CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF ELECTRICAL ENGINEERING

DEPARTMENT OF TELECOMMUNICATION ENGINEERING

B(E)2M32BTS - Wireless Technologies

IoT in Mobile Networks

Cellular IoT

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Outline

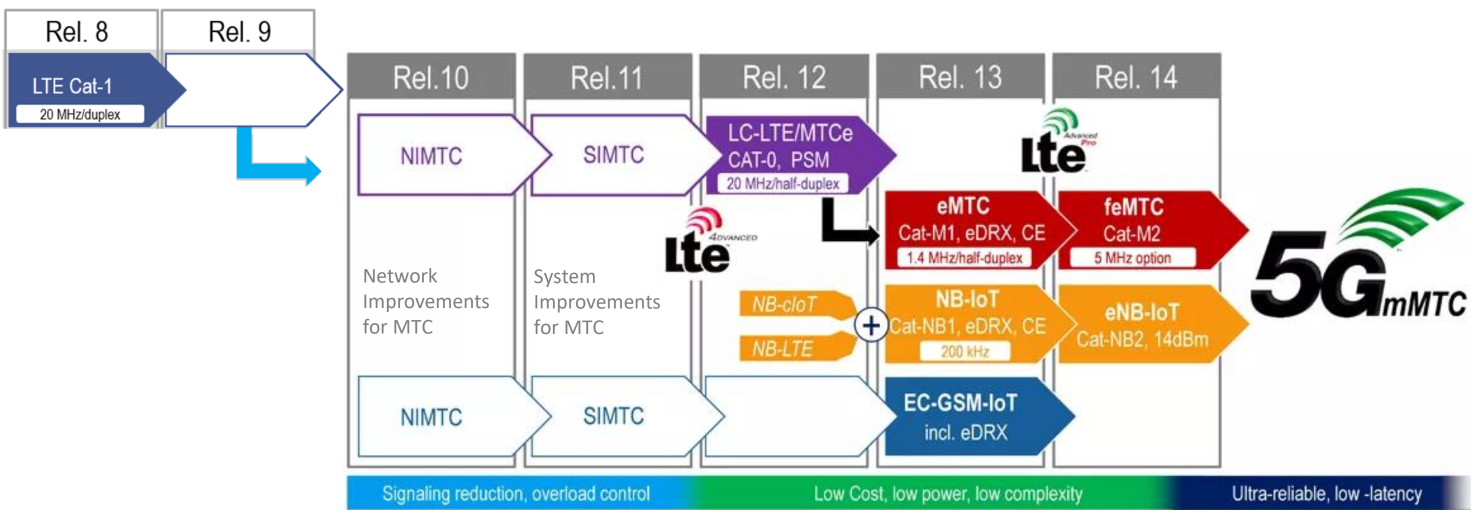
Internet of Things (IoT) in mobile networks

- Overview
- Basic features of individual solutions
  - Long-Term Evolution for Machine-Type Communications
  - Extended Coverage Global System for Mobile Communications Internet of Things
  - Narrowband Internet of Things
- Services and applications
- Architecture
- Communication
- Energy and coverage

Cellular Internet of Things

Technologies for Cellular IoT (C-IoT)

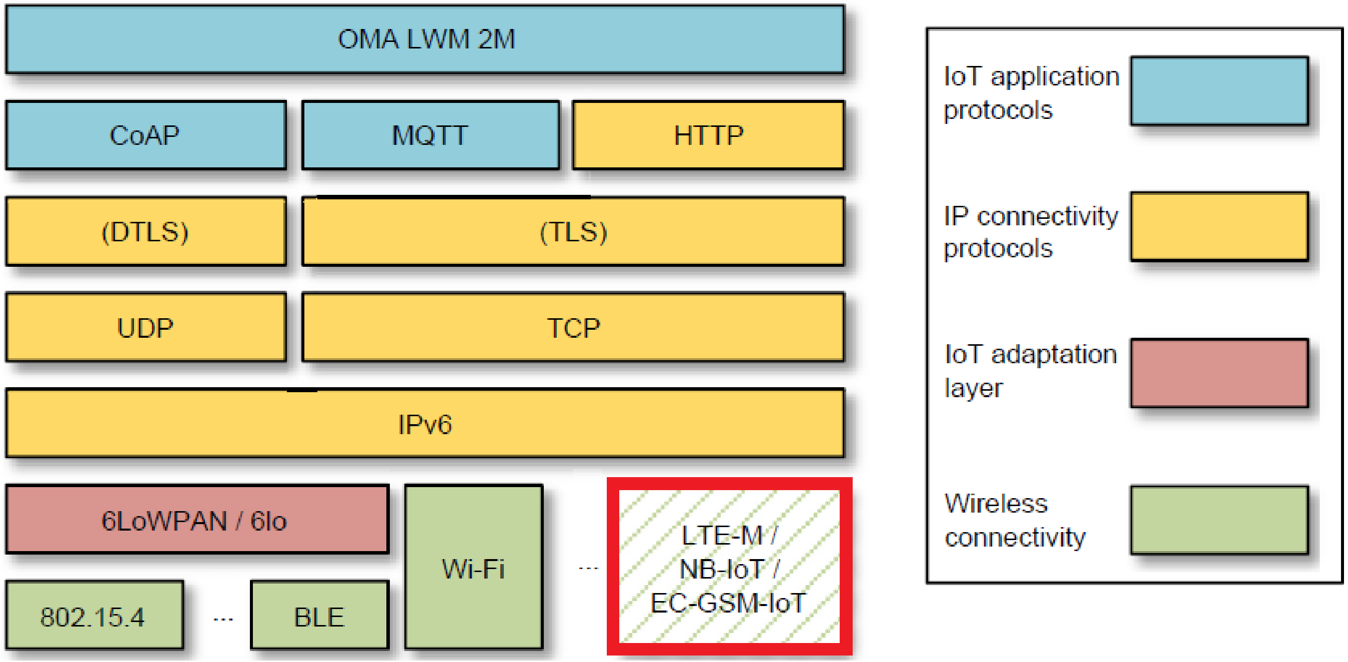
- Long-Term Evolution for Machine-Type Communications (**LTE-M(TC)** or (f)**eMTC**)
  - Enhancement of LTE for support of machine type communication and IoT
- Narrowband Internet of Things (**NB-IoT**)
  - New radio interface for IoT
- Extended Coverage Global System for Mobile Communications Internet of Things (**EC-GSM-IoT**)
  - Enhancements and optimizations of GSM for IoT



