Cellular Internet-of-Things – Explained

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Outline

Before the break

- Use Cases, Roadmap and KPI
- eMTC in Rel.13
- Support of VoLTE with eMTC
- FeMTC in Rel.14

After the break

- NB-IOT in Rel.13 and Rel.14 enhancements
- Towards 5G Internet-of-Things
- Wrap-up and conclusions

Introduction –
Use cases, Cellular IoT Roadmap and KPI

Presenting: Stefania Sesia

Contributors: Stefania Sesia, Sabine Roessel, Christian Drewes, Josef Hausner

Cellular Phone Evolution 1990 – 2015

extension to 2020?

Source: 3 Denmark, 2015

The Internet of Things

50 BN Things[1+2]

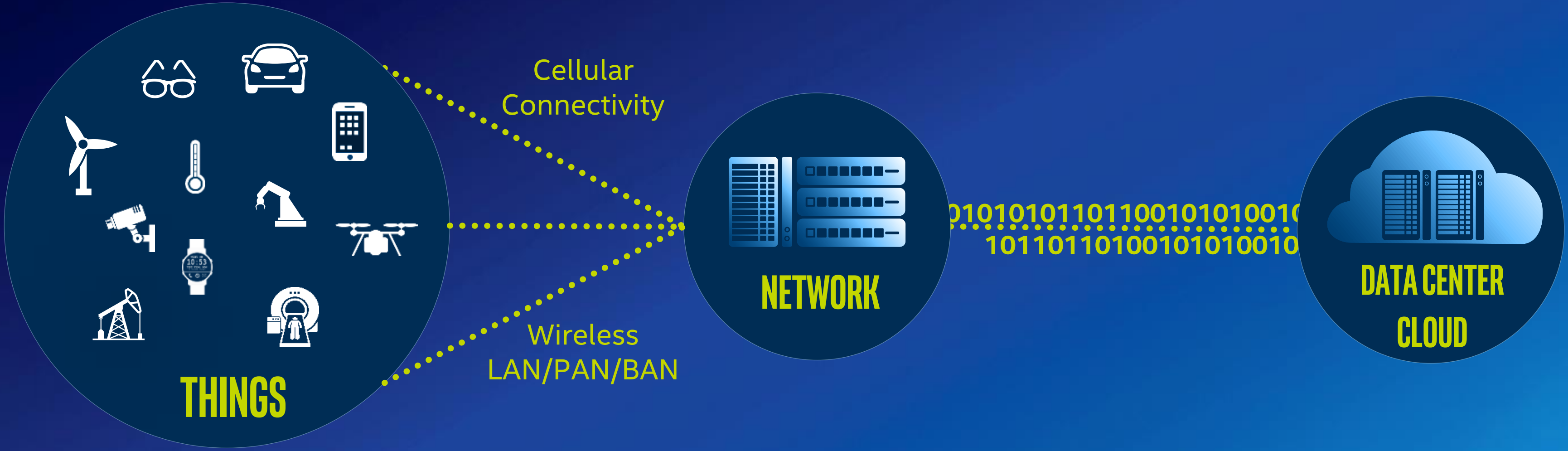
1.5 GB Internet user per day

4,000 GB Self-driving car per day

40,000 GB Connected aircraft per day

1,000,000 GB Connected factory per day

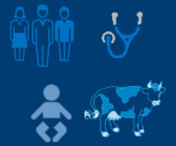
2.5 ZB IP data[3] per year



1. IDC 2016:
2. 4Q15 Gartner connected devices forecast; installed base 20 Bn devices in 2020
3. Generated IP data; 2016 Cisco VNI Global IP Traffic Forecast for 2020: 1 ZB = 1Zettabyte = 1 Bn Terabytes

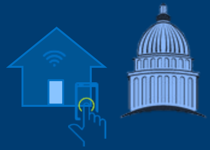
Everything Can Be A „Thing“

Consumer - remote monitoring, eHealth, VIP tracking



Smart City – e-meters, surveillance cameras, PoS, smart street light

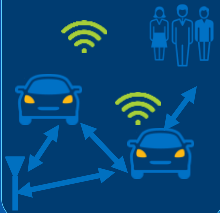
Smart Home/ Building - access control, alarm panel, light control, connected appliances



Logistics – real-time inventory, employee security, asset tracking firmware updates

Wearables - entertainment, fitness, audio streaming, monitoring, location and tracking

Automotive – infotainment, ADAS, autonomous driving



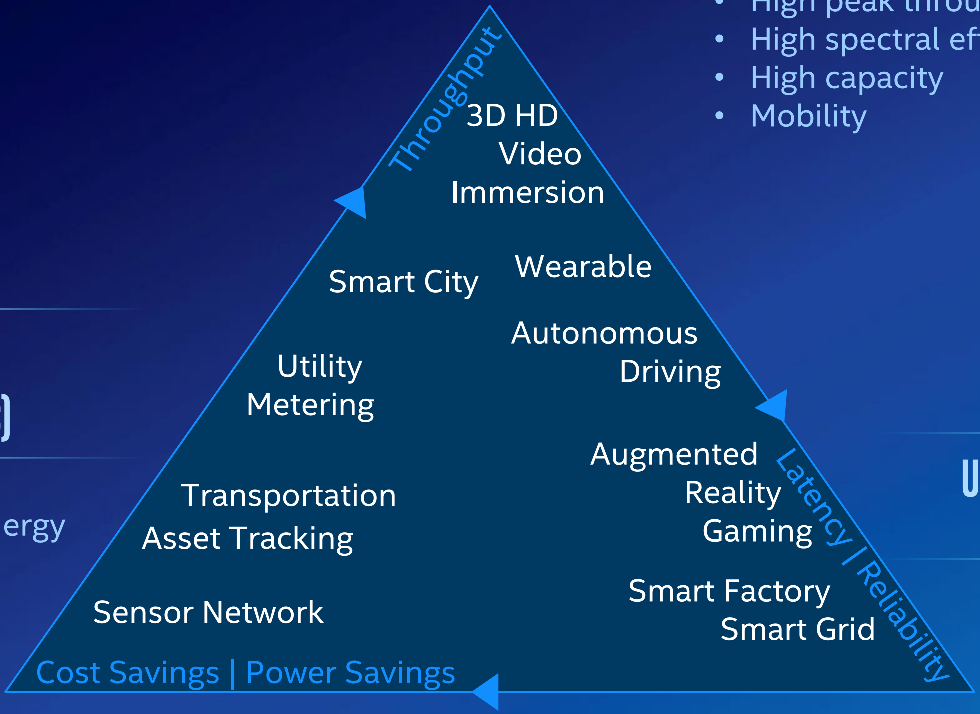
Smart Factory/ Industrial - industrial control, robot control, machine to machine, process control

Applications	Description	Battery Life <2yrs/ Mid/ >10 (Long)	Coverage Normal/ Extended/ Extreme	Latency Low/Mid/ High (Low ~ LTE, High sec to h)	Mobility Mobile/ Nomadic/ Stationary	Data rate
Utility meters	Smart meters, they require un-frequent exchange of small data.	Long	Deep indoor coverage (Extreme coverage)	High	Stationary	Low ~ 100bps to some kpbs
Payment transactions (POS terminals at retail establishments and kiosks)	Case 1. Entry Level Vending – Case 2.High level vending management, dynamic control.	Wall powered.	Outdoor/indoor, deep coverage	Mid to high	Stationary	Low some kbps for Case 1. Potentially higher for case 2
Tracking of people, pets, vehicles and assets	In general communication can be periodic or event triggered.	Long	Outdoors / indoors (extreme coverage)	Low/Mid	Mobile/Nomadic	Low ~ up to 100kbps
Wearable	Smart watch which can be used as a normal phone (calls/data download and upload even when the phone is left home).	Same as smart phone	Normal coverage	Low	As LTE	High
Home alarm panels with and without voice	Device sends the information about alarm state to a security company.	High/Mid	Normal to extended	Mid	Stationary	Low/high depending on voice/video
Automotive	Communication with Road Side Unit (V2I) or communication V2N or V2V	On car battery	Normal to extended coverage	Mid to low or very low	Mobility	From low to high
Industrial control	Communication between machine in a factory	Wall powered	Normal	Low to extremely low	Stationary	Might be large

All About Things ...

ENHANCED MOBILE BROADBAND (E-MBB)

- High peak throughput
- High spectral efficiency
- High capacity
- Mobility



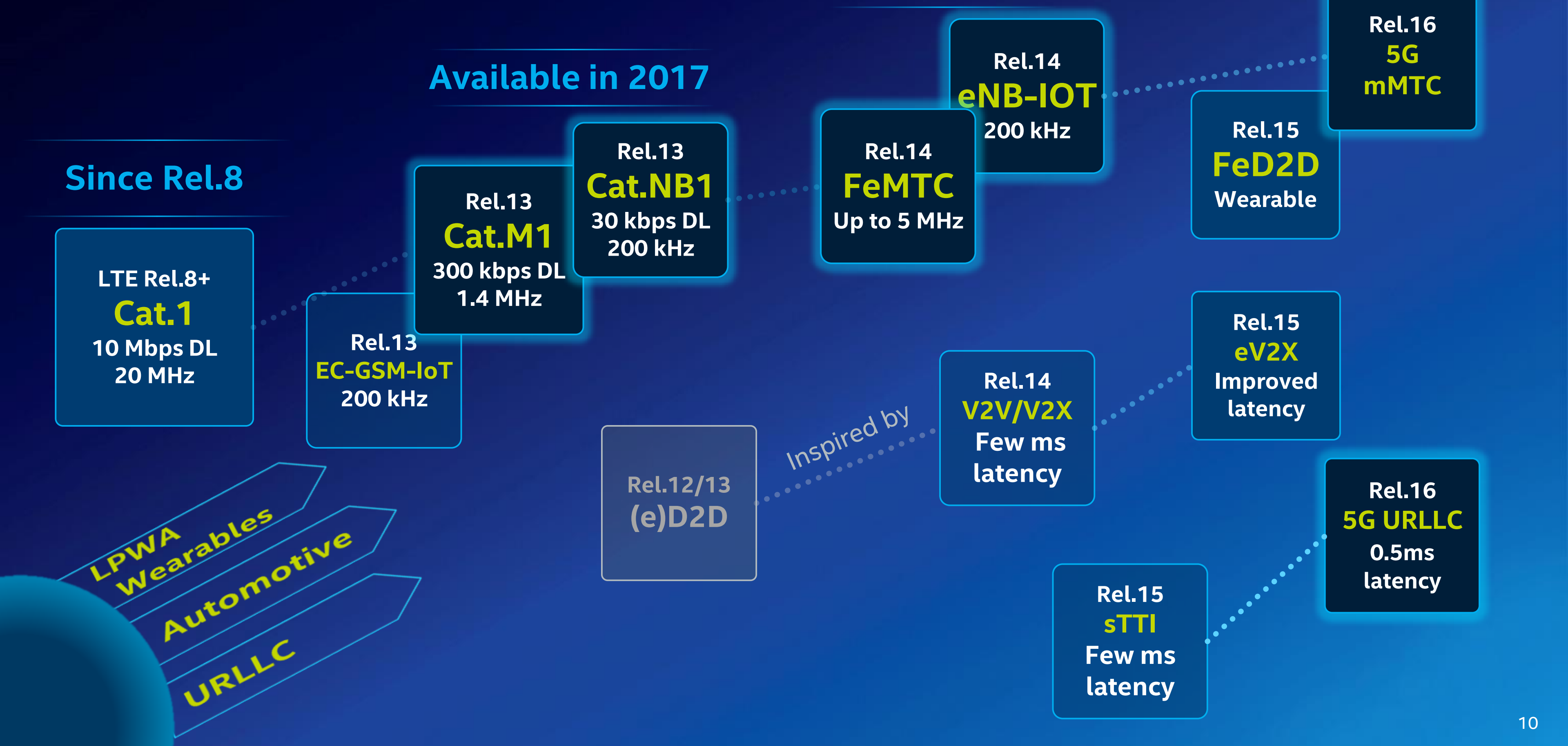
MASSIVE MACHINE-TYPE COMMUNICATION (M-MTC)

- Very large coverage
- Network and Device energy efficiency
- Massive number of connections

ULTRA-RELIABLE LOW LATENCY COMMUNICATION (URLLC)

- Ultra High reliability
- Ultra low latency

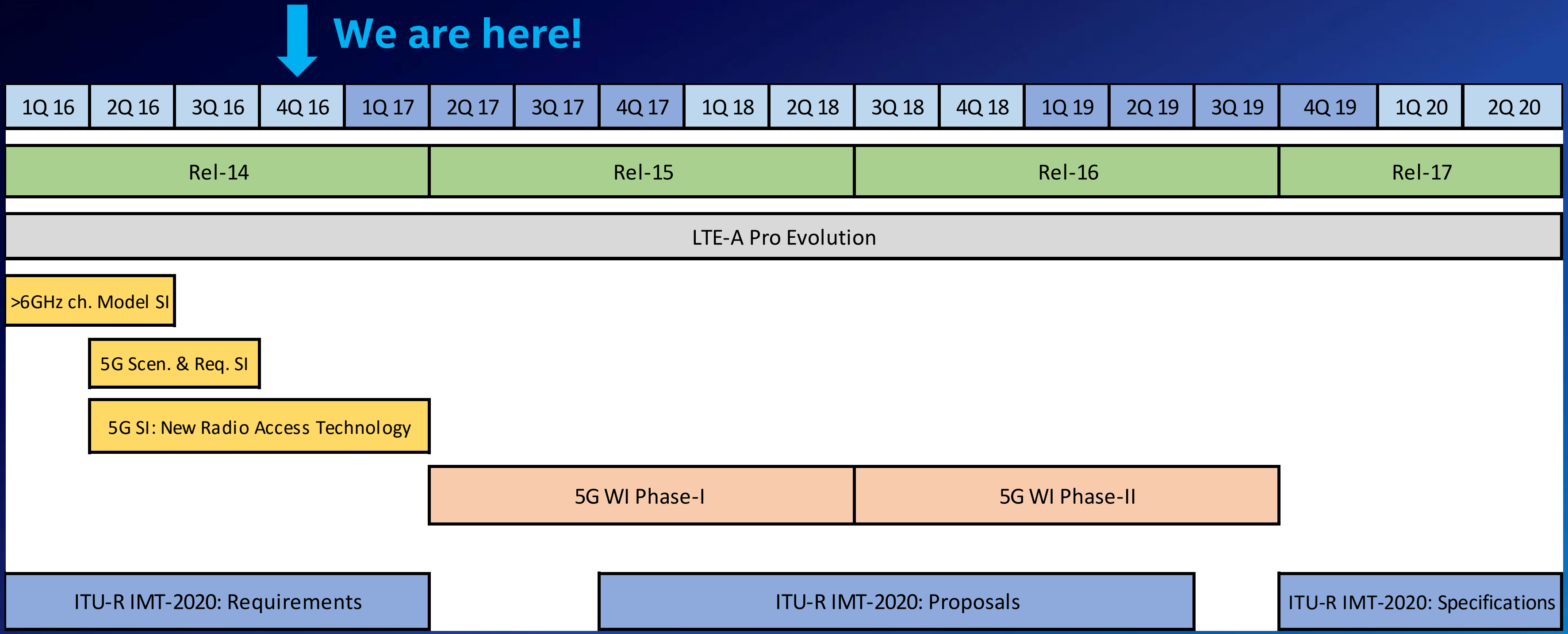
Cellular IoT in 3GPP



Comparison of Cellular IOT – LPWA segment

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%]

