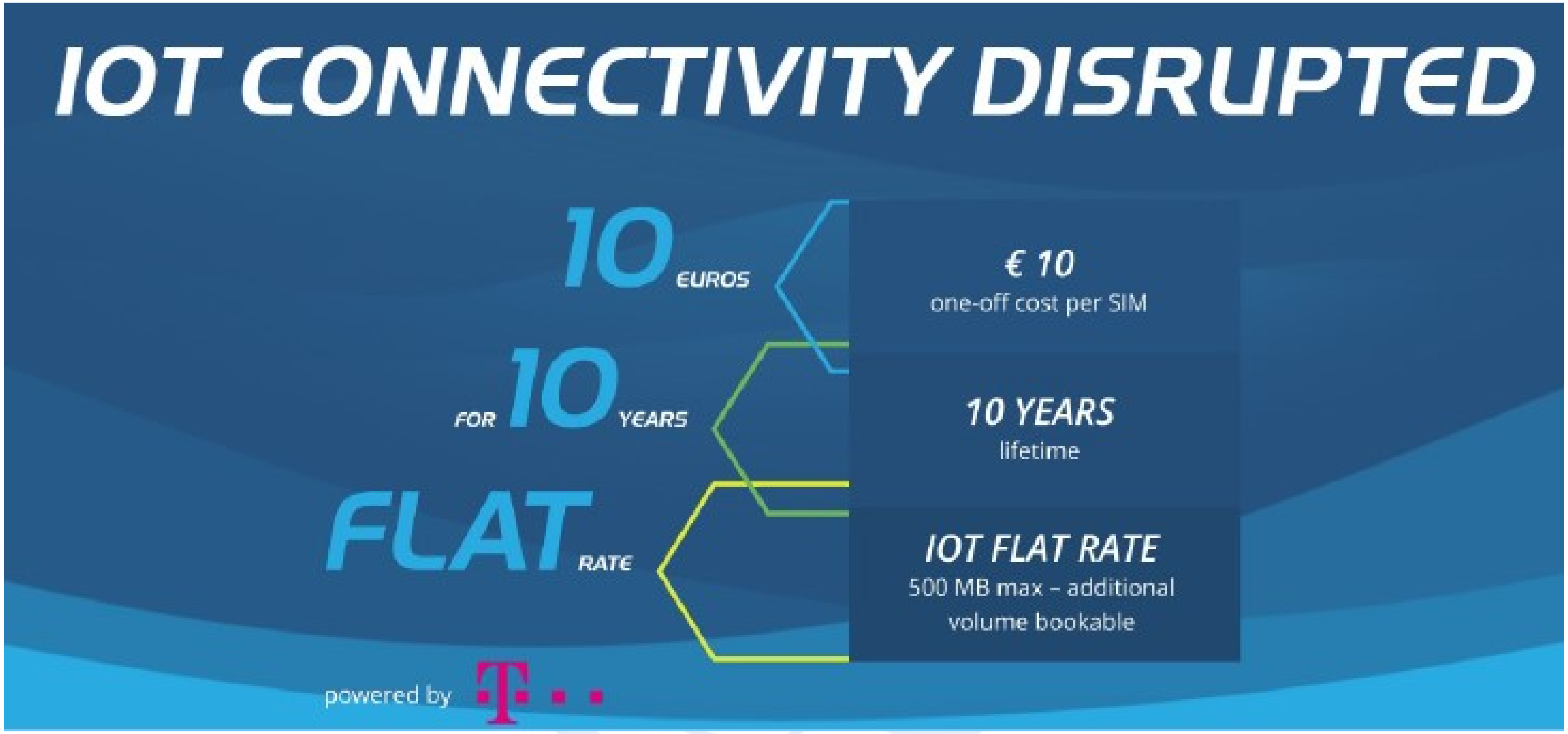
B. Prices

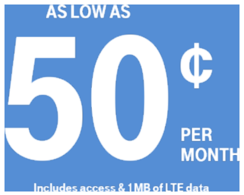
NB-IoT pricing in Deutsche Telekom

Deutsche Telekom

1. The **NB-IoT Access** entry package is available from **EUR 199** and includes a **6-month activation of up to 25 SIM-cards with 500 KB per SIM** pooled in Germany's NB-IoT network. As a further optional add-on – a private APN with IPsec-key encryption is available.
2. The **NB-IoT Access & Cloud of Things** entry package is available from **EUR 299** and additionally includes direct access to Deutsche Telekom's Cloud of Things platform for device and data management.

