IoT Standards
Part II: 3GPP Standards

Training on PLANNING INTERNET OF THINGS (IoTs) NETWORKS

25 – 28 September 2018

Bandung – Indonesia

Sami TABBANE

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Objectives

- Discuss the 3GPP standardization activities undertaken around IoT ecosystem enablers
- Present the main characteristics of LTE-M and NB-IoT
- Benchmark the IoT systems in 2017 and their forecasted evolution

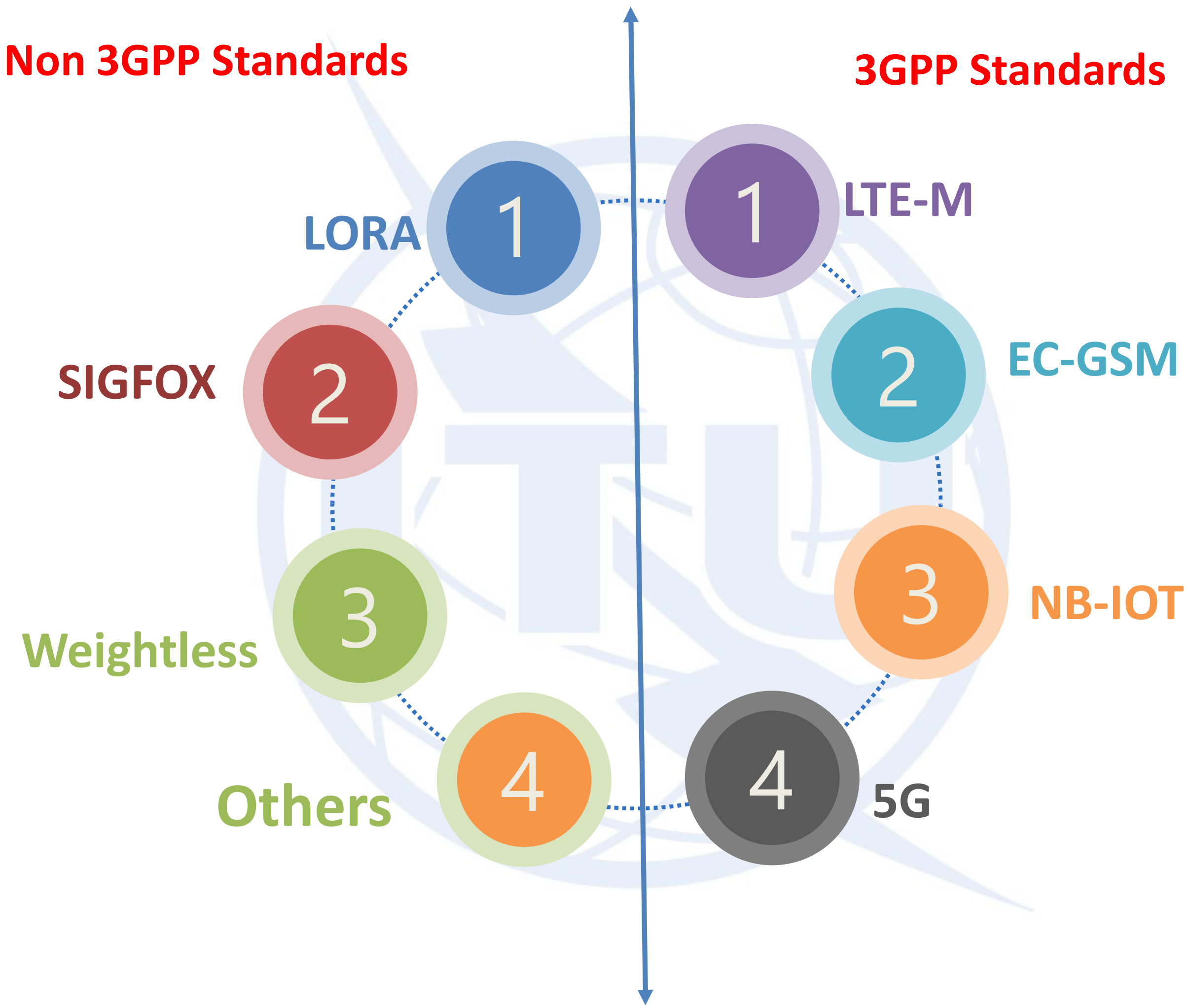
I. Introduction

II. LPWAN Architecture

III. IoT Short Range and Long Range Systems

IV. State of Art

LONG RANGE TECHNOLOGIES



Summary

A. Fixed & Short Range

B. Long Range technologies

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

2. 3GPP Standards

i. LTE-M

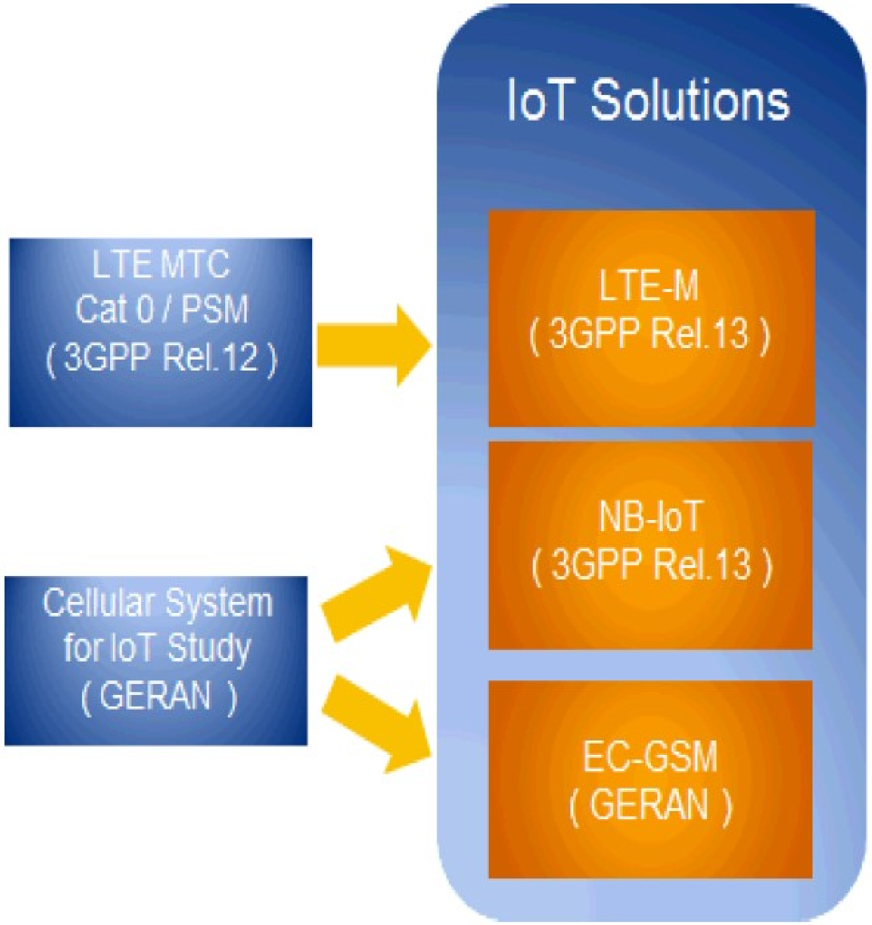
ii. NB-IOT

iii. EC-GSM

iv. 5G and IoT

Release-13 3GPP evolutions to address the IoT market

- **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

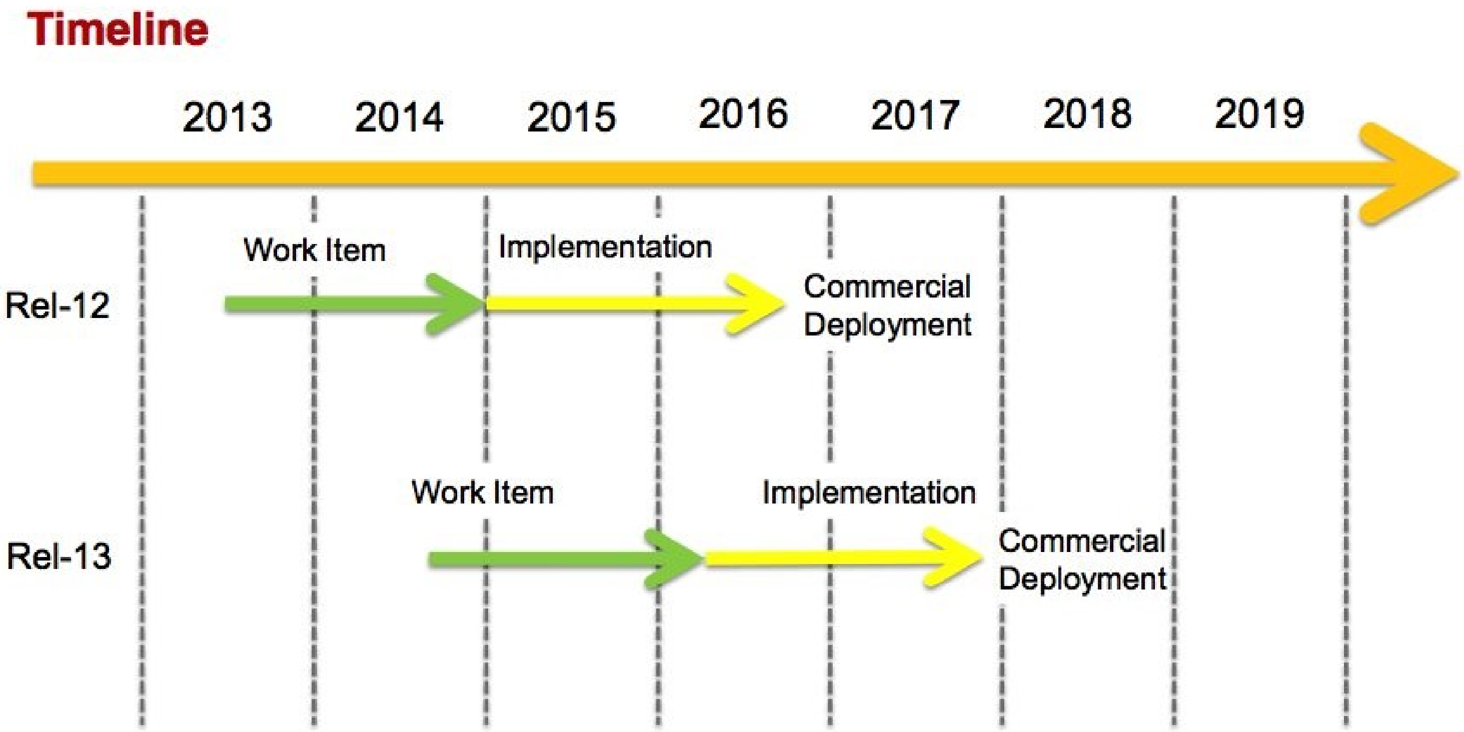
Technology

- **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**

A GLOBAL INITIATIVE

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**

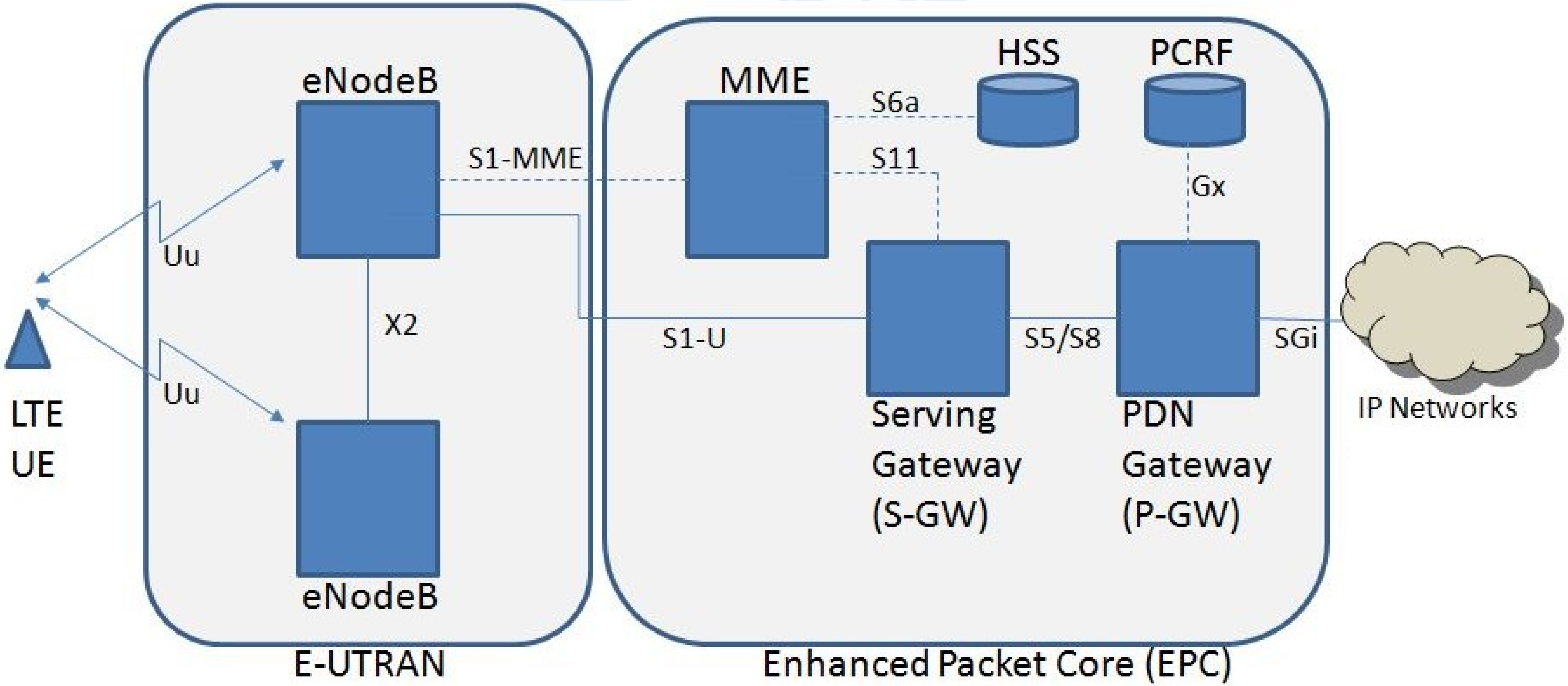
Release 12

- 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

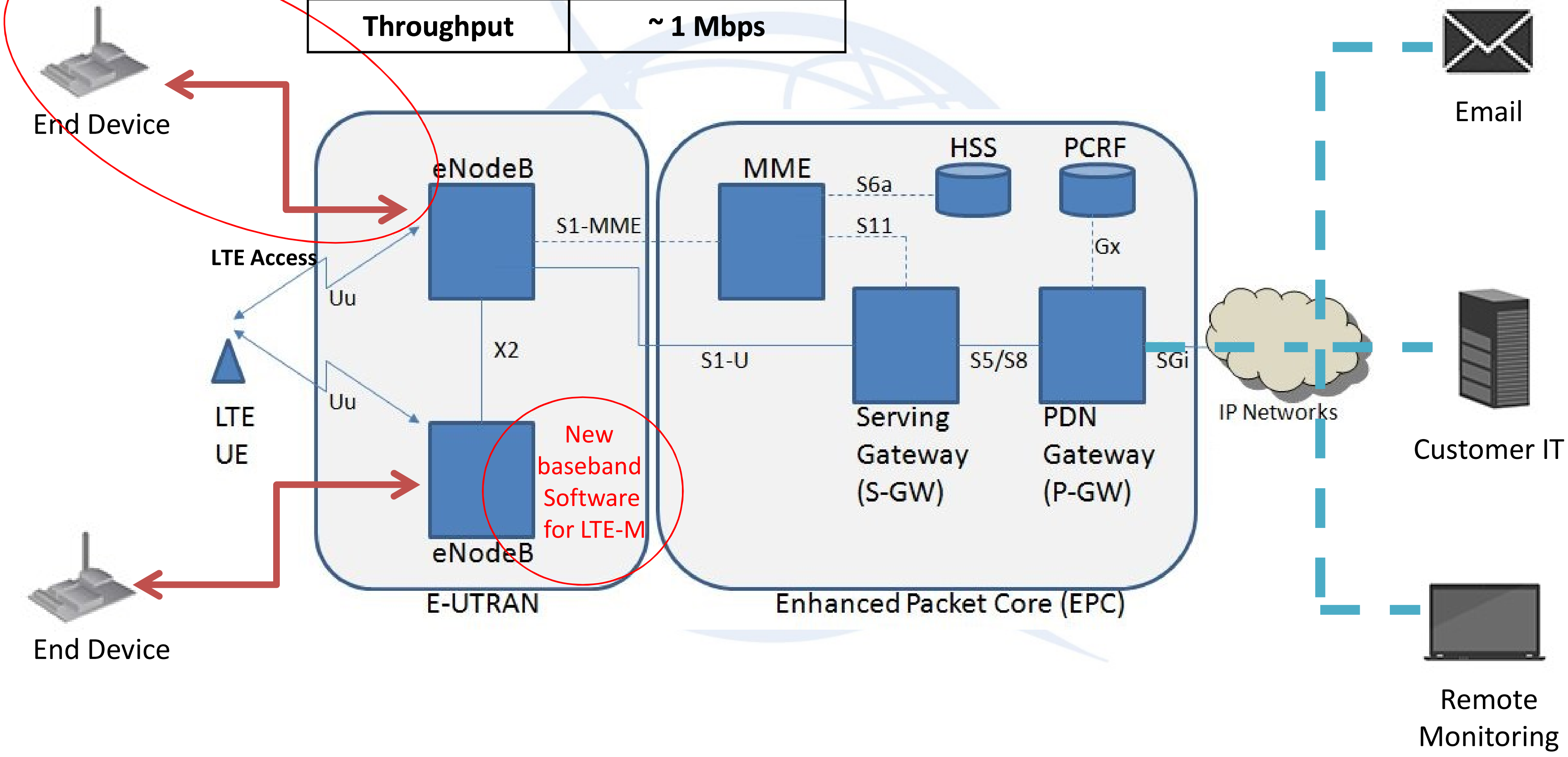
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

Present LTE Architecture

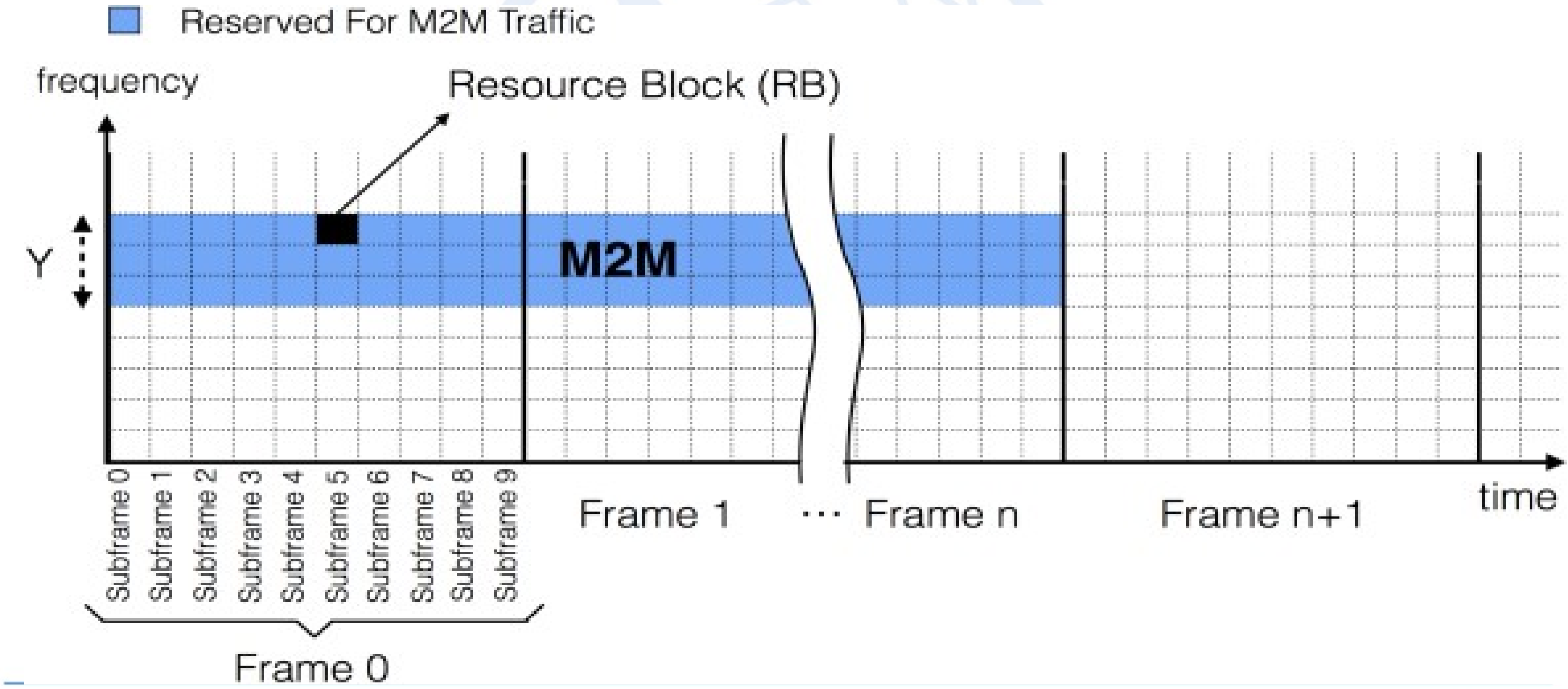


Architecture

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

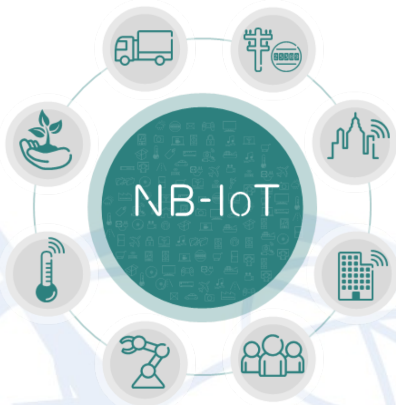


- **Licensed Spectrum**
- **Bandwidth: 700-900 MHz for LTE**
- **Some resource blocks allocated for IoT on LTE bands**



ii. NB-IOT

Current status



- April 2014 — Narrowband proposal to Connected Living
- May 2014 — 3GPP 'Cellular IoT' Study Item
- March 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

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.

Main features

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 features

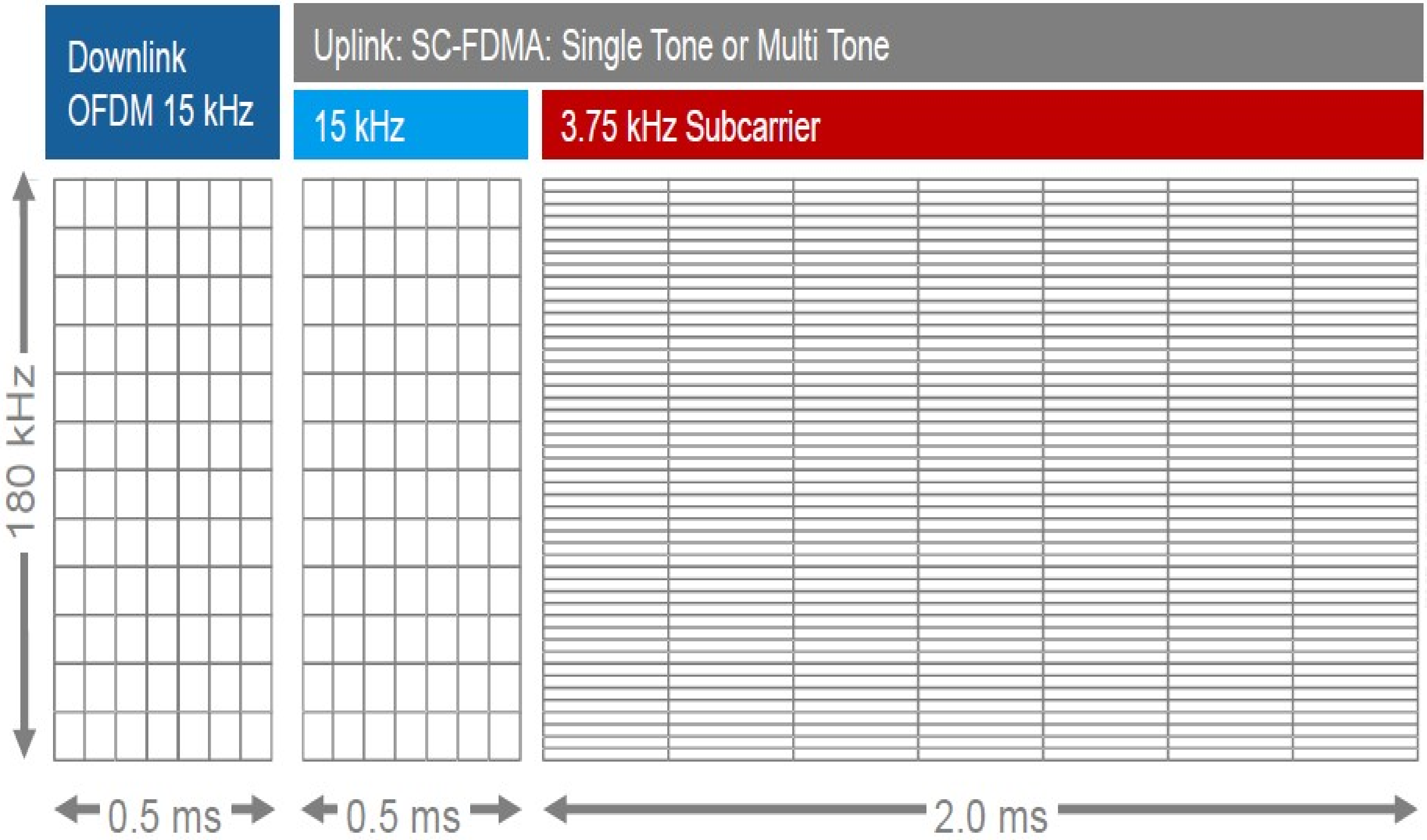
Main **PHY features**:

- 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

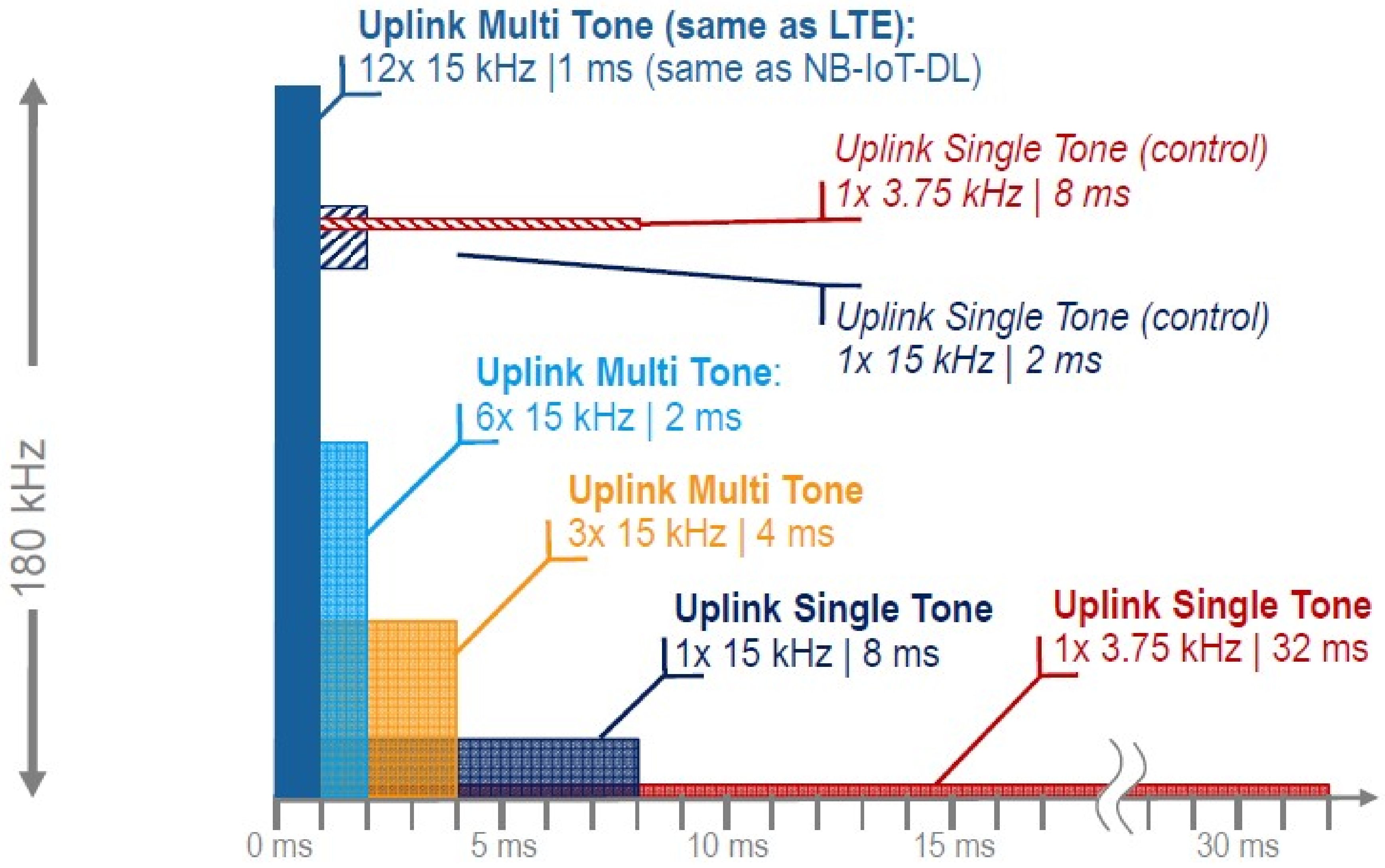
Main **radio protocol features**:

- 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

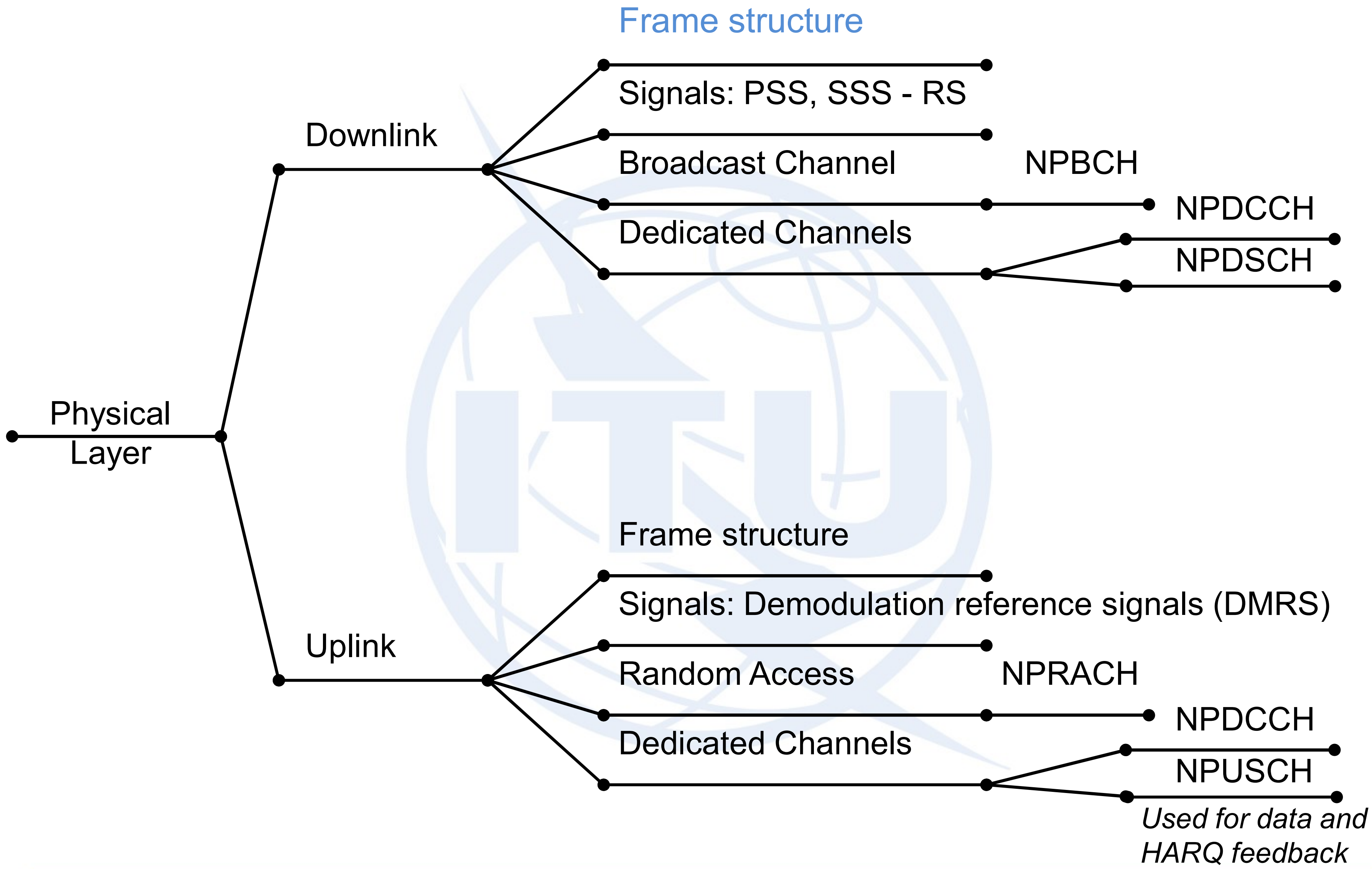
Frame and Slot Structure – NB-IoT – 7 symbols per slot



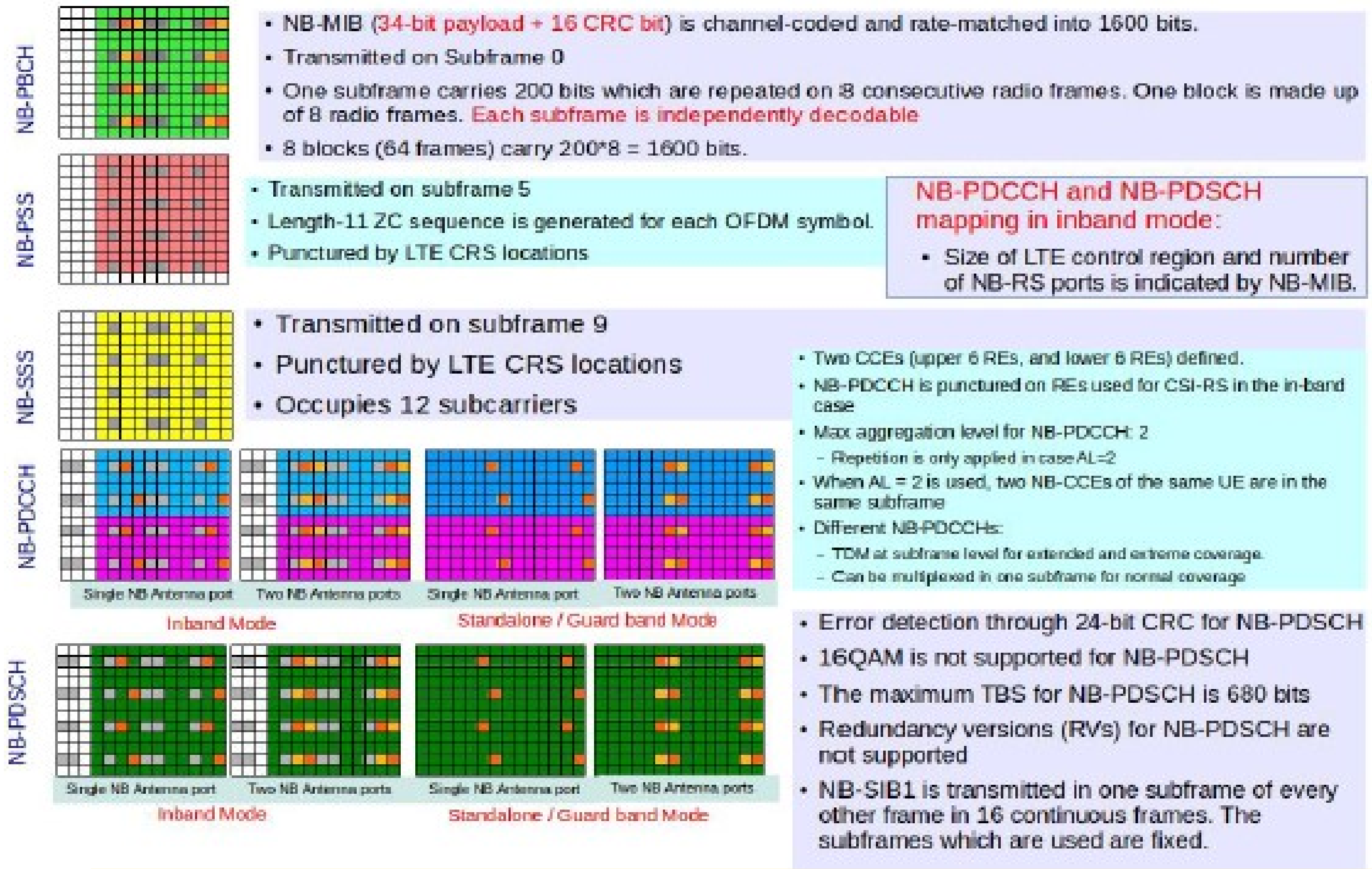
Transmission bandwidth and delays



NB-IoT Channels



Physical downlink channels



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

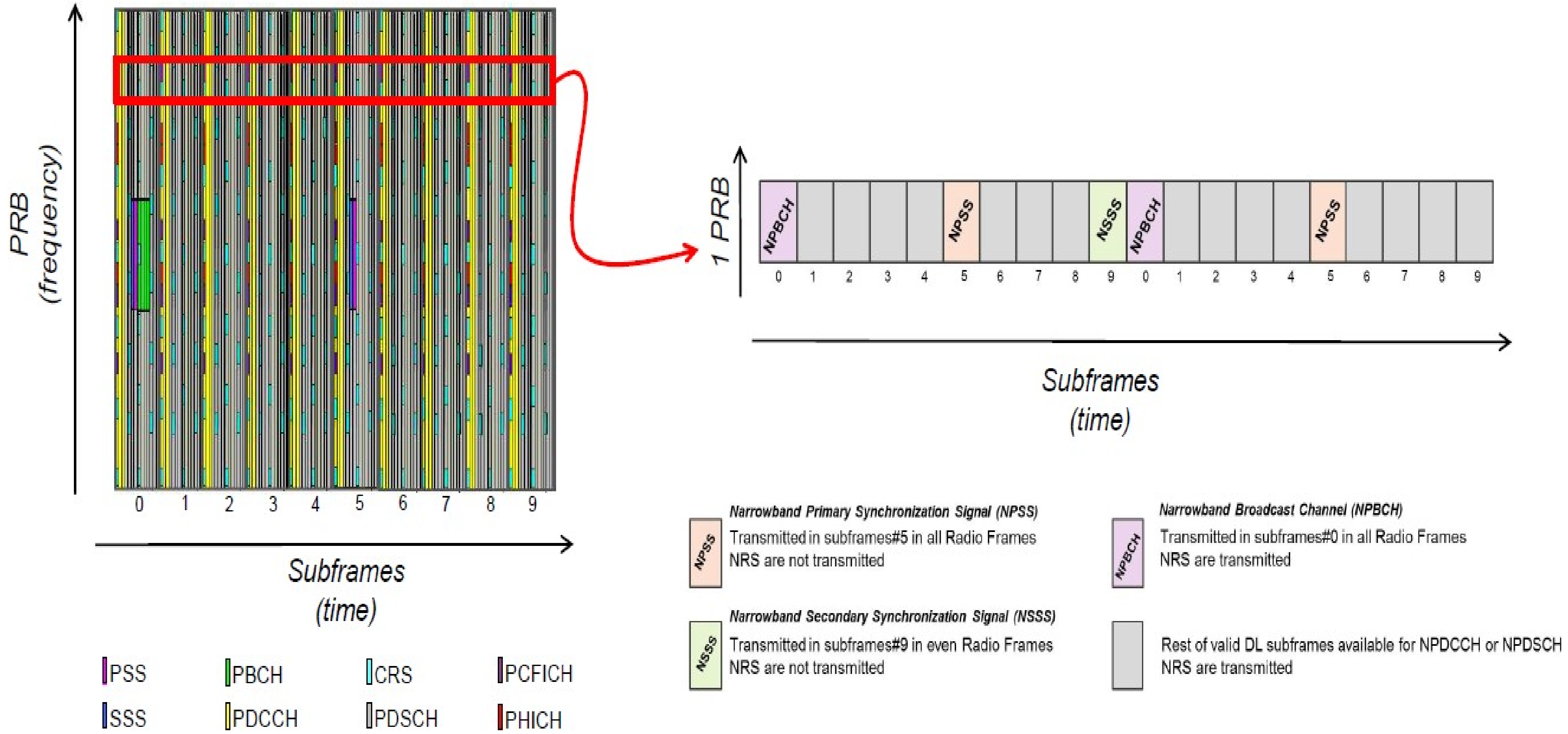
Downlink Frame Structure

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



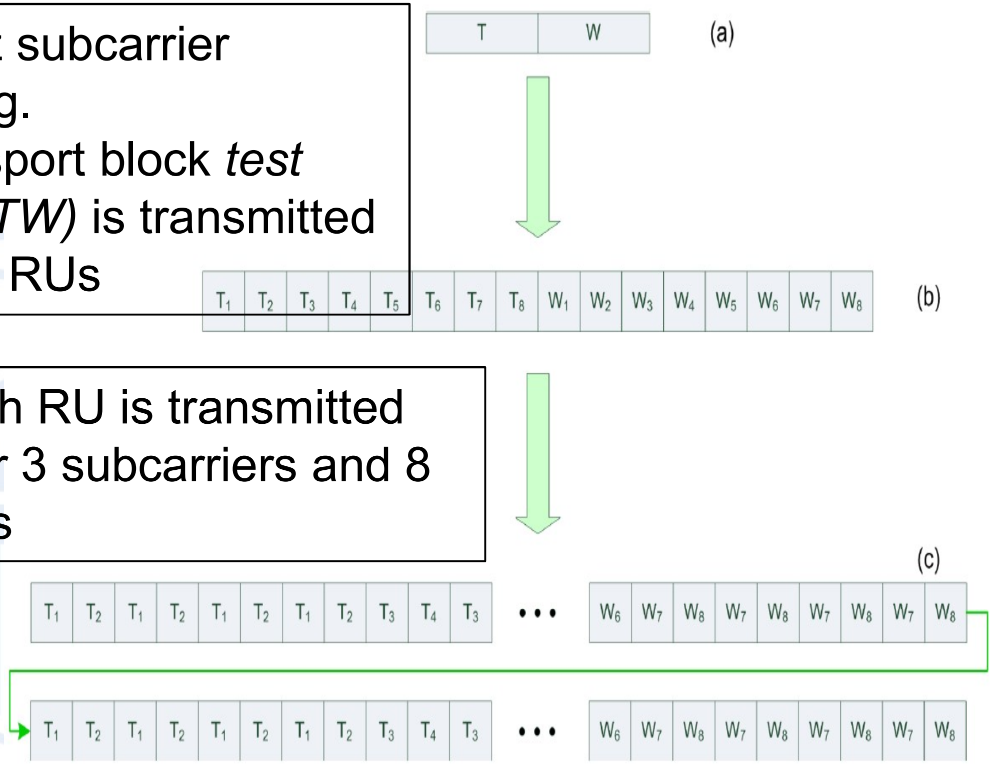
NB-IoT Repetitions

Consists on repeating the same transmission several times:

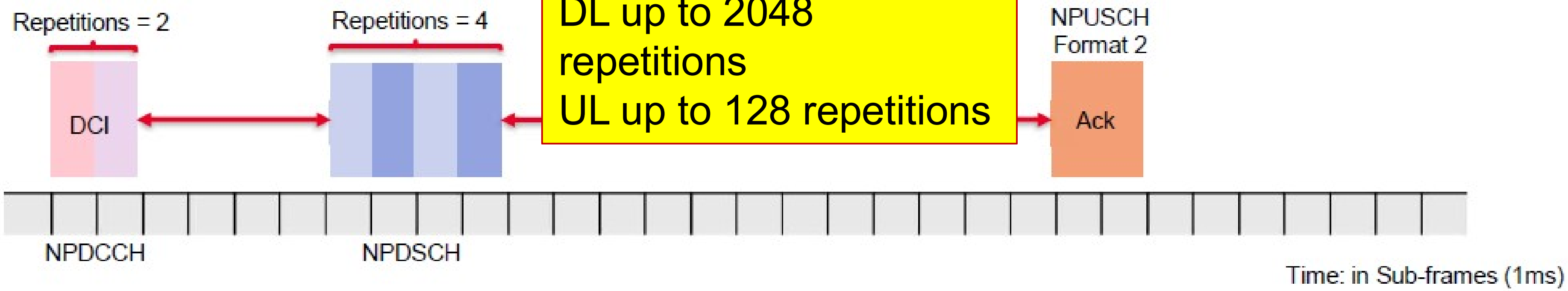
- Achieve extra coverage (up to 20 dB compared to GPRS)
- Each repetition is self-decodable
- SC is changed for each transmission to help combination
- Repetitions are ACK-ed just once
- All channels can use Repetitions to extend coverage

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

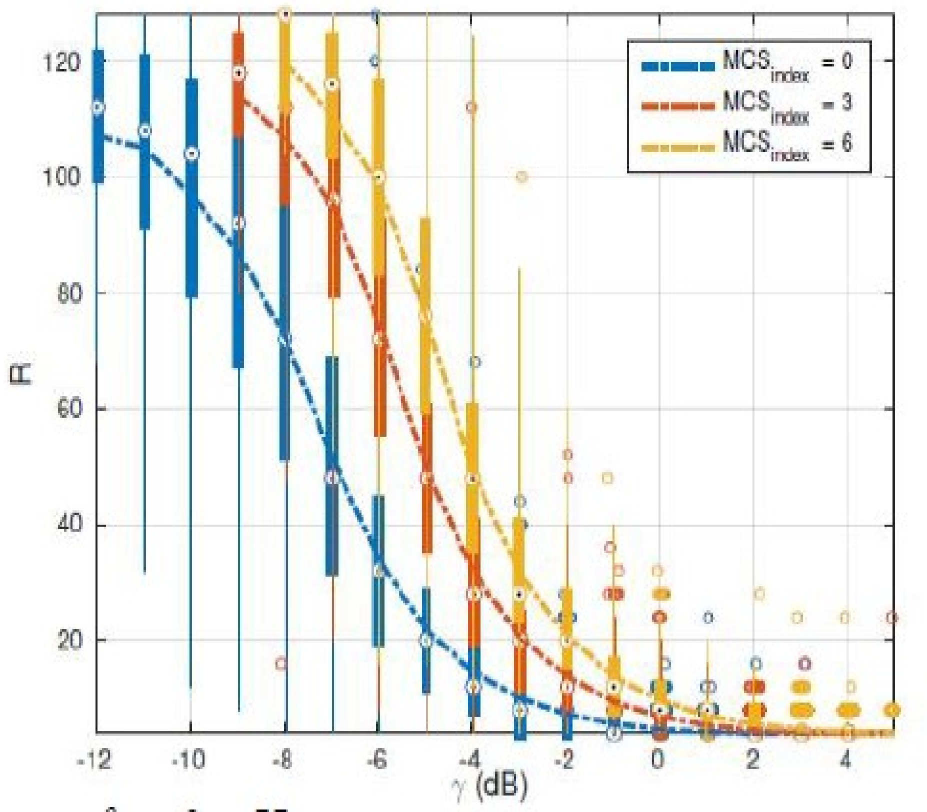


DL up to 2048 repetitions
UL up to 128 repetitions

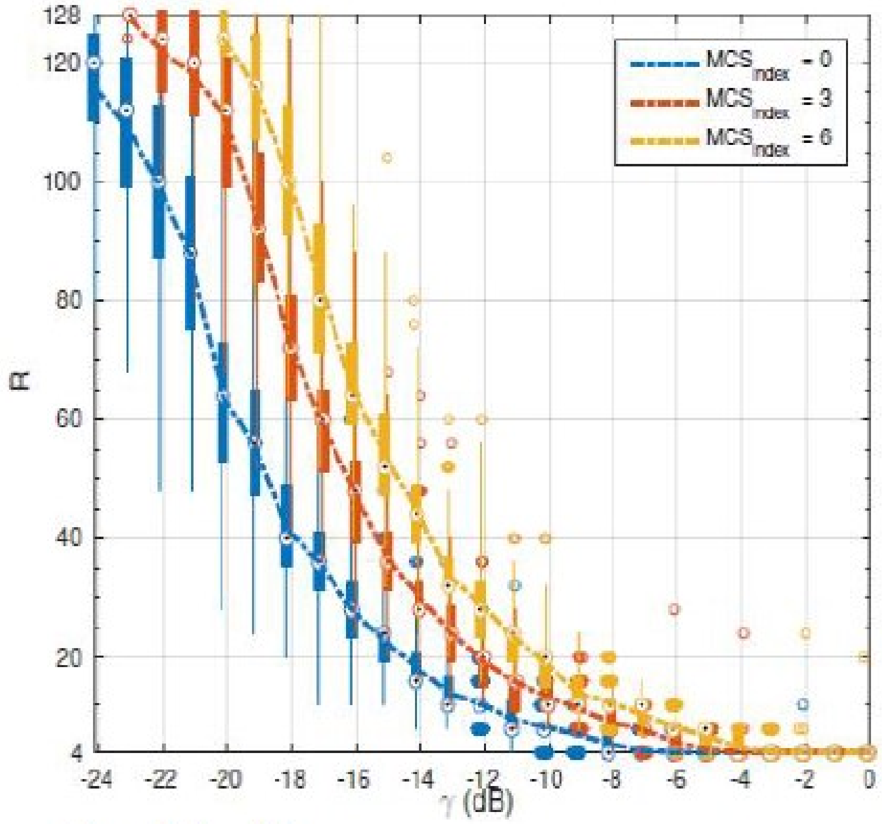


***Example**: Repetitions used in NB-IoT in NPDCCH and NPDSCH channels*

Repetitions number to decode a NPUSCH



$f_D = 0 \quad Hz$



$f_D = 80 \quad Hz$

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

Peak Data Rates

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).

Capacity

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.

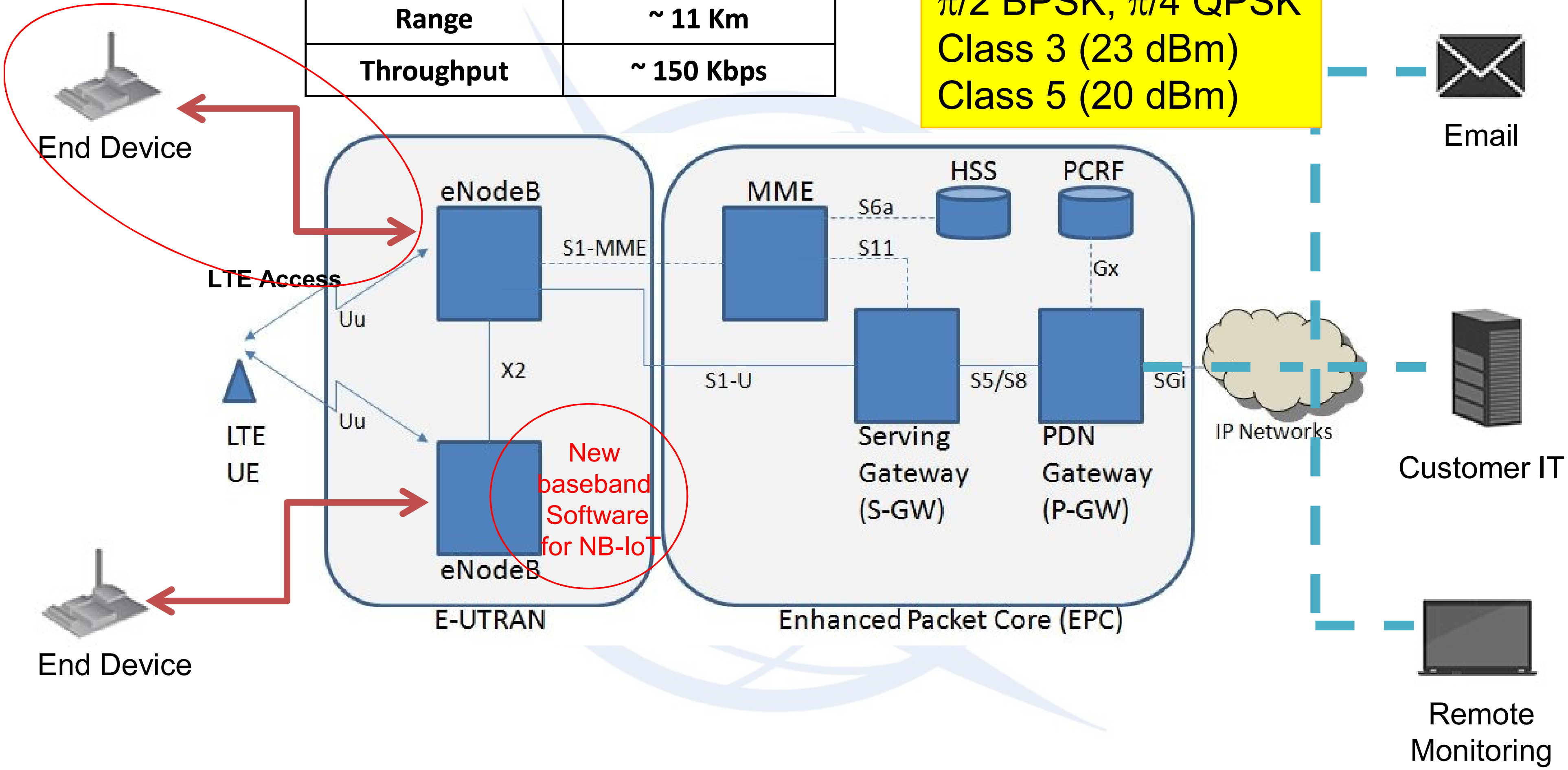
Extended C-DRX and I-DRX operation

- 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

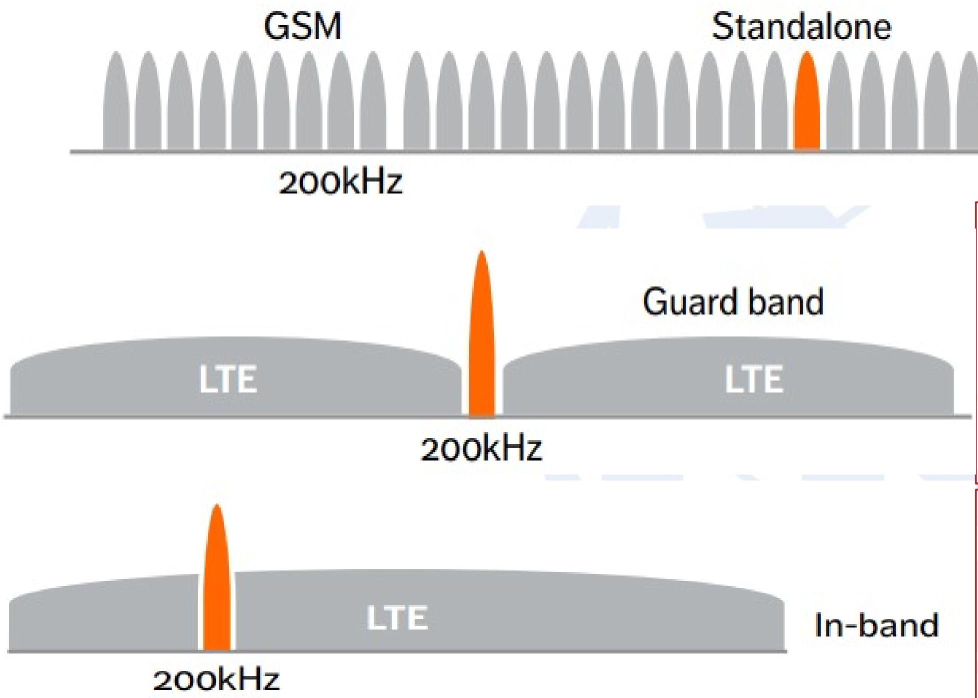
Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps

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.

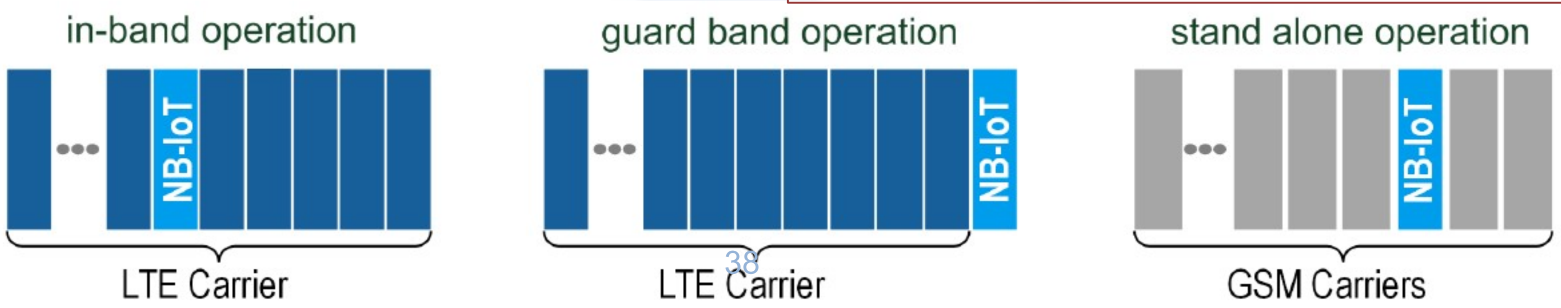
Ex.: By **re-farming GSM channels**

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

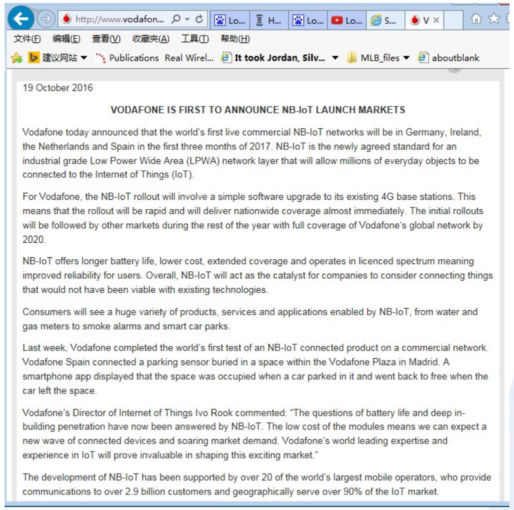


LTE-M to NB-IoT

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**

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.