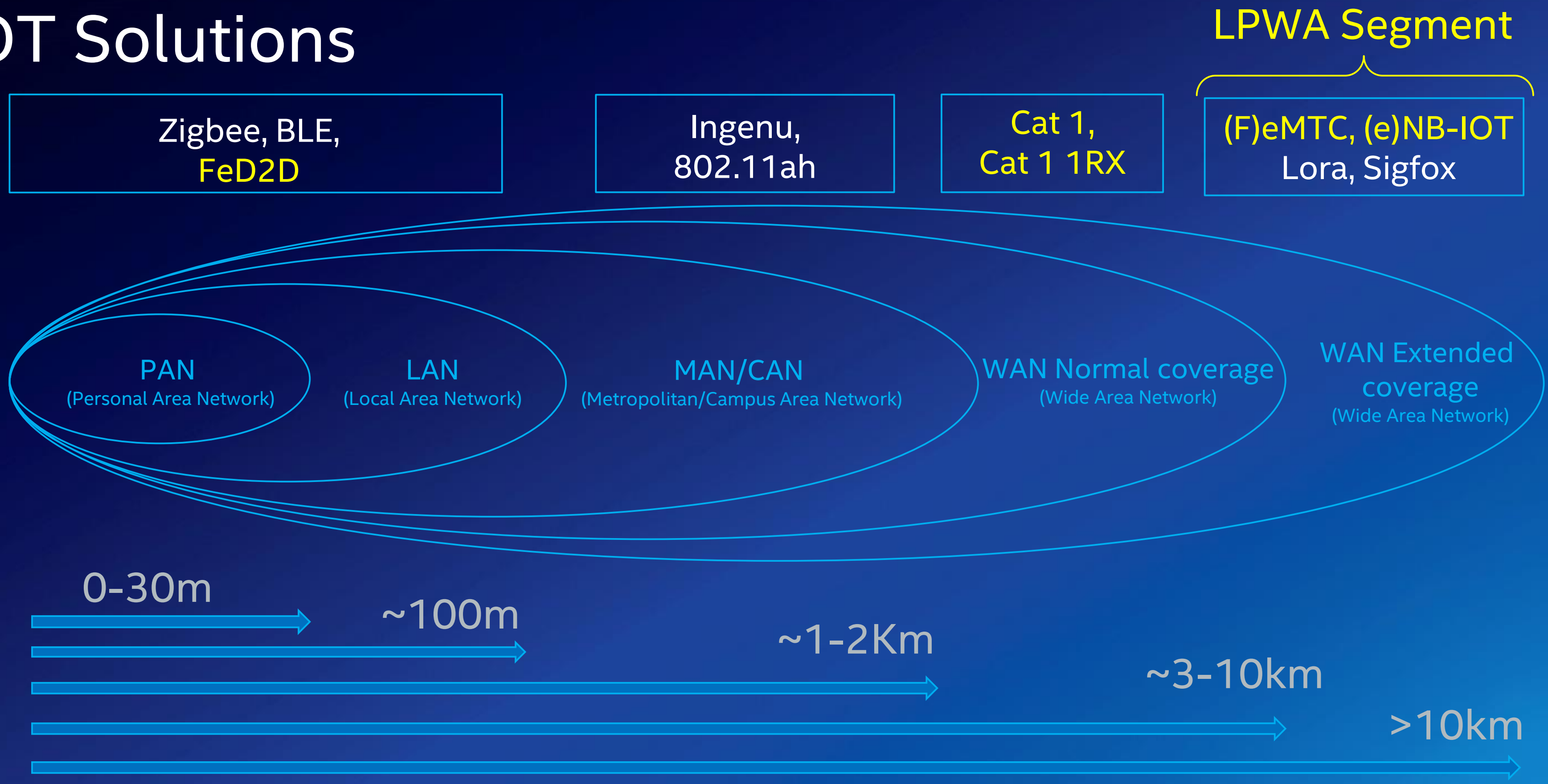
3GPP Time Line



Everything Can Be A „Thing“

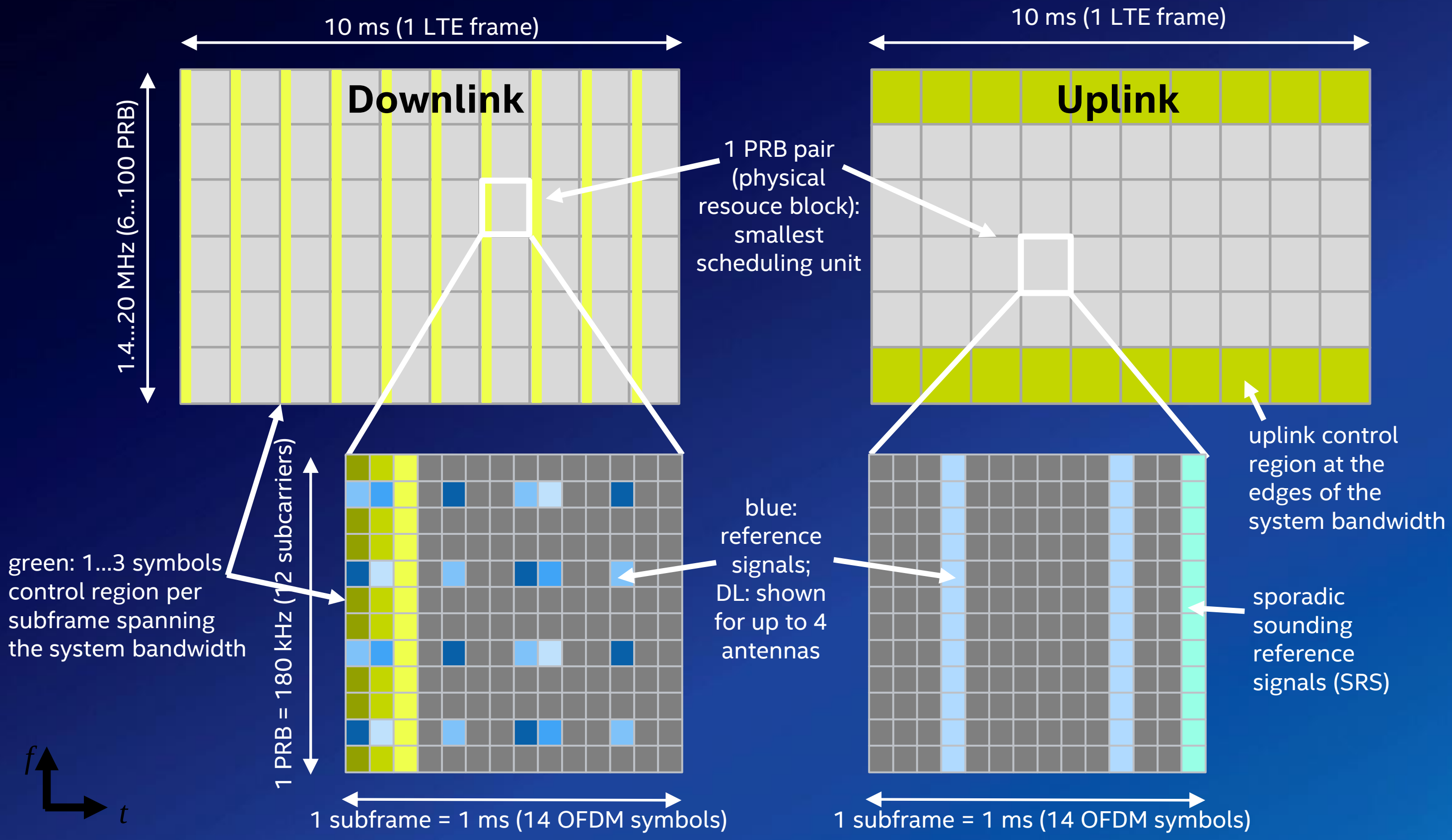
(e)NB-IOT			eNB-IOT	FeD2D	V2X/V2V	
(F)eMTC			FeMTC		Rel.14 sTTI	
5G Massive MTC					5G URLLC	
Consumer - remote monitoring, eHealth, VIP tracking	**Smart City** – e-meters, surveillance cameras, PoS, smart street light	**Smart Home/ Building** - access control, alarm panel, light control, connected appliances	**Logistics** – real-time inventory, employee security, asset tracking firmware updates	**Wearables** - entertainment, fitness, audio streaming, monitoring, location and tracking	**Automotive** – infotainment, ADAS, autonomous driving	**Smart Factory/ Industrial** - industrial control, robot control, machine to machine, process control

IOT Solutions



Disclaimer: the ranges are provided as a matter of example and depends on frequency, channel mode, line of sight etc..

Just a recall…



FDD vs TDD

FDD, frequency division duplex: separate frequency bands for uplink and downlink

TDD, time division duplex: same frequency band; up- and downlink subframes separated by guard periods: 1 or 2 “special subframes” which can also extend the neighboring UL/DL subframes

Overview of Categories

3GPP R8
3GPP R10
3GPP R11
3GPP R12
3GPP R13

cat	DL cat	UL combo	max DL Mbps	max DL MIMO	max DL BW [MHz]	max DL QAM
	NB1	*NB1*	0.03	–	0.2	4
	M1	*M1*	1	–	1.4	64
	0	*0*			20	
1			10	–	20	64
2			50	2	20	64
3			100	2	20	64
4			150	2	20	64
5			300	4	20	64
6	6	*5*	300	2 or 4	2 * 20	64
7	7	*13*				
8			3000	8	5 * 20	64
9	9	*5*	450	2 or 4	3 * 20	64
10	10	*13*				
11	11	*5*	600	2 or 4	4 * 20	64 or 256
12	12	*13*				
	13	*3,5,7,13*	400	2 or 4	2 * 20	256
	14	*8*	4000	8	5 * 20	256
	15	*3,5,7,13*	800	2 or 4	5 * 20	64 or 256
	16	*3,5,7,13*	1000	2 or 4	5 * 20	64 or 256
	17	*14*	25000	8	32*20	256
	18	*3,5,7,13*	1200	2,4,[8]	6 * 20	64 or 256
	19	*3,5,7,13*	1600	2,4,[8]	8 * 20	64 or 256

cat	UL cat	max UL Mbps	max UL MIMO	max UL BW [MHz]	max UL QAM
	NB1	0.06	–	0.2	4
	M1	1	–	1.4	16
	0			20	
1		5	–	20	16
2		25	–	20	16
3	3	50	–	20	16
4		50	–	20	16
5	5	75	–	20	64
6		50	–	20	16
7	7	100	1 or 2	2 * 20	16
8	8	1500	4	5 * 20	64
9		50	–	20	16
10		100	1 or 2	2 * 20	16
11		50	–	20	16
12		100	1 or 2	2 * 20	16
	13	150	1 or 2	2 * 20	64
	14	10000	4	32*20	64
	15	225	1 or 2	3 * 20	64
	16	300	1 or 2	4 * 20	64

← NB-IoT: Cat. NB1
← eMTC: Cat. M1

CA Carrier Aggregation
BW Bandwidth

Remarks

From Rel-12 on DL and UL categories are signaled independently

The peak data rate requirements need only to be supported on at least one band or band combination

CA/MIMO capabilities are signaled individually for each band in every supported band combination.

In case DL 256-QAM or UL 64-QAM is supported, it shall be supported in all bands.

UL cat. 15 and 16 are not yet specified (2016-09)

150 Mbps: 20 MHz, 2x2, 64 QAM
400 Mbps: 20 MHz, 4x4, 256 QAM

Introduction to Rel.13 IoT Solutions

Rel.13 eMTC

Presenting: Stefania Sesia

Contributors: Stefania Sesia, Debdeep Chatterjee, Marta Tarradell, Qiaoyang Ye

experience what's inside™

Key Definitions

Bandwidth Reduced (BR)	Refers to operation in downlink and uplink with a limited channel bandwidth of 1.4MHz (6 PRBs)
BR Low Complexity (BL)	Rel-13 LC UEs operating in BR (1.4MHz) and mandatory support of CE mode A (i.e. category M1 UE)
Coverage Enhancement (CE)	Rel-13 Coverage Enhancement (CE) or Enhanced Coverage operation (where CE mode A could be supported only, or CE mode A and B)
eMTC	BL UEs and UEs in CE

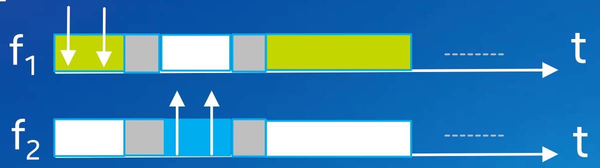
Rel.13 Machine Type Communications: Overview

- Introduction of a new **low complexity, low power, wide range** category: **Cat M1**

TDD

- **Low complexity:**
  - A bandwidth reduced low complexity (BL) UE can operate in any LTE system BW but with a limited channel bandwidth of 6 PRBs (1.4MHz) in DL and UL (TS 36.300)
  - Supports: FDD (FD-FDD and HD-FDD UEs) and TDD
    - Optimized support of Half Duplex (HD)-FDD operation using a single local oscillator → Type B HD-FDD operation is assumed
    - Guard-time of 1 subframe (1ms) is provisioned for DL-to-UL and UL-to-DL switching
  - Reduced maximum DL and UL transport block (TB) sizes of 1000 bits
    - No simultaneous reception/transmission of multiple TBs
  - Single rx antenna reception is assumed to limit the complexity
- **Low power:**
  - eDRX or PSM (see power reduction techniques)
- **Wide range:**
  - Support of coverage enhancement feature targeting 155dB Maximum Coupling Loss (MCL)

FD-FDD

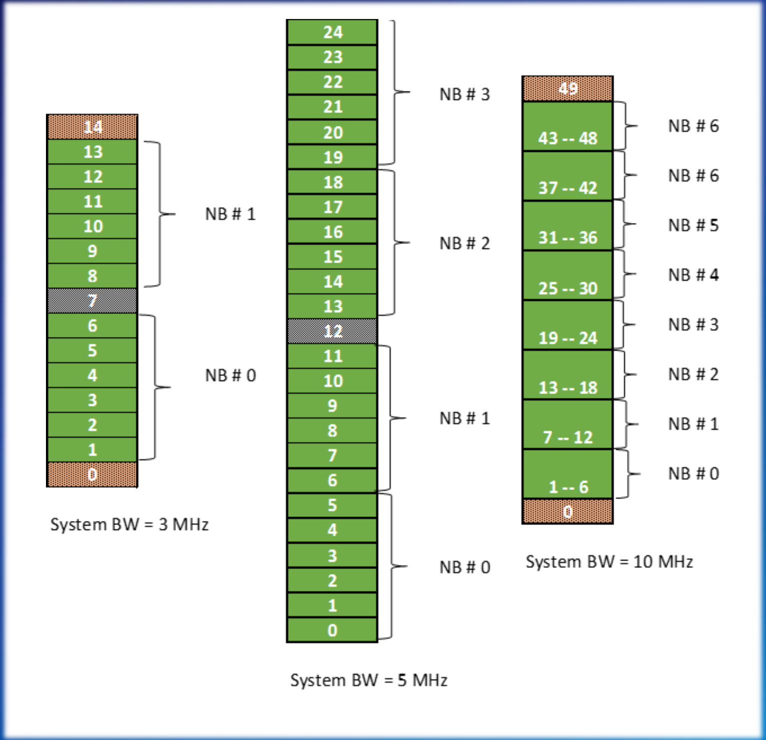


HD-FDD

Rel-13 eMTC: Narrowband (NB) Definitions

For DL and UL, the LTE system BW is divided into a set of non-overlapping narrowbands (NBs)

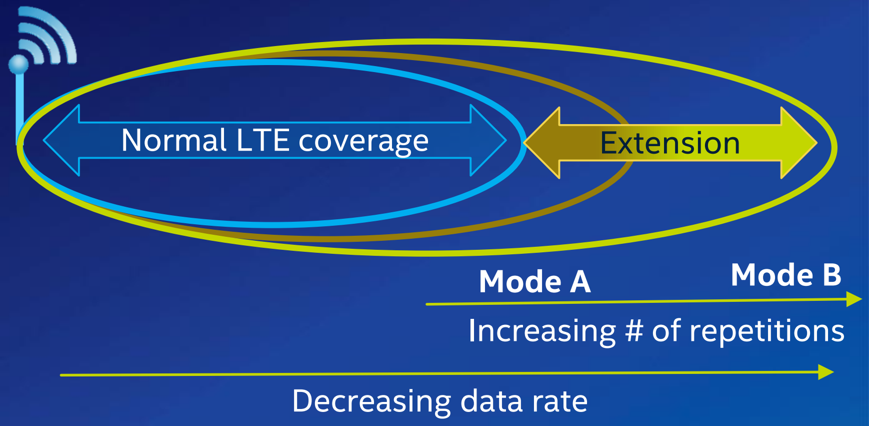
- A narrowband comprises of 6 contiguous PRBs
- Total number of NBs for DL and UL are $\lfloor N_{RB}^{DL}/6 \rfloor$ and $\lfloor N_{RB}^{UL}/6 \rfloor$ respectively
  - Remaining RBs divided evenly at both ends of the system bandwidth
  - The extra PRB for odd system BWs (e.g. 3, 5, and 15 MHz) is located at the centre of the system BW
- PSS/SSS/PBCH are mapped to the central 72 subcarriers as in LTE
  - Location of PSS/SSS/PBCH is independent of the narrowbands defined
- Retuning from one 6-PRB Narrowband (NB) to another within the LTE system bandwidth



Note: For eMTC, when referring to 1.4MHz RB(s), the specification also use the term narrowband (NB); however this term should not be confused with the 180kHz NB(s) term used for NB-IoT.