T-Mobile NB-IoT Offer





SK Telecom (South Korea) LoRaWan prices

SK Telecom completed a nationwide LTE-M rollout in March 2017 but only LoRaWAN services are available.

Price plans for LoRaWAN-based IoT services:

1. 350 won (**$0.30**) per month per device for a 100kb allocation
2. 2,000 won (**$1.77**) for a 100MB allocation.

Discounts available for multiple lines, ranging from 2% for those using 500 lines for 10% for those using 10,000 lines. Excess data will be charged at 0.005 won per 0.5KB.

LoRa plans cost just a tenth of the price of its LTE-based IoT services.

Price Plan	Data Allowance* (Frequency of communication)	Monthly Flat Rate (VAT Excluded)	Examples of Services	Note
Band IoT 35	100KB	KRW 350	Metering and monitoring services (e.g. Advanced Metering Infrastructure (AMI), environmental monitoring, water leakage monitoring, etc.)	- Discount benefits for long-term contracts: Ranging from a 5% discount for two-year contracts to a 20% discount for 5 year-contracts - Multi-line discount: Ranging from a 2% discount for those using 500 lines to a 10% discount to those who use 10,000 lines
Band IoT 50	500KB	KRW 500		
Band IoT 70	3MB	KRW 700	Tracking services (e.g. locating tracking For people/things, asset management, etc.)	
Band IoT 100	10MB	KRW 1,000		
Band IoT 150	50MB	KRW 1,500	Control service (e.g. safety management, lighting control, shared parking, etc.)	
Band IoT 200	100MB	KRW 2,000		

*Data usage exceeding the data allotment provided will be charged at KRW 0.005 per 0.5KB.

UnaBiz (Singapore) Sigfox prices

Network subscription charges: **US$0.75 per device per month**, which comes with a data plan for up to 140 messages per day.

Qualified channel partners who **commit to volume** can ultimately enjoy subscription charges from as low as **US$0.75 per device per year**.

Jonathan Tan, Vice President Business Development & Sales, UnaBiz said, *"Sigfox's technology is built for massive deployment and we are offering ultra-low cost connectivity to grow exponentially the base of devices that can access the network. Compared to existing local networks, businesses on our global network can generate savings of at least 90% off data plan subscription charges."*

The new prepaid plans, which target develc businesses, include three tiers of data and text messages:

1. 1 gigabyte of data valid for up to 1 year and 500 text messages for **$25**;
2. 3 GB of data valid for up to 1 year and 1,000 text messages for **$60**;
3. 5 GB of data valid for up to 2 years and 1,500 text messages for **$100**.

Synthesis

Country	Operator	Technology	Price/End-device/month	Conditions (/end-device/month)
Germany	DT	NB-IoT	US$ 1.60	85 KB
			US$ 2.40	" + Cloud
South Korea	SK Telecom	LoRaWAN	US$ 0.30	100 KB
			US$ 1.77	100 MB
Singapore	UnaBiz	Sigfox	US$ 0.75	140 messages
USA	AT&T	LTE-M	US$ 2.08	83 MB and 42 messages
			US$ 5	250 MB and 84 messages
			US$ 4,2	210 MB and 63 messages

LoRaWAN end-devices prices

Interface	UART
Stack / MAC	LoRaWAN
Stack implementation	Microchip proprietary
Price	$14.27 @ single unit $10.90 @ 1000 units

Interface	UART
Stack / MAC	LoRaWAN
Stack implementation	proprietary MultiTech
Form factor	XBee compatible
Price	~$30.00 @ single unit

NB-IoT end-devices prices

NB-IoT Quectel BC95

AT Commands
3GPP Rel-13
Interfaces SIM/USIM 1 Transmission 100bps
€ 35,00

Quectel GSM/GPRS/UMTS/HSPA/NB-IoT Module

€ 60,00

[Digi XBee Cellular NB-IOT]

