IoT radio access technologies

ITG 5.2.4 Workshop

“Cellular Internet of Things”

Dr. Berthold Panzner

München 2017-12-01

NOKIA

Internet of Things
E2E IoT Connectivity

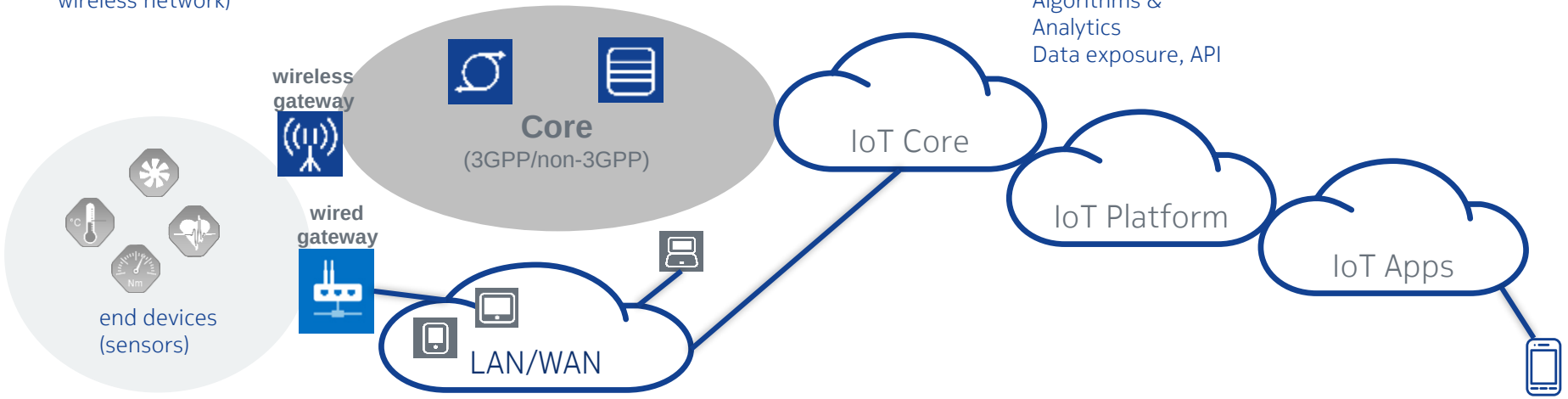
Radio Access Network
Sensors/tags, actuators behind a GW (connected to cloud using fixed or wireless network)

Wide Area Network

Cloud Connectivity
IoT optimized core solution

central IoT platform
Device connectivity mgmnt
Data collection
Algorithms & Analytics
Data exposure, API

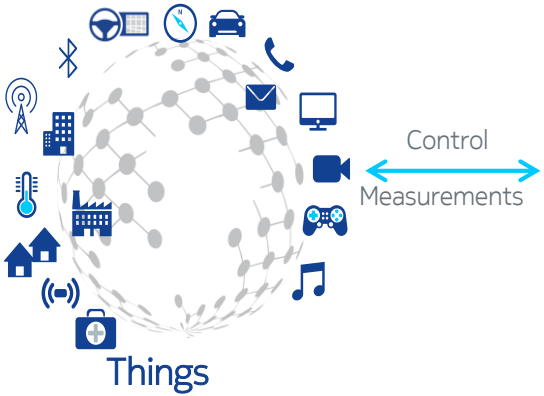
Verticals
Applications



Local Connectivity	Core Network Wide Area Connectivity	Mobile/IoT Core Connectivity	IoT Platforms	IoT Apps

NOKIA

Internet of Things
E2E IoT chain



Control
Measurements

IoT Backhaul Network

IoT Platforms

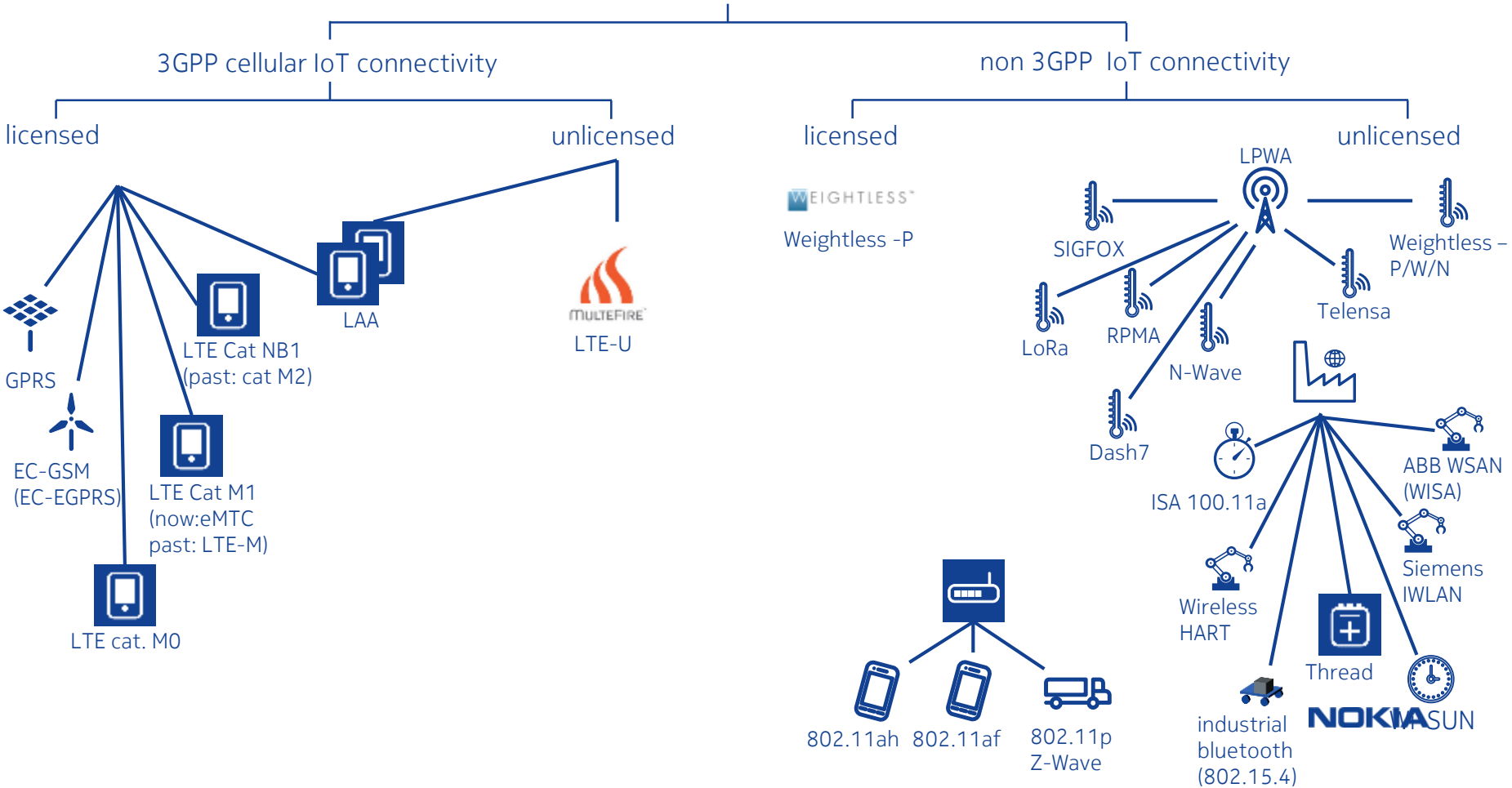
IoT Cloud

Applications

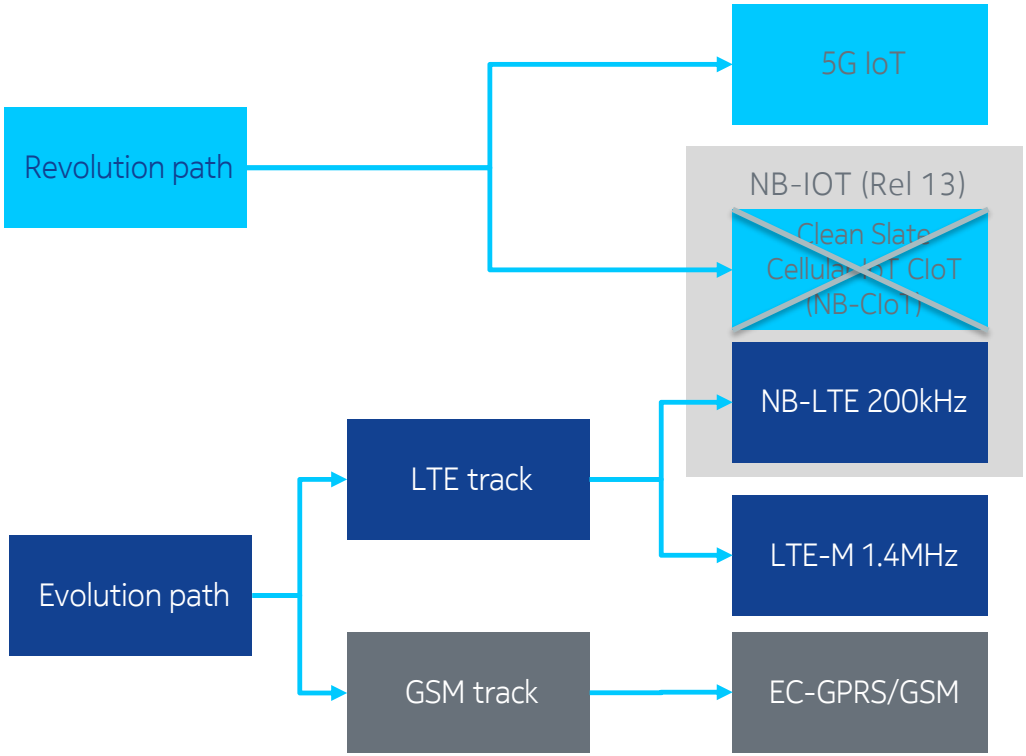
Sensors & Actuators	Connectivity	Platform	Analytics	Application
Sense and React	Wired and Wireless	Connectivity Management, Applications APIs	Insights, correlations, smart decision	A unified end to end solution

NOKIA

A myriad of IoT Connectivity Solutions



Cellular IoT Connectivity Solutions
3GPP CIoT consolidation



- New radio, new spectrum, new core network
- 1st phase: Enhanced Mobile Broadband
- 2nd phase: Massive Machine Type and , Ultra-reliable / Low Latency Communication

- Cheap low end solution
- New radio technology
- Joint proposal by Huawei and Qualcomm, rejected during #83 3GPP TSG RAN WG1 Meeting