Rel.13 eMTC – Coverage Enhancement

- **Coverage Enhancement** is defined for BL UEs and higher cat. UEs
  - Target **155.7 dB** Maximum Coupling Loss (MCL) for both UL and DL.
- Two CE modes configurable via RRC
  - **CE mode A**
    - For no repetitions and small number of repetitions
  - **CE mode B**
    - For large number of repetitions
    - UE supporting CE mode B also supports CE mode A
- A **UE supporting CE** requires the use of **CE functionality** to access the cell
  - A higher category UE when in CE mimics the behavior of BL Ues
  - A UE may access a cell using CE only if MIB indicates the scheduling info. of SIB1-BR (same as for BL UEs)

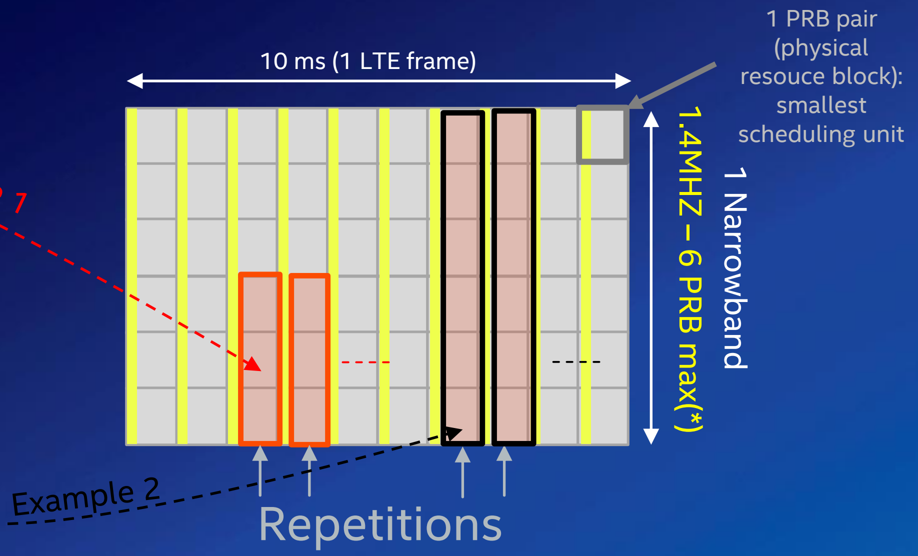


- **Key Characteristics**
  - Flexible numbers of **repetitions** supported
    - MPDCCH, PDSCH, PUSCH, PUCCH, and PRACH
  - Cross-subframe channel estimation, RV cycling
  - Multi-subframe frequency hopping from one NB to another within LTE system BW

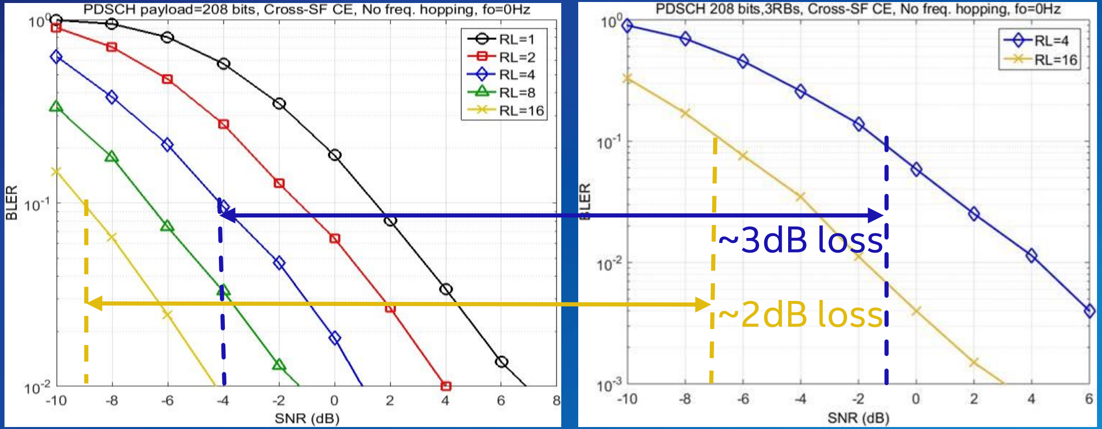
PDSCH

Indicates the modulation orderr

I_{TBS}	RB					
	1	2	3	4	5	6
0	16	32	56	88	120	152
1	24	56	88	144	176	208
2	32	72	144	176	208	256
3	40	104	176	208	256	328
4	56	120	208	256	328	408
5	72	144	224	328	424	504
6	328	176	256	392	504	600
7	104	224	328	472	584	712
8	120	256	392	536	680	808
9	136	296	456	616	776	936
10	144	328	504	680	872	



- CE Mode A: QPSK and 16QAM, Mode B: only QPSK. **Max TBS 936 bits(*)** (e.g. mapped on 6PRBs only for CE Mode B).
  - Coverage enhancement is achieved via repetitions
- **Supported TM: 1, 2, 6, 9 with no MIMO(*)**
- **Performance requirements are set under the assumption of single RX antenna**
- HARQ processes: in Mode A max 8 for FDD and variable for TDD, For Mode B max 2. HARQ asynch and adaptive

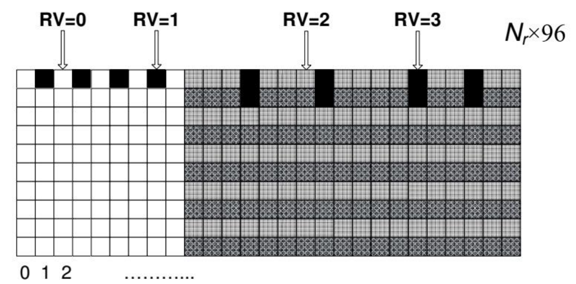


(*) Items that enable complexity reduction

PDSCH cont'd

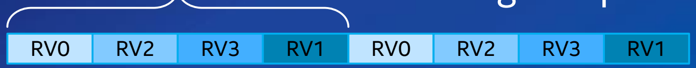
Coverage enhancements

- Preconfigured set: {1, 2, 4, 8, 16, 32, 64, 128, 192, 256, 384, 512, 768, 1024, 1536, **2048**}
- Default values Mode A set = {1,2,4,8}, Mode B: set = {4,8,16,32,64,128,256,512}.
- Max # of RL configurable via MTC-SIB, network dependent.
- Repetitions are across valid DL subframes, with redundancy version cycling
  - every Z subframes, with Z=1 for CE Mode A and Z=4/10 for CE Mode B in FDD/TDD



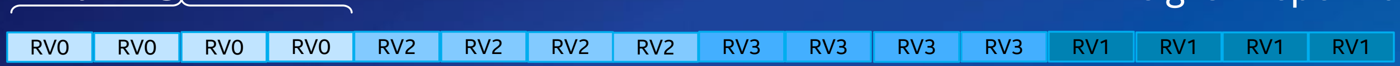
RV cycling Z=1 for CE Mode A

e.g. 8 repetitions



RV cycling Z=4 for CE Mode B, FDD

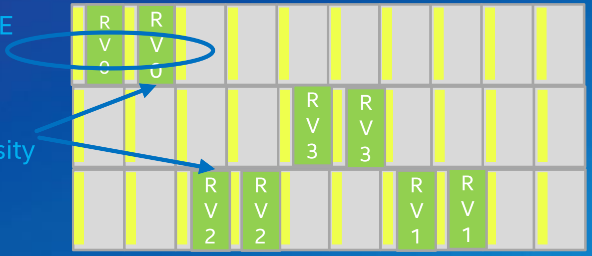
e.g. 32 repetitions



- Multi-Frame Frequency Hopping with "Y_{ch}" interval
  - **CE Mode A FDD {1,2,4,8}, TDD {1,5,10,20}**
  - **CE Mode B, FDD {2,4,8,16}, TDD {5, 10,20, 40}**

This allows for cross subframe CE

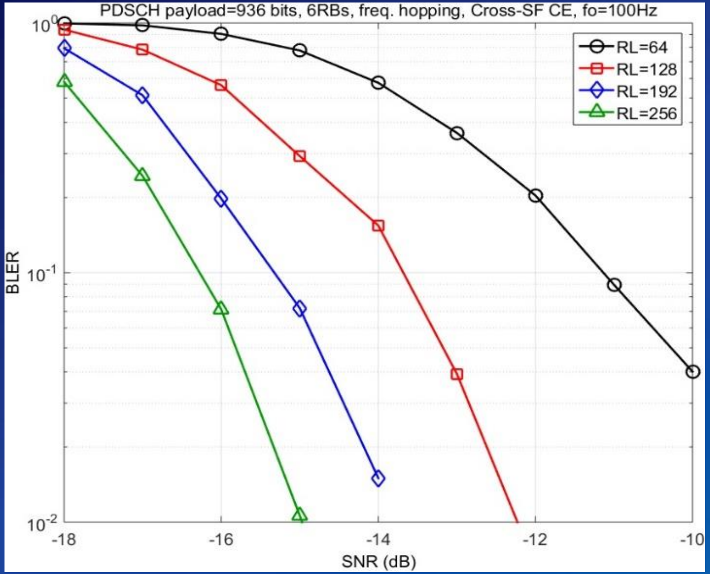
This provides frequency diversity



e.g. CE Mode B, 8 RL, FDD, Y_{ch}=2

Coverage for PDSCH

Technology	LTE Cat 1+	Cat M1
Physical channel name	PDSCH	PDSCH 6PRB
Data rate(kbps)	20	**4.8**
Repetitions	--	192
Transmitter		
Max Tx power (dBm)	46	46
(1) Actual Tx power (dBm)	32.0	36.8
Receiver		
(2) Thermal noise density (dBm/Hz)	-174	-174
(3) Receiver noise figure (dB)	9	9
(4) Interference margin (dB)	0	0
(5) Occupied channel bandwidth (Hz)	360000	1080000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-109.4	-104.7
(7) Required SINR (dB)	-4.0	**-14.2**
(8) Receiver sensitivity = (6) + (7) (dBm)	-113.4	-118.9
(9) MCL = (1) – (8) (dB)	145.4	**155.7**
NOTE 1: eNB is assumed with 2 Tx and 2 Rx in FDD systems		



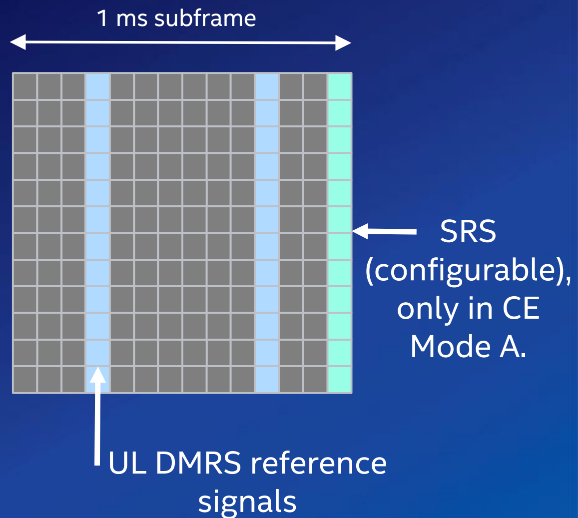
TBS 936bits, 6PRB - 1.4MHz, # RL: 192
Data rate= ~4.8Kbps, Target SNR @BER 10^{-1} <-14.2dB,
Coverage level >155dB

In downlink the best strategy is to map the TBS over the largest bandwidth **to maximize the data rata**

PUSCH

Similar functionalities as for PDSCH

- **PUSCH** transport block (TB) mapped to a single subframe and repeated using same or different RVs and predefined set of repetitions
  - QPSK and 16QAM for Mode A and QPSK for Mode B
- **Cross-subframe** channel estimation for performance improvements
- **Multi-Subframe Frequency Hopping** across narrow-bands to realize frequency diversity
  - Configured via RRC
- In CE Mode B, allocated PUSCH bandwidth can be either 1 PRB or 2 PRB
- **Asynchronous and adaptive HARQ**
  - Same amount of processes as for PDSCH
  - No PHICH for carrying HARQ-ACK feedback in response to PUSCH
    - feedback is realized using **MPDCCH**
  - Retransmission or transmission of new TB is indicated via toggling of the New Data Indicator (NDI) bit
  - UE UL grant includes the HARQ process number and RV number (for CE Mode A)



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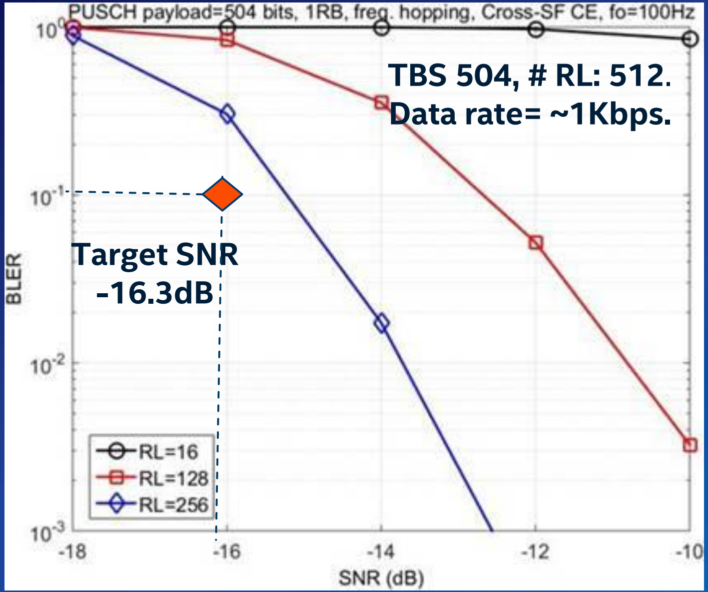
6	328	176	256	392	504	600
7	104	224	328	472	584	712
8	120	256	392	536	680	808
9	136	296	456	616	776	936
10	144	328	504	680	872	

PUSCH performance

Technology	LTE Cat 1+	Cat M1	
Physical channel name	PUSCH	PUSCH 1PRB	PUSCH 3PRB
Data rate(kbps)	20	1	~0.240
Transmitter			
Max Tx power (dBm)	23	23	23
(1) Actual Tx power (dBm)	23	23	23
Receiver			
(2) Thermal noise density (dBm/Hz)	-174	-174	-174
(3) Receiver noise figure (dB)	5	5	5
(4) Interference margin (dB)	0	0	0
(5) Occupied channel bandwidth (Hz)	360000	180000	540000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-113.4	-116.4	-111.7
(7) Required SINR (dB)	-4.3	-16.3	-21
(8) Receiver sensitivity = (6) + (7) (dBm)	-117.7	-132.7	-132.7
(9) MCL = (1) – (8) (dB)	140.7	155.7	**155.7**
NOTE 1: eNB is assumed with 2 Tx and 2 Rx in FDD systems. NOTE 2: Coverage enhancement is achieved thanks to repetitions			

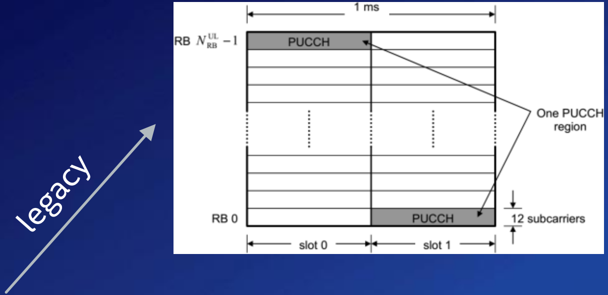


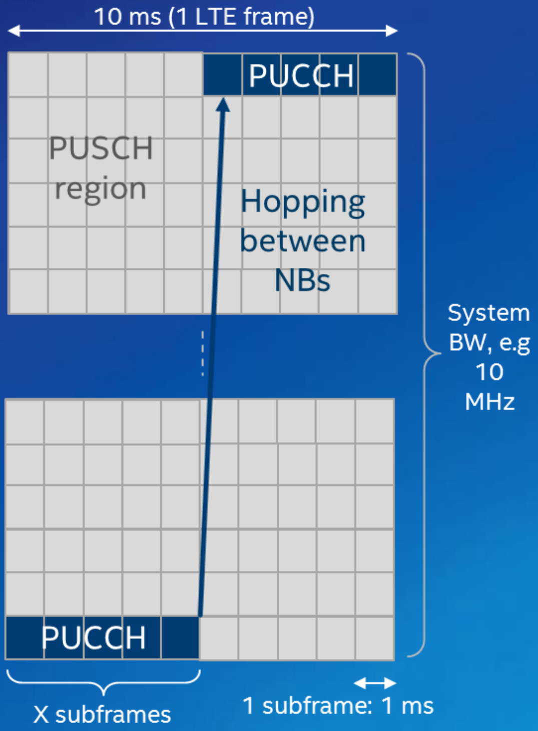
Very low SNR requirements to meet target MCL for larger BW. **Challenging!**

In uplink the best strategy is to concentrate the power over an **as narrowband as possible** allocation (1PRB)

PUCCH design

- Feedback (ACK/NACK) and Scheduling Requests
- Periodic CSI feedback supported over PUCCH for CE Mode A
- Both slots in a subframe are used for transmission of a PUCCH
  - Slot-based frequency hopping is not supported
  - Frequency hopping at the subframe-level **is always used** when PUCCH is transmitted with repetitions
  - Narrowbands for PUCCH frequency hopping are symmetric to the central frequency of system bandwidth
  - PUCCH transmissions are maintained at the same PRBs for at least ‘Y_{ch}’ subframes – configured via higher layers
- PUCCH coverage enhancement techniques
  - Repetitions across multiple subframes
    - RRC CONNECTED: # of repetitions for PUCCH: {1,2,4,8} for CE Mode A, **{4, 8,16, 32}** for CE mode B (signalled via RRC)
    - Before RRC connection is established, (as part of random access procedure, in response to Msg4 transmissions)
      - signalled via MTC-SIB *per PRACH CE level* CE level 0 or 1, {1, 2, 4, 8} or CE level 2 or 3, {4, 8, 16, 32}
- Formats
  - In CE mode A PUCCH format 1/1a/2/2a
  - In CE mode B PUCCH format 1/1a





PUCCH coverage

Physical channel name	PUCCH (1a)	PUCCH (1a) (Cat M1)
Data rate(kbps)		
Transmitter		
Max Tx power (dBm)	23	23
(1) Actual Tx power (dBm)	23.0	23.0
Receiver		
(2) Thermal noise density (dBm/Hz)	-174	-174
(3) Receiver noise figure (dB)	5	5
(4) Interference margin (dB)	0	0
(5) Occupied channel bandwidth (Hz)	180000	180000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-116.4	-116.4
(7) Required SINR (dB)	-7.8	**-15.3**
(8) Receiver sensitivity = (6) + (7) (dBm)	-124.24	-132.74
(9) MCL = (1) – (8) (dB)	147.2	**155.7**

Good coverage already in legacy LTE network

16 repetitions enough to achieve ~8dB SNR improvement

Rel-13 eMTC: New DL control channel (MPDCCH)

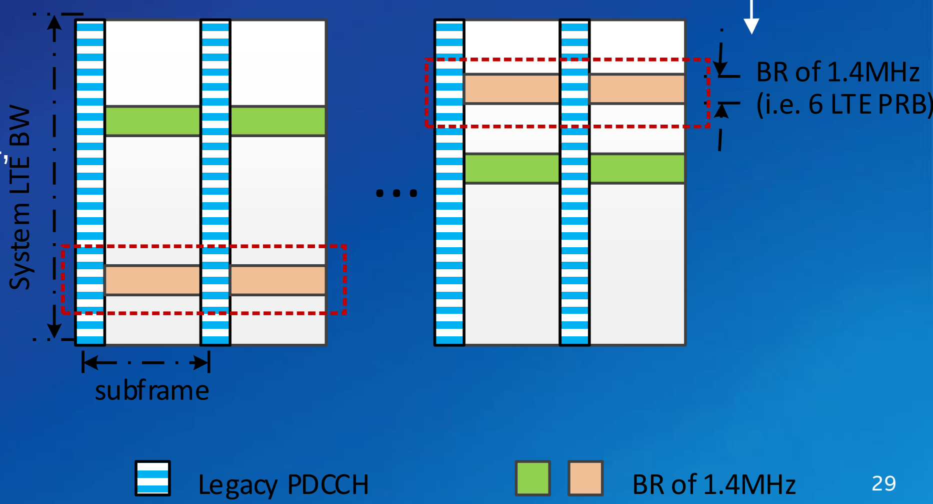
BL/CE UEs are not able to receive wide-band LTE PDCCH → New Control Channel **MPDCCH**

MPDCCH brings DCI in DL , UL Grant, ACK/NACK info for UL HARQ and it is used for the paging and random access procedure.