Solution Highlights: Up to ~60Kbps Downlink, 25Kbps Uplink
4-7x better range - strong building penetration
Simple 1 antenna design
200 mW (23 dBm)
Band 20 (800MHz)
Band 8 (900MHz

Digi XBee Cellular LTE-M

Solution Highlights: Up to ~350Kbps Down/Uplink

PSM (Power Saving Mode) and eDRX supported for ultra-low power consumption

Simple 1 antenna design

200 mW (23 dBm)

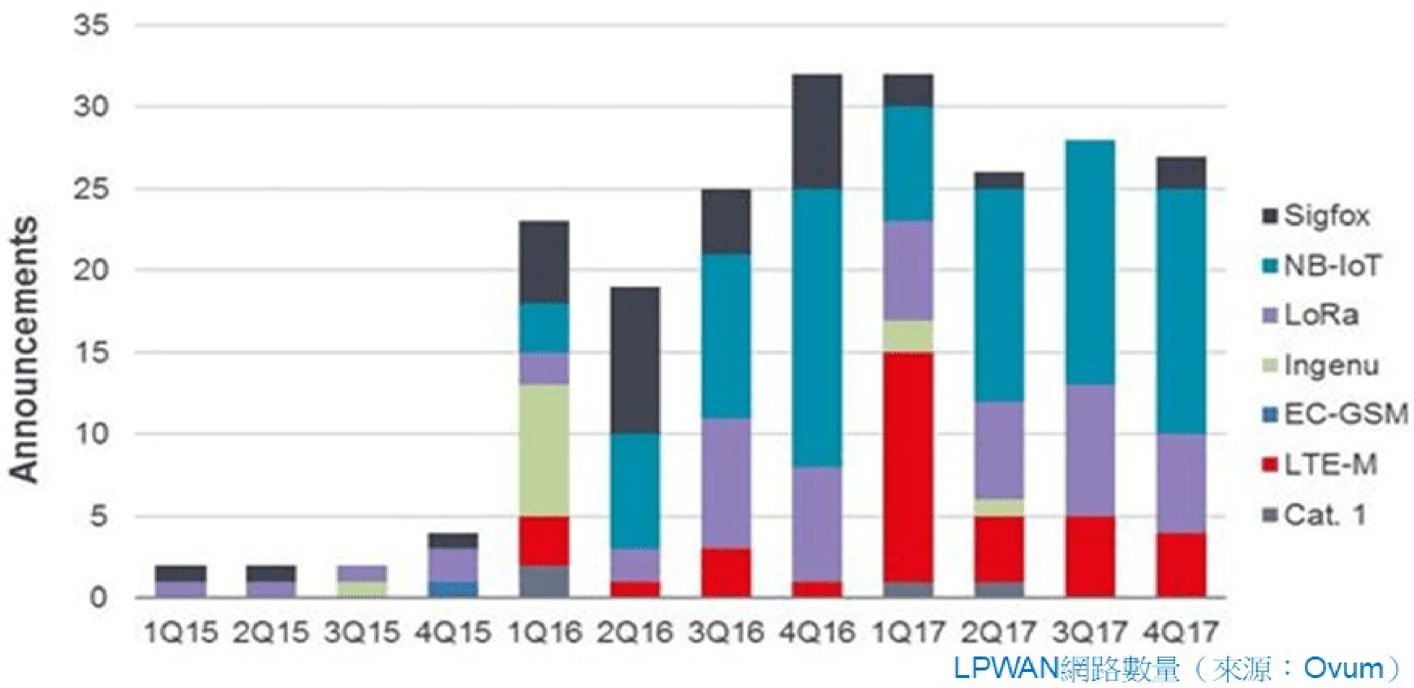
Verizon: Band 13 (700MHz) Band 4 (1700MHz)

AT&T: Band 2 (1900MHz) Band 4 (1700MHz) Band 12 (700MHz)