NB-IoT extension to **satellite access** Release 17 (~March 2022)

https://blog.mobile-network-testing.com/market-technology-trends/evolving-technologies/overview-internet-of-things-technologies/

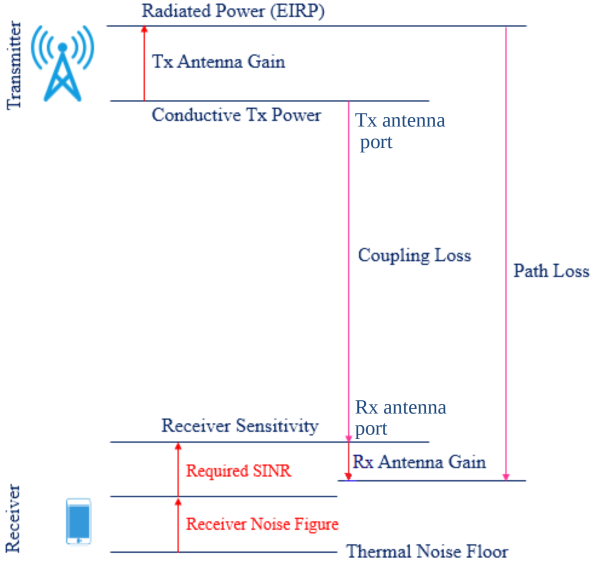
Protocol architecture



EC-GSM-IoT

Objectives

- **~10 years of operation** (5 Wh battery, depends on traffic pattern and coverage)
- **Low device cost** compared to GPRS/GSM devices
- **Extended coverage** (154 dB max coupling loss, 23 dBm UE)
- **Variable rates**
  - GMSK: 350 bps to 70 kbps (depends on coverage level)
  - 8PSK: up to 240 kbps
- **~50.000 devices per cell**



Main features

- **Narrowband channels** (200 kHz)
- **New control channels**
  - Extended coverage and low energy consumption
- **Repetitions** to increase coverage
- TDMA/FDMA
- Extended discontinuous reception to save energy (up to ~52 min)
- Optimized system information (i.e. no inter-RAT support)
- Relaxed idle mode behavior (e.g. reduced monitoring of neighbor cells)

LTE-M / eMTC

Objectives

- **~10 years of operation, but rather much less** (5 Wh battery, traffic pattern and coverage)
- **Low device cost** (similar to GPRS/GSM devices)
- **Extended coverage** (155.7 dB maximum coupling loss)
- **Variable rates:** ~10 kbps to 1 Mbps

Main features

- **Narrowband** channels (1.08/1.4 MHz channel bandwidth)
- **Repetition** to extend coverage
- Reuse existing LTE base stations with software update
- Can be deployed in any LTE spectrum
- UE power class of 20 dBm
- **Simplified control and management**
  - No wideband control channel, reduced support of transmission modes, limited number of antennas, reduced support of hybrid automatic repeat request (HARQ)...
- OFDMA/SC-FDMA
- FDD/TDD
- QPSK, 16QAM modulations

Devices **Cat-M1**

Release 13 (March 2016)

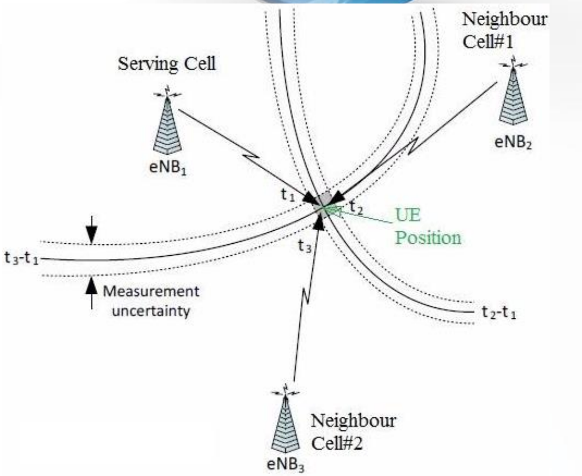
further enhanced MTC (feMTC)

Devices **Cat-M2**

- Release 14 by 3GPP (June 2017)

New features

- Support for **positioning**
  - Observed Time Difference of Arrival (OTDoA)
    - Special reference signal (Positioning reference signal, QPSK)
  - Enhanced Cell ID
    - Reporting time Rx and Tx difference (timing advance) of reference signals together with cell ID
  - UL: Base stations (eNBs) measure signal level from UE (Rel. 9)
  - DL: Device (User Equipment - UE) measures signal level from eNBs (Rel. 11)
- **Voice over LTE (VoLTE)**
- **Multicast** transmission
- **Higher bit rates**
  - Larger transport block size and 5 MHz bandwidth → ~**4 Mbps** (in UL and DL)
- Increased number of HARQ processes
  - Up to ten for lower coverage (Cell enhancement mode A)
- Enhanced mobility support (seamless mobility)



NB-IoT

Objectives

- **~10 years of operation** (5 Wh battery, depends on traffic pattern and coverage)
- **Lower cost than eMTC** (<5 USD)
- **Extended coverage** (164 dB maximum coupling loss)
- **~50.000 devices per cell**

Main features

- **Narrowband** (180 kHz) → low data rates
- Two modes for uplink
  - **Single tone** with 15 kHz and/or 3.75 kHz tone spacing
  - **Multiple tone** transmissions with 15 kHz tone spacing
- **Simplifications** of control and management
  - Single HARQ process, RLC Acknowledged mode with simplified status reporting,...
  - Significantly reduced broadcast system information
- OFDMA/SC-FDMA
- FDD
- $\pi/2$ BPSK, ($\pi/4$) QPSK modulations

Devices **Cat-NB1**

Release 13 (March 2016)

NB-IoT enhancement

Devices **Cat-NB2**

- Release 14 by 3GPP (June 2017)

New features

- **Positioning** of devices
  - OTDoA
  - Similar to LTE-M, Narrowband Positioning Reference Signal (NPRS)
- **Mobility enhancement** from seamless cell re-selection
- Push to talk voice messaging
- **New power class** – 14 dBm
  - Low power applications
  - Lower range
- **Multicast** transmission
- Larger **Transport Blocks**
  - 2536 bits instead of 680 bits in Cat-NB1
    - More efficient transmission of larger blocks