MPDCCH construction

- Control Channel Elements (CCEs) aggregated in frequency domain → **Aggregation levels (ALs)**
- Aggregated CCEs repeated across subframes → **Repetition levels (RLs)**
  - ALs for MPDCCH: L = 8, 16, 24 CCEs corresponding to 2, 4, 6 PRBs
  - RLs for MPDCCH: R = {1, 2, 4, 8, 16, 32, 64, 128, 256}
  - L is the same for R retransmission
- UE blindly decodes for MPDCCH candidates with different ALs and RLs
- MPDCCH can be multiplexed with an unassociated PDSCH if R=1 otherwise no multiplexing

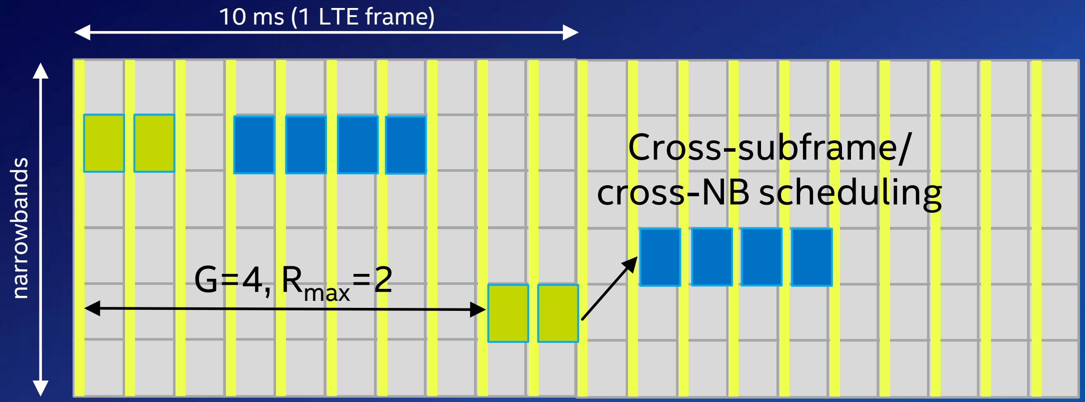
- Narrowband DL control channel based on Rel-11 EPDCCH
  - Not mapped to legacy control regions
  - Narrowband control channel limited to no more than 6 PRBs



MPDCCH con't'd

Starting subframe

- The starting subframe of the MPDCCH Search Space (SS) is configured as part of the MPDCCH SS configuration
- Repetitions for MPDCCH are indicated in the DCI
- The periodicity of starting subframes of UE-SS can be longer than maximum number of R.
  - **$T = R_{max} * G$**, G $\in$ {1, 1.5, 2, 2.5, 4, 5, 8, 10} for FDD; G $\in$ {1, 2, 4, 5, 8, 10, 20, reserved} for TDD;



Cross-subframe scheduling

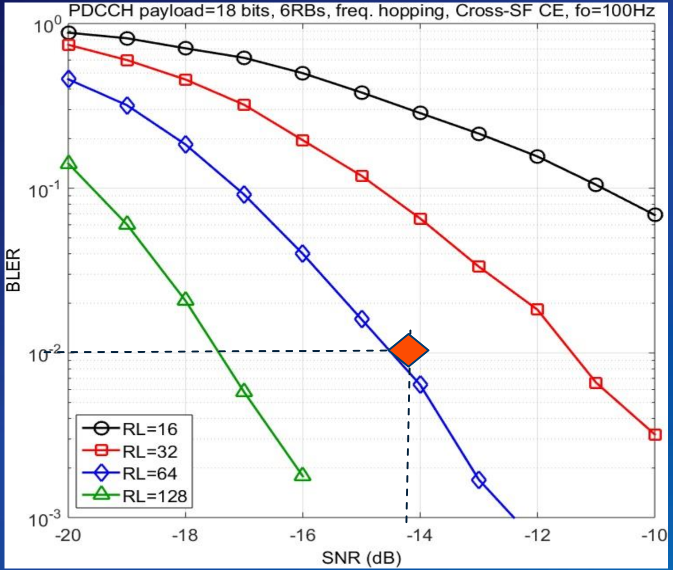
- Reduction in UE complexity
- PDSCH (new and re-transmissions) starts from the second valid downlink subframe after the end of the corresponding transmitted MPDCCH with the given repetition level
- No support of same-subframe scheduling

Cross-NB scheduling

- For unicast PDSCH, DCI indicates one of narrowband and further indicates resource allocation within narrowband requirement

Coverage for MPDCCH

Technology	LTE Cat 1+	Cat M1
Physical channel name	PDCCH (1A)	MPDCCH
Payload (bits)	36bits	34bits
Transmitter		
Max Tx power (dBm)	46	46
(1) Actual Tx power (dBm)	42.8	36.8
Receiver		
(2) Thermal noise density (dBm/Hz)	-174	-174
(3) Receiver noise figure (dB)	9	9
(4) Interference margin (dB)	0	0
(5) Occupied channel bandwidth (Hz)	4320000	1080000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-98.6	-104.7
(7) Required SINR (dB)	-4.7	-14.2
(8) Receiver sensitivity = (6) + (7) (dBm)	-103.34	-118.9
(9) MCL = (1) – (8) (dB)	146.1	155.7
NOTE 1: eNB is assumed with 2 Tx and 2 Rx in FDD systems. NOTE 2: Coverage enhancement is achieved thanks to repetitions		



64 Repetitions can achieve the target coverage.

Frequency Retuning and Timing Relationships

Frequency Retuning

Due to reduced bandwidth support, BL UE needs to perform RF retuning as they switch narrowbands within the larger system bandwidth

The maximum retuning time between narrowband regions is 2 symbols including CP length

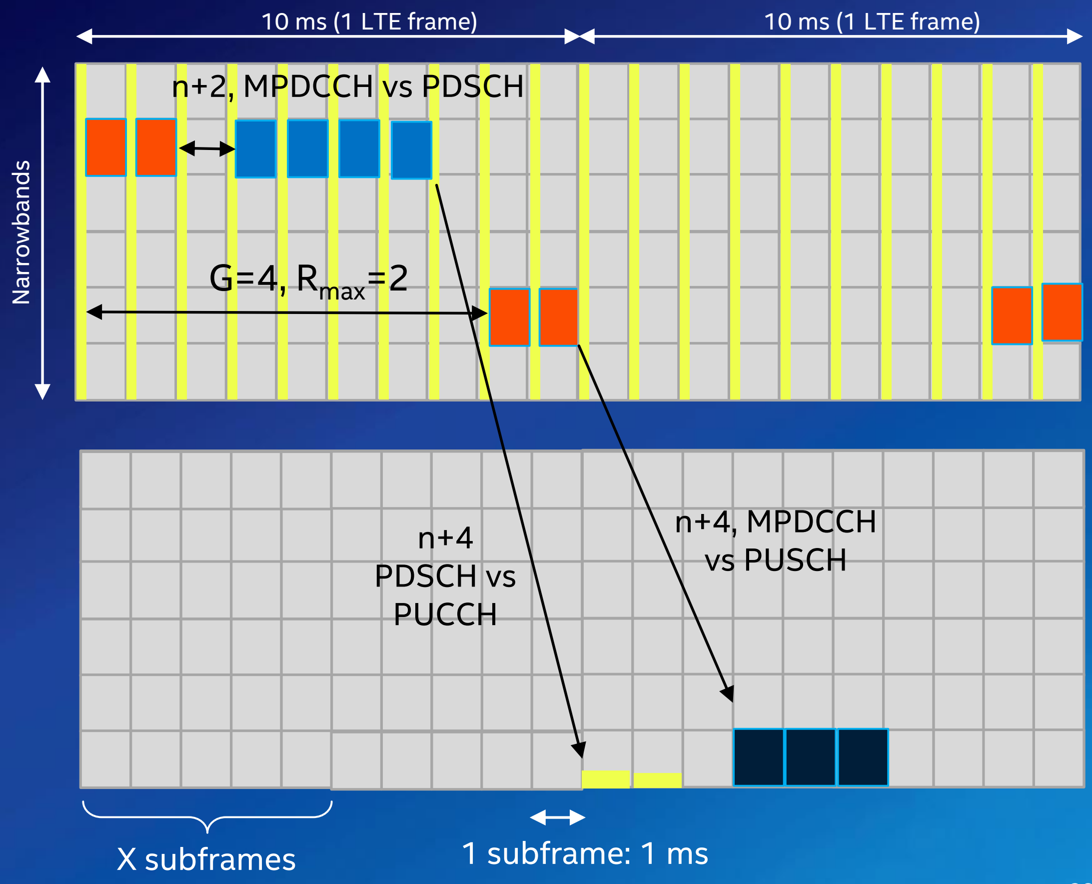
DL retuning

- Retuning between DL NBs (or UL to DL NBs for TDD):
  - It is assumed that UE uses the legacy PDCCH duration to perform retuning

UL retuning

- PUSCH→PUSCH and PUCCH → PUCCH: Last symbol of the earlier subframe + first symbol of the latter subframe
- PUCCH → PUSCH or PUSCH→PUCCH: First/last two symbols of PUSCH

Timing Relationship



Data rate computations

Two ways to compute the data rate

- **“Instantaneous” data rate:** It corresponds to the amount of information bits sent over a period of time starting from the beginning of the PDSCH transmission
- “Effective” data rate: It corresponds to the amount of information bits sent over a period of time from the time when the grant is sent to the time when a new grant can be transmitted

Example of instantaneous data rate

- TBS 936 bits transmitted with 192 repetitions → **936bits/192ms = 4.8Kbps**

Example of effective data rate

- TBS 936 bits transmitted with 192 repetitions
- MPDCCH RL 64
- Minimum time required for the transmission: T_{min} > 64(MPDCCH RL) + 1(MPDCCH→ PDSCH) + 192 (PDSCH RL) + 3 (PDSCH →PUCCH) +16 (PUCCH RL) = 276ms
- Starting MPDCCH subframe >T_{min} → G=5 , T=G R_{max}= 320ms
- **Average data rate: 936bits/320ms = 2.9Kbps**

Rel.13 eMTC – Cell Acquisition

Synchronization signals (PSS/SSS)

- Rel-13 BL/CE UEs use LTE PSS/SSS for time/frequency synchronization and cell identification

Broadcast channel (PBCH)

- A BL UE may access a cell only if the MIB indicates the scheduling information of SIB1-BR. If not, the UE considers the cell as barred
- LTE PBCH enhanced to support repetitions at symbol and subframe levels
  - Up to the NW to support PBCH repetitions, but once detected, the UE may assume presence of PBCH repetitions for future acquisitions/reacquisitions
  - "Keep trying" method to enable MIB acquisition
- 5 of the 10 spare bits from LTE MIB used to indicate support of BL/CE UEs in the cell and for SIB1-BR scheduling information

System information

- **New SI**: Bandwidth Reduced (BR) versions of the SIB1 or SI messages are introduced
- **Scheduling**: SI messages carried on PDSCH using semi-static resource allocation
  - MIB indicates scheduling information for SIB1-BR
  - SIB1-BR carries scheduling information for other SI messages
    - Scheduling information includes NB index, MCS/TBS, repetition patterns, etc.
  - PDSCH carrying SI messages always use 6 PRBs
  - SIB1-BR is periodically repeated every 8 frames
    - Within a period, SIB1-BR can be repeated a number of times $\in \{4, 8, 16\}$ with RV cycling
    - The duration over which the content of SIB1-BR that the UE can assume to NOT change is 512 radio frames
- **Reservation of OFDM symbols for LTE DL control**: Starting OFDM symbol in a DL subframe for MPDCCH and/or PDSCH is signaled via the SIB1-BR

Introduction to Rel.13 IoT Solutions

VoLTE over eMTC

Presenting: Stefania Sesia

Contributors: Stefania Sesia, Debdeep Chatterjee, Marta Tarradell, Qiaoyang Ye

experience what's inside™

eMTC and VoLTE

Why VoLTE support with IoT?

- Some use cases require the support of Voice to some extent
  - Home Security
  - Emergency
  - POS …

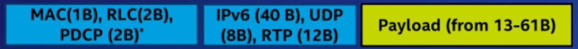
Why type of voice user experience is it required?

- **Still not finalized and not clear.**
  - Discussion on going to understand what is feasible
  - Tradeoff between complexity/coverage/quality
    - Complexity is mainly driven by HD-FDD vs FD-FDD 1 RX antenna vs 2 RX antennas
    - Coverage is limited by the latency budget → # RL
    - Quality depends on BLER target, presence of HARQ, packet aggregation

Which IoT Technology?

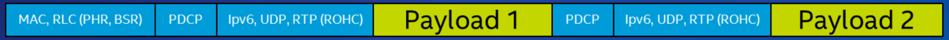
- Cat M1 is under analysis
- Cat M1: Coverage extension is achieved via repetitions which impact the support of real time services such as voice or audio streaming.
- **3GPP does not preclude the support of voice!**

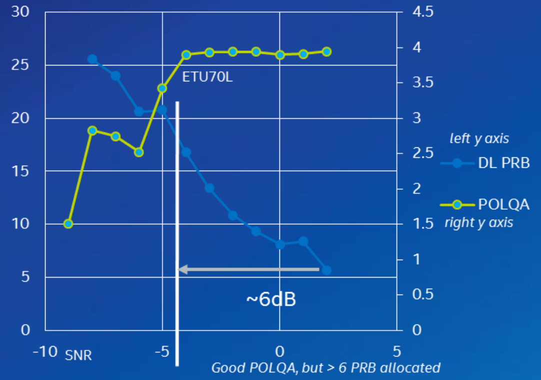
A VoLTE packet is composed of 20ms speech burst in case of no aggregation



Aggregation possible at the RTP level (codec frame bundling) (Called "H" – Higher layer)

Aggregation possible at the RLC layer





Scenario:

- DL 2 RX; BW: 20 MHz, **CAT 1 UE**
- Each SNR point consists of 50 Harvard sentences (~ 50*10 sec.)
- Averaging of POLQA and PRB allocation over 500sec. is done for each SNR point.
- AMR-WB 12.65 kbps TBS 712 bits
  - IPv4 (20 byte) + RoHC + C-DRX-40
- Target Coverage: SNR_{Target} = –4 dB (R1-143769)

➔ For Cat 1, an allocation with up to a maximum of 6 PRB is only possible for SNR ≥ 2 dB.

Simulation results

- HD-FDD for PDSCH and PUSCH, AMR-WB **6.6kbps and EVS 7.2kbps, target BLER 2%, CE Mode A**
- Fixed latency of < 40ms. Aggregation of 40ms. RTP aggregation when < 1000 otherwise split at MAC layer into two packets

SF#	0	1	2	3	4	5	6	7	8	9	0	1	2
PDSCH	D1	D1	D1	D1									
Switch					S								
PUCCH								A1					
PUSCH						U1	U1		U1	U1	U1	U1	U1

Example of timing relationship for HD-FDD, where PDSCH and PUSCH are SPS scheduled, and PUCCH has no repetition, which punctures PUSCH.

# of DL repetitions + # of UL repetitions + 1 ≤ time budget

ROHC	Type of channel	TBS	# PRB	RL				
				2	4	8	16	32
YES	PDSCH	408	6	136.76	139.46	141.76	144.96	--
YES	PUSCH	456	3	130.08	132.98	135.88	138.78	142.08
NO	PDSCH	712 (x 2)	6	134.06	137.06	139.86	143.06	--
NO	PUSCH	744 (x2)	3	126.38	129.88	132.48	135.68	138.68

Overall MCL 139dB

Overall MCL 134dB

VoLTE over Cat M1 is feasible but achieving good coverage is challenging

Introduction to Rel.14 IoT Solutions

Rel.14 FeMTC

Presenting: Stefania Sesia

Contributors: Stefania Sesia, Debdeep Chatterjee, Marta Tarradell, Christian Drewes

experience what's inside™

FeMTC

Use cases:

- Several use cases require higher data rate (e.g. audio streaming), broadcast support (e.g. for software updates), positioning (e.g. asset tracking, fleet management) and support of voice (e.g. wearables)
  - While guaranteeing low power consumption, low complexity and extended coverage

Wearables

Entertainment, fitness, audio streaming, monitoring, location and tracking

Smart manufacturer

Real-time inventory, employee security, asset tracking firmware updates

50B Connected Objects in 2020!