C. Forecasts

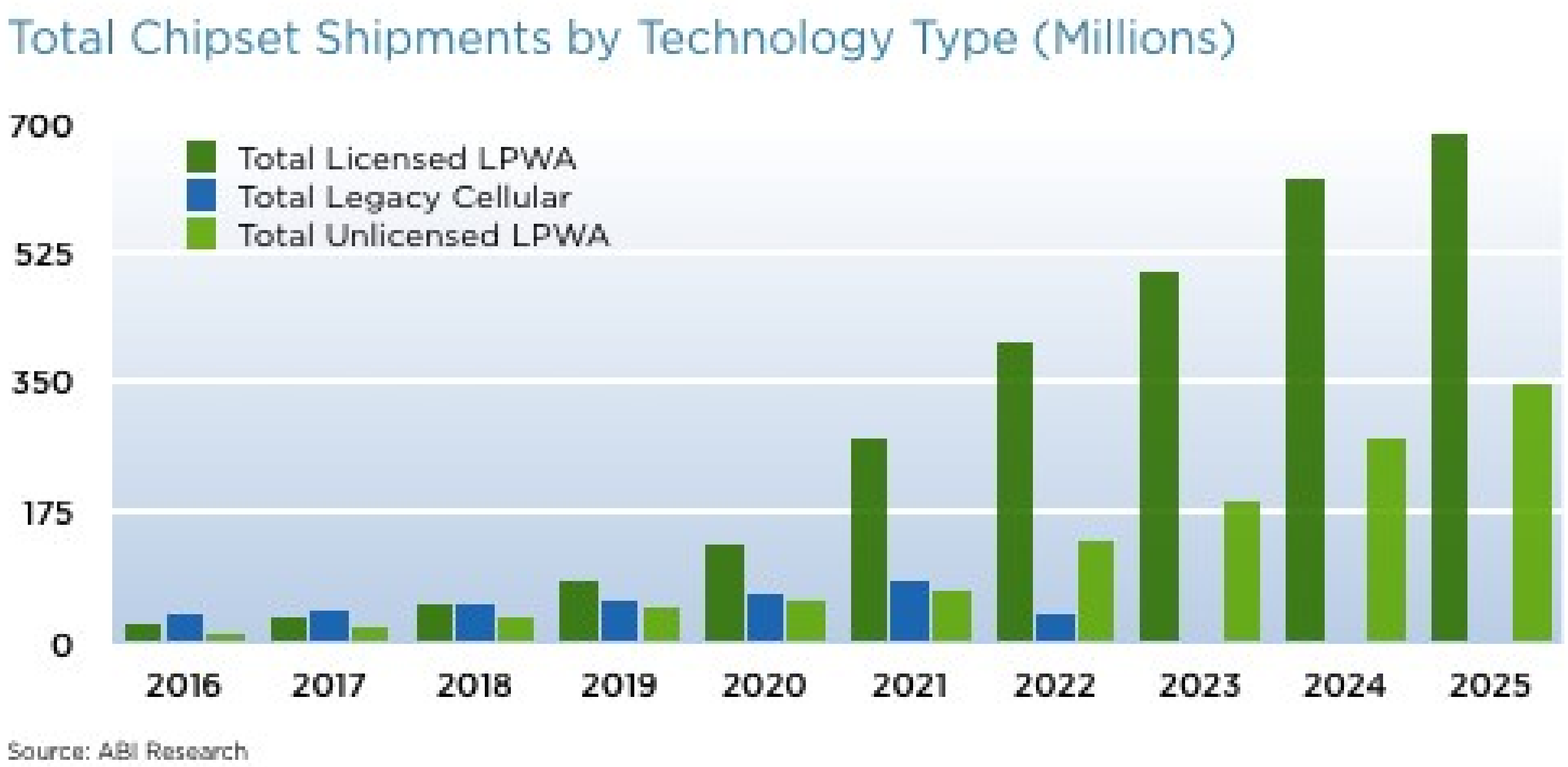
Main technologies for LPWANs

Technologies evolution 2015-2017



Enabling an Intelligent Planet ADVANTECH

Chipset Shipments Evolution



Evolution of LPWA Modules Sales

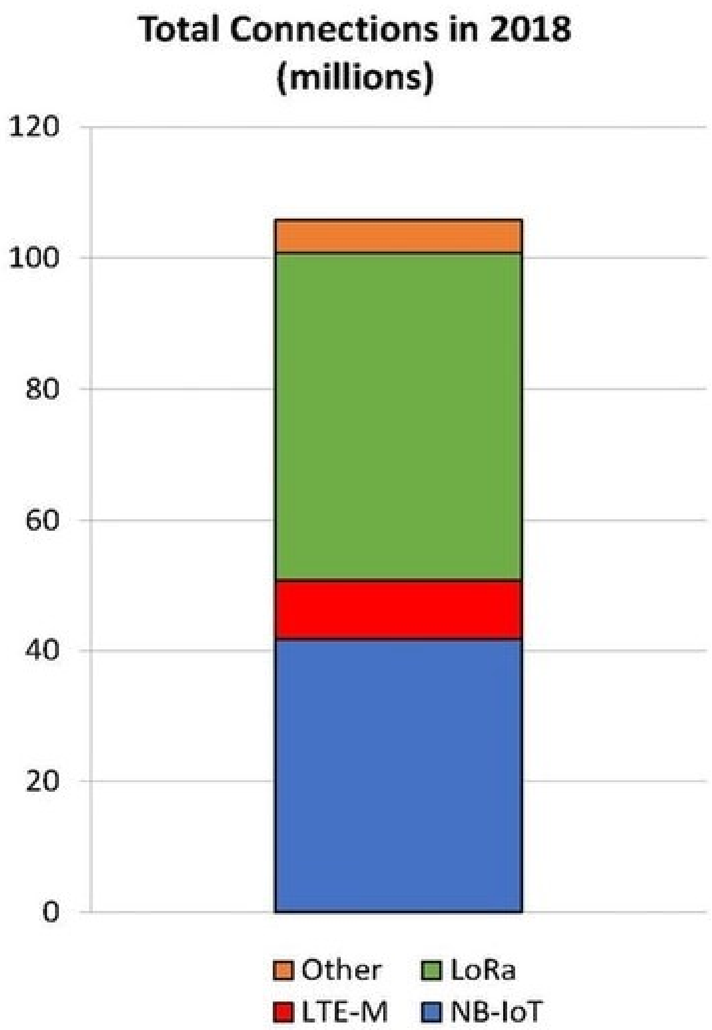
Annual Unit Shipments of LPWA Modules (in thousands)

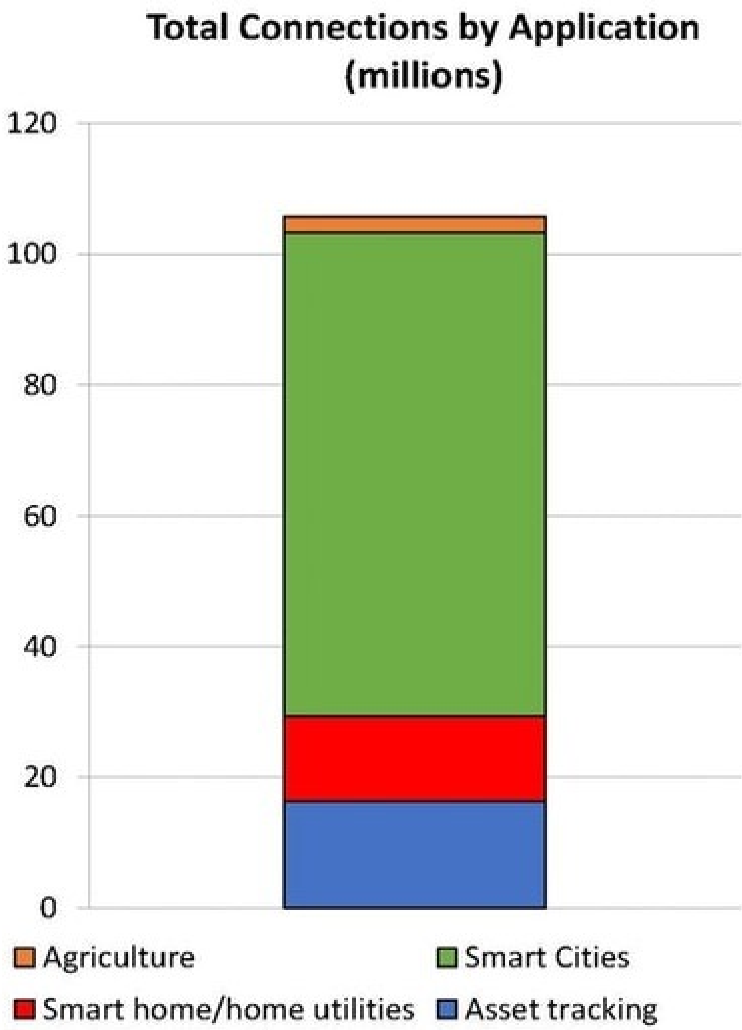
	2017	2018	2019	2020	2021	CAGR
Sigfox	8,424	14,538	27,951	52,821	85,042	219.5%
LoRa	32,316	57,298	98,162	161,561	249,724	92.3%
LTE Cat-M1	1,978	8,571	20,284	28,801	52,288	--
NB-IoT	16,166	34,062	84,885	161,628	222,902	--
Other	4,022	6,201	8,714	7,069	8,402	14.7%
Totals	**62,905**	**120,667**	**239,996**	**411,881**	**622,358**	**95.0%**