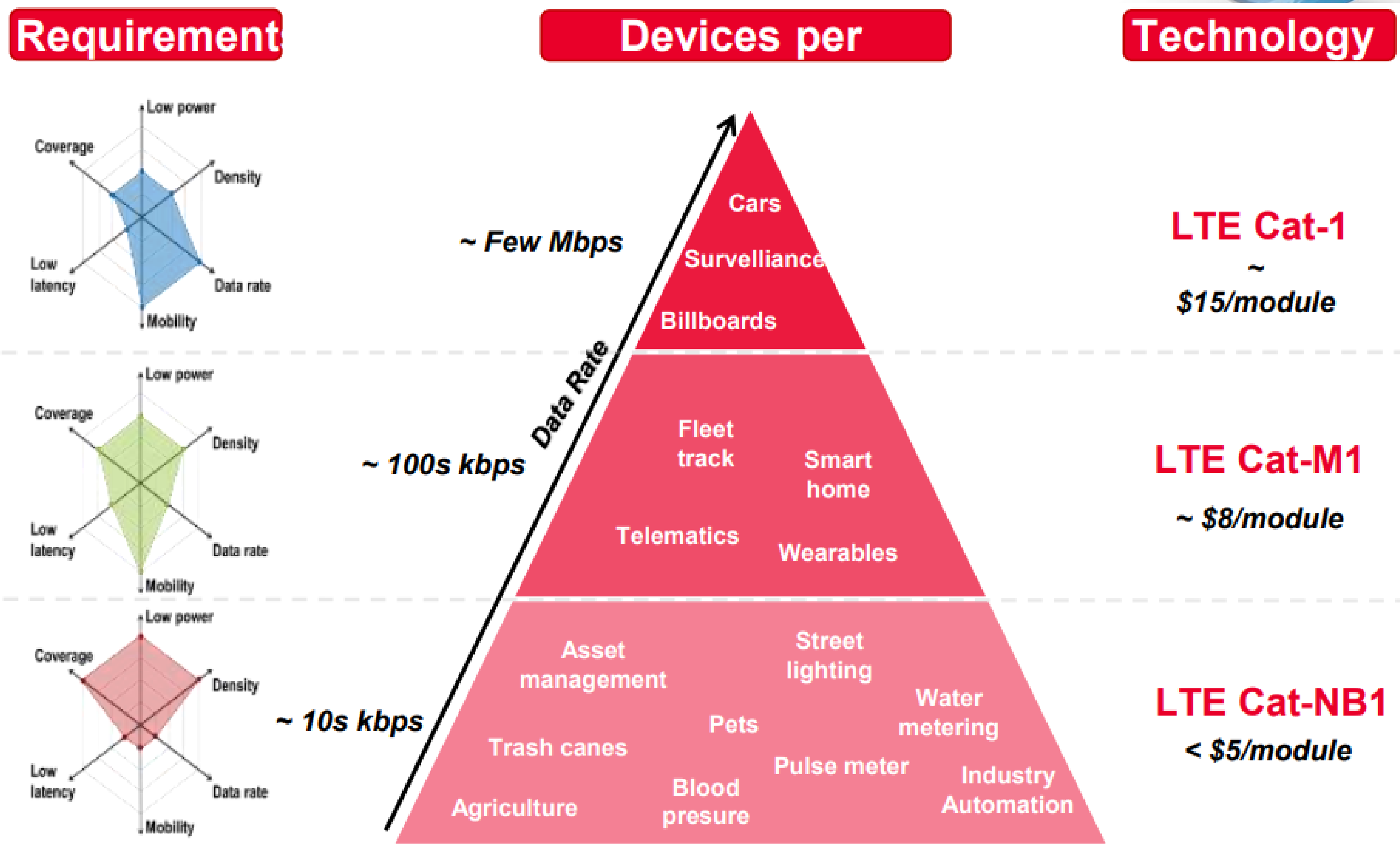
Summary of technologies

	eMTC (LTE Cat M1)	NB-IOT	EC-GSM-IoT
Deployment	In-band LTE	In-band & Guard-band LTE, standalone	In-band GSM
Coverage*	155.7 dB	164 dB for standalone, FFS others	164 dB, with 33dBm power class 154 dB, with 23dBm power class
Downlink	OFDMA, 15 KHz tone spacing, Turbo Code, 16 QAM, 1 Rx	OFDMA, 15 KHz tone spacing, TBCC, 1 Rx	TDMA/FDMA, GMSK and 8PSK (optional), 1 Rx
Uplink	SC-FDMA, 15 KHz tone spacing Turbo code, 16 QAM	Single tone, 15 KHz and 3.75 KHz spacing SC-FDMA, 15 KHz tone spacing, Turbo code	TDMA/FDMA, GMSK and 8PSK (optional)
Bandwidth	1.08 MHz	180 KHz	200kHz per channel. Typical system bandwidth of 2.4MHz [smaller bandwidth down to 600 kHz being studied within Rel-13]
Peak rate (DL/UL)	1 Mbps for DL and UL	DL: ~250 kbps UL: ~250 for multi-tone, ~20 kbps for single tone	For DL and UL (using 4 timeslots): ~70 kbps (GMSK), ~240kbps (8PSK)
Duplexing	FD & HD (type B), FDD & TDD	HD (type B), FDD	HD, FDD
Power saving	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX, C-DRX	PSM, ext. I-DRX
Power class	23 dBm, 20 dBm	23 dBm, 20 dBm, 14 dBm (Cat NB2, Rel 14)	33 dBm, 23 dBm

** 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).*

D. Fiore, 3GPP Standards for the Internet-of-Things, presentation GSMA MIoT, 2016.

Requirements and servivces

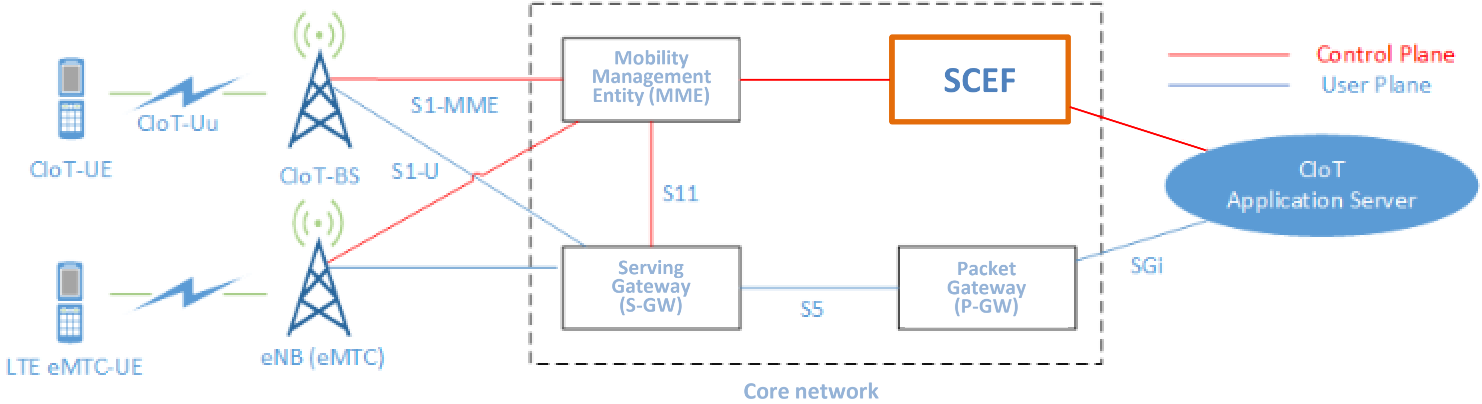


J.H. Wu, "CAT-M & NB-IoT Design and Conformance Test," Keysight Technologies presentation, 2017.

Architecture

Service Capability Exposure Function (SCEF)

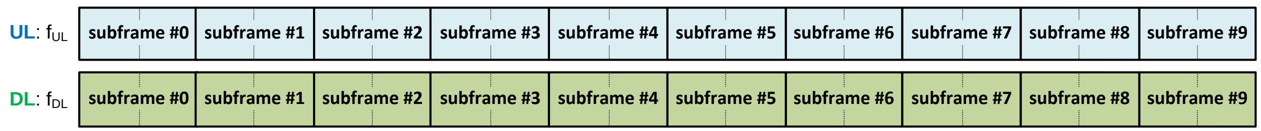
- Rel. 13 (2016)
- Securely **expose services and capabilities** of mobile network
  - Set QoS, group messaging, network parameters configuration (e.g., energy saving modes), device triggering, change billing party of a session
- Interface for **small data and control msgs** between third parties and core network
  - **Application programing interface** (API) for third parties (enterprises, service providers)
    - Obtain info about devices and send instructions (e.g., UE available?)
  - **External ID** <LocalID>@<DomainID>
    - No need to know ID of UE defined by mobile network
  - **Non-IP Data delivery**
    - IP protocol is complex and energy hungry → **small amounts of data over control plane**
    - Data **buffering** if device is in energy saving mode



Duplexing and bands for CIoT

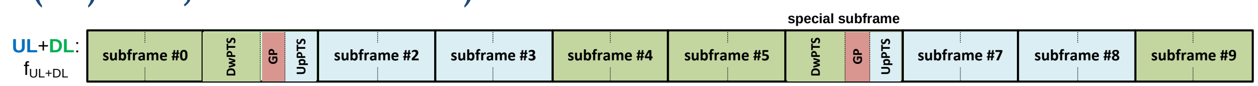
Frequency division duplex (FDD)

- Low complexity (NB-IoT & (fe)MTC)



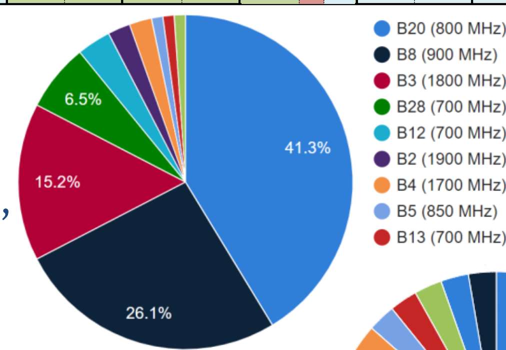
Time division duplex (TDD)

- More complex (in (fe)MTC, not in NB-IoT)



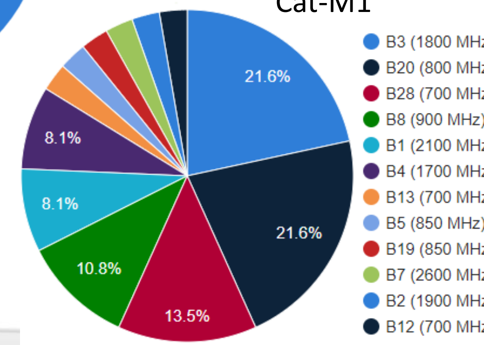
Bands between **450 MHz and 2100 MHz**

- **Europe:** **B3 (1800), B8 (900) and B20 (800)**
- **North America:** B4 (1700), B12 (700), B66 (1700), B71 (600), B26 (850)
- **Latin America:** B2(1900), B3(1800), B5(850), B28(700)
- **Asia Pacific:** B1(2100), B3(1800), B5(850), B8(900), B18(850), B20(800), B26(850), B28(700)
- Approx. 25+ bands defined by 3GPP
  - Rel.13, Rel. 14, Rel. 15



Cat-NB1

Cat-M1

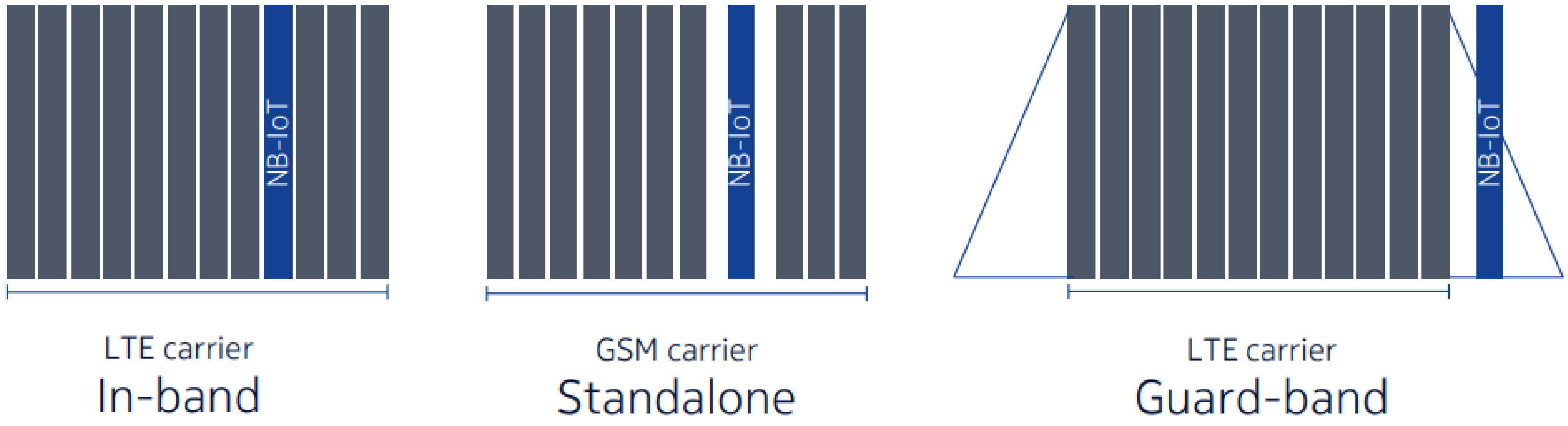


https://halberdbastion.com/technology/iot/iot-protocols/emtc-lte-cat-m1
https://halberdbastion.com/technology/iot/iot-protocols/nb-iot-lte-cat-nb1

Modes of operation

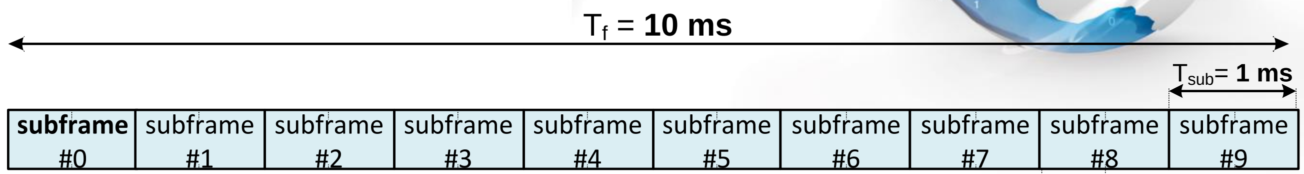
Modes of operation

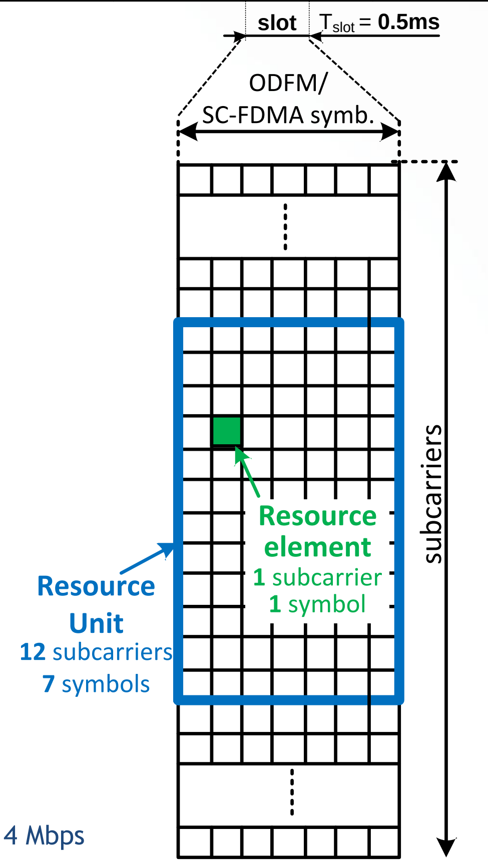
- **In-band:** utilizing resource blocks within normal LTE carrier
  - NB-IoT and (fe)MTC
- **Standalone:** utilizing standalone carrier, e.g. spectrum currently used in GSM and replace one or more GSM carriers
  - NB-IoT
- **Guard band:** utilizing unused resource blocks within LTE carrier's guard-band
  - NB-IoT



NOKIA, "LTE evolution for IoT connectivity", whitepaper, 2017.

Physical layer - Downlink





Similar as physical layer in LTE(-A-Pro,...)

OFDMA multiplex

Frame structure

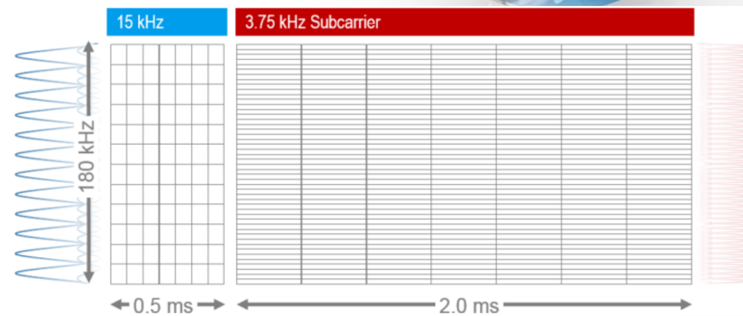
- **10 ms frame**
  - 10 subframes
  - 20 slots
- **Resource Unit** (RU)
  - 180 kHz
    - **12 subcarriers** with spacing of **15 kHz**
  - **7 symbols**
    - 500/7 µs per symbol
  - **eMTC**: up to **six RU** for communication → **1.08 MHz**
    - In theory: 14 000 (symbols/s) x 12 (subcarriers/RU) x 6 (RUs) x 4 (bits/symbols) = 4 Mbps
    - In practice: reference signals, signaling, not always 16 QAM, errors, …
  - **NB-IoT: single RU** for communication → **180 kHz**
    - In theory: 14 000 (symbols/s) x 12 (subcarriers/RU) x 1 (RUs) x 2 (bits/symbols) = 336 kbps
    - In practice: reference signals, signaling, not always QPSK, errors, …

Physical layer - Uplink

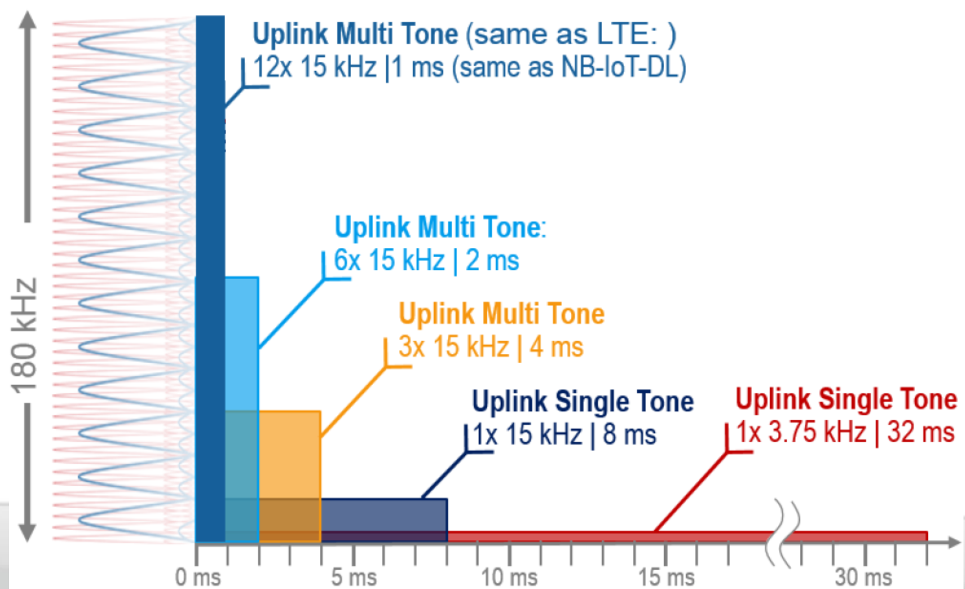
SC-FDMA to reduce energy consumption

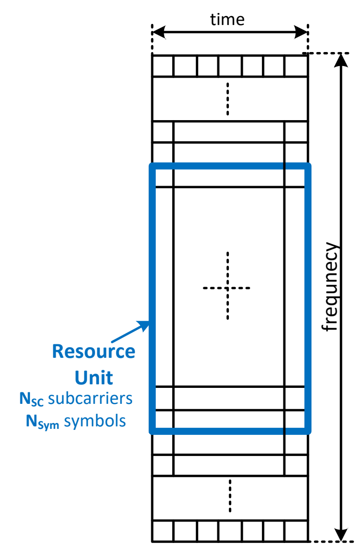
Frame of 10 ms as in LTE

- (fe)MTC – same format as in DL
- NB-IoT – different numerology of RU
  - **Single-tone** – higher power spectral density
    - **Subcarrier spacing:** 15 kHz and 3.75 kHz – **single subcarrier**
    - **Slot duration:** 0.5 ms and 2 ms – 8/32 ms per RU
  - **Multi-tone** – compatible with LTE
    - Subcarrier spacing: 15 kHz
    - 3, 6, 12 subcarriers over 4, 2, 1 ms, respectively, per RU



Subcarrier spacing	N_{SC} per RU	Duration
$\Delta f = 3.75\text{kHz}$	48	2 ms
$\Delta f = 15\,\text{kHz}$	12 4x	0.5 ms



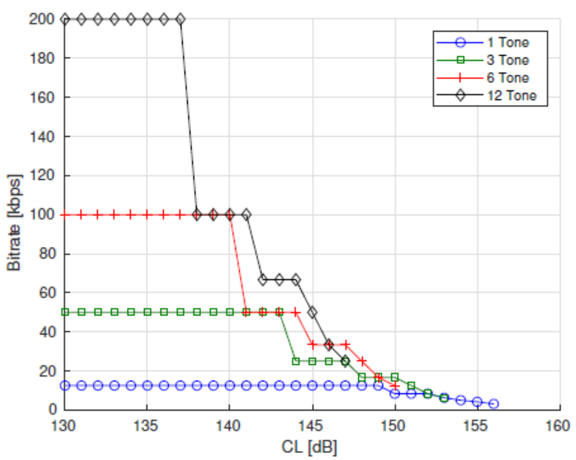


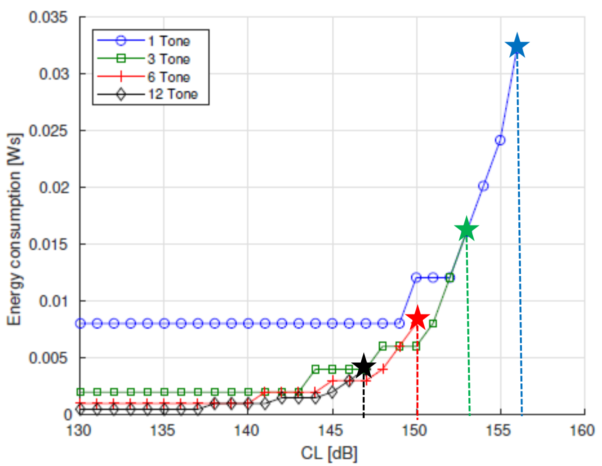
3GPP TS 36.211, "Physical channels and modulation", v15.5.0 March 2019.

Single-tone vs Multi-tone

Multi-tone (vs Single-tone)

- **Higher bitrates**
- **Lower energy consumption**
  - Shorter transmission time
- **Limited coverage**
  - Power spread over wider band





Suitable scenarios

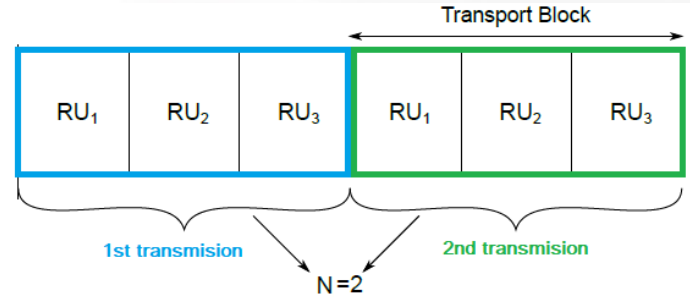
- **Single-tone** – scenarios with large coverage and low bitrates
- **Multi-tone** – higher capacity - many devices in good coverage, but shorter range

J. Rindt, “Analysis of Energy Consumption for IoT Devices Communicating in Mobile Network,“ Diploma Thesis, CTU in Prague, 2019.

Repetition of transmissions

Each **transmission** (transport block) **repeated 2^N times**

- Coherent transmissions
  - Same phase of Tx signal
- Each transmission self-decodable
  - Independent transmissions
- Higher probability of decoding
- One ACK for all repetitions

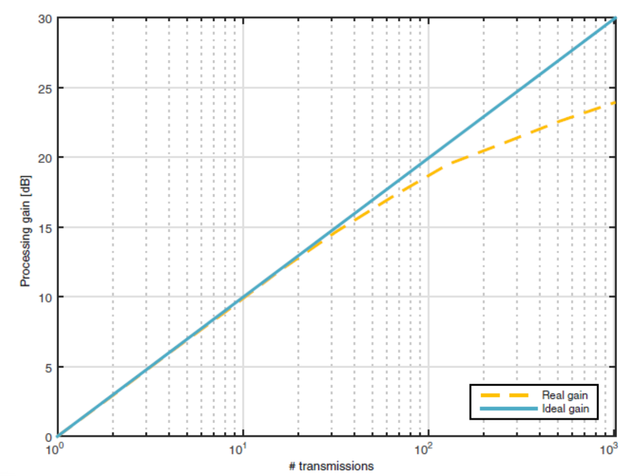


Uplink: up to 128 repetitions ($N = 7$)

Downlink: up to 2048 repetitions ($N = 11$)

Double number of TXs → approx. +3 dB gain

- Coverage extension

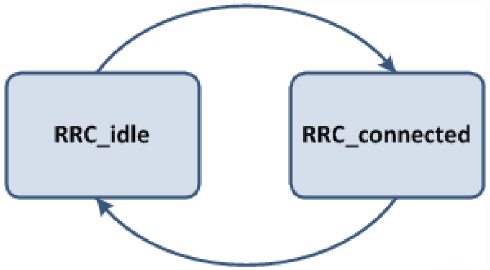


O. Liberg et al, "Cellular Internet of Things: Technologies, standards and performance," Academic Press/Elsevier, 2018.

Energy saving

Communication in **Connected state** (@ Radio Resource Control layer)

- Energy consumption depends on device type (~ tens/hundreds mW to W)
- Full activity incl. data transmission



Energy saving in **Idle state** (@ RRC layer)

- Energy consumption ~ **mW**
- Detect incoming connections and broadcasts/multicasts, update system information

Further possibilities to save energy:

- **Discontinuous reception** (DRX)
  - enhanced DRX (eDRX) for IoT
  - Allowed for Connected as well as Idle states
- **Power saving mode** (PSM)
  - Max energy saving (~μW)

enhanced DRX

Normal operation (Connected state)

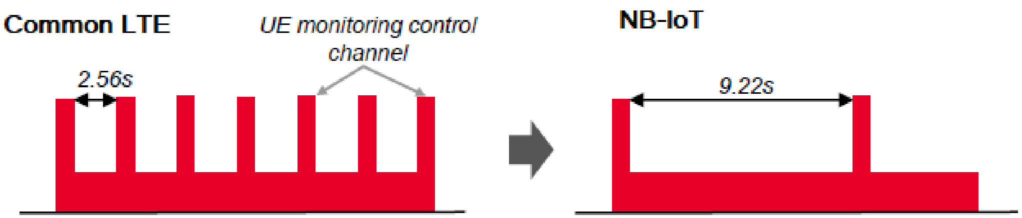
- ▶ Device monitors control channels every subframe in normal operation

Discontinuous reception (DRX)

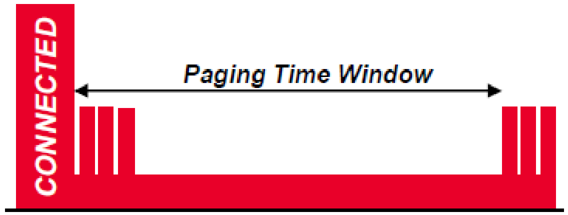
- ▶ Control channels monitored at predefined periods (up to 2.56 s interval)

enhanced DRX (eDRX)

- ▶ Longer periods between monitoring of control channels
- ▶ **Connected state DRX** (C-eDRX)
  - ➢ extended DRX for IoT prolonged to 10.24 s (hyperframe)



- ▶ **Idle state DRX** (I-eDRX):
  - ➢ up to ~43.7 minutes for MTC (up to 2^8 hyperframes)
    - ▪ Hyperframe duration 10.24s (2^{10} frames)
  - ➢ up to ~3 hours for NB-IoT (up to 2^{10} hyperframes)

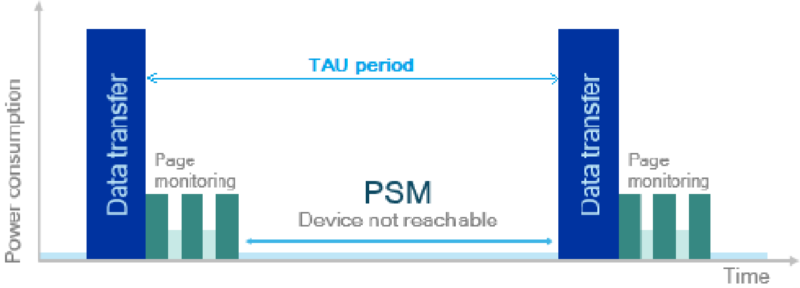


J.H. Wu, "CAT-M & NB-IoT Design and Conformance Test," Keysight Technologies presentation, 2017.

Power Saving Mode (PSM)

Dormant state

- All circuitry **turned off**
- Device **remains registered** with network
  - No need to re-attach or re-establish connection



Device is NOT reachable by network

PSM initiation and activation

- Device includes duration in attach request message
  - Tracking Area Update (TAU) period (Timer T3412) – max 413 days
  - Page monitoring window (Timer T3324) – max 186 minutes
    - Device remains active/reachable (acc. to eDRX setting) after data transmission

Network congestion avoidance via PSM

- Manage timers of all the devices
- Adjust wake-up periods to be offset
- Devices do not wake at the same time

Questions?

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