NB-IoT
IoT Celular (CIoT)

NEON
Network of Competence on Internet of Things

FACULTAD DE INGENIERIA

UNIVERSIDAD DE LA REPUBLICA
URUGUAY

Objetivos

- Describir genarlidades de 3GPP (normas)
- Explicar principales elementos de una red celular y su funciones.
- Identificar características y requerimientos IoT
- Comparar tecnologías CIoT
- Describir técnicas para “low-power”

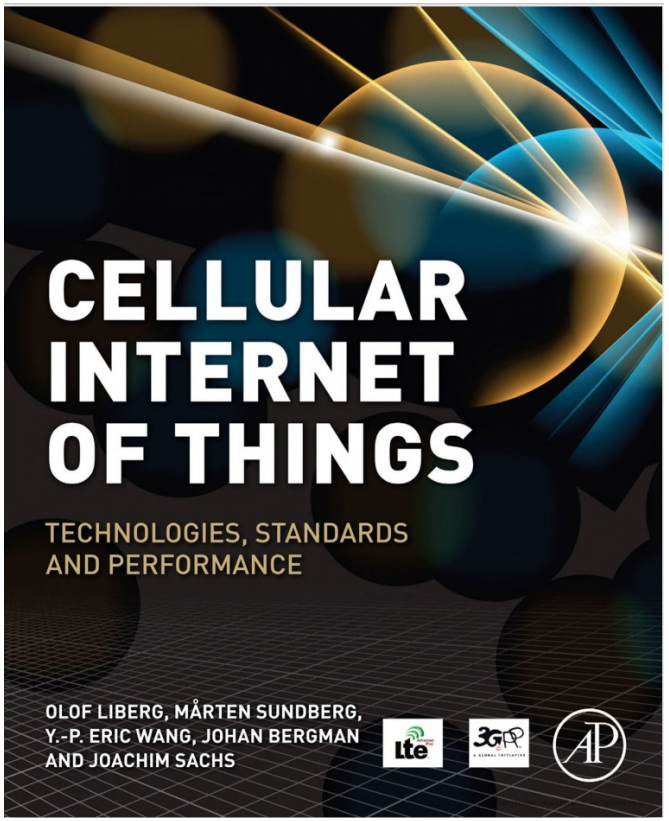
Agenda

- 3GPP: procesos normalización, releases...
- IoT Celular (CIoT): tecnologías
- Arquitectura
- Mejoras para IoT (MTC, machine type comm.)
  - Device power savings (PSM, eDRx)
  - Coverage enhcement
- Módulo LTE/NB-IoT

Bibliografía

- Cellular Internet of Things
  Technologies, Standards, and Performance
  - Olof Liberg
  - Mårten Sundberg
  - Y.-P. Eric Wang
  - Johan Bergman
  - Joachim Sachs

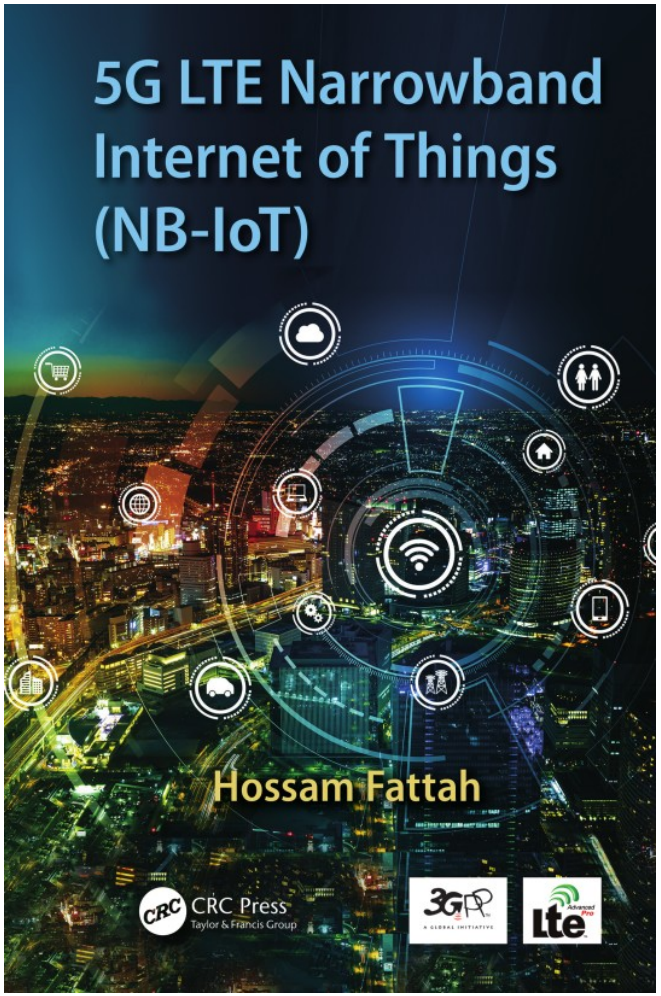
    2018



Liberg, Olof, et al. Cellular Internet of things: technologies, standards, and performance. Academic Press, 2017.

Bibliografía

- 5G LTE Narrowband Internet of Things (NB-IoT)
  - Hossam Fattah
    (c) 2018 3GPP ™



Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

Normas

- 3GPP: Third Generation Partnership Project
  - global standardization forum behind the evolution and maintenance of GSM, UMTS, LTE
    - GSM (2G): Global System for Mobile Communications
    - UMTS (3G): Universal Mobile Telecomm. System
    - LTE (4G): Long-Term Evolution

Redes de comunicación móvil
Evolución

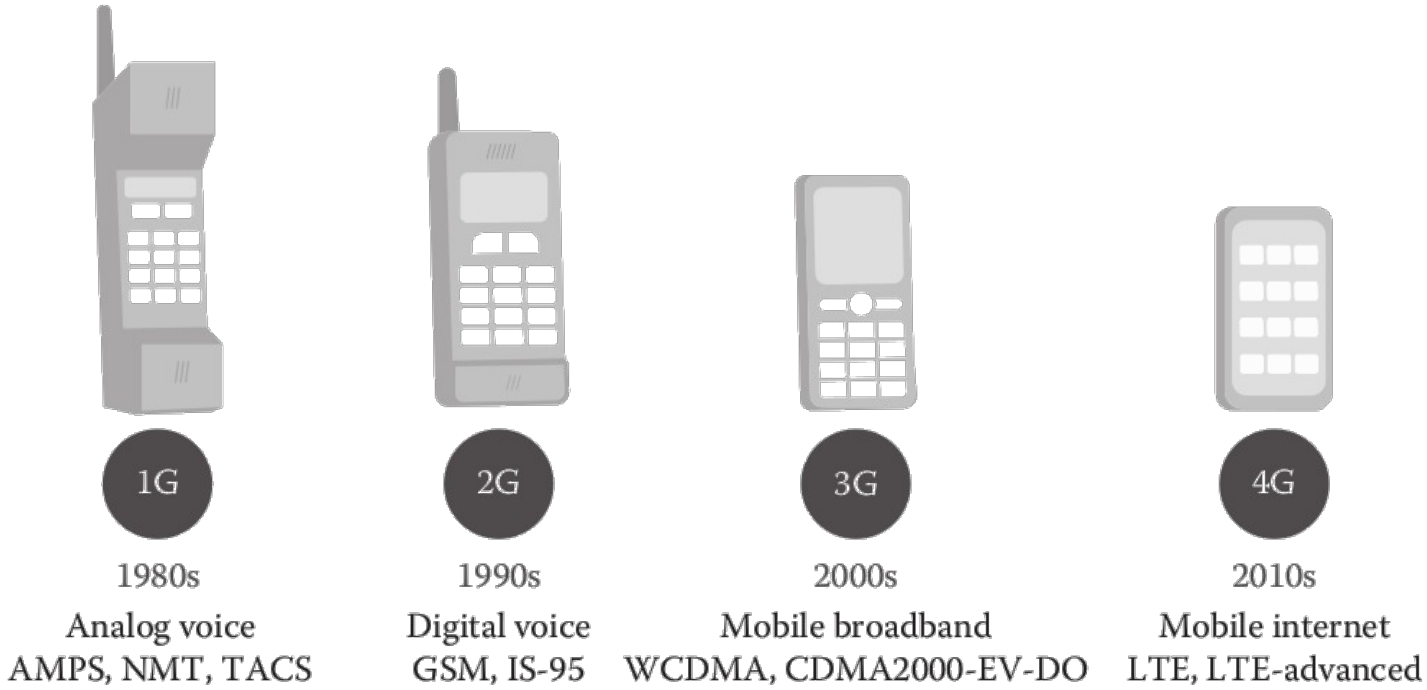
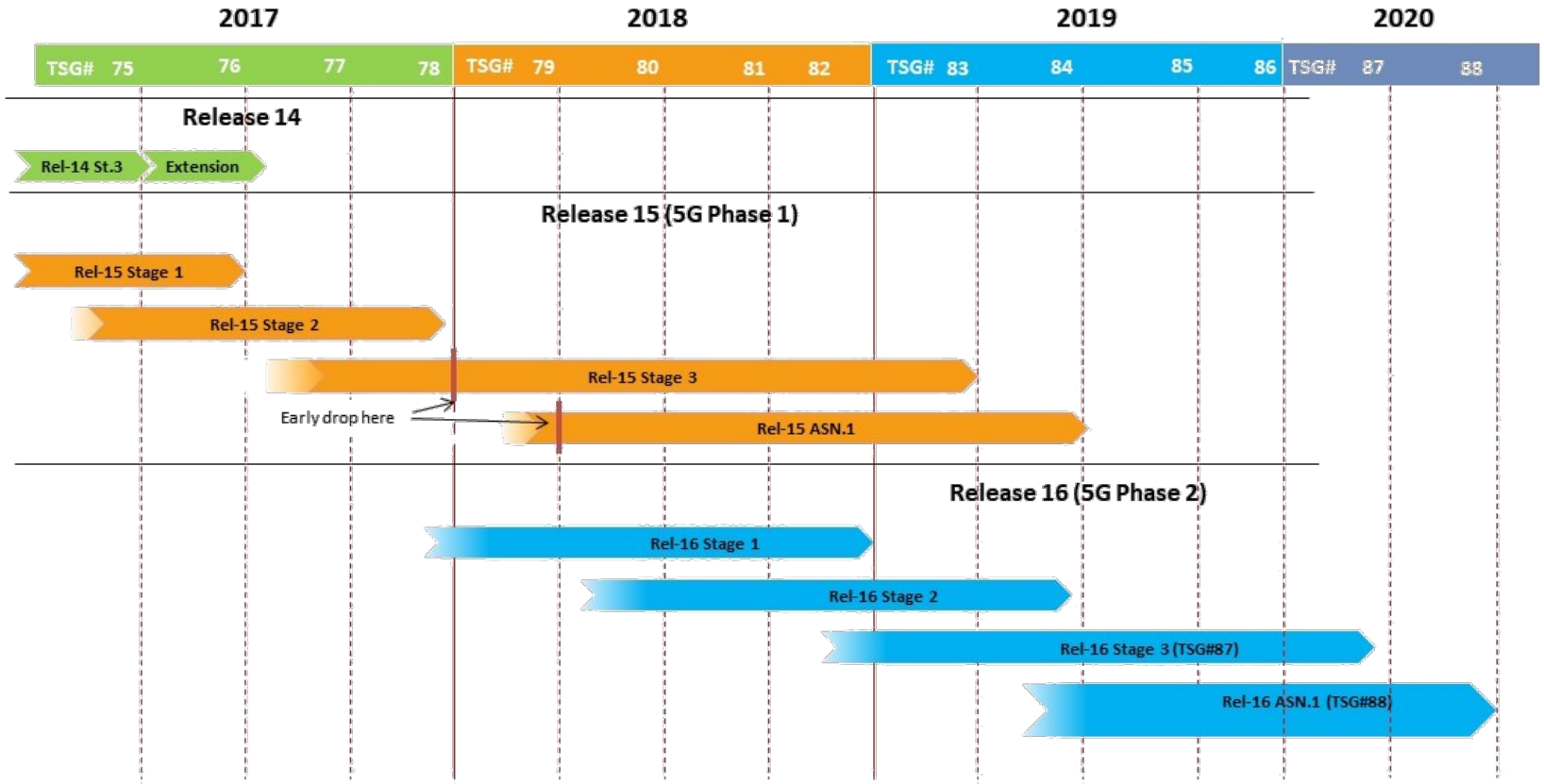