Source: IHS Markit

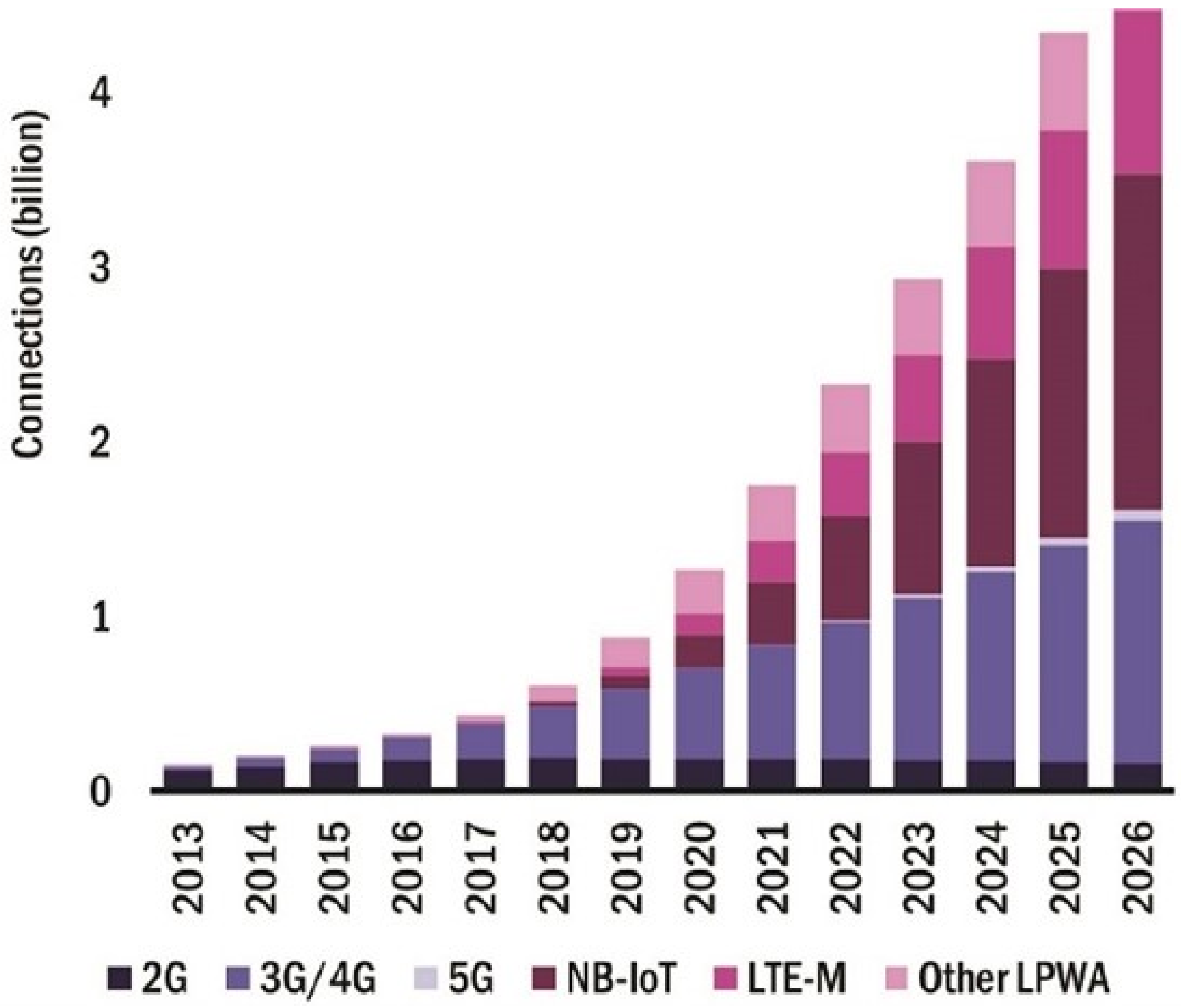
Devices prices (2017)