Criterion	Cat. 1 (Rel. 8)	Cat. M1 (Rel. 13)	FeMTC (Rel. 14)
Bandwidth	20 MHz	1.4 MHz	Up to 5 MHz for BL UE DL/UL
Deployments/ HD-FDD	LTE channel, no HD-FDD	standalone, in LTE channel / HD-FDD preferred	standalone, in LTE channel / HD-FDD, FD-FDD, TDD
MOP	23 dBm	23 dBm, 20dBm	23 dBm, 20 dBm
Rx ant / layers	2/1	1/1	1/1
Coverage, MCL	145.4 dB DL, 140.7 dB UL	155 dB	155 dB
Data rates (peak)	DL: 10 Mbps, UL: 5 Mbps	~800 kbps (FD-FDD) 300/375 kbps DL/UL (HD-FDD)	DL/ UL: 4 Mbps FD-FDD @ 5MHz
Latency	Legacy LTE: < 1s	~ 5s at 155dB	at least the same as Cat.M1 Improved for good coverage
Mobility	Legacy support	Legacy support	Legacy support
Positioning	Legacy support	Partial support	OTDOA with legacy PRS and Frequency hopping
Voice	Yes	No	Yes + audio streaming

Increased Bandwidth and TBS

Larger channel BW operation

- Enabled by eNB via RRC signalling in a semi static manner.
- **Rel-14 BL UEs**
  - In RRC connected max BW 5MHz or 1.4MHz for DL and UL (configured independently)
    - 5MHz BL UE: Max TBS 4008 (DL/UL)
    - 1.4Mhz BL UE: Max TBS 2984 (UL)
  - In Idle mode the UE fallsback to eMTC.
  - CE Mode A both 1.4MHz and 5MHz max BW possible for both DL and UL
  - CE Mode B 1.4 and 5MHz max BW possible for DL; 1.4MHz only possible for UL
- **Rel-14 non BL UEs**
  - Max BW 1.4MHz, 5MHz or 20MHz for DL and 1.4MHz and 5MHz for UL
  - CE Mode A 1.4, 5 and 20MHz max BW possible for DL and 1.4 and 5MHz for UL
  - CE Mode B 1.4, 5, 20MHz max BW possible for DL; 1.4MHz only possible for UL
  - TBS depends on the UE category

A Rel-14 UE BL or non BL supporting CE will support the MPDCCH for scheduling

Other enhancements

Broadcast operation → SC-PTM: Single Cell Point to Multipoint Transmission

- **MDPCCH is used to schedule broadcast operation, i.e. SC-MCCH and SC-MTCH.**
  - **SC-MCCH is carried by PDSCH over 6PRB and max 1000bits TBS**
  - **SC-MTCH is carrier by PDSCH with higher TBS (potentially 4008bits).**

Enhanced Volte support

- New # of repetitions for PUSCH → {1, 2, 4, 8, 12, 16, 24, 32}:
- Adjusted scheduling relationships between physical channels TBD

Positioning: Observed Time Difference Of Arrival

- Based on the transmission of Positioning Reference Signals PRS
- PRS BWs same as LTE PRS: {1.4, 3, 5, 10, 15, 20} MHz
- One cell can transmit multiple PRS time-freq configurations with possibly different PRS BWs
- M**ultiple PRS occasions** can be configured in a legacy PRS period

Rel.13 NB-IOT and Rel.14 enhancements

Presenting: Sabine Roessel

Contributors: Sabine Roessel, Debdeep Chatterjee, Stefania Sesia, Marta Tarradell, Biljana Badic, Arjang Hessamian-Alinejad, Ansgar Scherb, Xinrong Wang
Intel Corporation

Rel.13 NB-IOT waveform and numerology

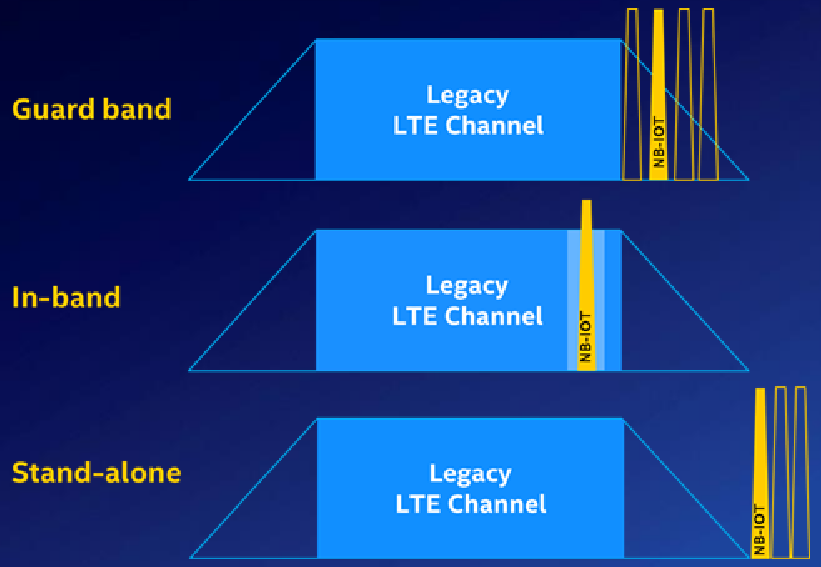
Downlink

- 15 kHz subcarrier spacing (SCS) with OFDMA
  - DL LTE coexistence in in-band and in guard band operation mode

Uplink

- SC-FDMA for multi-tone transmissions
- Single-tone incl. Cyclic Prefix (CP) w/ frequency domain sinc pulse-shaping
  - New CP for 3.75kHz UL of 8.33μs with symbol duration of $528T_s$ = 275μs
- 15 kHz subcarrier spacing (SCS): single-tone & multi-tone
  - UL LTE coexistence
  - Lowered power consumption in good radio conditions
- 3.75 kHz SCS: single-tone
  - Worst-case coverage requirements
  - Increased user multiplexing in UL

Rel.13 NB-IOT deployment (1/2)



Guard-band in LTE spectrum

- No use of LTE resources by NB-IoT
- No additional spectrum used by NB-IoT
- NB-IoT channels in guard band limited

In-band in LTE channel

- Use of LTE resources by NB-IoT
- Trade NB-IoT carriers vs. LTE capacity
- No additional spectrum used by NB-IoT

Stand-alone in refarmed GSM spectrum

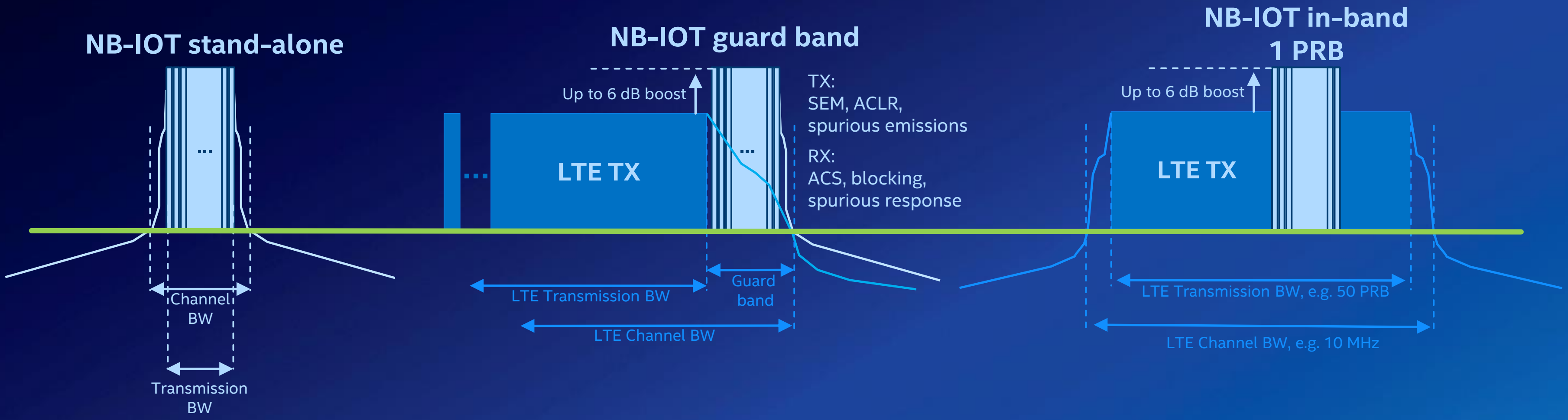
- No use of LTE resources by NB-IoT
- Additional spectrum used by NB-IoT

Rel.13 NB-IOT deployment (2/2)

LTE BW	3MHz	5MHz	10MHz	15 MHz	20 MHz
Anchor NB-IOT carrier above DC	2	2, 7	4, 9, 14, 19	2, 7, 12, 17, 22, 27, 32	4, 9, 14, 19, 24, 29, 34, 39, 44
And below LTE carrier center	12	17, 22	30, 35, 40, 45	42, 47, 52, 57, 62, 67, 72	55, 60, 65, 70, 75, 80, 85, 90, 95

- The 100kHz carrier allocation grid is maintained from legacy LTE for NB-IOT.
- The distance of the PRB center from the 100kHz grid varies with PRB instance and LTE channel bandwidth.
- Hence, only a subset of PRBs are eligible for NB-IOT anchor carrier:
    - For 10 MHz and 20MHz channels, the NB-IOT anchor PRB shall only be 2.5kHz off the nearest 100kHz grid point.
    - For 3 MHz, 5 MHz, and 15 MHz, the NB-IOT anchor PRB shall only be 7.5kHz off the nearest 100kHz grid point.
- The center 6 PRBs cannot be assigned an NB-IOT anchor carrier as they carry the legacy PSS/SSS/PBCH channels.

Rel.13 NB-IOT coexistence analysis (1/2)



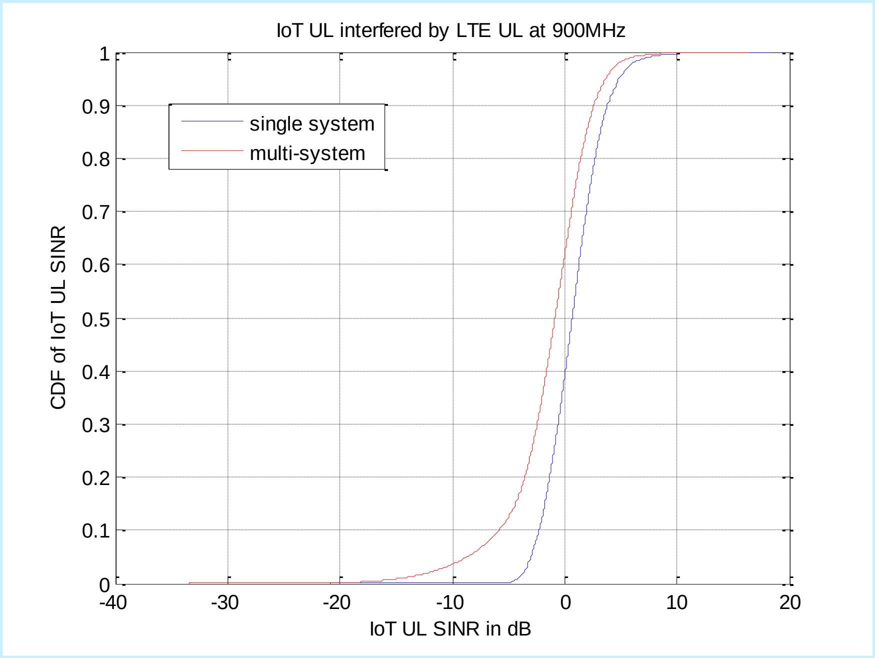
Stand-alone
Typically in sub-1GHz spectrum like GSM; needs to coexist with other RATs deployed in the vicinity

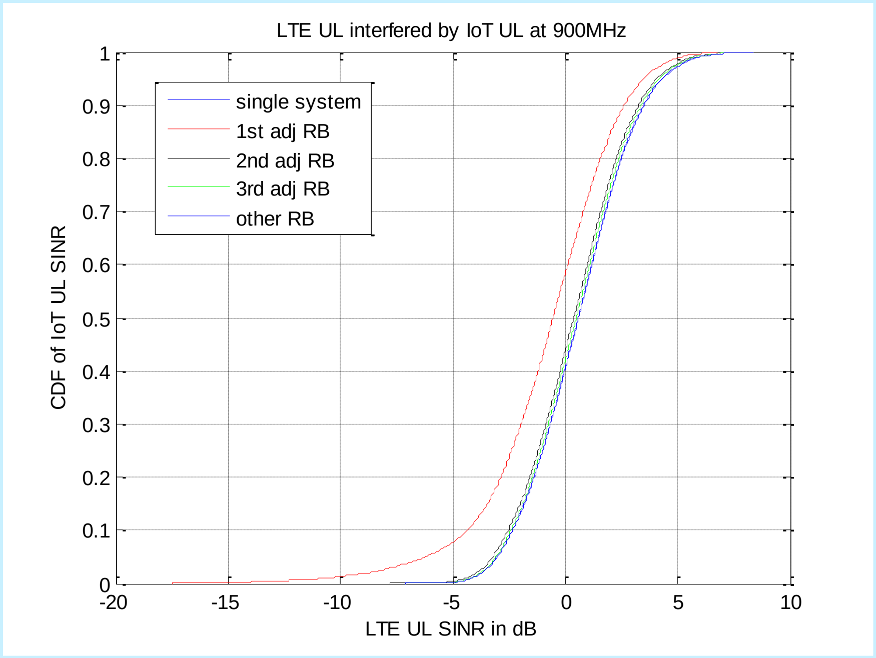
Guard band
Deployed in LTE guard bands, e.g. for 20MHz 2 guard bands 1MHz wide, in 5 MHz 2 guard bands 250kHz wide; coexistence of 3.75kHz subcarrier spacing in UL and LTE system to be studied

In-band
Close to 100kHz grid single PRB locations within LTE transmission BW, DL supposed to be orthogonal; coexistence of 3.75kHz subcarrier spacing in UL and LTE system to be studied