Figure 1.1: Emergence of wireless and cellular networks.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

3GPP: release cycle



https://www.3gpp.org/specifications/releases
https://www.icode9.com/content-4-142122.html

3GPP

- **release cycle**:
  - set of work items where each typically delivers a **feature**
  - organized as **Technical Specifications** (TSs)
  - at the end: a release is **frozen and published**
- **feature**: specified in four stages
  - Stage 1: contains the *service requirements*
  - Stage 2: high-level *feature description*
  - Stage 3: *detailed description* that is needed to implement
  - Stage 4: development of the *performance requirements* and *conformance testing procedures* for ensuring proper implementation of the feature.

Evolución histórica

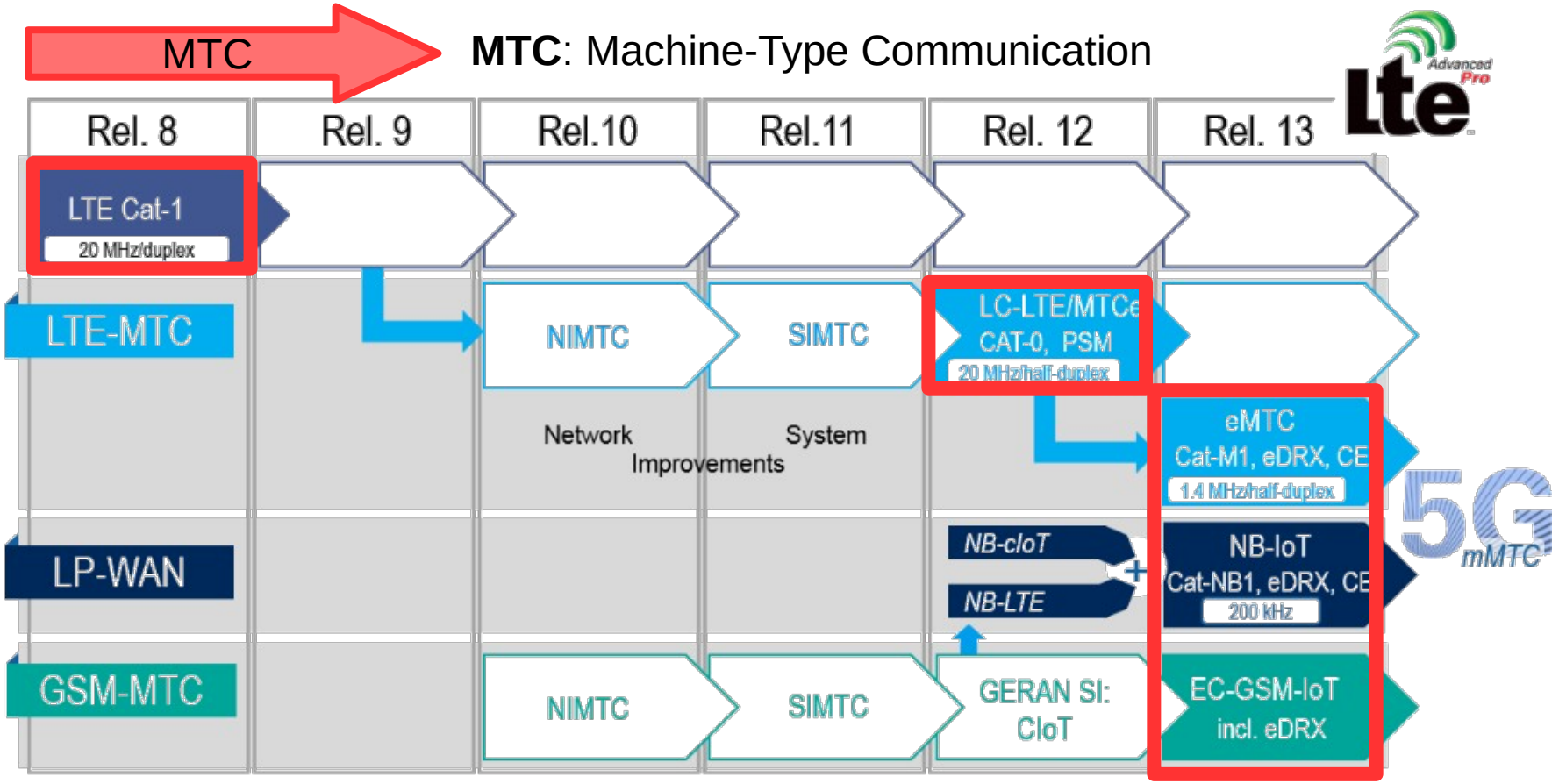
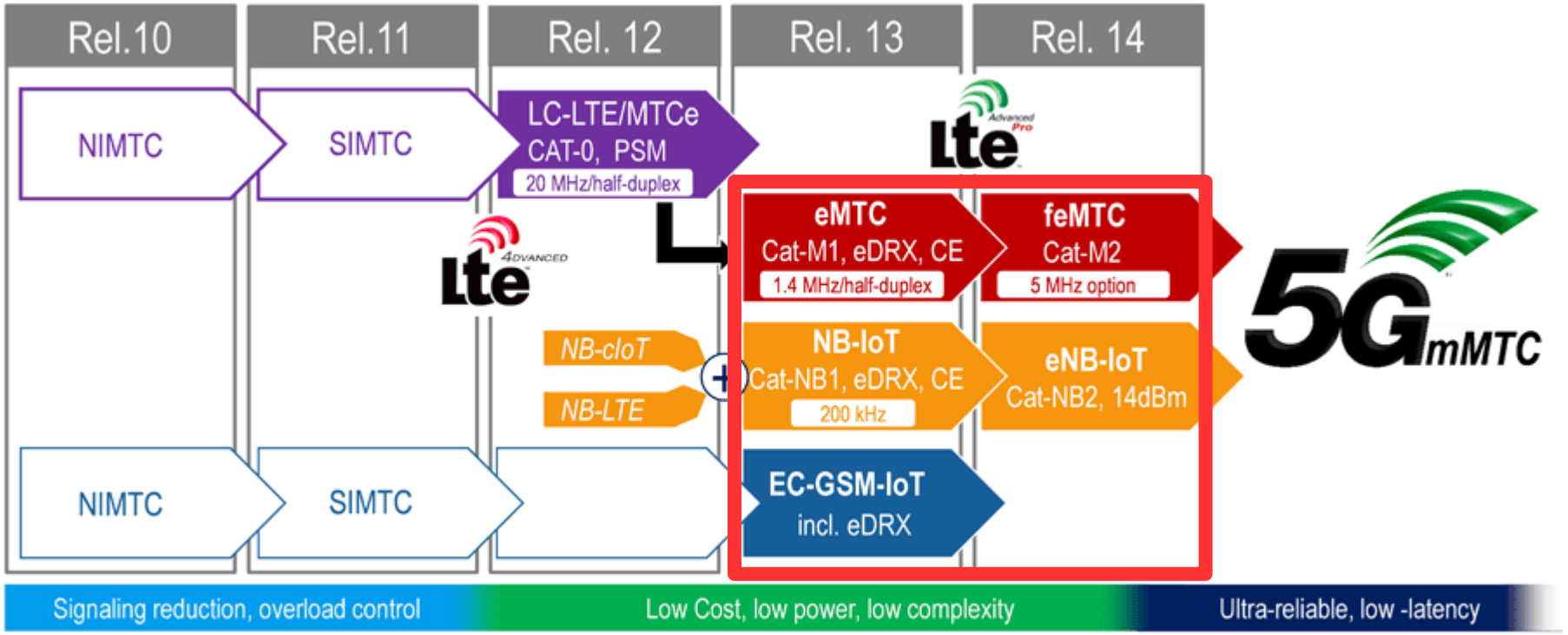


Figure 1-2: IoT in 3GPP

Application Note NB-IoT Measurements – 1MA296_2e (Rohde & Schwarz)
www.rohde-schwarz.com/appnote/1MA296

Evolución histórica



3GPP: organiz. structure

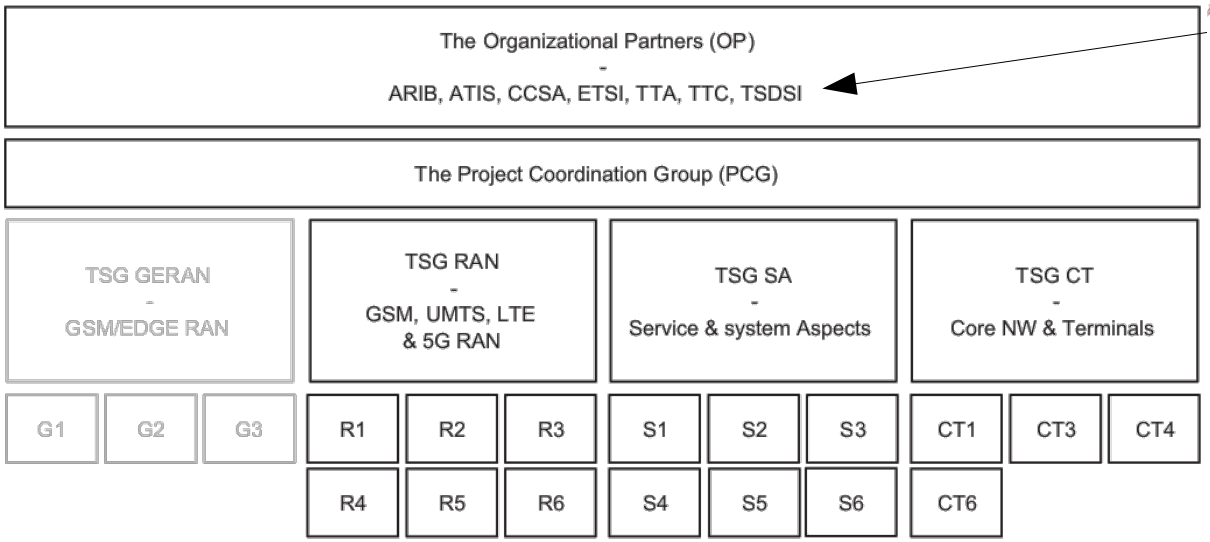


FIGURE 2.1

Organizational structure of 3GPP.