2018 Connections Status





Future of IoT connectivity by network type across the world



NB-IoT will be the dominant network for IoT in 2026 (Analysys Mason)

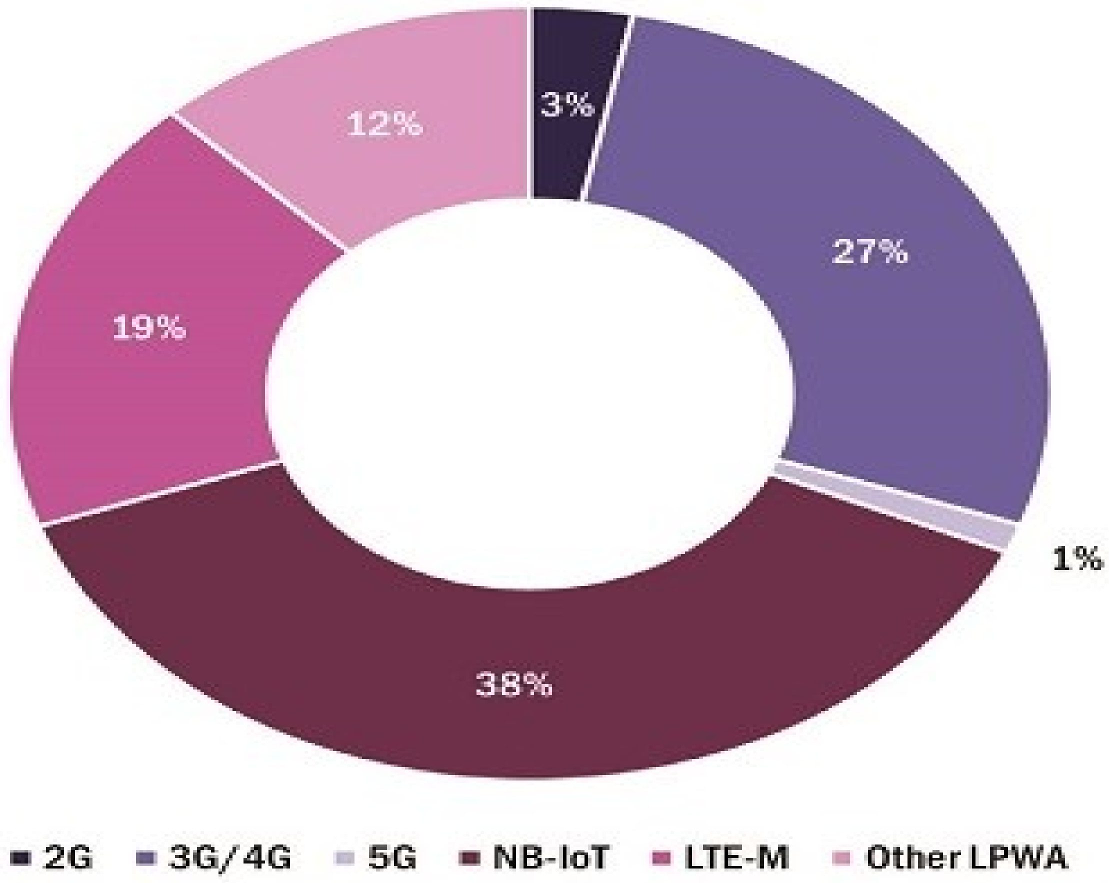

LPWAN Forecast
2017 - 2023
NB-IoT
LTE-M
Wi-SUN
LoRaWAN
Sigfox

2025 forecasts

LPWAN Technology Share Forecast, 2025 (%)

Source: Global IoT Forecast, Machina, 2017

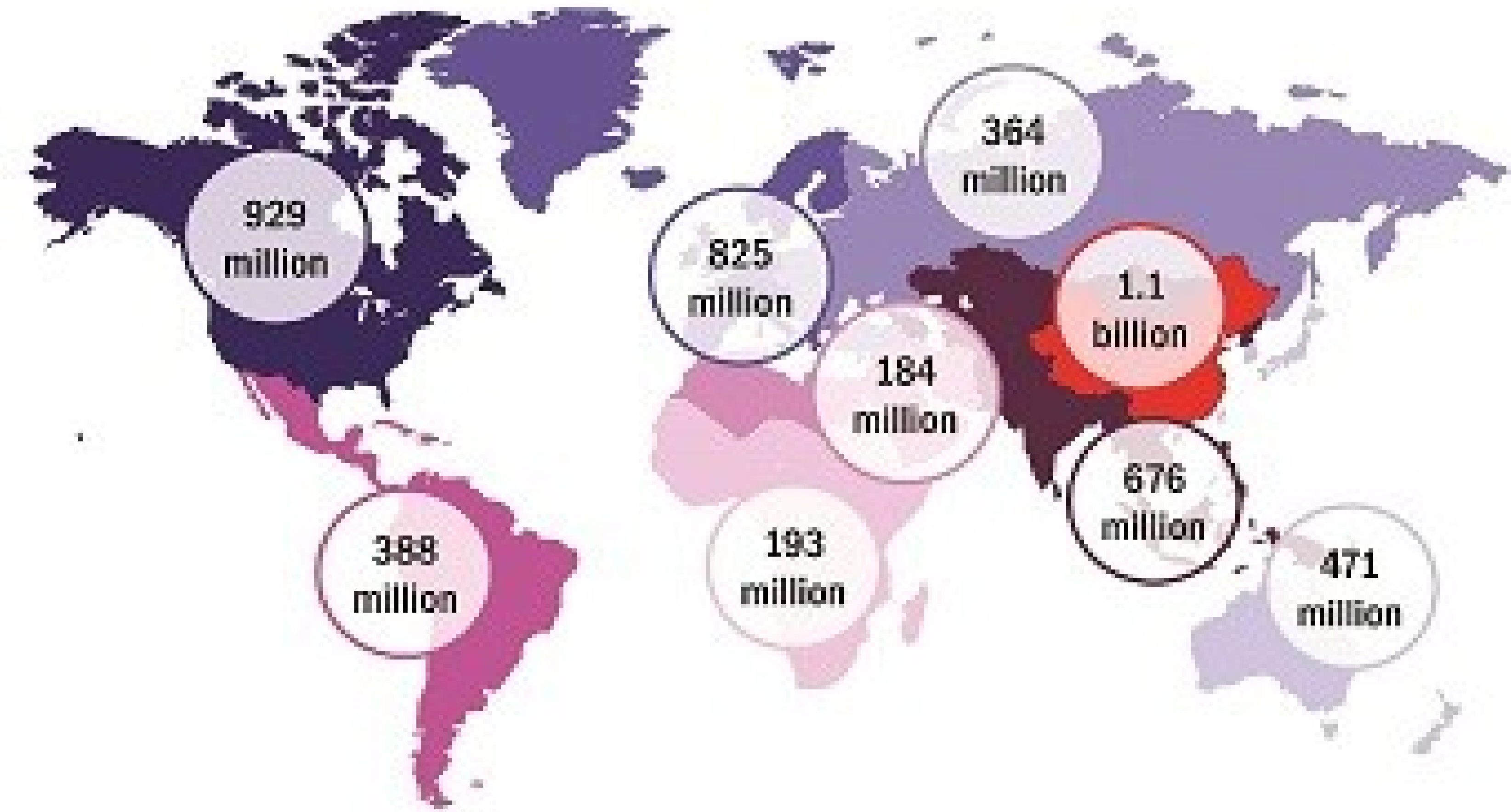
Share of LPWAN Connections in 2026



Share of worldwide connections by network type, 2026

NB-IoT will have 38% of total connections in 2026, backed by Chinese market

Forecasts in 2026



Total IoT connections (cellular and LPWA) by region, 2026

China will dominate the market by 2026 with 1.1 billion connections

Thank you!