In-band: NB-IOT (3.75KHz) UL ↔ LTE UL

Note: 15kHz NB-IOT is considered orthogonal to legacy LTE

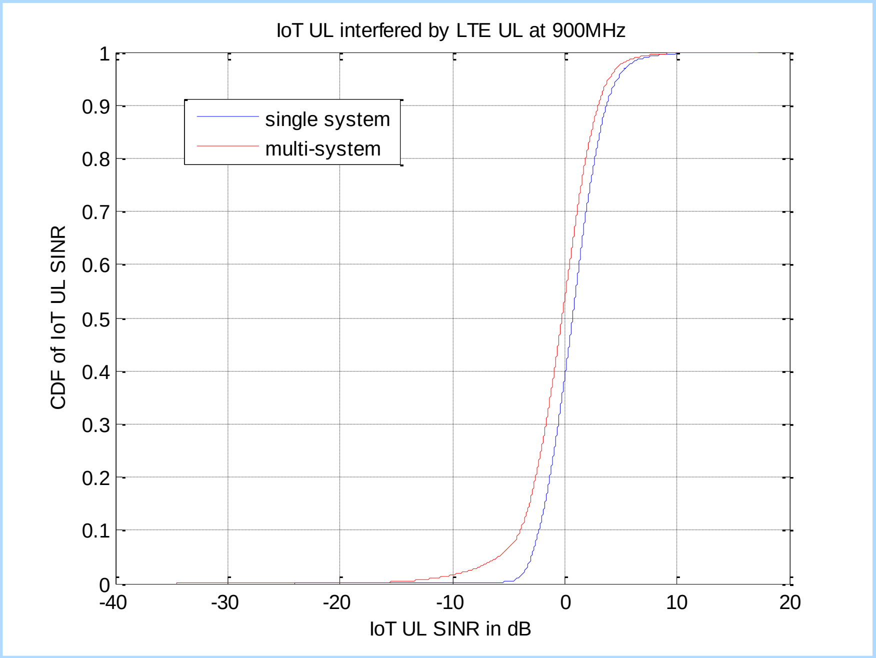


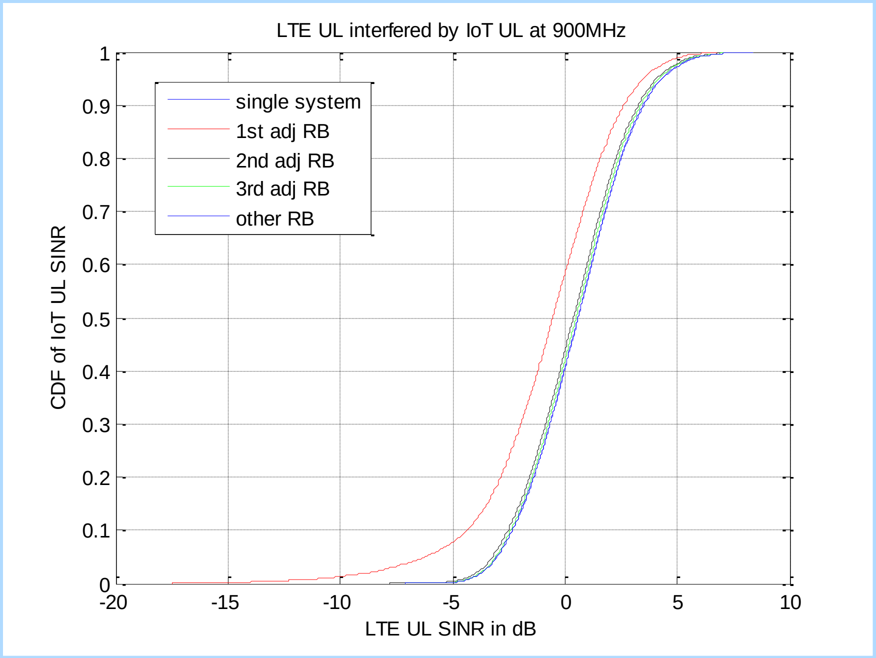


See also: Intel contribution R4-161811

Guard-band: NB-IOT (3.75KHz) UL ↔ LTE UL

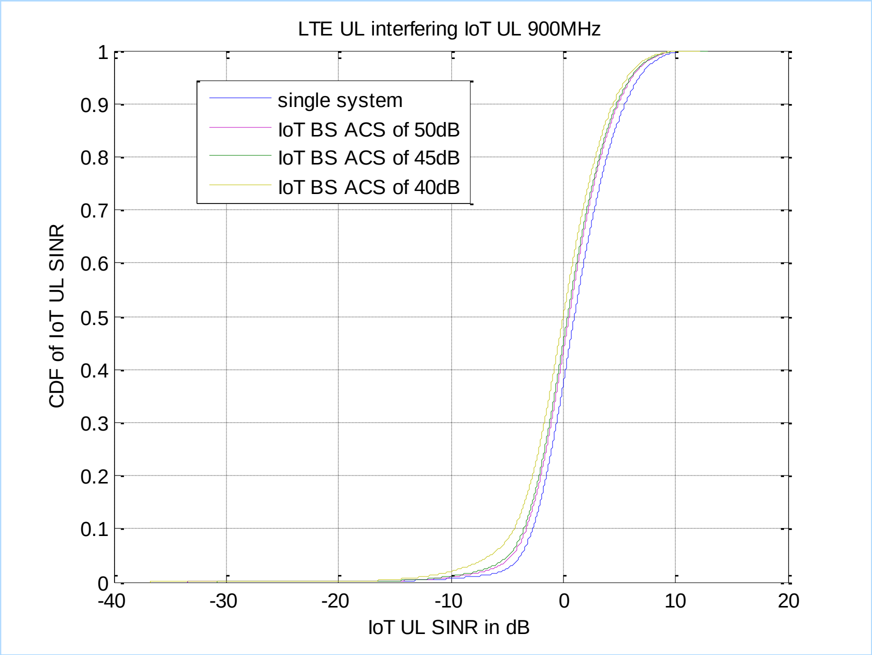
Note: 15kHz NB-IOT is considered orthogonal to legacy LTE

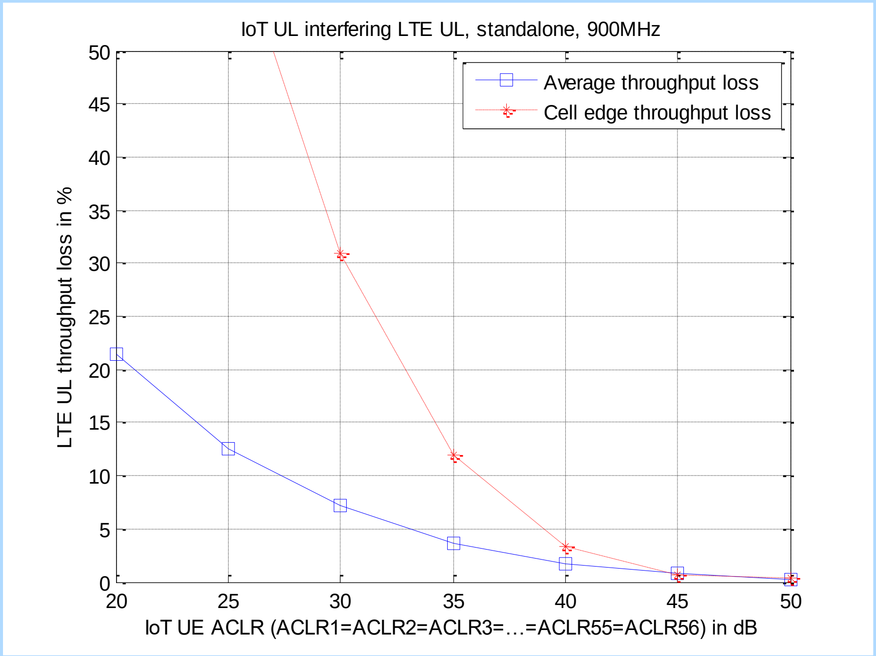




See also: Intel contribution R4-161812

Stand-alone: NB-IOT (3.75kHz) UL ↔ LTE UL

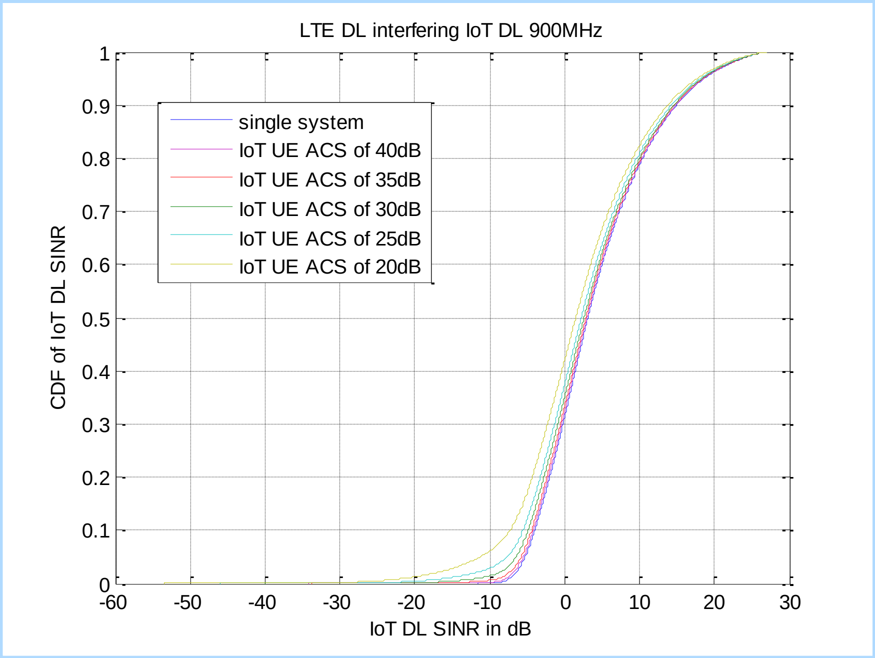


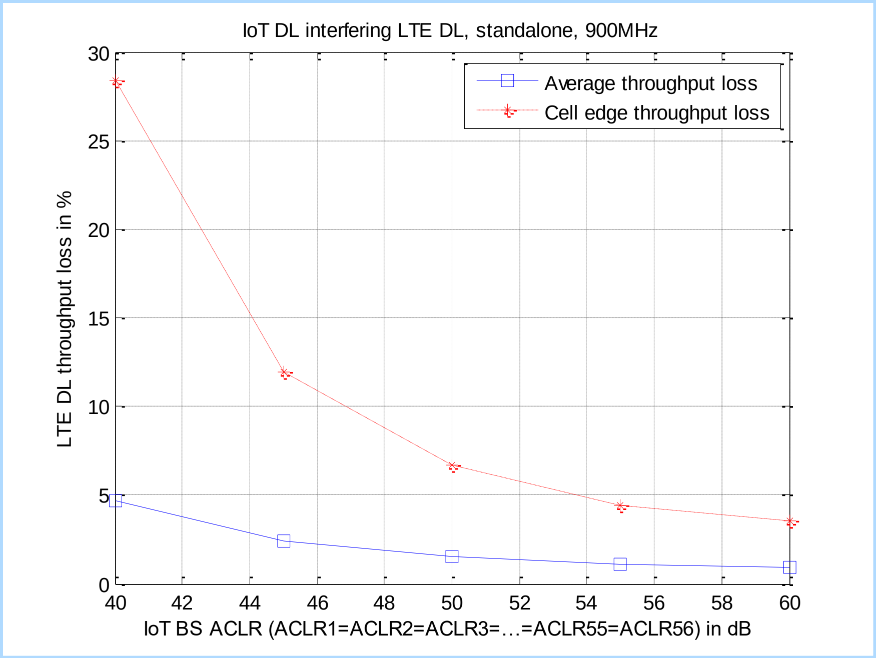


See also: Intel contribution R4-160138

UL conclusions: The simulations of LTE UL performance degradation were based on very pessimistic and unrealistic assumption of NB-IoT UE ACLR (ACLR1=ACLR2=ACLR3=…=ACLR55=ACLR56). The simulation results of in-band (R4-160139) and guard-band (R4-160140) cases show that the NB-IoT attenuation at the 2nd adjacent channel is much larger than that at the first adjacent channel. The attenuation at the 3rd adjacent channel and beyond is even larger.

Stand-alone: NB-IOT (15kHz) DL ↔ LTE DL





See also: Intel contribution R4-160137

DL Conclusions: The simulations of LTE DL performance degradation were based on the very pessimistic and unrealistic assumption of NB-IoT BS ACLR (ACLR1=ACLR2=ACLR3=…=ACLR55=ACLR56). The simulation results of in-band (R4-160139) and guard-band (R4-160140) cases show that the NB-IoT attenuation at the 2nd adjacent channel is much larger than that at the 1st adjacent channel. The attenuation at the 3rd adjacent channel and beyond is even larger.

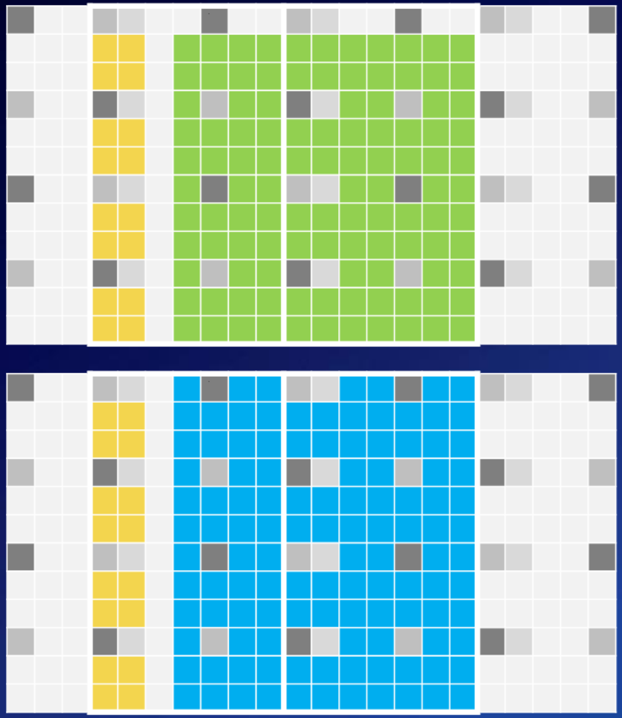
Rel.13 NB-IOT coexistence analysis (2/2)

Scenario @900MHz	NB-IOT degraded by LTE with SINR loss @95%-ile to @5%-ile	LTE @1st PRB degraded with SINR loss @95%-ile to @5%-ile
In-band UL 3.75kHz [Intel R4-161811]	1.2dB to 5.6dB	1.1dB* to 3.1dB *: 50%-ile
Guard band UL 3.75kHz [Intel R4-161812]	0.8dB to 2.9dB	1.1dB to 3.1dB

Scenario @900MHz	NB-IOT degraded by LTE with SINR loss @95%-ile to @5%-ile	LTE average throughput loss
Stand-alone UL 3.75kHz [Intel R4-160138]	1.1dB to 2.7dB [modeled as BS ACS[1]: 40dB]	5% [@NB-IOT UE ACLR[2] of 33dB]
Stand-alone DL 15kHz [Intel R4-160137]	1dB to 5.9dB [modeled as UE ACS[2]: 20dB]	~<5% [@NB-IOT BS ACLR[1] of 40dB]

1) TS 36.104 provides as NB-IOT BS ACLR (stand-alone): 40dB for 300kHz, 50 dB for 500kHz offset; several NB-IOT standalone BS ACS and NB blocking tests of wanted vs. interferer signal (c.f. Chapter 7.5.x)
2) TS 36.101 provides as NB-IOT UE ACLR: (E-)UTRA_ACLR 37dB; several NB-IOT UE ACS and NB blocking tests wanted vs. interferer signal (c.f. Chapter TBD)

Synchronization channels NPSS and NSSS

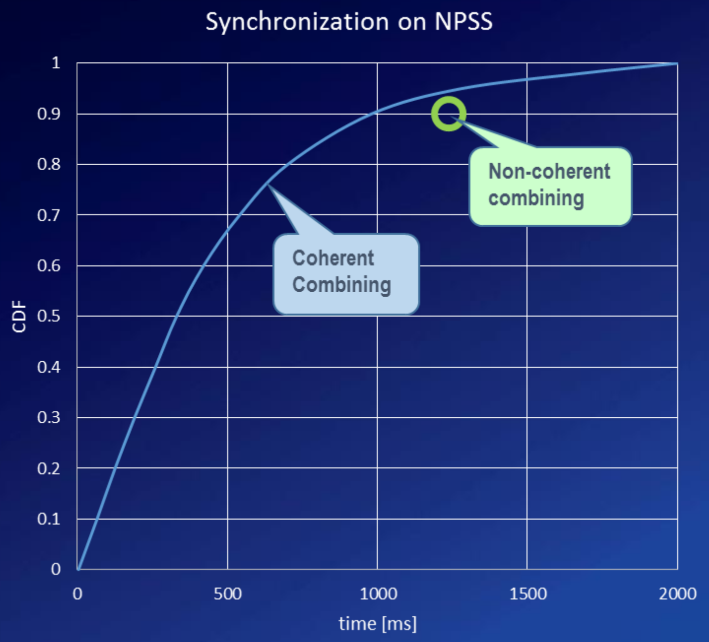


- Common synchronization signal for all deployment modes
- **NPSS:** Base sequence Length-11 Zadoff-Chu (ZC) sequence w/ root index 5, no cyclic shift;
  code cover: [1 1 1 1 -1 -1 1 1 1 -1 1]
- **NSSS:** Length-131 Zadoff Chu sequence with time-domain cyclic shifts and binary scrambling sequence (Hadamard)

Signal	Subframe	Periodicity	Purpose
NPSS	#5	10ms	Time and frequency synchronization
NSSS	#9	20ms	PCID information and 80ms boundary

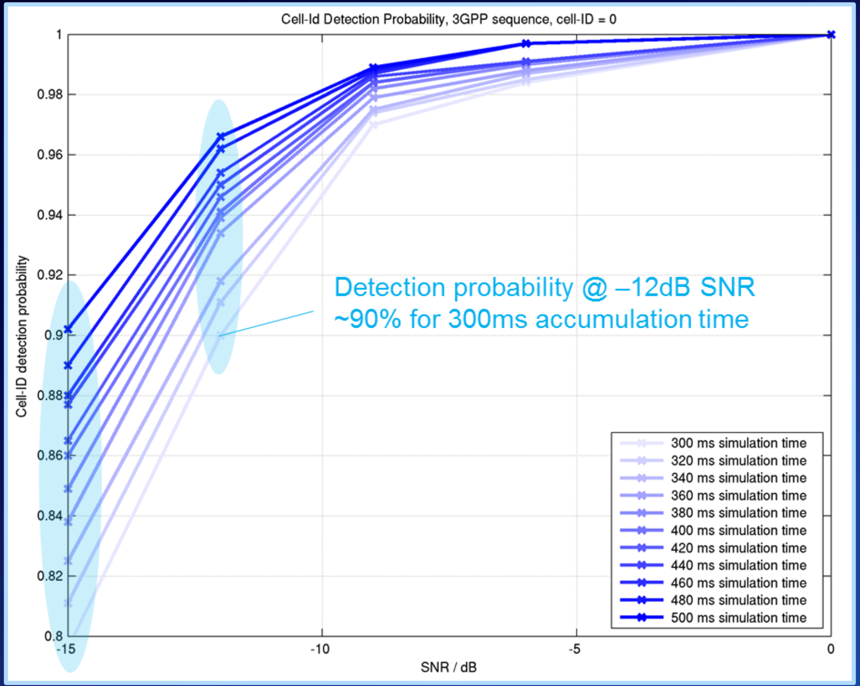
- **PDCCH** OFDM symbols are avoided, punctured by **LTE CRS**, and punctured by LTE CSI-RS and PRS if colliding
- Note: ZC sequences are CAZAC (Constant Amplitude Zero Auto Correlation) sequences

Synchronization performance on NPSS



- The **green circle** represents the performance of AC-based NPSS detection in extended coverage (less than –12dB SNR) with incoherent combining.
- Acquiring cell timing by AC-based NPSS detection with coherent combining shortens the required time by ~25%.