Organizational Partners (SDOs)

- Regional standards organizations:
  - ARIB (Japan),
  - ATIS (USA),
  - CCSA (China),
  - ETSI (Europe),
  - TTA (Korea),
  - TTC (Japan),
  - TSDSI (India)

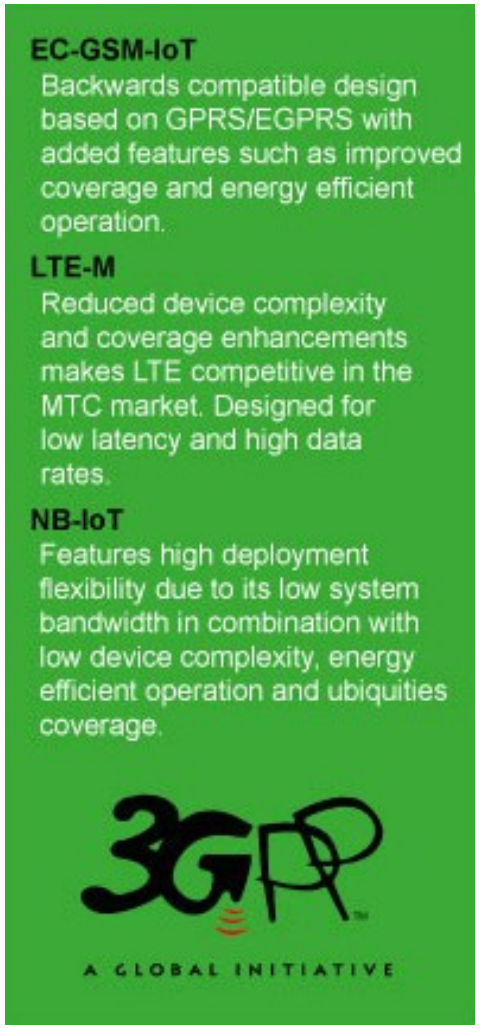
https://www.3gpp.org/images/presentations/2016_11_3gpp_Standards_for_IoT.pdf

Example:
after Release 13

- Technical Specifications Groups (TSGs)
  - GSM/EDGE Radio Access Network (GERAN) [closed]
  - Radio Access Network (RAN)
  - Service and system Aspects (SA)
  - Core network and Terminals (CT)

3GPP release 13

- EC-GSM-IoT (Cap. 3 y 4) (*)
  - **E**xtended **C**overage **GSM** **I**nternet **o**f **T**hings
  - fully backgward compatiblitiy w/GSM
- LTE-M (Cap. 5 y 6)(*)
  - **LTE** for **M**achine-Type Communications flexible system bandwidth of 1.4 MHz or +
  - capable of serving higher-end applications (+ req. on throughput and latency)
- NB-IoT (Cap. 7 y 8) (*)
  - new radio access technology
  - reuses technical components from LTE
  - narrow spectrum



https://www.3gpp.org/news-events/3gpp-news/1906-c_iot

(*) Liberg, Olof, et al. Cellular Internet of things: technologies, standards, and performance. Academic Press, 2017.

Cat (category)

- Cat (user equipment o device):
  - capability and performance
  - EC-GSM-IoT (Release 13)
  - LTE-M
    - LTE Cat 0 (Release 12)
    - **LTE Cat M1** (Release 13)
    - LTE Cat M2 (Release 14)
  - NB-IoT
    - **LTE Cat NB1** (Release 13)
    - LTE Cat NB2 (Release 14)

Categorías

V • T • E [12][13]	LTE Cat 1	LTE Cat 1 bis	LTE-M				NB-IoT		EC-GSM-IoT
			LC-LTE/MTCe	eMTC					
			LTE Cat 0	LTE Cat M1	LTE Cat M2	non-BL	LTE Cat NB1	LTE Cat NB2	
3GPP Release	Release 8	Release 13	Release 12	Release 13	Release 14	Release 14	Release 13	Release 14	Release 13
Downlink Peak Rate	10 Mbit/s	10 Mbit/s	1 Mbit/s	1 Mbit/s	~4 Mbit/s	~4 Mbit/s	26 kbit/s	127 kbit/s	474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Uplink Peak Rate	5 Mbit/s	5 Mbit/s	1 Mbit/s	1 Mbit/s	~7 Mbit/s	~7 Mbit/s	66 kbit/s (multi-tone) 16.9 kbit/s (single-tone)	159 kbit/s	474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Latency	50–100 ms		not deployed	10–15 ms			1.6–10 s		700 ms – 2 s
Number of Antennas	2	1	1	1	1	1	1	1	1–2
Duplex Mode	Full Duplex		Full or Half Duplex	Full or Half Duplex	Full or Half Duplex	Full or Half Duplex	Half Duplex	Half Duplex	Half Duplex
Device Receive Bandwidth	1.4–20 MHz		1.4–20 MHz	1.4 MHz	5 MHz	5 MHz	180 kHz	180 kHz	200 kHz
Receiver Chains	2 (MIMO)		1 (SISO)	1 (SISO)	1 (SISO)	1 (SISO)	1 (SISO)	1 (SISO)	1–2
Device Transmit Power	23 dBm	23 dBm	23 dBm	20 / 23 dBm	20 / 23 dBm	20 / 23 dBm	20 / 23 dBm	14 / 20 / 23 dBm	23 / 33 dBm

https://en.wikipedia.org/wiki/Narrowband_IoT

3GPP release 13

Summary for eMTC, NB-IOT and EC-GSM-IoT

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

** 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).*

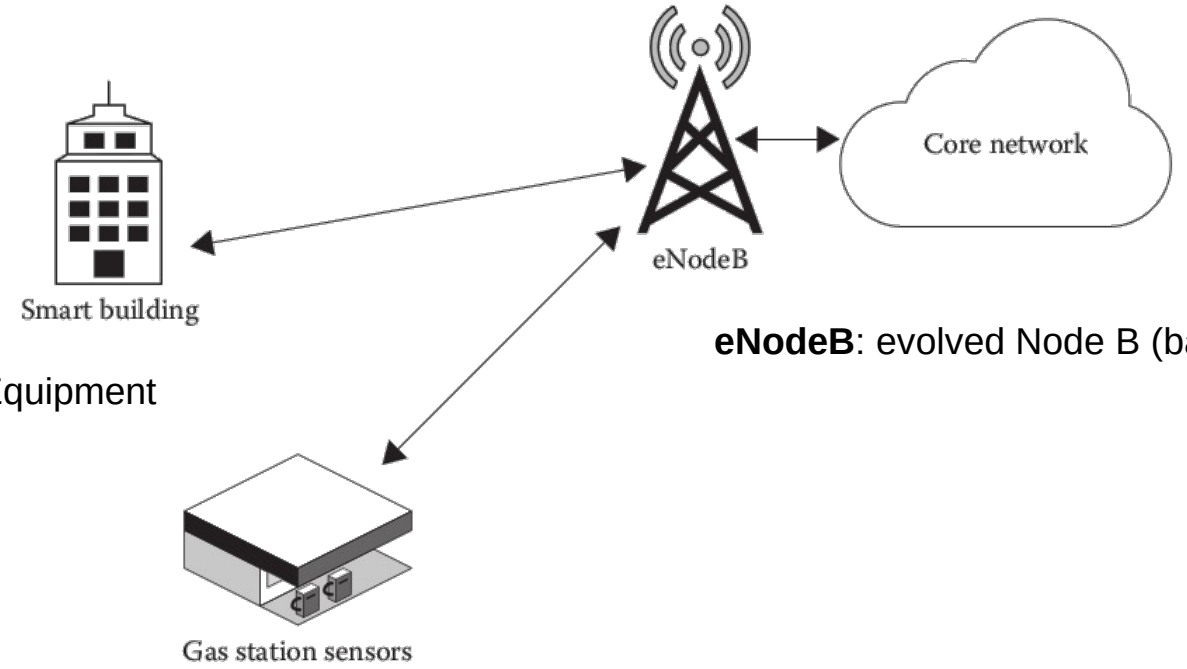
https://www.3gpp.org/news-events/3gpp-news/1805-iot_r14