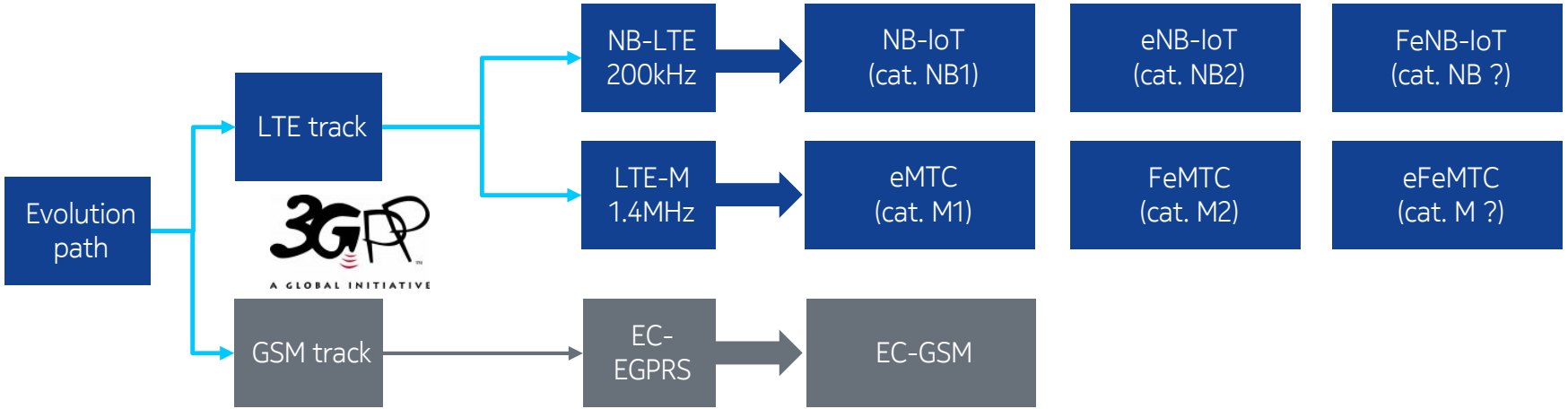
- Cheap low end solution
- Based on LTE architecture
- Joint proposal by Nokia, Ericsson and Intel

- Standalone or multiplexed within LTE carrier
- From low to high end uses cases up to 1 Mbps
- Rel. 12/13

- Evolution on top of existing GSM networks
- Supported by Nokia and Ericsson
- Global support for GSM operators

NOKIA

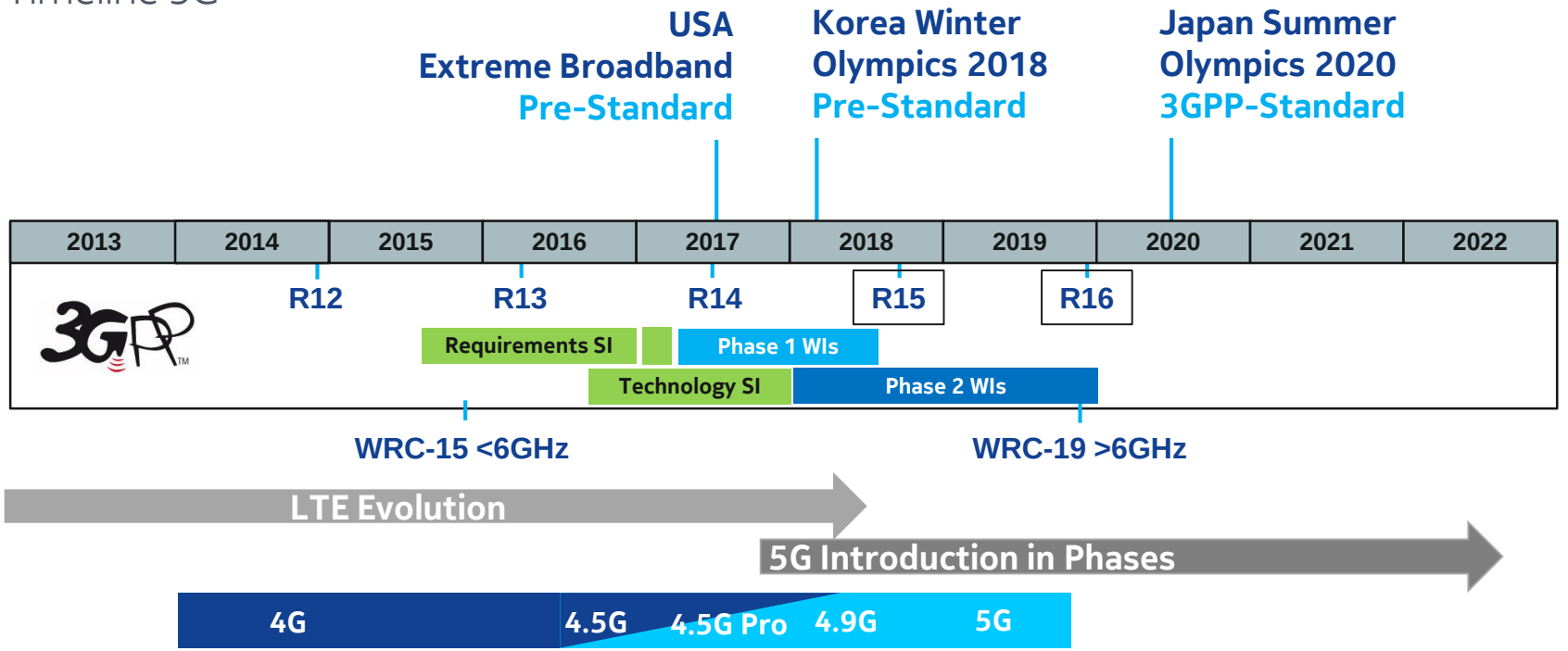
Cellular IoT Connectivity Solutions
3GPP CIoT consolidation



NOKIA

3GPP Standardization Roadmap

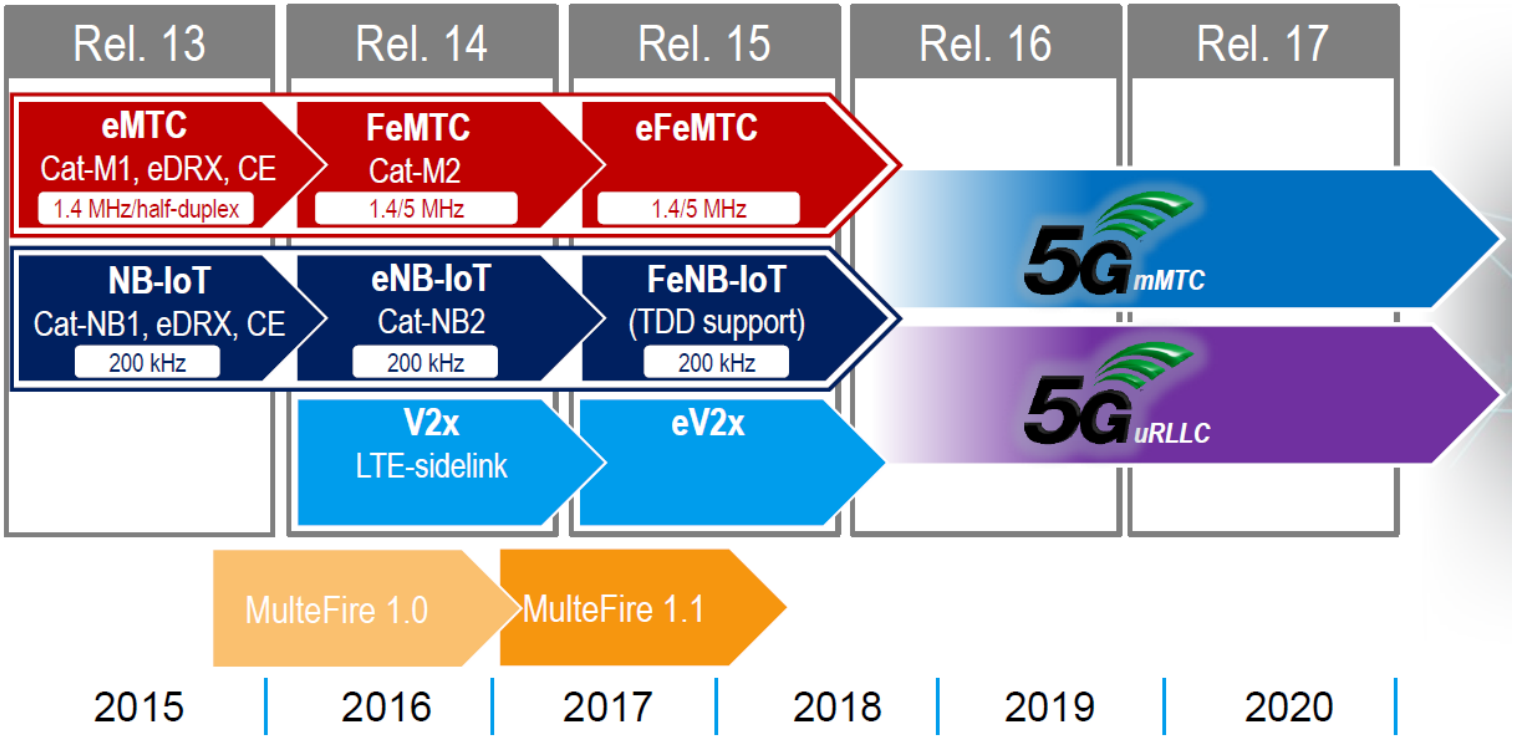
Timeline 5G



NOKIA

3GPP Standardization Roadmap

Timeline CIoT



NOKIA

3GPP Rel. 13 CIoT
Radio Technology Space

- Coverage: 164 dB
- Module cost: $2-4
- Battery life: +10 years
- Scalability: +50k/cell*
- Bit rate per UE : <56kbit/s

- Network upgrade: SW
- Spectrum: GSM /LTE (200kHz or shared)

RAN Rel. 13

NB-IoT 200kHz

- Coverage: 156 dB
- Module cost: $3-5
- Battery life: +10 years
- Scalability: +50k/cell*
- Bit rate per UE : <1Mbit/s

- Network upgrade: SW
- Spectrum: LTE (1.4 MHz or shared)

RAN Rel. 13

LTE-M 1.4MHz

Massive IoT connectivity

- Simple cheap devices
- Low energy consumption
- Massive number of devices
- Improved coverage, low datarate

Internet of Things

- Coverage: 164 dB
- Module cost: $3-5
- Battery life: +10 years
- Scalability: +50k/cell*
- Bit rate per MS : <70kbit/s

- Network upgrade: SW
- Spectrum: GSM (200kHz or shared)

GERAN Rel. 13

EC-GSM

*Note: Assumptions according to the Traffic Model defined by 3GPP (3GPP TS 45.820). Different assumptions will lead to different numbers.

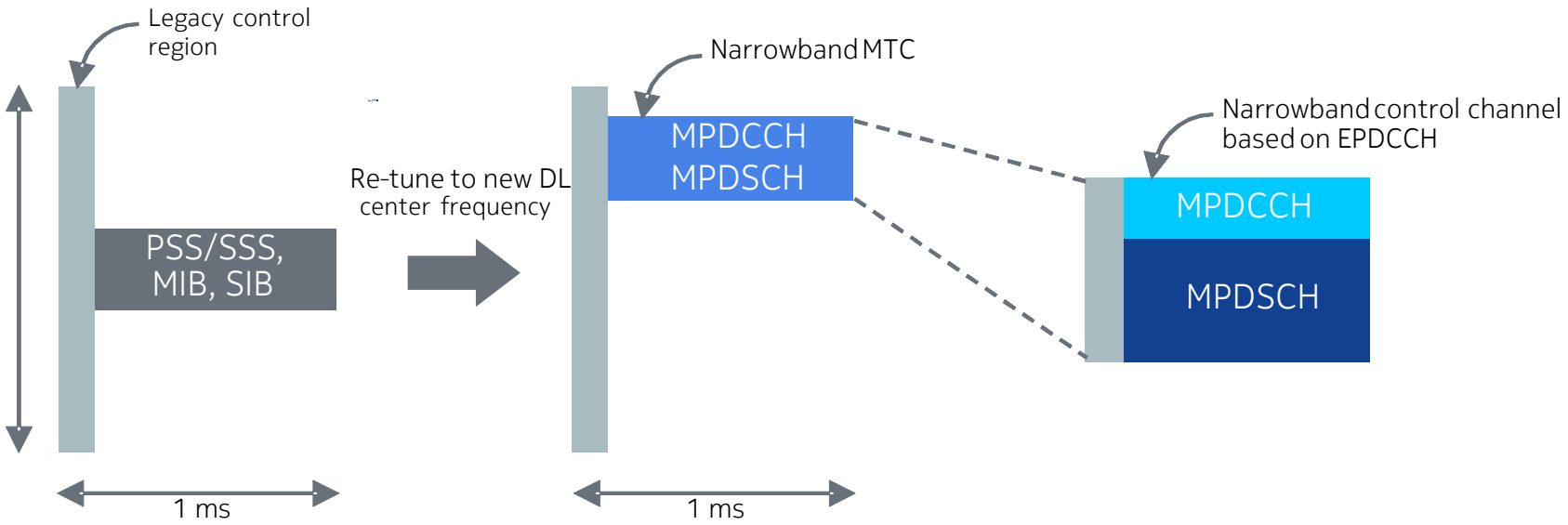
NOKIA

LTE-based IoT radio solutions

		Release 8	Release 12	Release 13		
Modem/device chip category		**Category 4**	**Category 1**	**Category 0**	**Category M1 (eMTC)**	**Category NB1 (NB-IoT)**
Peak data rate instantaneous	Downlink	150 Mbps	10 Mbps	1 Mbps	1 Mbps	170 kbps
	Uplink	50 Mbps	5 Mbps	1 Mbps	1 Mbps	250 kbps
Peak data rate sustained	Downlink	150 Mbps	10 Mbps	1 Mbps	890 kbps	300 kbps	26 kbps
	Uplink	50 Mbps	5 Mbps	1 Mbps	1 Mbps	375 kbps	62kbps
Duplex mode		Full duplex	Full duplex	Half duplex (opt)	Full duplex	Half duplex	Half duplex
Number of antennas		2	2	1	1	1
UE receive bandwidth		20 MHz	20 MHz	20 MHz	1.4 MHz	200 kHz
UE transmit power		23 dBm	23 dBm	23 dBm	20/23 dBm	20/23 dBm
Multiplexed within LTE		Yes	Yes	Yes	Yes	Yes/No
Modem complexity		**100%**	**80%**	**40%**	**20%**	**<15%**

NOKIA

Multiplexing LTE-M with legacy LTE

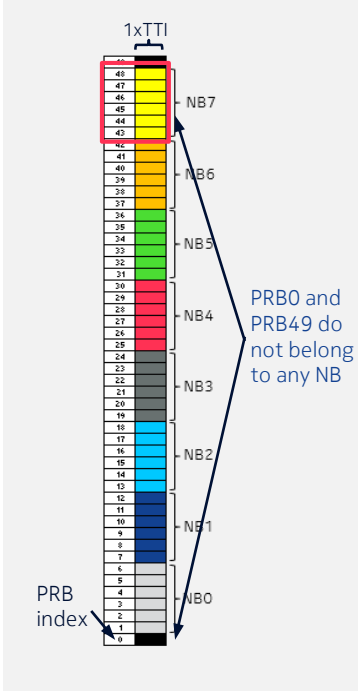


NOKIA

LTE-M
NB in DL frame

LTE-M multiplexed with legacy LTE carrier

50PRBs (10MHz) are divided by 3GPP into 8 possible narrowbands (NB0-NB7)



NB (Narrow Band): new logical entity in LTE-M (6PRBs)

At one time only one NB is used by CAT-M UE in DL

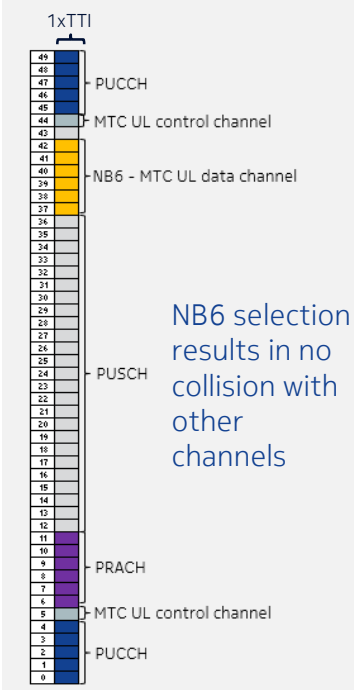
NB index for DL transmissions

3GPP allows for different NB for MTC DL control and data channels (including different NB for Paging/SIB transmission).

CAT-M UE is instructed which NB should be used in SIBs (information about the NB index of MTC control channel) as well as in DCI - Downlink Control Information (NB used for UL and DL data transmission)

NOKIA

LTE-M
NB in UL frame



NB6 selection results in no collision with other channels

NB index for UL transmissions

→ NB6 for UL data transmissions

CAT-M UE is instructed which NB should be used in UL via DCI that carries UL grant

NOKIA

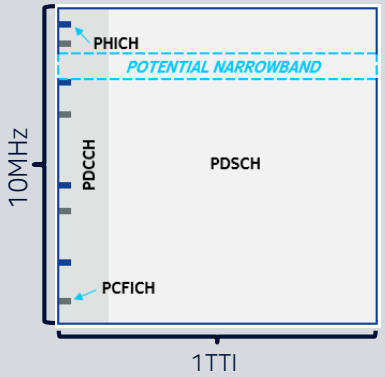
LTE-M
Redesign of physical channels

The need of physical channels redesign was addressed by 3GPP specification

Some of legacy LTE physical channels i.e. PDCCH, PCFICH, PHICH are not possible to be correctly decoded by CAT-M UEs. This is a consequence of their supported bandwidth (1.4 MHz)

As a consequence, functions of missing channels are provided by:

- MPDCCH which replaces PDCCH and PHICH for CAT-M UEs*
- PCFICH replacement is not needed (MPDCCH size is fixed)



CAT-M1 UE is able to fully read DL channels like PBCH, Primary Synchronization Signal (PSS) and Secondary Sychronization Signal (SSS) as they fall into a 6PRB bandwidth supported by CAT-M1 UE.

*Note: HARQ feedback after UL transmission is not provided. Instead, eNB informs about the need of retransmission via proper NDI (New Data Indicator)

NOKIA

LTE-M
Redesign of downlink physical channels

Some of legacy downlink physical channels are reused by LTE-M

LTE	Short description	LTE-M	Short description
PDCCH	First 1-4 OFDM symbols of each TTI. Used for DCI carrying	MPDCCH*	All PDSCH resources (REs) within NB7 (6PRBs) can be reused for MPDCCH
PCFICH	Indicates the number of OFDM symbols used by PDCCH. PCFICH is located within the first OFDM symbol of each TTI	N/A	No equivalent in LTE-M. MPDCCH size is fixed
PHICH	Used to carry HARQ feedbacks of UL transmissions. PHICH is located within the first OFDM symbol of each TTI	N/A	No equivalent in LTE-M. MPDCCH is used for carrying of HARQ feedback after UL transmission
PBCH	Transmitted with fixed periodicity of 40ms (10ms taking into account repetitions). PBCH carries MIB	MPBCH*	When MIB repetitions are not enabled MPBCH = PBCH, otherwise, PBCH symbols are repeated (each symbols occurs 5 times instead of one). MIB transmitted over PBCH is enhanced with IE that determines if CAT-M UEs are supported by given cell
PSS/SSS	Used for synchronization aspects. 6th and 5th OFDM symbol for PSS/SSS respectively. Transmitted once per 10ms	PSS/SSS	Fully reused by CAT-M UE. CAT-M UE connects to the same LTE cell
RS	Number of RE designated for carrying of DL Reference Signal is determined by the cells` antenna configuration	RS	Fully reused by CAT-M UE. CAT-M UE connects to the same LTE cell
PDSCH	All resources (REs) within TTI excluding PDCCH, PCFICH, PHICH, PBCH, PSS, SSS, RS, MPDCCH and MPDSCH (NB7)	MPDSCH*	All RE of configured NB7 that are not used by other physical DL channels/reference signals

*Note: For the simplification, the ‚M' prefix is added to all channels when it comes to LTE-M feature description. It does not always mean new channel, but also usage of full or part of the legacy channel resources for CAT-M UE transmission

NOKIA

LTE-M
Primary (PSS) and Secondary Synchronization Signal (SSS)

After a switch on, CAT-M1 UE is looking for a cell that it is allowed to be camped on

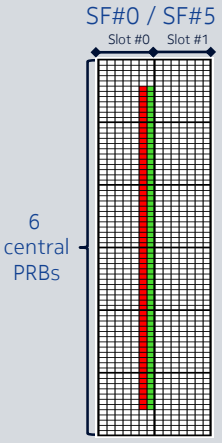
At the beginning, once UE detects cell`s broadcasted PSS/SSS, it has to synchronize itself with the cell which it is trying to connect with

Primary Sychronization Signal (PSS):

- transmitted in 6th OFDM symbol (LTE FDD) in each Radio Frame (SF#0 and #5)
- consists of 62 subcarriers (frequency domain) and one OFDM symbol in time domain

Secondary Sychronization Signal (SSS):

- transmitted in 5th OFDM symbol (LTE FDD) of each Radio Frame (SF#0 and #5)
- consists of 62 subcarriers (frequency domain) and one OFDM symbol in time domain



UE relies on the signals decoded from the PSS and SSS, transmitted every 10ms in subframe #5 (SF#5) which are different for each cell. As a result of PSS/SSS decoding, UE is able to obtain, subframe number* and the PCI**.

*Note: UE is synchronized on subframe level (accuracy 5ms) as PSS and SSS are sent in SF#0 and SF#5 (fixed timing)
**PCI (Physical Cell ID) of the LTE cell

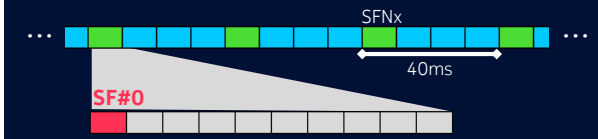
NOKIA

LTE-M
MPBCH

Once preliminary time synchronization procedure is completed, UE is able to read the MIB encoded in MPBCH

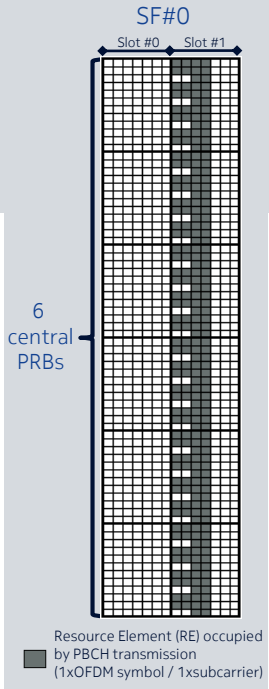
UE is looking for a centrally located MPBCH (PBCH). **PBCH carries the MIB (Master Information Block)**, 24bits, that are the main source of the primary information about cell, like bandwidth or System Frame Number

PBCH (6PRBs) is transmitted every 40ms with 4 repetitions, what means that PBCH occurs every 10ms (in subframe #0)



Legend:

- Radio Frame (SFN) with initial PBCH transmission
- Radio Frame (SFN) with repeated PBCH transmission
- Subframe #0, PBCH transmission (1ms)



NOKIA

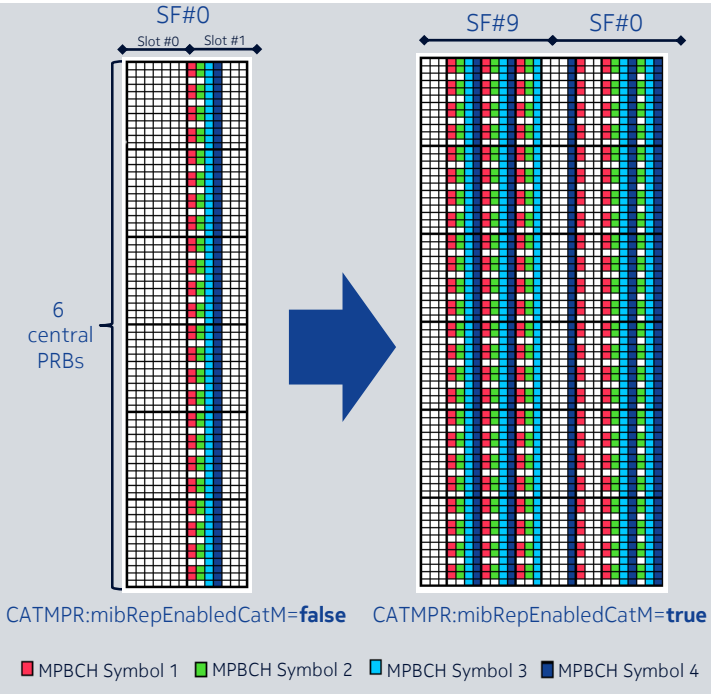
LTE-M
MPBCH

MPBCH detectability can be improved by increasing the number of PBCH repetitions

Number of (M)PBCH copies is configurable

Whenever parameter CATMPR:mibRepEnabledCatM is set to true, each MPBCH symbol occurs fivefold

Additional repetitions of MPBCH symbols will appear in SF#9 as well



NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (1/7)

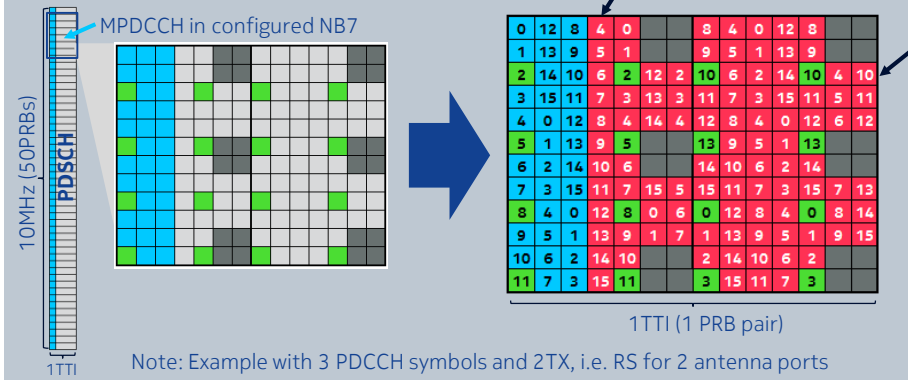
UL and DL grants for CAT-M UE scheduling are provided via MTC Downlink Control Channel (MPDCCH)

MPDCCH is limited to 6 PRBs of NB, what means it is fully decodable by CAT-M1 UE

MPDCCH occupies whole NB and it is located within the legacy downlink data channel (PDSCH)

MPDCCH starting symbol is broadcasted in SIB2-BR*

MPDCCH structure



EREG number (EREG - Enhanced Resource Element Group)

Note: EREG consists of all resource elements within PRB pair that are assigned the same EREG number

- RE carrying the PDCCH
- RE carrying the Cell specific Reference Signal (RS)
- RE carrying the PDSCH
- RE carrying the DMRS
- RE carrying the PDSCH, reused for MPDCCH

Note: Example with 3 PDCCH symbols and 2TX, i.e. RS for 2 antenna ports

*Note: BR stands for Bandwidth Reduced

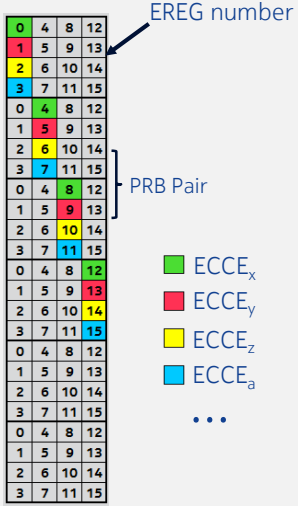
NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (2/7)

UL and DL grants for CAT-M UE scheduling are carried over Enhanced Control Channel Elements (ECCE*)

MPDCCH allocations

LTE-M supports distributed allocations only, i.e. four EREGs that create the ECCE* are spread over PRB pairs



EREGs - Logical representation
(not identical to physical resource element mapping)

LTE-M supports scheduling of **single CAT-M1 UE per TTI**, either in UL or in DL. **24ECCEs**, the highest Aggregation Level defined for MPDCCH by 3GPP is always used for grants allocation

EREG consists of 6REs, hence single CAT-M UE allocation consumes 576 REs (6PRBs). For MPDCCH, always QPSK is used.

*Note: Single ECCE is the smallest MPDCCH allocation unit

NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (3/7)

LTE-M feature provides an opportunity of MPDCCH repetitions

Number of MPDCCH repetitions depends on parameterization as well as on the transmitted message type

USS (UL/DL, C-RNTI) and CSS Type 0

R_{max}	n_1	n_2	n_3	n_4
32	4	8	16	32
16	2	4	8	16
8	1	2	4	8
4	1	2	4	-
2	1	2	-	-
1	1	-	-	-

Where:
R_{MAX}: CATMPR:mpdcchMaxNumRepCatM
n_x: as configured by CATMPR:mpdcchRepLevCatM

CSS Type 1 (Paging, P-RNTI)

R_{max}	n_1	n_2	n_3	n_4
256	2	16	64	256
128	2	16	64	128
64	2	8	32	64
32	1	4	16	32
16	1	4	8	16
8	1	2	4	8
4	1	2	4	-
2	1	2	-	-
1	1	-	-	-

Where:
R_{MAX}: CATMPR:mpdcchMaxNumRep**Pag**CatM
n_x: as configured by CATMPR:mpdcchRepLev**Pag**CatM

CSS Type 2 (MSG2, HARQ for MSG3 and MSG4)*

R_{max}	n_1	n_2	n_3	n_4
32	4	8	16	32
16	2	4	8	16
8	1	2	4	8
4	1	2	4	-
2	1	2	-	-
1	1	-	-	-

Where:
R_{MAX}: CATMPR:mpdcchMaxNumRep**Ra**CatM
n_x: as configured by CATMPR:mpdcchRepLev**Ra**CatM

Number of repetitions is at the intersection of row and column. CAT-M UE is informed about the row index (SIB2-BR) and column index (via DCI). Default values indicated by green color

NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (4/7)

Downlink Control Information (DCI) format determines which search space is needed

Two types of Search Spaces are available – Common Search Space (CSS) and UE specific Search Space (USS)

CSS – Common Search Space

- Type0-MPDCCH CSS is used for power control
- Type1-MPDCCH CSS is used for Paging (P-RNTI)
- Type2-MPDCCH CSS is used for sending DCIs related to RA messages MSG2, HARQ of MSG3, MSG4

USS – UE specific Search Space

USS is used for regular user data allocations (C-RNTI)

CSS and USS are scheduled alternatively

TTI that carries MPDCCH will be designated either for CSS scheduling when any DCI to be carried over the CSS is pending or for USS scheduling, when no more DCIs to be carried over the CSS are in queue

NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (5/7)

Carriage of UL or DL grant and all its repetitions happens within one MPDCCH search space

MPDCCH is allocated in valid DL subframes only

Whenever invalid DL SF* is met, MPDCCH is always postponed

MPDCCH allocation (all repetitions) must fit to single Search Space (SS) boundary**

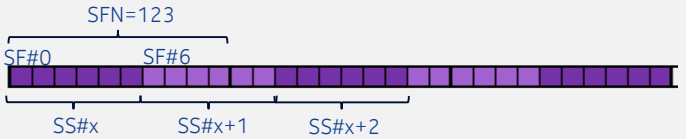
SS duration (**T**) is expressed as **R_{MAX} * G factor** and depends on parameters:

- **R_{MAX}** – CATMPR:mpdcchMaxNumRepCatM***
- **G factor:**
  - USS – CATMPR:mpdcchStartSfUessCatM
  - CSS – CATMPR:mpdcchStartSfCssCatM

When invalid DL subframes are expected to appear and R_{MAX} for MPDCCH is higher than 1, **G factor should be higher than 1**. When R_{MAX} is set to 1 **then G factor must be set to 1 as well.**

MPDCCH search space starts in each subframe that satisfies the formula:

(10*SFN + subframe number) mod T = 0



Assumption:
G=1.5
R_{MAX}=4

NOKIA

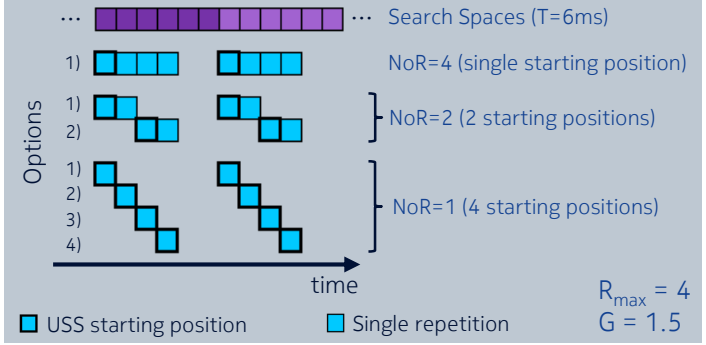
LTE-M
MPDCCH - MTC Physical Downlink Control Channel (6/7)

Starting positions of DCI transmission in the MPDCCH search space depend on the selected repetition level

DCI allocation usually starts from the search space beginning

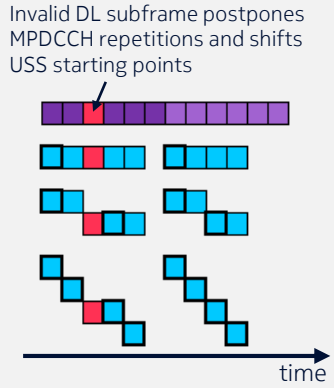
Possible USS* starting positions

When configured **number of repetitions is not equal to R_{max},** there is more than one starting position in which first repetition of DCI can be allocated**.



R_{max} = 4
G = 1.5

Possible USS starting positions when invalid DL subframe is met



Invalid DL subframes cause MPDCCH repetitions shifts to next TTIs

G = 1.5 guarantees 2 additional TTIs within the same SS that can be reused by eNB for MPDCCH allocation (for R_{max} = 4)

(SS duration [**T**] – 6ms)

* Note: CSS starting positions are determined in the analogical way. Note that difference in SS duration may be seen as different G factor can be used (CATMPR:mpdcchStartSfCssCatM).
** Note: When there is a collision between e.g. 1st USS starting position in SS and other channel (MPDSCH), MPDCCH SS will not be always lost. Other positions can be used by eNB.

NOKIA

LTE-M
MPDCCH - MTC Physical Downlink Control Channel (7/7)

eNB sends Downlink Control Information messages for the CAT-M UE over the MPDCCH

DCI carries information about UL or DL data transmission aspects

DCI formats supported by LTE-M are summarized in the table below

UL/DL	Purpose	DCI format	Search Space	CSS Type	RNTI
UL	Regular Data	**6-0A**	**USS**	**N/A**	**C-RNTI**
DL	Regular Data	**6-1A**	**USS**	**N/A**	**C-RNTI**
DL	RAR	**6-1A**	**CSS**	**2**	**RA-RNTI**
DL	Paging	**6-2**	**CSS**	**1**	**P-RNTI**

NOKIA

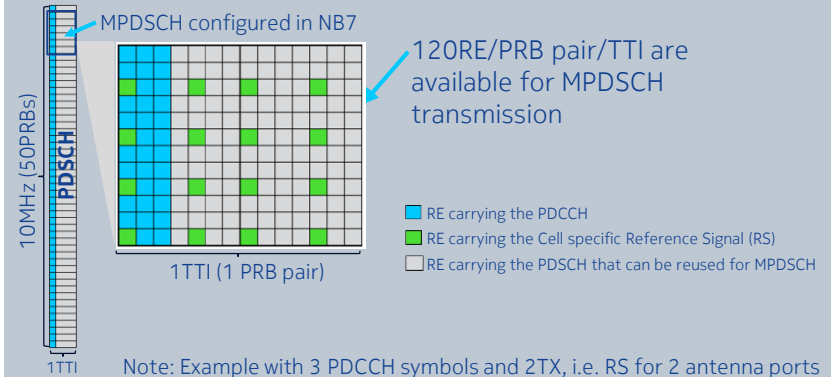
LTE-M
MPDSCH - MTC Physical Downlink Shared Channel (1/2)

Transport blocks with user data are sent over the MPDSCH channel

MPDSCH is transmitted on selected legacy PDSCH resources (as limited by NB7)

MPDSCH structure

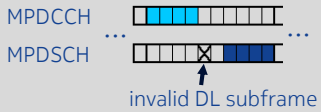
MPDSCH consists of all Resource Elements of NB7 that are not used for any other DL transmission



Note: Example with 3 PDCCH symbols and 2TX, i.e. RS for 2 antenna ports

MPDCCH as well as MPDSCH occupy the whole NB7 therefore only one of them is transmitted at one TTI

MPDSCH is always preceded by grant allocation on MPDCCH. Between MPDCCH and MPDSCH there is a break of one DL valid SF



Example with:
4 MPDCCH Repetitions
4 MPDSCH Repetitions

NOKIA

LTE-M
MPDSCH - MTC Physical Downlink Shared Channel (2/2)

LTE-M gives an opportunity to enable MPDSCH repetitions

Number of MPDSCH repetitions depends on parameterization as well as on the transmitted message type

Transmission scheduled in DL by DCI 6-1A (scrambled with C-RNTI or RA-RNTI)

R_{max}	n_1	n_2	n_3	n_4
32	1	4	16	32
16	1	4	8	16
8	1	2	4	8

Where:

R_{MAX}: CATMPR:pdschMaxNumRep**ModeA**CatM

n_x: as configured by CATMPR:pdschRepLev**ModeA**CatM*

Transmission scheduled by DCI 6-2A (Paging, P-RNTI)

R_{max}	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
n2	4	8	16	32	N/A	N/A	N/A	N/A
n1	1	2	4	8	16	32	N/A	N/A

Where:

R_{MAX}: value of CATMPR:mpdcchRepLev**Pag**CatM determines at the same time the MPDSCH repetition set

n_x: as configured by CATMPR:pdschRepLev**Pag**CatM**

Number of repetitions is at the intersection of row and column. CAT-M UE is informed about the row index (SIB2-BR) and column index (via DCI). Default values indicated by green color

NOKIA

LTE-M
Redesign of uplink physical channels

Some of legacy uplink physical channels are reused by LTE-M

LTE	Short description	LTE-M	Short description
PRACH	6 contiguous PRBs. Starting PRB is defined by offset (LNCEL_FDD:prachFreqOff) or, if LTE1130 is activated, the appropriate offset is automatically being found (. Frequency of RACH opportunity is as defined by LNCEL_FDD:prachConfIndex	MPRACH*	MPRACH = PRACH (the same PRBs will be reused). The only difference can appear in timing. It is possible to limit MPRACH occasions in which initial MSG1 transmission can happen (CATMCEL:prachStartsSFCatM). Please note that repetitions can happen in each PRACH occasion
PUCCH	Whenever LTE1130 is used, PUCCH size is automatically being adjusted based on number of connected UEs. If LTE1130 is not used, required PUCCH size has to be calculated and configured accordingly	MPUCCH*	MPUCCH always occupies 2 PRBs from the legacy PUCCH. Single configuration for 2 MPUCCH PRBs - one PRB is for SR and the second is for HARQ feedbacks. Please note that LTE1130 is a prerequisite for LTE3128 activation thus the size of the legacy PUCCH can vary
PUSCH	All resources unused for PRACH/PUCCH/MPUCCH/MPUSCH are designated for UL data transmissions over PUSCH	MPUSCH*	All resources unused for all other UL channels and limited to NB6 create MPUSCH

*Note: For the simplification, the ‚M' prefix is added to all channels when it comes to LTE-M feature description. It does not always mean new channel, but also usage of full or part of the legacy channel resources for CAT-M UE transmission

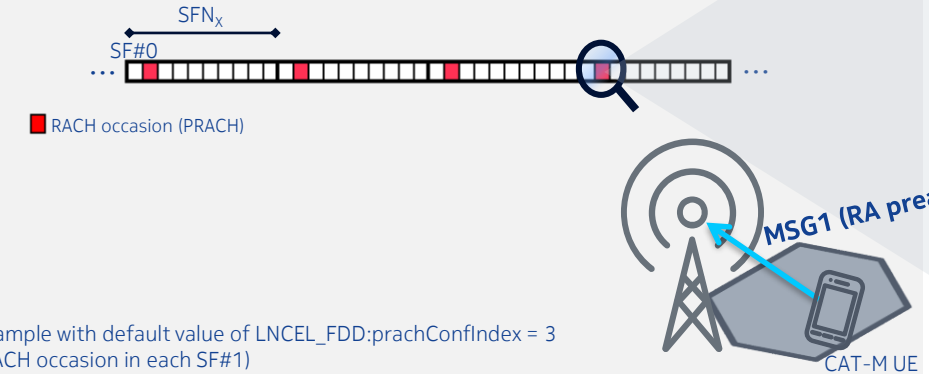
NOKIA

LTE-M
MPRACH – MTC Physical Random Access Channel (1/5)

MPRACH will be used by idle CAT-M UE to start RRC connection establishment

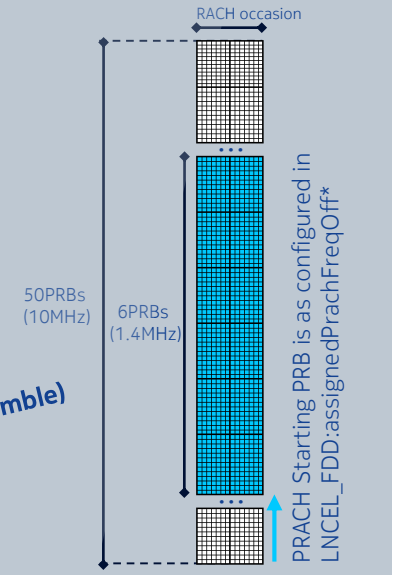
CAT-M UE sends RA preamble on MTC Physical Random Access Channel (MPRACH)

From the frequency domain perspective, MPRACH fully overlaps with PRACH as the same PRBs will be used by CAT-M UE and non-CAT-M UE for RA preamble sending



Example with default value of LNCEL_FDD:prachConfIndex = 3 (RACH occasion in each SF#1)

PRACH resources are reused by CAT-M UEs

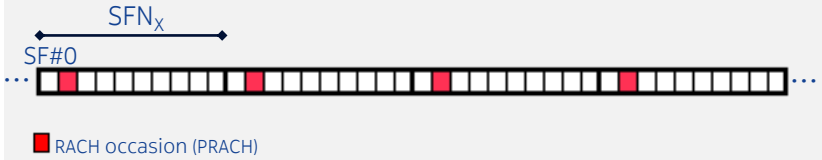


NOKIA

LTE-M
MPRACH – MTC Physical Random Access Channel (2/5)

Number of PRACH occasions depends on the selected PRACH configuration index

Number of PRACH occasions as well as the exact timing is determined by the legacy configuration (LNCEL_FDD:prachConfIndex) that determines in which SFNs and which subframe numbers UE is allowed to send RA preamble



Example with default value of LNCEL_FDD:prachConfIndex = 3 (RACH occasion in each SF#1)

Supported PRACH Configuration Indexes for cells with LTE-M feature enabled → 3-8*

PRACH Configuration Index	Preamble Format	System Frame Number	Subframe Number
0	0	Even	1
1	0	Even	4
2	0	Even	7
3	0	Any	1
4	0	Any	4
5	0	Any	7
6	0	Any	1,6
7	0	Any	2,7
8	0	Any	3,8

Number of PRACH occurences as well as exact PRACH timing is determined based on LNCEL_FDD:prachConfIndex

*Note: LTE-M supports Preamble format 0 only.

NOKIA

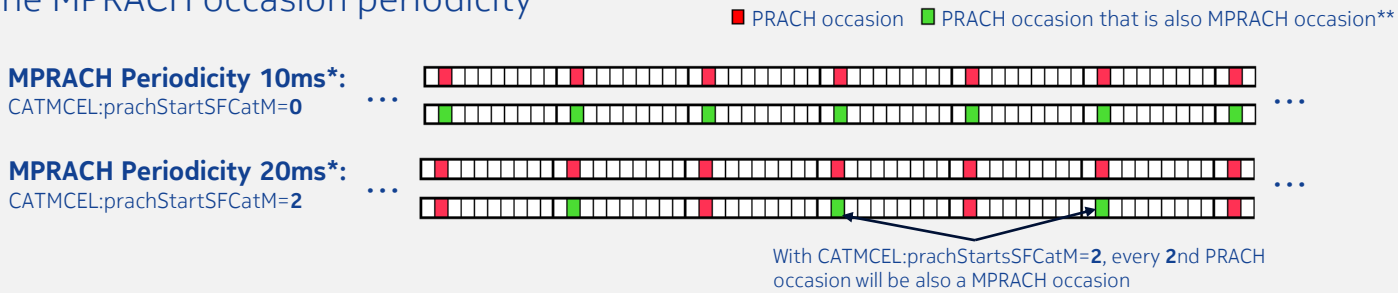
LTE-M
MPRACH – MTC Physical Random Access Channel (3/5)

CAT-M UE is allowed to use PRACH occasions for MSG1 sending

Some of PRACH occasions (or all) are also MPRACH occasions

MPRACH timing (MPRACH occasions)

CATMCEL:prachStartSFCatM determines the MPRACH occasion periodicity



CAT-M UE can transmit initial RA preamble (i.e. the 1st repetition of RA preamble) only in MPRACH occasions

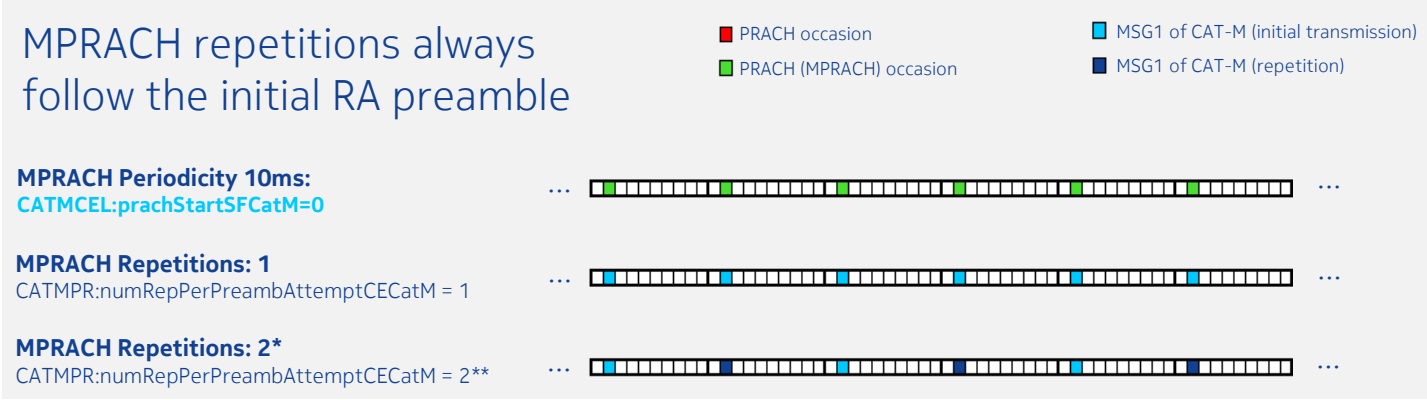
NOKIA

LTE-M
MPRACH – MTC Physical Random Access Channel (4/5)

CAT-M UE can transmit one RA preamble with repetitions

Number of repetitions of each RA preamble attempt is configurable by CATMPR:numRepPerPreambAttemptCECatM

MPRACH repetitions always follow the initial RA preamble



Whenever CATMPR:numRepPerPreambAttemptCECatM is greater than one, the same preamble (MSG1) will be sent over configured number of MPRACH occasions. eNB will combine the energy from multiple subframes to detect the initial UE message

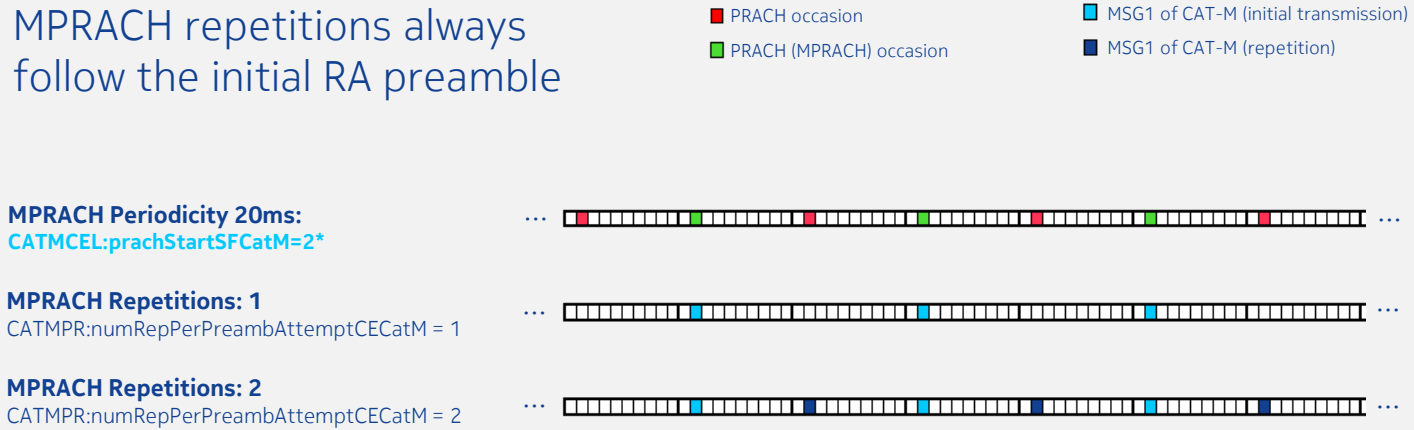
NOKIA

LTE-M
MPRACH – MTC Physical Random Access Channel (5/5)

When CATMCEL: prachStartSF CatM > 0 repetitions can be sent in non MPRACH occasions only

MPRACH occasions are reserved for the initial preambles sent by CAT-M UEs

MPRACH repetitions always follow the initial RA preamble

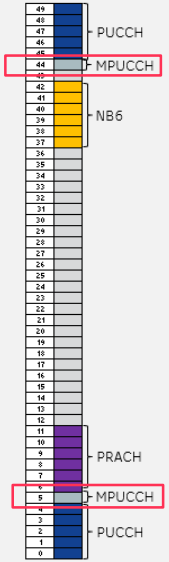


LTE-M
MPUCCH - UL control channel (1/2)

There are two main use cases for MTC Uplink Control Channel (MPUCCH)

MPUCCH will be used by CAT-M UEs to provide a HARQ feedback after DL transmission as well as to request resources via Scheduling Request (SR)

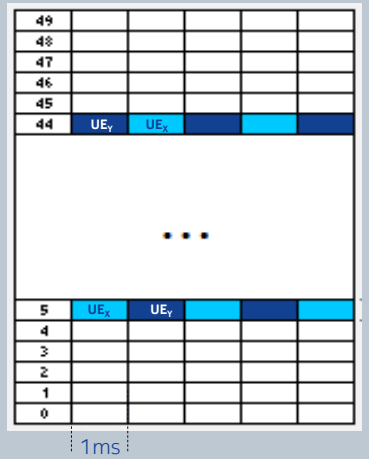
MPUCCH reuses 2 outer PRBs from legacy PUSCH that stick to the legacy PUCCH*



Note:
PRACH is permanently moved beyond the MPUCCH by LTE1130

MPUCCH hopping is supported

MPUCCH hops every single subframe what will result in diversity gain



NOKIA

LTE-M
MPUCCH - UL control channel (2/2)

LTE-M gives an opportunity to enable MPUCCH repetitions

MPUCCH can be sent by UE with repetitions. Number of repetitions depends on parameters (CATMPR:pucchF1NumRepModeACatM** and CATMPR:pucchNumRepMsg4ModeACatM for repetitions of HARQ feedback in response to the MSG4)

Whenever MPUCCH resources are not used for CAT-M UEs, they can be reused for legacy PUSCH transmissions*

Supported MPUCCH Uplink Control Information formats are format 1 for SR and format 1a for ACK/NACK

ACK/NACK will be scheduled with BPSK while SR with on/off keying

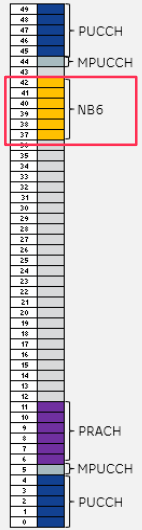
NOKIA

LTE-M
MPUSCH - UL data channel (1/2)

User data, including e.g. measurements results from smart meters are carried over MPUSCH

User data in uplink will be sent over all Resource Elements of NB6 that are not used for any other UL transmission

In case when LTE3128 is enabled, MPUSCH spans over PRB37 to PRB42



MPUSCH, similarly to MPDSCH is always preceded by grant allocation on MPDCCH. Between MPDCCH and MPUSCH there is a break of three subframes

Example with:
4 MPDCCH Repetitions
4 MPUSCH Repetitions

Note: UL resources (MPUCCH and MPUSCH) can be reused for non-CAT-M UEs when there is **no RRC Connected CAT-M UE in the cell**

NOKIA

LTE-M
MPUSCH - UL data channel (2/2)

LTE-M gives an opportunity to enable MPUSCH repetitions

Number of MPUSCH repetitions depends on parameterization

UL transmission scheduled by DCI 6-0A (C-RNTI) and transmission of MSG3 (scheduled with RA-RNTI)

R_{max}	n_1	n_2	n_3	n_4
32	1	4	16	32
16	1	4	8	16
8	1	2	4	8

Where:
R_{MAX}: CATMPR:puschMaxNumRep**ModeA**CatM
n_x: as configured by CATMPR:puschRepLev**ModeA**CatM

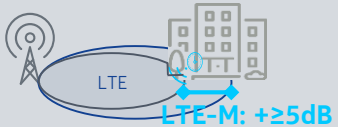
Number of repetitions is at the intersection of row and column. CAT-M UE is informed about the row index (SIB2-BR) and column index (via DCI). Default values indicated by green color

NOKIA

LTE-M
coverage enhancement (CE)

Many MTC devices are expected to be located indoors

Coverage enhancement techniques are expected to improve the signal penetration into buildings



LTE-M feature offers the possibility of **enabling of multi subframe repetitions**, resulting in higher energy per information bit

CE modes defined by 3GPP

CE mode A
CE mode A provides relatively modest coverage enhancement. **Maximum Coupling Loss (MCL) is expected to be improved about at least 5dB.** Smaller, comparing to CE mode B, number of repetitions is allowed to be used.

CE mode B

CE mode B is expected to improve the MCL about ~15dB, as a result of much more extensive repetition (up to 2048 repetitions)

*Note: NoR stands for Number of Repetitions

NOKIA

LTE-M
CE: repetition in LTE-M

Idea of repetition is similar to HARQ retransmission

The major difference between repetition and HARQ retransmission is related to the necessity of sending

Repetition

Configured number of repetitions are always mandatorily sent

Note: Repetitions can be retransmitted as well

HARQ Retransmission

HARQ retransmission is done only when needed. Whenever the latest (re)transmission is not acknowledged, HARQ retransmission will take place (provided that maximum number of HARQ retransmissions is not reached)

Both HARQ retransmissions and repetitions are characterized by different RV (Redundancy Versions). RV sequence {0,2,3,1} defined by 3GPP for LTE is kept for LTE-M as well

Please note that preserving 3GPP wording, **repetition means both the initial transmission (1st repetition) as well as additional 'copies'**. When single repetition is to be used, only an initial transmission is sent. In turn, when 4 repetitions are configured, initial transmission + 3 'copies' are sent.

NOKIA

LTE-M
Absolution repetition number in Physical Channels

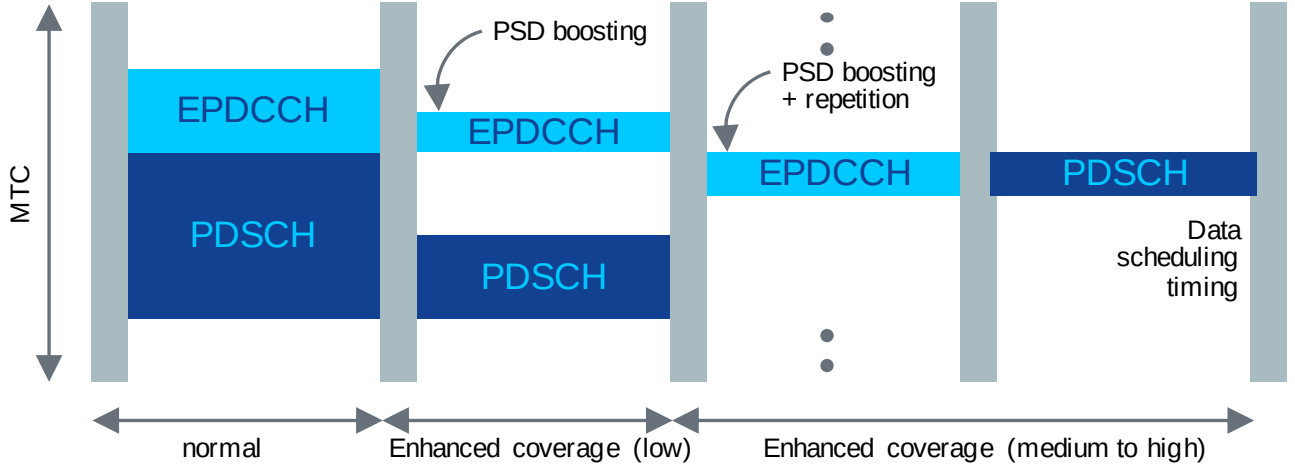
Maximum repetition of Physical Channels

Physical channel	3GPP CE Mode-A limit
MPUSCH	32
MPUCCH	8
MPRACH	128 (the same as for CEModeB)
MPDSCH	32
MPDSCH for Paging	2048 (the same as for CEModeB)
MPDCCH for USS/RA CSS	256 (the same as for CEModeB)
MPDCCH for Paging	256 (the same as for CEModeB)

NOKIA

LTE-M
Absolution repetition number in Physical Channels

Extended coverage – 155.7 dB path loss
Coverage extended via repetition and power spectral density boosting



NOKIA

LTE-M
Acquiring information about cell support for CAT-M UEs

The next step after the cell selection and preliminary synchronization is MIB reading from MPBCH

CAT-M1 UE, comparing to legacy LTE will pay attention to **schedulingInfoSIB1-BR*-r13 Information Element**

MIB CONTENT**			
Information Element/ Group name	Need	3GPP-Range	Source
dl-Bandwidth	MP	Enumerated: (n6, n15, n25, n50, n75, n100)	eNB
...	...	...	...
schedulingInfoSIB1-BR-r13 Information Element	**MP**	**INTEGER (0...31)**	**eNB**

Whenever schedulingInfoSIB1-BR-r13 value **is higher than 0, CAT-M UE support is enabled** in given cell

schedulingInfoSIB1-BR-r13 value found in MIB is additionally used by CAT-M UE to determine:

1) repetition level of SIB1-BR* transmissions
2) TBS (Transport Block Size) for SIB1-BR* transmission

*Note: BR stands for Bandwidth Reduced

NOKIA

LTE-M
Acquiring configuration of SIB1-BR broadcast

schedulingInfoSIB1-BR-r13 value

Whenever LNCEL:actCatM is set to enabled, value of schedulingInfoSIB1-BR-r13 broadcasted in PBCH is determined based on configured the number of SIB1-BR repetitions (CATMPR:numRepSib1BRCatM) as well as SIB1-BR Transport Block Size (TBS)

The eNB determines the TBS for SIB1-BR by selection of the smallest one from the set {208, 256, 328, 504, 712, 936} which is equal to or larger than the SIB1-BR message size

Value of MIB-> *schedulingInfoSIB1-BR-r13*	numRepSib1BRCatM	SIB1-BR TBS
1	4	208
2	8	208
3	16	208
4	4	256
5	8	256
6	16	256
7	4	328
8	8	328
9	16	328
10	4	504
11	8	504
12	16	504
13	4	712
14	8	712
15	16	712
16	4	936
17	8	936
18	16	936

NOKIA

LTE-M
SIB1-BR provides further details about the cell configuration

Once MIB is decoded, CAT-M UE will read SIB1-BR, containing i.a. configuration of other SIBs, PLMN and Tracking Area Code

SIB1-BR in frequency domain

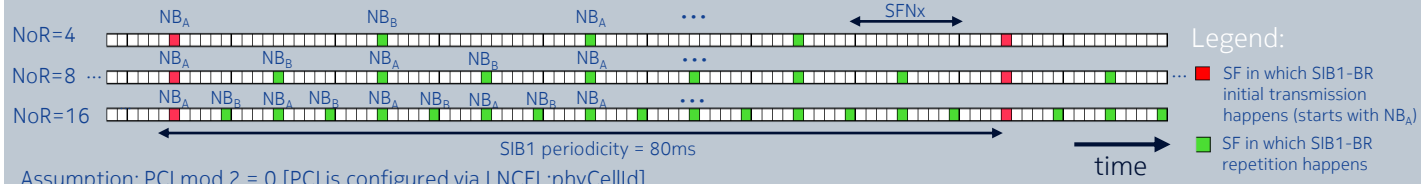
SIB1-BR has no fixed location in the frequency domain, i.e. frequency hopping in the shape of NB hopping is possible. 2 narrowbands are selected based on the PCI and used alternatively.

PCI Mod 6	NB_A	NB_B
0	NB0	NB5
1	NB1	NB6
2	NB2	NB7
3	NB5	NB0
4	NB6	NB1
5	NB7	NB2

SIB1-BR in time domain

SIB1-BR together with all repetitions are transmitted over the MPDSCH in 80ms period. Number of SIB1-BR repetitions (NoR) over 80ms is configured by CATMPR:numRepSib1BRCatM*. System Frame Number (SFN) and Subframe numbers, in which SIB1-BR transmission will happen, depend on the configured NoR as well as on the PCI.

NoR	PCI mod 2	SFN mod 2	SF#
4	0	0	4
	1	1	4
8	0	0, 1	4
	1	0, 1	9
16	0	0, 1	4, 9
	1	0, 1	0, 9



Assumption: PCI mod 2 = 0 [PCI is configured via LNCEL:phyCellId]

NOKIA

LTE-M
System Information provisioning (1/3)

Information about other SIB(s) scheduling is included in SIB1-BR

LTE-M supports also SIB2-BR, SIB3-BR, SIB4-BR and SIB16-BR

SIB	Purpose
SIB1-BR	Carries basic information about the serving cell, e.g. PLMN, Tracking Area Code, Min. RX level needed to access the cell, cell barring information, information about other SIB configuration in time domain.
SIB2-BR	Contains radio resource configuration information that is common for all CAT-M UEs, e.g. (M)PRACH, UL power control configuration, Timing alignment configuration, etc.
SIB3-BR	Carries information common for cell re-selection (intra-frequency, inter-frequency, inter-RAT), e.g. power and quality thresholds.
SIB4-BR	Provides information about the **intra-frequency** neighbouring cells relevant for cell re-selection.
SIB16-BR	Carries GPS related information

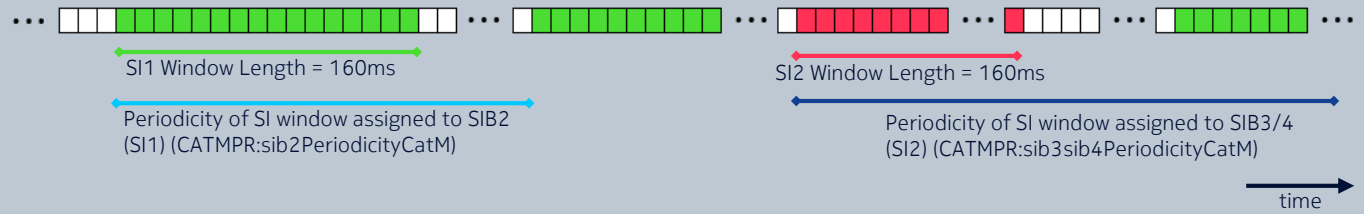
LTE-M
System Information provisioning (2/3)

Periodicity of other SIB messages depends directly on the periodicity of SI windows

SIBs other than SIB1 are assigned dedicated SI (System Information) windows that will not overlap

System Information Messages (SIM) broadcast

Periodicity of SI windows for SIBs are configurable via following parameters CATMPR:sib2PeriodicityCatM, CATMPR:sib3sib4PeriodicityCatM, CATMPR:sib16PeriodicityCatM)



SIx window length is common for all SIBs and possible to be configured via CATMPR:siWindowLenCatM parameter value (160ms by default)

NOKIA

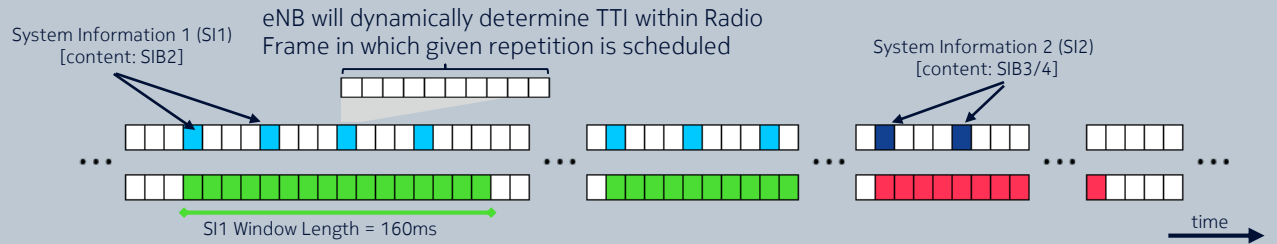
LTE-M
System Information provisioning (3/3)

Repetitions of SI messages for CAT-M UEs improving the detectability of SIM are also in scope of LTE-M

Number of SIB repetitions (common for all SIBs other than SIB1-BR) is controlled via CATMPR:siRepPatternCatM parameter value

System Information Messages (SIM) broadcast

SIB transmission (including all repetitions) have to fit to the SI window (SIW) boundaries. CATMPR:siRepPatternCatM determines the periodicity of SIB repetitions within SIW. As a result exact number of repetitions depends on SIW length and CATMPR:siRepPatternCatM parameter value. Combination of them determine radio frames within SIW that will contain SIB repetition.



Example with CATMPR:siRepPatternCatM = every4thRF and SI and CATMPR:siWindowLenCatM = 160ms

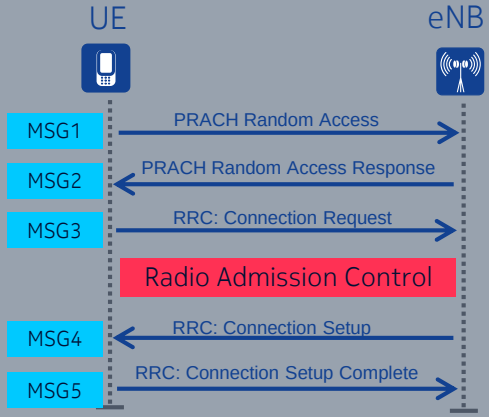
NOKIA

Random Access Procedure in LTE-M (1/4)

Random Access (RA) procedure will precede any data transmission to/from the idle UE

Before any transmission happens, Idle CAT-M1 UE has to establish the RRC Connection

Everything starts with the RA procedure during which CAT-M UE randomly selects one preamble and sends it over the MPRACH (MSG1)



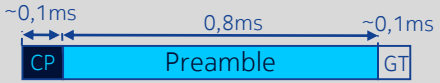
LTE-M1 provides support for contention based random access only

NOKIA

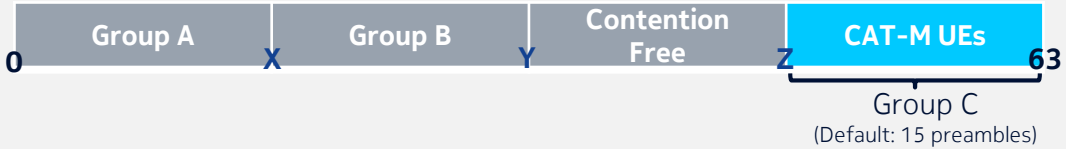
LTE-M
Random Access Procedure in LTE-M (2/4)

RA procedure is started with the initial UE message (MSG1) that contains the RA preamble

LTE-M provided by LTE3128 supports **PRACH preamble format 0 only**. PRACH config indexes which can be used in the cell where LTE-M is activated are limited (3-8).



When LTE3128 is used, 64 preambles are split into 4 groups, including a **new**, **separate group** for CAT-M UEs. Each group contains a configurable number of preambles



Where:
X – LNCEL:raPreGrASize – 1
Y – LNCEL:raNondedPreamb – 1
Z – 63 – **CATMPR:raPreGrCSizeCatM** - 1

NOKIA

LTE-M
Random Access Procedure in LTE-M (3/4)

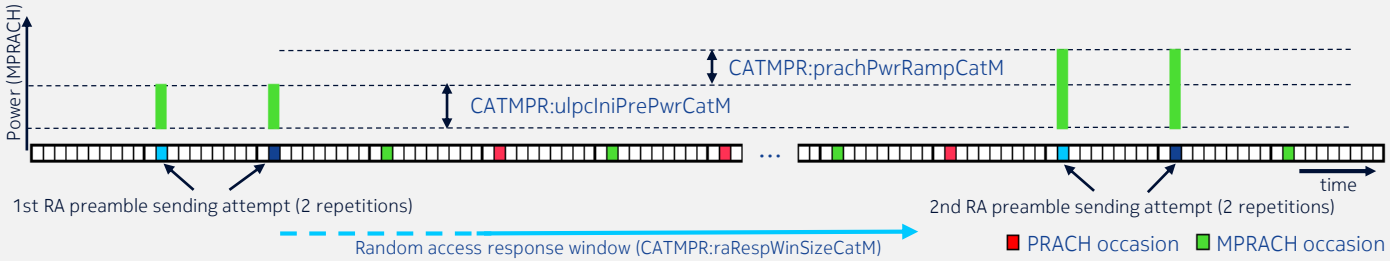
CAT-M1 UE has multiple attempts of one RA preamble sending, as configured by CATMPR:preambTxMaxCatM*

The first RA preamble transmission attempt is done with the initial UL power (CATMPR:ulpcIniPrePwrCatM)

Once all repetitions of RA preamble are sent by CAT-M UE, PDCCH is being monitored. CAT-M UE is looking for the RA-RNTI indicating the RAR, i.e. the Random Access Response (MSG2)

If RAR is not received during so called **Random access response window** (CATMPR:raRespWinSizeCatM), CAT-M UE starts the next attempt of RA preamble increasing the power

A stepwise power boosting is the next method that improves the RACH preamble detectability



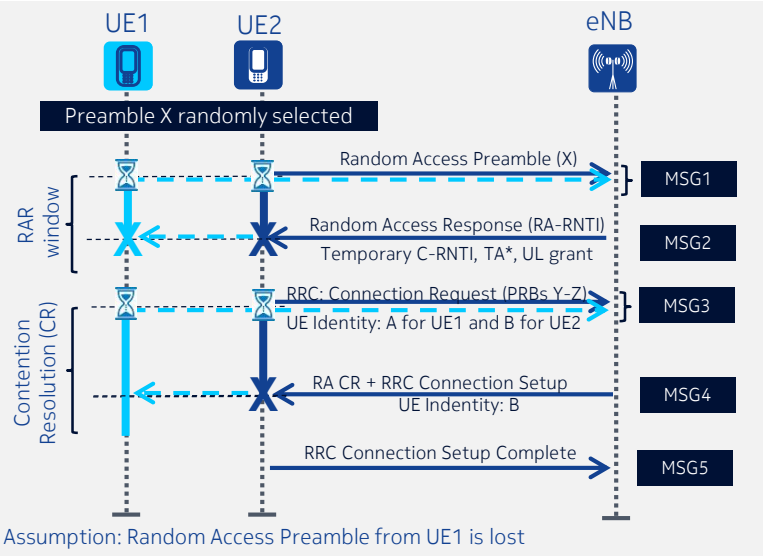
One RA preamble attempt is always transmitted with the same power

NOKIA

LTE-M
Random Access Procedure in LTE-M (4/4)

As many CAT-M1 UEs compete for the limited number of RA preambles, it can happen that more than one select the same Zadoff–Chu sequence in the same MPRACH occasion

The same RA preamble detection by eNB will lead to assignment of the same temporary C-RNTI as well as the same resources where MSG3 will be allocated by the CAT-M UE



After MSG3 sending CAT-M UE expects to receive MSG4 within the time limited by Contention Resolution timer (CATMPR:raContResoTmrCatM)

When CAT-M UE detects its identity in MSG4, it will confirm MSG3 correct reception by ACK. Otherwise it sends nothing (DTX) what will lead to Contention Resolution timer expiry (RA failure)

*Note: TA stands for Timing Advance

NOKIA

LTE-M
Radio Admission Control (RAC)

RAC role is to control availability of radio resources

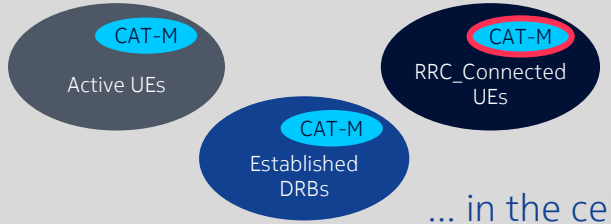
Radio Admission Control controls number of simultaneous RRC_Connected UEs, Active UEs as well as the number of established DRBs

Connected CAT-M UE can have **up to 3 nonGBR DRBs (QCIs 6-9) established** (including default bearer).

CAT-M UE is counted as legacy LTE UE as well. That means that RAC takes connected CAT-M UE into account while legacy LTE thresholds are being checked as well

CAT-M UE will not be admitted by Radio Admission Control, regardless of which threshold is reached first, i.e. either CATMPR:maxNumRrcCatM or MPUCCH_FDD:maxNumRrc or LNCEL_FDD:maxNumActDrb or LNCEL_FDD:maxNumActUe

Total number of ...



... in the cell

Number of connected CAT-M UEs as configured by CATMPR:maxNumRrcCatM

Minimum number of Cat-M RRC connections as configured by CATMPR:minNumRrcCatM to grant cell access for Cat-M UEs(Airscale SM)

NOKIA

eMTC vs. FeMTC vs. eFeMTC

Rel. 13 → Rel.14 → Rel. 15 Improvements

Mobility

Intra-frequency and inter-frequency measurements in enhanced coverage mode

Group Messaging

Adoption of Rel.13 single Cell point-to-Multipoint (SC-PTM) feature

VoLTE improvements

optimized parameter for VoLTE

- reduce DL repetitions
- new repetition factors in CE
- adjusted scheduling delays

PHY/MAC layer enhancements

- Max uplink TBS of 2984 bits (M1)
- new UE category (M2) with max TBS of 4008/6968 bits (UL/DL) and optionally support of 5 MHz
- 10 DL HARQ processes

Device positioning

- E-CID support
- OTDOA support based on positioning reference signal (PRS) adapted for LTE-M (e.g. frequency hopping support)

- Latency and power consumption reduction
- Higher velocity (e.g. 200 km/h)
- Lower UE power class
- Improved spectral efficiency (e.g. 64 QAM)
- Load control improvements

expected in Rel. 15

NOKIA


NOKIA