Cell-ID detection performance on NSSS



- Detection probability @ –12dB SNR ~90% for 300ms accumulation time
- Increased accumulation time to 500ms improves detection probability by ~10% @ –15dB SNR.
- Increased accumulation time to 500ms improves detection probability by ~7% @ –12dB SNR.
- [Not shown:] Impact of frequency offset is worse at low SNR. For example: for frequency offset of 900Hz, detection probability decreases by ~20% @ –6dB SNR and by ~80% @ –15dB SNR.

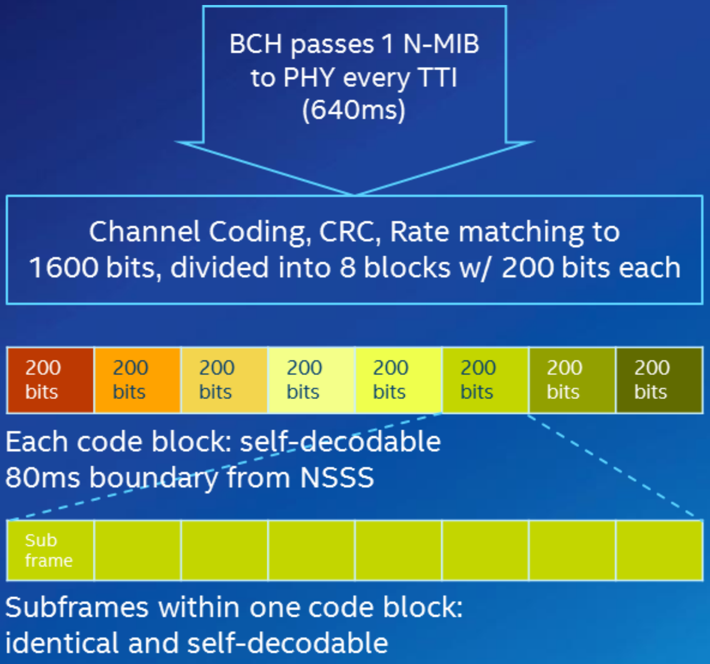
Rel.13 NB-IOT – NPBCH

Basic structure

- Transmission of Master Information Block (MIB-NB)
- Demodulation based on Narrowband RS (NRS)
- Uses Subframe #0 of every radio frame
  - MIB-NB TTI is 640 ms
  - NPBCH consists of 8 independently decodable 80ms blocks
  - 80 ms boundary is identified from NSSS

MIB-NB

- 4 most significant bits of NB-IOT SFN, remaining bits from NPBCH
- 4 bits for SIB1-NB scheduling info incl. TBS, R, SFs for SIB1-NB repetitions
- Deployment mode, 100kHz raster offset
- #LTE CRS ports, LTE CRS sequence info, same-PCI indicator
- 5 bits to indicate PRB for in-band operation
- 2 bits in MIB-NB to indicate 2 LSB of HyperSFN (Build of HyperSFN together with 8 HyperSFN-bits in SIB1-NB; HyperSFN is incremented by one when the SFN wraps around.)
- [No need to differentiate FDD and TDD as TDD not supported in Rel.13]

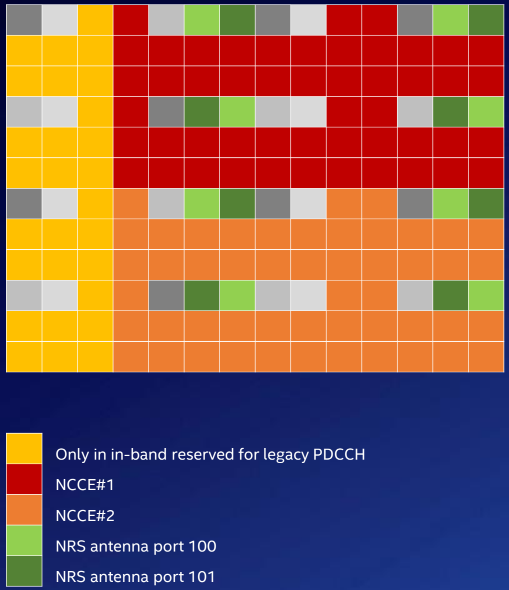


Summary of acquisition delays in NB-IOT

Parameter	Cat.NB1 NC	Cat.NB1 EC
T_MIB-NB	640 ms	2560 ms
T_SIB1-NB	5120	29440
T_SIB2-NB	2560	9560
T_SI for cell re-selection	8320	41560
T_SI for RRC re-establishment	8320	41560

NOTE 1: The parameters T_MIB-NB and T_SI are defined in TS 36.133
NOTE 2: The terms NC and EC are abbreviations for normal coverage and enhanced coverage, respectively
NOTE 3: The values for SI acquisition delays for Category NB1 UEs have been derived using baseband only simulations and do not include RF impairment margin
NOTE 4: The SIB2-NB acquisition delay depends on network configuration.

Rel.13 NB-IOT – NPDCCH (1/2)



DL transmission

- Single AP (port 0) and two AP (ports 0 and 1) w/ transmit diversity (SFBC)
- Modulation scheme: QPSK

Structure – follows LTE PDSCH

- 2 NB-IOT Control Channel Elements (NCCE) per PRB pair: Upper 6 SC allocated to one NCCE, lower 6 SC to the other
- No Resource Element Groups (REG)
- Legacy PDCCH avoided only in in-band case
- LTE CRS and NRS rate-matched
- Frequency duplex of NPDCCH is only supported for R=1
- No support of frequency duplex with NPDSCH

Repetitions, Aggregation

- Max aggregation level (L): 2, both NCCE in same subframe
- Multiple repetitions R_{max} : {1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024, 2048}

Rel.13 NB-IOT – NPDCCH (2/2)

Search spaces and monitoring

- Common (CSS-paging, CSS-RA) and UE-specific search spaces (USS)
- Either UE monitors CSS-paging, or CSS-RA, or USS when RRC-connected

Multiplexing search spaces by starting SF

$(10 \cdot n_f + \lfloor n_s/2 \rfloor) \bmod R_{max} \cdot G = \lfloor \alpha_{offset} \cdot R_{max} \cdot G \rfloor$

n_f: radio frame number

n_s: slot number

G: {1.5, 2, 4, 8, 16, 32, 48, 64}

α_{offset}: {0, 1/8, 2/8, 3/8}

Where G and α_{offset} are UE-specific for USS

Where G and α_{offset} are cell-specific and NPRACH resource-specific for CSS-RA

DCI format N0 for UL grants (NPUSCH scheduling)

Flag for format N0/format N1 differentiation	1 bit
Subcarrier indication	6 bits
Resource assignment	3 bits
Scheduling delay	2 bits
Modulation and coding scheme	4 bits
Redundancy version	1 bit
Repetition number	3 bits
New data indicator	1 bit
DCI subframe repetition number	2 bits

DCI format N1 for DL assignments (NPDSCH scheduling)

Flag for format N0/format N1 differentiation	1 bit
NPDCCH order indicator	1 bit
Scheduling delay	3 bits
Resource assignment	3 bits
Modulation and coding scheme	4 bits
Repetition number	4 bits
New data indicator (reserved if CRC is scrambled with a RA-RNTI)	1 bit
NPUSCH format 2 (HARQ-ACK) resource (reserved if CRC is scrambled with a RA-RNTI)	4 bits
DCI subframe repetition number	2 bits

DCI format N2 for scheduling of paging NPDSCH

Flag for paging/direct indication differentiation	1 bit
Direct Indication information	8 bits

Rel.13 NB-IOT – NPDSCH (1/2)

DL transmission

- Single AP (port 0) and two AP (ports 0 and 1) w/ transmit diversity (SFBC)
- Modulation scheme: QPSK

Structure – follows LTE PDSCH

- Narrowband RS (NRS) for demodulation
- Maximum Transport Block Size (TBS): 680
- Codeword across 1 – 6, 8, or 10 subframes
- Separate I_TBS (4 bits), N_SF (3 bits) indication in DCI
- Tail-biting Convolutional Code (TBCC) [5.1.3.1 in TS 36.212]
- 24-bits CRC [Section 5.3.2.1/TS36.212]
- 2112 soft channel bits in Cat.NB1
- Scrambling sequence [Section 7.2/ TS 36.211]
- Scrambling initialization [based on 6.3.1/TS 36.211 PDSCH]

Transport Block Table: I_TBS\N_SF

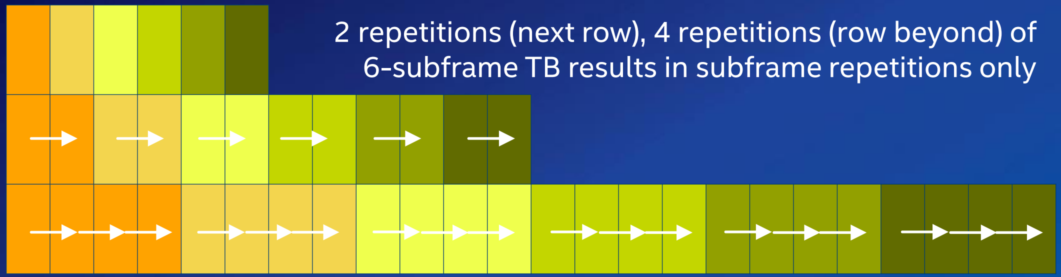
	1	2	3	4	5	6	8	10
0	16	32	56	88	120	152	208	256
1	24	56	88	144	176	208	256	344
2	32	72	144	176	208	256	328	424
3	40	104	176	208	256	328	440	568
4	56	120	208	256	328	408	552	~~696~~ 680
5	72	144	224	328	424	504	680	
6	~~328~~ 88	176	256	392	504	600		
7	104	224	328	472	584	~~712~~ 680		
8	120	256	392	536	680			
9	136	296	456	616				
10	144	328	504	680				
11	176	376	584					
12	208	440	680					

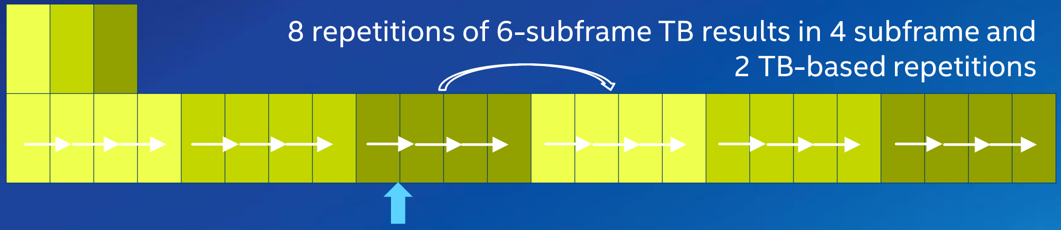
Rel.13 NB-IOT – NPDSCH (2/2)

- Repetition cycle is the basic unit in which a full Transport Block (TB) is repeated.
- Hybrid scheme of cyclic (subframe-based) and TB-based repetitions (c.f. examples in figure on the right)
- Max subframe accumulation inside Transport Block is 4.

And HARQ on top:

- 1 HARQ process supported
- Adaptive and asynchronous HARQ
- No redundancy version (RV) scheme supported in NPDSCH HARQ





Rel.13 NB-IOT – Narrowband RS (NRS)

Presence of NB-RS (NRS)

- NRS always present and used for single antenna port and 2 antenna ports transmission schemes
- NRS present w/o condition for NPDCCH/ NPDSCH in-band; only NRS in stand-alone, guard-band
- In cell-specific valid DL PRB pairs, NRS is present; in invalid DL PRB pairs: no NRS
- No NRS in NPSS and NSSS
- In in-band NB-IoT carrier, w/o cell-specific valid DL subframes NB-IoT device expects NRS in subframes #0 and #4 and in subframe #9 if it does not contain NSSS
- In guard-band or stand-alone NB-IoT carrier, assume NRS in all subframes except for NPSS/ NSSS
- Not precluded: LTE CRS for DL demod or measurements if #AP for LTE CRS and NRS same and either 1 or 2

NRS and LTE CRS

- When same-PCI indicator set to true: Cell ID identical for NB-IoT and LTE, #antenna ports is the same for LTE CRS as for NRS, channel estimation possible on NRS and on LTE CRS , LTE CRS available in NB-IoT PRB wherever NRS available

Structure of PRB with NRS

- NRS for antenna ports 0 and 1 mapped to last two OFDM symbols of a slot
- NRS uses a cell-specific frequency shift derived as NB-IoT Cell ID mod 6
- NRS sequence reuses LTE CRS sequence; center of LTE CRS sequence is NRS sequence for all PRBs.

Rel.13 NB-IOT – NPUSCH (1/3)

UL transmission

- SC-FDMA for 15kHz multi-tone allocations (optional in Rel.13)
- 15kHz multi-tone & single-tone allocations {12, 6, 3, 1}
- 3.75kHz single-tone allocation:
  - CP of 8.33µs and symbol duration of $528T_s$ = 275µs
  - After 7 OFDM symbols 75µs guard period up to 2ms slot (enables also collision avoidance with legacy LTE SRS)

Modulation scheme, coding, scrambling

- Multi-tone: QPSK
- Single-tone: $\pi/2$ BPSK and $\pi/4$ QPSK for minimization of PAPR
- Phase-rotated BPSK/ QPSK applied to data and DMRS, new UL DRS for single-tone and sub-PRB multi-tone

NPUSCH format 1 → UL data

- Convolutional Turbo Coding (CTC), 2 RVs (RV#0, RV#2)
- Single Transport Block (TB) can be scheduled over multiple Resource Units (RU)
- Enhanced scrambling and cyclic repetition patterns for NPUSCH format 1

NPUSCH format 2 → "NPUCCH" and UCI

- Single-tone only with $\pi/2$-BPSK
- Repetition coding
- Frequency and time locations w.r.t. baseline resource indicated via DL assignment (DCI format N1)
- UCI = 1-bit A/N feedback only, no CSI feedback, no SR

Rel.13 NB-IOT – NPUSCH (2/3)

Table 1 for NPUSCH	Allocation size and SCS	Resource Unit (RU) [ms]
Format 1	12 tones @ 15 kHz	1
Format 1	6 tones @ 15 kHz	2
Format 1	3 tones @ 15 kHz	4
Format 1	1 tone @ 15 kHz	8
Format 1	1 tone @ 3.75 kHz	32
Format 2	1 tone @ 15 kHz	2
Format 2	1 tone @ 3.75 kHz	8

Transport Block Table: I_TBS\N_RU

	1	2	3	4	5	6	8	10
0	16	32	56	88	120	152	208	256
1	24	56	88	144	176	208	256	344
2	32	72	144	176	208	256	328	424
3	40	104	176	208	256	328	440	568
4	56	120	208	256	328	408	552	696
5	72	144	224	328	424	504	680	872
6	~~328~~ 88	176	256	392	504	600	808	~~1032~~ 1000
7	104	224	328	472	584	712	~~968~~ 1000	
8	120	256	392	536	680	808		
9	136	296	456	616	776	936		
10	144	328	504	680	872	~~1032~~ 1000		
11	176	376	584	776	1000			
12	208	440	680	~~904~~ 1000				

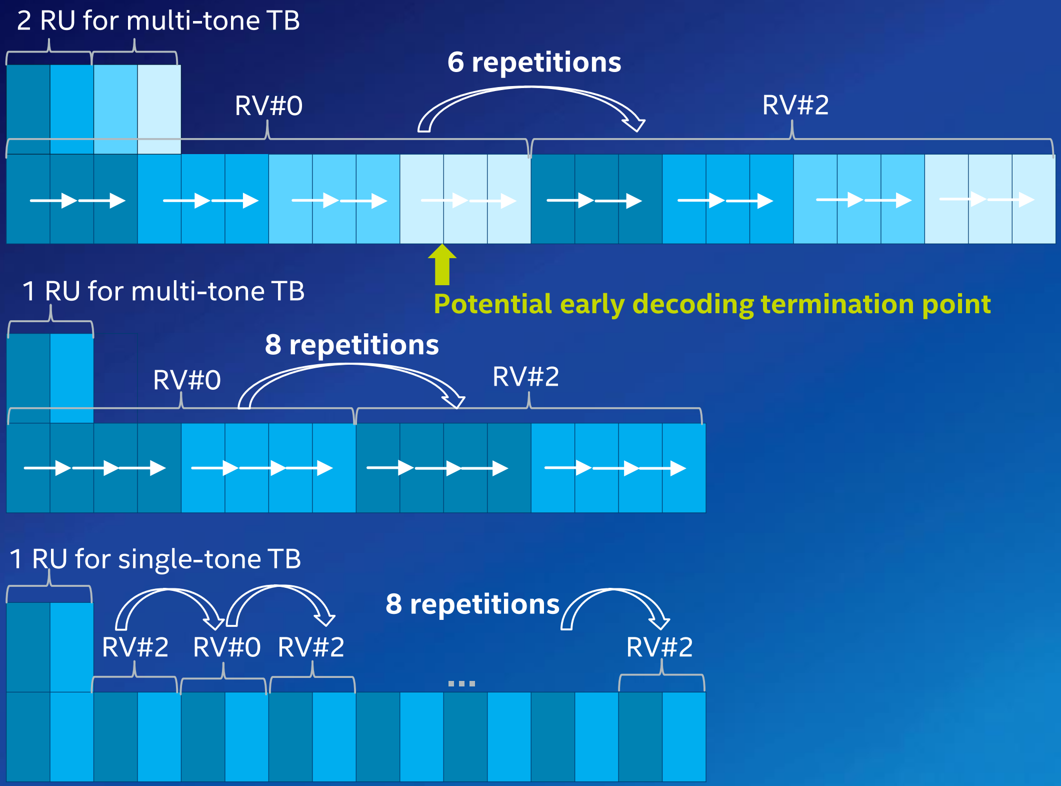
Set of fixed Resource Units (RU) are scheduling units for NPUSCH. A single Transport Block (TB) can be scheduled across multiple RUs. Maximum TB size (TBS): 1000; TBS (I_{TBS}) is a 4-bit field in N0 DCI. Range of I_{TBS} for multi-tone: 0 – 12; range of I_{TBS} for single-tone: 0 – 10. Modulation order for single-tone: if I_{TBS} = {0,2} MO = 1 else MO = 2