3GPP release 13

Criterion	Cat. 1 (Rel. 8+)	Cat. M1 (Rel. 13)	Cat. NB1 (Rel. 13)	FeMTC (Rel. 14)	eNB-IOT (Rel. 14)
Bandwidth	20 MHz	1.4 MHz	180 kHz	Up to 5 MHz (CE Mode A and B for PDSCH and A only for PUSCH)	180 kHz
Deployments/ HD-FDD	LTE channel / No HD-FDD	Standalone, in LTE channel / HD-FDD preferred	Standalone, in LTE channel, LTE guard bands, HD-FDD	Standalone, in LTE channel / HD-FDD, FD-FDD, TDD	Standalone, in LTE channel, LTE guard bands, HD-FDD preferred
MOP	23dBm	23dBm/ 20dBm	23dBm/ 20dBm	23dBm / 20dBm	23dBm/ 20dBm/ 14dBm
Rx ant / layers	2/1/	1/1	1/1	1/1	1/1
Coverage, MCL	145.4dB DL, 140.7dB UL (20 Kbps, FDD)	155.7dB	Deep coverage: 164dB +3	155.7dB (at 23dBm)	Deep coverage: 164dB
Data rates (peak)	DL: 10 Mbps, UL: 5 Mbps	~800 Kbps (FD-FDD) 300/375 Kbps DL/UL (HD-FDD)	30kbps (HD-FDD)	DL/ UL: 4 Mbps FD-FDD@5MHz	TBS in 80/ 105Kbps 1352/ 1800 peak rates t.b.d.
Latency	Legacy LTE: < 1s	~ 5s at 155dB	<10s at 164 dB	At least the same as Cat. M1 Legacy LTE (normal MCL)	At least the same as Cat. NB1, some improvements are FFS
Mobility	Legacy support	Legacy support	Cell selection, re-selection only	Legacy support	More mobility compared to Cat. NB1
Positioning	Legacy support	Partial support	Partial support	OTDA with legacy PRS and Frequency hopping	50m H target, new PRS introduced. details FSS. UTDOA under study
Voice	Yes (possible)	No	No	Yes	No
Optimizations	n/a	MPDCCH structure, Frequency hopping, repetitions	NPDCCH, NPSS/NSSS, NPDSCH, NPUSCH, NPRACH etc.., frequency hopping, repetitions, MCO	Higher bandwidth will be DCI or RRC configured, Multi-cast e.g. SC-PTM	Multi-cast e.g. SC-PTM
Power saving	DRX	eDRX, PSM	eDRX, PSM	eDRX, PSM	[eDRX, PSM]
UE complexity BB	100%	~45%	< 25%	[~55%]	[~25%]

https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2018/IoT-BDG/7. IoT Standards Part II - Sami Tabbane.pdf

Arquitectura



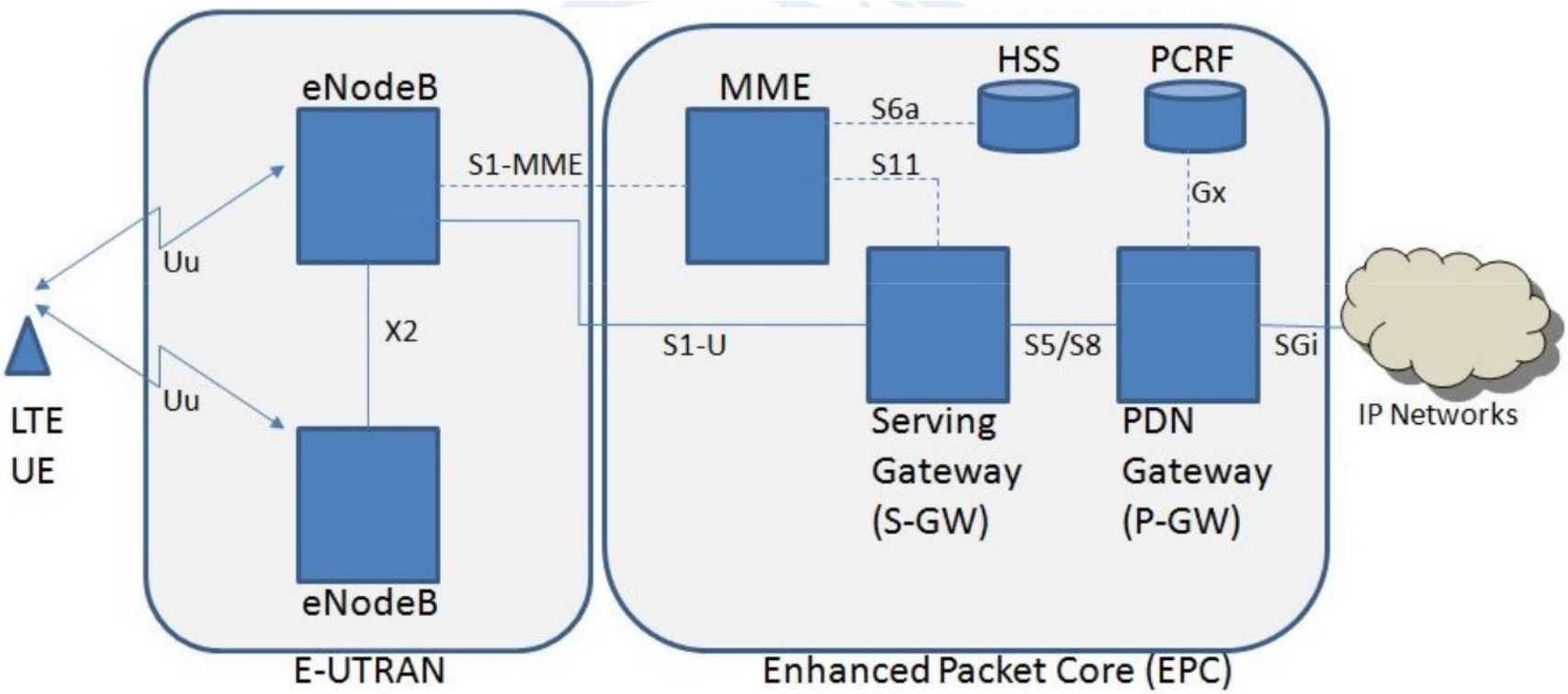
eNodeB: evolved Node B (base)

UE: User Equipment

Figure 1.2: Internet of Things applications in smart building and meters.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

Arquitectura



https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2018/IoT-BDG/7. IoT Standards Part II - Sami Tabbane.pdf

Arquitectura

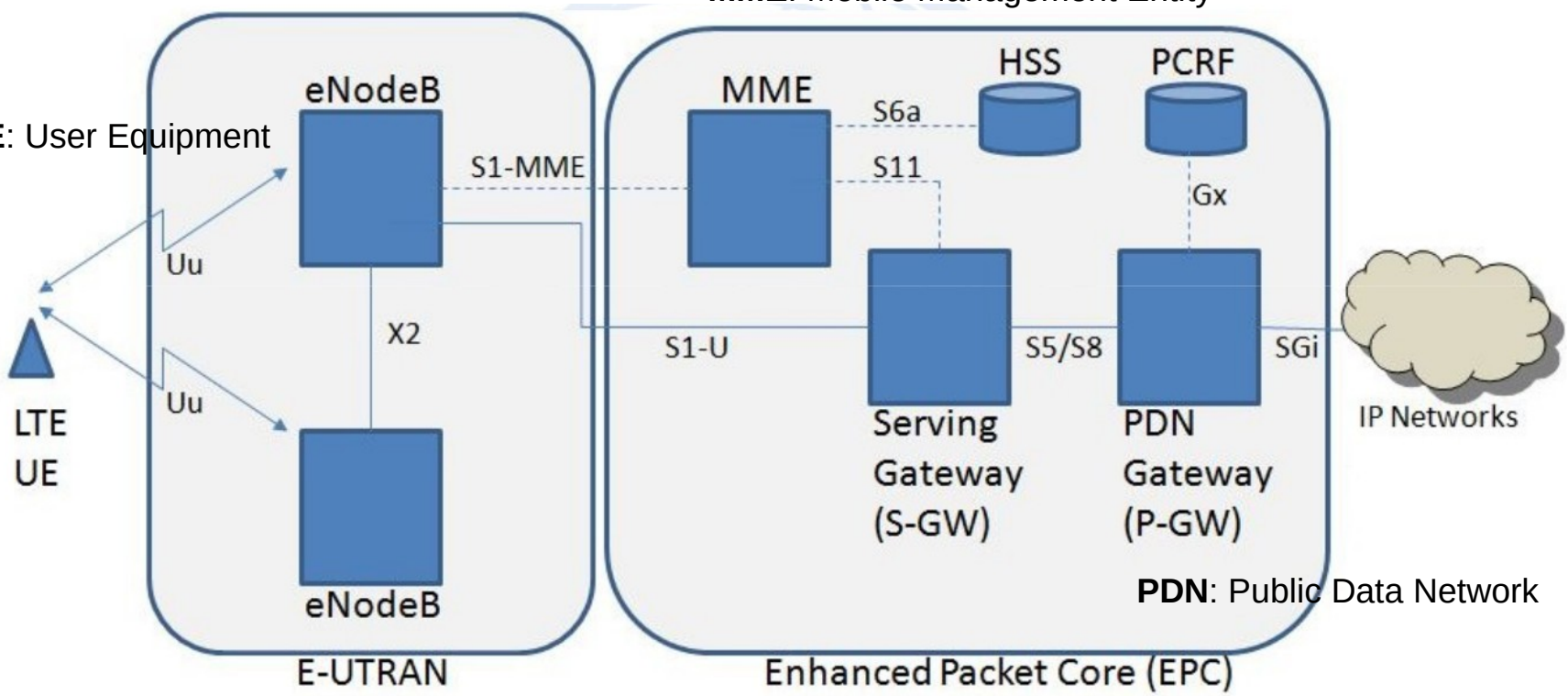
PCRF: Policy and Charging Rules Function

eNB: Evolved Node B

HSS: Home Subscriber Server

MME: Mobile Management Entity

UE: User Equipment



PDN: Public Data Network

E-UTRAN: Evolved Universal Terrestrial Radio Access Network

X2: Control Plane and User Plane

S1: interface connects the eNB to the EPC

https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2018/IoT-BDG/7. IoT Standards Part II - Sami Tabbane.pdf

Protocol stack

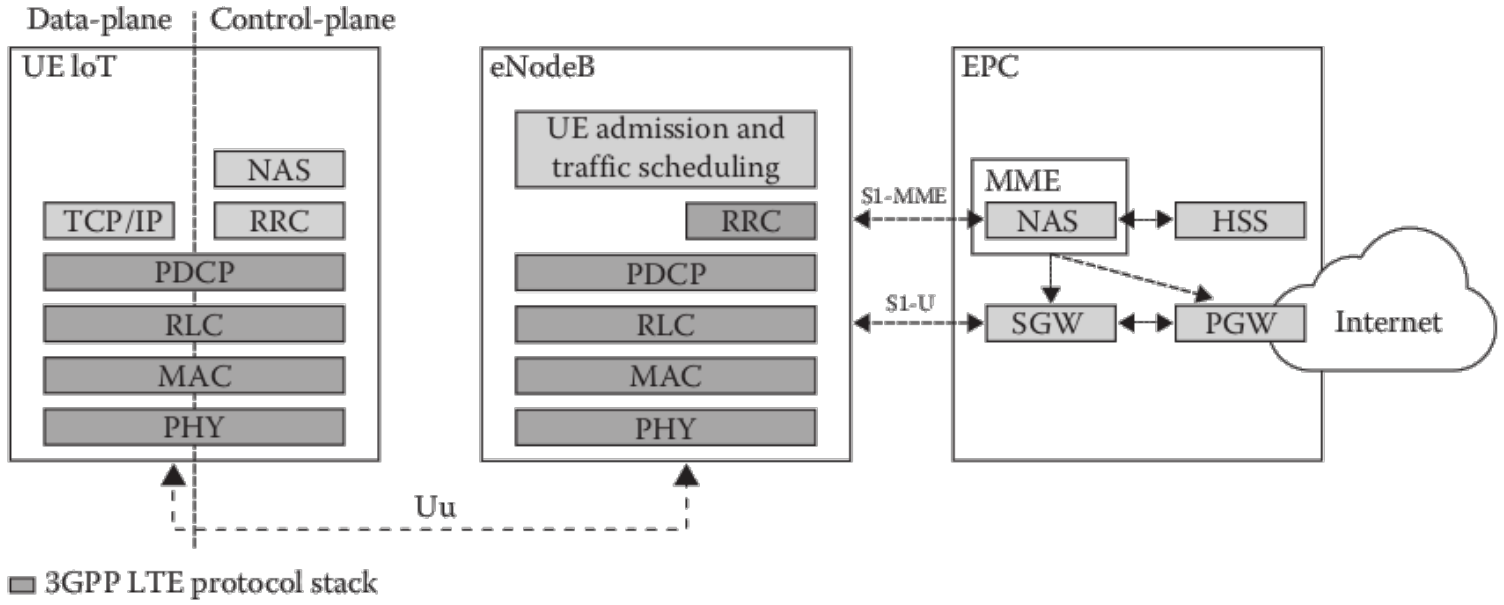


Figure 2.11: 3GPP LTE NB-IoT protocol stack for both UE and eNodeB.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

Protocol stack

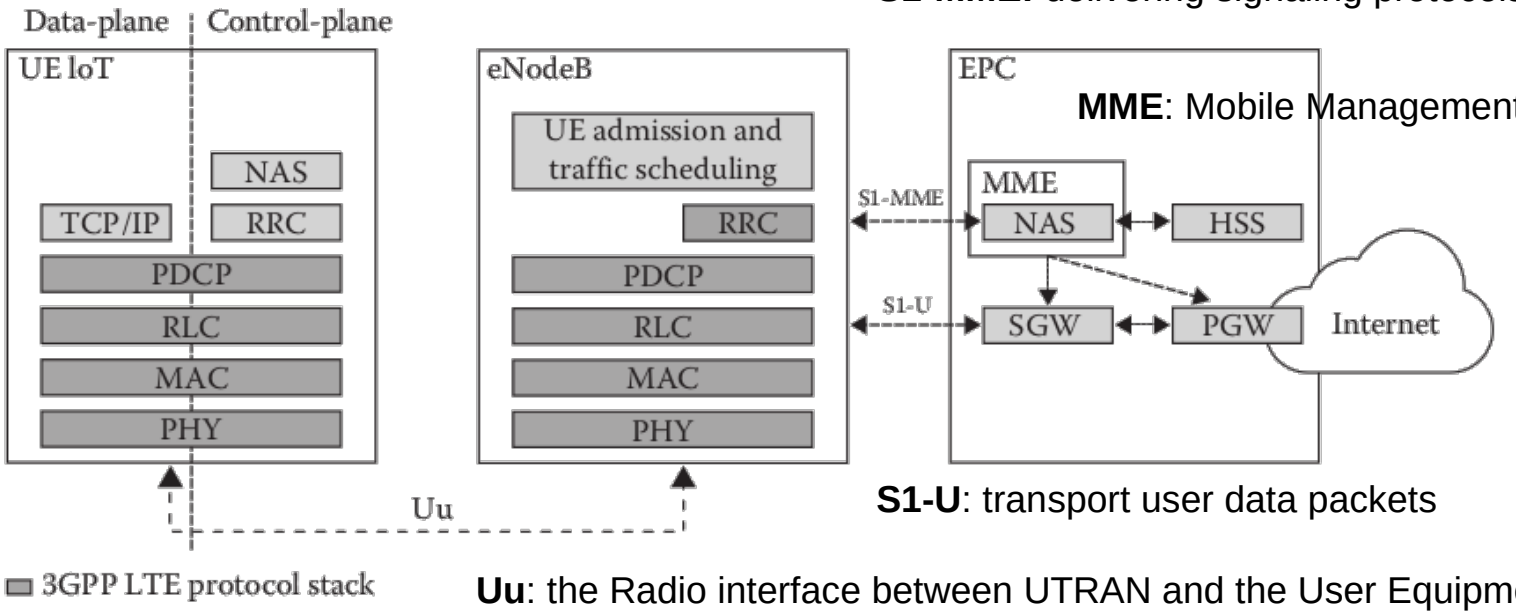
NAS: Non-Access Stratum

RRC: Radio Resource Control

PDCP: Packet Data Convergence Protocol

RLC: Radio Link Control

S1-MME: delivering signaling protocols



MME: Mobile Management Entity

S1-U: transport user data packets

Uu: the Radio interface between UTRAN and the User Equipment

Figure 2.11: 3GPP LTE NB-IoT protocol stack for both UE and eNodeB.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

NB-IoT: modos operación

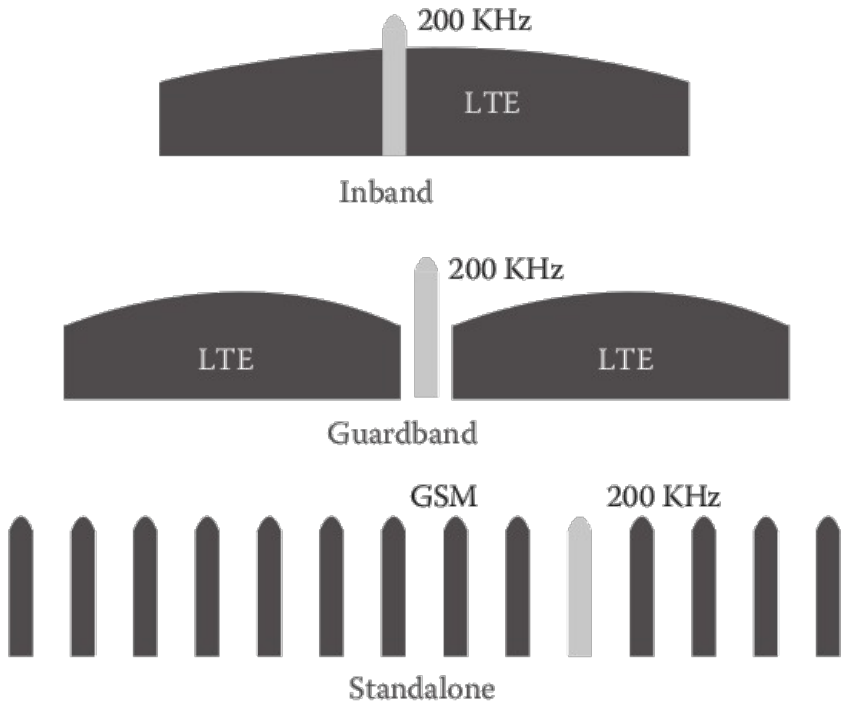


Figure 2.12: NB-IoT modes of operation.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

PHY

Table 7.3 Channel Frequency Band

Band	*Downlink* F_{DL}^{low} *(MHz)*	*Downlink* F_{DL}^{high} *(MHz)*	*Uplink* F_{UL}^{low} *(MHz)*	*Uplink* F_{UL}^{high} *(MHz)*	*Region*
1	2110	2170	1920	1980	Europe, Asia
2	1930	1990	1850	1910	Americas, Asia
3	1805	1880	1710	1785	Europe, Asia, Americas, Africa
4	2110	2155	1710	1755	Americas
5	869	894	824	849	Americas, Asia
8	925	960	880	915	Europe, Asia, Africa
11	1844.9	1879.9	1749.9	1784.9	Japan
12	729	746	699	716	United States
13	746	756	777	787	United States
14	758	768	788	798	United States
17	734	746	704	716	United States
18	860	875	815	830	Japan
19	875	890	830	845	Japan
20	791	821	832	862	Europe, Africa
21	1495.9	1510.9	1447.9	1462.9	Europe
25	1930	1995	1850	1915	Americas
26	859	894	814	849	Americas, Japan
28	758	803	703	748	Americas, Asia Pacific
31	462.5	467.5	452.5	457.5	Americas
66	2110	2200	1710	1780	Americas
70	1995	2020	1695	1710	Americas
71	461	466	451	456	United States
72	460	465	450	455	Europe, Middle East, Africa
73	1475	1518	1427	1470	Asia and Pacific

Traffic exchange

- Data reporting
  - triggered reporting
  - exception reports
  - periodic reports
  - software upgrades and updates
- Low latency and low power...

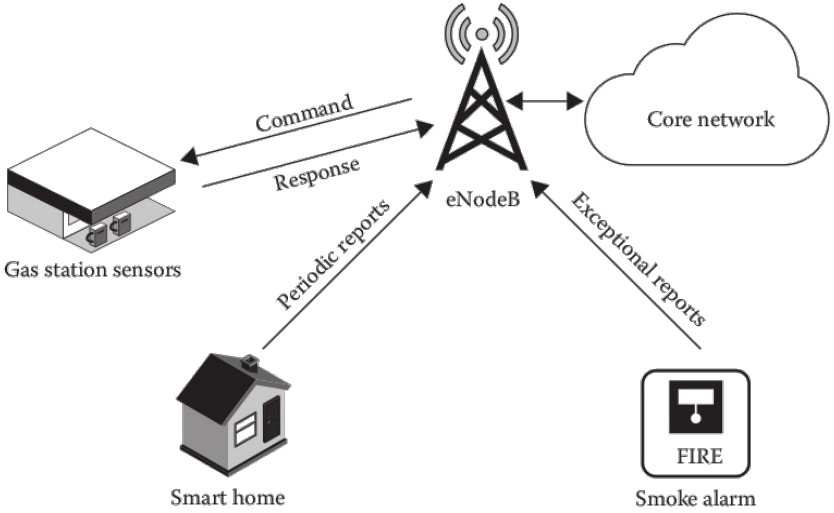


Figure 2.4: Different reports transmitted by CIoT.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

Power savings: but...

- Data transmision
  - Mobile Originated (MO)
  - Mobile Terminated (MT)

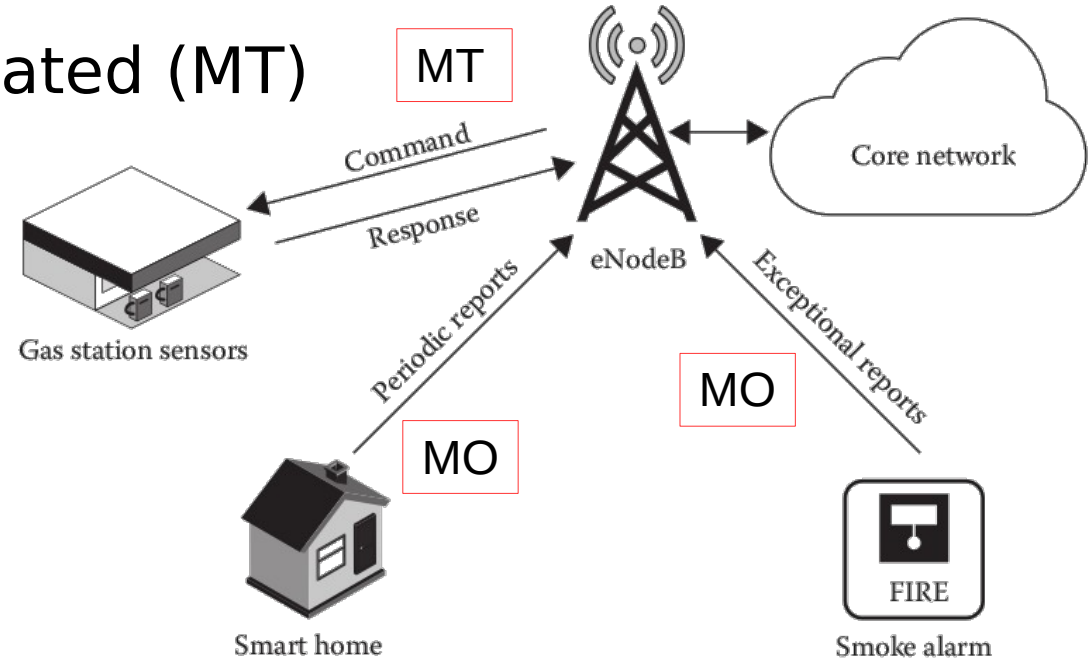
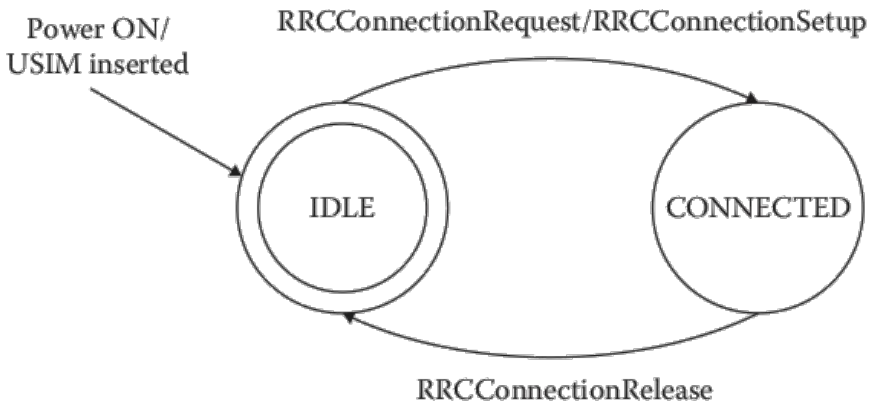


Figure 2.4: Different reports transmitted by CIoT.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

RRC: Radio Resource Control

- Protocol for communication between the UE and the eNB
- UE modes of operation
  - IDLE
  - CONNECTED



RRC: Radio Resource Control

Figure 3.1: RRC modes of operation.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

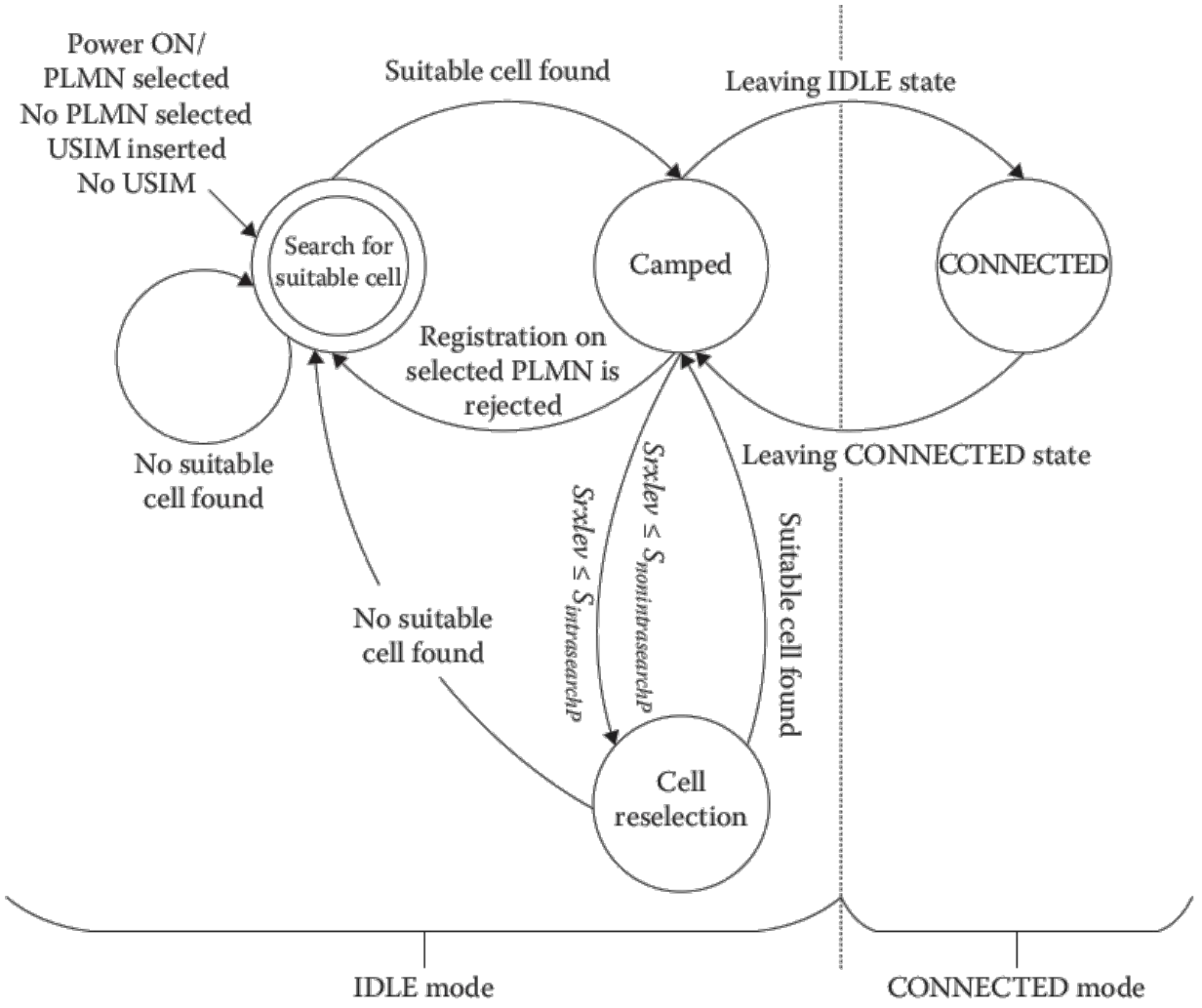


Figure 3.3: UE behavior in IDLE mode.

Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.

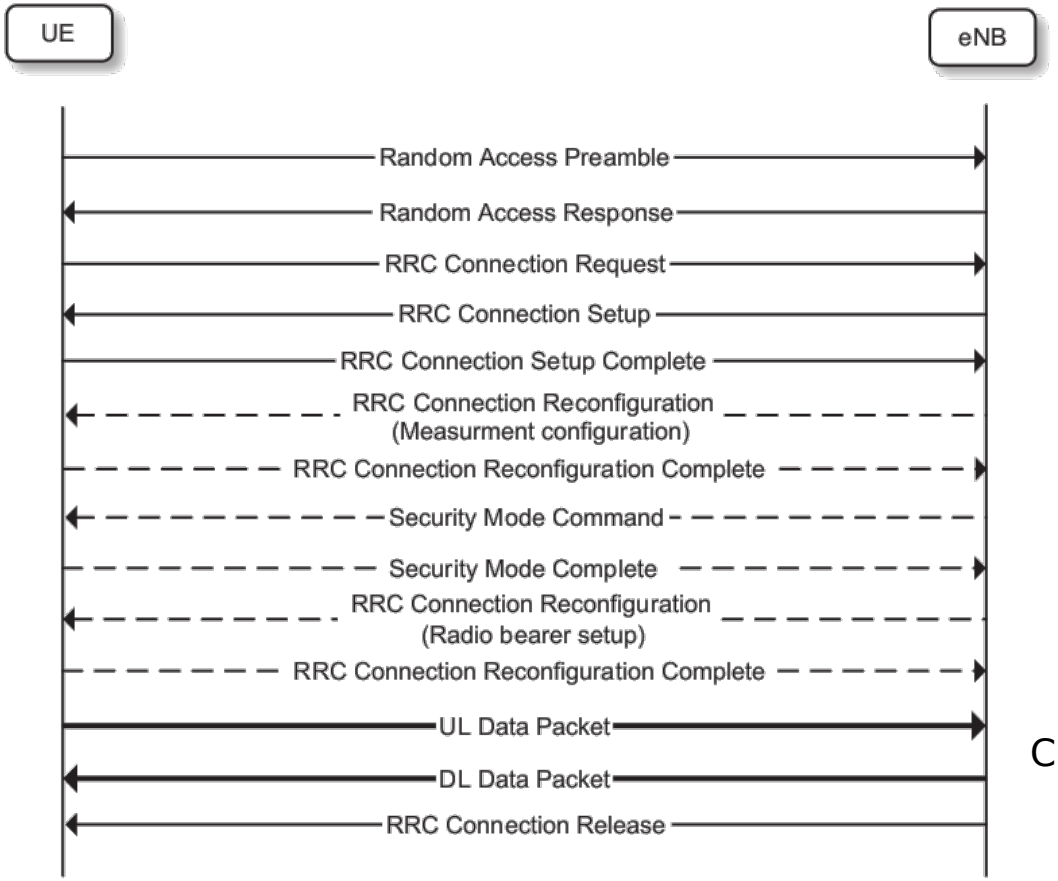
UE mode operation

- **CONNECTED**
  - UE's radio is actively sending or receiving messages.
  - UE must maintain its synchronization with the network
- Radio: mostly used for **application-specific activity**
  - UL messages (i.e. reporting a sensor value)
  - DL messages (i.e. configuration updates)
  - Neighbor cell measurements
- Power consumption:
  - radio activity consumes a lot of power

UE mode operation

- **IDLE**
  - UE is switched on, but does the bare minimum
  - UE stay connected to the network and to stay reachable
- Radio: performs **keep-alive activities**
  - Listening paging messages (to be informed when the eNB requires a status update or value reporting)
  - Performing tracking area updates (TAUs) (update the eNB about the UE's location information for reachability)
- Power consumption
  - lower compared to connected but still high

Mobile Originated (MO)



Case: small data transm.

FIGURE 2.2

LTE message transfer associated with the transmission a single UL and single DL data packet. Messages indicated with dashed arrows are eliminated in the *RRC Resume procedure* solution [9].

Paging

- Paging (mechanism)
  - network inform the UE has data

    (also notify UE about various events)
  - UE monitor paging in RRC **IDLE** mode.
- Paging Occasion (PO)
  - specific time interval during which a UE is expected to monitor for incoming paging messages
- Discontinuous Reception (DRX)
  - UE sleeps between monitoring page (remind: idle)

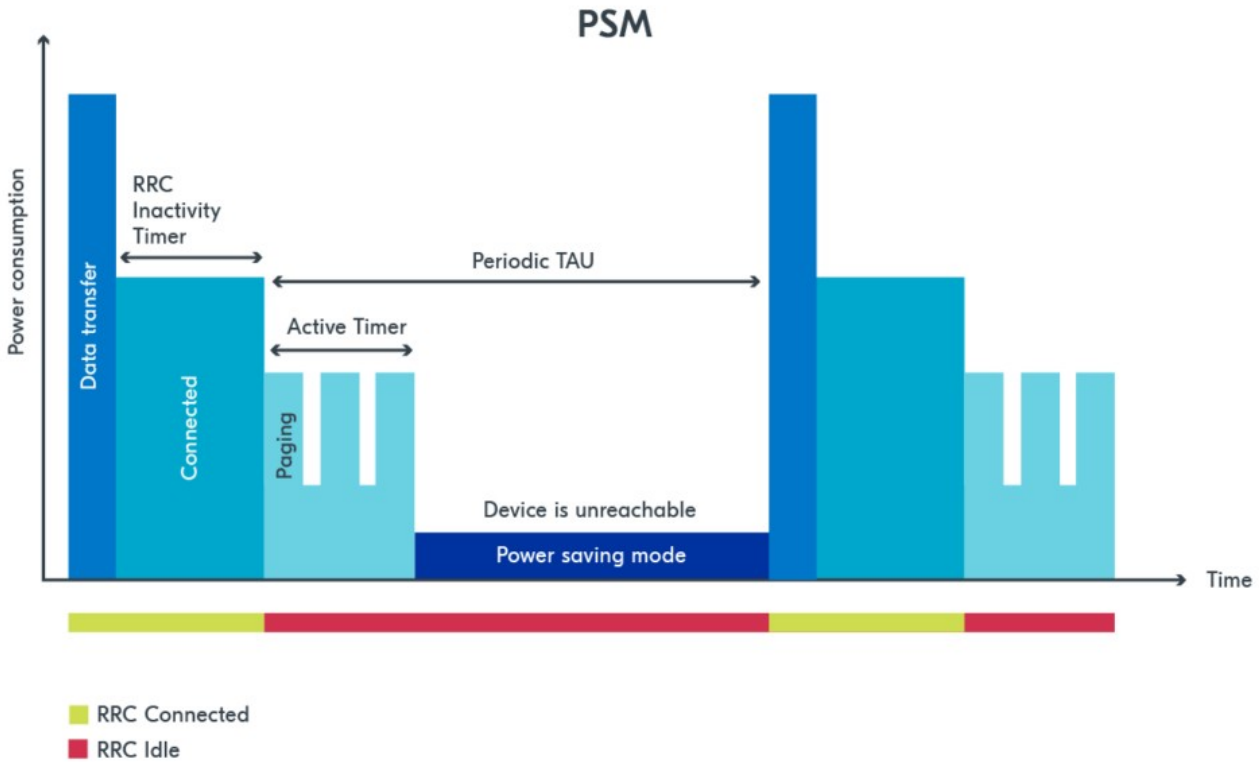
Power savings: options

- eDRX (extended Discontinous Reception)
  - extend the DRX cycles
  - remain longer in a power saving state between paging occasions (PO)
  - periodically available for MT services
- PSM (Power Saving Mode)
  - UE is not monitoring paging (state) so becomes unreachable (for periods)
  - UE is allowed to keep its connectivity status

Timers

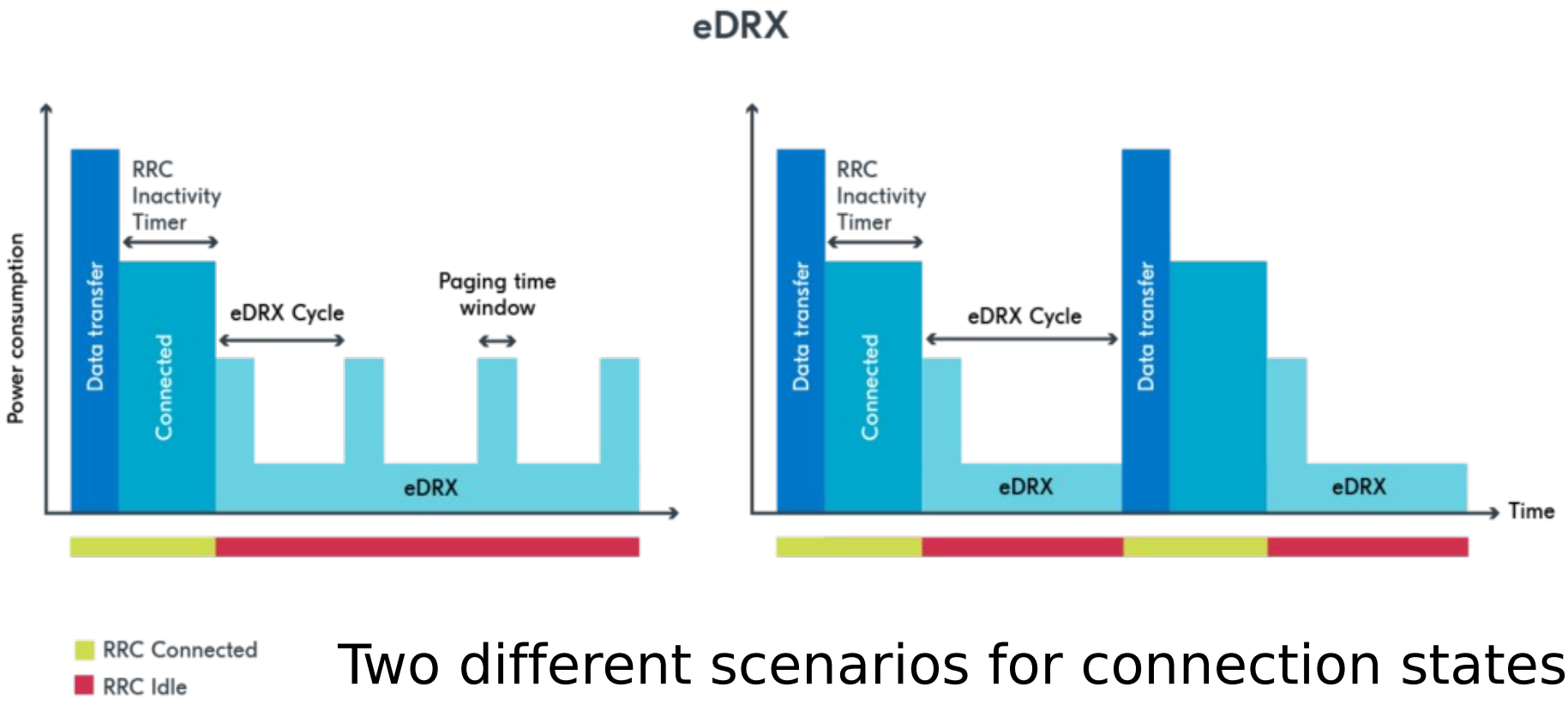
- **Periodic TAU timer** (T3412)
  - time before waking up to send a Tracking Area Update (TAU) to the network.
- **Active timer** (T3324)
  - monitoring paging in RRC Idle mode, before going into PSM.
- **RRC Inactivity timer**:
  - stays in RRC Connected mode after transferring data
  - then the UE receives the event RRC Release (from the network)

PSM



Nordic Semiconductor - Cellular IoT Fundamentals (Lesson 1 – Basics of cellular IoT)

eDRX



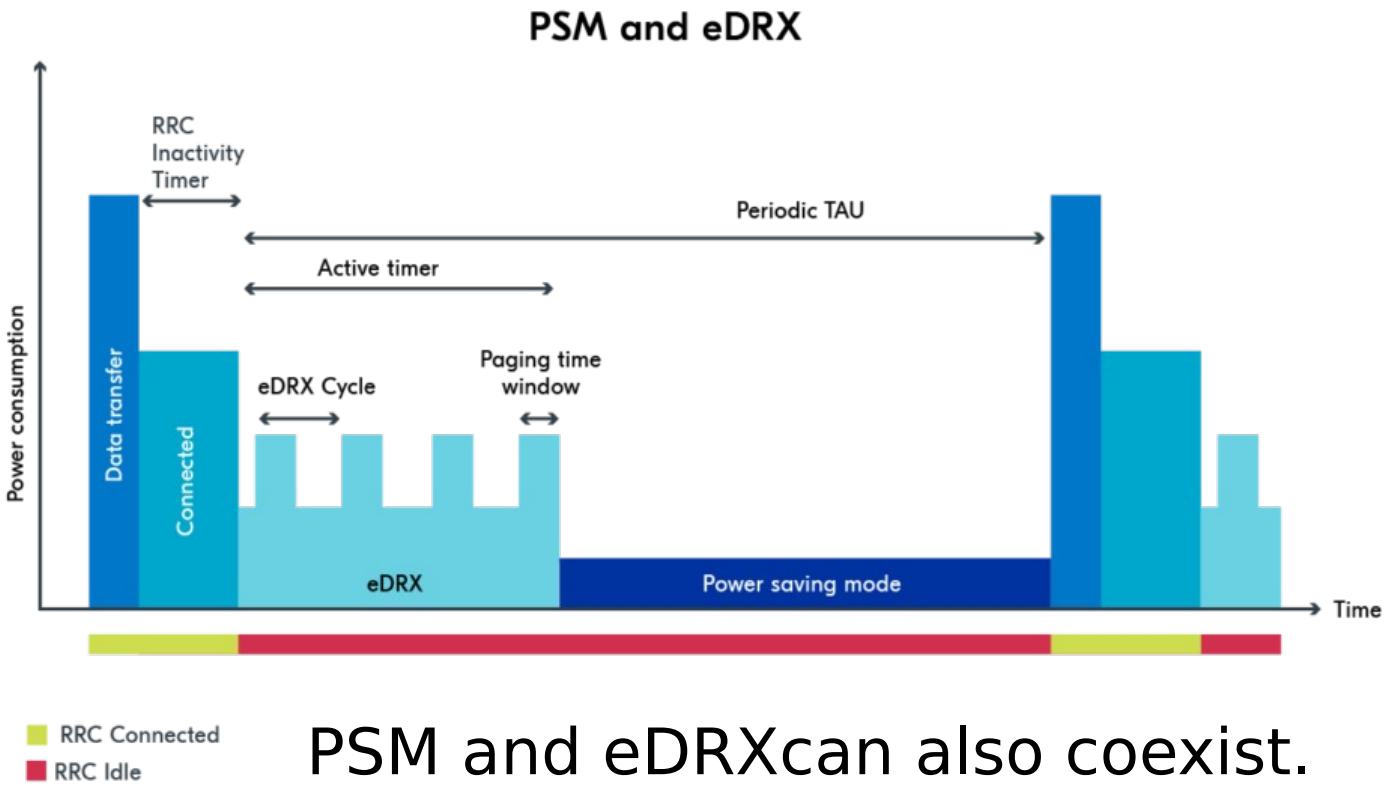
Two different scenarios for connection states.

Nordic Semiconductor - Cellular IoT Fundamentals (Lesson 1 – Basics of cellular IoT)

Power savings: summary

- PSM
  - becomes unreacheble for MT
  - leaves PSM and enters RRC Connected mode when triggers MO
    - UL data transfer or
    - periodic Tracking Area Update/Routing Area Update (TAU/RAU)
- eDRX
  - unreachable during eDRX Cycle

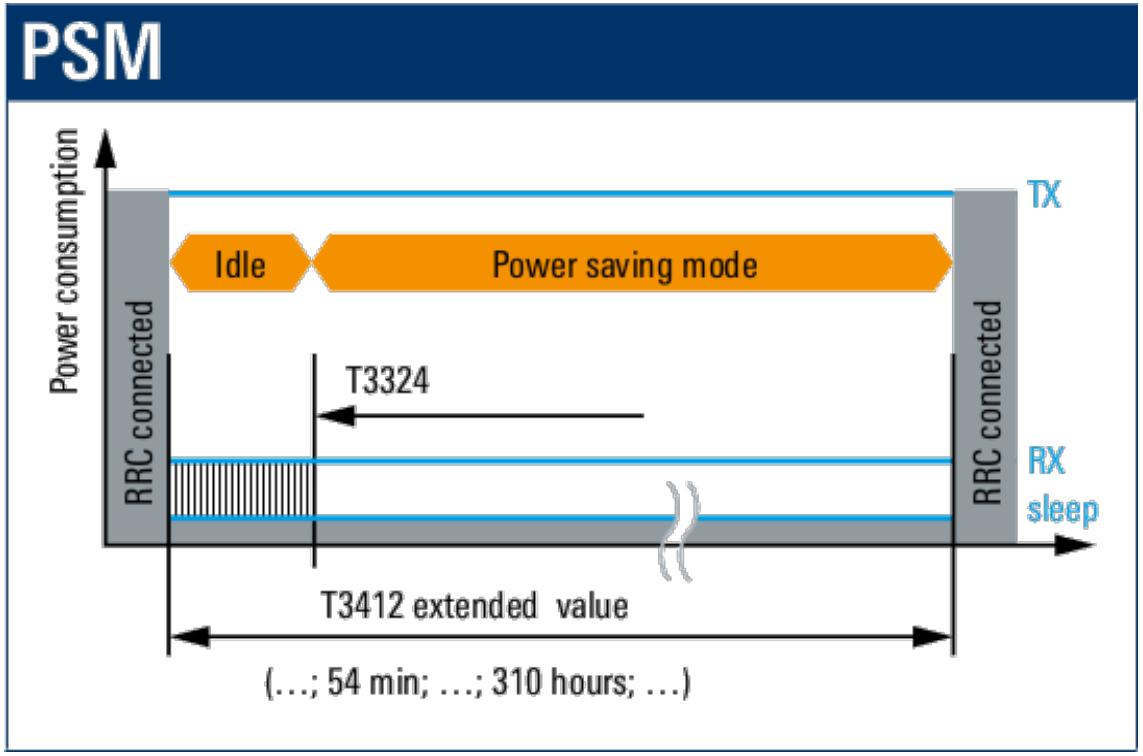
PSM and eDRX



PSM and eDRXcan also coexist.

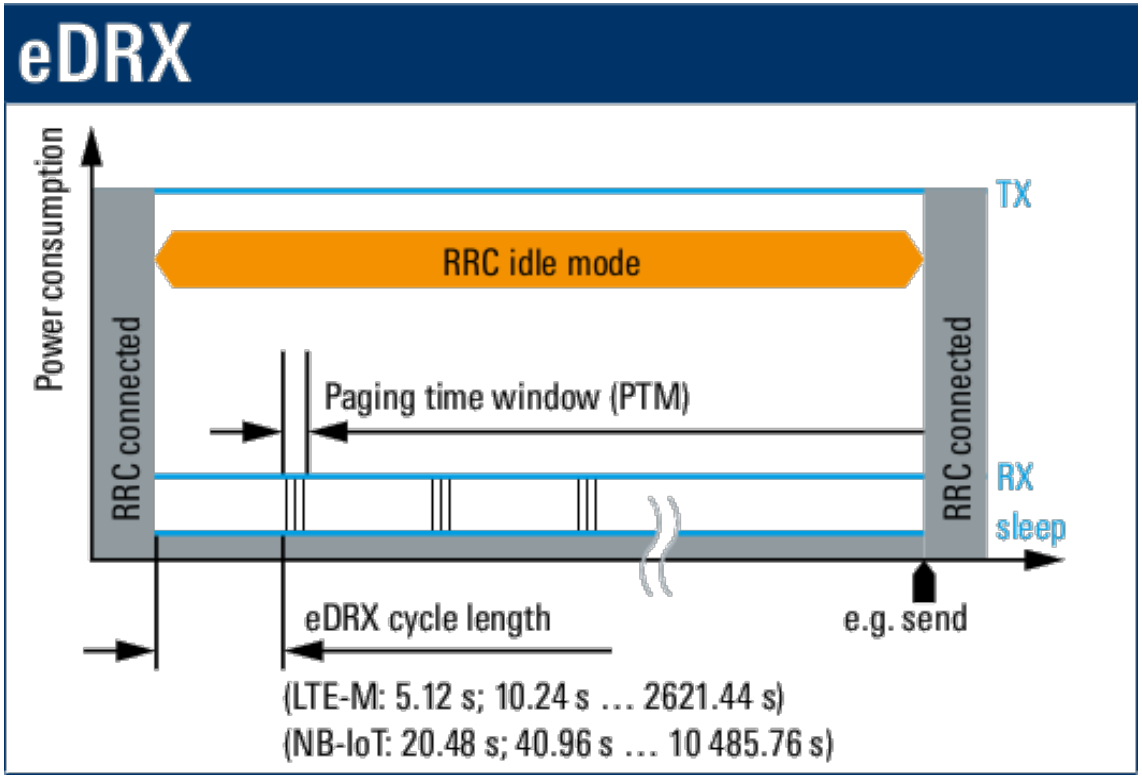
Nordic Semiconductor - Cellular IoT Fundamentals (Lesson 1 – Basics of cellular IoT)

PSM



RRC: Radio Resource Control

eDRX


eDRX
Power consumption
RRC connected
RRC idle mode
TX
RX
sleep
RRC connected
Paging time window (PTM)
eDRX cycle length
e.g. send
(LTE-M: 5.12 s; 10.24 s … 2621.44 s)
(NB-IoT: 20.48 s; 40.96 s … 10 485.76 s)

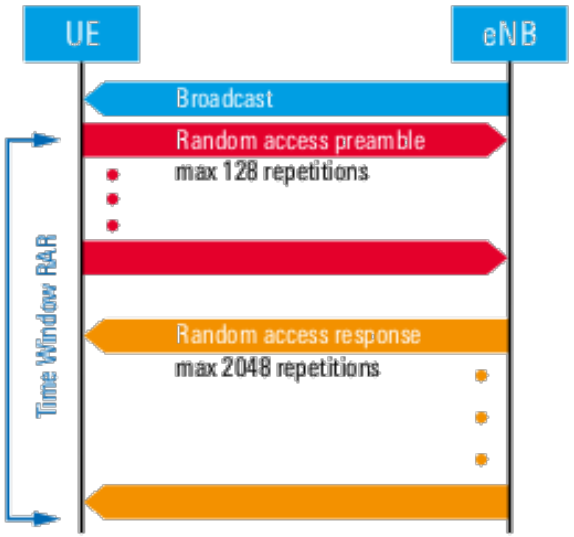
CE (coverage enhancement)

Coverage enhancement

Introduction of coverage enhancement (CE) levels CE0, 1 and 2 specifying:

- Number of repetitions of physical access channels
- Number of allowed attempts (NPRACH)
- Time window size for
  - Random Access Response (RAR)
  - Contention Resolution (CR)

Initial CE level defined based on signal measurements can be changed in case that the access failed



LTE IOT 2 CLICK




PID: MIKROE-3144

Weight: 31 g

LTE IoT 2 click is a Click board™ that allows connection to the LTE networks, featuring Quectel BG96 LTE module, which offers two LTE technologies aimed at Machine to Machine communication (M2M) and Internet of Things (IoT). This module is an embedded IoT communication solution which supports the LTE Cat M1 and NB1 technologies, offering an alternative to similar Low Power Wide Area Network (LPWAN) solutions, such as the ones provided by Sigfox and LoRa. The LTE CAT1 and NB1 technologies are designed with specific requirements of the IoT network in mind. LTE IoT 2 click also offers various other features, allowing simple and reliable connection to these new 3GPP IoT technologies.

https://www.mikroe.com/lte-iot-2-click

Two SMA connectors on board for the main and the secondary (GNSS) antennas, network and status indicators, familiar 3GPP standard AT commands set, as well as the Quectel enhanced AT commands over the UART interface, USB connector for interfacing it with the software application from Quectel, are just some of the features available on the LTE IoT 2 click. A rich set

Referencias

- 3GPP
- Liberg, Olof, et al. Cellular Internet of things: technologies, standards, and performance. Academic Press, 2017.
- Fattah, Hossam. 5G LTE Narrowband Internet of Things (NB-IoT). CRC Press, 2018.
- Cellular IoT Fundamentals (Nordic Semi. Academy)

Gracias!