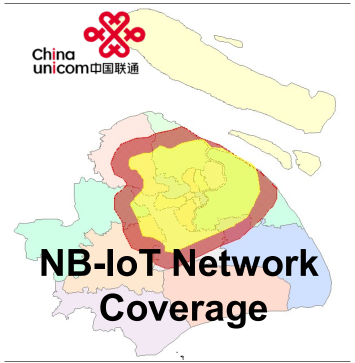
- Announced the commercialization of NB-IoT on 23rd Jan 17
- **1000** sites activated NB-IoT in Spain by the end of march 2017
- Took just a few hours to deploy NB-IoT with software upgrade in Valencia

- 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:



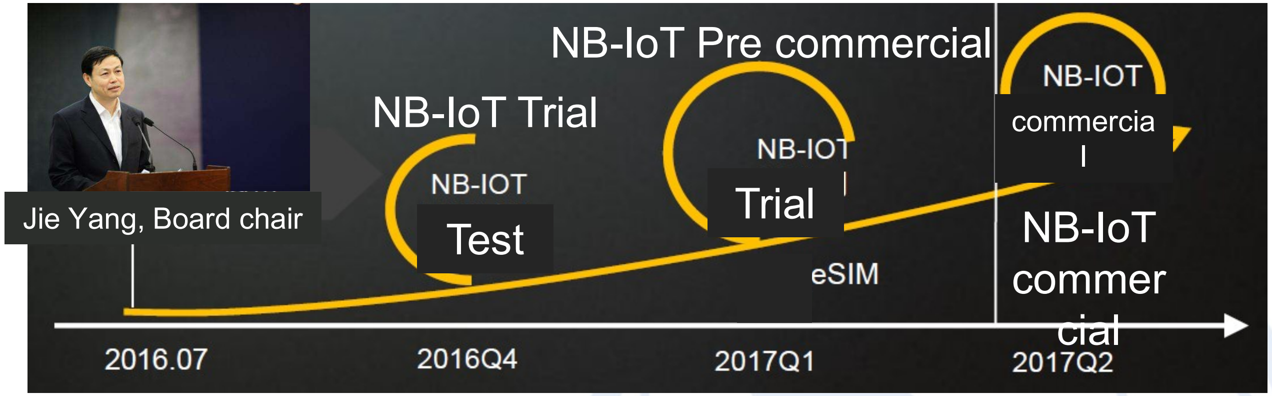
- **800+** base stations covered Shanghai in 2016Q4

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

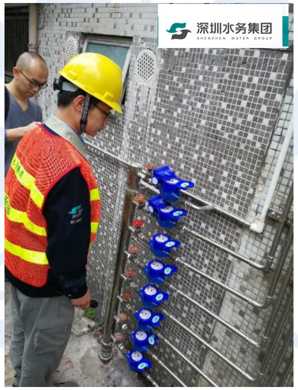


- 2017H1, NB-IoT enabled in L850 to achieve national wide coverage

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

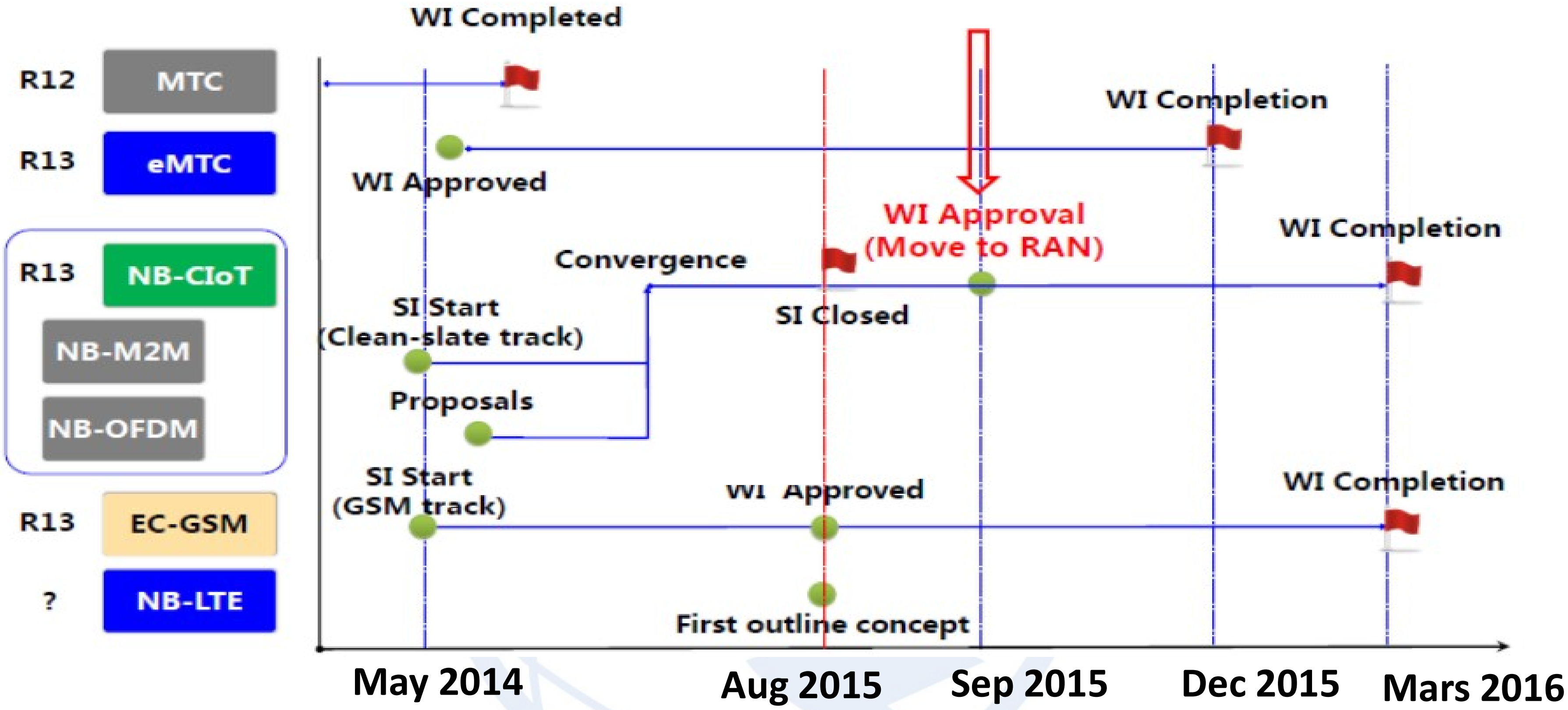


- Mar 22 2017, Shenzhen water utility announced commercialization;
- 1200 meters (phase 1) running in live network;

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

EC-GSM

- **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

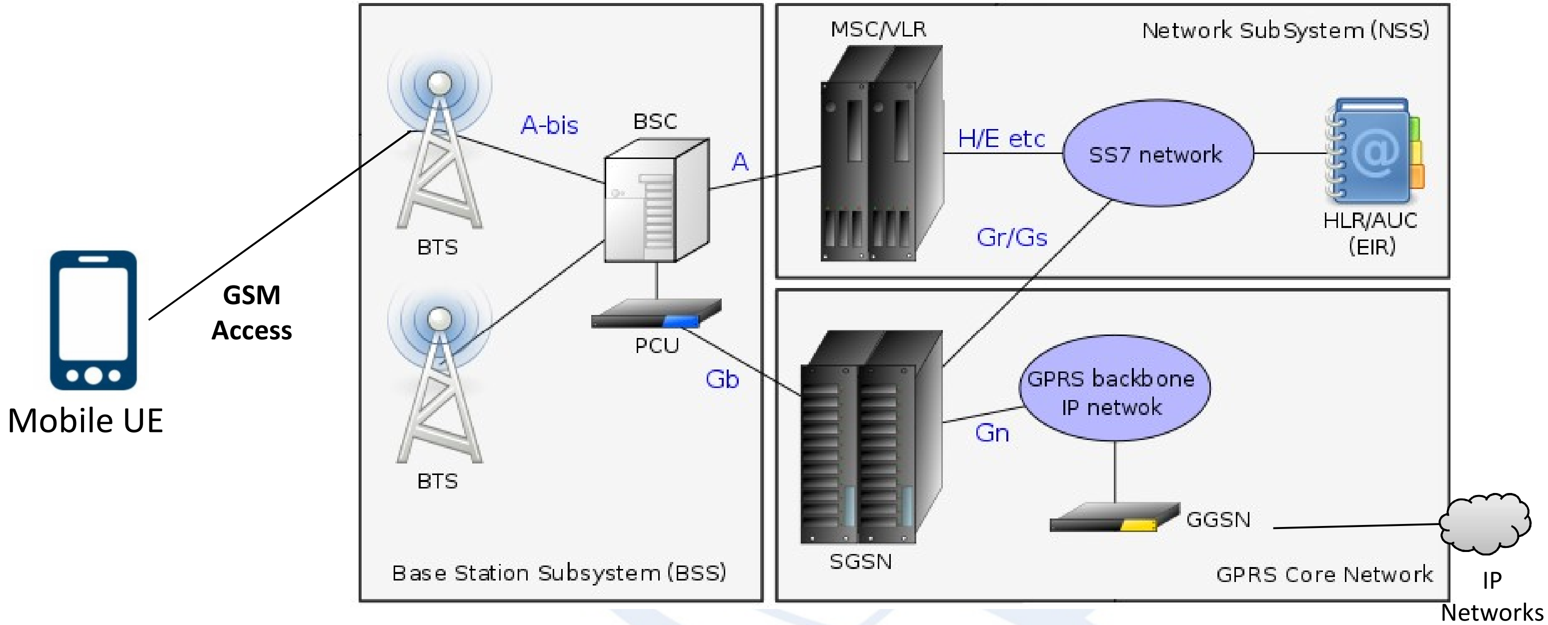
- Beacon and Synchronization channel don't use coverage class
  - EC-BCCH: always repeated 16 times
  - EC-SCH: always repeated 28 times
  - FCCH: legacy FCCH is used.

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

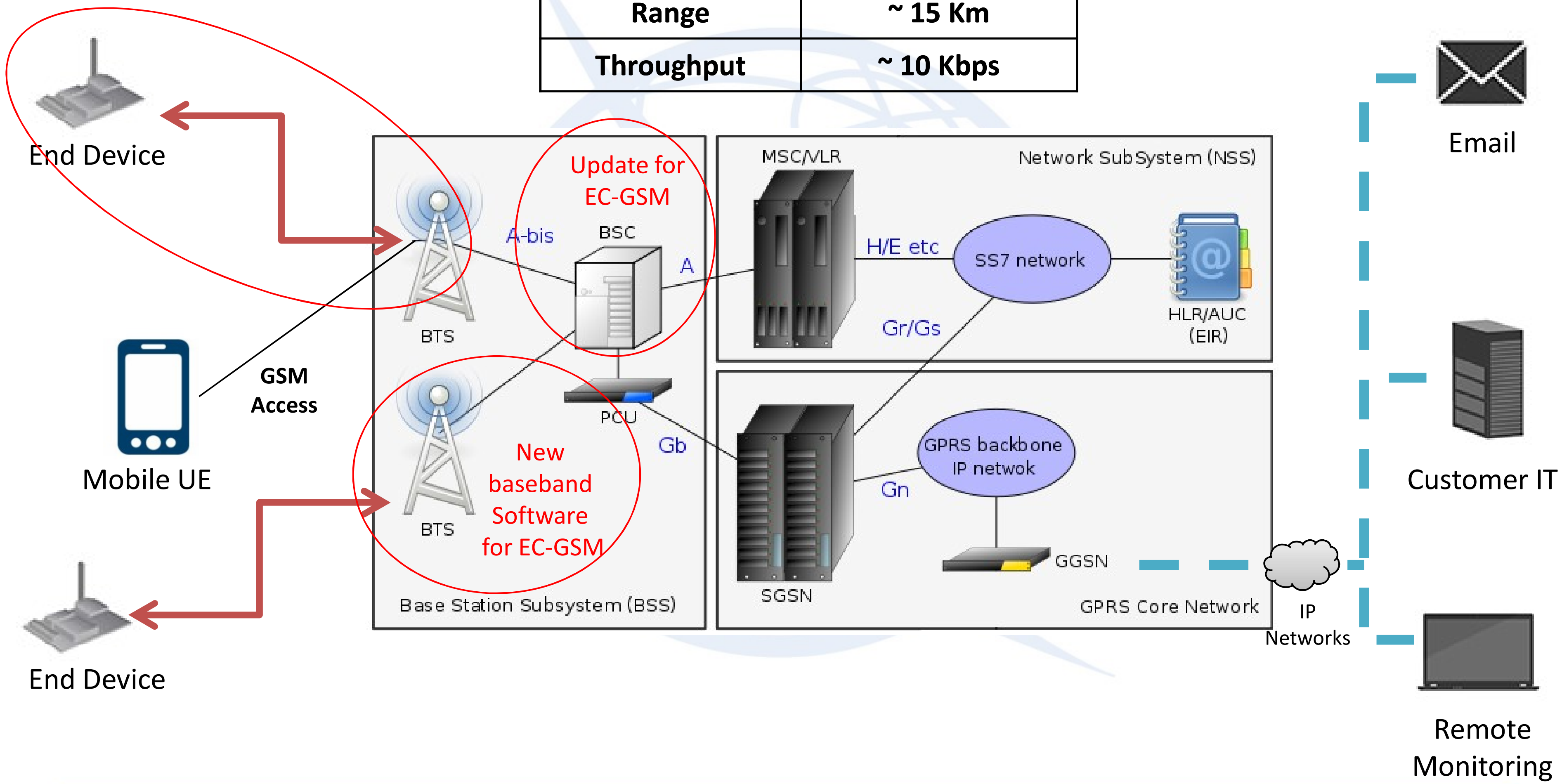
Actual GSM/GPRS Architecture



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

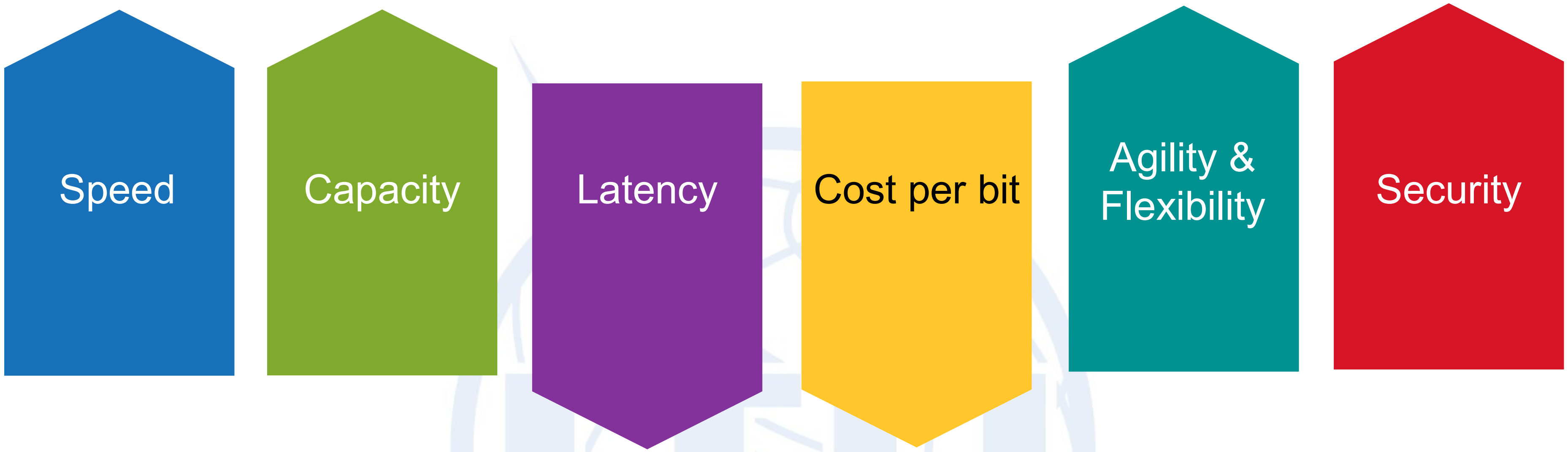
Architecture

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



iv. 5G and IoT

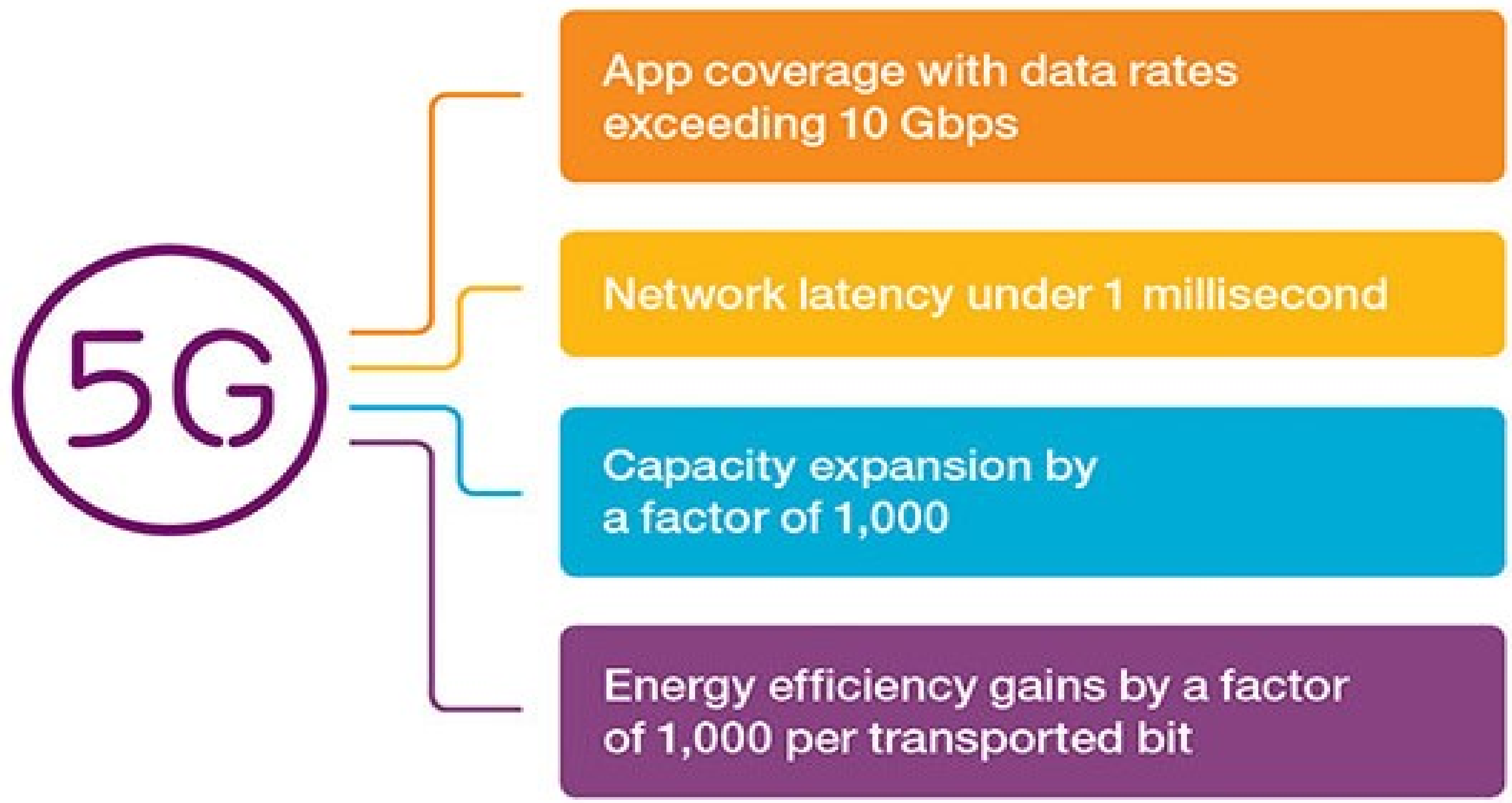
Context: the evolving demands on the network



"Maybe along with the three legs that 5G stands on (**massive Machine Type Communication** (mMTC), **enhanced Mobile Broadband** (eMBB), and **Ultra Reliable Communication** (URC)) we need to add a fourth leg of **ultra low cost broadband** (ULCBB)."

Alan Gatherer, Editor in Chief, ComSoc Technology News

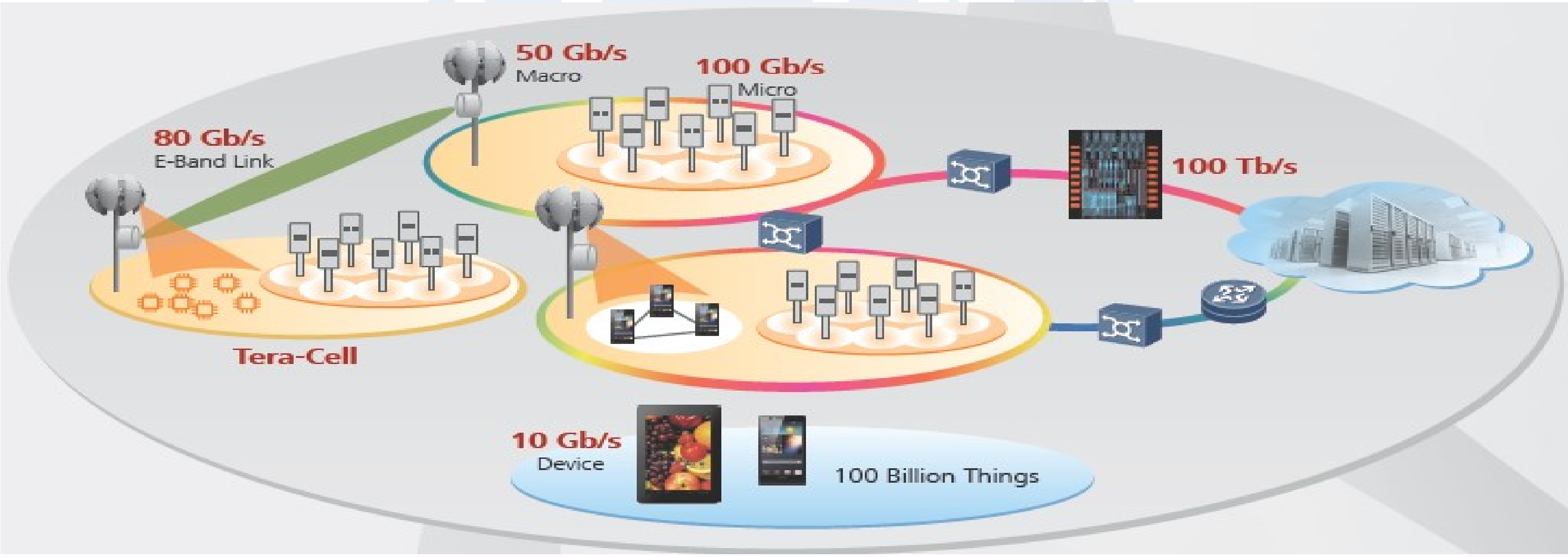
5G Main Objectives



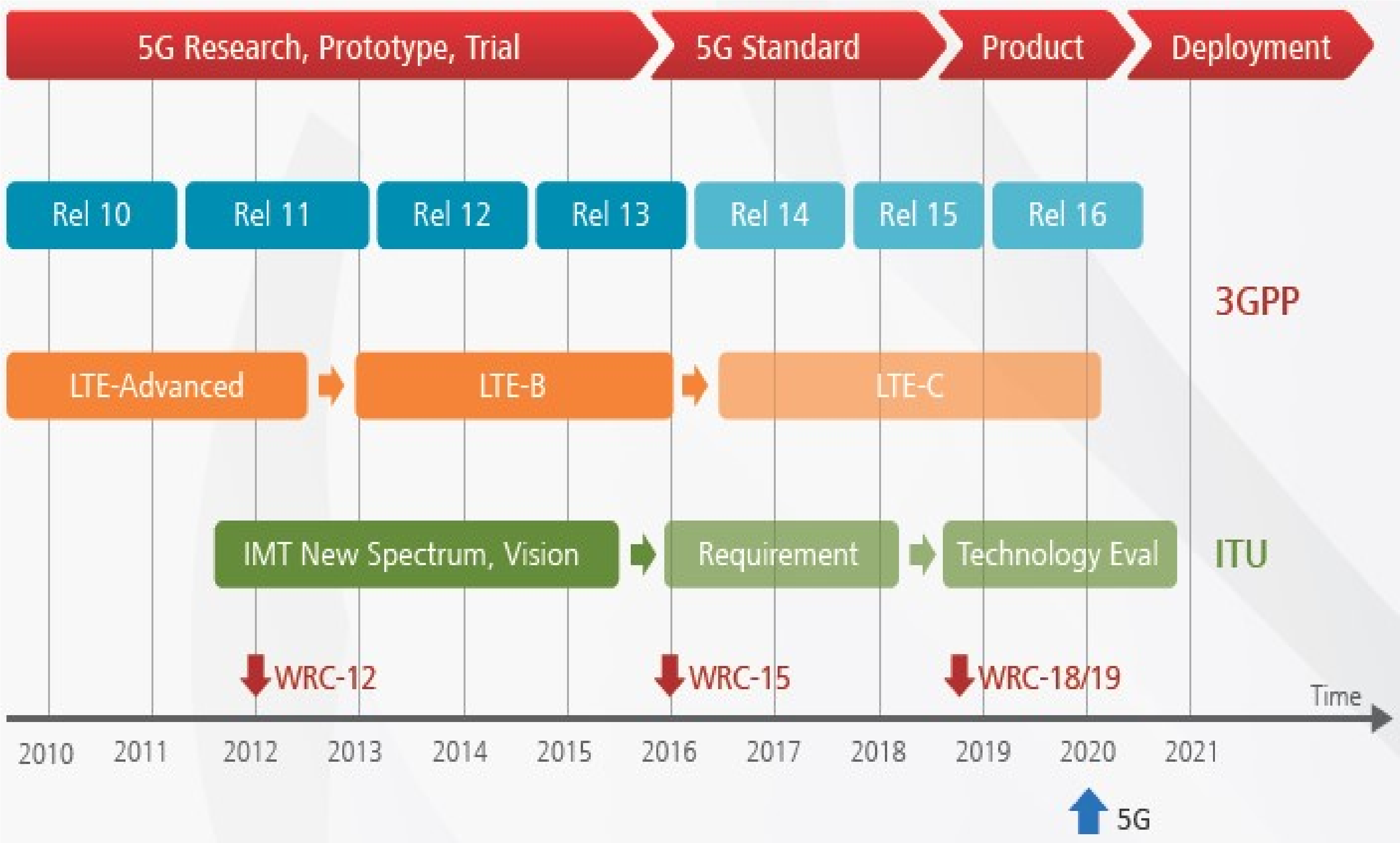
Optimize the bit/s/Hz/m^2/Joule/$

5G objectives and the IoT

- **Ubiquitous, faster, better, stronger**
  - ➢ 10 Gb/s, 1 ms latency
  - ➢ More secure, lower energy consumption, lower operating costs
- **M2M, Internet of Things**
  - ➢ 100B connected objects
- **New services and applications**
  - ➢ SDN, integration with cloud
  - ➢ Innovations yet to be invented

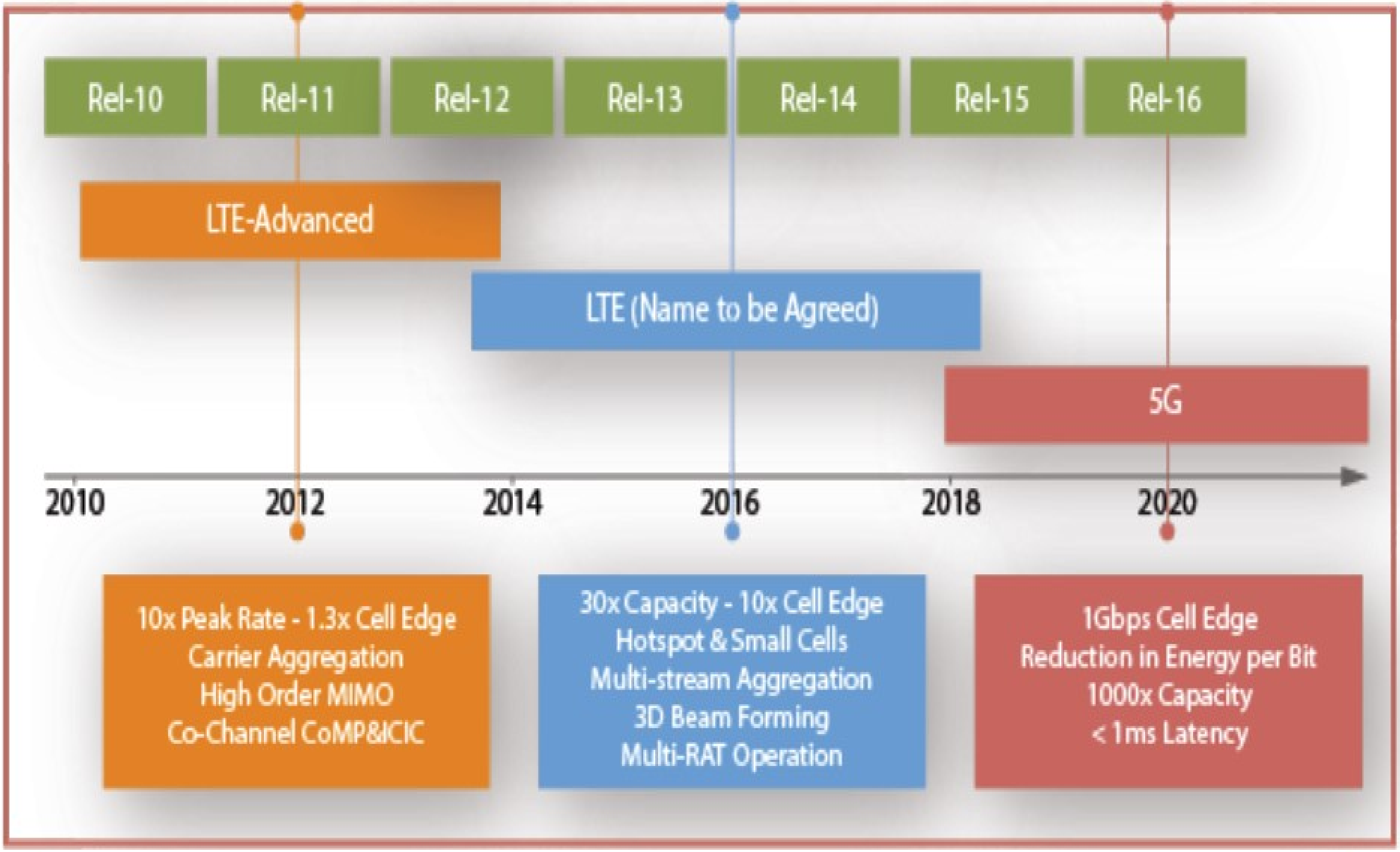


5G Roadmap

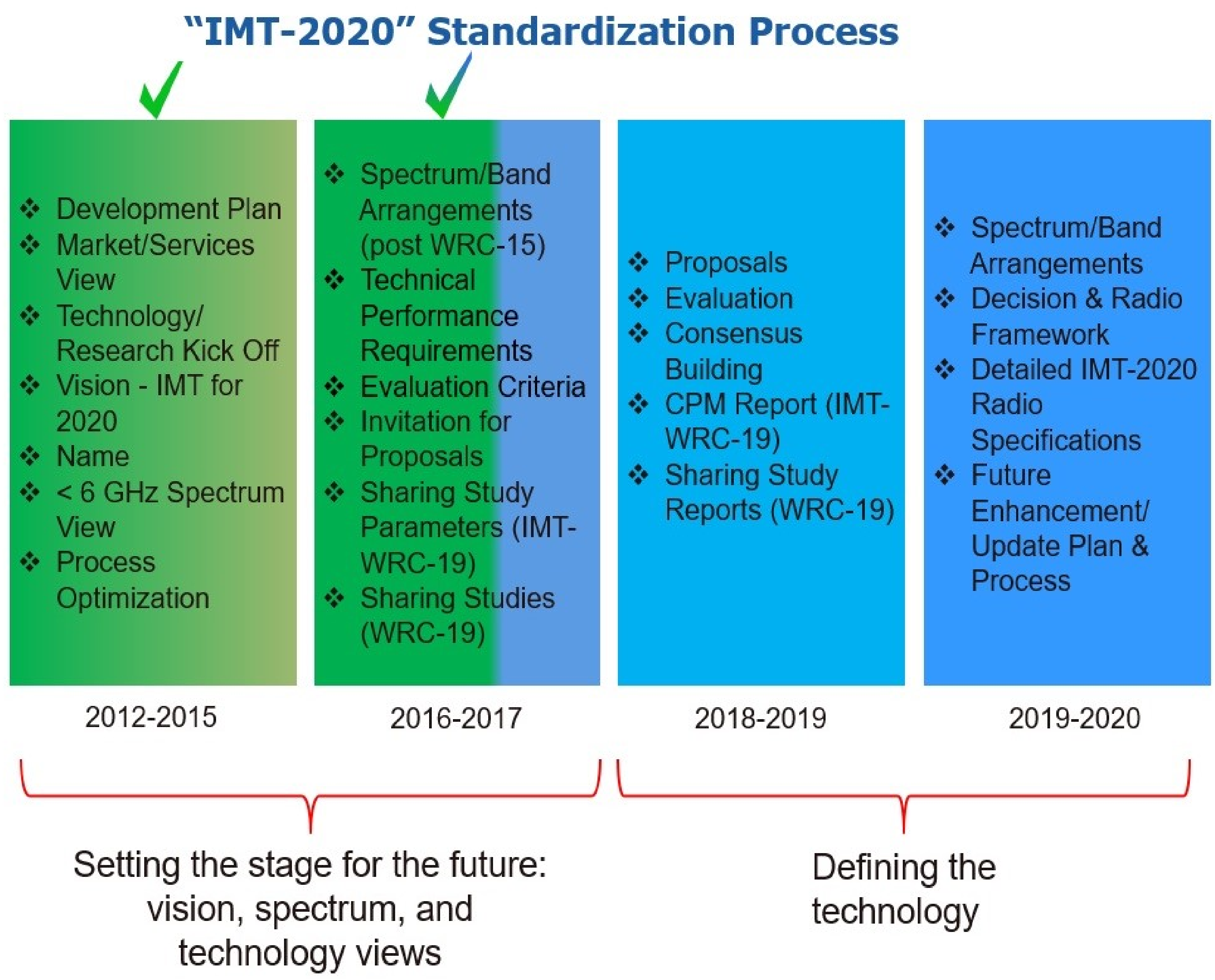


5G Research, Prototype, Trial
5G Standard
Product
Deployment
Rel 10
Rel 11
Rel 12
Rel 13
Rel 14
Rel 15
Rel 16
3GPP
LTE-Advanced
LTE-B
LTE-C
IMT New Spectrum, Vision
Requirement
Technology Eval
ITU
WRC-12
WRC-15
WRC-18/19
Time
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
5G

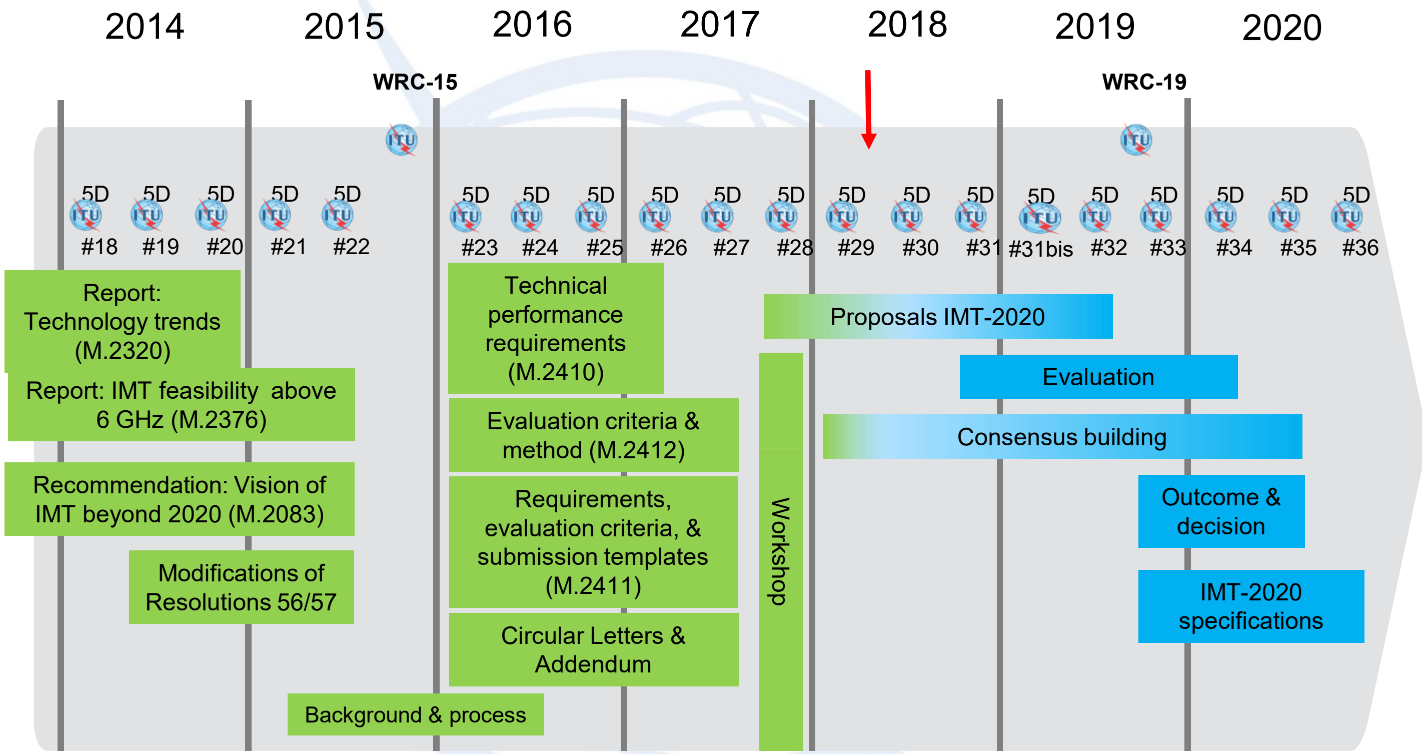
5G and 3GPP Releases evolution



ITU Timetable for IMT2020



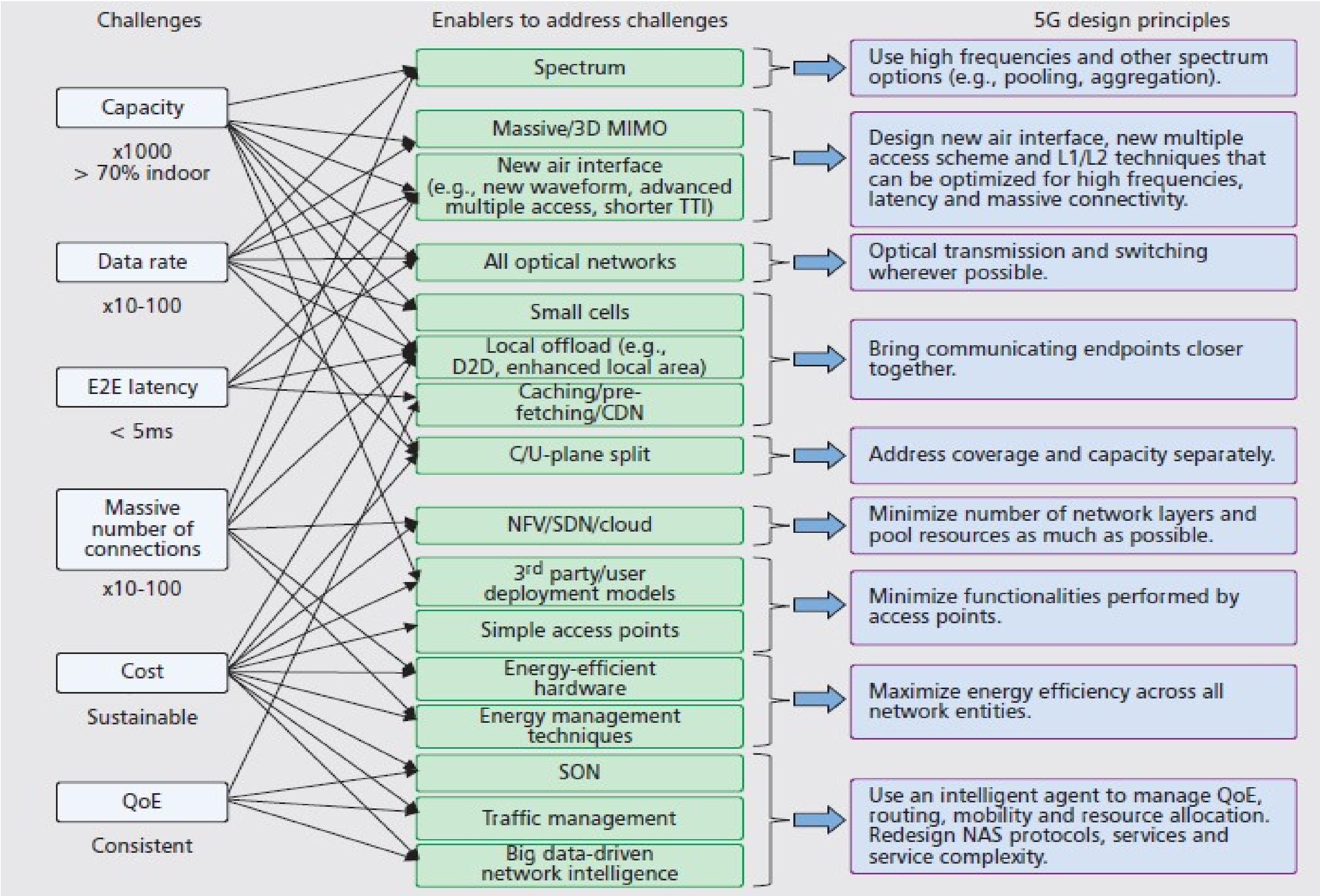
ITU-R WP 5D timeline for IMT-2020
Detailed specifications for the terrestrial radio interfaces



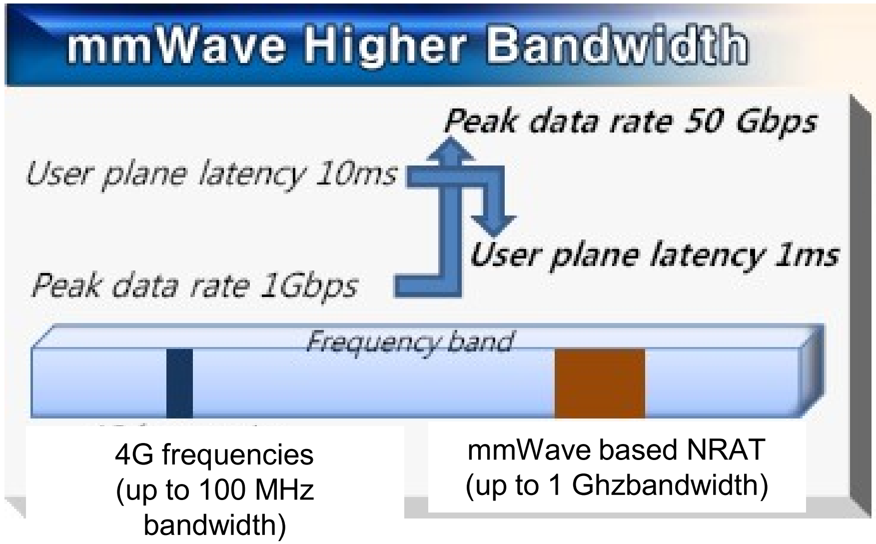
- Initial technology submission: Meeting 32 (**June 2019**)
- Detailed specification submission: Meeting 36 (**October 2020**)

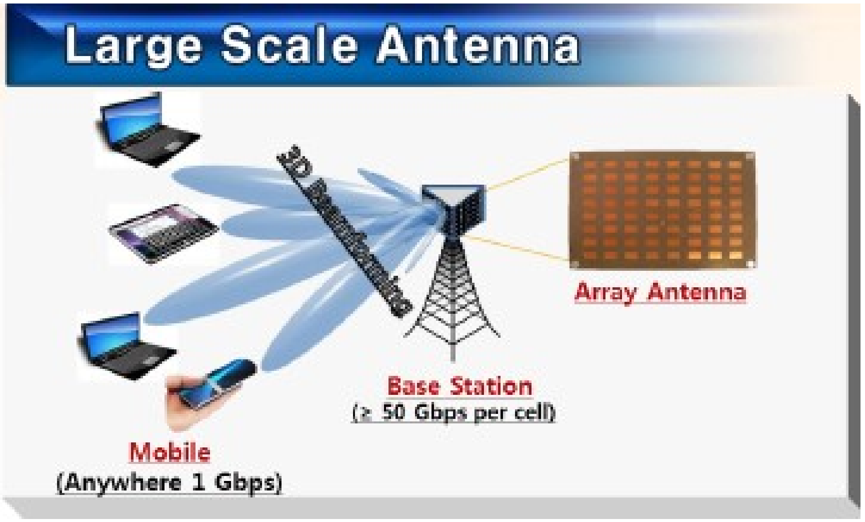
II. Concepts and Technologies

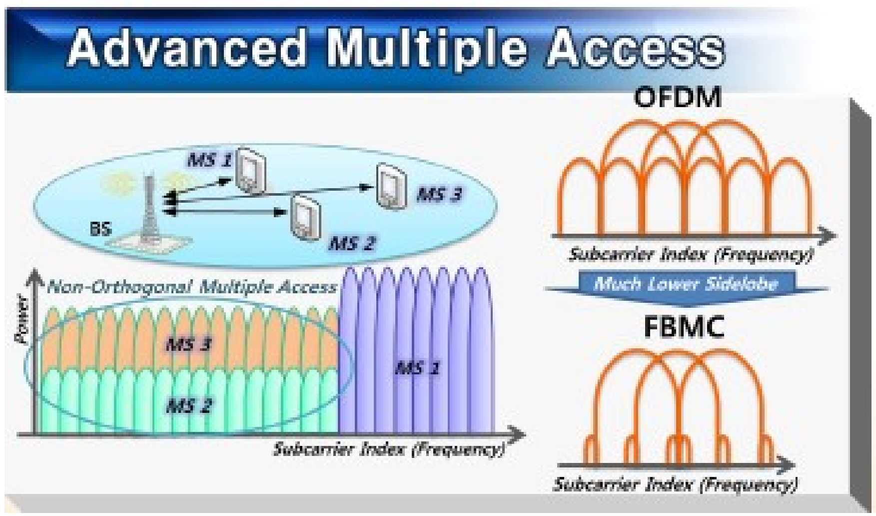
5G challenges, potential enablers, and design principles

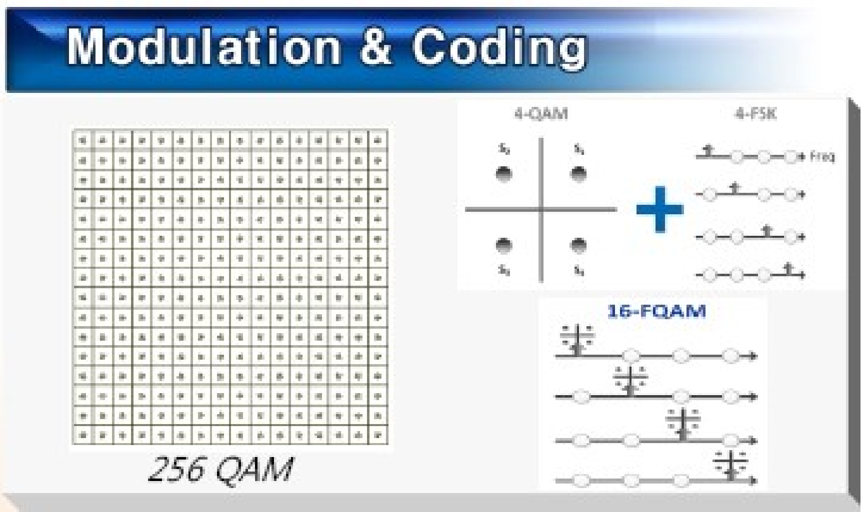


5G Enabling Technologies









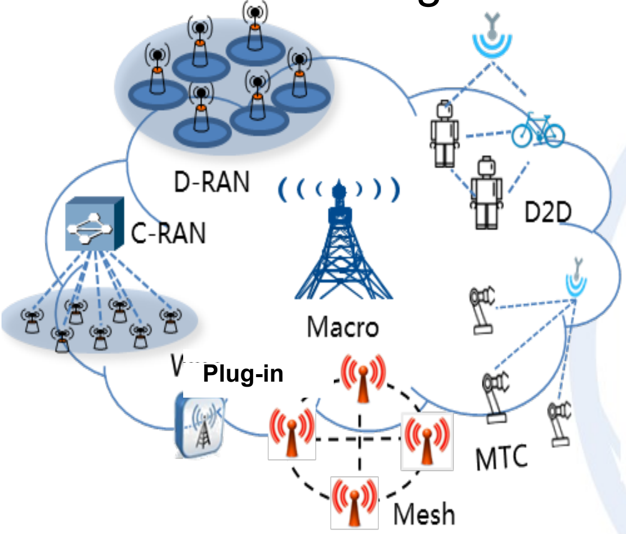
Source: 5G Forum

NRAT: New Radio Access Technology, FBMC: Filter-Bank Multi-Carrier
FQAM: Frequency, Quadrature Amplitude Modulation

5G Network Technology Features

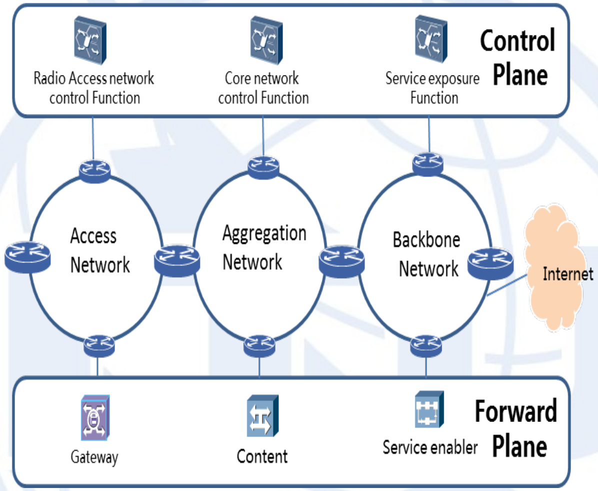
The innovative features of 5G network can be summarized as diversified RAN networking, flexible function deployment, and on-demand slicing.

Diversified RAN networking



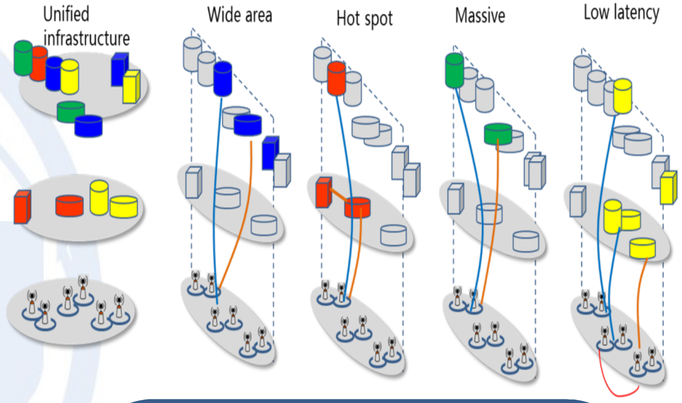
- Support diverse networking mode: C-RAN, D-RAN, mesh,D2D, BS plug-in
- To fit different 5G wireless scenarios

Flexible function deployment



- Modularized Network function
- Network functions can be deployed flexibly based on NFV platform

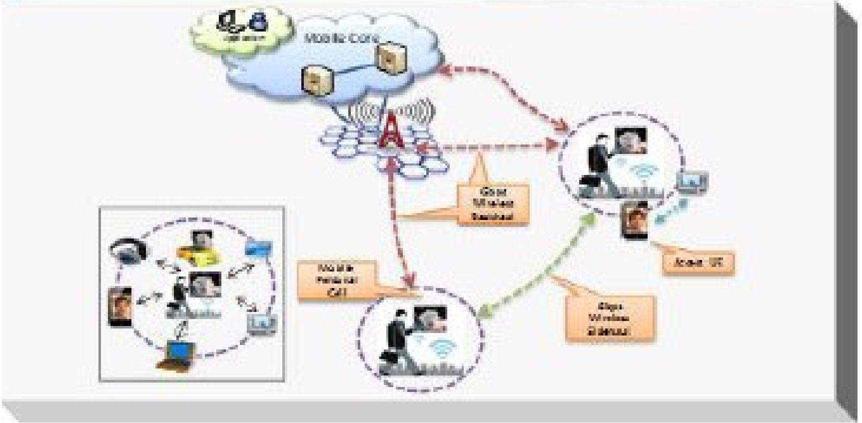
On-demand slicing



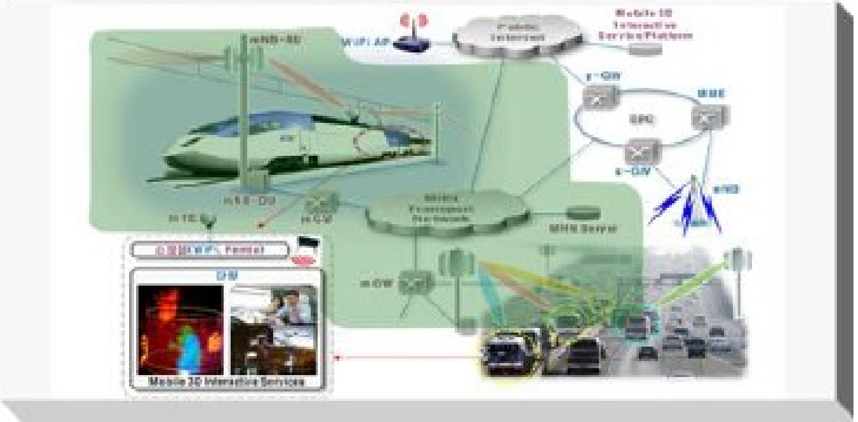
- One Logical Architecture, maps to multiple Service Slices.
- Orchestrating network resource on-demand for each slice.
- Isolated slices ensure efficiency, elasticity, security and robustness

5G Wireless Network Requirements

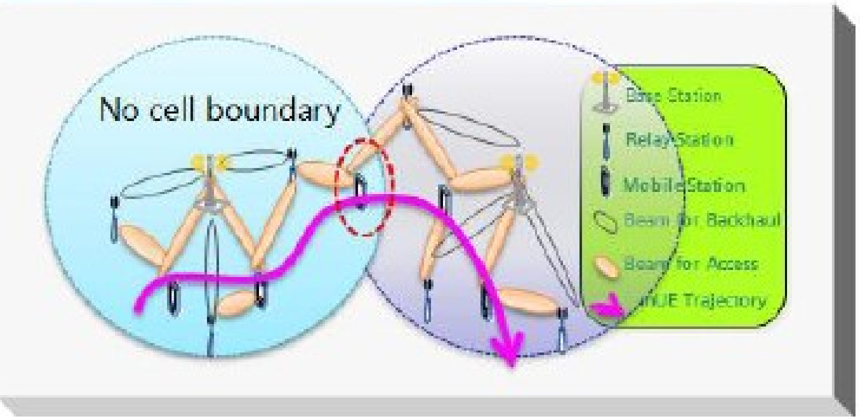
Advanced Small Cell



Moving Backhaul



Fast and Seamless Handover



Fully Distributed Network

Source: 5G Forum

Disruptive Technology Directions for 5G

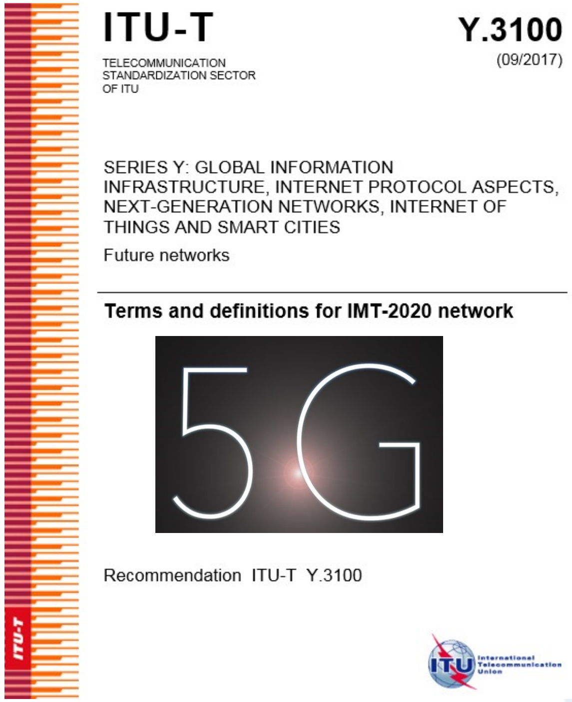
- **Device-centric architectures**: Better routes information flows with different priorities and purposes toward different sets of nodes.
- **Millimeter wave (mmWave)**: mmWave technologies standardized for short-range services and niche applications (small-cell backhaul).
- **Massive MIMO**: very high number of antennas to multiplex messages for several devices on each time-frequency resource, focusing the radiated energy toward the intended directions while minimizing intra and intercell interference.
- **Smarter devices**: 2G-3G-4G cellular networks were built with complete control at the infrastructure side. 5G based on the device intelligence within different layers of the protocol stack (e.g., D2D) or smart caching at the mobile side.
- **Native support for M2M and D2D communication**.
- **SDN and NFV**
- **CloudRAN**

Disruptive Technology Directions for 5G

- **Full duplex**
- **NOMA multiplexing**
- **QAM256**
- **Flexible and powerful nodes at the edge:**
  - Offload the traffic from the core network,
  - Manage data flows efficiently by dynamically adjusting network resources to insure high QoE for each application flow.
- **Mobile Edge Computing (MEC):** More content cached at the edge (reduces core network traffic at BH and reduces latency).
- **Optimized content delivery, Pre-caching of user generated content and Internet content** based on estimated popularity, social trends and used presence and preferences. Better utilize network pipelines based on context information.

ITU IMT2020 Concepts

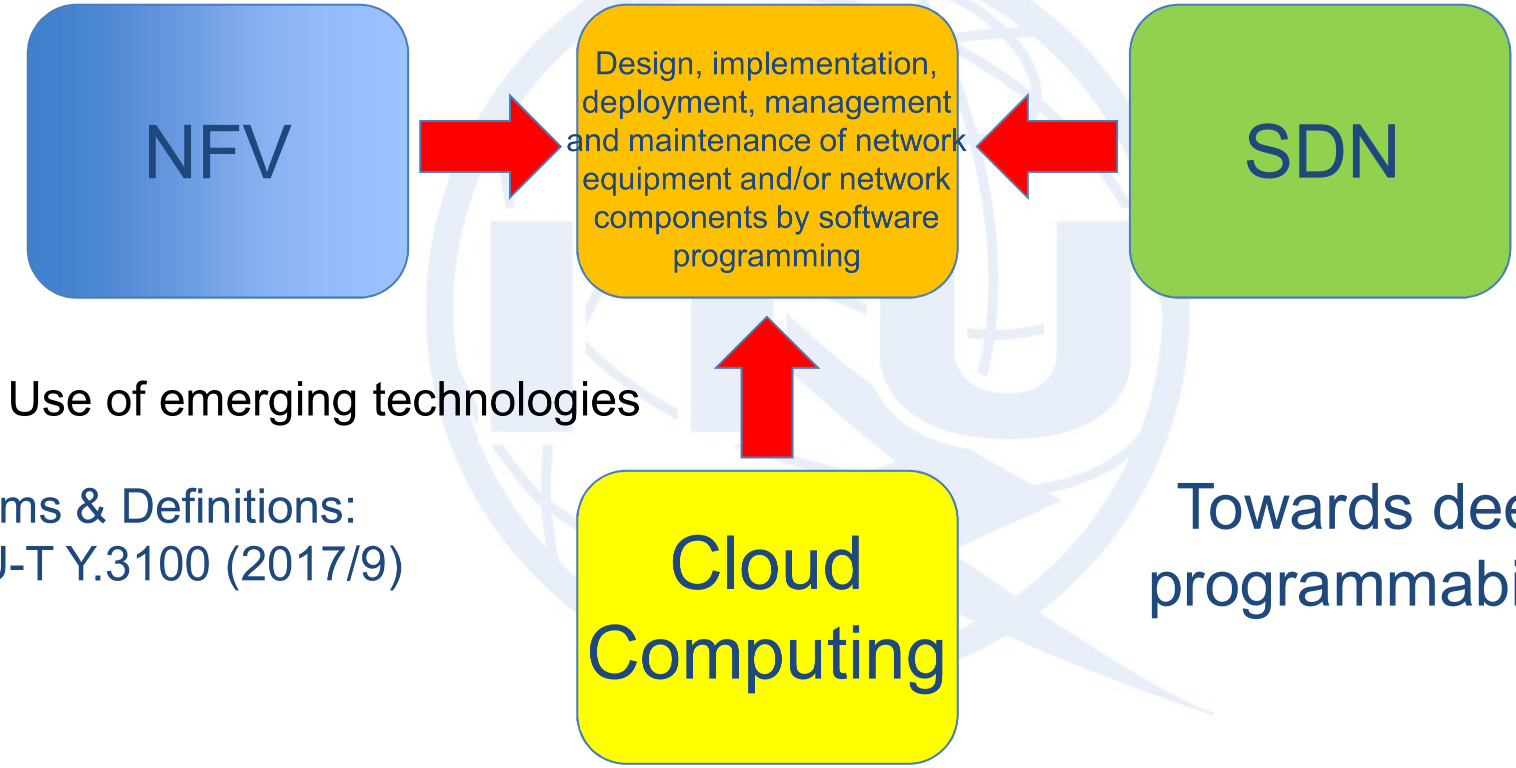
Softwarization, Slicing, and FMC



- **Softwarization:** Designing, implementing, deploying, managing and maintaining networks using software
- **Slicing, e.g. separate slices for**
  - voice communications
  - automated driving
  - wide range of other use cases
- **Fixed Mobile Convergence:** Network architecture to support fixed / mobile convergence, with seamless user experience

Network softwarization

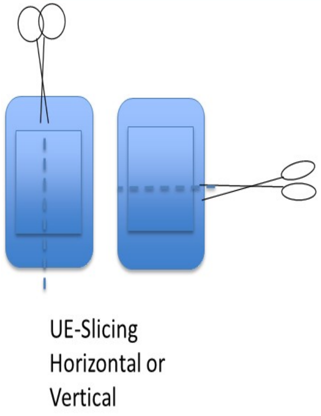
Enabling the (re-)design of network and services architectures, optimizing costs and processes, enabling self-management.

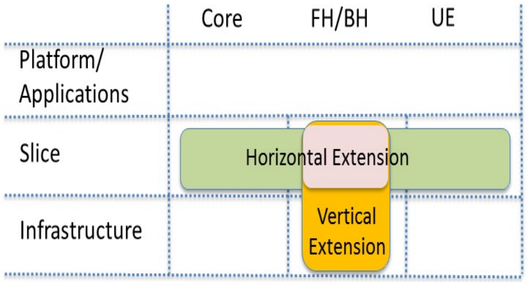


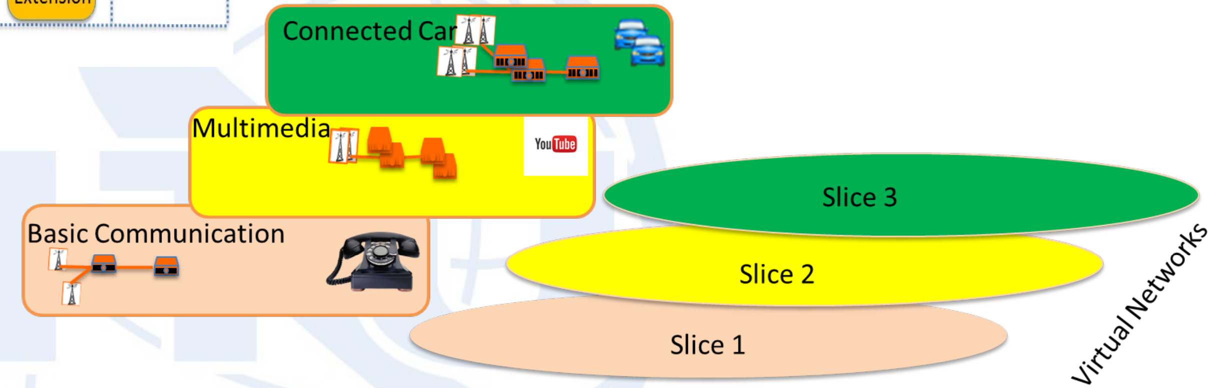
Terms & Definitions:
ITU-T Y.3100 (2017/9)

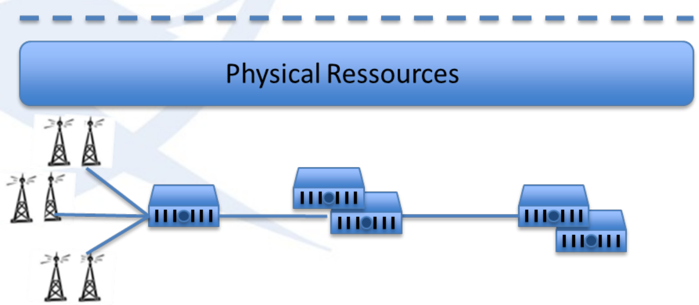
Towards deep programmability

Network slicing general principles



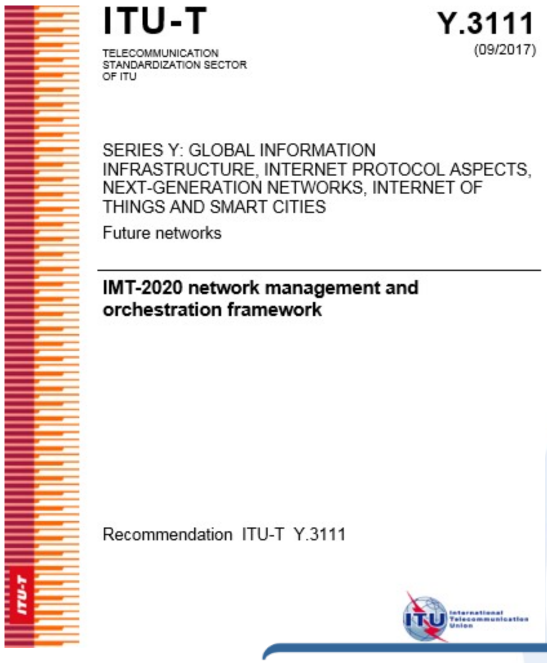






Network slice [ITU-T Y.3100 (2017/9)]: A logical network that provides specific network capabilities and network characteristics.

5G Network Slice



ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

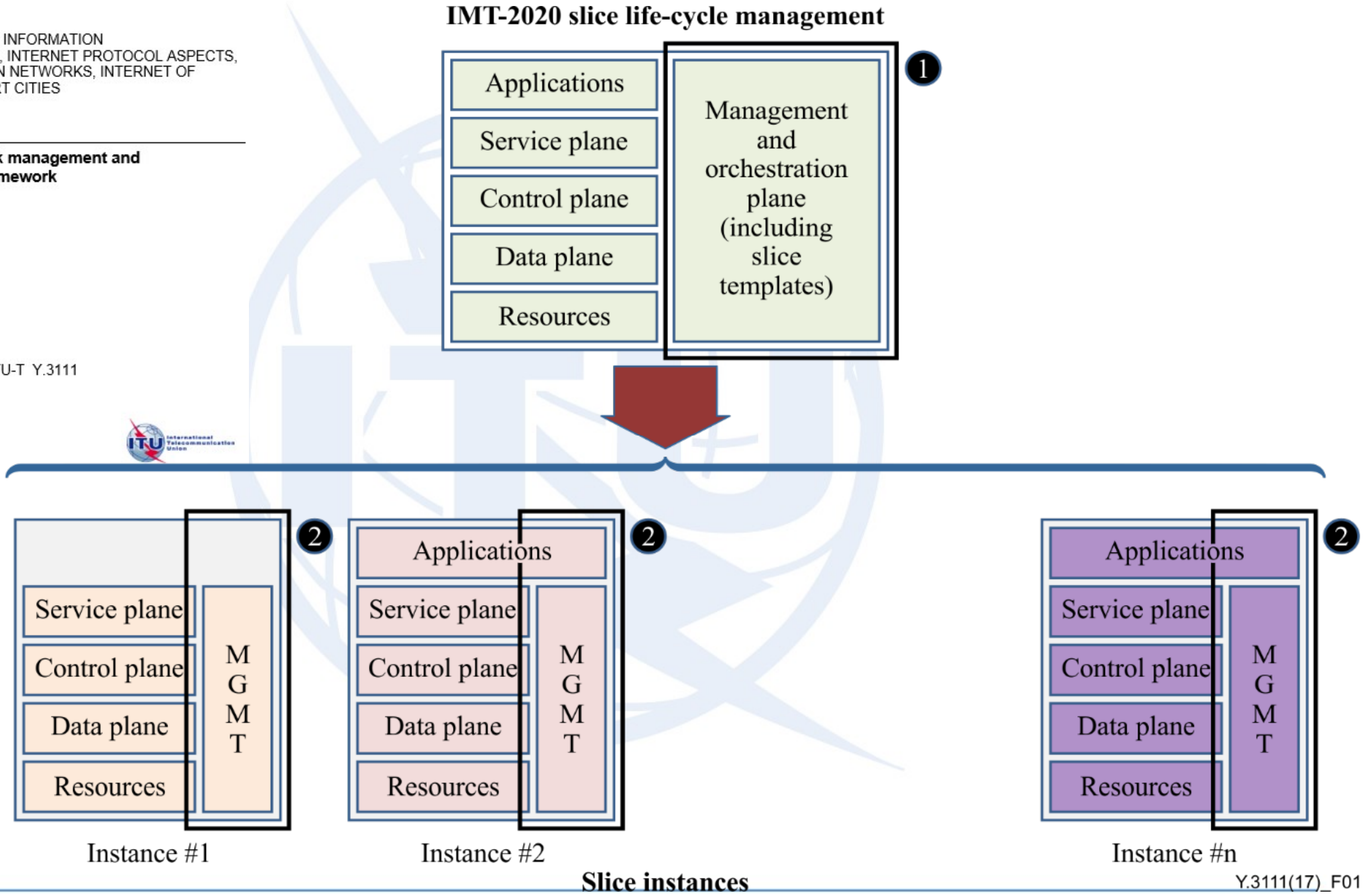
Y.3111
(09/2017)

SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

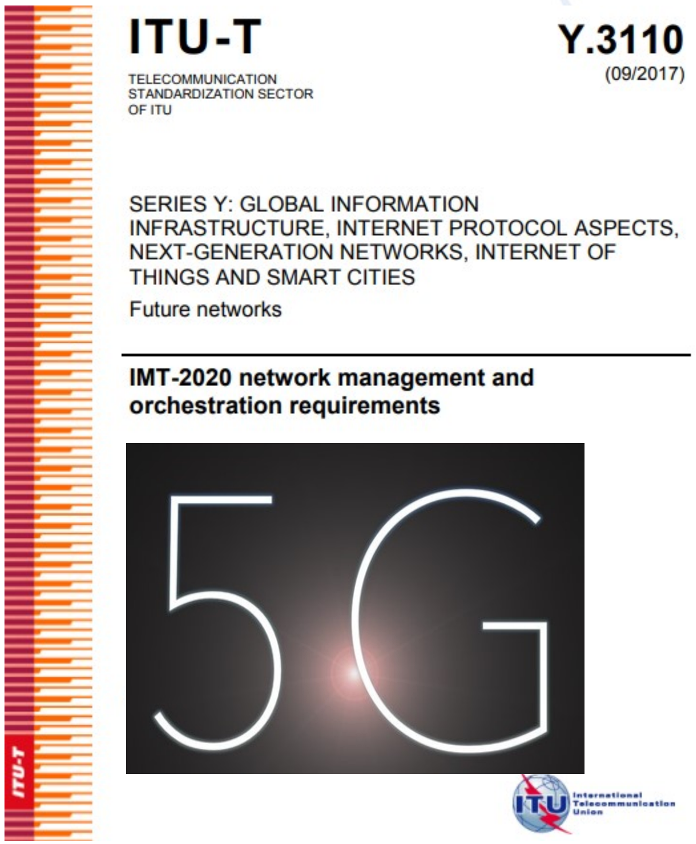
Future networks

IMT-2020 network management and orchestration framework

Recommendation ITU-T Y.3111

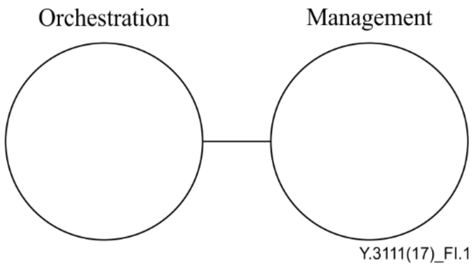


5G Network Management and Orchestration

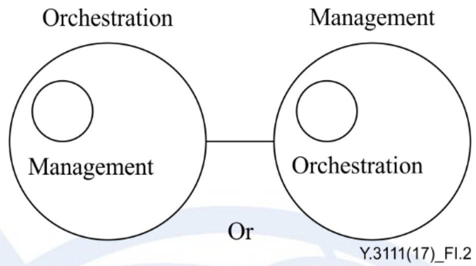


- **Management:** In the context of IMT-2020, the processes aiming at fulfillment assurance, and billing of services, network functions, and resources in both physical and virtual infrastructure including compute, storage, and network resources.
- **Orchestration**: In the context of IMT-2020, the processes aiming at the automated arrangement, coordination, instantiation and use of network functions and resources for both physical and virtual infrastructure by optimization criteria.

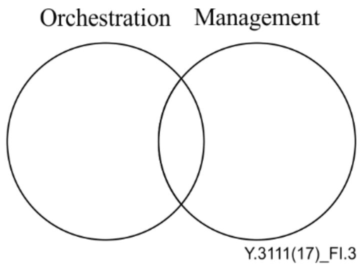
5G Network Orchestration vs Management



1. Independent orchestration and management



2. Management/orchestration includes the other

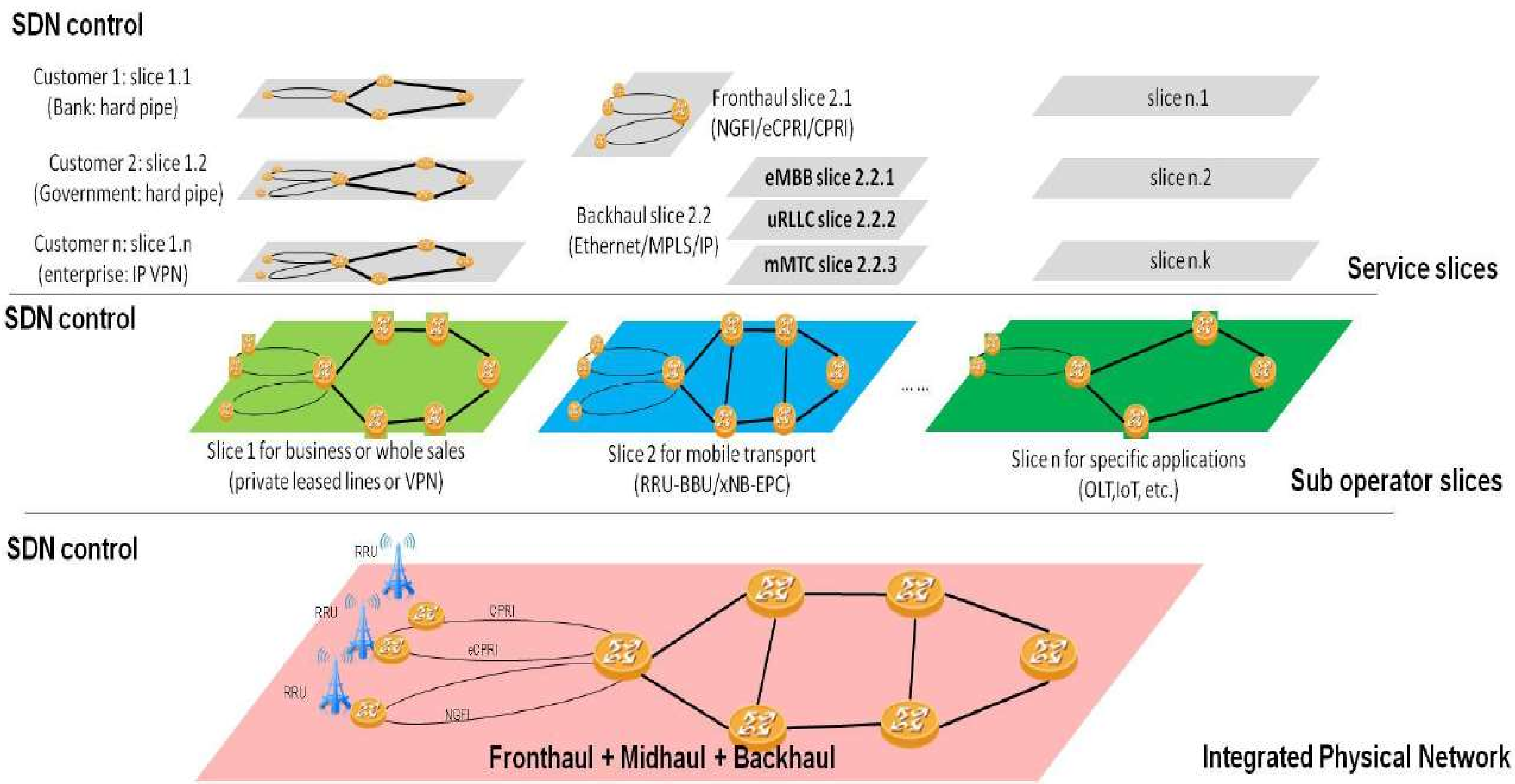


3. Orchestration and management with an intersection

	Orchestration	Management
Monitoring purpose	Availability	Healthiness
Action purpose	Provisioning	Maintaining
Representative actions	Control/Configuration Create/Destroy/Move	Monitor/Alarm for event Detection/Isolation/Resolve for fault
Target resources	Dissimilar devices	Similar devices

IMT2020/ 5G transport aspects (ITU-T Study Group 15)

Studies related to transport layer of IMT20207 5G networks including application of slicing techniques in the transport



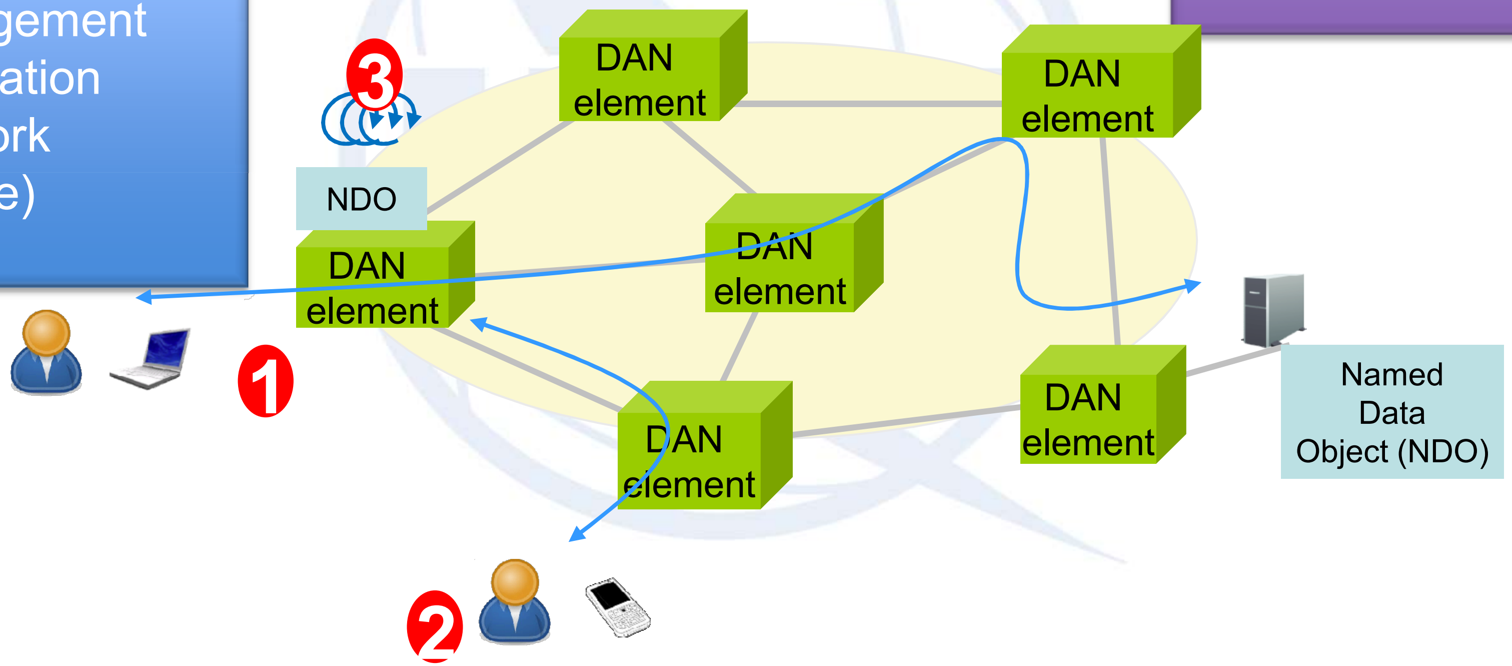
Source: China Mobile

DAN and ICN

New networking technology: Data Aware Networking (DAN) (aka Information Centric Networking (ICN))

ICN capabilities
- Data
- Control
- Security
- Management
- Application (network service)

ITU-T Y.3071 on requirements and capabilities of ICN (2017/3)



3GPP Release 15

5G New Radio (NR) specifications in Release 15

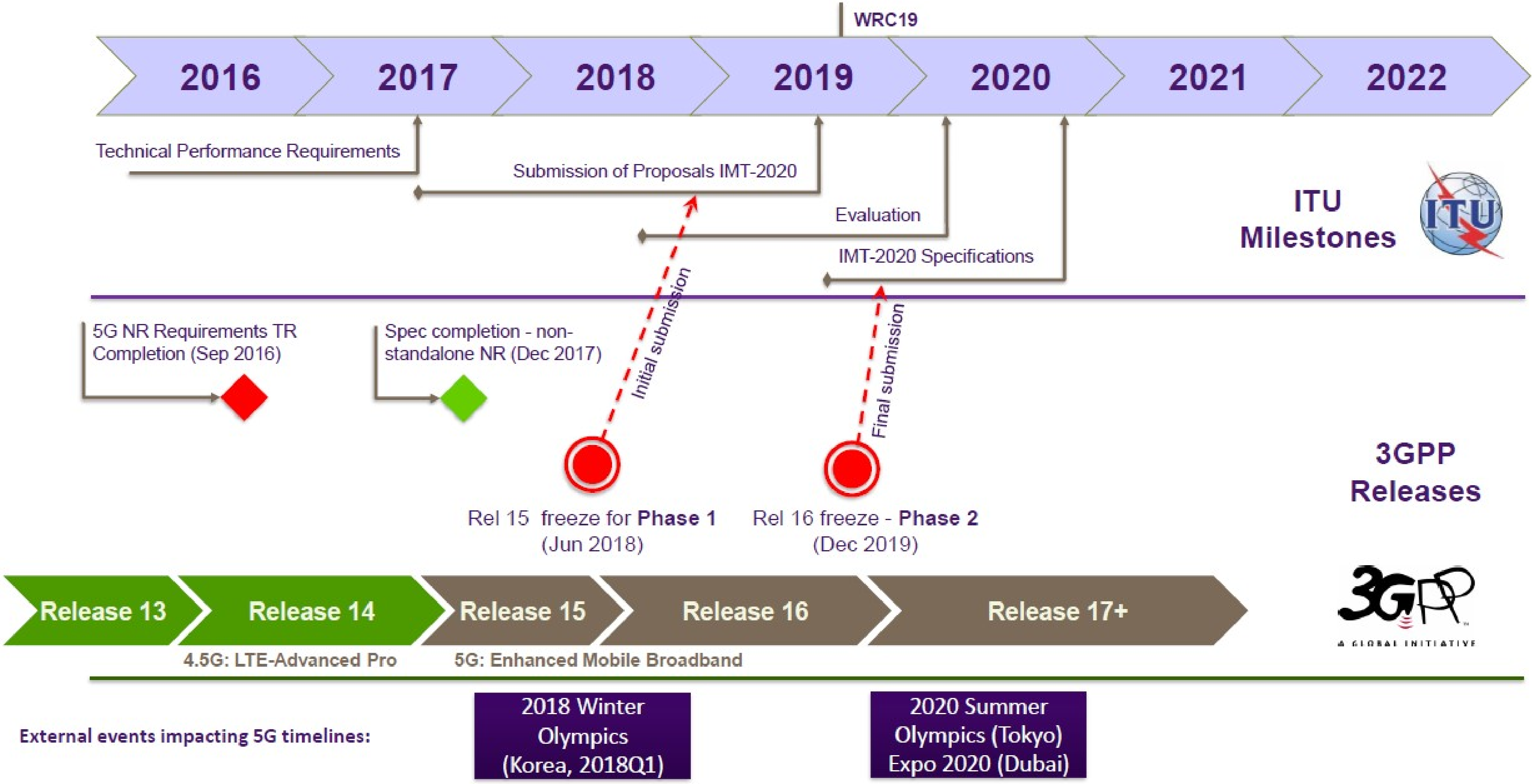
- Scope:
  - **Standalone** (full control plane and data plane functions are provided in NR) and **Non-Standalone NR** (control plane functions of LTE and LTE-A are utilized as an anchor for NR) Operations
  - **Spectrum Below and Above 6 GHz**
  - **Enhanced Mobile Broadband** (eMBB: supports high capacity and high mobility (up to 500 km/h) radio access (with 4 ms user plane latency)
  - **Ultra-Reliable and Low Latency Communications** (URLCC): provides urgent and reliable data exchange (with 0.5 ms user plane latency).
  - **Massive Machine-Type Communications** (mMTC): infrequent, massive, and small packet transmissions for **mMTC** (with 10 s latency).

Preliminary 5G (NR) KPIs

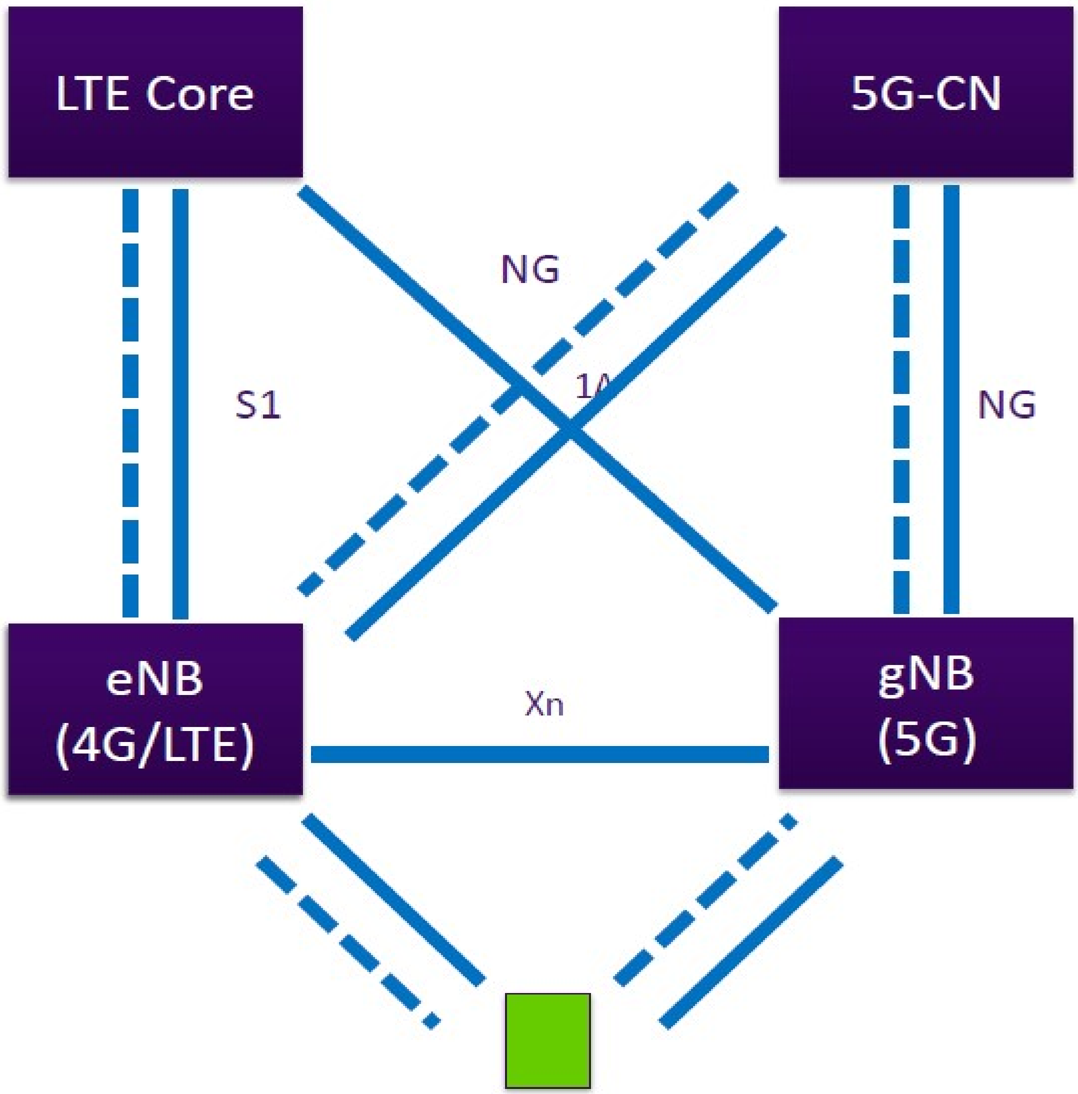
Item	Value
Peak data rate	20 Gbps for downlink, 10 Gbps for uplink
Peak spectral efficiency	30bps/Hz for downlink and 15bps/Hz for uplink
Bandwidth	Up to 1 GHz (DL+UL). Pending ITU-R
Control plane latency	10ms
User plane latency	URLLC: 0.5ms for DL and 0.5ms for UL, eMBB: 4ms for DL and 4ms for UL
Latency for infrequent small packets	No worse than 10 ms
Mobility interruption time	0ms
Inter-system mobility	At least with LTE/LTE evolution (other systems TDB)
Reliability	99.999% for URLLC and eV2X
Coverage	UL link budget will provide at least the same MCL as LTE
UE battery life for mMTC	>10 years requirement, 15 years desirable
Cell/Cell edge spectral efficiency	3x spectral efficiency of IMT-Advanced
Connection density	1000000 device/km2 in urban environment
Mobility	500 km/h

3GPP TR 38.913 (Draft 2016-09)

5G Timelines: ITU-R and 3GPP



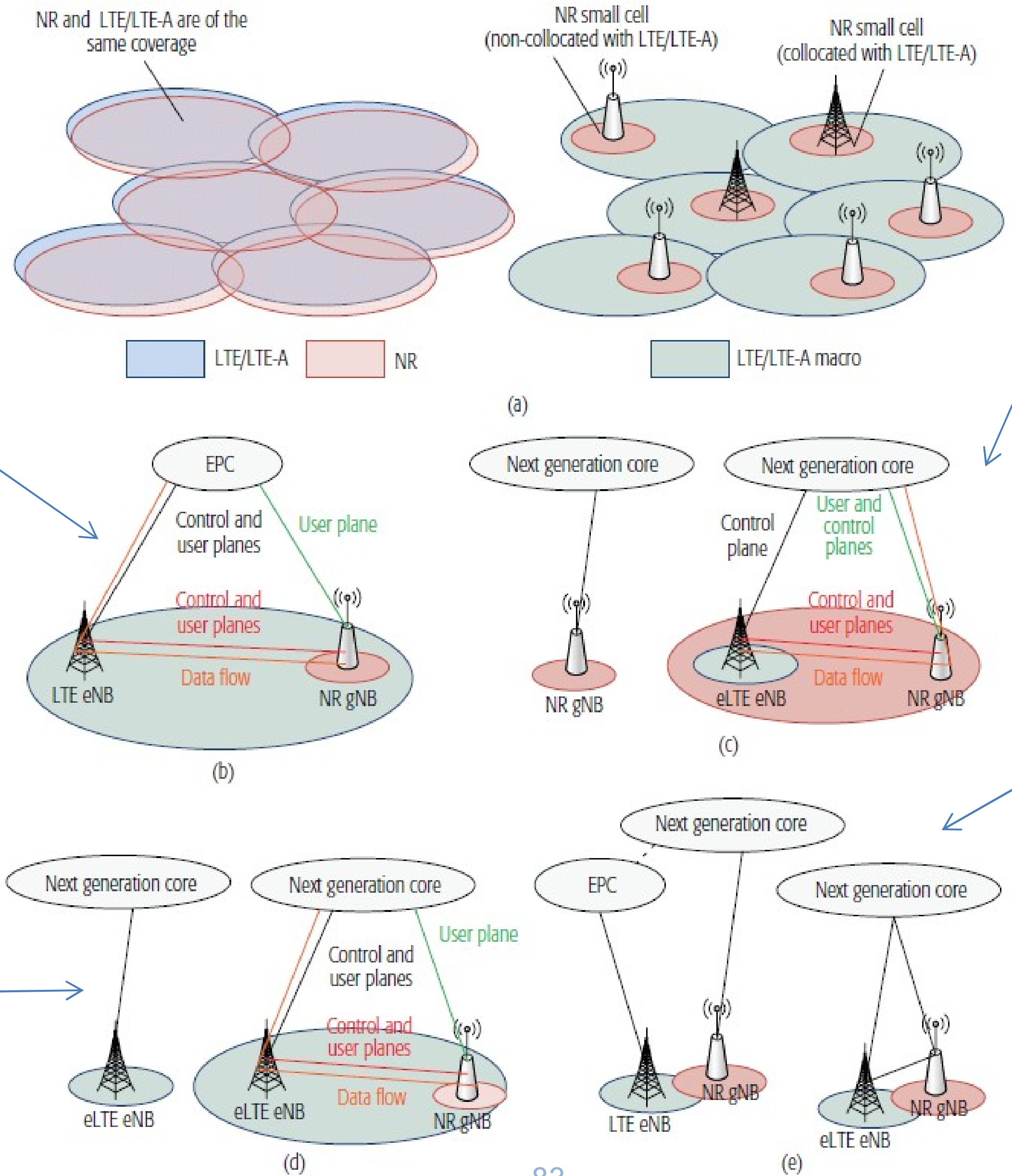
5G Architecture Evolution



Deployment scenarios of NR

LTE/LTE-A eNB Is a Master Node: An LTE/LTE-A eNB offers an anchor carrier (control and user planes), and an NR gNB offers a booster carrier. Data flow aggregates across an eNB and a gNB via the EPC

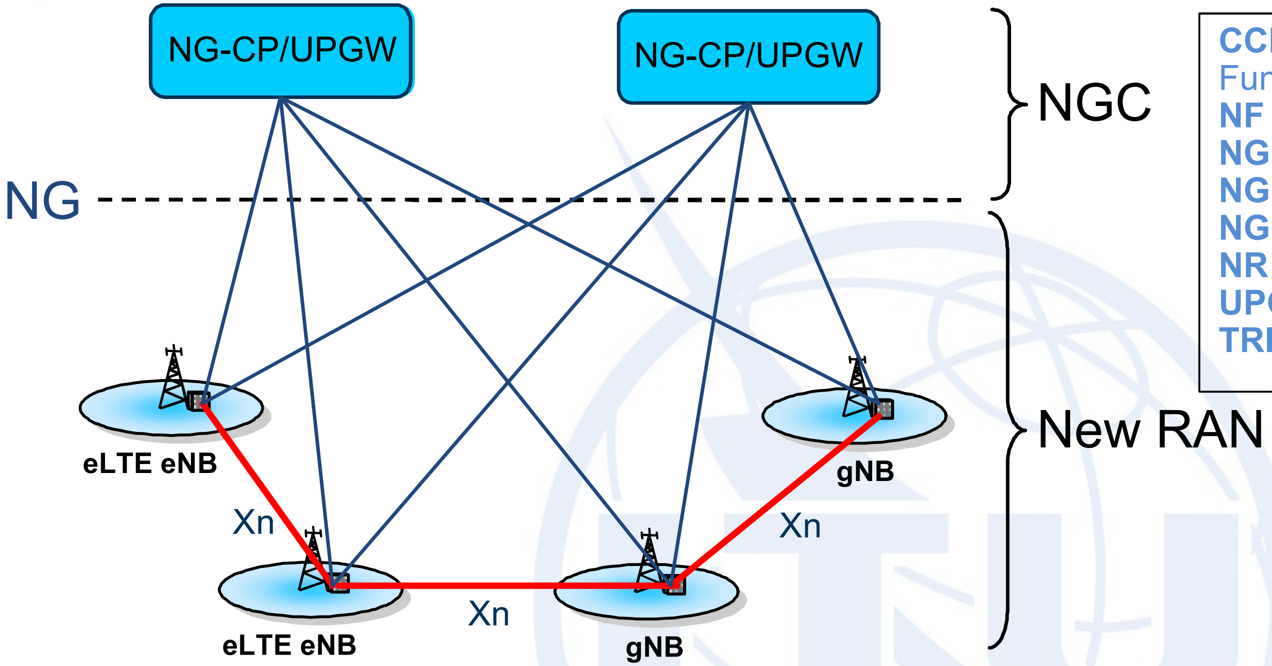
eLTE eNB Is a Master Node: A standalone eLTE eNB offers wireless services (control and user planes) via the NG core, or a collocated NR gNB is able to provide booster carriers



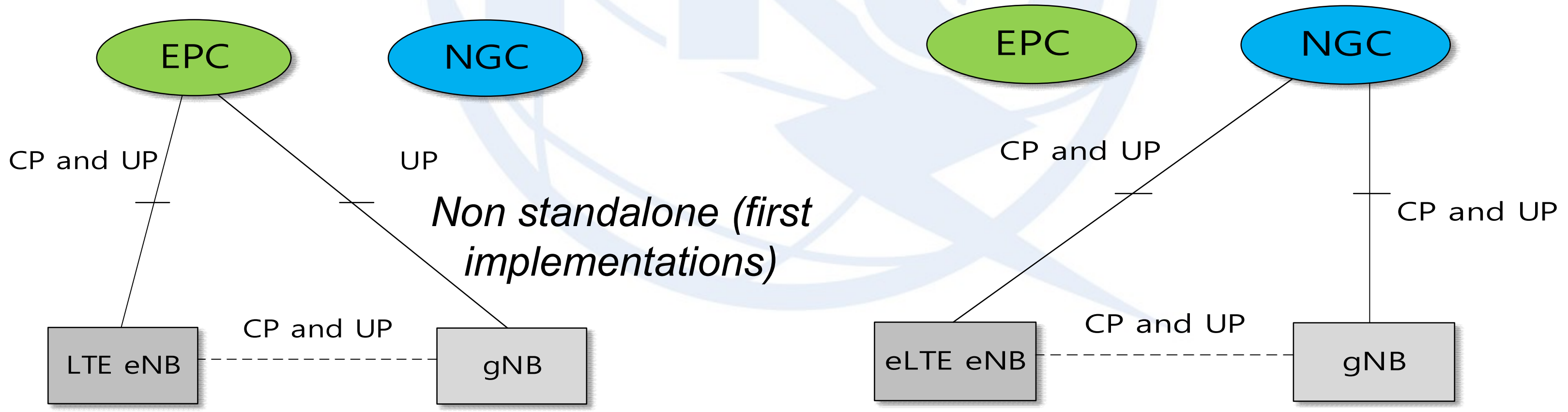
NR gNB Is a Master Node: A standalone NR gNB offers wireless services (control and user planes) via the NG core. A collocated enhanced LTE (eLTE) eNB is able to additionally provide booster carriers for dual connections

Inter-RAT HO between (e)LTE/LTE-A eNB and NR gNB: An LTE/LTE-A eNB connects to the EPC, and an NR gNB connects to the NG core to support HO between eNB and gNB. An eLTE eNB can also connect to the NG core, and HO between eNB and gNB can be fully managed through the NG core

New RAN architecture



CCNF Common Control Network Function
NF Network Function
NGC Next Generation Core
NG-C NG Control Plane interface
NG-U NG User Plane interface
NR New Radio
UPGW User Plane Gateway
TRP Transmission Reception Point



Non standalone (first implementations)

E-UTRA and NR connected to the EPC

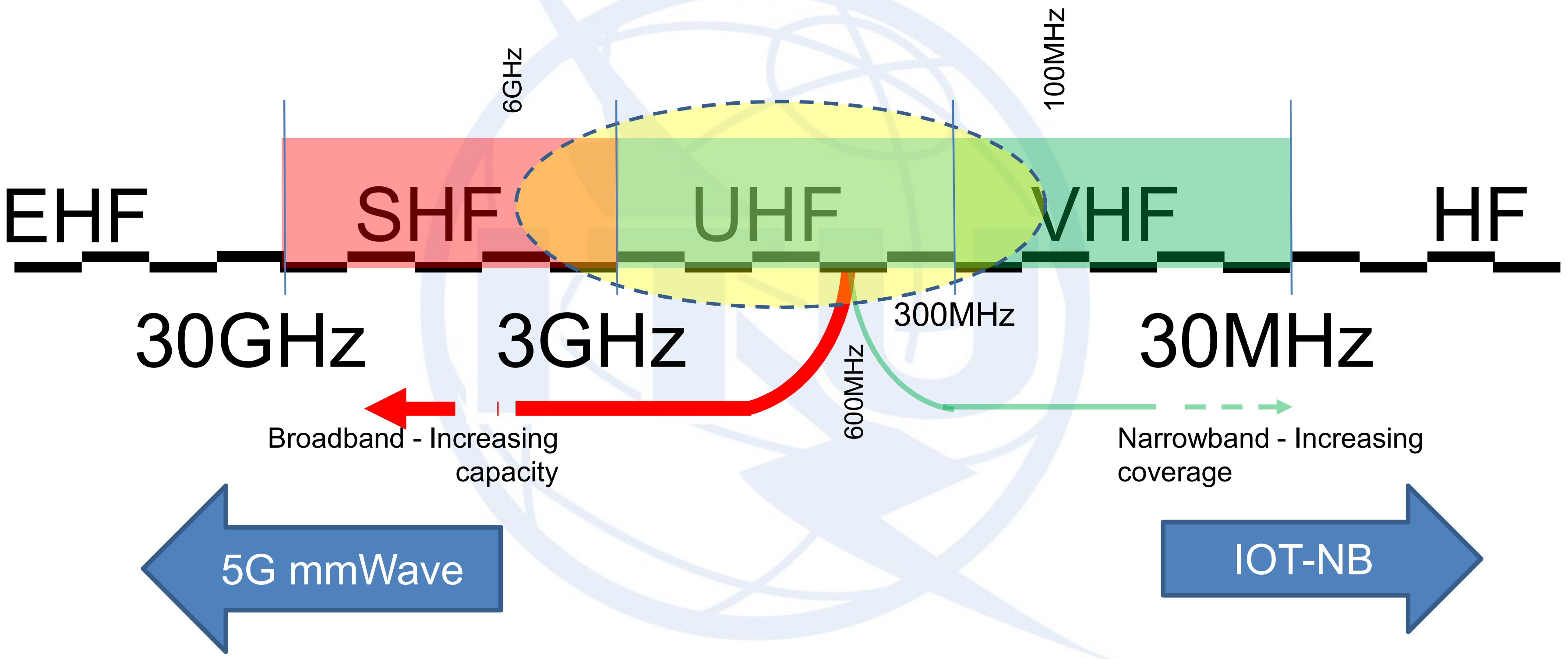
E-UTRA and NR connected to the NGC

5G Radio Features

Directions to increase mobile data traffic volume

- 3GPP has encouraged the research community to move in 3 directions:
  - **Spectral efficiency improvement**: includes CoMP, MIMO, techniques and interference management mechanisms.
  - **Higher network cell density**: addition of extra layer cells in the network with BSs that cover smaller areas compared to macro and micro BSs.
  - **Exploitation of underutilized radio spectrum resources**

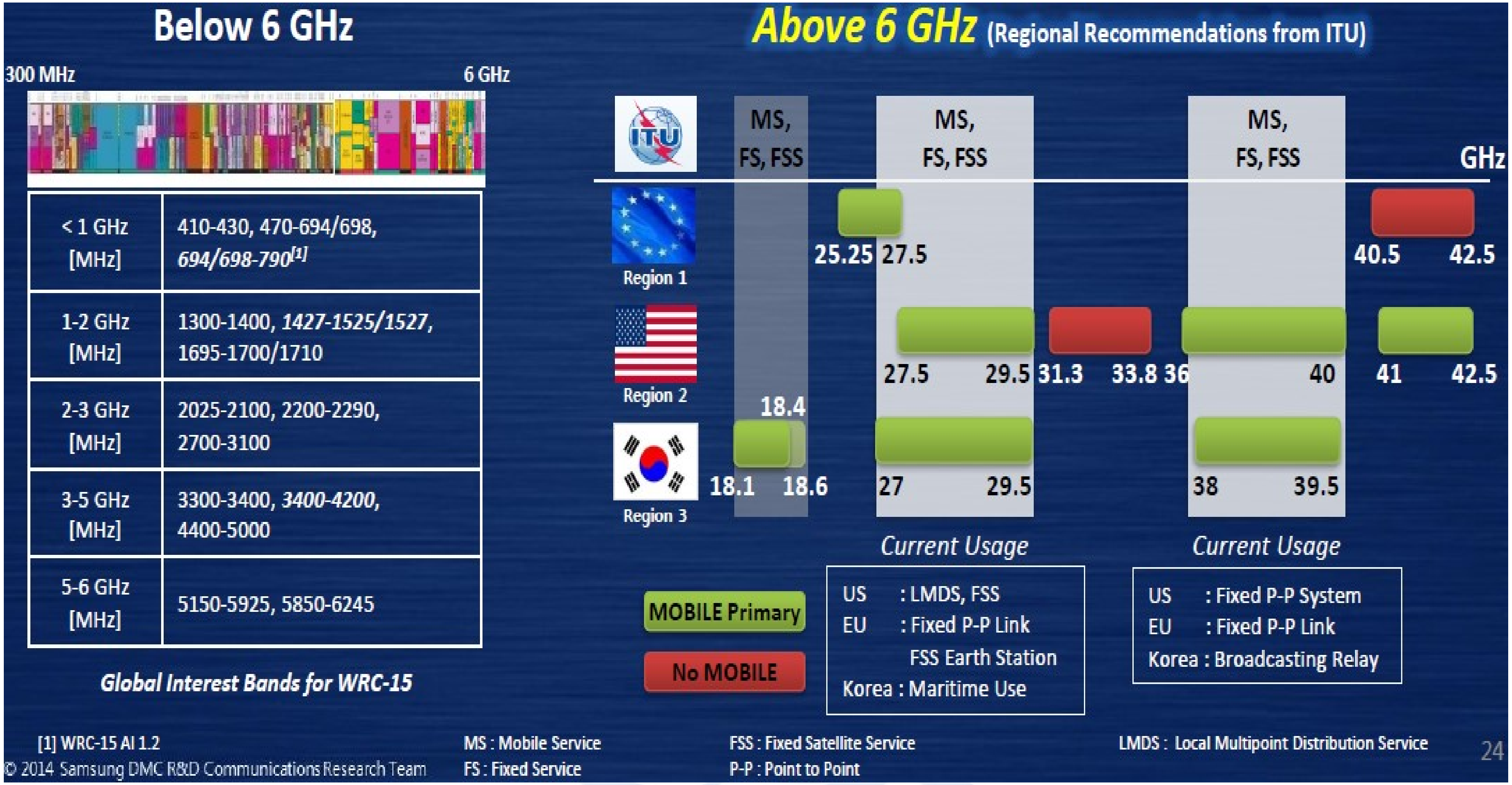
5G Radio Frequency Spectrum



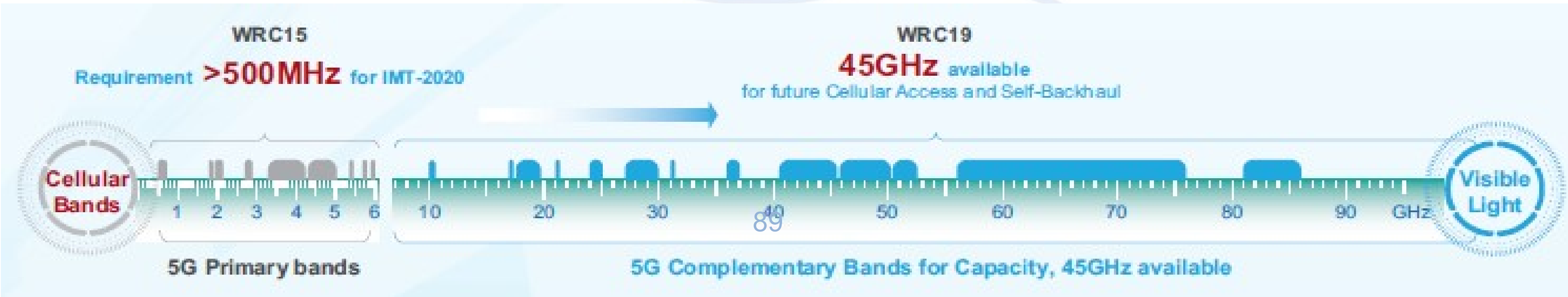
System configuration for LTE-A and 5G systems from 6-100 GHz

Parameter	LTE-Advanced	cmWave	mmWave
Frequency band	≤6 GHz	6-30 GHz	30-100 GHz
Carrier bandwidth	100 & 200 MHz	500 MHz	2 GHz
Modulation order	64 QAM	256 QAM	64 QAM
MIMO combination	8x8	8x8	2x2
SU-MIMO rank	8	8	2
MU-MIMO rank	2	2	2
Antenna configuration	10x1 AAS 8 antenna ports MIMO (macro)	Omni directional 4 antenna ports	4x4 AAS 4 sectors 2 antenna ports

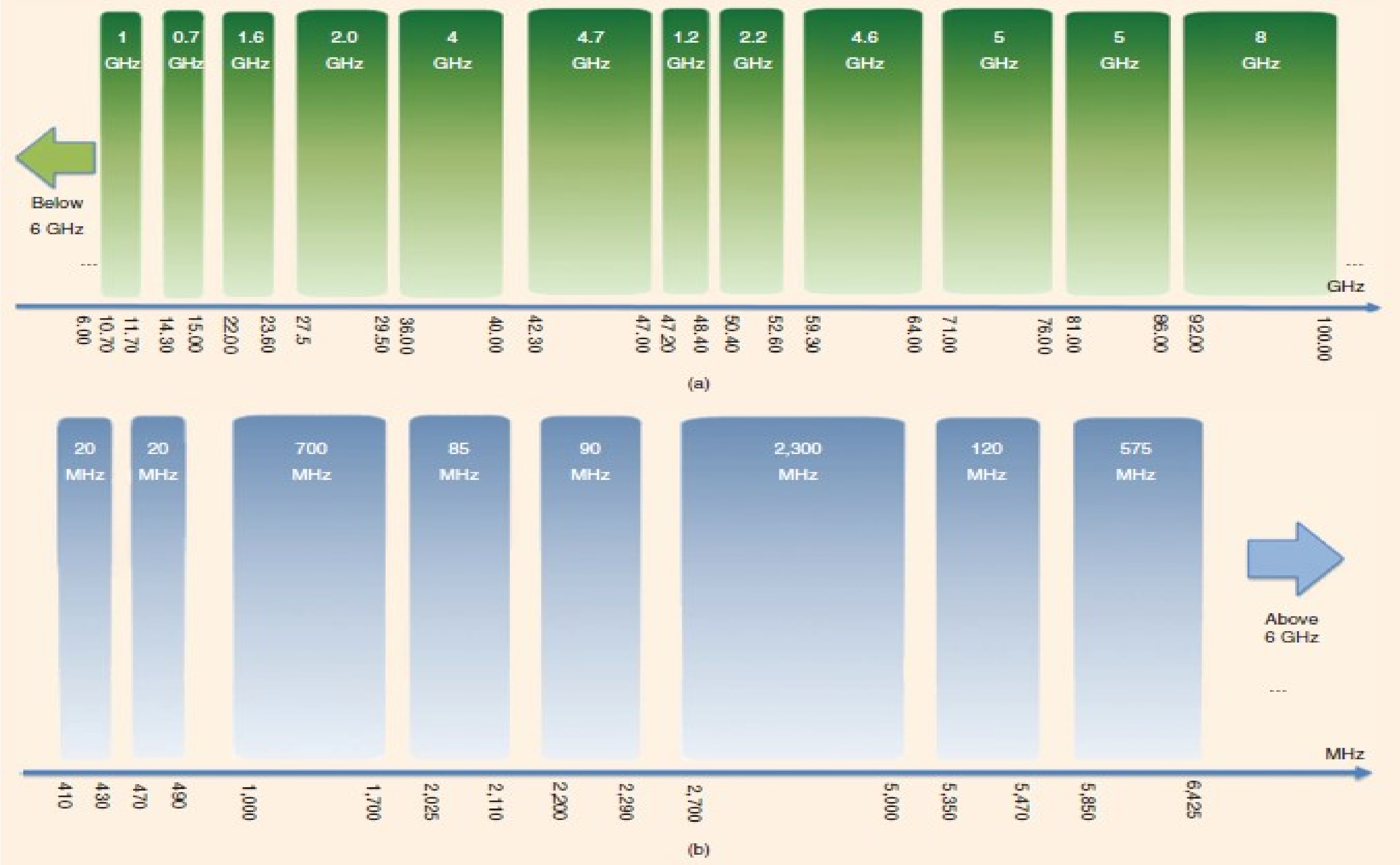
Identified frequency bands



< 1 GHz [MHz]	410-430, 470-694/698, *694/698-790*[1]
1-2 GHz [MHz]	1300-1400, *1427-1525/1527*, 1695-1700/1710
2-3 GHz [MHz]	2025-2100, 2200-2290, 2700-3100
3-5 GHz [MHz]	3300-3400, *3400-4200*, 4400-5000
5-6 GHz [MHz]	5150-5925, 5850-6245



Candidate frequency bands for 5G



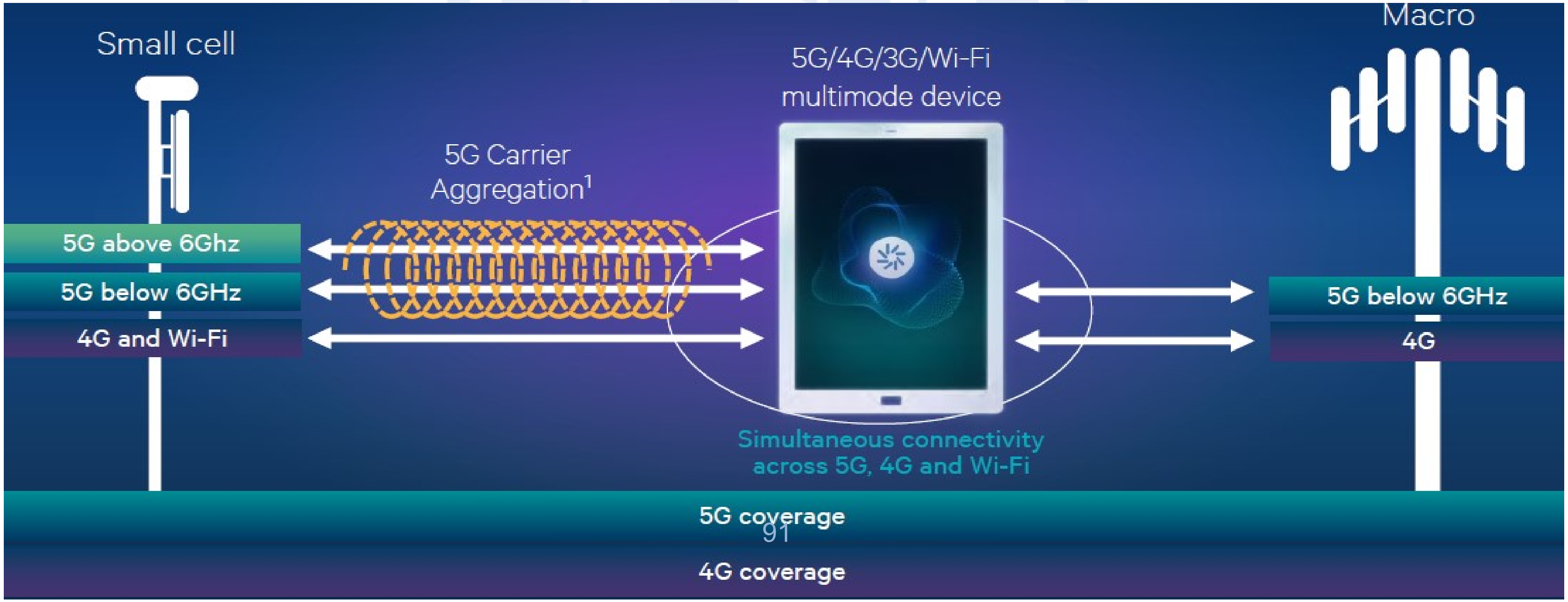
Unified 5G design across spectrum types and bands

Licensed Spectrum	Shared Licensed Spectrum	Unlicensed Spectrum
Cleared spectrum	Complementary licensing	Multiple technologies
EXCLUSIVE USE	SHARED EXCLUSIVE USE	SHARED USE

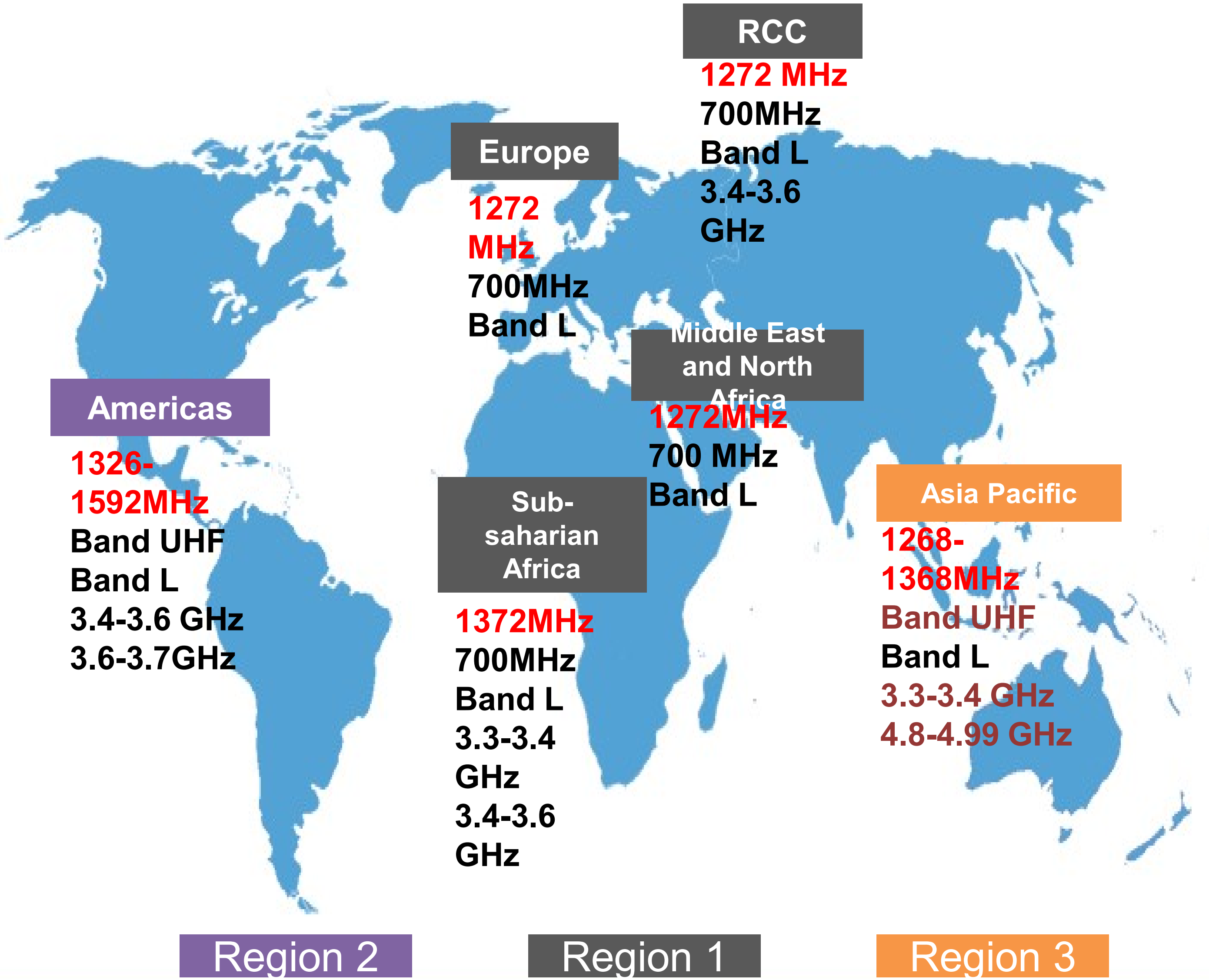
Below 1 GHz: longer range, massive number of things

Below 6 GHz: mobile broadband, mission critical

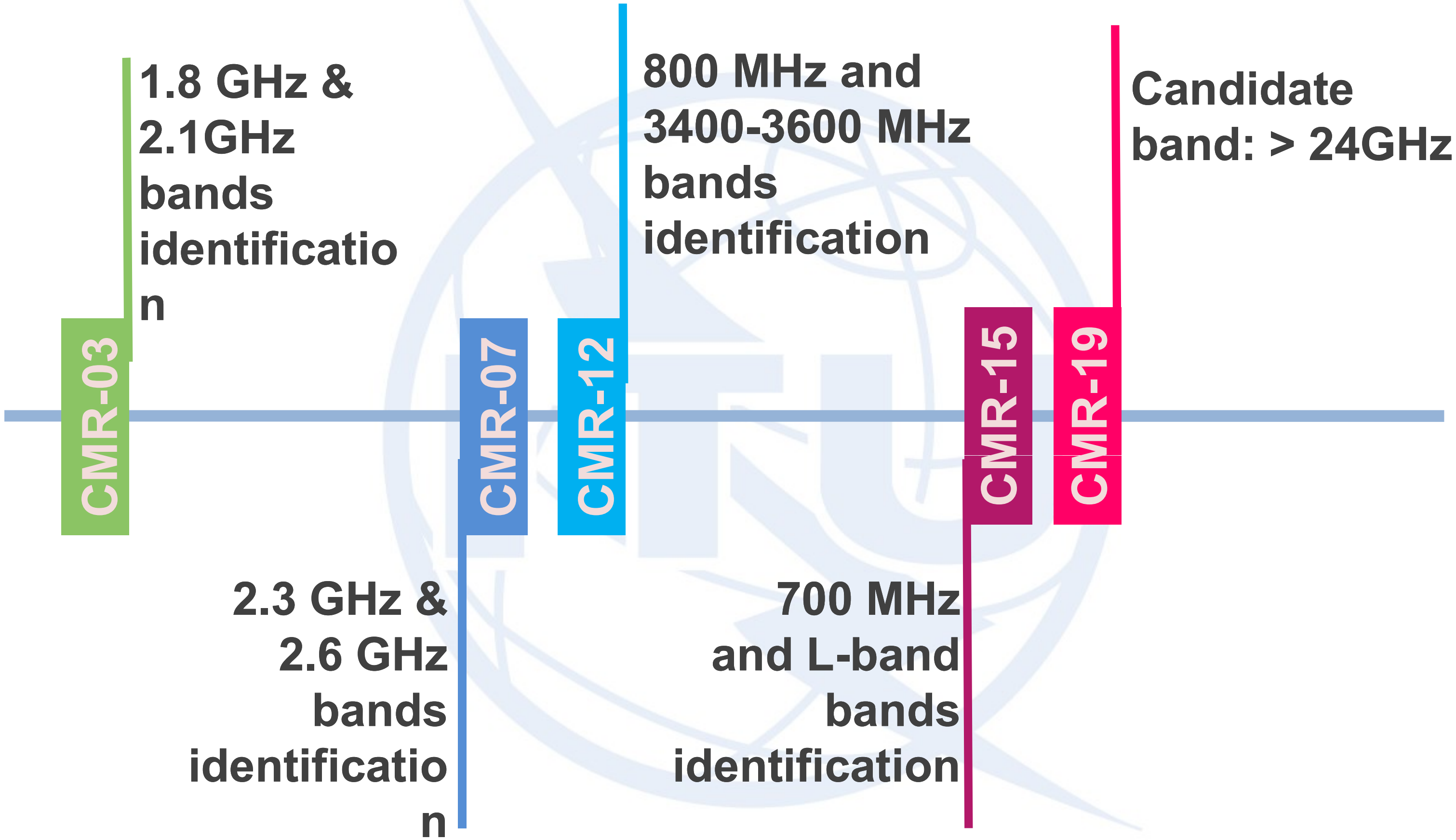
Above 6 GHz including mmWave: for both access and backhaul, shorter range



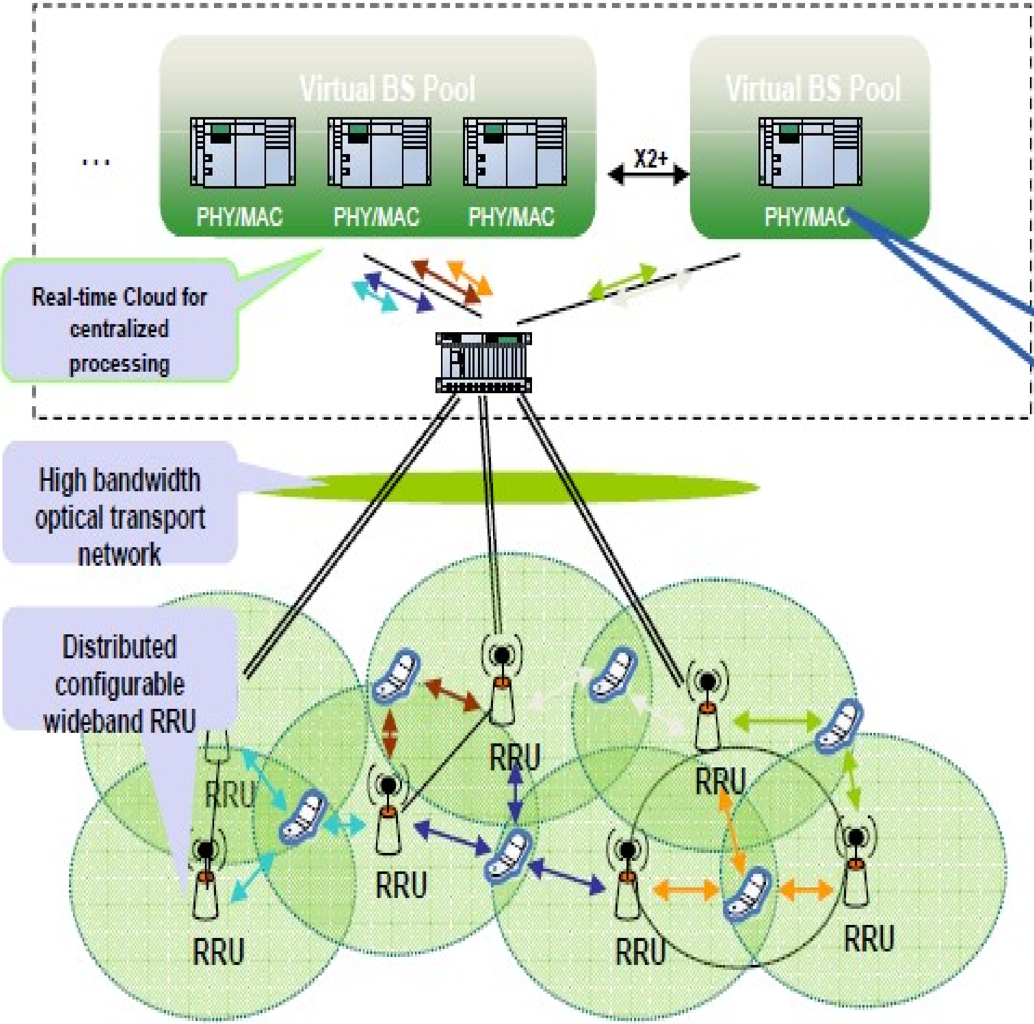
CMR15 Identified frequency bands



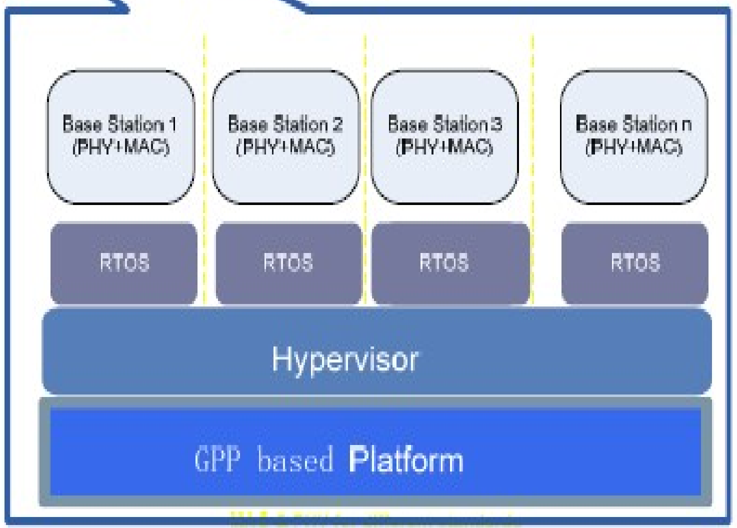
IMT Spectrum – Deadlines



C-RAN



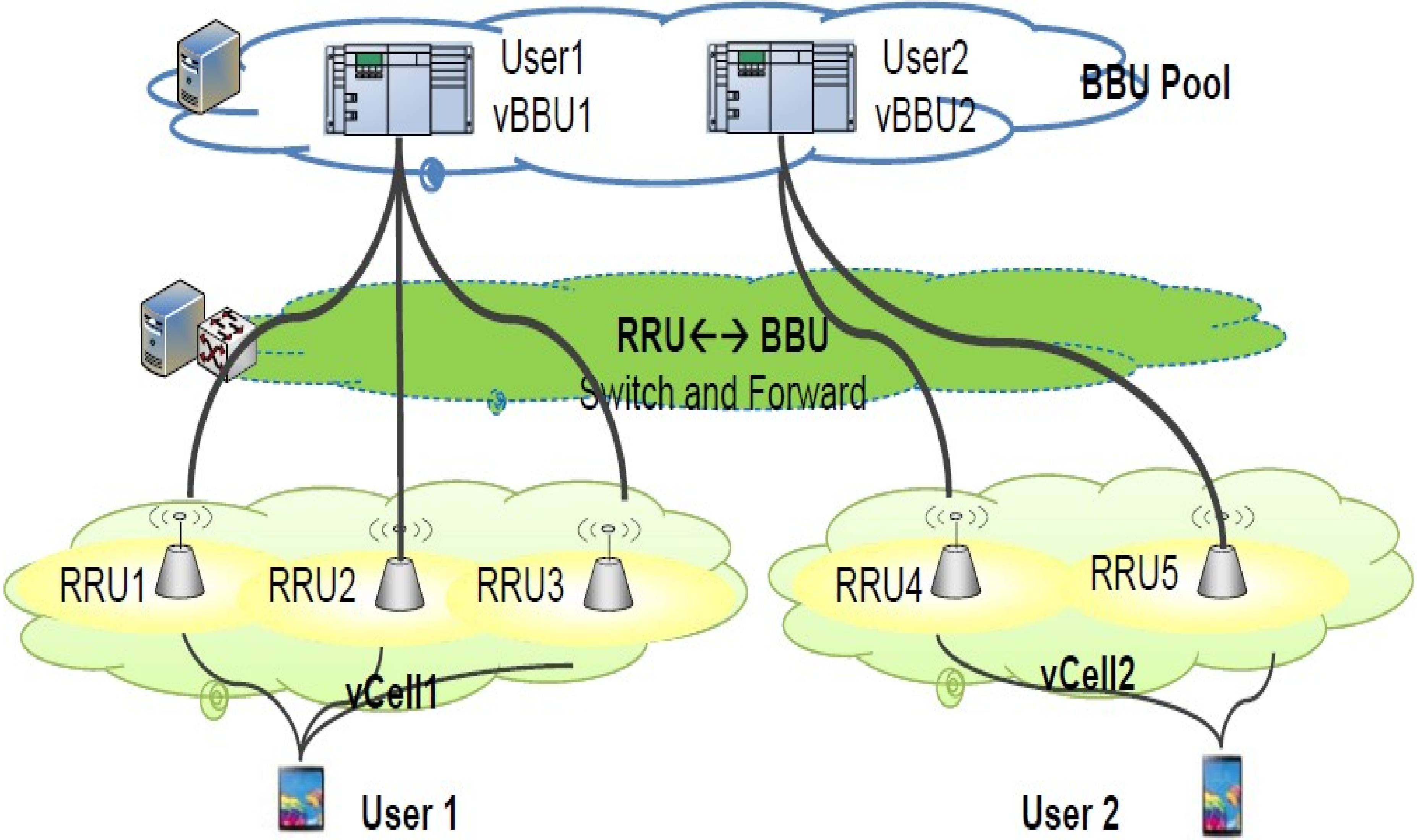
- Common platform, software based solution
- Live (soft) computation resource transition
- Inherent cooperation



BS virtualization

C-RAN allows significant savings in OPEX and CAPEX.
Ex. China Telecom: 53% savings in OPEX and 30% in CAPEX.

User-centric cells



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

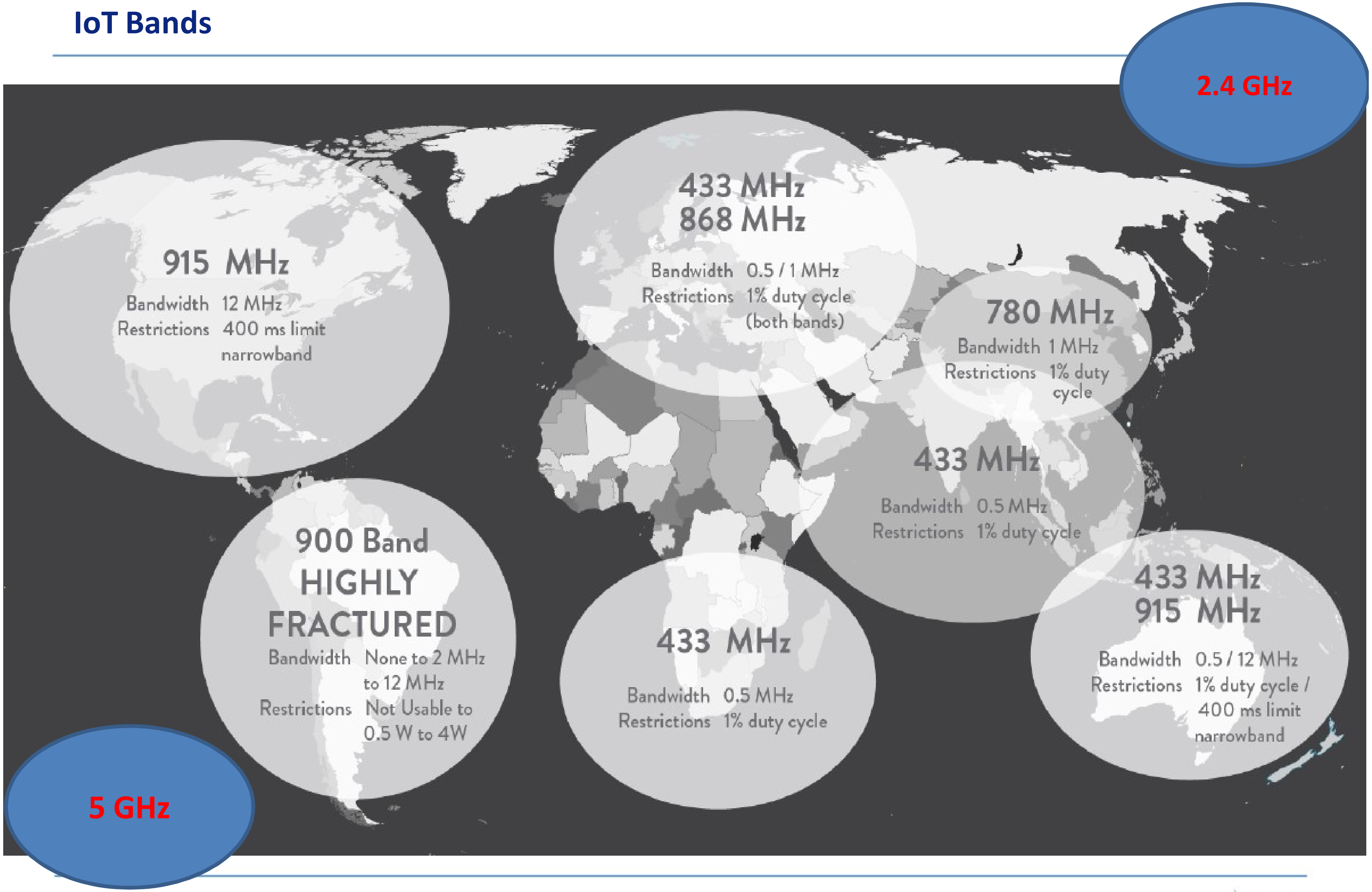
non-ISM candidate bands for SRDs

Add specific RF to IoT at SRD bands?

1. Resolution 958 (WRC-15), Annex item 3 and WRC-19 Agenda Item 9.1 (issue 9.1.8) 'Studies on the technical and operational aspects of radio networks and systems, as well as **spectrum needed**, including possible harmonized use of spectrum to support the implementation of **narrowband and broadband machine-type communication infrastructures**'

2. In addition to mobile systems (such as GSM), without prejudging WRC-19 results, the **present SRDs RF bands, shown at previous slide, may provide to IoT the necessary coverage and capacity** for narrow and wideband, in narrow and wide area

IoT Bands

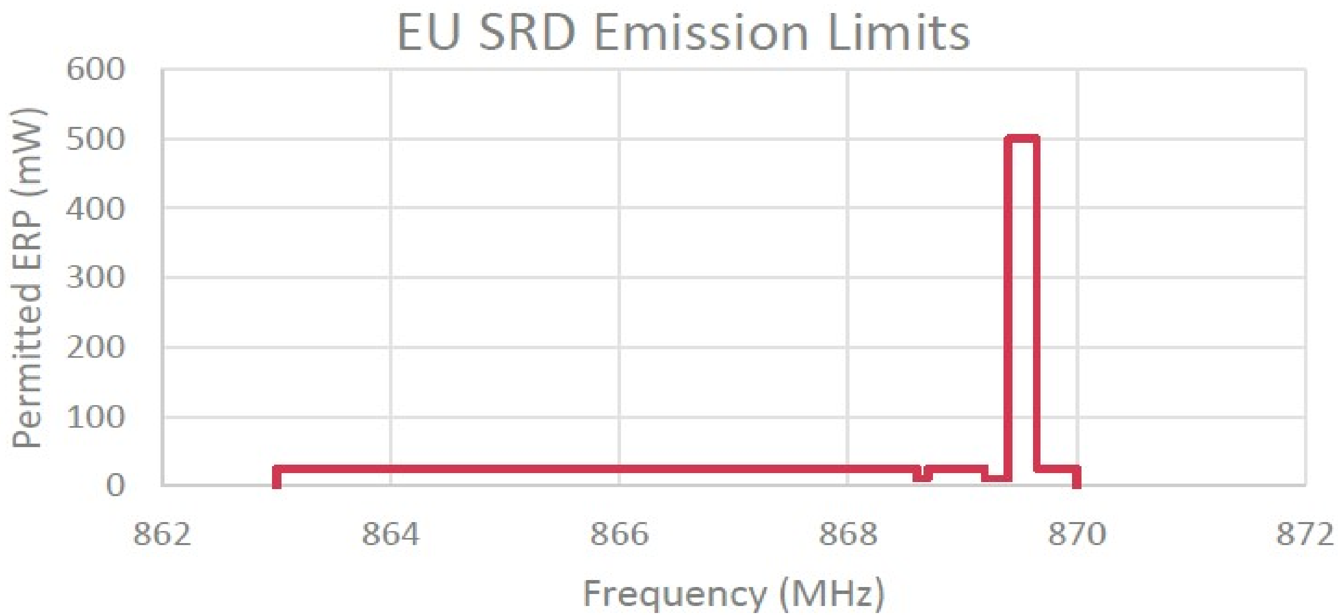


2.4 GHz
915 MHz
Bandwidth 12 MHz
Restrictions 400 ms limit narrowband
433 MHz
868 MHz
Bandwidth 0.5 / 1 MHz
Restrictions 1% duty cycle (both bands)
780 MHz
Bandwidth 1 MHz
Restrictions 1% duty cycle
433 MHz
Bandwidth 0.5 MHz
Restrictions 1% duty cycle
900 Band
HIGHLY FRACTURED
Bandwidth None to 2 MHz 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

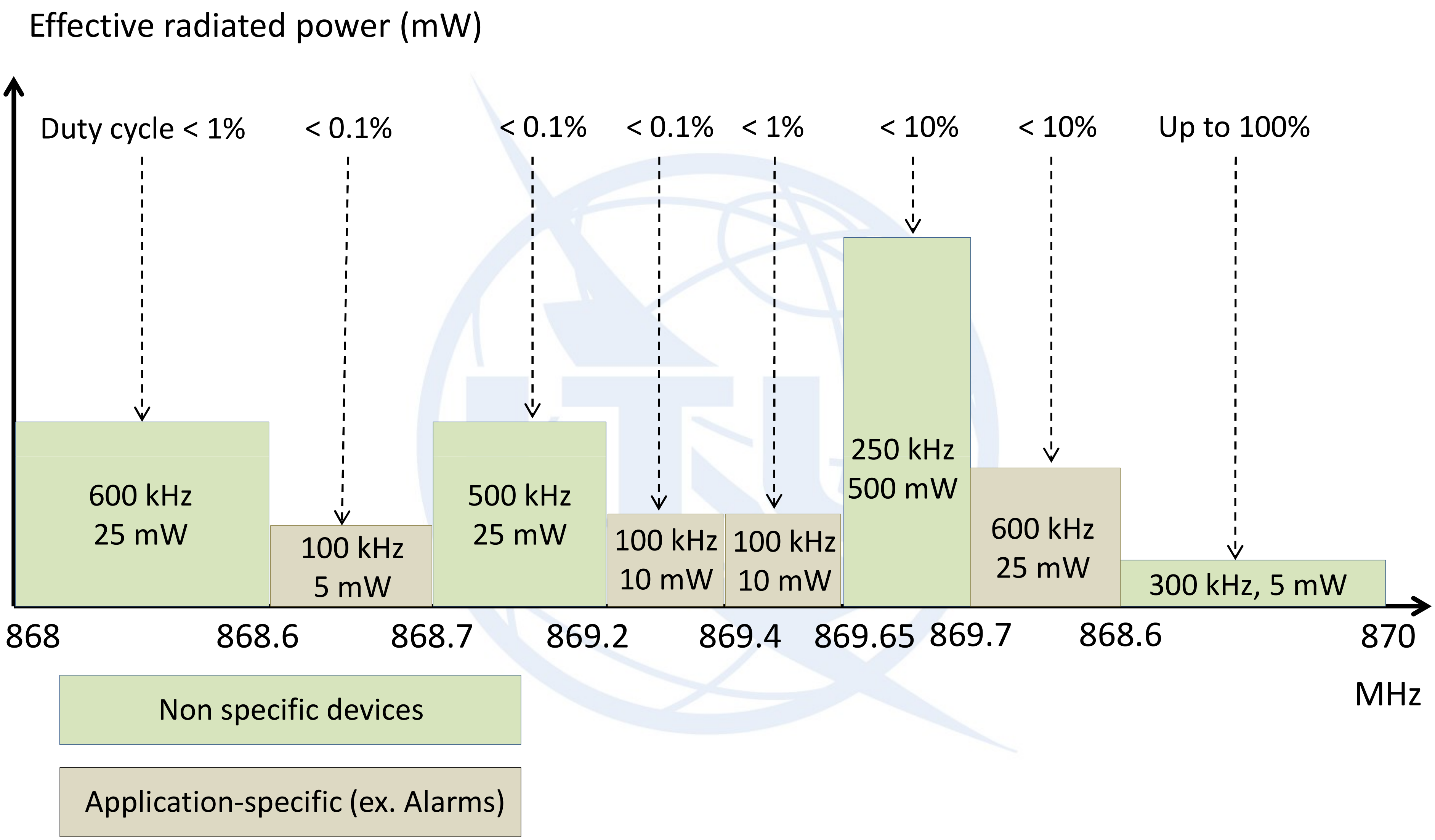
IOT regulations

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

Arcep France

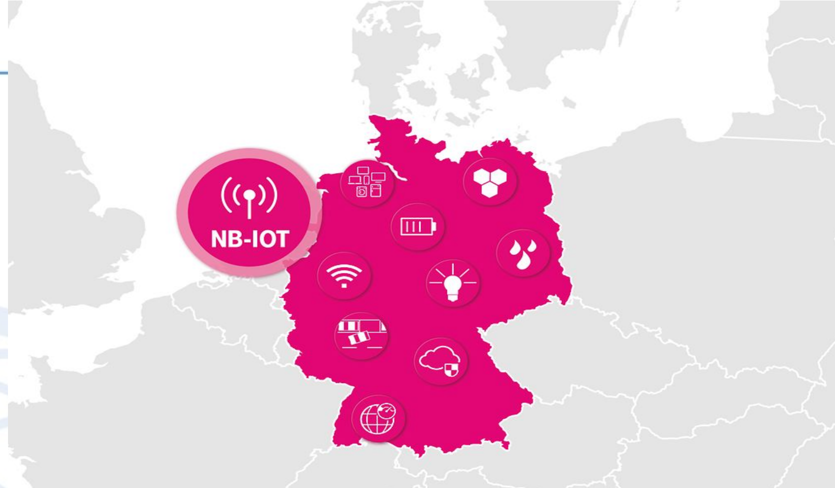


ISM 868MHz Band Plan



B. Prices

NB-IoT pricing in Deutsche Telekom



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.

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.

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.”*

AT&T LTE-M services pricing

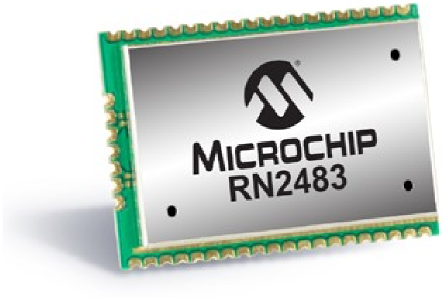
The new prepaid plans, which target develc . businesses, include three tiers of data and text messages:

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**.

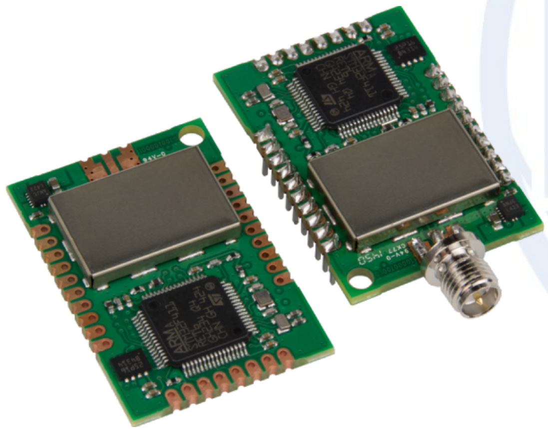
Synthesis

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

LTE-M end-devices prices

[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

2017 Facts

- Most of the commercial **NB-IoT** contracts were in **China**.
- Several operators launched **LTE-M in 2017**, including AT&T, Telstra and Verizon.
- The **LTE-M** share: **less than 1%** but this will grow significantly during the forecast period to reach **19% by 2026**.
- LTE-M is a substitute for some 2G telematics applications in the automotive and fleet sectors, and has been adopted first by many of those operators that have decommissioned their 2G networks.
- Analysys Mason: **3G and 4G will capture a 27% market share in 2026**
- 5G will constitute just over **1% of the total connections in 2026**, but this will be the average across all application groups. For automotive and embedded SIMs specifically, 5G will have a 4% share of the total connections

Sigfox

- **2018**: about **1,000 customers**, including Airbus, Bosch, and Fujitsu, with services available in 42 countries and 18 more expected by the end of 2018
- **2 million active devices** with an additional 10 million in the pipeline
- **Issue**: Sigfox is a service provider without an option for private networks
- **September 2017**: End-node design capable of sending a Sigfox message that cost just 20 cents using a printed antenna and oscillator. One of the lowest cost of many ultra-simple designs
- **Global roaming** capabilities with nodes that automatically switch among four frequencies, depending on their region
- Enhance its **location-tracking** capabilities to within a kilometer using a form of triangulation

Forecasts in 2026

- **NB-IoT** will form the **largest market in 2026**
- Many operators are deploying **more than one LPWA** technology as all are relatively inexpensive to deploy
- **LTE-M** is better suited to supporting **mobility**, whereas **LoRa or Sigfox** better support **static applications**
- Analysys Mason: **China** will be the biggest market for IoT of all types by 2026 with **North America** and **Europe** in second and third places.
- Both Canada and the US are in the process of closing 2G networks, even though 2G connections formed 17% of the total in 2017.
- The market **share for 3G/4G networks – 55% of the total IoT connections in 2017** – will decrease over the forecast period as LPWA networks take over.

LoRa networks

- Comcast and Verizon: plans to deploy LoRa
- Semtech 2017 revenue for LoRa chips doubled to $50 million and forecast that it will hit $100 million in 2018
- HIS: **LoRa** has about **three times** the unit sales of modules for IoT end nodes as **Sigfox**.

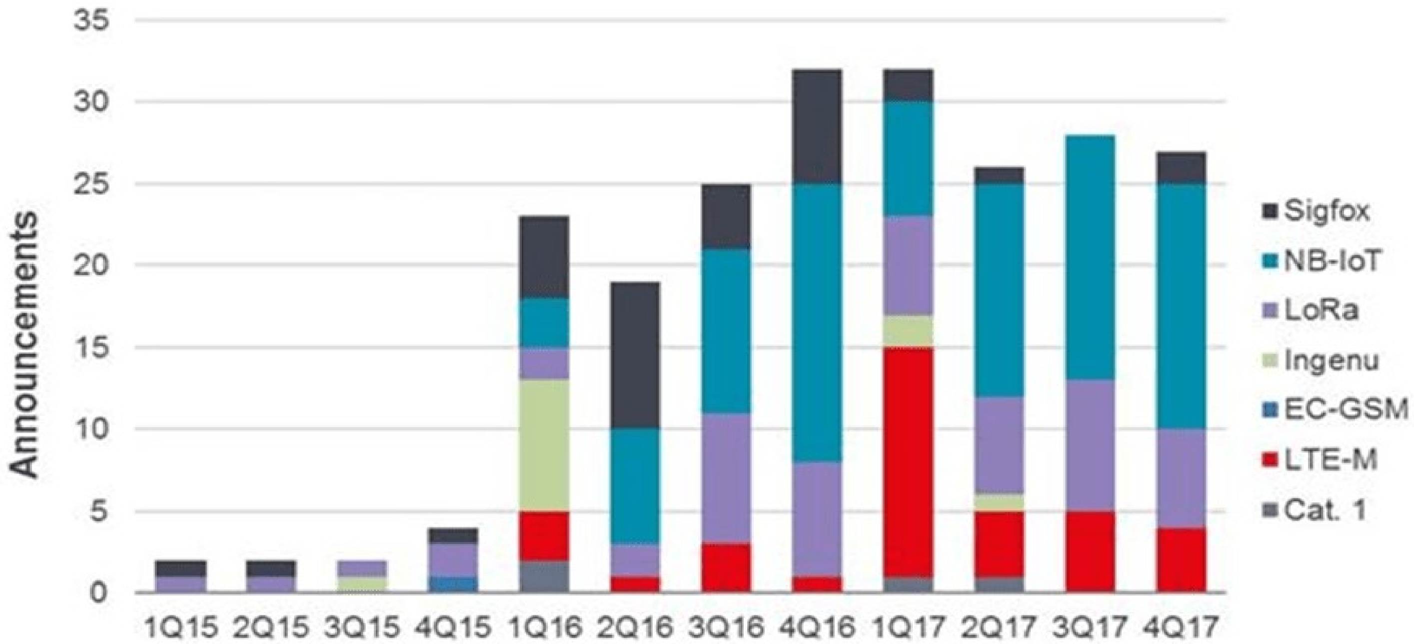
NB-IoT

- **China** (June 2018): the government announced a policy with goals of reaching **600 million NB-IoT nodes by 2020**.
- **Will dominate IoT**, but 3G and 4G cellular technologies, followed by LTE-M
- Analysys Mason: overall number of connections will reach **5.1 billion** in 2026, of these, **1.6 billion will use 2G, 3G, 4G and 5G cellular** connections and 3.5 billion will use low-power wireless access (LPWA) including NB-IoT and LTE-M.
- No dominant LPWA technology
- LTE-M connections, which are largely complementary to those using NB-IoT, will grow at 131% a year to 9 million
- Other LPWA connections that are more direct substitutes for NB-IoT will grow in number to 617 million, driven by new network operators such as Thinxtra as well as traditional players such as Orange

Some issues with NB-IoT

- *Actility*: “Some companies oversold NB-IoT and now the operators realize it is not that easy a deployment. The **software upgrades are quite expensive**, there is still no ecosystem, there is still a Huawei implementation that is not the same as an Ericsson one -- it seems they are not interoperable.“
- **Interoperability problems between Ericsson and Huawei** are hindering the rollout of NB-IoT services (industry experts).

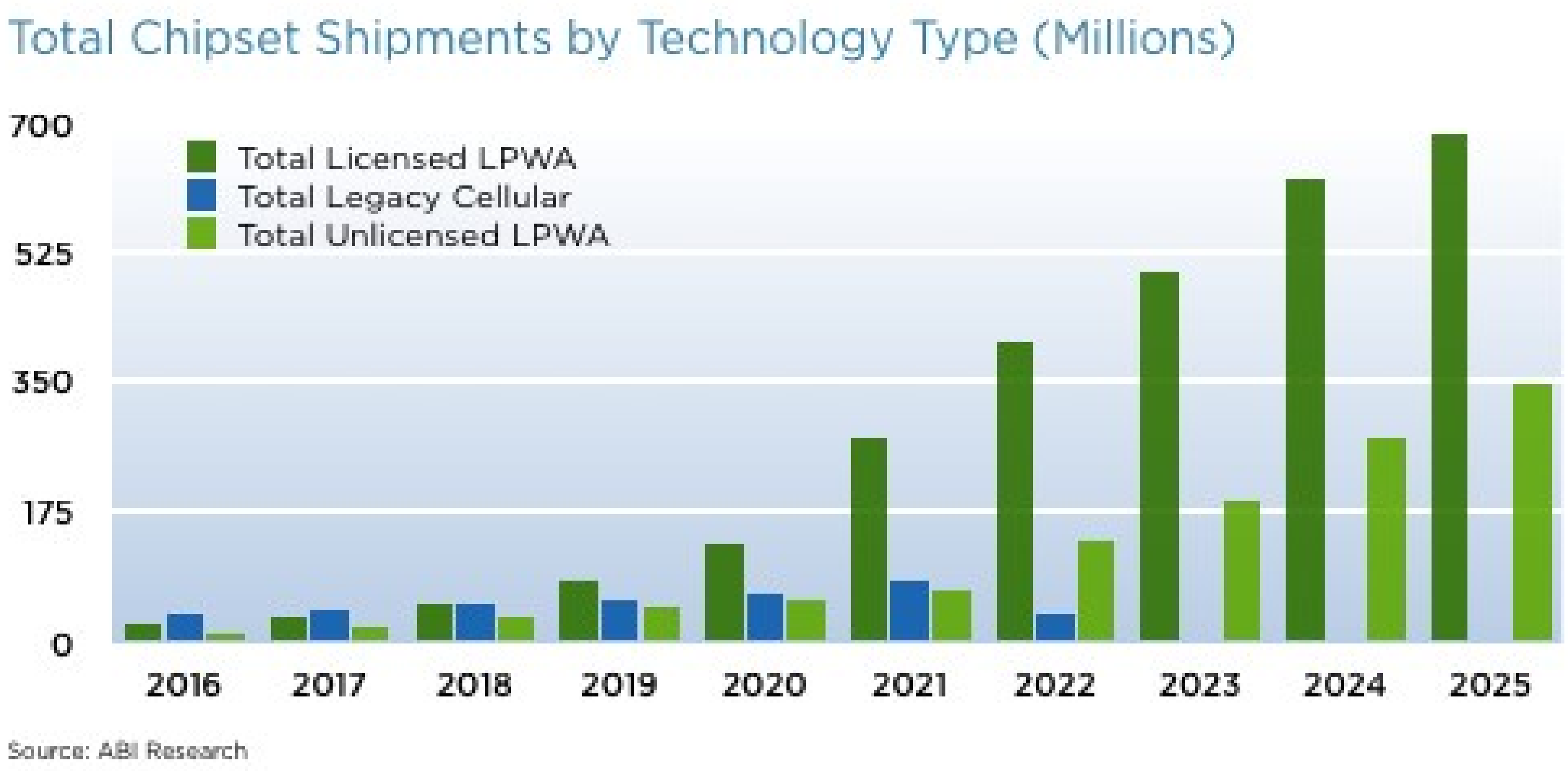
Technologies evolution 2015-2017



LPWAN網路數量（來源：Ovum）

Enabling an Intelligent Planet ADVANTECH

Chipset Shipments Evolution



Evolution of LPWA Modules Sales

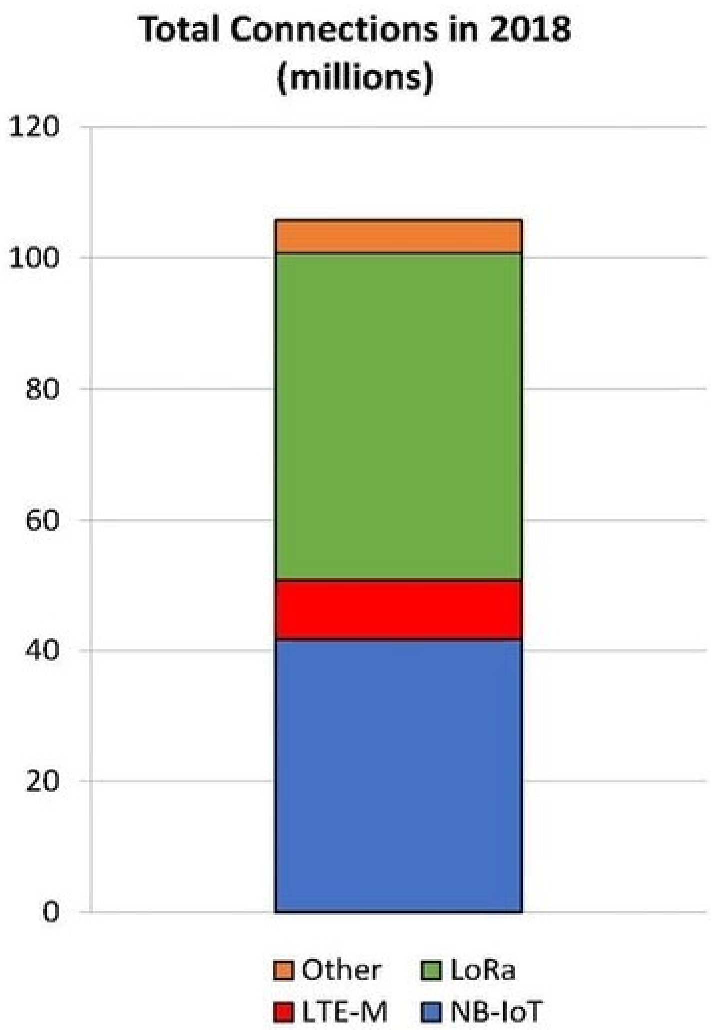
Annual Unit Shipments of LPWA Modules (in thousands)

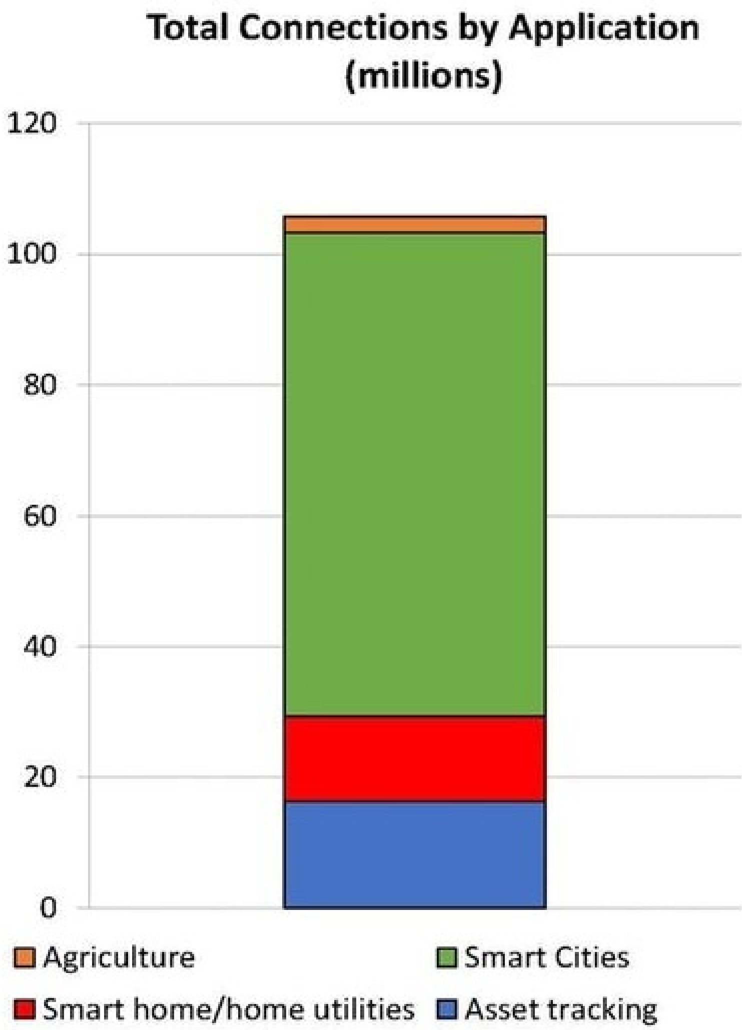
	2017	2018	2019	2020	2021	CAGR
Sigfox	8,424	14,538	27,951	52,821	85,042	219.5%
LoRa	32,316	57,298	98,162	161,561	249,724	92.3%
LTE Cat-M1	1,978	8,571	20,284	28,801	52,288	--
NB-IoT	16,166	34,062	84,885	161,628	222,902	--
Other	4,022	6,201	8,714	7,069	8,402	14.7%
Totals	**62,905**	**120,667**	**239,996**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

Source: IHS Markit

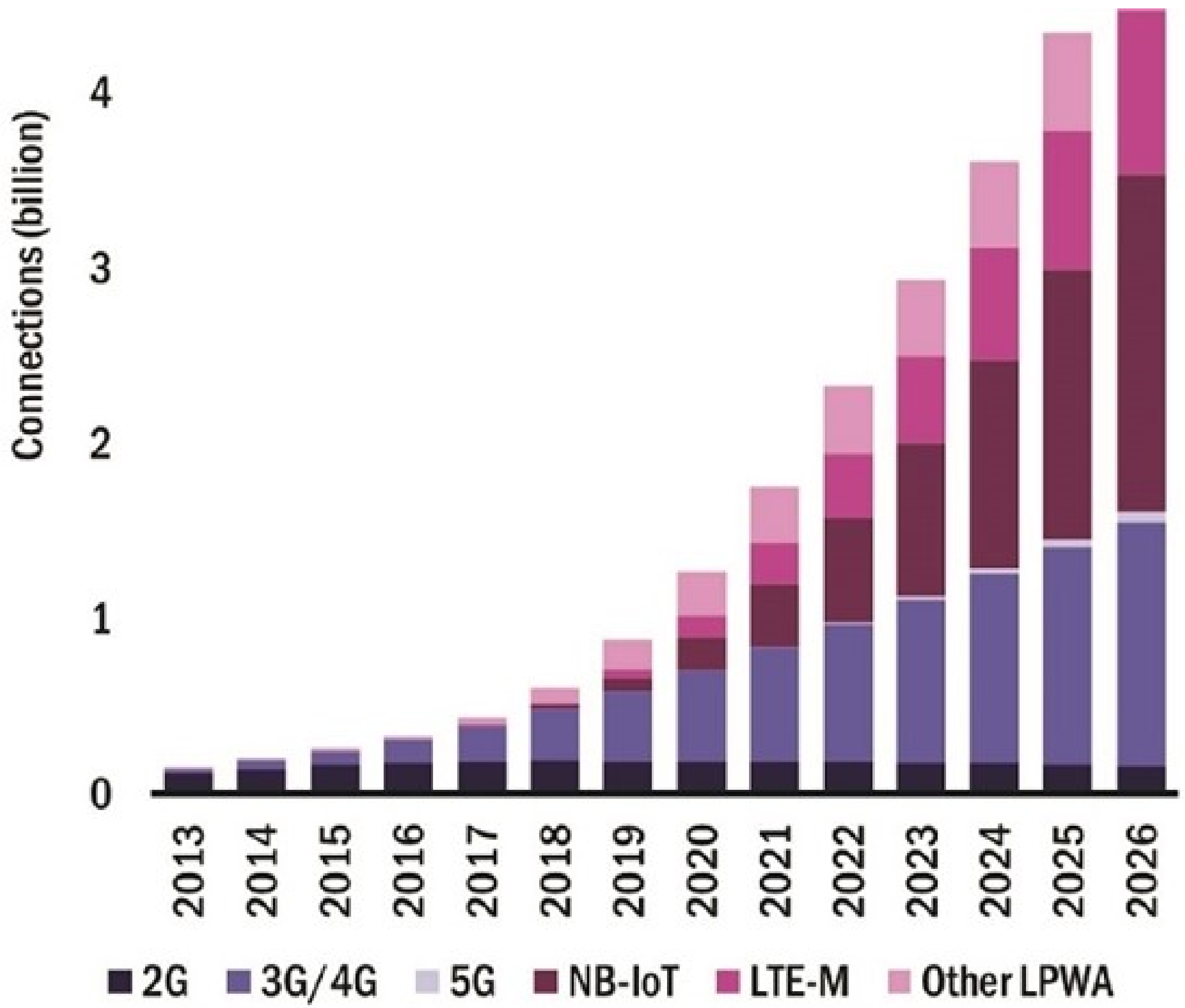
Devices prices (2017)

2018 Connections Status





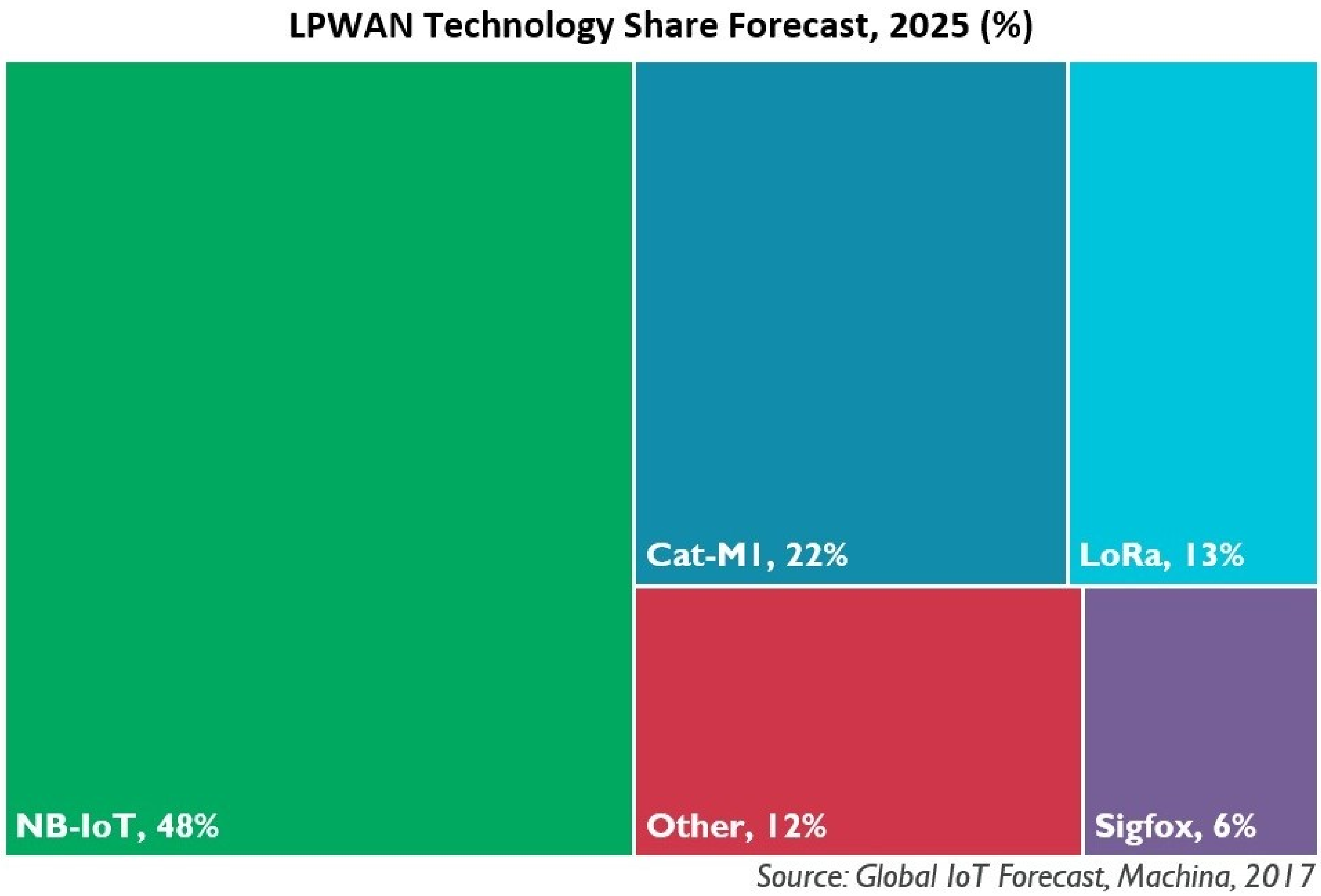
Future of IoT connectivity by network type across the world



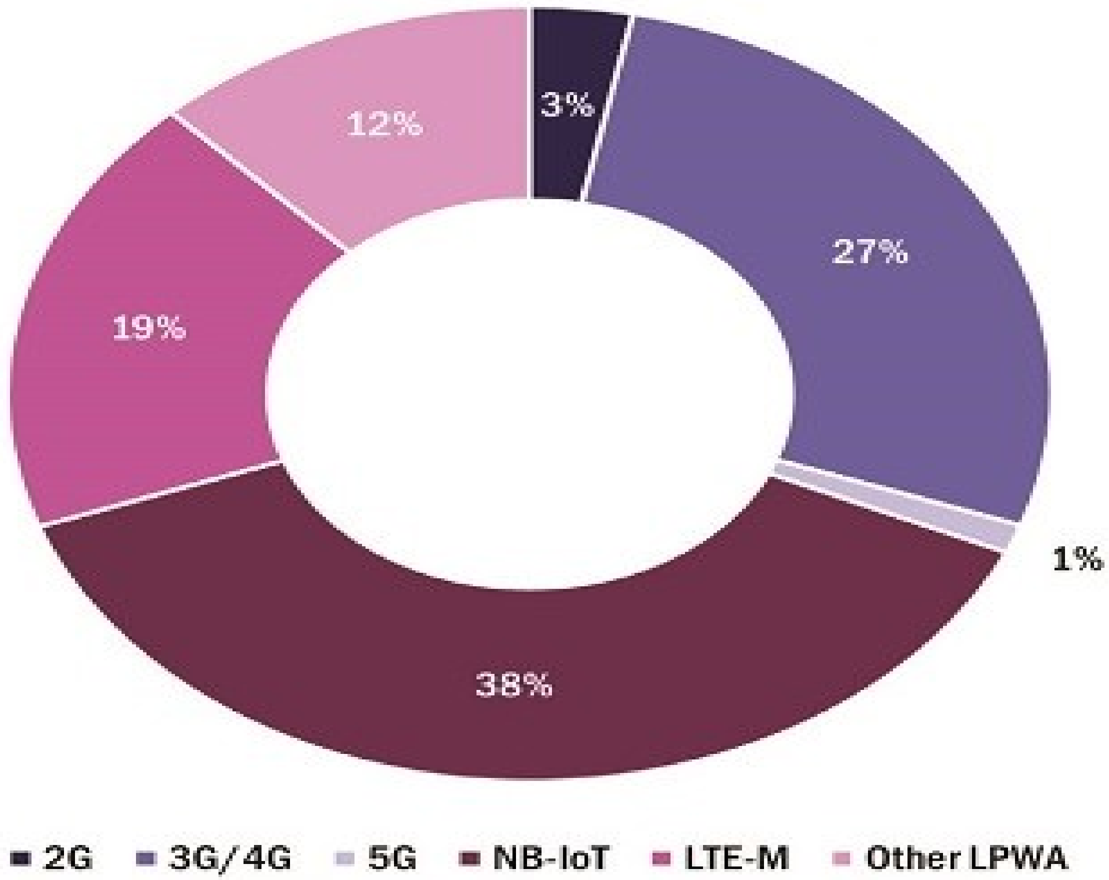
NB-IoT will be the dominant network for IoT in 2026 (Analysys Mason)

2017-2026 IoT standards evolution

2025 forecasts



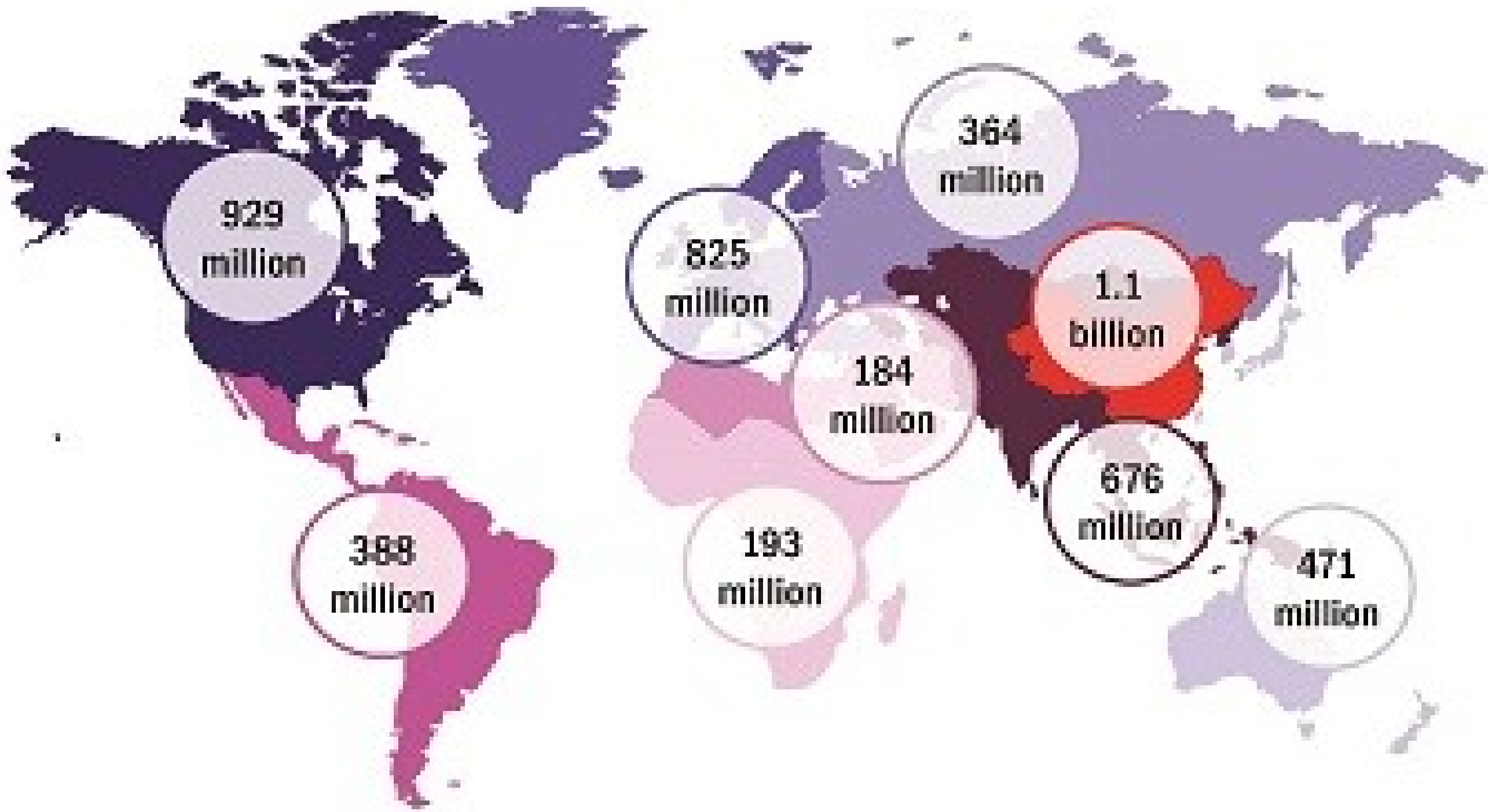
Share of LPWAN Connections in 2026



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!