Rel.13 NB-IOT – NPUSCH (3/3)

- Redundancy Versions (RV) cyclic repetitions
- In each cycle of a RV, subframes are repeated Z times:
  - Z = min{4, repetitions/2} for multi-tone
  - Z = 1 for single-tone
- After cycling within the first RV, the next RV is treated analogously.
- Set of possible repetitions for NPUSCH {1, 2, 4, 8, 16, 32, 64, 128}

And HARQ on top:

- 1 HARQ process supported
- Adaptive and asynchronous HARQ
- PHICH not supported for NPUSCH, UL HARQ-ACK indicated by NPDCCH carrying UL grant (DCI format N0) and (non-)toggled NDI

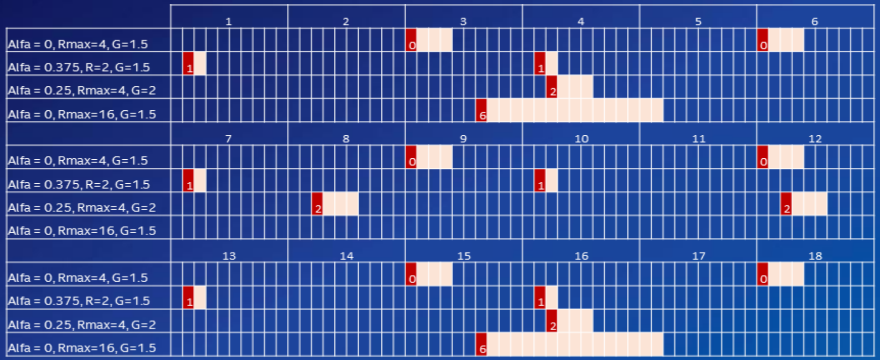


Multiplexing in NPDCCH, NPDSCH, and NPUSCH

NPDCCH search space starting subframe:

$(10 \cdot n_f + \lfloor n_s/2 \rfloor) \bmod R_{max} \cdot G = \lfloor \alpha_{offset} \cdot R_{max} \cdot G \rfloor$

n_f: radio frame number
n_s: slot number
G: {1.5, 2, 4, 8, 16, 32, 48, 64}
α_{offset}: {0, 1/8, 2/8, 3/8}
(different specificness for USS and CSS)



NPDSCH multiplexing with other UEs:

- 3-bit info in DCI (N1) indexes a list with possible number of (valid) DL subframes for scheduling delay: if R_{max} <128: {0,4,8,12,16,32,64,128} else: {0,16,32,64,128, 256,512,1024}
  Actual NPDSCH scheduling delay: number of (valid) DL SFs + 4 SFs after end of NPDCCH

NPUSCH multiplexing with other UEs

- 2-bit info in DCI (N0) indicates NPUSCH scheduling delay of {8, 16, 32, 64} ms

Rel.13 NB-IOT – NPRACH and Random Access

- Single-tone NPRACH preamble with 3.75kHz subcarrier spacing
- Coverage extension by NPRACH symbol group repetitions (NPRACH symbol = 266.7 µs)
- NPRACH transmissions identified by their starting subcarrier location (i.e., FDM instead of CDM)
- Multi-level NPRACH frequency hopping
  - Single-subcarrier hopping between 1^{st}/ 2^{nd} and between 3^{rd}/ 4^{th} symbol groups
  - 6-subcarrier hopping between 2^{nd}/ 3^{rd} symbol groups
  - Pseudo-random hopping used every 4 symbol groups
- UE support of single-/multi-tone Msg3 indicated via NPRACH resource partitioning
- Up to 3 NPRACH resource configurations in a cell
- Random access procedure and related NPDCCH CSS design follows Rel.13 eMTC

Rel.13 NB-IOT – Summary of physical layer channels

	Channel	NB-IOT	Legacy LTE
DL	NPSS	• New ZC sequence for single PRB fit • All cells share one NPSS	• LTE PSS part of six center PRBs • Three different LTE PSSs
	NSSS	• New ZC sequence for single PRB fit • NSSS provides 3 least significant bits of SFN	• LTE NSS part of six center PRBs • n/a for LTE NSS
	NPBCH	• 640ms TTI (decodable 80ms blocks)	• 40ms TTI
	NPDCCH	• Uses single PRB on multiple subframes in TD	• Uses a single subframe with multiple PRBs in FD
	NPDSCH	• QPSK, TBCC, only 1 Redundancy Version (RV), single-layer transmission, max TBS 680 bits	• Up to 64QAM [256QAM], CTC, multiple RVs, multi-layer transmission, max TBS per layer >70,000 bits
UL	NPRACH	• New preamble format based on 3.75kHz single-tone frequency hopping • Coverage extension by NPRACH symbol group repetitions (NPRACH symbol = 266.7 µs)	• LTE PRACH occupies six PRBs using multi-tone format based on 1.25kHz SCS
	NPUSCH Format 1	• Min allocation: single-tone, max TBS 1000 bits, 15kHz, 3.75kHz (single-tone), π/2 BPSK, π/4 QPSK, single-layer transmisson	• Min allocation: 1 PRB, max TBS per layer >70,000 bits, 15kHz SCS only, QPSK up-to 64QAM [256QAM], multi-layer transmission
	Format 2	• Single-tone, repetition coding, 1-bit A/N	• n/a
	[PUCCH]	• n/a	• LTE PUCCH dedicated channel for A/N, SR, CSI FB

Coverage study for NPUSCH

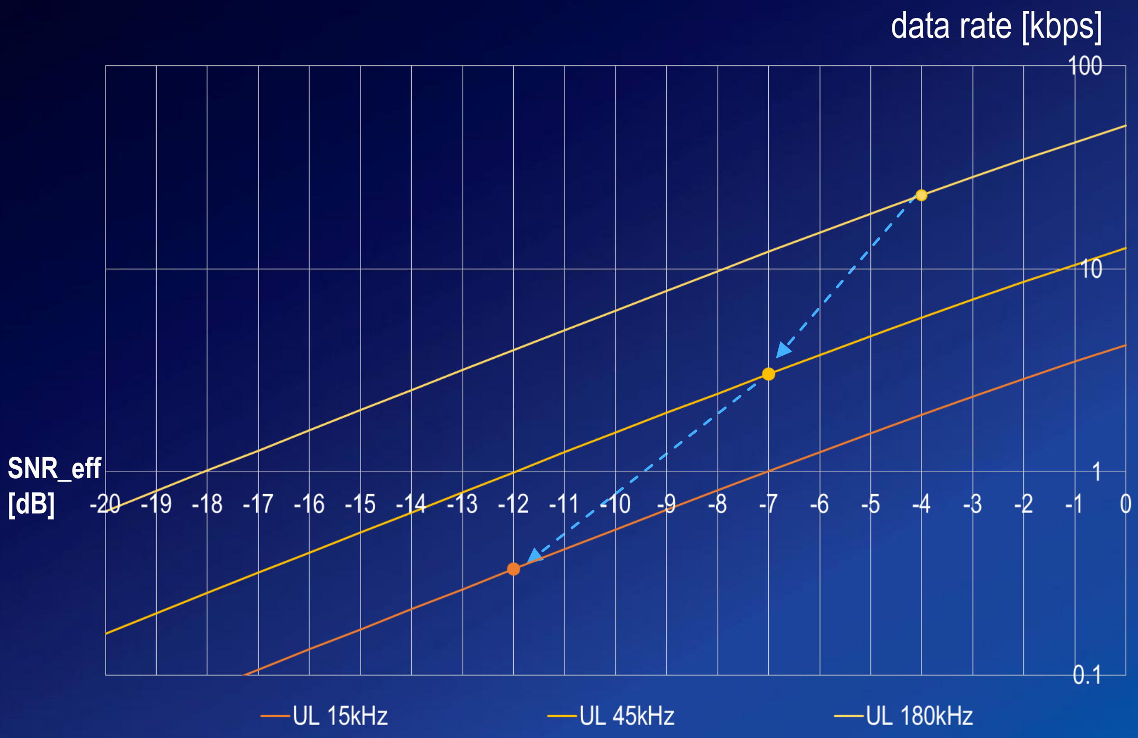
	Extreme	Robust	Normal
Subcarrier Spacing (kHz)	15	15	15
Data Rate (kbps)	0.332	3.03	21.25
Burst duration (ms)	2048	224	32
Number of subcarriers in a burst	1	3	12
Modulation	BPSK	QPSK	QPSK
Transmitter			
(1) Tx power (dBm)	23	23	23
Receiver			
(2) Thermal noise density (dBm/Hz)	-174	-174	-174
(3) Receiver noise figure (dB)	3	3	3
(4) Interference margin (dB)	0	0	0
(5) Occupied channel bandwidth (Hz)	15,000	45,000	180,000
(6) Effective noise power = (2) + (3) + (4) + 10 log ((5)) (dBm)	-129.2	-124.5	-118.4
(7) Required SINR (dB)	-11.8	-6.6	-3.4
(8) Receiver sensitivity = (6) + (7) (dBm)	-141	-131.1	-121.8
(9) Rx processing gain	0	0	0
(10) MCL = (1) – (8) + (9) (dB)	164	154.1	144.8

SINR of -11.8dB for MCL 164dB:

TBS: 256
Repetitions: 16x
Burst mapping: 52ms
[R1-161901]

NB-IOT
TBS: 680
Repetitions: 32x
Burst mapping: 64ms

UL coverage performance*



NB-IOT UL 180kHz
21kbps @145dB MCL

NB-IOT UL 45kHz
3.03kbps @154dB MCL

NB-IOT UL 15kHz
332bps @164dB MCL

*) Based on an adaptation to NB-IOT of *LTE Capacity compared to the Shannon Bound*, Preben Mogensen et al, 1550-2252/$25.00 ©2007 IEEE

Timing relationships

Timing relationships to meet principle of „*one thing at a time*“
Start of UL A/N transmission is >= 12ms after the end of the corresponding NPDSCH transmission
Start of DL A/N transmission is >= 3ms after the end of the corresponding NPUSCH transmission
Start of NPUSCH transmission is >= 8ms after the end of its associated NPDCCH transmission
Start of an NPDCCH search space is >=4ms after the end of the last NPDCCH search space
Start of NPDSCH transmission is >= 4ms after the end of its associated DL assignment
Start of DL transmission is >= 3ms after the end of any NPUSCH transmission of same UE
Timing relationship to enable HD-FDD (Type B, cf. TS 36.211)
When NB-IOT UE is transmitting, UE is not expected to monitor or receive any DL channels.

Rel.13 NB-IOT „effective“ peak data rates

DL Peak Rate Calculation

Subframe Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Grant DL Data#1 **NPDCCH** to DL Data#1 **NPDSCH**	N1	**1**	**2**	**3**	**4**	680																				
DL Data#1 **NPDSCH** to **NPUSCH** ACK#1						680			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	A/N	A/N	Switch			
NPUSCH ACK#1 to NPDCCH						680														Switch	A/N	A/N	**1**	**2**	**3**	Gr

NPDSCH: 680 TBS across 3 SF

A/N across 2 SF (15 kHz, single tone)

DCI: Aggregation Layer = 1 (best condition for peak rate, 69 encoded bits, 14 OFDM symbols and 6 SC sufficient)

DCI: Repetitions = 1 (best condition for peak rate, no repetitions needed)

DL peak data rate for NB-IoT 27.2 kbps

UL Peak Rate Calculation

Subframe Count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Grant UL Data#1 **NPDCCH** to UL Data#1 **NPUSCH**	N0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	1000				Switch			
UL Data#1 **NPUSCH** to **NPDCCH**									Switch	1000				**1**	**2**	**3**	Gr

NPUSCH: 1000 TBS across 4 SF

DCI: Aggregation Layer = 1 (best condition for peak rate, 69 encoded bits, 14 OFDM symbols and 6 SC sufficient)

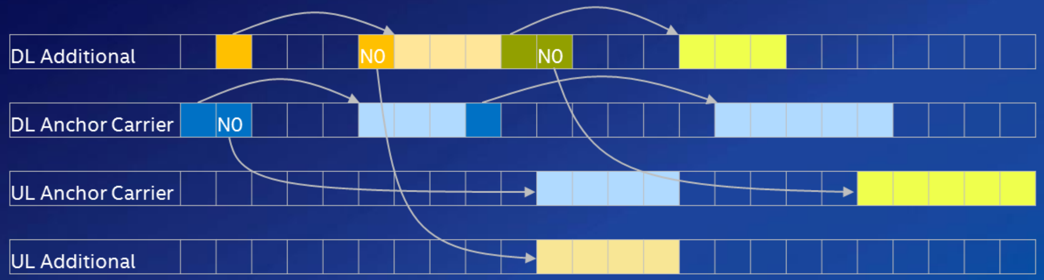
DCI: Repetitions = 1 (best condition for peak rate, no repetitions needed)

UL peak data rate for NB-IoT 62.5 kbps

Rel.13 NB-IOT – Miscellaneous

Multi-carrier operation (MCO)

- NB-IOT supports operation of multiple NB-IOT carriers for in-band, guard-band and standalone mode of operation.
- One NB-IOT PRB with NPSS/NSSS/NPBCH is defined as the anchor carrier.



Flexible time-domain scheduling

- Support of dynamic indication of DL and UL scheduling delays for easier time-domain resource multiplexing.

UL compensation gaps (UCG)

- Introduced in NB-IOT considering long continuous UL transmissions by HD-FDD UEs

Coexistence considerations

- Introduction of bitmap-based valid subframes concept (termed as “NB-IOT DL/UL subframes”)

Summary of NB-IOT higher layer features

Feature	Brief Description
Power Savings	• PSM, DRX in connected mode, DRX in idle mode • Max PSM time: 310 hours (>12 days) • Rel.13 Extended C-DRX and I-DRX operation • Connected Mode (C-eDRX): Extended DRX cycles of 5.12s and 10.24s are supported • Idle mode (I-eDRX): Extended DRX cycles up to ~44min for Cat.M1, up to ~3hrs for Cat.NB1
Limited Mobility Support	• Intra-frequency and inter-frequency cell-reselection • Support of dedicated priorities • MFBI (multi-frequency band information) Not supported : • Network-controlled HO, Inter-RAT cell-reselection and mobility in connected mode, Speed-dependent scaling of mobility parameters and mobility
Limited Positioning Support	• UE and network implementation to support positioning for NB-IoT. • Subject to the final NB-IoT design all methods and protocols (LPP, LPPa) can be used where applicable, e.g. the RAT-independent methods such as GNSS, WLAN, BT, MBS, and RAT-dependent methods such as E-CID. • eNB-assisted methods such as E-CID using the TA Type 2 method can be supported if dedicated RACH for positioning purposes is supported. • On the other hand E-CID using the TA Type 1 method cannot be supported as in Rel.13 no UE support for RAT-measurements (such as UE RX-TX time difference measurement) was assumed.
Not supported	• PWS, ETWS, CMAS, CSG, Relaying, RS services, MBMS, CS services, CSFB, Limited service state and Emergency Call • VoLTE, Dual Connectivity, IDC, RAN-Assisted WLAN interworking, D2D / ProSe, MDT

Summary of Rel.14 NB-IOT status (Nov 2016)

General enhancements	Positioning	SC-PTM multi-cast

Introduction of RA and paging transmissions in non-anchor carriers
 	
New category for power savings and latency reduction:
• Max DL/ UL TBS: 2536 bits; support of 1 HARQ process: ~80kbps/ ~105kbps DL/ UL data rates
• Optional: 2 HARQ DL/UL with [1352] DL/ [1800] UL TBS
  • More monitoring on NPDCCH: until 2 ms before start of first NPDSCH
  • Gap: NPUSCH to any DL receive ≥ 1ms
  • Rel.13 timings applied per HARQ process
 	
Working assumption in RAN4:
• Additional power class: 14dBm MOP
	OTDOA
	• NPRS based on LTE PRS; pattern and sequence for in-band and stand-alone/guard-band agreed
	• Capability signaling of maximal BW for RSTD measurement
	• Assistance information signaling
	
	UTDOA
	• No convergence on feasibility of Rel.13 NPRACH-based approach
		• UE expected to receive SC-PTM only in Idle mode (to reduce UE complexity)
		• A single SC-MCCH session using NPDCCH-based scheduling, one or more SC-MTCH session(s) using NPDCCH-based scheduling
		• Search space designs are based on NPDCCH CSS types from Rel.13
		• Max TBS for SC-MCCH and SC-MTCH is 2536 bits.

Towards 5G Internet-of-Things

Presenting: Sabine Roessel

Contributors: Sabine Roessel, Mehrzad Malmirchegini, