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envision:ensure

There is not enough testing.

Testing Methodology for Cellular IoT

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envision : ensure

Agenda

- Internet of Things (known facts)
- Cellular IoT Technologies
- Release Enhancements
- NB-IoT technology
- Phases in Device Development Cycle
- Phases of Testing and Measurements
  - Core Development Testing
  - Integration and Verification Testing
  - Certification Testing
  - Production Line Testing

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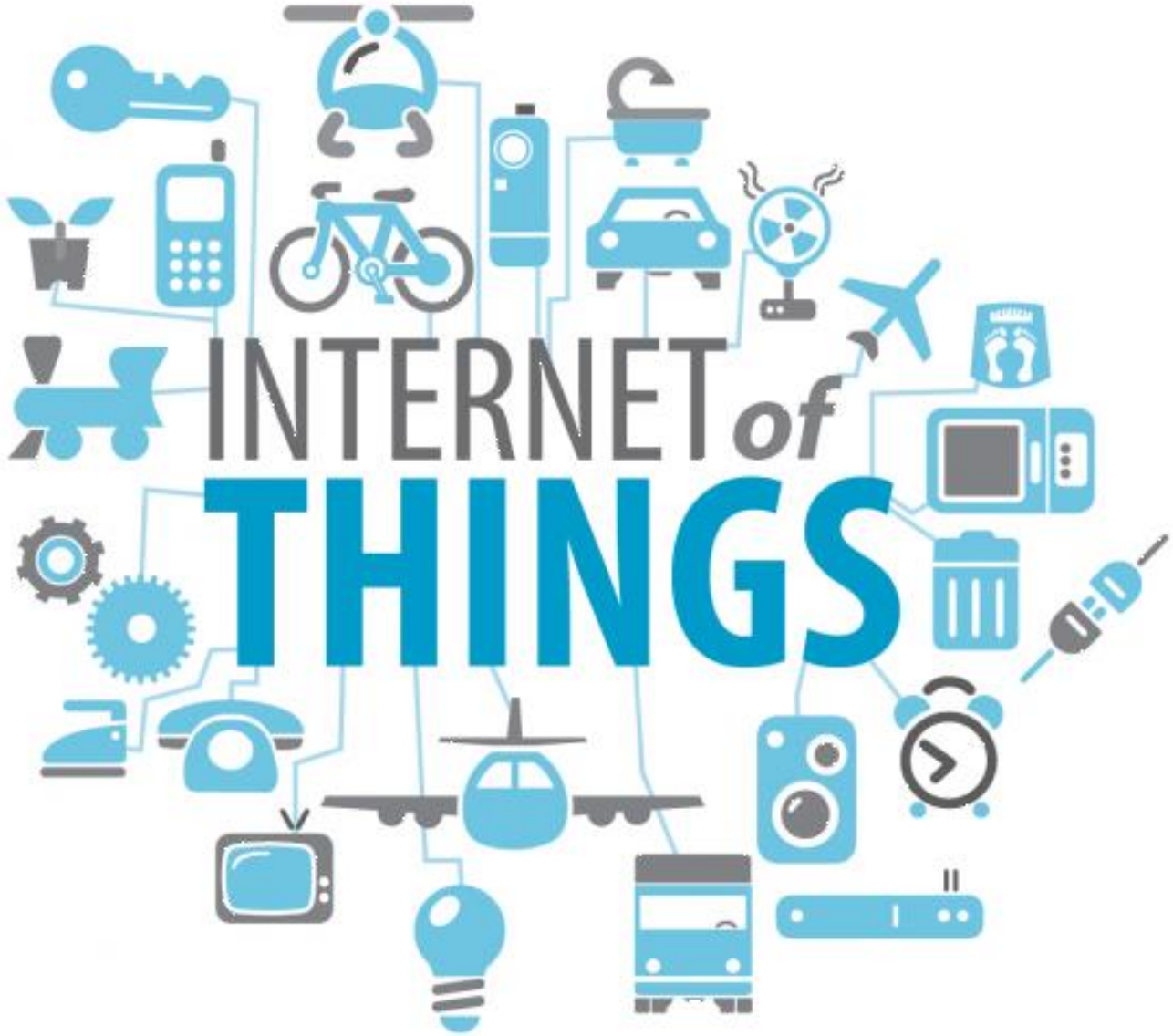
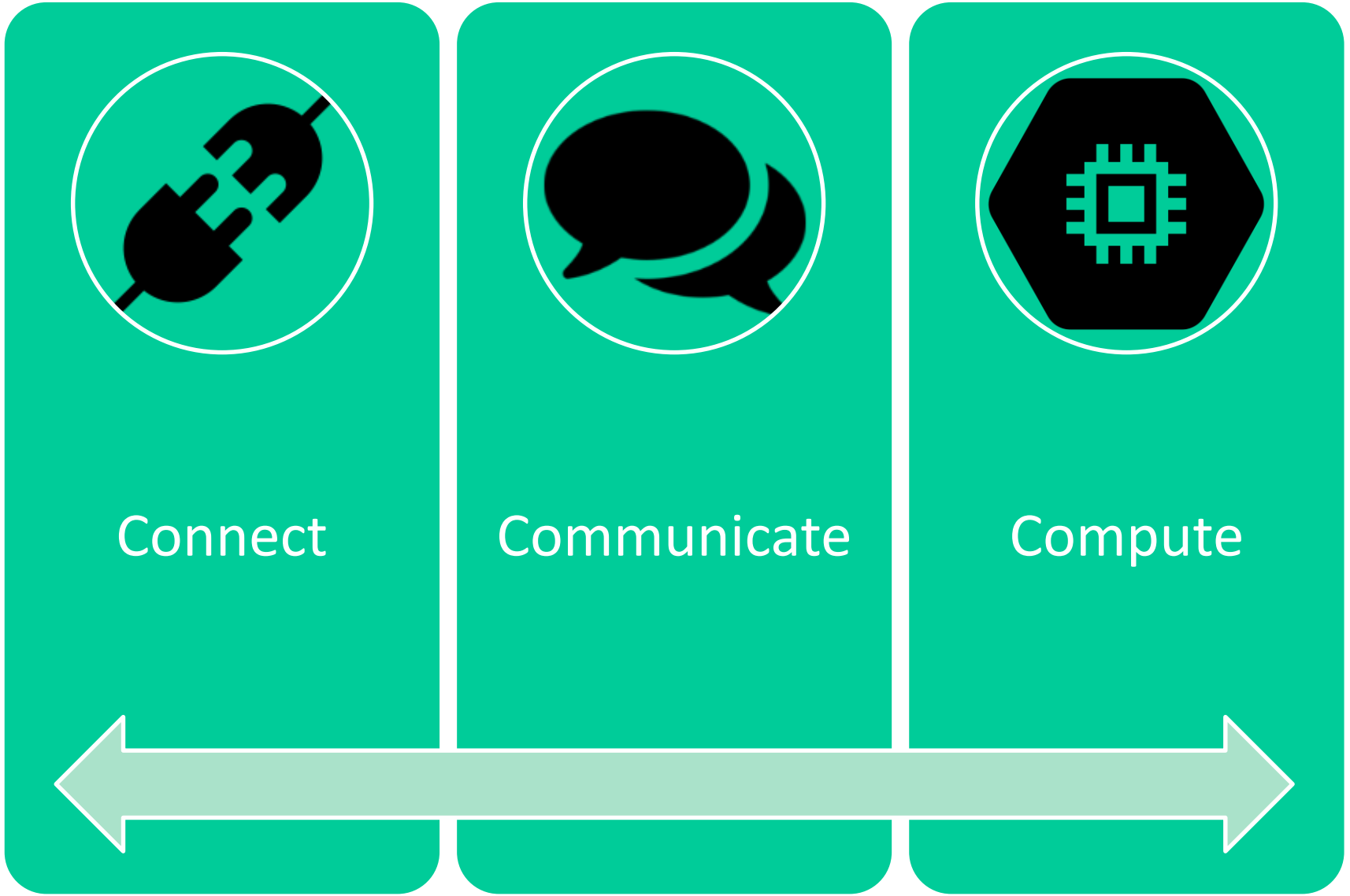
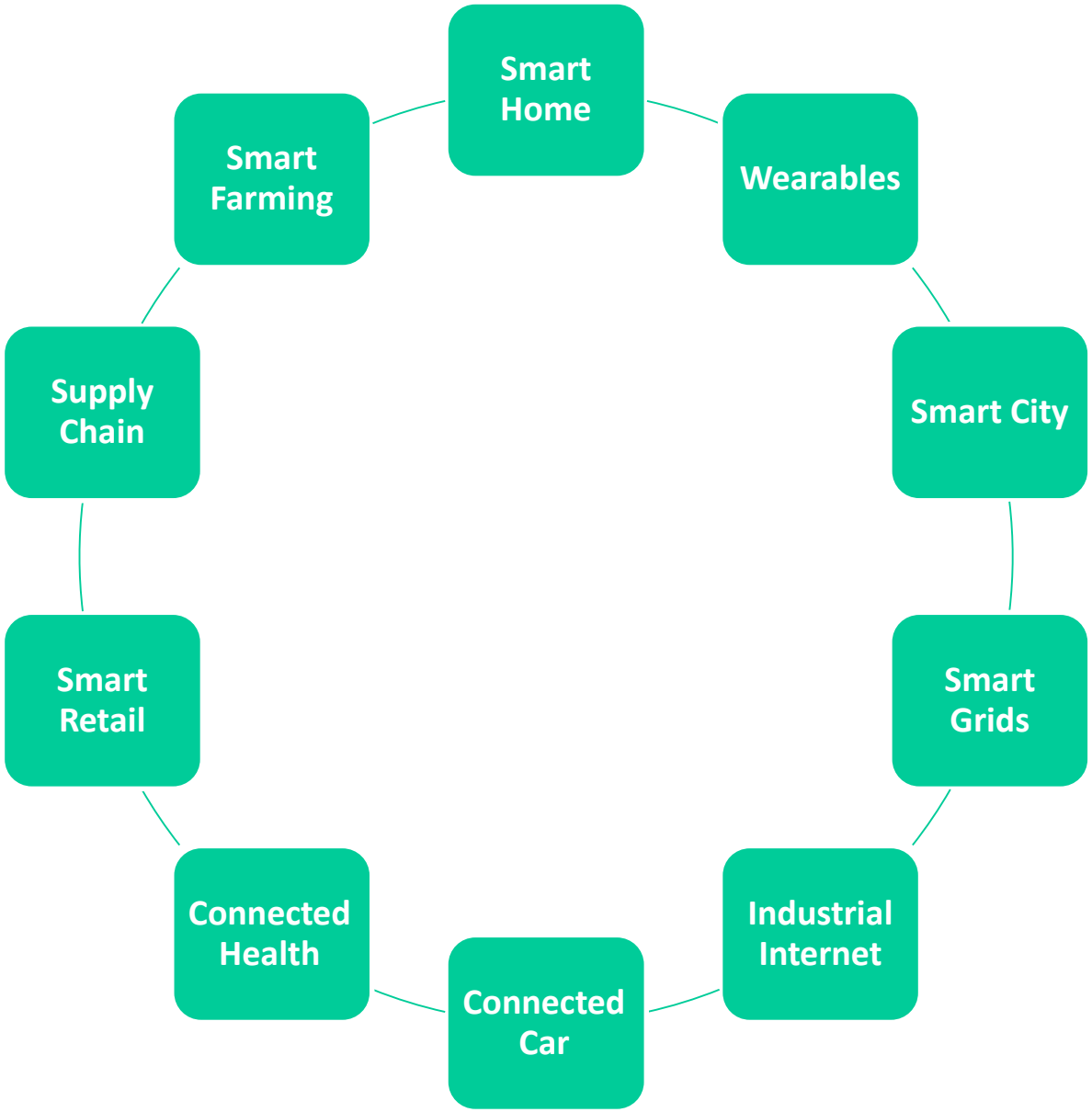

INTERNET of
THINGS

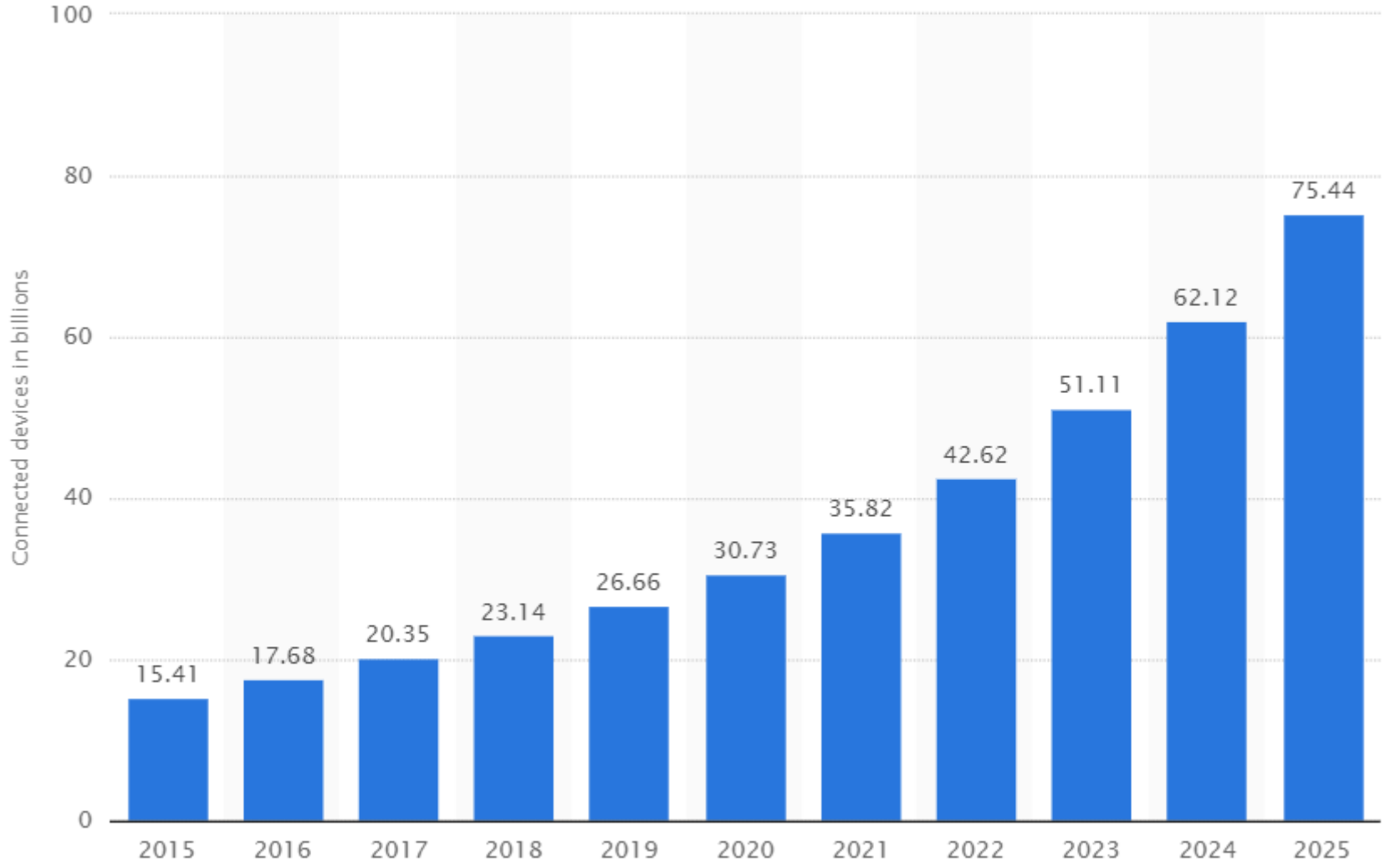
Principle



Applications



Trends

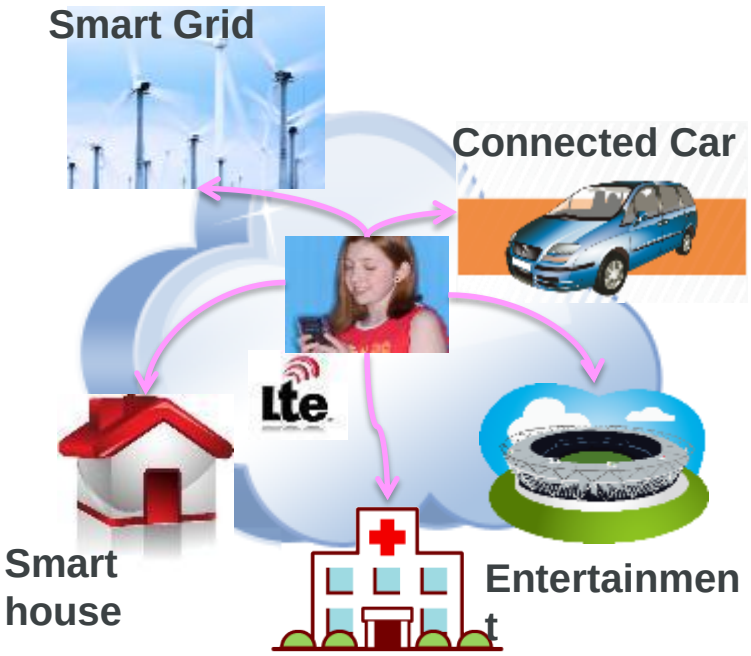


Change in Consumer Value

Source : European commission

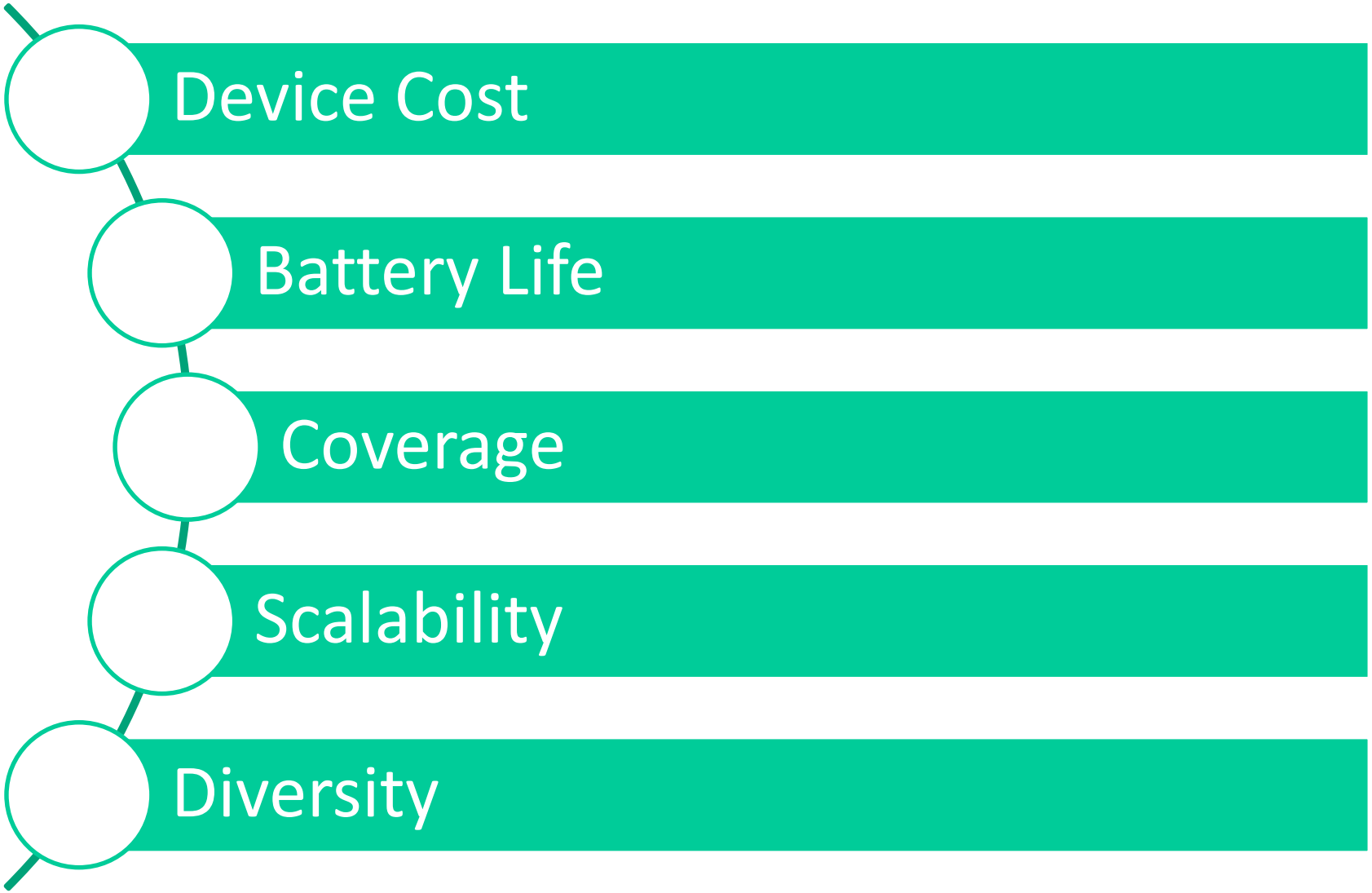
Value = High-capacity and high-speed communication **device**

Internet of Things



Value = **Service/Application** on connected device

Challenges



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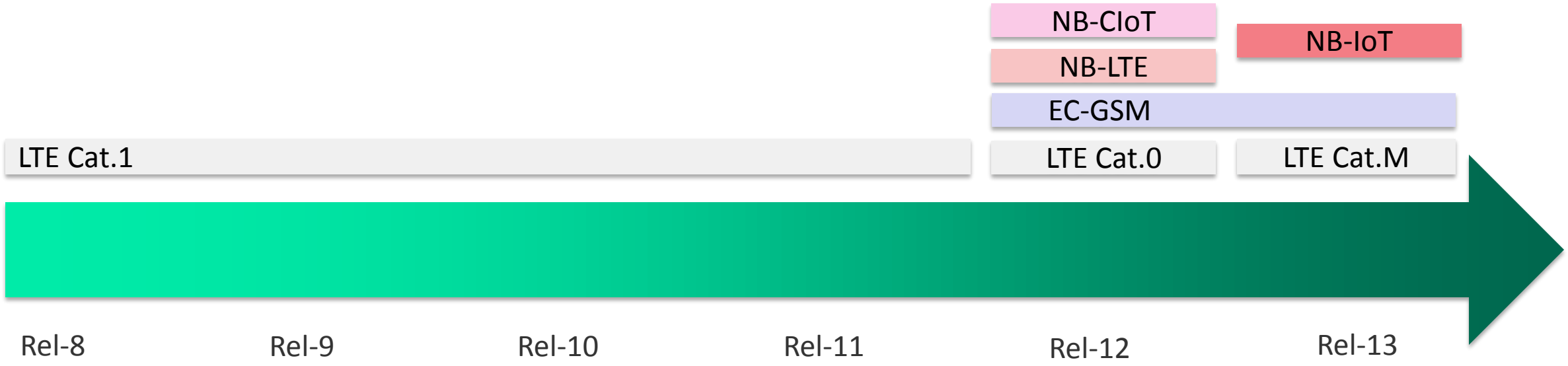
Cellular IoT Evolution



Licensed vs. Unlicensed Spectrum

Definition	Segment	Name	Frequency	Data TP	Coverage	End Application
Cellular	Cellular	LTE-A	Cellular Band	1Gbps	10km	Car Infotainment
		LTE Cat. 1		10Mbps		Remote Monitoring & Control
		LTE Cat. 0 / M		1Mbps		Vehicle Tracking
		NB-IoT		100kbps	20km	Smart Meter, Asset Tracking
		EC-GSM		10kbps		
Connectivity	WLAN	Wi-Fi (11n/ac)	5G (ISM)	6.9Gbps	50m	Home Entertainment
		WiGig (11ad)	60GHz (ISM)	6.8Gbps	10m	Wireless Display
		HaLow (11ah)	900MHz (ISM)	7.2Mbps	1km	Smart Home
		WAVE (11p)	5.8GHz (ISM)	6Mbps	1km	Automotive
	LPWAN	Sigfox	900MHz (ISM)	1kbps	50km	Smart Meter, Asset Tracking Home Security
		LoRa	900MHz (ISM)	50kbps	15km	
	WPAN	Bluetooth	2.4GHz (ISM)	24Mbps	100m	Smart Home
		BLE	2.4GHz (ISM)	10kbps	5m	Wearable, Payment
	Mesh Net.	ZigBee/Thread	2.4GHz (ISM)	250kbps	100m	Smart Home
		Z-Wave	900MHz (ISM)	40kbps	30m	Smart Home
		Wi-SUN	900MHz (ISM)	200kbps	1km	HEMS
	Proximity	NFC	13.56M (ISM)	420kbps	10cm	Payment, Identification
		TransferJet	4.48GHz (ISM)	560Mbps	3cm	Wireless Data Transfer

MCL Comparison

- Maximum Coupling Loss:

Maximal total channel loss between UE and Base Station at which the data service can still be delivered

MCL = max Tx power – Rx sensitivity

Technology	MCL
GSM	144 dB
EC-GSM-IoT	164 dB
LTE Rel-8	144 dB
eMTC Rel-13	156 dB
NB-IoT	164 dB

Note:

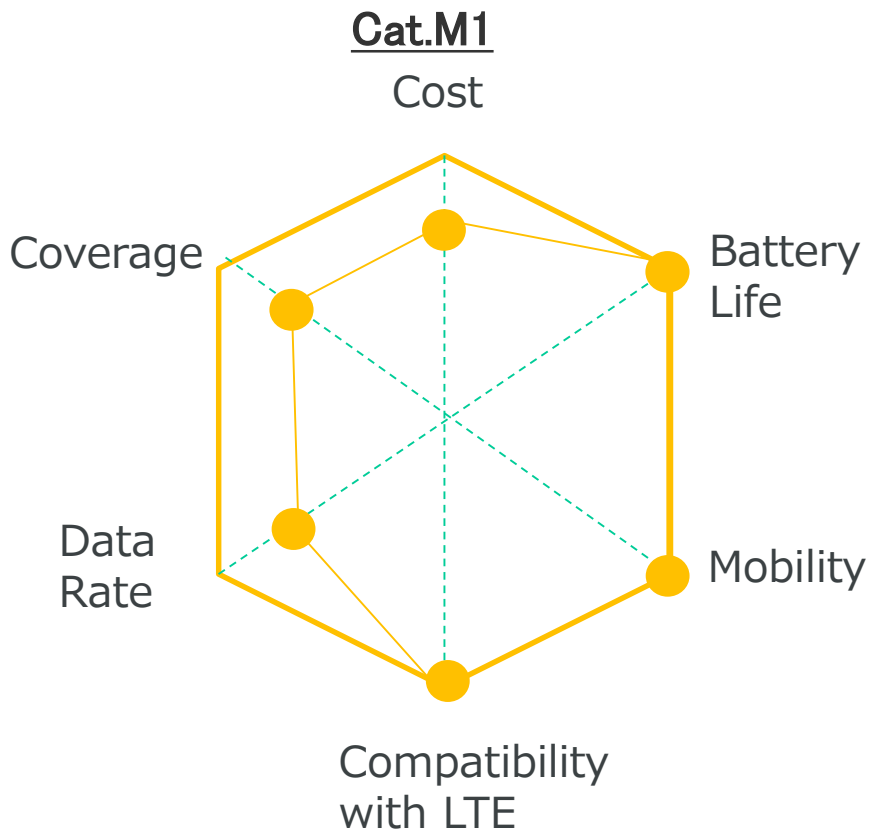
$$10\log_{10}\left(\frac{1}{2}\right) \approx -3.0103\,\text{dB}$$

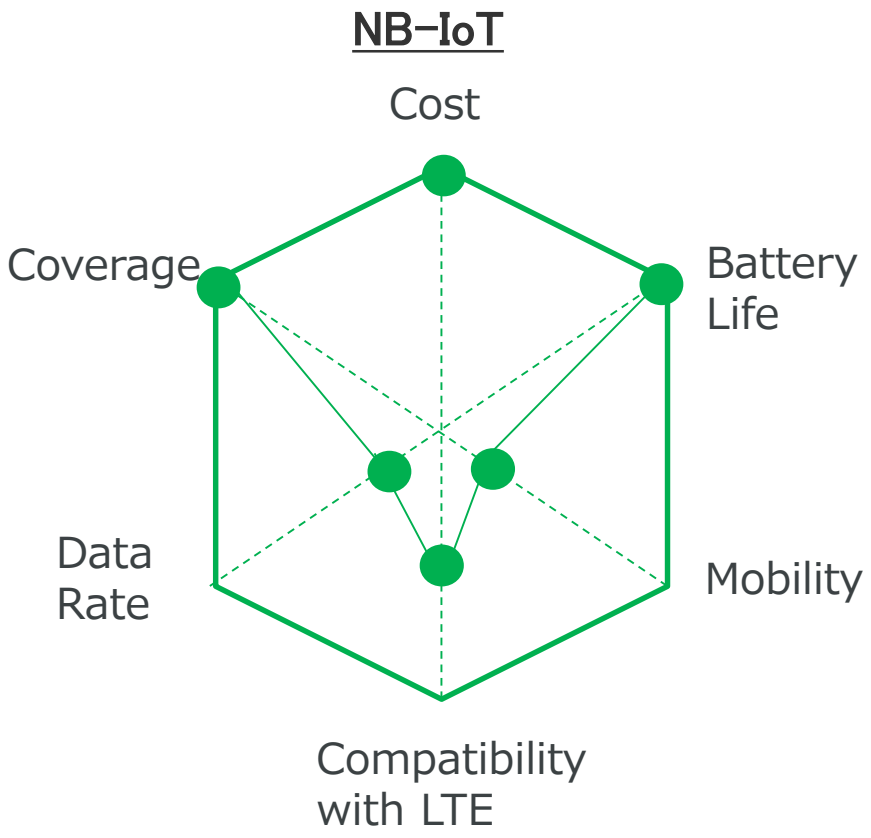
Cellular IoT Comparison

	Cat.M1	EC-GSM	NB-IoT	LoRa	SigFox
NW category	Licensed	Licensed	Licensed	Unlicensed	UnLicensed
Frequency	LTE Bands	GSM Bands	LTE and GSM Bands	ISM Bands e.g. 867-869MHz	ISM Bands e.g. 867-869MHz
Bandwidth	1.4MHz	200kHz	200kHz	125kHz	200Hz
Modulation	QPSK,16QAM	GMSK	QPSK, BPSK	LoRa Modulation	BPSK
DL Peak Rate	1Mbps	250kbps	60kbps	50kbps	100bps
Coverage	10km	20km	20km	15km	50km
Battery Life	>10 years	>10 years	>10 years	>10 years	>10 years
Mobility	Full Mobility	Full Mobility	No Mobility[1] (reselection)	Mobility[2]	No Mobility

1) Mobility is considered in 3GPP Rel14　2) From LoRa V1.1

Cellular IoT Mapping





Cat M1 vs. Cat NB1

Cat M1 (eMTC)

- Faster data rates
- Full to limited mobility
- Voice/Volte supported
- Lower coverage

- Health/fitness wearables
- Warning or alarm systems
- Patient monitors
- Electric meter
- Pet trackers
- Asset trackers
- Smart Watch

Cat NB1 (NB-IoT)

- Ultra low cost
- Ultra low power
- Delay tolerant
- High coverage

- Temperature Sensors
- Metering
- Parking control
- Agriculture monitoring
- Industrial monitoring
- Lighting
- Smoke Detectors

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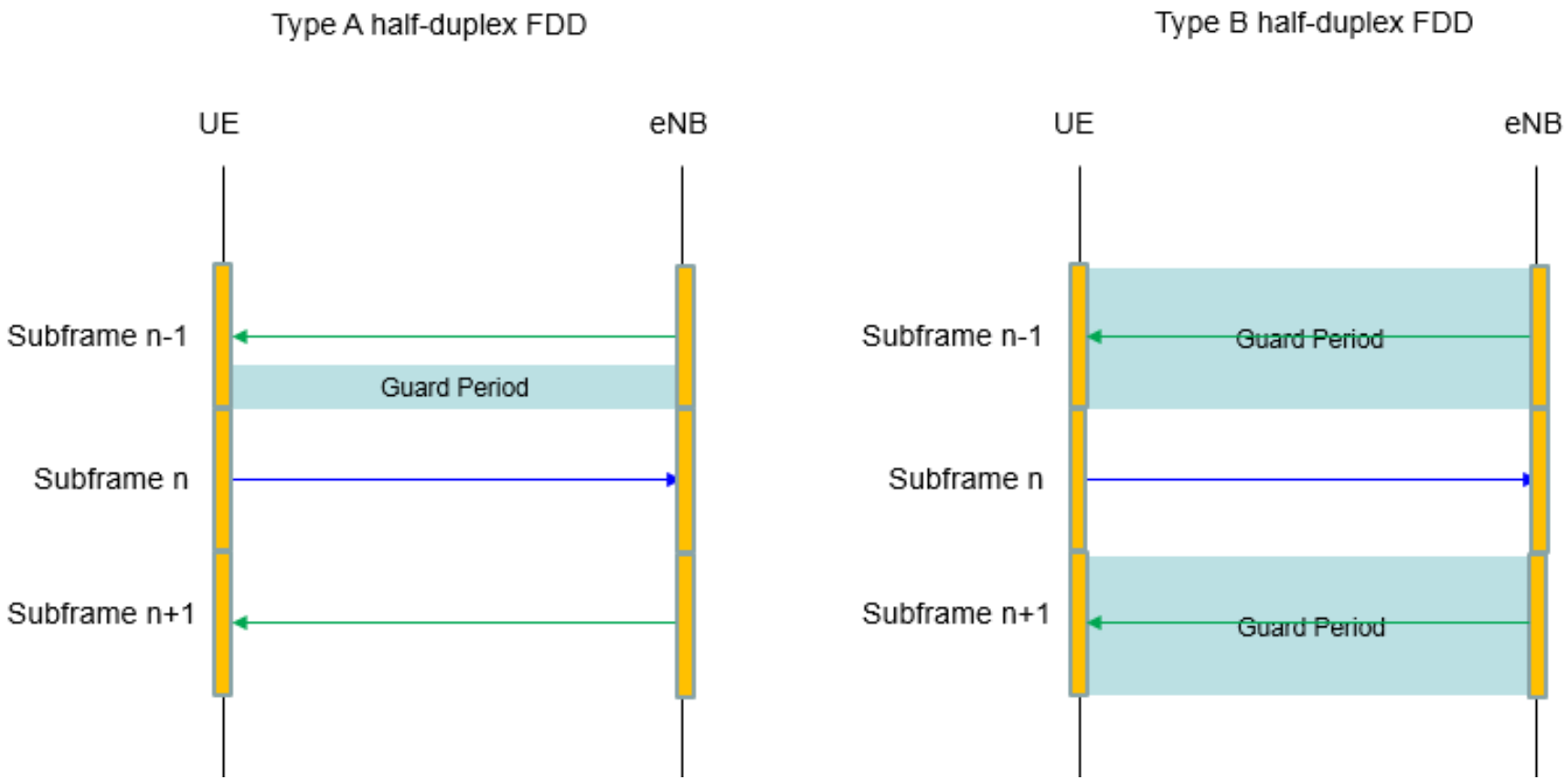
Release 12 Enhancements

- UE Category 0

	Rel-8 Cat4	Rel-8 Cat1	Rel-12 Cat0
Downlink Peak Rate	150 Mbps	10 Mbps	1 Mbps
Uplink Peak Rate	50 Mbps	5 Mbps	1 Mbps
Max num. of downlink spatial Strems	2	1	1
Number of UE RF Receiver Chains	2	2	1
Duplex Mode	Full Duplex	Full Duplex	Half Duplex (opt)
UE receive bandwidth	20 MHz	20MHz	20MHz
Maximum UE transmit power	23 dBm	23 dBm	23 dBm

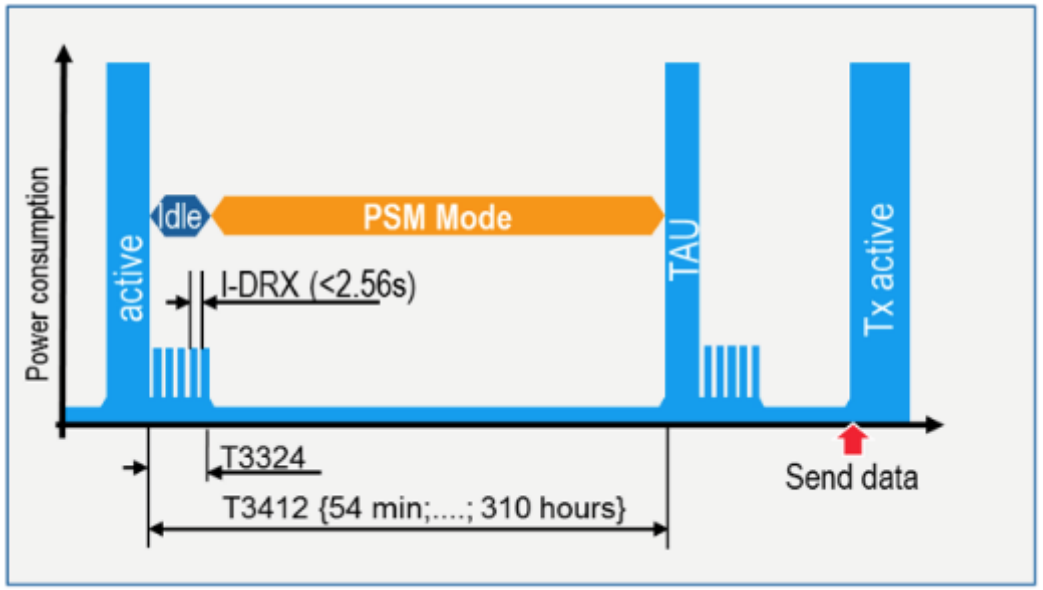
Release 12 Enhancements

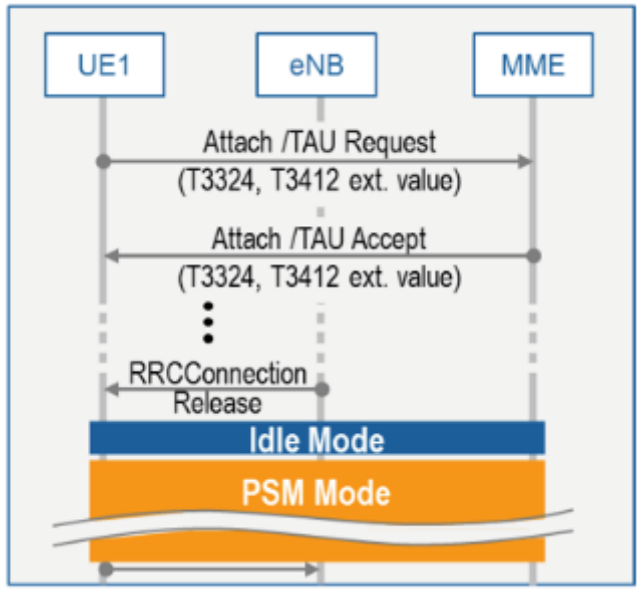
- Type B Half Duplex Operation

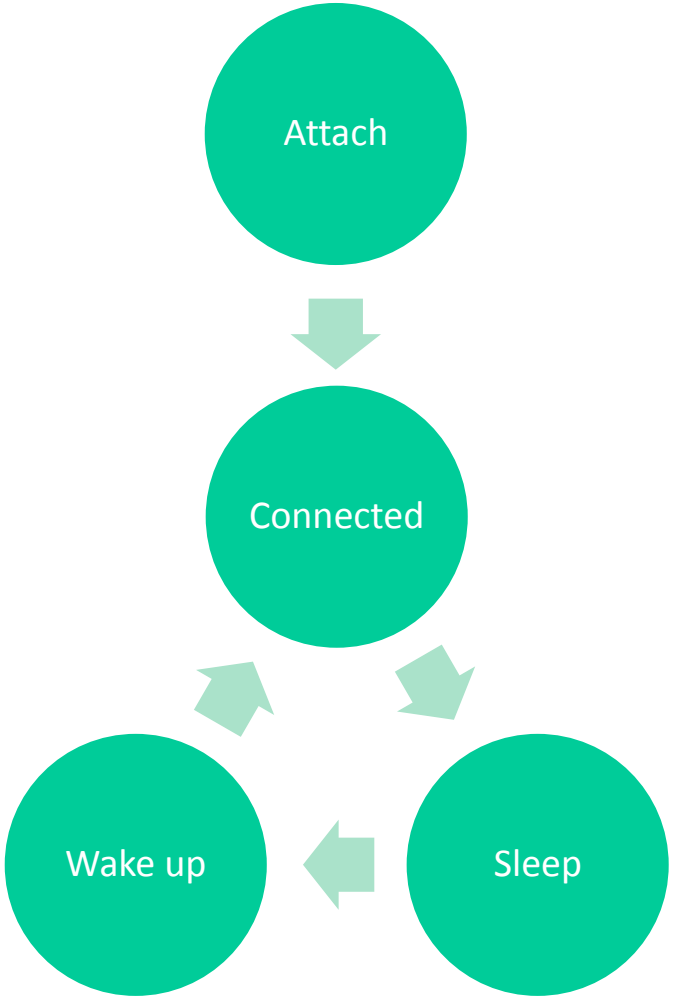


Release 12 Enhancements

- Power Saving Mode
  - Similar to power-off but UE remains registered to network
  - No need to re-attach or re-establish PDN connections
  - UE not immediately reachable from network
  - Suitable for device-triggered applications







Release 13 - Category M1

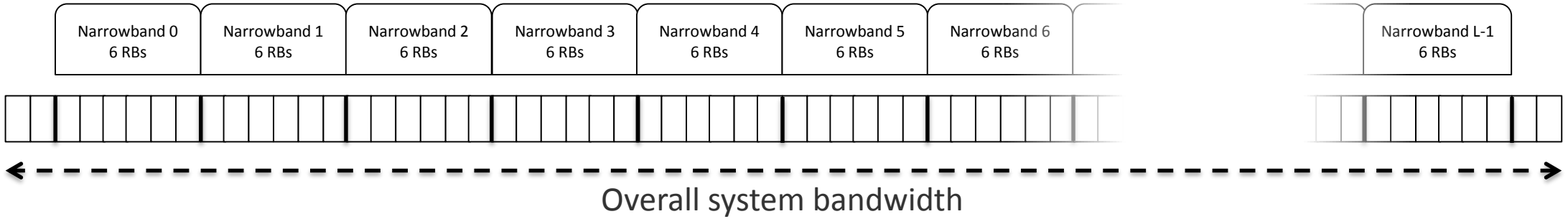
	Rel-12 Cat0	Rel-13 CatM1	Rel-13 CatNB1
Downlink Peak Rate	1 Mbps	1 Mbps	20 kbps
Uplink Peak Rate	1 Mbps	1 Mbps	60 kbps
Max num. of downlink spatial Strems	1	1	1
Number of UE RF Receiver Chains	1	1	1
Duplex Mode	Half Duplex (opt)	Half Duplex	Half Duplex
UE receive bandwidth	20MHz	1.4 MHz	200 kHz
Maximum UE transmit power	23 dBm	20 dBm	23 dBm

Release 13 - Category M1 (eMTC)

Device Cost Reduction	Extended coverage	Energy Consumption
• Narrow RF Bandwidth	• Extensive Repetition	• Extended DRX

Narrow RF Bandwidth

- Only 6 resource blocks for transmission/reception
- Capability of switching narrow bands between subframes
    - » Last and first OFDM symbols used in subframe for retuning



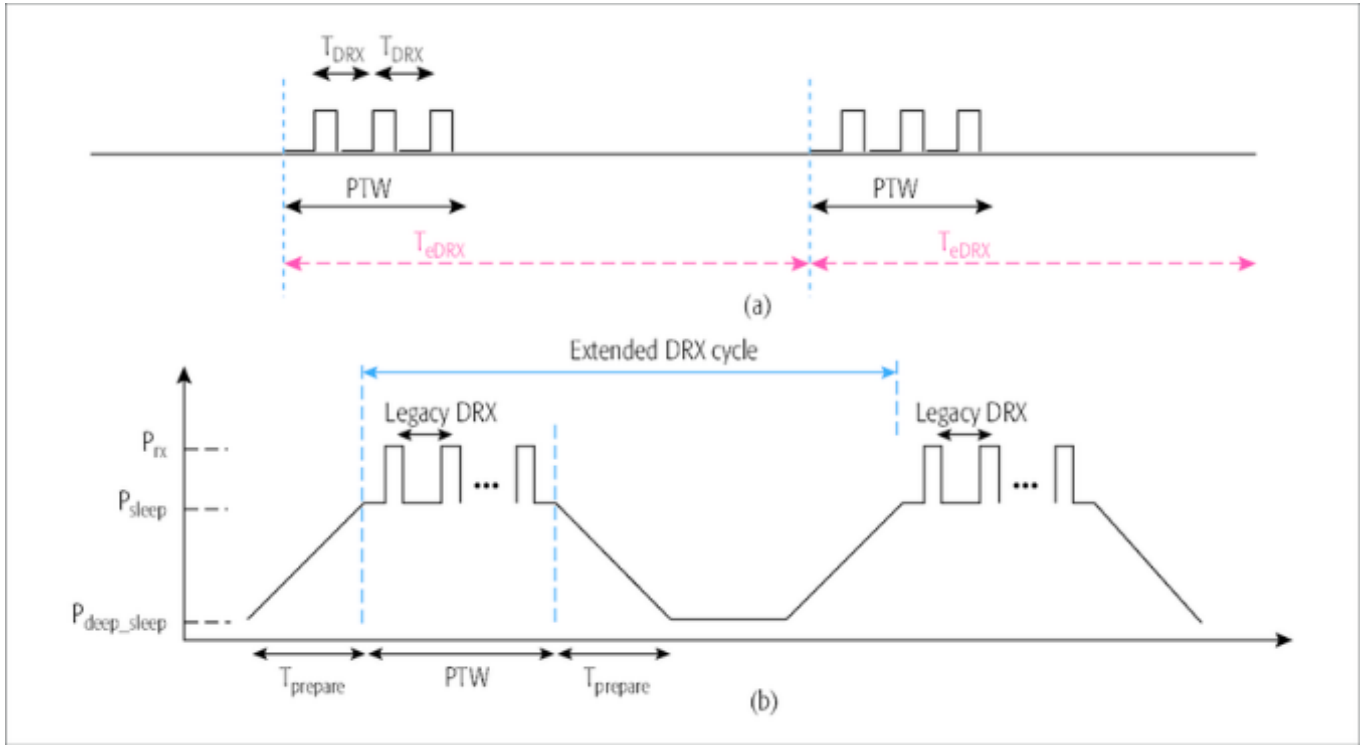
Coverage Extension

CE Mode A	CE Mode B
Small number of repetitions	Large number of repetitions
Maximum 32 repetitions	Maximum 2048 repetitions
Compensation to have same coverage as Cat1 device	15 dB coupling loss enhancement compared to Cat1 device
Output power change same as non-MTC device (TPC commands)	Always max output power

- Repetition in consecutive subframes
- Semi-static configuration with dynamic selection on a per-transmission basis by network

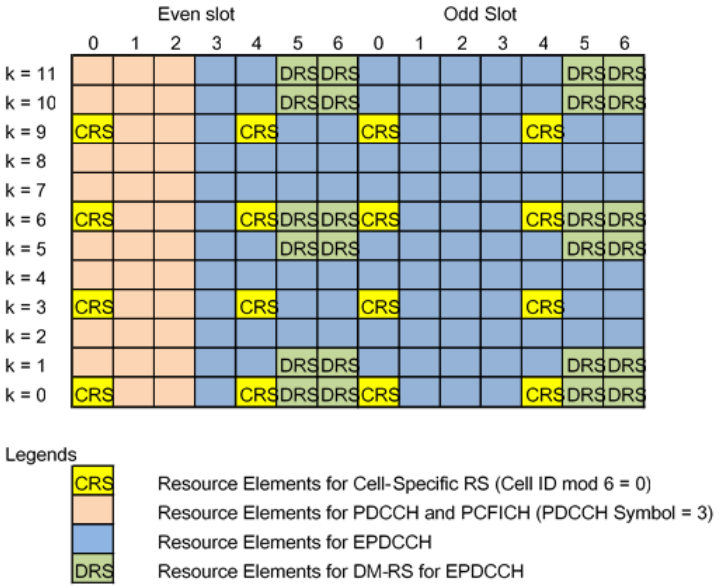
Extended DRX

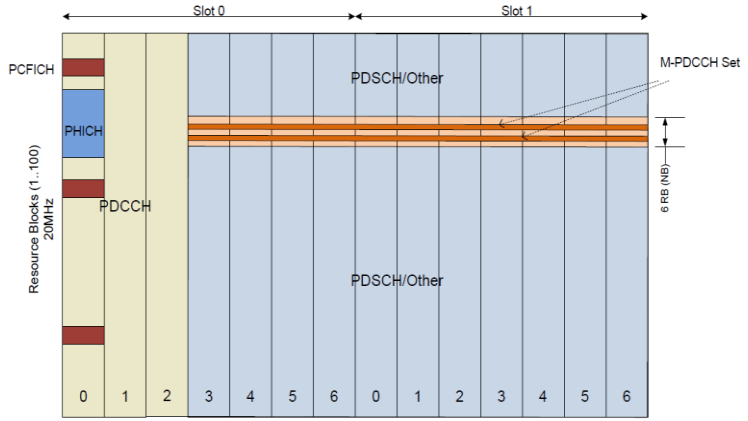
- Extension of traditional DRX cycle from 2.56s to 10.24s (connected state) or 2621.44s (idle state)
- Suitable for network-triggered data transmission
- Hyper-SFN introduced in order to support time sync



MPDCCH for eMTC

- MTC Physical Downlink Control Channel
- Use the structure of EPDCCH (Enhanced Physical Downlink Shared Channel)
  - Carries common and UE specific information
  - Repetitions used
  - Multiple channels





Release 13 – Category NB1

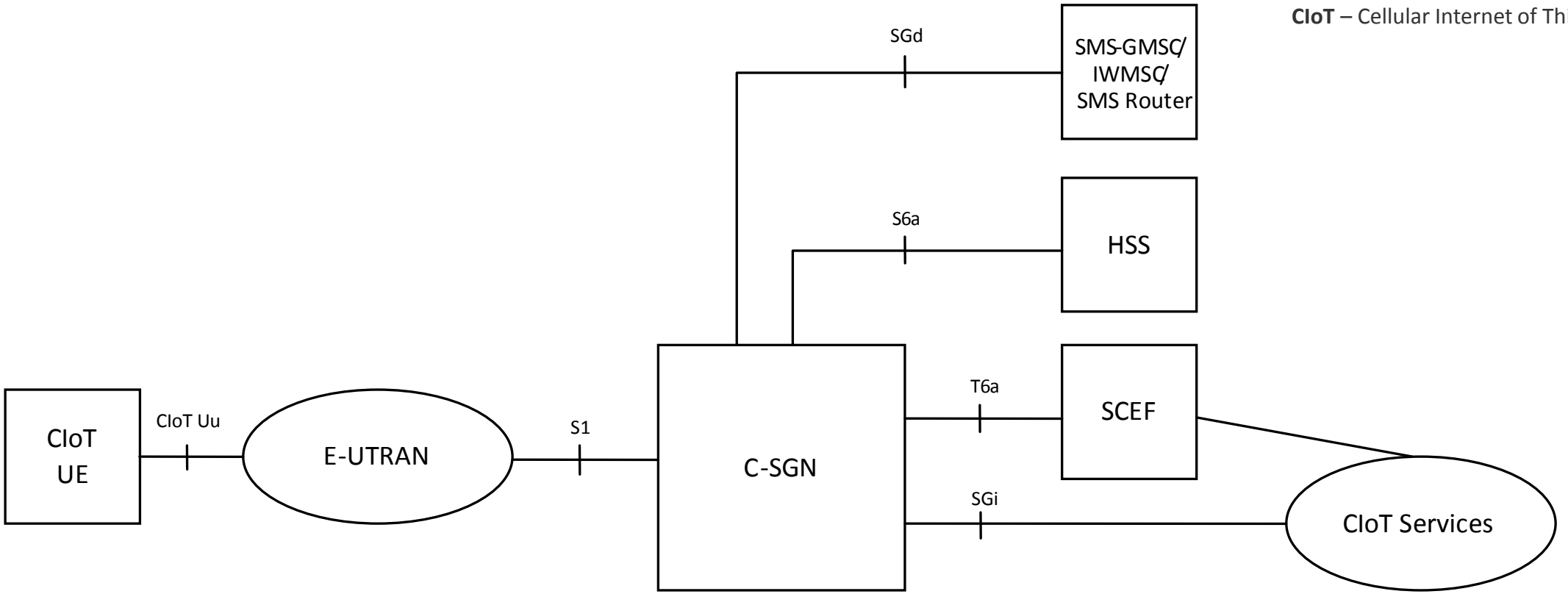
	Rel-12 Cat0	Rel-13 CatM1	Rel-13 CatNB1
Downlink Peak Rate	1 Mbps	1 Mbps	20 kbps
Uplink Peak Rate	1 Mbps	1 Mbps	60 kbps
Max num. of downlink spatial Strems	1	1	1
Number of UE RF Receiver Chains	1	1	1
Duplex Mode	Half Duplex (opt)	Half Duplex	Half Duplex
UE receive bandwidth	20MHz	1.4 MHz	200 kHz
Maximum UE transmit power	23 dBm	20 dBm	23 dBm

Core Network

C-SGN - CIoT Serving Gateway Node
SCEF - Service Capability Exposure Function

HSS – Home Subscriber Server

CIoT – Cellular Internet of Things

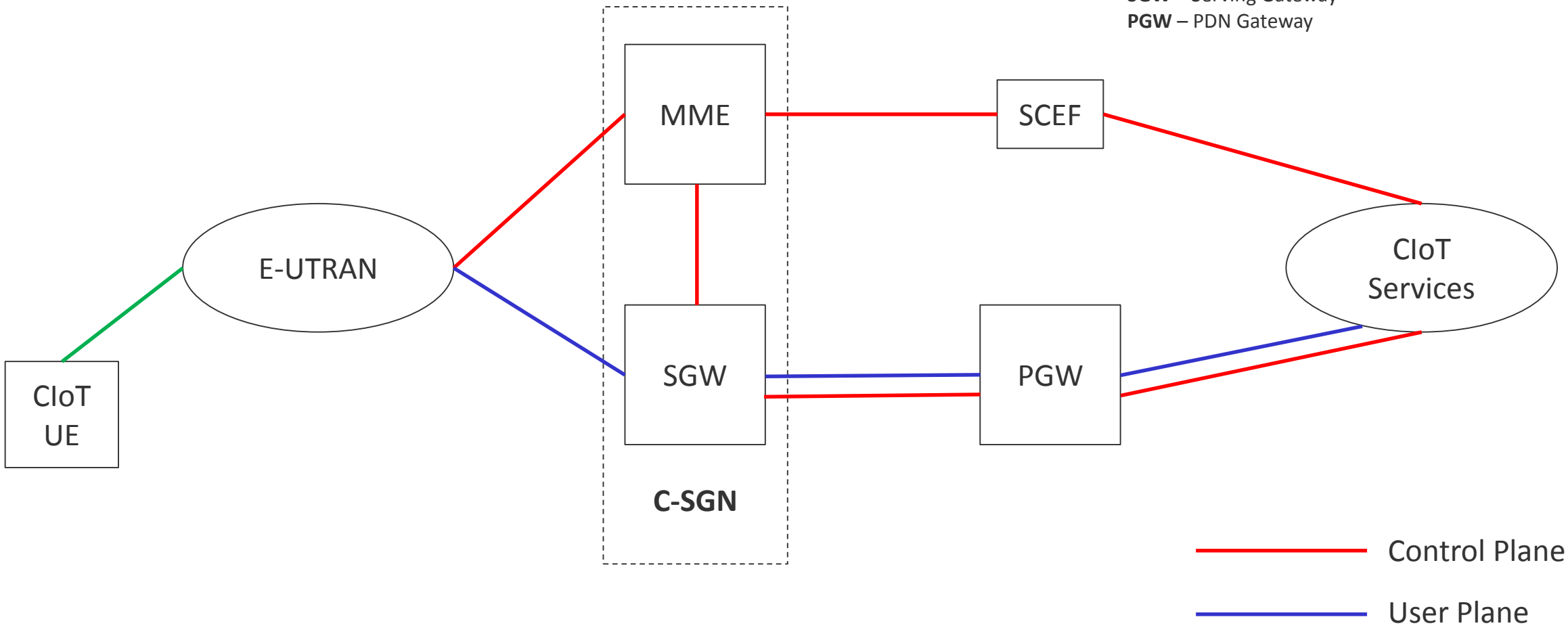


Source: 3GPP TS 23.401

CIoT Serving Gateway Node

C-SGN - CIoT Serving Gateway Node
SCEF - Service Capability Exposure Function

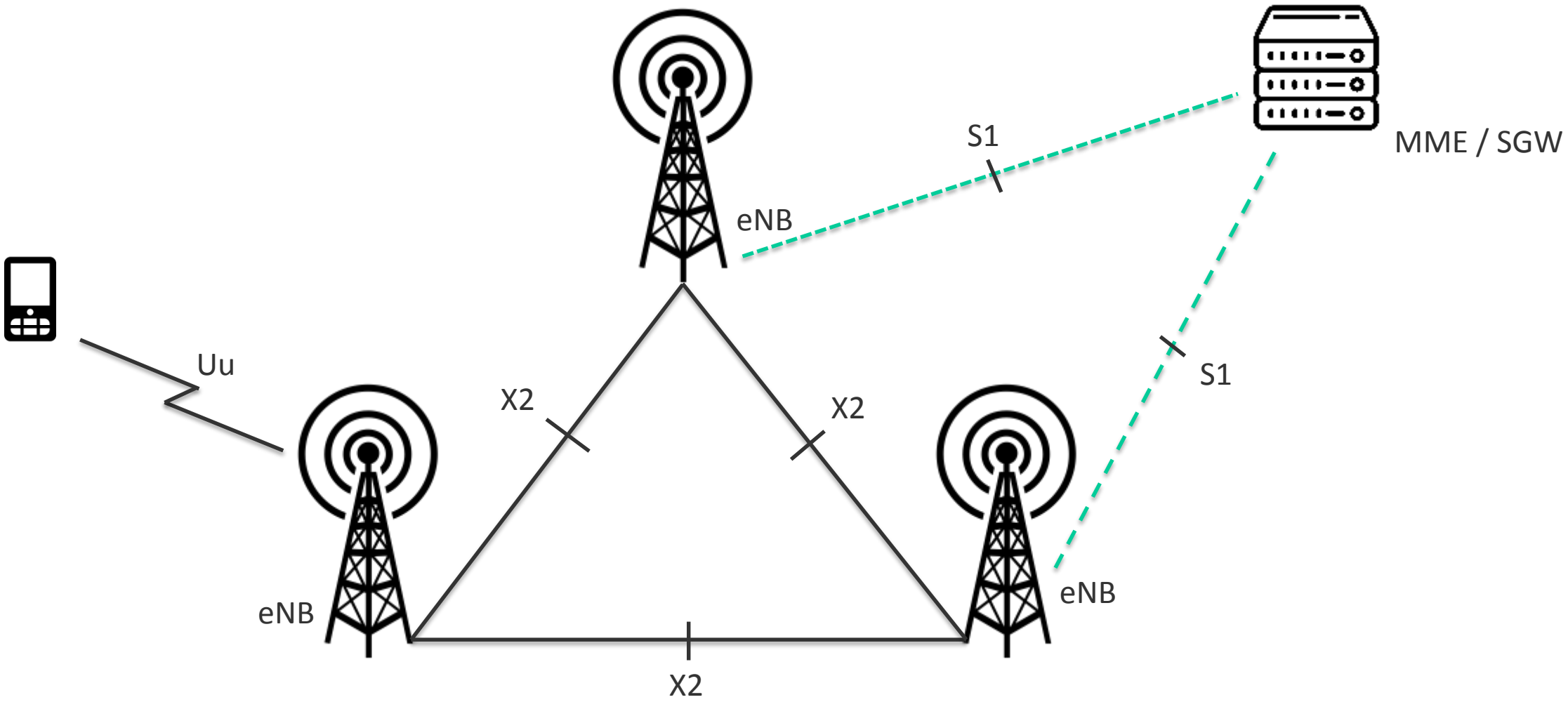
MME – Mobility Management Entity
SGW – Serving Gateway
PGW – PDN Gateway



Functions of C-SGN

- Control plane CIoT EPS optimization for small data transmission.
- User plane CIoT EPS optimization for small data transmission.
- Necessary security procedures for efficient small data transmission.
- SMS without combined attach for NB-IoT only UEs.
- Paging optimisations for coverage enhancements.
- Support for non-IP data transmission via SGi tunnelling and/or SCEF.
- Support for Attach without PDN connectivity.

Access Network



Frequency

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz	FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
6[1]	830 MHz – 840 MHz	875 MHz – 885 MHz	FDD
7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
9	1749.9 MHz – 1784.9 MHz	1844.9 MHz – 1879.9 MHz	FDD
10	1710 MHz – 1770 MHz	2110 MHz – 2170 MHz	FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
15	Reserved	Reserved	FDD
16	Reserved	Reserved	FDD
17	704 MHz – 716 MHz	734 MHz – 746 MHz	FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
21	1447.9 MHz – 1462.9 MHz	1495.9 MHz – 1510.9 MHz	FDD
22	3410 MHz – 3490 MHz	3510 MHz – 3590 MHz	FDD
23[1]	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
24	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
27	807 MHz – 824 MHz	852 MHz – 869 MHz	FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
29	N/A	717 MHz – 728 MHz	FDD[2]
30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz	FDD
32	N/A	1452 MHz – 1496 MHz	FDD[2]
33	1900 MHz – 1920 MHz	1900 MHz – 1920 MHz	TDD
34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
35	1850 MHz – 1910 MHz	1850 MHz – 1910 MHz	TDD
36	1930 MHz – 1990 MHz	1930 MHz – 1990 MHz	TDD
37	1910 MHz – 1930 MHz	1910 MHz – 1930 MHz	TDD
38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
41	2496 MHz 2690 MHz	2496 MHz 2690 MHz	TDD
42	3400 MHz – 3600 MHz	3400 MHz – 3600 MHz	TDD
43	3600 MHz – 3800 MHz	3600 MHz – 3800 MHz	TDD
44	703 MHz – 803 MHz	703 MHz – 803 MHz	TDD
45	1447 MHz – 1467 MHz	1447 MHz – 1467 MHz	TDD
46	5150 MHz – 5925 MHz	5150 MHz – 5925 MHz	TDD[8]
47	5855 MHz – 5925 MHz	5855 MHz – 5925 MHz	TDD
48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
…			
64	Reserved		
65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD[4]
67	N/A	738 MHz – 758 MHz	FDD[2]
68	698 MHz – 728 MHz	753 MHz – 783 MHz	FDD
69	N/A	2570 MHz – 2620 MHz	FDD[2]
70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD[10]

E-UTRA operating bands

NB-IoT

1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 21, 25, 26, 28, 31, 66 and 70:

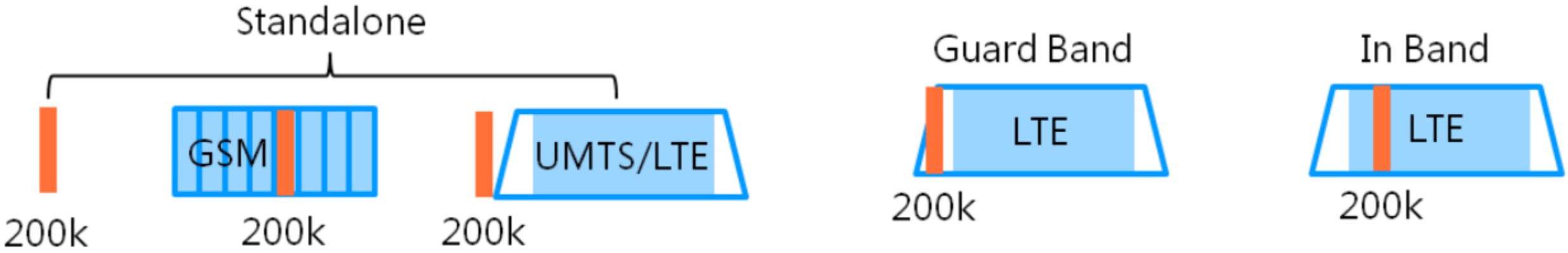
Half Duplex FDD

Cat-M

1, 2, 3, 4, 5, 7, 8, 11, 12, 13, 18, 19, 20, 21, 25, 26, 27, 28, 31 and 66: Half and Full Duplex FDD

39, 40 and 41: TDD mode

Deployment in frequency spectrum



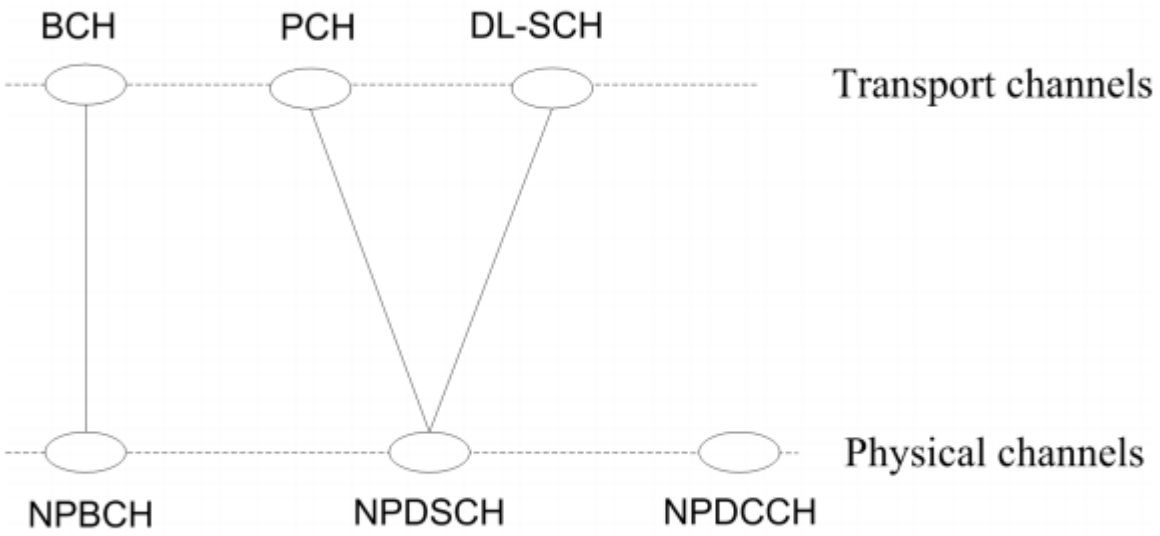
NB-IoT bandwidth = **180KHz** = 1 LTE Resource block

Allowed LTE PRB for in-band NB-IoT operation

LTE system bandwidth	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
LTE PRB indices for NB-IoT synchronization	2, 12	2, 7, 17, 22	4, 9, 14, 19, 30, 35, 40, 45	2, 7, 12, 17, 22, 27, 32, 42, 47, 52, 57, 62, 67, 72	4, 9, 14, 19, 24, 29, 34, 39, 44, 55, 60, 65, 70, 75, 80, 85, 90, 95

Downlink – Physical Channels and signals

- **Channels:**



BCH – Broadcast Channel
PCH – Paging Channel
DL-SCH – Downlink Shared Channel

NPBCH – NarrowBand Physical Broadcast Channel
NPDSCH – NarrowBand Physical Downlink Shared Channel
NPDCCH – NarrowBand Physical Downlink Control Channel

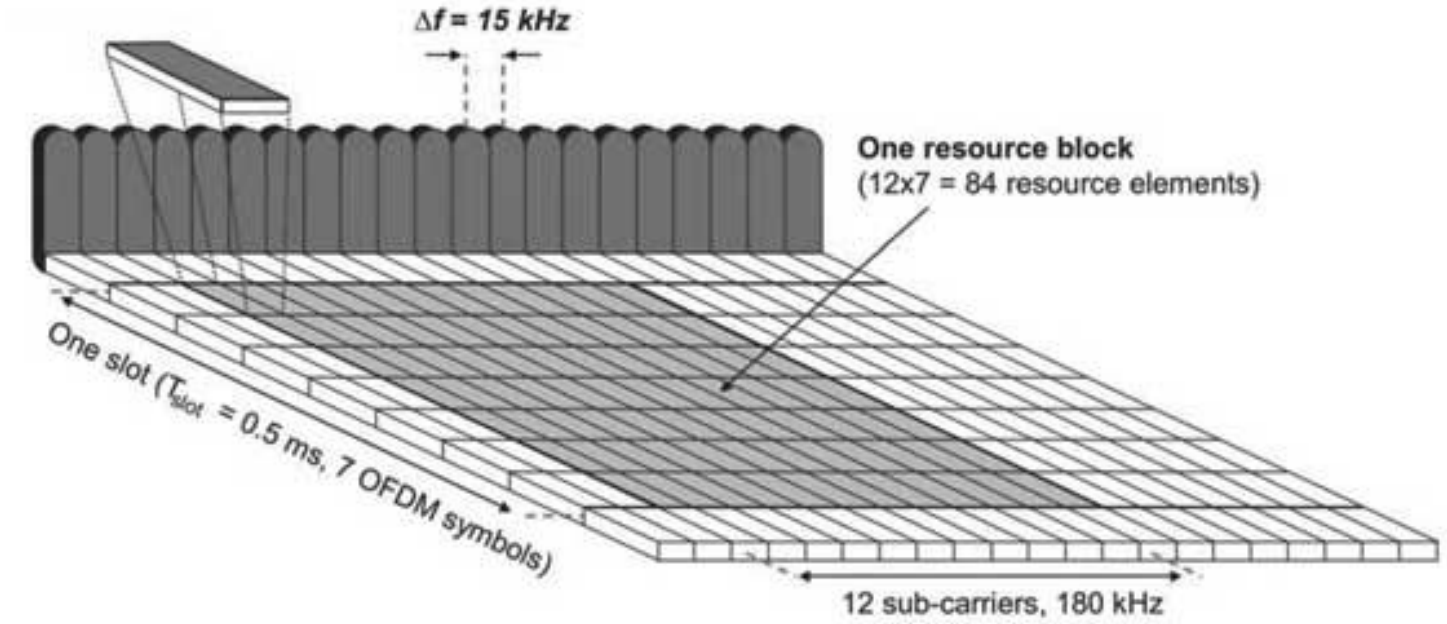
- **Signals:**

NRS – NarowBand Reference Signal
NPSS – NarrowBand Primary Synchronization Signal
NSSS – NarrowBand Secondary Synchronization Signal

Downlink – Resource Grid

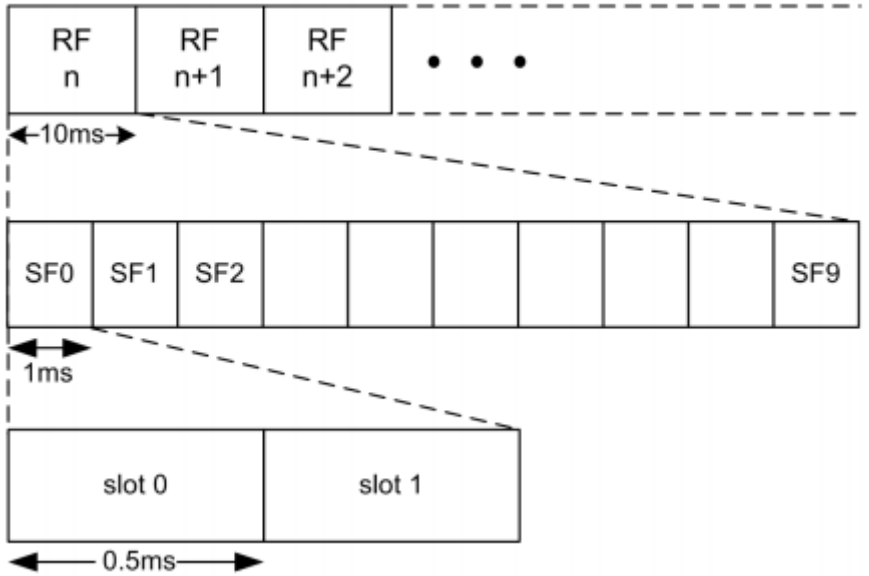
- Fully aligned with LTE -> OFDM
- Subcarrier spacing 15kHz
- Same time-domain structure as LTE
- NB-IoT carrier consists of 12 sub-carriers (1 NB-IoT carrier = 1 LTE Resource Block)

  Bandwidth = 12 sub-carriers x 15kHz = 180kHz
- QPSK Modulation



Downlink – Frame Structure

- 1 Frame = 10 subframes (1024 SFN)
- 1 subframe = 2 slots (1ms)
- 1 slot = 0.5ms (7 OFDM symbols)
- 1 Hyperframe= 1024 x 1024 radio frames (~ 3hours)

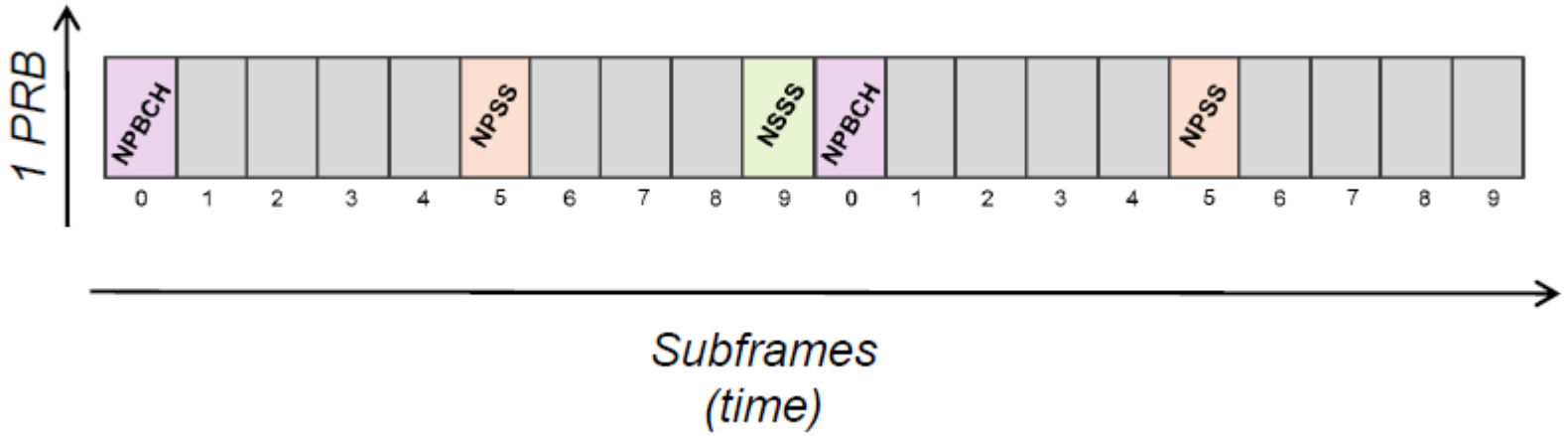


Downlink – Frame Structure

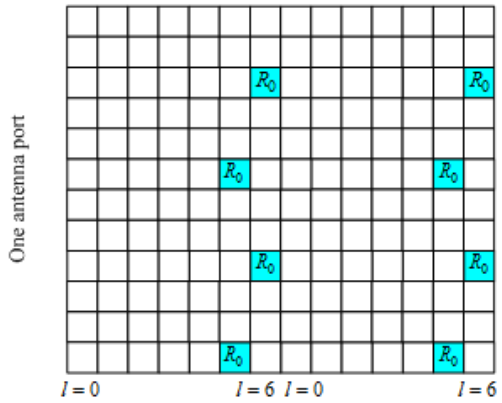
- NPBCH – transmitted in subframe #0 in all radio frames
- NPSS – transmitted in subframe #5 in all radio frames
- NSSS – transmitted in subframe #9 in even radio frames

- Rest available for NPDCCH and NPDSCH

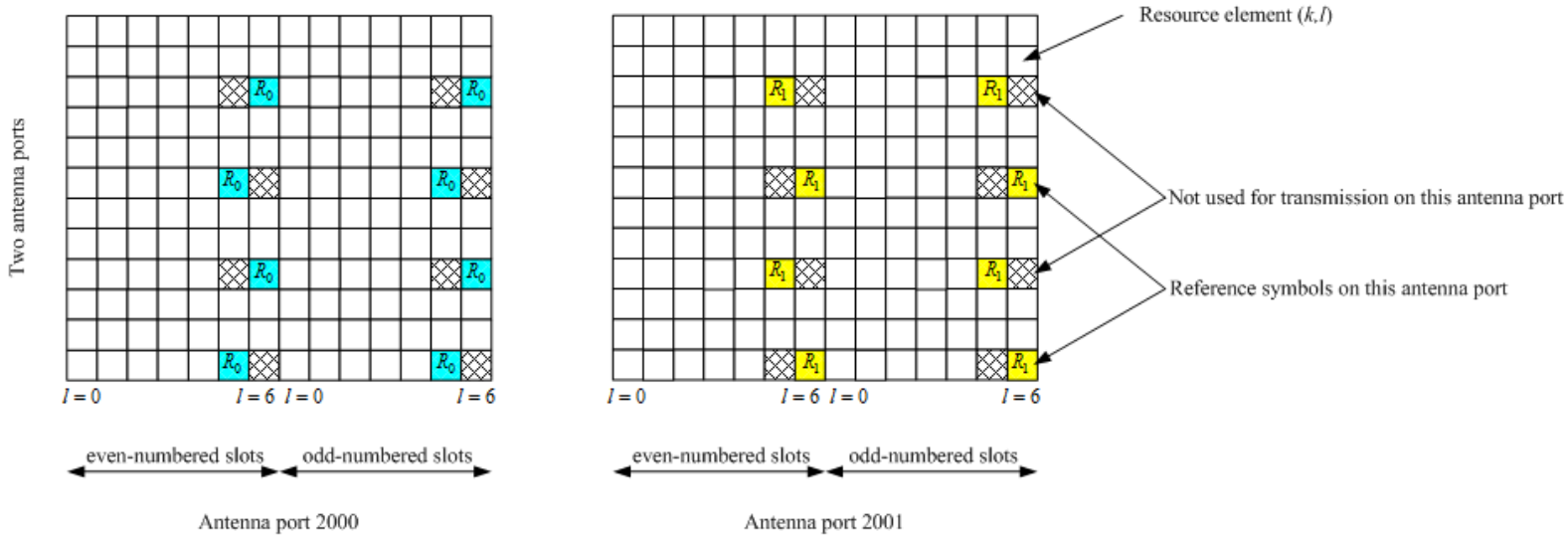
- Each Physical channel occupies whole PRB -> Only one channel per subframe



Narrowband Cell Reference Signals

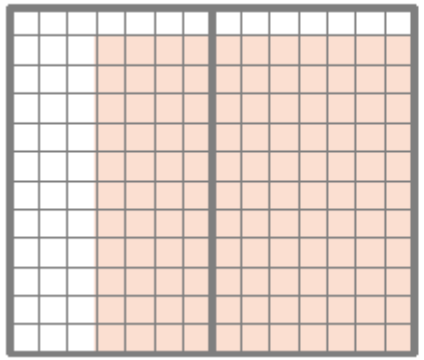


- Used to estimated the channel
- Transmitted in every valid downlink subframe except NPSS/NSSS
- Transmitted with 1 or 2 antenna ports
- Values are created as CRS in LTE where NCellID is taken for PCI.

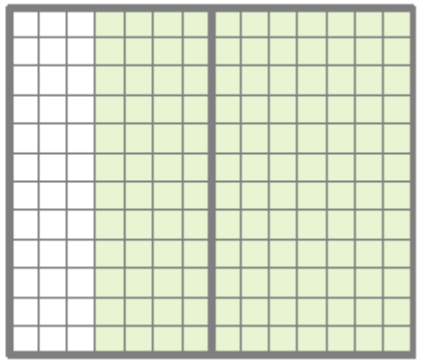


Narrowband Primary/Secondary Sync Signals

- Used to estimate the frequency and timing as well as derive NCellID
- NarrowBand Reference Signal not transmitted
- Zadoff-Chu seguence used for generation
- NPSS fixed and used for detection of frame boundary
- NSSS used for derivation of NCellID



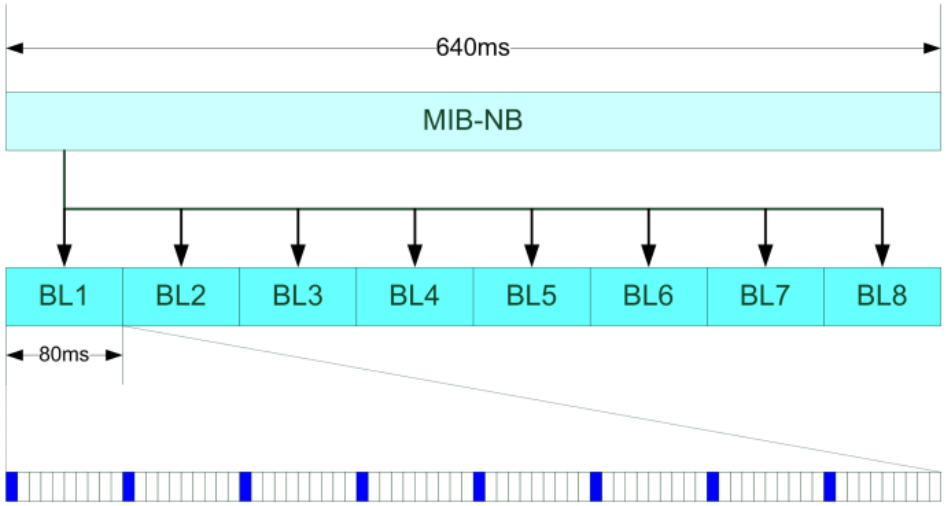
NPSS



NSSS

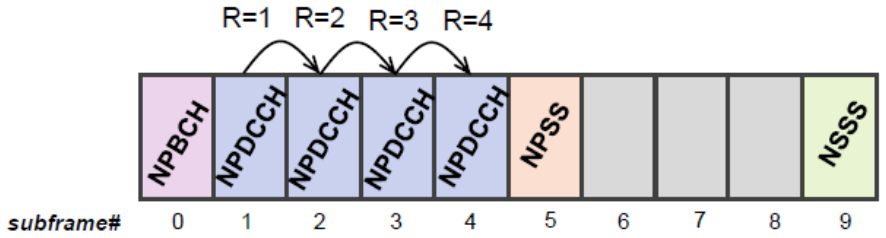
NarrowBand Physical Broadcast channel

- Used to carry NarrowBand Master Information Block (MIB-NB)
- Transmitted over 640ms (8 blocks x 80ms)
- Contains:
  - Part of a System Frame Number
  - Part of a Hypersubframe number (Rest in SIB1-NB)
  - SIB-NB1 scheduling information (number of repetitions)
  - SystemInfoValue tag
  - Access Barring enabled
  - Operation mode (standalone, In-band, Guard-band)
- Modulation: QPSK

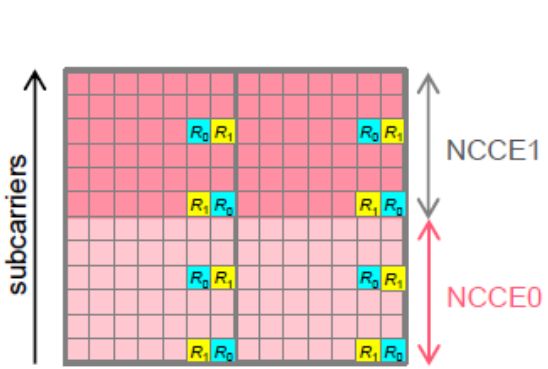


NarrowBand Physical Control Channel

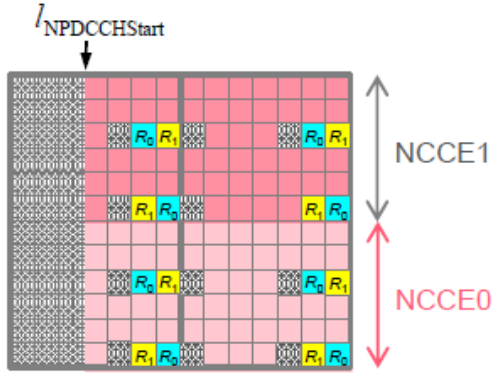
- Indicates for which UE are data transmitted in NPDSCH, where there are located and how often they are repeated
- Indicates UL grant -> resources for UE Uplink transmission
- Indicates Paging and system information update
- Contains 1 or 2 control channels (NCCE)
- Repetitions may be used to increase coverage
- Modulation: QPSK



Example where same NPDCCH is Repeated 4 times



Two Antenna ports Standalone



Two Antenna ports In-Band

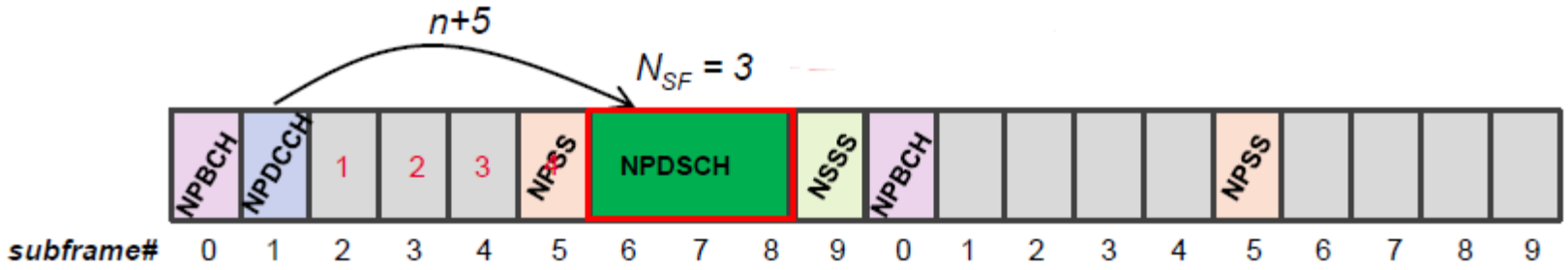
DCI Format	Size / bit	Content
N0	23	UL grant
N1	23	NPDSCH scheduling RACH procedure initiated by NPDCCH order
N2	15	Paging and direct indication

UL grant in DCI

- Start time of PUSCH
- Number of repetitions
- Number of RUs
- Number of subcarriers including their position in the frequency
- MCS index -> modulation and coding scheme

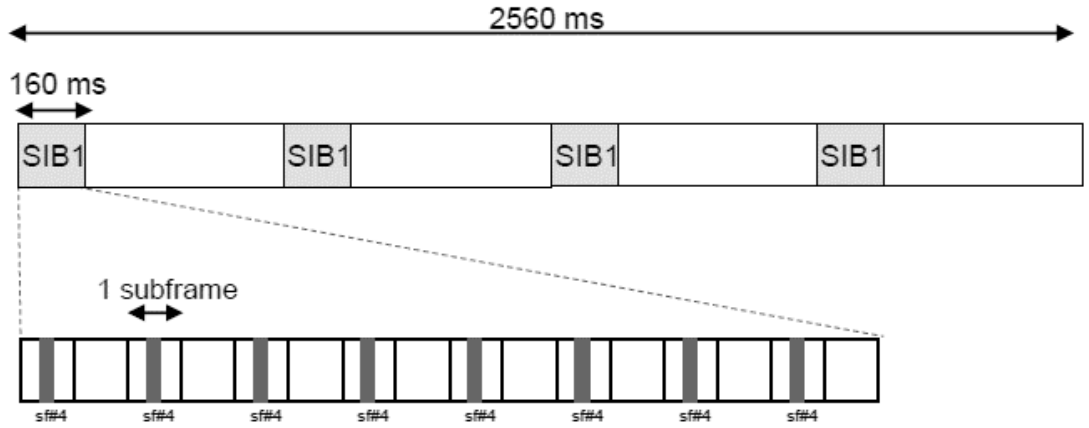
NarrowBand Physical Shared Channel

- Used to carry used data and broadcast information not transmitted on NPBCH (SIB-NB, paging, dedicated RRC)
- Maximum TBS (Transport Block Size) is 680 bits
- Single TBS can be mapped to multiple subframes
- Up to 2048 repetitions to extend coverage
- Modulation: QPSK



System Information Block

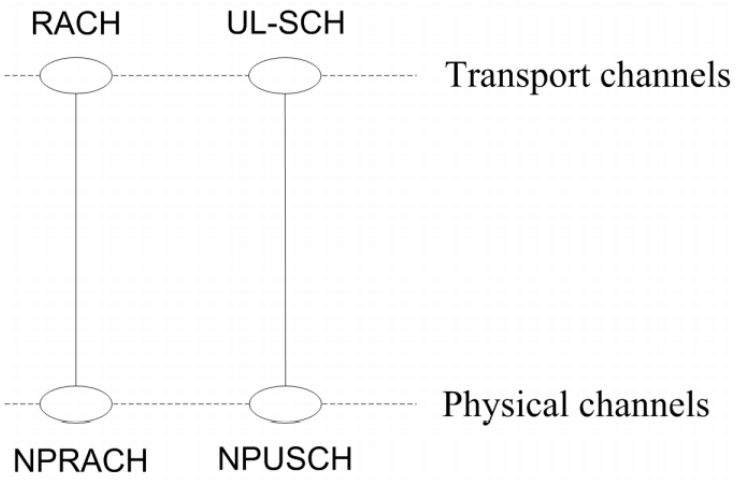
- SystemInformationBlockType1-NB (SIB1-NB)
  - Periodicity of 2560ms with 4, 8 or 16 repetitions within that period
  - Transmitted in subframe #4 in every even frame
  - Providing information of PLMN, TA code, Identity and Cell Selection
- Remaining SIB as in LTE (SI windows)
  - Scheduling indicated in SIB1-NB
  - SIB2-NB: Radio Resource configuration common to all UEs
  - SIB3-NB: Cell Reselection common
  - SIB4-NB: Neighbour cells intra-frequency
  - SIB5-NB: Neighbour cells inter-frequency
  - SIB14-NB: Access Barring
  - SIB16-NB: GPS and UTC



Example: SIB1-NB is Repeated 4 times

Uplink – Physical Channels and signals

- **Channels:**



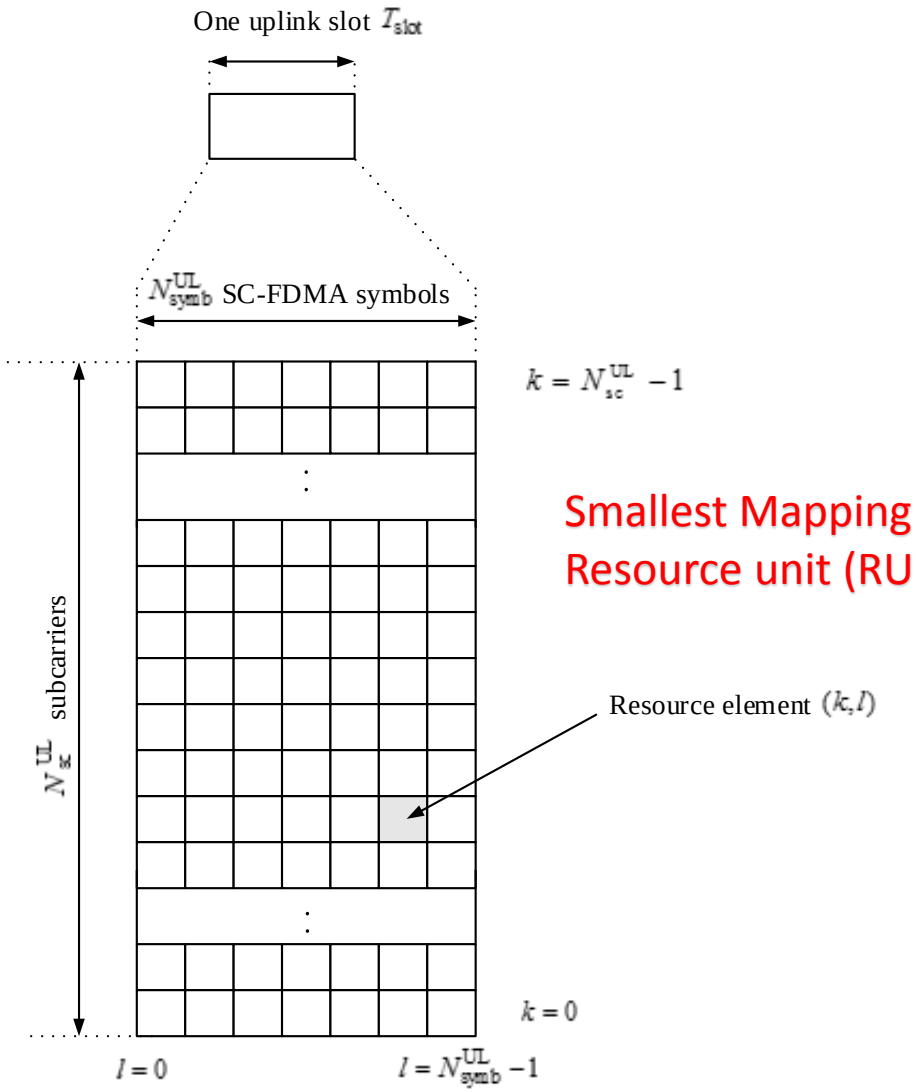
RACH – Random Access Channel
UL-SCH – Uplink Shared Channel

NPRACH – NarrowBand Physical Random Access Channel
NPUSCH – NarrowBand Physical Uplink Shared Channel

- **Signals:**

DMRS – Demodulation Reference Signal

Uplink – Resource grid



Subcarrier spacing	N_{sc}^{UL}	T_{slot}
$\Delta f = 3.75$ kHz	48	$61440 \cdot T_s$
$\Delta f = 15$ kHz	12	$15360 \cdot T_s$

2 ms

0.5 ms

Smallest Mapping Unit:
Resource unit (RU) = Nsc x Nslots

NPUSCH format	Δf	N_{sc}^{RU}	N_{slots}^{UL}	N_{symb}^{UL}
1	3.75 kHz	1	16	7
	15 kHz	1	16	
		3	8	
		6	4	
		12	2	
2	3.75 kHz	1	4	
	15 kHz	1	4	

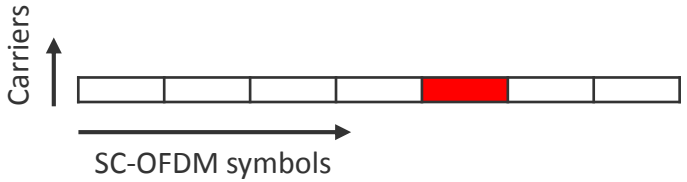
User data

UCI

NPUSCH format	N_{sc}^{RU}	Modulation scheme
1	1	BPSK, QPSK
	>1	QPSK
2	1	BPSK

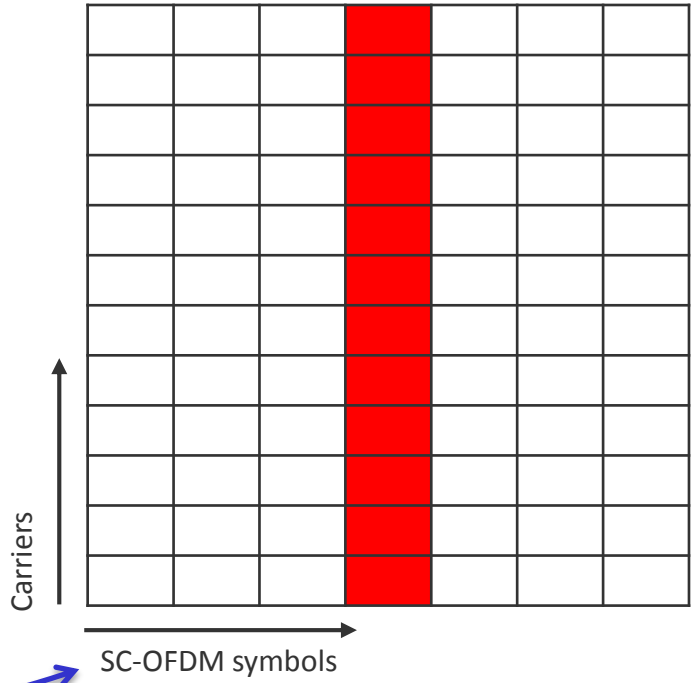
Demodulation Reference Signal

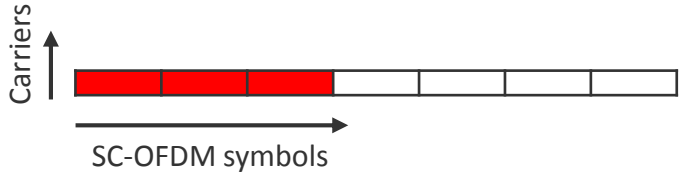
- It is multiplexed with data transmission in NPUSCH

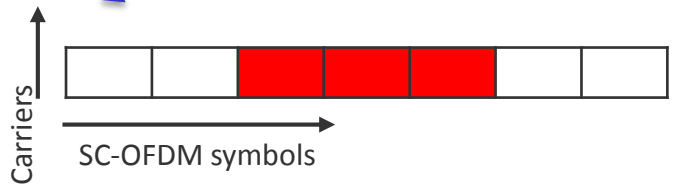


Demodulation reference signal location for NPUSCH

NPUSCH format	Values for l	
	$\Delta f = 3.75$ kHz	$\Delta f = 15$ kHz
1	4	3
2	0,1,2	2,3,4







NarrowBand Physical Random Access Channel

- Based on single-subcarrier frequency-hopping symbol groups
- Consist of 1 cyclic prefix and 5 identical symbols
- 3.75kHz sub-carrier spacing applied
- Higher layer configuration consits of:
  - resource periodicity (*nprach-Periodicity*)
  - frequency location of the first subcarrier (*nprach-SubcarrierOffset*),
  - number of allocated subcarriers (*nprach-NumSubcarriers*)
  - number of starting sub-carriers *(nprach-NumCBRA-StartSubcarriers*)
  - number of NPRACH repetitions per attempt (*numRepetitionsPerPreambleAttempt*)
  - NPRACH starting time (*nprach-StartTime*)

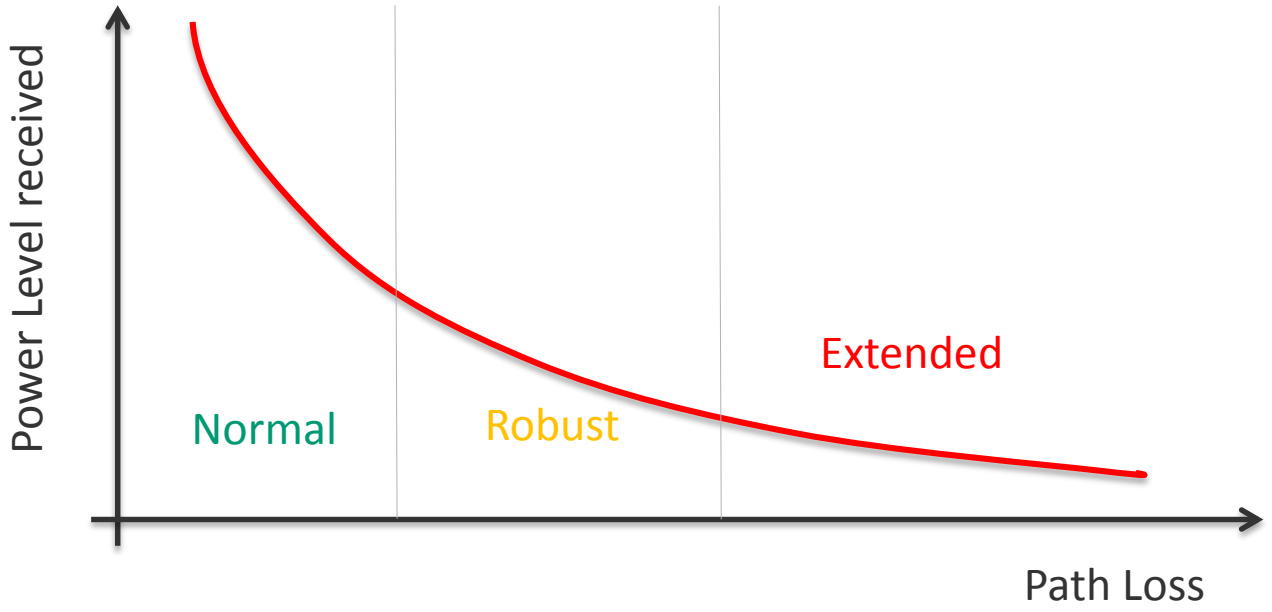
Random Access Symbol Group

Random Access Parameters

Preamble format	T_{CP}	T_{SEQ}
0	$2048T_s$	$5 \cdot 8192T_s$
1	$8192T_s$	$5 \cdot 8192T_s$

NPRACH parameters

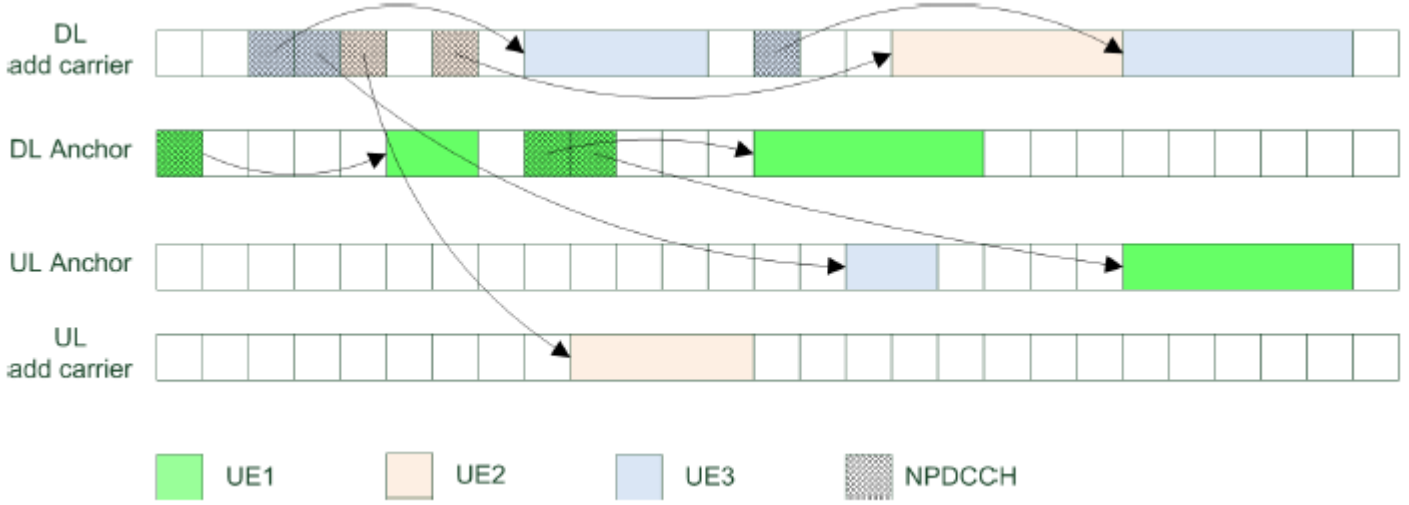
- UE measures NRSRP (NarrowBand Reference signal Received Power)
- UE derives Coverage Level (Normal, Robust, Extended)
- Coverage level determines NPRACH parameters :
  - subset of sub-carries, repetitions, number of attempts, …



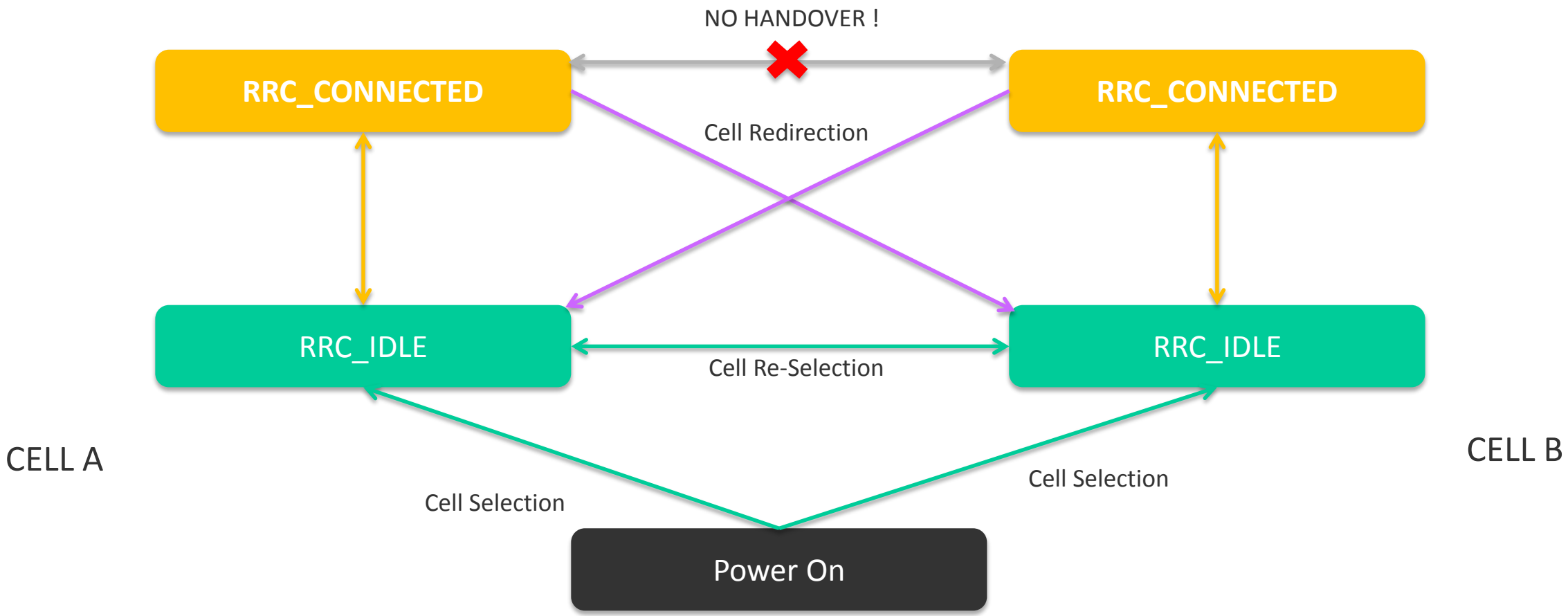
Multi-Carrier Configuration

- *RRCConnectionReconfiguration* may contain configuration of additional carrier in UL and DL
  - **non-anchor carrier**
- Non-anchor carrier is used to receive all date except:
  - synchronization
  - broadcast information
  - paging

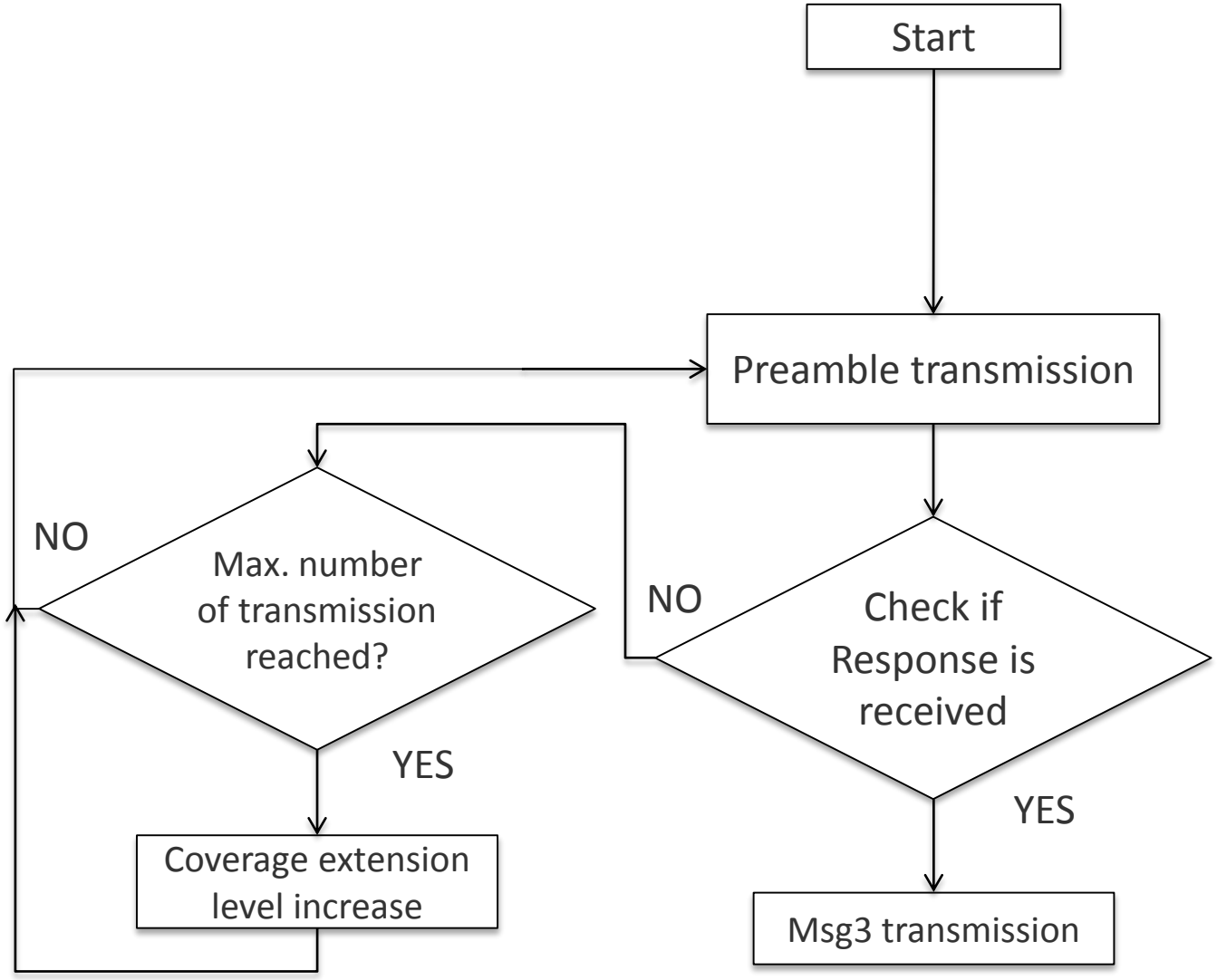
  } Only **anchor carrier**
- Same principle in UL
- Only 1 carrier used for transmission / no simultaneous transmission

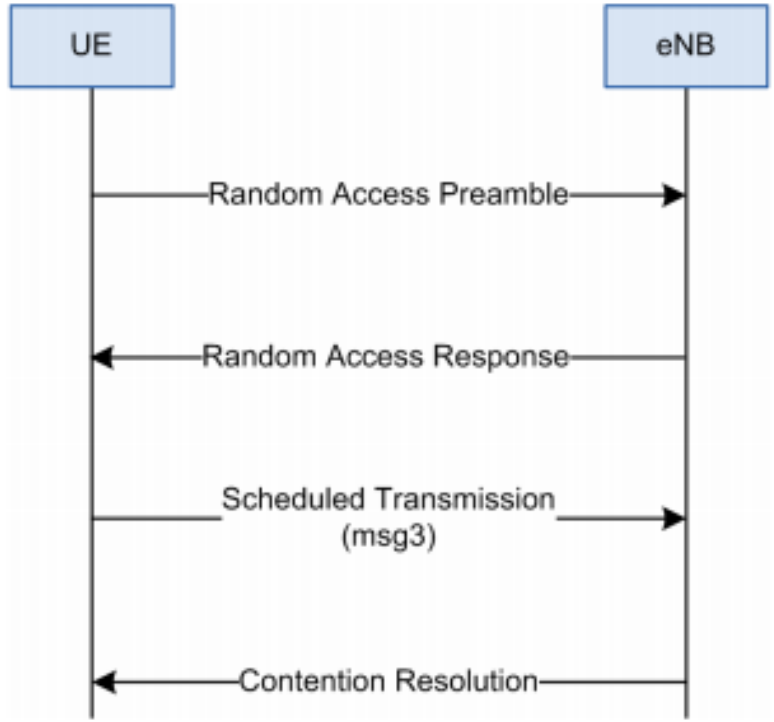


Cell Selection and Mobility in NB-IoT



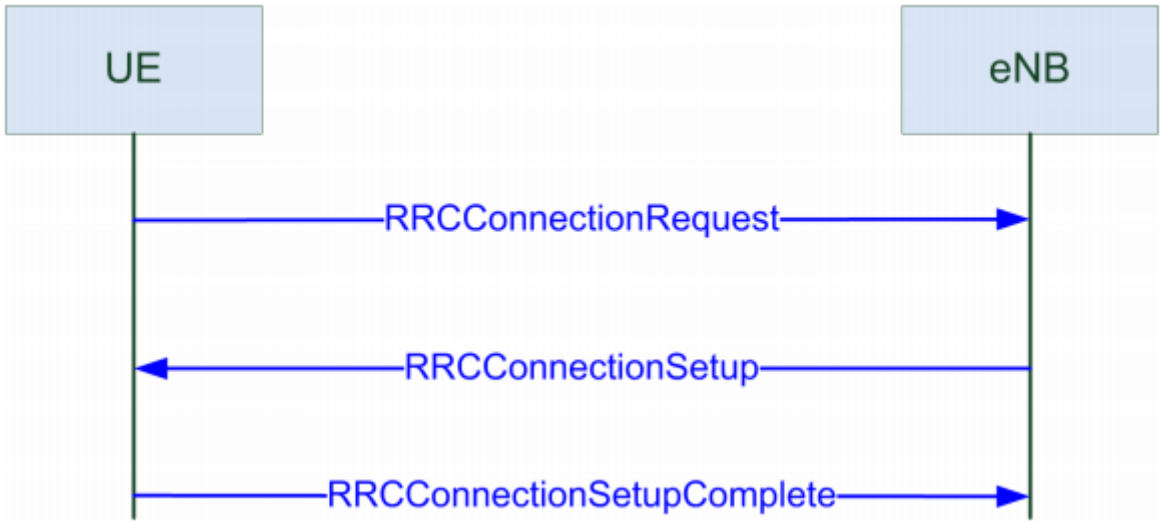
Random Access Procedure



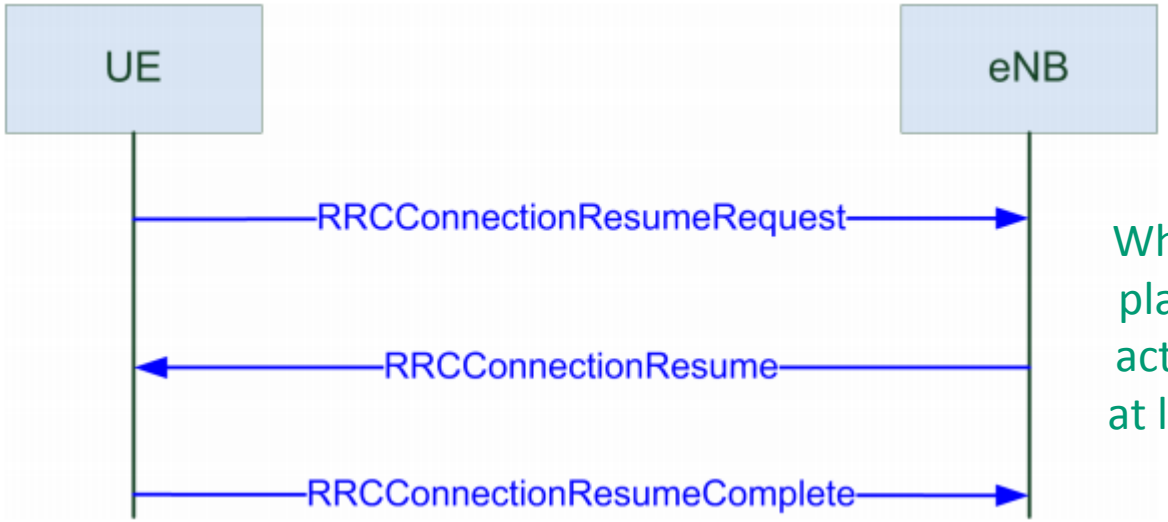


Connection Establishment

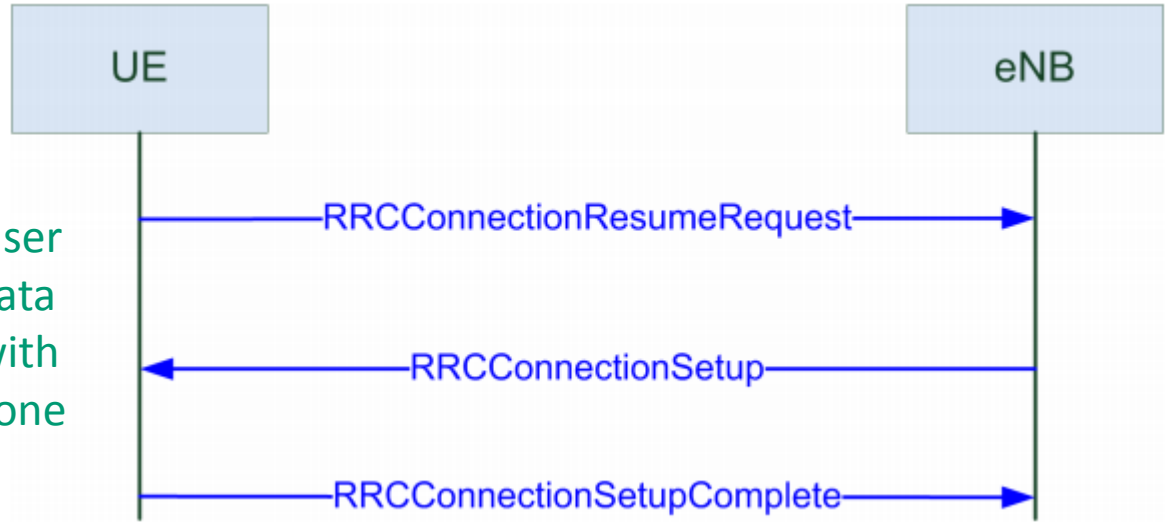
- Message flow same as in LTE
- Content of messages different
  - Indication of Multi-tone traffic and multicarrier support
  - Establishment Cause:
    - *mobile originated signalling*
    - *mobile originated data*
    - *mobile terminated access*
    - *exceptional reports*
- 1 SRB and up to 2 DRB



Connection Release and Re-establishment



When User plane data active with at least one DRB



Accepted by eNodeB

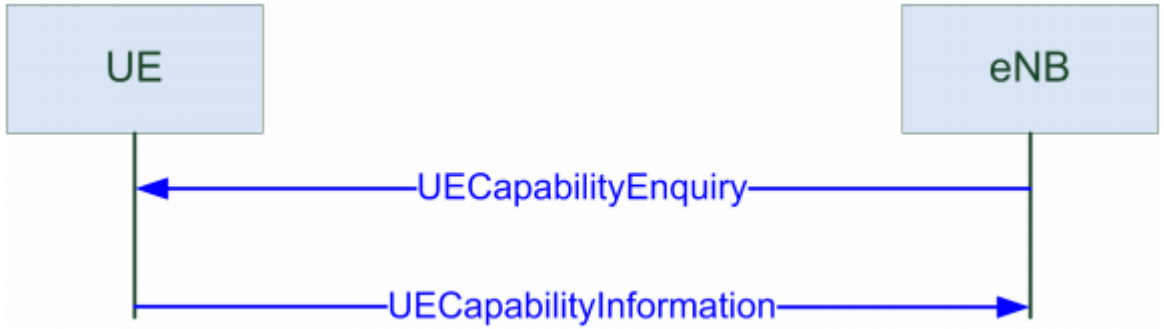
Not Accepted by eNodeB

Connection reject

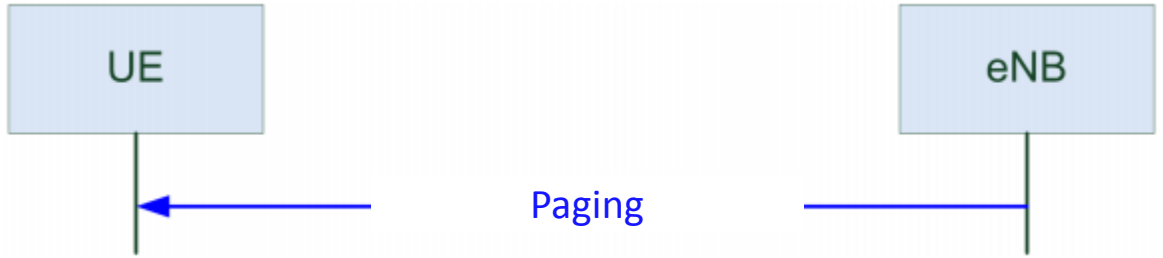
- Rejection of *RRCConnectionRequest* or *RRCConnectionResumeRequest*
- For example in case of no free resources
- UE has to wait for an amount of time signalled in a message
- Traffic jam prevention

- In case of *RRCConnectionResumeRequest:*
  - eNB to inform whether current AS context can be kept and stored or released for following resume request

UE Capability and Paging



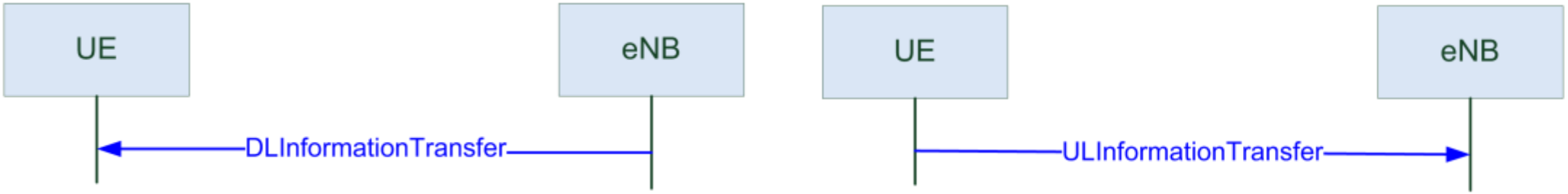
- Always initiated by network
- Contains:
  - UE Category
  - List of Supported bands
  - Capability of multiple bearers
  - Multicarrier operation
  - Mutli-tone transmission
  - RoHC profiles



- Used to trigger RRC_CONNECTION mode and to indicates system information change for UE in IDLE mode
- Sent over NPDSCH
- Contain list of UE to be paged
- Triggers Random access procedure or reading of system information by UE

Data Transfer - Control Plane

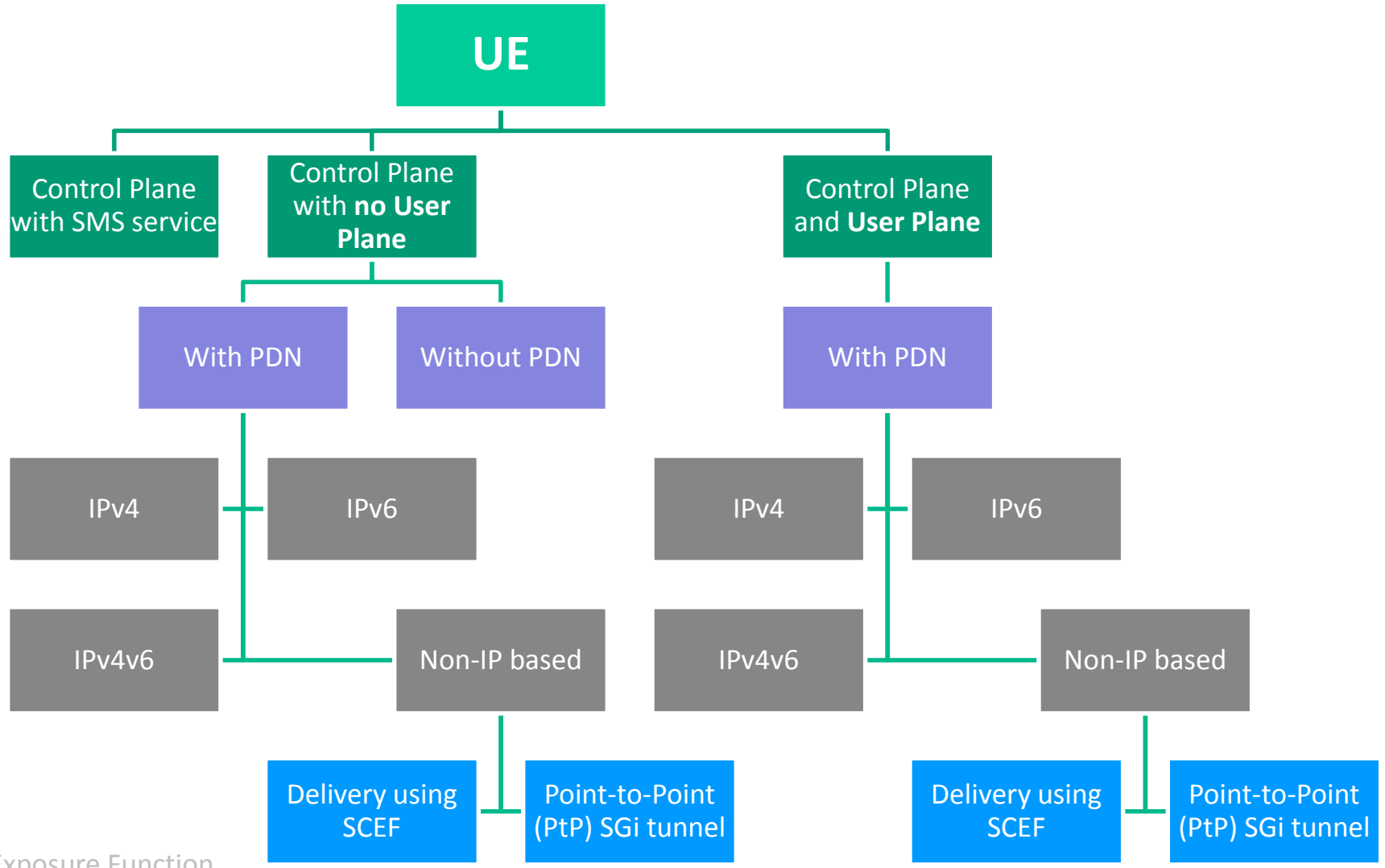
- Control Plane EPS optimisation
  - Data exchanged in a level of RRC messages
  - Piggybacked to *RRCConnectionSetup* in DL or *RRCConnectionSetupComplete* in UL
  - If not sufficient *DLInformationTransfer* and *ULInformationTransfer* message used
  - AS security not applied



Data Transfer – User Plane

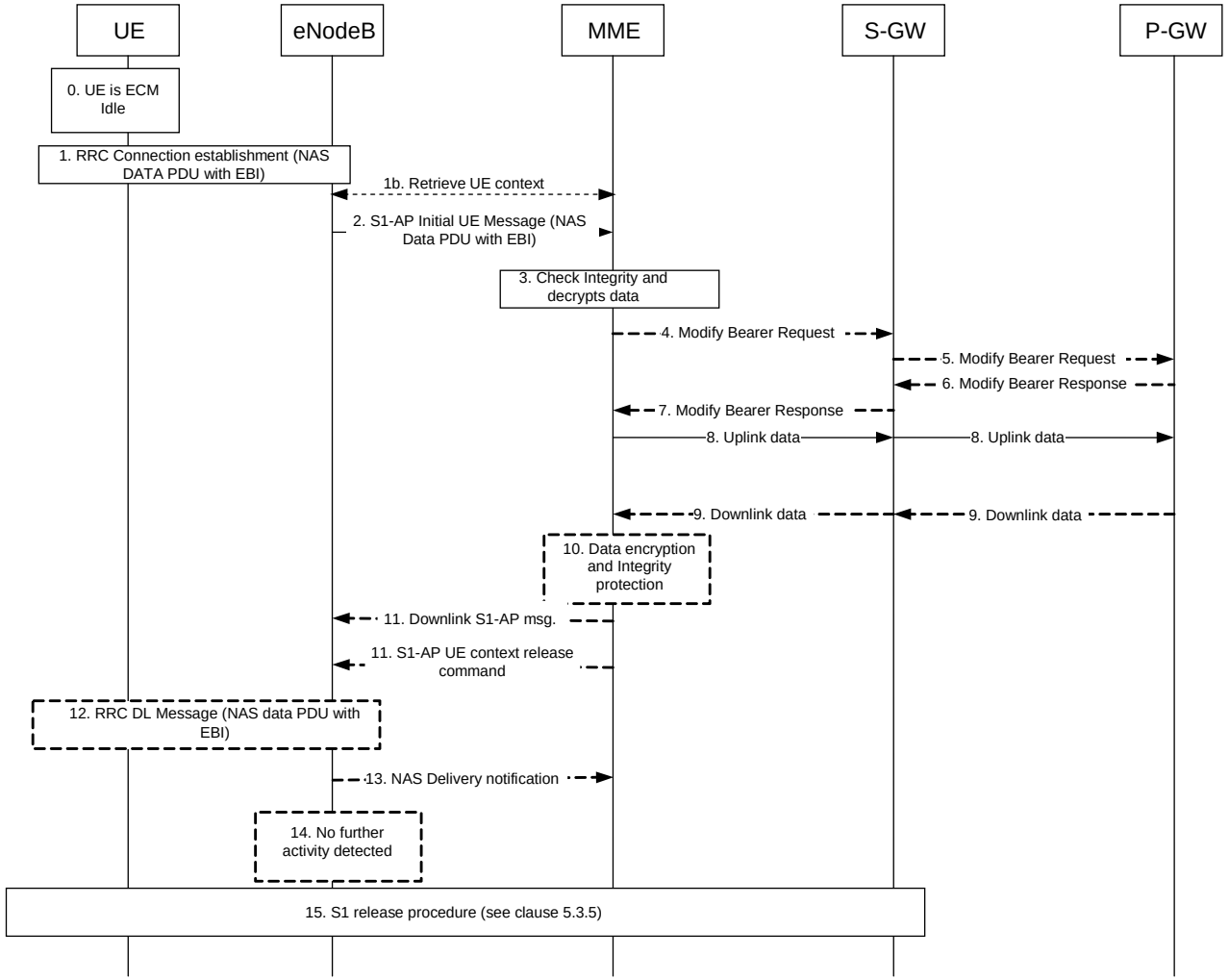
- Up to 2 simultaneous Data Radio Bearers (DRB)
- Conventional data transfer through SGW and PGW
- AS security establishment:
  - Cyphering and Integrity protection of SRB and DRB
- After Security, *RRCConnectionReconfiguration*:
  - Radio bearers (SRB1, DRBs)
  - Configuration of RLC and logical channels
  - PDCP use for DRBs
  - Mac configuration for BSR (Buffer status report), SR (Scheduling Request), Time Alignment, DRX
  - Physical layer reconfigurations

Data Transfer in CIoT EPS Optimisation



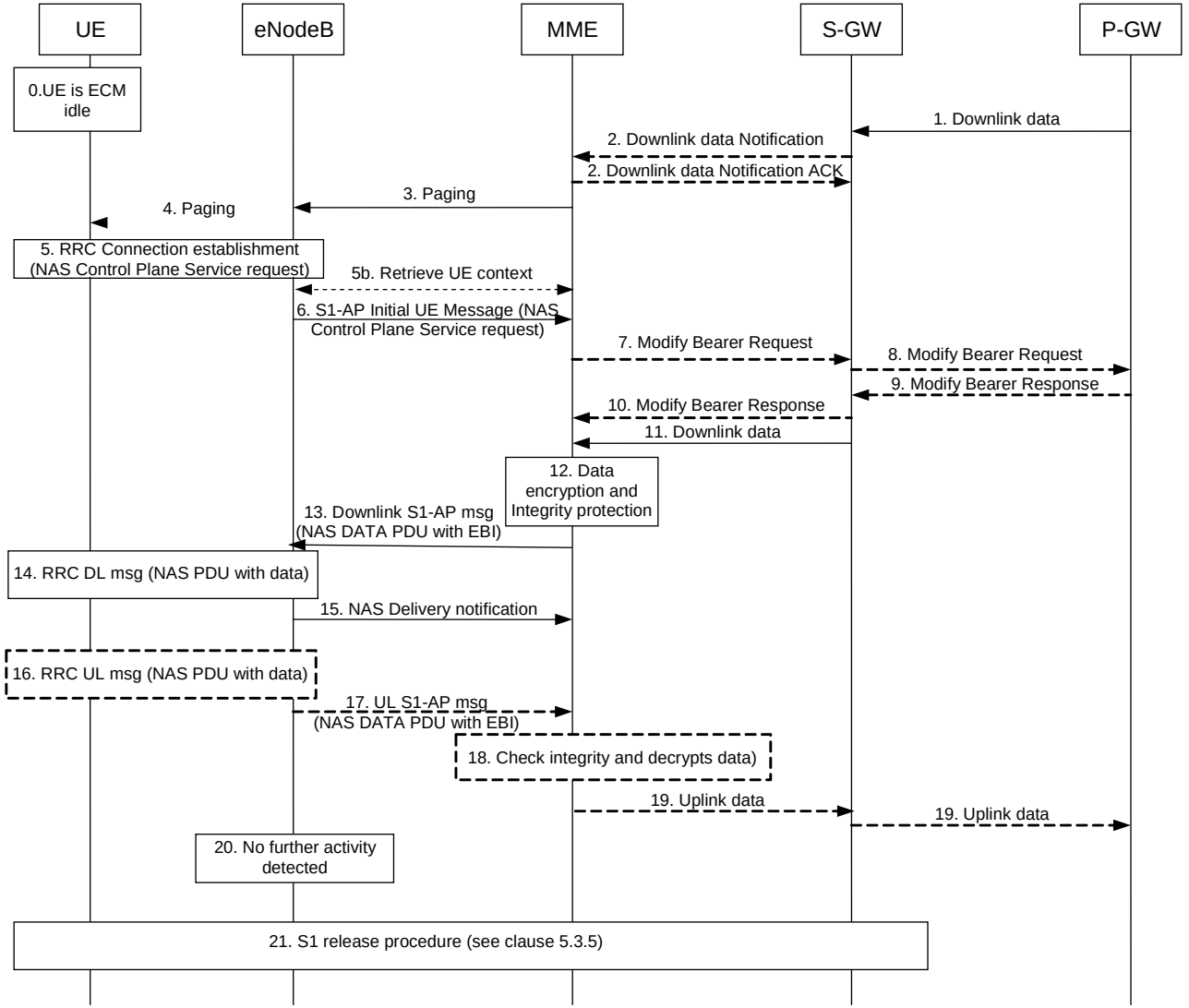
SCEF = Service Capability Exposure Function

MO data transfer in Control Plane



Source: 3GPP TS 23.401

MT data transfer in Control Plane



Source: 3GPP TS 23.401

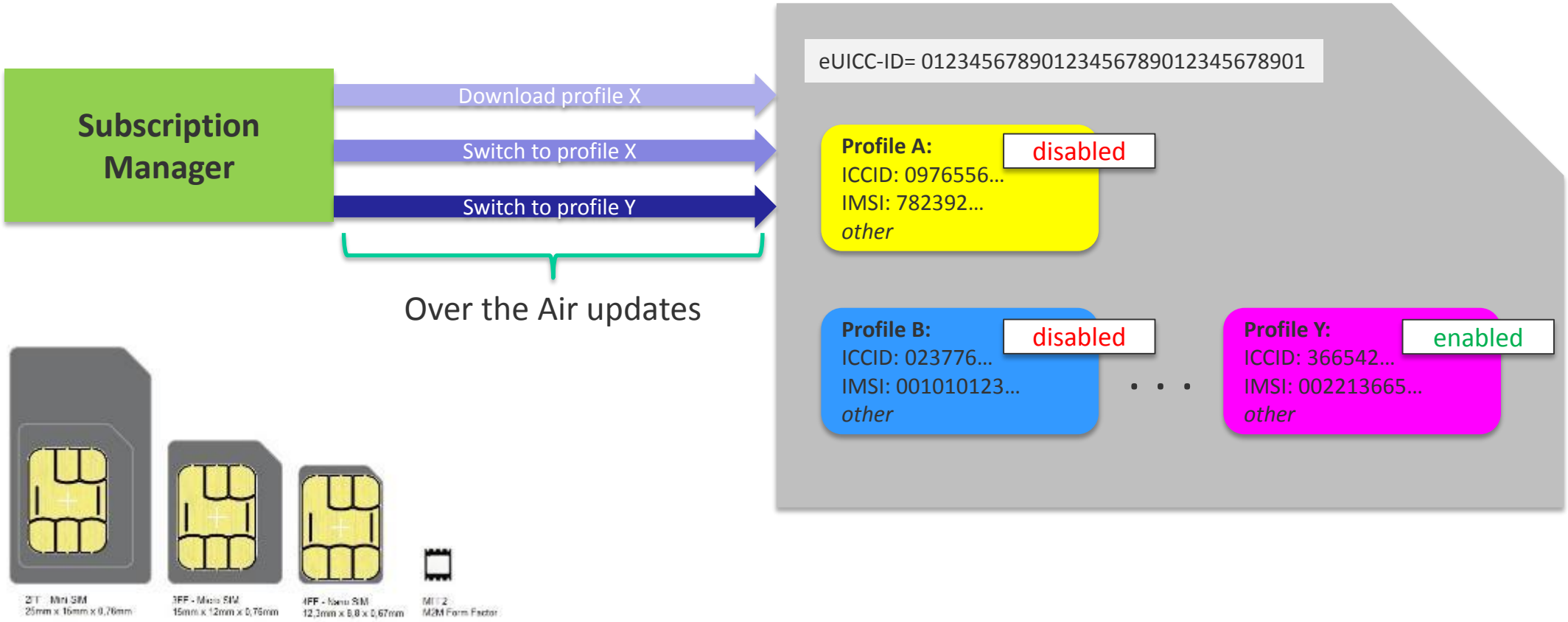
Enhancements for IoT in R14

- Cat-M1:
  - Maximum bandwidth of 5MHz
  - New category M2 for higher data rates
  - Enhancements for VoLTE, extended repetitions, HARQ-ACK bundling,…
  - Addition of positing signals (OTDOA, PRS)

- NB-IoT:
  - Positioning (UTDOA – Uplink Time Difference Of Arrival, OTDOA – Observed Time Difference Of Arrival)
  - Multicast – New channels for multicasting to enable reception on multiple nodes (software updates,…)
  - New Power class – lower power transmission capabilities (14dBm)
  - Adding paging reception and PRACH over Non-anchor carriers
  - User plane data without CIoT optimisation (suspend/resume)

Embedded Universal Integrated Circuit Card (eUICC)

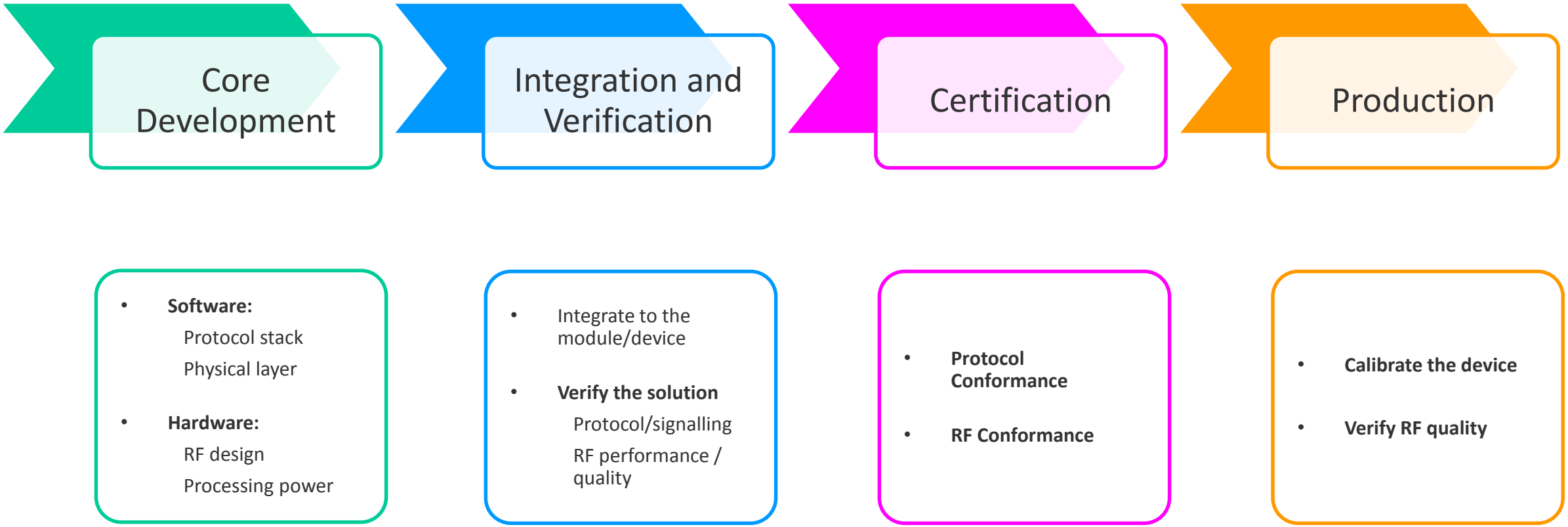
- "eSIM, embedded SIM, SIM on Chip, …"



Agenda

- Internet of Things (known facts)
- Cellular IoT Technologies
- Release Enhancements
- NB-IoT technology
- Phases in Device Development Cycle
- Phases of Testing and Measurements
  - Core Development Testing
  - Integration and Verification Testing
  - Certification Testing
  - Production Line Testing

From Nothing to Something



Agenda

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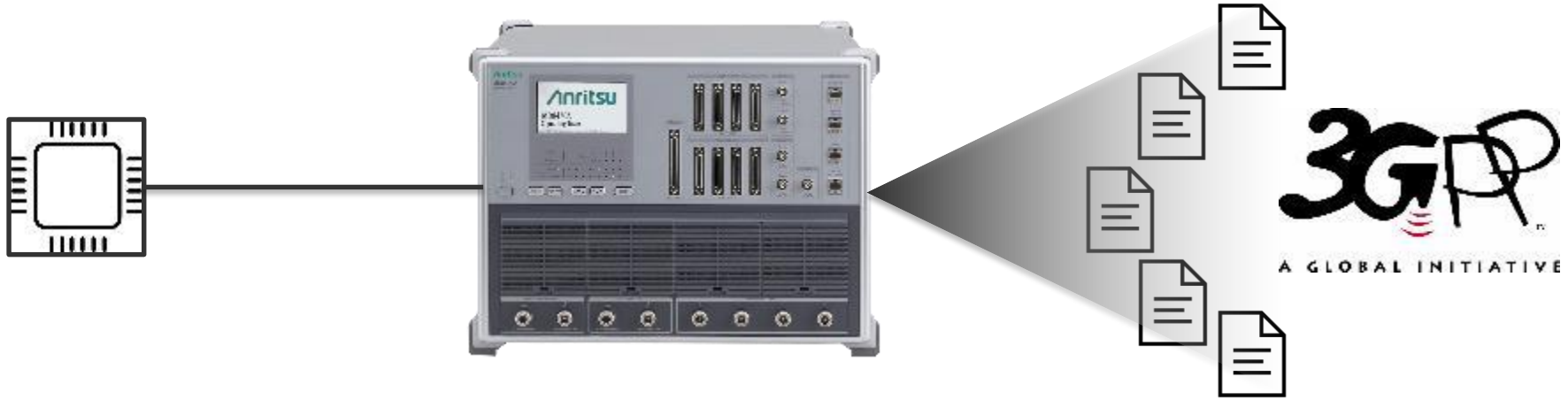
Core Development Testing Phase

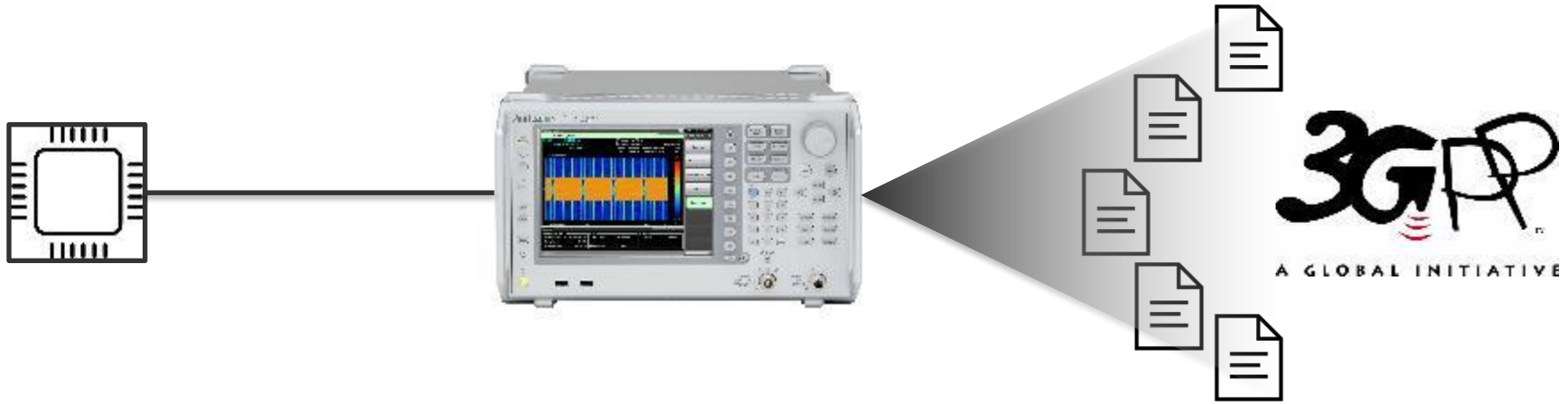
- Protocol stack

TS 36.321 MAC
TS 36.322 RLC
TS 36.323 PDCP
TS 36.331 RRC
TS 24.301 NAS
TS 24.308 Core Network
…



- RF design

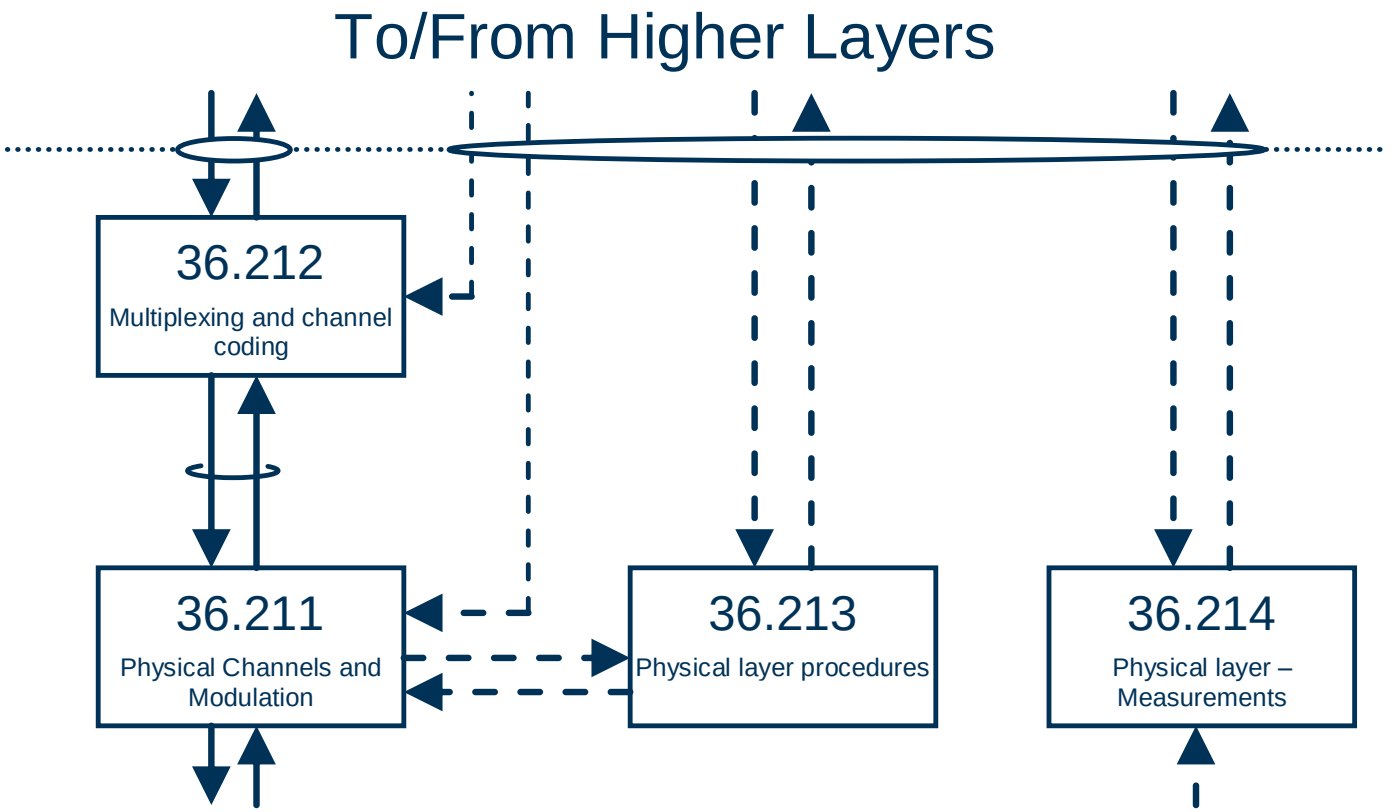
TS 36.101 UE Transmission and Reception
TS 36.211 Phy. Channel and Modulation
TS 36.212 Multiplexing and Channel Coding
TS 36.213 PHY layer
TS 36.214 Measurements
…



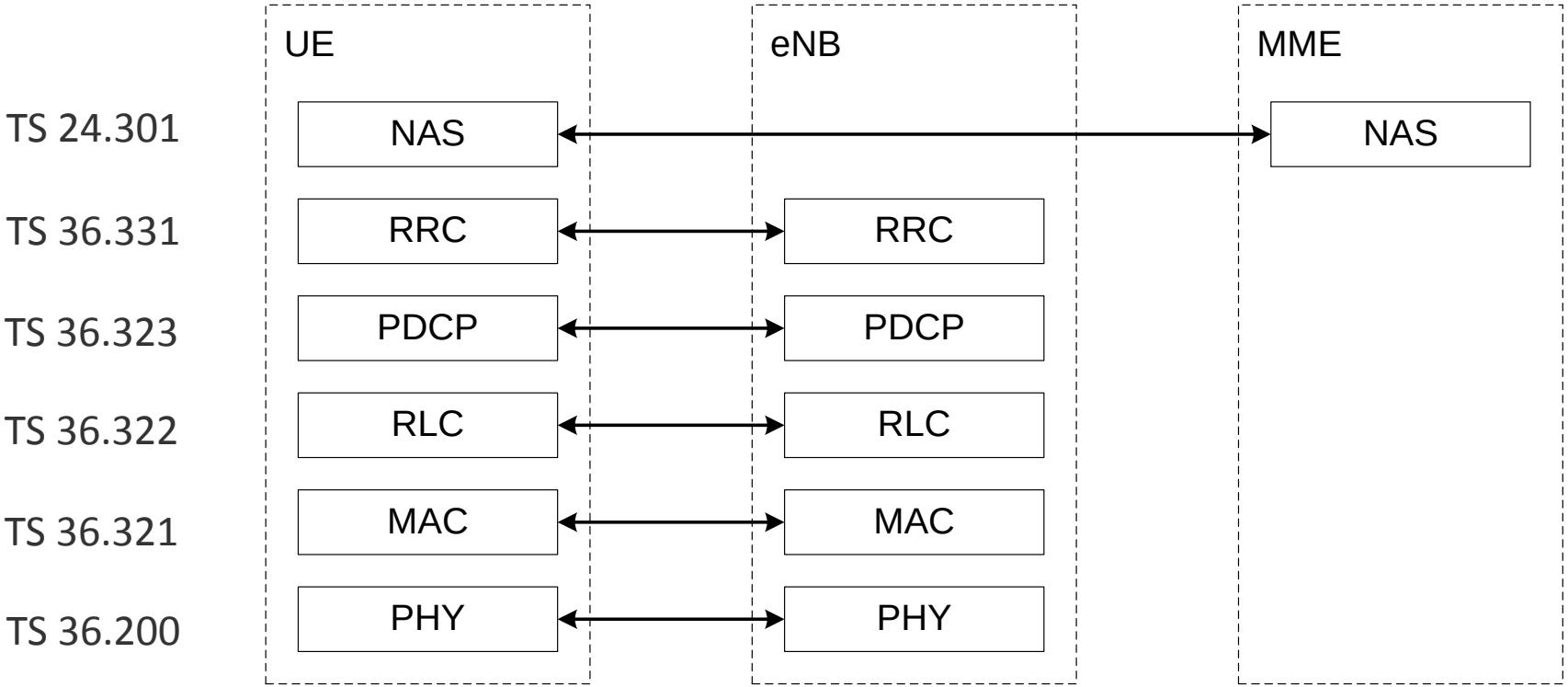
3GPP TS 36.101 User Equipment (UE) radio transmission and reception

- Defines minimum RF characteristics and minimum performance requirements for E-UTRAN UE
  - Operation bands
    - Frequency and bandwidth
  - Channel arrangements
    - Channel spacing and raster
  - Transmitter characteristics
    - Output signal power, quality of modulation, RF spectrum emissions,…
  - Receiver characteristics
    - Sensitivity, channel selectivity, intermodulation characteristics,…
  - Performance requirements
    - Modulation and demodulation of Physical channels

3GPP TS 36.200 series



Protocol stack development



Integration and Verification Testing Phase

- Signalling

Real life scenarios
Mobile network operators
Roaming scenarios
Application services testing
oneM2M service layer testing
Power consumption
Remote eUICC Provisioning
Througput
…

- RF Performance

3GPP TS 36.521-1
Quality of transmission and reception
EVM
Max. Output Power
OTA: 3GPP TS 34.114
3GPP TS 37.544
…

GSMA Guidelines

- CLP.22 - MIoT Test Requirements
  - Cell Selection
  - Registration
  - Device capability
  - Data transfer
  - Mobility
  - Suspend/Resume in CIoT EPS optimization
  - Enhanced Coverage

- TS.34 - IoT Device Connection Efficiency Guidelines

RF Performance Verification

- Based on 3GPP TS 36.521-1

Chapter 6	Chapter 7	Chapter 8	Chapter 9
• Transmission Characteristics • Quality of UL	• Receiver Characteristics • Quality of DL	• Performance Characteristics • Channel Demodulation	• Reporting functionalities • Channel State Information

Transmit Power

UE Maximum Output Power

- An excess maximum output power has the possibility to interfere to other channels or other systems. A small maximum output power decreases the coverage area.

Maximum Power Reduction

- To verify that the error of the UE maximum output power does not exceed the range prescribed by the specified nominal maximum output power and tolerance covering configurations where a maximum power reduction is allowed in the UE.

Additional Maximum Power Reduction

- Additional ACLR and spectrum emission requirements can be signalled by the network to indicate that the UE shall also meet additional requirements in a specific deployment scenario.

Configured UE transmitted Output Power

- To verify the UE does not exceed the minimum between the P_{EMAX} maximum allowed UL TX Power signalled by the E-UTRAN and the P_{UMAX} maximum UE power for the UE power class.

Output Power Dynamics

Minimum Output Power

- To verify the UE's ability to transmit with a broadband output power below the value specified in the test requirement when the power is set to a minimum value.

Transmit OFF power

- To verify that the UE transmit OFF power is lower than the value specified in the test requirement.

ON/OFF time mask

- To verify that the general ON/OFF time mask meets the requirements.
- The time mask for transmit ON/OFF defines the ramping time allowed for the UE between transmit OFF power and transmit ON power.
- Transmission of the wrong power increases interference to other channels, or increases transmission errors in the uplink channel.

Power Control

- To verify the ability of the UE transmitter to set its initial output power to a specific value at the start of a contiguous transmission or non-contiguous transmission with a long transmission gap, i.e. transmission gap is larger than 20 ms.

Transmit signal Quality

Frequency Error

- This test verifies the ability of both, the receiver and the transmitter, to process frequency correctly.
- Receiver: to extract the correct frequency from the stimulus signal, offered by the System simulator, under ideal propagation conditions and low level.
- Transmitter: to derive the correct modulated carrier frequency from the results, gained by the receiver.

Error Vector Magnitude

- The Error Vector Magnitude is a measure of the difference between the reference waveform and the measured waveform. This difference is called the error vector. Before calculating the EVM the measured waveform is corrected by the sample timing offset and RF frequency offset. Then the carrier leakage shall be removed from the measured waveform before calculating the EVM.

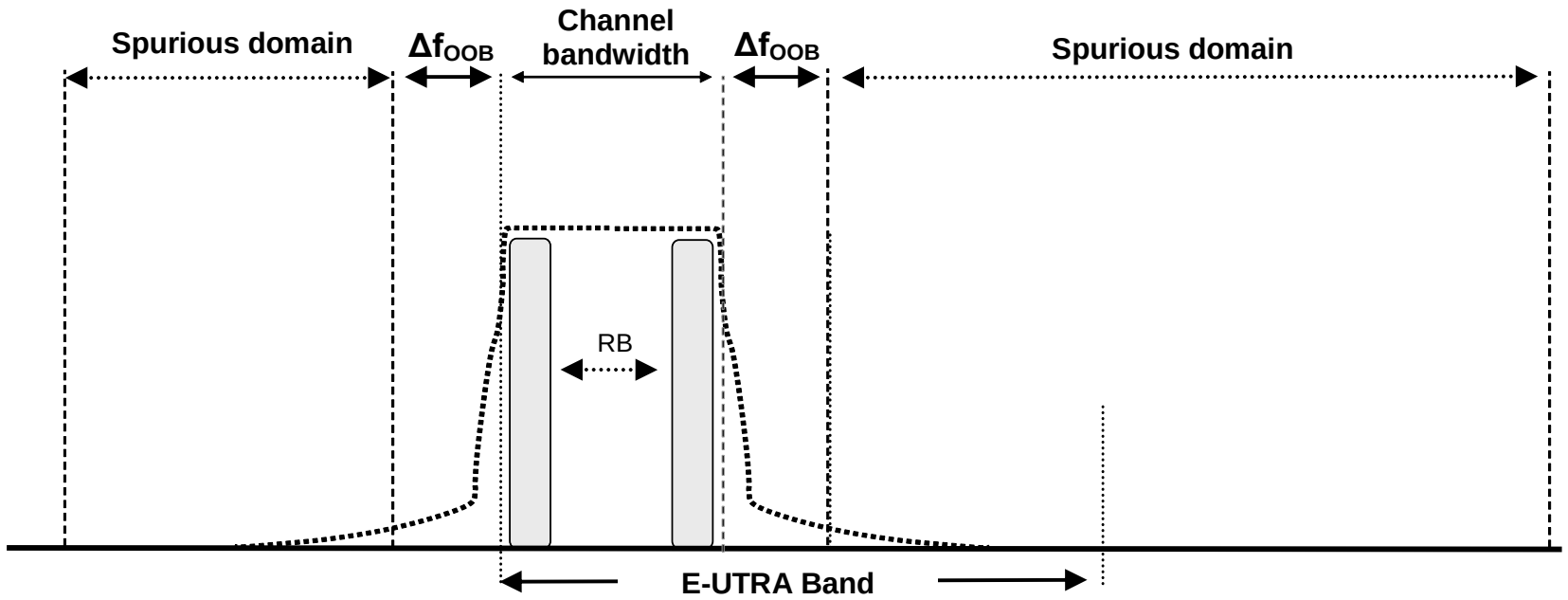
Carrier Leakage

- Carrier leakage expresses itself as unmodulated sine wave with the carrier frequency or centre frequency of aggregated transmission bandwidth configuration. It is an interference of approximately constant amplitude and independent of the amplitude of the wanted signal. Carrier leakage interferes with the centre sub carriers of the UE under test (if allocated), especially, when their amplitude is small. The measurement interval is defined over one slot in the time domain.
- The purpose of this test is to exercise the UE transmitter to verify its modulation quality in terms of carrier leakage.

In-band emissions for non allocated RB

- The in-band emissions are a measure of the interference falling into the non-allocated tones.
- The in-band emission is defined as a function of the tone offset from the edge of the allocated UL transmission tone(s) within the transmission bandwidth configuration. The in-band emission is measured as the ratio of the UE output power in a non–allocated tone to the UE output power in an allocated tone. The basic in-band emissions measurement interval is defined over one slot in the time domain.

Output RF spectrum



ITU defines:

Out-of-band emission = Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions.

Spurious emission = Emission on a frequency, or frequencies, which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products but exclude out-of-band emissions.

Unwanted emissions = Consist of spurious emissions and out-of-band emissions.

Output RF spectrum

Occupied bandwidth

- To verify that the UE occupied bandwidth for all transmission bandwidth configurations supported by the UE are less than their specific limits.

Spectrum Emission Mask

- To verify that the power of any UE emission shall not exceed specified lever for the specified channel bandwidth.

Additional Spectrum Emission Mask

- To verify that the power of any UE emission shall not exceed specified level for the specified channel bandwidth under the deployment scenarios where additional requirements are specified.

Adjacent Channel Leakage power Ratio

- To verify that UE transmitter does not cause unacceptable interference to adjacent channels in terms of Adjacent Channel Leakage power Ratio (ACLR).

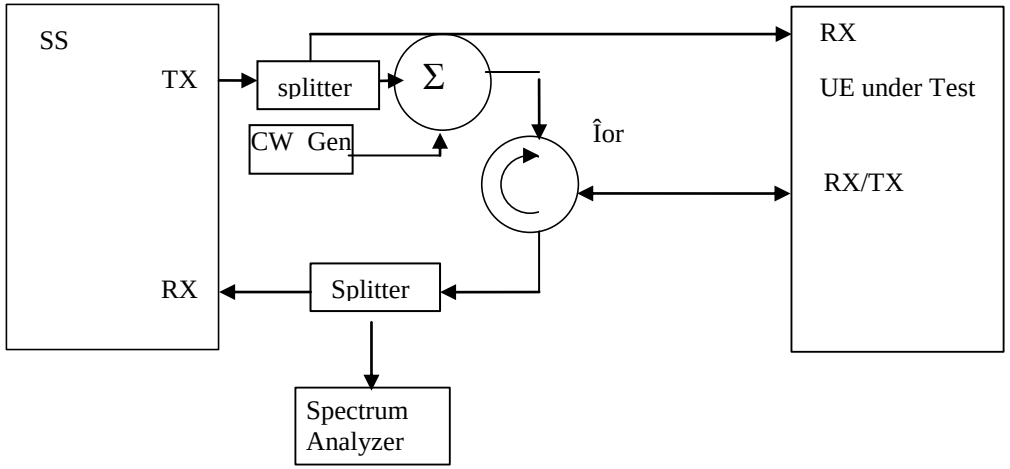
Transmitter Spurious emissions

- To verify that UE transmitter does not cause unacceptable interference to other channels or other systems in terms of transmitter spurious emissions.

Transmit Intermodulation

Transmit Intermodulation

- To verify that the UE transmit intermodulation does not exceed the described value in the test requirement.
- The transmit intermodulation performance is a measure of the capability of the transmitter to inhibit the generation of signals in its non linear elements caused by presence of the wanted signal and an interfering signal reaching the transmitter via the antenna.



Receiver Characteristics

Reference sensitivity level

- To verify the UE's ability to receive data with a given average throughput for a specified reference measurement channel, under conditions of low signal level, ideal propagation and no added noise.
- A UE unable to meet the throughput requirement under these conditions will decrease the effective coverage area of an e-NodeB.

Maximum input level

- Maximum input level tests the UE's ability to receive data with a given average throughput for a specified reference measurement channel, under conditions of high signal level, ideal propagation and no added noise.
- A UE unable to meet the throughput requirement under these conditions will decrease the coverage area near to an e-NodeB.

Adjacent Channel Selectivity (ACS)

- Adjacent channel selectivity tests the UE's ability to receive data with a given average throughput for a specified reference measurement channel, in the presence of an adjacent channel signal at a given frequency offset from the centre frequency of the assigned channel, under conditions of ideal propagation and no added noise.
- A UE unable to meet the throughput requirement under these conditions will decrease the coverage area when other e-NodeB transmitters exist in the adjacent channel.

Blocking Characteristics

In-band blocking

- In-band blocking is defined for an unwanted interfering signal falling into the range from 15MHz below to 15MHz above the UE receive band, at which the relative throughput shall meet or exceed the requirement for the specified measurement channels.
- The lack of in-band blocking ability will decrease the coverage area when other e-NodeB transmitters exist (except in the adjacent channels and spurious response).

Out-of-band blocking

- Out-of-band band blocking is defined for an unwanted CW interfering signal falling more than 15 MHz below or above the UE receive band, at which a given average throughput shall meet or exceed the requirement for the specified measurement channels.
- The lack of out-of-band blocking ability will decrease the coverage area when other e-NodeB transmitters exist (except in the adjacent channels and spurious response).

Narrow band blocking

- Verifies a receiver's ability to receive an E-UTRA signal at its assigned channel frequency in the presence of an unwanted narrow band CW interferer at a frequency, which is less than the nominal channel spacing.
- The lack of narrow-band blocking ability will decrease the coverage area when other e-NodeB transmitters exist (except in the adjacent channels and spurious response).

Intermodulation characteristics and Spurious emissions

Wide band Intermodulation

- Intermodulation response tests the UE's ability to receive data with a given average throughput for a specified reference measurement channel, in the presence of two or more interfering signals which have a specific frequency relationship to the wanted signal, under conditions of ideal propagation and no added noise.
- A UE unable to meet the throughput requirement under these conditions will decrease the coverage area when two or more interfering signals exist which have a specific frequency relationship to the wanted signal.

Spurious emissions

- The spurious emissions power is the power of emissions generated or amplified in a receiver that appear at the UE antenna connector.
- Excess spurious emissions increase the interference to other systems.

Example of Maximum Output Power for NB1

Test Environment as specified in TS 36.508[7] subclause 8.1.1		Normal, TL/VL, TL/VH, TH/VL, TH/VH		
Test Frequencies as specified in TS 36.508 [7] subclause 8.1.3.1		Frequency ranges defined in Annex K.1.2		
Test Parameters				
Configuration ID	**Downlink Configuration**	**Uplink Configuration**		
	N/A	Modulation	N_{tones}	Sub-carrier spacing (kHz)
1 (Note 2)		BPSK	1@0	3.75
2 (Note 3)		BPSK	1@47	3.75
3 (Note 2)		QPSK	1@0	15
4 (Note 3)		QPSK	1@11	15
5 (Note 1)		QPSK	3@3	15
Note 1: Applicable to UE supporting UL multi-tone transmissions Note 2: only applicable for low range Note 3: only applicable for high range				

Test Conditions

EUTRA band	Class 3 (dBm)	Tolerance (dB)	Class 5 (dBm)	Tolerance (dB)
1	23	±2.7	20	±2.7
2	23	±2.7	20	±2.7
3	23	±2.7	20	±2.7
5	23	±2.7	20	±2.7
8	23	±2.7	20	±2.7
12	23	±2.7	20	±2.7
13	23	±2.7	20	±2.7
17	23	±2.7	20	±2.7
18	23	±2.7	20	±2.7
19	23	±2.7	20	±2.7
20	23	±2.7	20	±2.7
26	23	±2.7	20	±2.7
28	23	±2.7	20	±2.7
66	23	±2.7	20	±2.7

Test Requirements

Measurement examples

Power Measurement - ✓ Pass (20/ 20)

	Avg.	Max.	Min.	Limit
TX Power	22.41	22.48	22.36 dBm	20.3 to 25.7 dBm
Channel Power	22.30	22.38	22.22 dBm	

Adjacent Channel Power - ✓ Pass (20/ 20) View

Offset Frequency	Power Avg.	Max.	Min.	Limit
E-UTRA				
-5MHz	-40.27	-40.11	-40.49 dB	≤ -29.2 dB
5MHz	-38.88	-38.72	-39.13 dB	≤ -29.2 dB
UTRA				
-10MHz	-55.37	-54.72	-56.10 dB	≤ -35.2 dB
-5MHz	-40.99	-40.79	-41.22 dB	≤ -32.2 dB
5MHz	-39.62	-39.51	-39.85 dB	≤ -32.2 dB
10MHz	-55.00	-53.98	-55.65 dB	≤ -35.2 dB

Spectrum Emission Mask - ✓ Pass (20/ 20) View

Worst Value of Each Frequency Range

Frequency Range	Level	Mask Margin	Frequency
Lower			
0 to 1MHz	-31.75 dBm	-18.25 dB	-0.015 MHz
1 to 5MHz	-24.94 dBm	-16.44 dB	-1.500 MHz
5 to 6MHz	-32.11 dBm	-20.61 dB	-5.500 MHz
6 to 10MHz	-35.66 dBm	-12.16 dB	-6.500 MHz
Upper			
0 to 1MHz	-30.97 dBm	-17.47 dB	0.015 MHz
1 to 5MHz	-23.59 dBm	-15.09 dB	1.500 MHz
5 to 6MHz	-31.57 dBm	-20.07 dB	5.500 MHz
6 to 10MHz	-35.55 dBm	-12.05 dB	6.500 MHz
Template Judgement	Pass		

Modulation Analysis - ✓ Pass (20/ 20) View

	Avg.	Max.	Min.	Limit
Carrier Frequency Error	-0.0023	0.0034	-0.0068 kHz	
	0.00	0.00	0.00 ppm	
EVM	1.83	2.07	1.39 %(rms)	
Peak Vector Error	3.79	4.88	2.59 %	
Phase Error	0.75	0.89	0.56 deg.(rms)	
Magnitude Error	1.29	1.57	0.95 %(rms)	
Rho	0.99967	0.99981	0.99958	
Carrier Leakage	-36.62	-36.00	-37.24 dBc	
In-Band Emissions				
General	-40.57	-38.21	-42.19 dB	≤ -17.3 dB
IQ Image	-40.93	-40.85	-41.04 dB	≤ -24.0 dB
Carrier Leakage	-68.29	-66.79	-70.45 dBc	≤ -24.0 dBc
Spectrum Flatness				
≥3MHz (R1 +)	0.19	0.29	0.14 dB	
≥3MHz (R1 -)	-0.14	-0.09	-0.19 dB	
≥3MHz (RP1)	0.33	0.48	0.24 dB(p-p)	

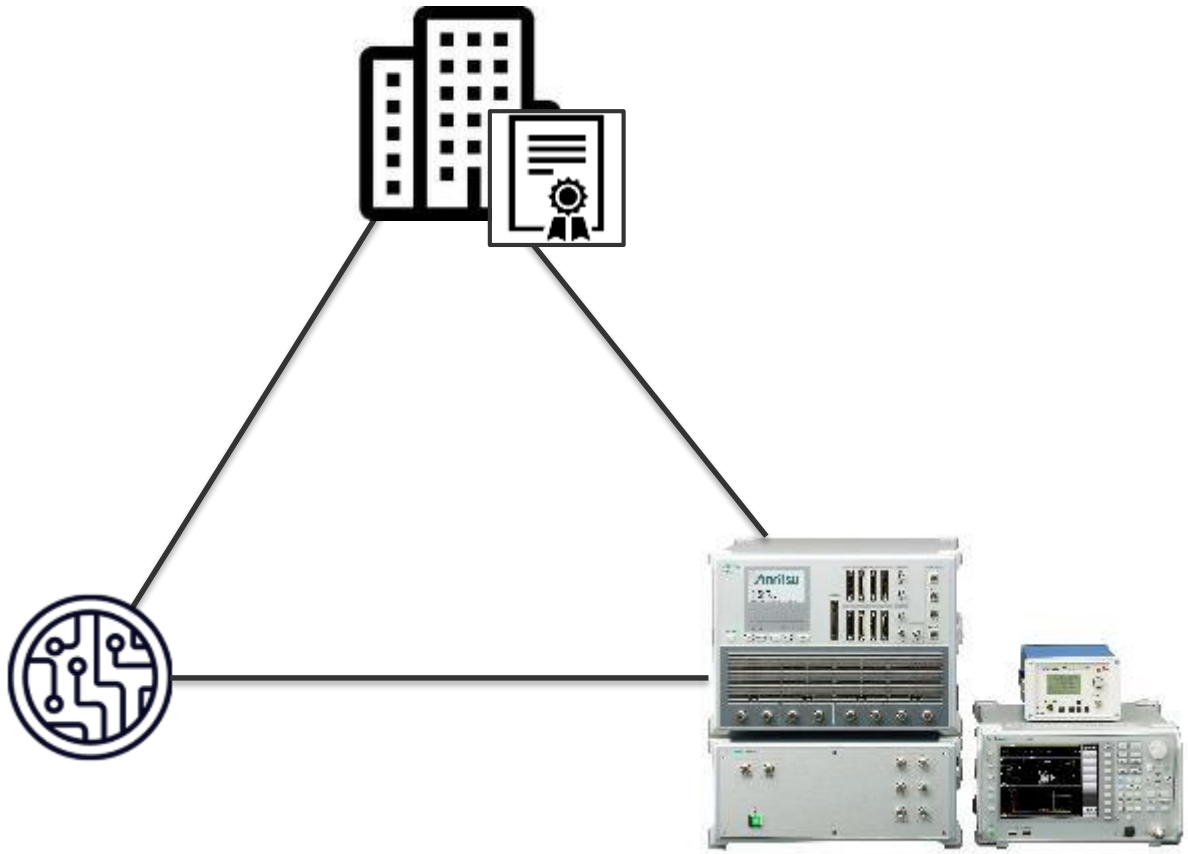
Certification Testing Phase

- Protocol Conformance

3GPP TS 36.523

- RF Conformance

3GPP TS 36.521



3GPP TS 36.523

Idle Mode Operations

- PLMN Selection
- Cell Selection

Layer 2

- MAC: RACH procedure, MAC PDU handling, DRX operation,…
- RLC: Sequence numbering, Segmentation and Reassembly of RLC PDU
- PDCP: Sequence numbering, ciphering and integrity protection, re-establishment procedures

RRC

- Connection Establishment, Re-establishment, Release
- UE capability transfer
- Radio Link Failure

EMM

- Attach, authentication,
- NAS security
- Tracking Are update procedures

ESM

- Packet Routing
- PDN connectivity handling

CIoT Optimisation

- MO ad MT data in IP and non-IP data transfer

22.5.17 NB-IoT / Attach Success /Normal tracking area update accepted / Periodic tracking area update T3412 Extended Value / PSM

(1)
with { the UE is switched-off with a valid USIM inserted and the UE is configured to attach with PSM }
ensure that {
when { UE is powered on }
then { the UE transmits an ATTACH REQUEST message including the T3324 IE }
}

(2)
with { the UE in IDLE mode }
ensure that {
when { UE receives a paging message before timer T3324 is expired }
then { the UE responds to the paging request }
}

(3)
with { UE in state EMM-REGISTERED and EMM-IDLE mode}
ensure that {
when { PSM is activated }
then { UE send TRACKING AREA UPDATE REQUEST message including the T3324 IE }
}

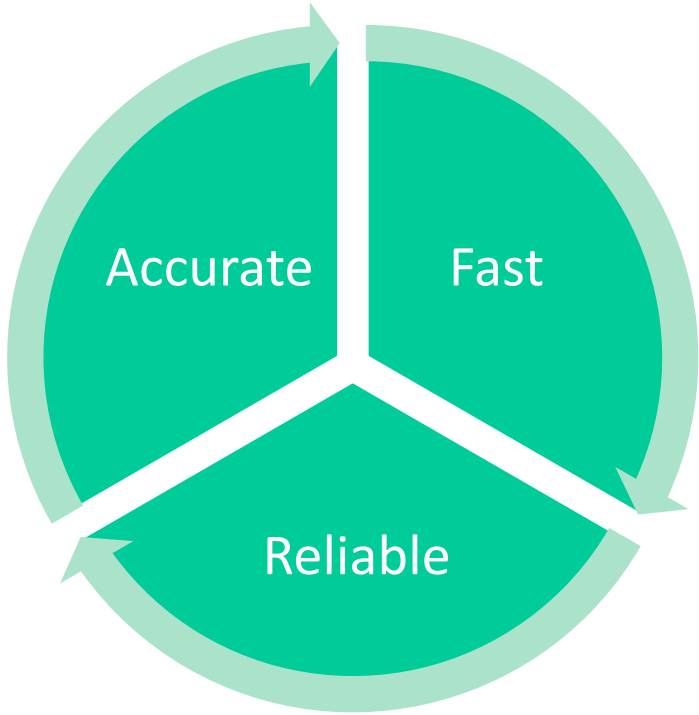
(4)
with { UE in state EMM-REGISTERED.NO-CELL-AVAILABLE }
ensure that {
when { the SS sends a *Paging-NB* message }
then { the UE does not answer the *Paging-NB* message }
}

(5)
with { UE in state EMM-REGISTERED.NO-CELL-AVAILABLE }
ensure that {
when { PSM is deactivated }
then { UE sends TRACKING AREA UPDATE REQUEST message including the T3324 IE }
}

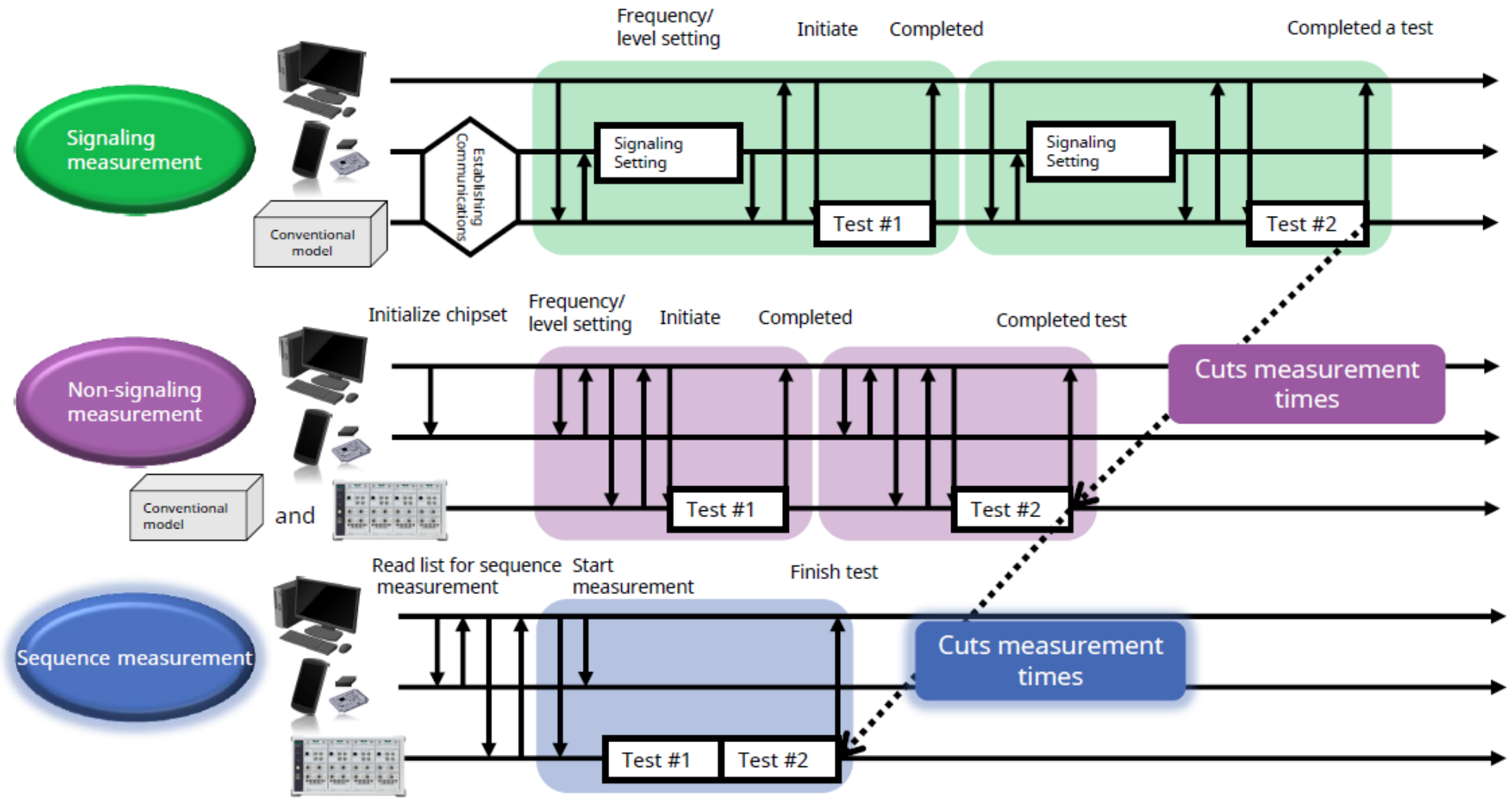
(6)
with { UE in state EMM-REGISTERED and EMM-IDLE mode with timer T3412 “normal” and extended values being allocated by the SS during attach procedure }
ensure that {
when { timer T3412 extended value expires }
then { UE sends TRACKING AREA UPDATE REQUEST message with EPS update type = “Periodic updating” }
}

St	Procedure	Message Sequence		TP	Verdict
		U - S	Message		
1-4b1	Steps 1 – 4b1 of the generic procedure specified in TS 36.508 subclause 8.1.5.2.3 is performed	-	-	-	-
5	Check: Does the UE transmit an ATTACH REQUEST message including the T3324 IE set to two minutes.	-->	ATTACH REQUEST	1	P
6-15b1	Steps 5 – 14b1 of the generic procedure specified in TS 36.508 subclause 8.1.5.2.3 is performed	-	-	-	-
-	The SS shall wait for 1 minute and then execute the following steps before timer T3324 expires.	-	-	-	-
16	Check: Does the UE accept the paging request. FFS: Steps X, from paging generic procedure in TS 36.508 are performed.	-	-	2	P
17	The user requests PSM by MMI or by AT command. The requested value of T3324 is 1 minute.	-	-	-	-
18	Check: Does the UE transmit a TRACKING AREA UPDATE REQUEST message?	-->	TRACKING AREA UPDATE REQUEST	3	P
19	The SS transmits a TRACKING AREA UPDATE ACCEPT message including GUTI-1.	<--	TRACKING AREA UPDATE ACCEPT	-	-
20	The UE transmits a TRACKING AREA UPDATE COMPLETE message.	-->	TRACKING AREA UPDATE COMPLETE	-	-
21	The SS releases the RRC connection.			-	-
22	When the T3324 timer expires the SS send Paging message including a matched identity	<--	*Paging-NB*	-	-
23	Check: Does the UE respond to the paging message?			4	F
24	The user requests to deactivate PSM by requesting to use a new value for timer T3324 (2 minutes). The request also include T3412 extended value set to 4 minutes. This can be initiated by MMI or AT command.	-	-	-	-
25	Check: Does the UE transmit a TRACKING AREA UPDATE REQUEST message?	-->	TRACKING AREA UPDATE REQUEST	5	P
26	The SS transmits a TRACKING AREA UPDATE ACCEPT message including GUTI-2.	<--	TRACKING AREA UPDATE ACCEPT	-	-
27	The UE transmits a TRACKING AREA UPDATE COMPLETE message?	-->	TRACKING AREA UPDATE COMPLETE	-	-
28	The SS releases the RRC connection.			-	-
29	The SS waits 4 minutes. (Expiry of T3412 extended value)	-	-	-	-
30	Check: Does the UE transmit a TRACKING AREA UPDATE REQUEST message?	-->	TRACKING AREA UPDATE REQUEST	6	P
31	The SS transmits a TRACKING AREA UPDATE ACCEPT message including GUTI-3.	<--	TRACKING AREA UPDATE ACCEPT	-	-
32	The UE transmits a TRACKING AREA UPDATE COMPLETE message?	-->	TRACKING AREA UPDATE COMPLETE	-	-
33	The SS releases the RRC connection.	-	-	-	-

Production Testing Phase



Methods of Production Line Testing



Development Cycle

Core Development

Integration and Verification

Certification

Production

Agenda

- Internet of Things (known facts)
- Cellular IoT Technologies
- Release Enhancements
- NB-IoT technology
- Phases in Device Development Cycle
- Phases of Testing and Measurements
  - Core Development Testing
  - Integration and Verification Testing
  - Certification Testing
  - Production Line Testing

CIoT Network roll-outs

- 2017 -> Deutsche Telekom in Netherlands, Austria, Croatia, Greece, Hungary, Poland, *Slovakia* -> **NB-IoT**
- 2017 -> Orange Belgium -> **NB-IoT** and **LTE-M**
- 2017 -> Vodafone Spain, Germany, Australia, New Zealand -> **NB-IoT**
- 2017 -> Singtel in Singapore -> **LTE-M**
- 2018 -> T-Mobile US -> **NB-IoT**

There is effective testing.

If right tool is used for right test!

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envision : ensure