CAT-M & NB-IoT Design and Conformance Test

20170614
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What’s IOT?
Internet of Things
物聯網
Diverse IoT Applications

- Long battery life
- Low device cost
- Low deployment cost

Extended coverage

Support for a massive number of devices.
Diverse IoT Applications

Data rate / Power consumption

- WiFi
- Cellular
- ZigBee
- BT LE
- NFC
- LPWAN

Range

Applications:
- Healthcare
- Agriculture
- Manufacturing
- Connected cities
- Asset tracking
- Connected cars
- Smart Energy
- Weareables
3GPP for IOT

R8
LTE Cat 1

R12
LTE Cat 0

R12
PSM
(Power Saving mode)

R13
e-DRX

R13
CAT-M1 / Nbiot / EC-GSM
- Provide an LTE coverage improvement – corresponding to 15dB for FDD
- Enhance the DRX cycle

- Reduced device bandwidth of 1.4MHz in downlink and uplink
- Reduced maximum transmit power of 20dBm
Evolution of MTC/CIoT in 3GPP

Clot GERAN Clean sheet proposals
- NB-M2M (Neul-Huawei, u-blox, Ericsson, Samsung)
- NB-OFDMA (Qualcomm)
- C-UNB (derivative of SIGFOX)
- NB-CSS (Semtech, derivative of LoRa)
  - NB-CloT (NB-M2M + NB-OFDMA) (Qualcomm, Neul-Huawei, u-blox others)

GSM Evolution proposals
- NB-GSM
  - EC-GSM (Ericsson others)

LTE Evolution proposal
- LTE-M 1.4MHz BW

Clean sheet proposal work item for further refinement
- NB-CloT
- NB-LTE

Output for R13 standardization
- LTE-M 1.4MHz
- EC-GSM
  - R13 spec June 2016, expect merged OFDMA DL and two separate UL TBC

Likely to move forward
- LTE-M 1.4MHz
- EC-GSM

TR 45.820
GERAN selection process

TR 36.888
LTE-M 1.4MHz BW

RAN #69 selection process
September 2015

RAN #70 selection process
December 2015

Almost certain for Rel-13
NarrowBand IOT

September 17, 2015, Phoenix, USA

A major milestone was achieved this week in RAN (Plenary meeting #69) with the decision to standardize NB-IoT, a new narrowband radio technology to address the requirements of the Internet of Things (IoT). The new technology will provide improved indoor coverage, support of massive number of low throughput devices, low delay sensitivity, ultra-low device cost, low device power consumption and optimized network architecture.

The technology can be deployed “in-band”, utilizing resource blocks within a normal LTE carrier, or in the unused resource blocks within a LTE carrier’s guard-band, or “standalone” for deployments in dedicated spectrum.

NB-IoT is also particularly suitable for the re-farming of GSM channels. “It took us some twists and turns to get there, but we have now set a clear path in Release 13 to meet the needs of the 3GPP industry to further address the promising IoT market.”

Dino Flore, the Chairman of 3GPP RAN said, adding; “We entered the meeting with competing technology proposals for standardization. After lengthy discussions we came up with a harmonized technology proposal with very broad industry support as can be seen from the number of companies supporting the approved Work Item.”
## Summary for eMTC, NB-IOT and EC-GSM-IoT

<table>
<thead>
<tr>
<th></th>
<th>eMTC (LTE Cat M1)</th>
<th>NB-IOT</th>
<th>EC-GSM-IoT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
<td>In-band LTE</td>
<td>In-band &amp; Guard-band LTE, standalone</td>
<td>In-band GSM</td>
</tr>
<tr>
<td>Coverage*</td>
<td>155.7 dB</td>
<td>164 dB for standalone, FFS others</td>
<td>164 dB, with 33dBm power class</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>154 dB, with 23dBm power class</td>
</tr>
<tr>
<td>Downlink</td>
<td>OFDMA, 15 KHz tone spacing, Turbo code, 16 QAM, 1 Rx</td>
<td>OFDMA, 15 KHz tone spacing, 1 Rx</td>
<td>TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx</td>
</tr>
<tr>
<td>Uplink</td>
<td>SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM</td>
<td>Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code</td>
<td>TDMA/FDMA, GMSK and 8PSK (optional)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.08 MHz</td>
<td>180 KHz</td>
<td>200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]</td>
</tr>
<tr>
<td>Peak rate (DL/UL)</td>
<td>1 Mbps for DL and UL</td>
<td>DL: &quot;~50 kbps</td>
<td>For DL and UL (using 4 timeslots): &quot;~70 kbps (GMSK), &quot;~240kbps (8PSK)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UL: &quot;~50 for multi-tone, &quot;~20 kbps for single tone</td>
<td></td>
</tr>
<tr>
<td>Duplexing</td>
<td>FD &amp; HD (type B), FDD &amp; TDD</td>
<td>HD (type B), FDD</td>
<td>HD, FDD</td>
</tr>
<tr>
<td>Power saving</td>
<td>PSM, ext. I-DRX, C-DRX</td>
<td>PSM, ext. I-DRX, C-DRX</td>
<td>PSM, ext. I-DRX</td>
</tr>
<tr>
<td>Power class</td>
<td>23 dBm, 20 dBm</td>
<td>23 dBm, others TBD</td>
<td>33 dBm, 23 dBm</td>
</tr>
</tbody>
</table>

* In terms of MCL target. Targets for different technologies are based on somewhat different link budget assumptions (see TR 36.888/45.820 for more information).
Wide Diversity of Communication Requirements
One transport technology does not fit all use cases

- **LTE Cat-1**
  - ~ Few Mbps
  - ~ $8/module

- **LTE Cat-M1**
  - ~ 100s kbps
  - ~ $8/module

- **LTE Cat-NB1**
  - ~ 10s kbps
  - < $5/module

**Devices per Application**
- Cars
- Surveillance
- Telematics
- Fleet track
- Smart home
- Wearables
- Street lighting
- Industry Automation

**Industry**
- Automation
- Telematics
- ~ 10s kbps

**Technology**

**Requirements**
- Low power
- Low latency
- Mobility
- Data rate

**Coverage**
- Density

**Price Range**
- ~ ~ $8/module
- ~ < $5/module
- ~ ~ $15/module
Marketing Status
Marketing Status

- We have counted 4 commercial NB-IoT networks, with several more very close to commercial launch; a further 40 networks in 29 countries trialling, demonstrating or planning to deploy NB-IoT (plus commitments to development by multi-country operator groups)
- 2 commercial LTE-M networks (Verizon USA and AT&T USA) and 12 other networks in 10 countries trialling, demonstrating or planning to deploy LTE-M.

Marketing Status

**CloT LPWA devices (LTE technologies)**

<table>
<thead>
<tr>
<th>LTE Cat-1</th>
<th>LTE-M (Cat-M1)</th>
<th>NB-IOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 10 Mbps</td>
<td>Up to 1 Mbps</td>
<td>10s of kbps to 100s of kbps</td>
</tr>
<tr>
<td>20 MHz</td>
<td>1.4 MHz narrowband</td>
<td>180 kHz narrowband</td>
</tr>
</tbody>
</table>

- 77 **Cat 1** devices are launched
- 19 **Cat M1** devices are launched
- 20 **Cat NB1** (NB-IoT) devices are launched
Low device cost
Low deployment cost

LTE Cat-NB1
- Low power
- Coverage
- Low latency
- Data rate
- Mobility

LTE Cat-M1
- Low power
- Coverage
- Low latency
- Data rate
- Mobility
## Low Device Cost – Reduce Complexity

<table>
<thead>
<tr>
<th>Modem/device chip category</th>
<th>Release 8</th>
<th>Release 8</th>
<th>Release 13</th>
<th>Release 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Category 4</td>
<td>Category 1</td>
<td>Category M1 (eMTC)</td>
<td>Category NB1 (NB-IoT)</td>
</tr>
<tr>
<td>Downlink peak rate</td>
<td>150Mbps</td>
<td>10Mbps</td>
<td>1Mbps</td>
<td>170kbps</td>
</tr>
<tr>
<td>Uplink peak rate</td>
<td>50Mbps</td>
<td>5Mbps</td>
<td>1Mbps</td>
<td>250kbps</td>
</tr>
<tr>
<td>Number of antennas</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Duplex mode</td>
<td>Full duplex</td>
<td>Full duplex</td>
<td>Full/Half duplex</td>
<td>Half duplex</td>
</tr>
<tr>
<td>UE receive bandwidth</td>
<td>1.08-18MHz</td>
<td>1.08-18MHz</td>
<td>1.08MHz</td>
<td>180kHz</td>
</tr>
<tr>
<td>UE transmit power</td>
<td>23dBm</td>
<td>23dBm</td>
<td>20/23dBm</td>
<td>20/23dBm</td>
</tr>
<tr>
<td>Multiplexed within LTE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes/No</td>
</tr>
<tr>
<td>Modem complexity</td>
<td>100%</td>
<td>80%</td>
<td>20%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Figure 7: Complexity/cost reductions for LTE-M and NB-IoT evolution

https://resources.ext.nokia.com/asset/200178
Cat M and NB-IoT
Deployment options

Typical 5MHz LTE
5MHz with 25 x 180kHz

LTE 180kHz PRB
(Physical Resource Block)

NB-IoT
200kHz from 1 x 180kHz

TBC NB-IoT excluded from central 6 PRB
NB-IoT LTE guard band

NB-IoT in 200kHz GSM spectrum no guard
NB-IoT in 200kHz GSM spectrum with guard

25x180kHz = 4.5MHz

180kHz from 12x15kHz subcarriers (OFDMA downlink)

Cat M and NB-IoT
Deployment options

NB-IoT in-band with LTE

NB-IoT LTE guard band

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NB-IoT in 200kHz GSM spectrum no guard
NB-IoT in 200kHz GSM spectrum with guard

25x180kHz = 4.5MHz

180kHz from 12x15kHz subcarriers (OFDMA downlink)
Cat M and NB-IoT

Deployment options

Typical 5MHz LTE
5MHz with 25 x 180kHz

Cat M
1.4MHz with 6 x 180kHz

NB-IoT
200kHz from 1 x 180kHz

LTE 180kHz PRB
(Physical Resource Block)

180kHz from 12x15kHz subcarriers (OFDMA downlink)

25x180kHz = 4.5MHz

6x180kHz = 1.08MHz

NB-IoT in-band with LTE

TBC NB-IoT excluded from central 6 PRB

NB-IoT LTE guard band

NB-IoT in 200kHz GSM spectrum no guard

NB-IoT in 200kHz GSM spectrum with guard

NB-IoT excluded from central 6 PRB

Cat M in-band with LTE

6x 180kHz = 1.08MHz
PSM and eDRX

LTE Cat-NB1

- Low power
- Coverage
- Low latency
- Mobility
- Density
- Data rate

LTE Cat-M1

- Low power
- Coverage
- Low latency
- Mobility
- Density
- Data rate
### PSM Flow

<table>
<thead>
<tr>
<th>UE NAS State</th>
<th>Registered (normal)</th>
<th>Registered (normal)</th>
<th>Registered (no cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRC State</td>
<td>Connected</td>
<td>Idle</td>
<td>Null</td>
</tr>
</tbody>
</table>

- **Power on / Attach**
- **T3324**
- **T3412**
- **Tracking Area update**
- **paging**
- **PSM mode**
Power Saving Mode

- It is a specially kind of UE status that can minimize the energy consumption that is supposed to be even lower than normal idle mode energy consumption.
- This is newly added feature in Release 12 and is specified in 3GPP 24.301-5.3.11 Power saving mode and 23.682-4.5.4 UE Power Saving Mode.
- Similar to power-off, but the UE remains registered with the network.
- No need to re-attach or re-establish PDN connections.
- A UE in PSM is not immediately reachable for mobile terminating services.
- 8.2.1.12 T3412 extended value

The network may include this IE to provide the UE with longer periodic tracking area update timer.

- 8.2.1.13 T3324 value

The network shall include the T3324 value IE if:
- the UE included the T3324 value IE in the ATTACH REQUEST message, and
- the network supports PSM and accepts the use of PSM.
PSM Power Consumption

- The maximum duration of PSM (T3412) is 12.1 days.
- PSM mode can be cancelled anytime by the device by sending a TAU to the network that does not include the PSM timers.
eDRX - Extended/Enhanced DRX – idle mode

S1 mode
The field contains the eDRX value for S1 mode. The E-UTRAN eDRX cycle length duration value and the eDRX cycle parameter ‘T_{eDRX}’ as defined in 3GPP TS 36.304 [121] are derived from the eDRX value as follows:

<table>
<thead>
<tr>
<th>bit</th>
<th>4 3 2 1</th>
<th>E-UTRAN eDRX cycle length duration</th>
<th>eDRX cycle parameter ‘T_{eDRX}’</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0 0</td>
<td>5.12 seconds (NOTE 4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 0 0 1</td>
<td>10.24 seconds (NOTE 4)</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>0 0 1 0</td>
<td>20.48 seconds</td>
<td>2^1</td>
<td></td>
</tr>
<tr>
<td>0 0 1 1</td>
<td>40.96 seconds</td>
<td>2^2</td>
<td></td>
</tr>
<tr>
<td>0 1 0 0</td>
<td>61.44 seconds (NOTE 5)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>0 1 0 1</td>
<td>81.92 seconds</td>
<td>2^3</td>
<td></td>
</tr>
<tr>
<td>0 1 1 0</td>
<td>102.4 seconds (NOTE 5)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>0 1 1 1</td>
<td>122.88 seconds (NOTE 5)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>1 0 0 0</td>
<td>143.36 seconds (NOTE 5)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>1 0 0 1</td>
<td>163.84 seconds</td>
<td>2^4</td>
<td></td>
</tr>
<tr>
<td>1 0 1 0</td>
<td>327.68 seconds</td>
<td>2^5</td>
<td></td>
</tr>
<tr>
<td>1 0 1 1</td>
<td>409.60 seconds</td>
<td>2^6</td>
<td></td>
</tr>
<tr>
<td>1 1 0 0</td>
<td>1310.72 seconds</td>
<td>2^7</td>
<td></td>
</tr>
<tr>
<td>1 1 0 1</td>
<td>2621.44 seconds</td>
<td>2^8</td>
<td></td>
</tr>
<tr>
<td>1 1 1 0</td>
<td>5242.88 seconds (NOTE 6)</td>
<td>2^9</td>
<td></td>
</tr>
<tr>
<td>1 1 1 1</td>
<td>10485.76 seconds (NOTE 6)</td>
<td>2^10</td>
<td></td>
</tr>
</tbody>
</table>

All other values shall be interpreted as 0000 by this version of the protocol.

Rel-12 Power Saving Mode (PSM)

Nokia_LTE_Evolution_for_IoT_Connectivity_White_Paper_EN.pdf

3gpp 24.008, section 10.5.5.32
eDRX - Extended/Enhanced DRX – connected mode

3gpp 36.213
Power Saving Mode and eDRX

Rel-12 Power Saving Mode (PSM)

- T3324 determines for how long the UE will monitor paging before entering in PSM
- While in PSM, UE is not reachable by the Network and all circuitry is turned off
- UE exits PSM when T3412 expires (TAU) or with a Mobile Originated transfer

Rel-13 Enhanced DRX (eDRX)

CONNECTED eDRX

- DRX cycles extended from 2.56 seconds:
  - To 9.22 seconds in NB-IoT
  - To 10.24 seconds in Cat-M

IDLE eDRX

- New Paging Time Window which allows longer paging cycles:
  - 3 hours in NB-IoT
  - 44mis in Cat M
Coverage Enhancement

LTE Cat-NB1

- Coverage
- Low power
- Density
- Low latency
- Data rate
- Mobility

LTE Cat-M1

- Coverage
- Low power
- Density
- Low latency
- Data rate
- Mobility
# NB-IoT: Key parameters

<table>
<thead>
<tr>
<th>Frequency range</th>
<th><strong>NB-IoT (LTE) FDD Bands:</strong> 1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 25, 26, 28, 66, 70</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplex Mode</td>
<td>FDD Half Duplex type B</td>
</tr>
<tr>
<td>MIMO</td>
<td>No MIMO support</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>180 kHz (1PRB)</td>
</tr>
</tbody>
</table>
| Multiple Access | **Downlink:** OFDMA  
|                 | **Uplink:** SC-FDMA                                             |
| Modulation Schemes | **Downlink:** QPSK  
|                 | **Uplink:** Single Tone: $\pi/4$-QPSK, $\pi/2$-BPSK  
|                 | Multi Tone: QPSK                                                |
| Coverage        | 164 dB (+20dB GPRS)                                             |
| Data Rate       | ~25 kbps in DL and ~64 kbps in UL (multi-tone UE)               |
| Latency         | < 10 seconds                                                    |
| Low Power       | eDRX, Power Saving Mode                                         |

**Support for other features:**

- HARQ (1 process only)
- UL Power Control (Open Loop only)
- RSRP, RSRQ Reporting
- CSI Reporting
- Handovers in CONNECTED
- Carrier Aggregation
- IMS
- eMBMS
NB-IoT: Coverage Levels

- Up to 3 different Coverage Levels signaled via SIB2-NB
  - (Normal, Robust, Extreme)
  - (CE Level: 0, 1, 2)
  - (MCL: 144 dB, 154 dB, 164 dB)

- The coverage level selected determines the NPRACH resources to use:
  - Subset of subcarriers, PRACH Repetitions, Max number of attempts, etc…

- UE derives the Coverage Level based on NRSRP measured
  - NPRACH resources to be used are determined by the Coverage Level
NB-IoT: Random Access Procedure

Preamble repetition: 1, 2, 4, 8, 16, 32, 64, or 128 times

Preambles can be repeated up to 128 times

1st Higher Layer Protocol Interaction

Random Access Preamble
Random Access Response
Scheduled Transmission (msg3)
Contention Resolution
NB-IoT Device
NB-IoT eNodeB

CP
T<sub>cp</sub>
T<sub>SEQ</sub>
Pseudo Random Hopping
1st Repetition
2nd Repetition
3rd Repetition
NB-IoT: Repetitions

- Technique consisting on repeating the same transmission several times:
  - Achieve extra coverage (up to 20 dB compared to GPRS)
  - Each Repetition is self-decodable
  - Scrambling code is changed for each transmission to help combination
  - Repetitions are ACK-ed just once
- For NB-IoT all channels can use Repetitions to extend coverage

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

Uplink Frame Structure

- **Single-Tone (MANDATORY):**
  - To provide capacity in signal-strength-limited scenarios and more dense capacity
  - Number of subcarriers: 1
  - Subcarrier spacing: 15 kHz or 3.75 kHz (via Random Access)
  - Slot duration: 0.5 ms (15 kHz) or 2 ms (3.75 kHz)

- **Multi-Tone (OPTIONAL capability):**
  - To provide higher data rates for devices in normal coverage
  - Number of subcarriers: 3, 6 or 12 signalled via DCI
  - Subcarrier spacing: 15 kHz
  - Slot duration = 0.5 ms

**Subcarrier Spacing**

- $\Delta f = 15$ kHz
  - Total available 12 subcarriers
  - 7 OFDM symbols
  - 1 slot = 0.5 ms

- $\Delta f = 3.75$ kHz
  - Total available 48 subcarriers
  - 7 OFDM symbols
  - 1 slot = 2 ms

**Guard Period**

- 2304 Ts (75us)

**OFDM Symbol Duration**

- 1 OFDM Symb = 2208 Ts for symb#0 (71.88us)
- 1 OFDM Symb = 2192 Ts for symb#1..6 (71.35us)
<table>
<thead>
<tr>
<th>Physical Channel</th>
<th>$\Delta f$</th>
<th>Resource Unit</th>
<th>Mod Scheme</th>
<th>$N_{\text{UL symb}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$N_{\text{RU}}$</td>
<td>$N_{\text{UL slots}}$</td>
<td>Slot length</td>
</tr>
<tr>
<td>NPUSCH format 1</td>
<td>3.75kHz</td>
<td>1</td>
<td>16</td>
<td>2ms</td>
</tr>
<tr>
<td>(UL-SCH)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15kHz</td>
<td>1</td>
<td>16</td>
<td>8ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>8</td>
<td>0.5ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>4</td>
<td>2ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>2</td>
<td>1ms</td>
</tr>
<tr>
<td>NPUSCH format 2</td>
<td>3.75kHz</td>
<td>1</td>
<td>4</td>
<td>2ms</td>
</tr>
<tr>
<td>(UCI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15kHz</td>
<td>1</td>
<td>4</td>
<td>0.5ms</td>
</tr>
</tbody>
</table>
NB-IoT Uplink Resource Unit (RU)

- **Δf = 3.75 kHz**
  - Single-tone
    - $N_{sc}^{RU} = 1$ SC
    - RU length = 16 slots = 32 ms

- **Δf = 15 kHz**
  - Single-tone
    - $N_{sc}^{RU} = 1$ SC
    - RU length = 8 slots = 4 ms
  - Multi-tone
    - $N_{sc}^{RU} = 3$ SCs
    - RU length = 4 slots = 2 ms
  - Multi-tone
    - $N_{sc}^{RU} = 6$ SCs
    - RU length = 2 slots = 1 ms

- RU length = 16 slots = 8 ms
NB-IoT: Downlink Frame Structure

Downlink Frame Structure
- Same numerology as LTE (co-existence with LTE)
- Bandwidth: 180 kHz = 12 subcarriers separated 15 kHz
  - Equivalent to 1 LTE PRB
- Durations:
  - 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 (~3 hours)

New Downlink signals
- **NPSS/NSSS** (primary and secondary synchronization channels)
- **NRS** (cell reference signals)

New Downlink channels
- **NPBCH** (physical broadcast channel)
- **NPDSCH** (physical downlink shared channel)
- **NPDCCH** (physical downlink control channel)
Each physical channel occupies the whole PRB; Only one channel per subframe

**LTE**

Channels are time and frequency multiplexed; Multiple channels per subframe

**NB-IoT**

Each physical channel occupies the whole PRB; Only one channel per subframe
NB-IoT: NPDCCH

**NPDCCH** (Narrowband physical downlink control channel)

- It carries Downlink Control Information (DCI). Three DCI types defined:
  - **N0**: Used to schedule **Uplink** transmissions
  - **N1**: Used to schedule **Downlink** transmissions
  - **N2**: Used to schedule **Paging** or **Direct Indication**
- It fully occupies one downlink subframe (Repetitions may be used to improve coverage)
- Resource elements are mapped around NRS
  - In the case of in-band also around LTE CRS and starting at l symbol to skip LTE PDCCH (as signaled by higher layers)
- Two Control Channel Elements (NCCE) in every NPDCCH
  - Aggregation Level 1 uses only one NCCE
  - Aggregation Level 2 uses both NCCE for more robust transmissions
NB-IoT: NPDSCH

NPDSCH (Narrowband physical downlink shared channel)

• It carries user data and broadcast information not transmitted on NPBCH (i.e. SIBs-NB, paging or dedicated RRC).

• For the case of user data:
  o QPSK only
  o Single HARQ process
  o TBS ≤ 680 bits
  o A single TBS can be mapped to multiple consecutive downlink subframes ($N_{SF}$) signaled in DCI N1:
    ➢ For example, TBS = 680 requires at least 3 subframes
  o Up to 2048 Repetitions used to reach larger coverage
  o Downlink scheduling signalled via DCI Format N1:
    ➢ Modulation and coding scheme
    ➢ Scheduling delay
    ➢ DCI Repetition number
    ➢ NPDSCH Repetition
    ➢ Resource Assignment
    ➢ HARQ-ACK Resource Index
### Summary for eMTC, NB-IOT and EC-GSM-IoT

<table>
<thead>
<tr>
<th></th>
<th>eMTC (LTE Cat M1)</th>
<th>NB-IOT</th>
<th>EC-GSM-IoT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
<td>In-band LTE</td>
<td>In-band &amp; Guard-band LTE, standalone</td>
<td>In-band GSM</td>
</tr>
<tr>
<td>Coverage*</td>
<td>155.7 dB</td>
<td>164 dB for standalone, FFS others</td>
<td>164 dB, with 33dBm power class</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>154 dB, with 23dBm power class</td>
</tr>
<tr>
<td>Downlink</td>
<td>OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx</td>
<td>OFDMA, 15 KHz tone spacing, 1 Rx</td>
<td>TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx</td>
</tr>
<tr>
<td>Uplink</td>
<td>SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM</td>
<td>Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code</td>
<td>TDMA/FDMA, GMSK and 8PSK (optional)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.08 MHz</td>
<td>180 KHz</td>
<td>200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]</td>
</tr>
<tr>
<td>Peak rate (DL/UL)</td>
<td>1 Mbps for DL and UL</td>
<td>DL: ~50 kbps</td>
<td>For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UL: ~50 for multi-tone, ~20 kbps for single tone</td>
<td></td>
</tr>
<tr>
<td>Duplexing</td>
<td>FD &amp; HD (type B), FDD &amp; TDD</td>
<td>HD (type B), FDD</td>
<td>HD, FDD</td>
</tr>
<tr>
<td>Power saving</td>
<td>PSM, ext. I-DRX, C-DRX</td>
<td>PSM, ext. I-DRX, C-DRX</td>
<td>PSM, ext. I-DRX</td>
</tr>
<tr>
<td>Power class</td>
<td>23 dBm, 20 dBm</td>
<td>23 dBm, others TBD</td>
<td>33 dBm, 23 dBm</td>
</tr>
</tbody>
</table>

* In terms of MCL target. Targets for different technologies are based on somewhat different link budget assumptions (see TR 36.888/45.820 for more information).
Names

- eMTC
- Cat M
- Cat M1
- LTE-BL/CE (Bandwidth reduced Low complexity / Coverage Enhancement) (36.300)
– LTE-M1 operate only in **1.4 Mhz (6 RB) bandwidth**.
– LTE-M1 operate in **Half Duplex mode**.
– LTE-M1 use the limited (**reduced**) max transmission power.
– LTE-M1 would mainly **operate with legacy LTE using wider system bandwidth** (e.g., 10 Mhz, 20Mhz system bandwidth).
– LTE-M1 **divide the legacy LTE system bandwidth into multiple sections of 1.4 Mhz and use any one of those sections** (theoretically, LTE-M1 can use different 1.4Mhz section within the system bandwidth at every subframe).
– LTE-M1 does **not use PCFICH, PHICH, PDCCH** which is required to be spreaded across the whole system bandwidth of legacy LTE.
- LTE-M1 use specially designed control channel called **MPDCCH**.
- In LTE-M1, MPDCCH and the corresponding PDSCH (i.e., the PDSCH scheduled by the MPDCCH) is **not in the same subframe**. This is called **'Cross-subframe scheduling'**.
- LTE-M1 use specially designed **DCI formats (6-0A, 6-0B, 6-1A, 6-1B, 6-2)**
- LTE-M1 can transmit PBCH, PRACH, M-PDCCH, PDSCH, PUCCH, PUSCH **in repeating fashion**. (This is to make these channels decodable even when the signal quality/power is very poor as in the harsh condition like basement. As a result, this kind of repeating transmission would make the effect of increasing cell radius and signal penetration)
· LTE-M1 support only the limited number of transmission mode: TM 1,2,6,9 which can operate in single layer.
· LTE-M1 utilize a new physical channel format that transmit SIB/RAR/Paging in repetitive mode without using control channel
· All the resource allocation information (subframe, TBS, Subband Index) for SIB1 decoding is determined by a MIB parameter (No Control Channel is used for this)
· All the resource allocation information (subframe, TBS, Subband Index) for SIB2 decoding is determined by several SIB1 parameters (No Control Channel is used for this)
· LTE-M1 support the **extended Paging (DRX) Cycle**
What’s common between LTE and LTE-M

- PSS (Primary Synchronization Signal) is common to both legacy LTE and LTE M1
- SSS (Secondary Synchronization Signal) is common to both legacy LTE and LTE M1
- CRS (Cell Specific Reference Signal) is common to both legacy LTE and LTE M1
CAT M: CE mode and CE level

<table>
<thead>
<tr>
<th>Mode</th>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode A</td>
<td>Level 1</td>
<td>No Repetition for PRACH</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>Small Number of Repetition for PRACH</td>
</tr>
<tr>
<td>Mode B</td>
<td>Level 3</td>
<td>Medium Number of Repetition for PRACH</td>
</tr>
<tr>
<td></td>
<td>Level 4</td>
<td>Large Number of Repetition for PRACH</td>
</tr>
</tbody>
</table>

- Who decide the mode? Who decide the level?
  - Operation mode is determined by eNB (informed to UE via RRC message).
  - The Level within each Mode is determined by UE (based on the RSRP it measures and informs to eNB via PRACH resource it uses).

```
RRC Connection Setup

ce-Mode-r13 CHOICE {
  release       NULL,
  setup         ENUMERATED {ce-ModeA, ce-ModeB}
}
```
As per the agreement, the connected LC-MTC UE can operate in either CE Mode A or CE Mode B. Since these two modes are specified for RRC Connected state, they are configured by the eNB. It is generally understood that which CE mode to use is dependent upon the LC-MTC UE CE level, i.e.:

- **CE Mode A** (no repetition and small number of repetition): Operation in CE Mode A would have an equivalent coverage as that of UE Category 1. The difference in coverage between LC-MTC and UE Category 1 due to 1 Rx, 6 PRB narrowband and reduced uplink transmit power in LC-MTC is compensated by utilising a small number of repetitions.

- **CE Mode B** (large number of repetitions): LC-MTC UE operating in CE Mode B has coverage up to 15 dB coverage enhancement with reference to that of UE Category 1.

CE Mode B is targeted at devices that are stationary (or with limited mobility) and inside buildings where the assumed use case is for smart meters operating in basements. It should be appreciated that the range of Rel-13 LC-MTC applications is not just for stationary smart meters in basements but rather for a large range of other applications such as smart watches, wearable devices, smart sensors, etc. For applications other than unfortunate smart meters in basements, deep coverage is unlikely to be used and moderate mobility is expected.
Table 7.1.6-1: Number of repetitions for PDSCH carrying SystemInformationBlockType1-BR for BL/CE UE.

<table>
<thead>
<tr>
<th>Value of schedulingInfoSIB1-BR-r13</th>
<th>Number of PDSCH repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>19-31</td>
<td>Reserved</td>
</tr>
</tbody>
</table>
• When PDSCH is scheduled by DCI format 6-1A
  • the number of MCS field is 4, it means the maximum MCS is 15
• When PDSCH is scheduled by DCI format 6-2
  • the number of MCS field is 3, it means the maximum MCS is 7
• When PDSCH is scheduled by DCI format 6-1B
  • the number of MCS field is 4 and $I_{MCS} = I_{TBS}$
Uplink TBS Determination

CEModeB UE is not expected to receive a DCI format 6-0B indicating $I_{MCS} \geq 10$.

CEModeA

< 36.213-Table 8.6.1-2: Modulation and TBS index table for PUSCH >
Which application need NB-IOT / CAT M?

LTE Cat-NB1

LTE Cat-M1
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<tr>
<td>Power class</td>
<td>23 dBm, 20 dBm</td>
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</tr>
<tr>
<td>Mobility</td>
<td>Support in CE mode A</td>
<td>Not support</td>
</tr>
<tr>
<td>Latency</td>
<td>Better</td>
<td>Worse</td>
</tr>
<tr>
<td>VoLTE</td>
<td>Support</td>
<td>No support</td>
</tr>
</tbody>
</table>

![Image of a smart meter](image1.png)

![Image of a mobile phone](image2.png)

![Image of a wristwatch](image3.png)
Keysight NBIOT/CAT M solution
NB-IoT Product Development workflow

R&D
- Design
- Simulate
- Protocol L2/L3 Develop
- L1/PHY Develop
- RF Develop

Verification
- Integrate
- System & performance verify
- RF Design Verify
- Protocol Verify

Acceptance
- Pre-cert
  - OTA test
- Certification
  - Operator acceptance
  - Lab IOT
  - Field trials
  - GCF/PTCRB
  - CTIA/CE/FCC regs

Anite A9000 protocol development, conformance and operator acceptance
Anite Propsim channel emulator
T4000S RF & RRM Conformance and Regulatory System

System Vue
VSA/VSG
UXM integrated test set
Battery drain analyser

Keysight covering the whole RF NB-IoT development cycle

- Leading in GCF RF-NB-IoT validations
- First to validate RF NB-IoT and CAT-M test cases together
Thank you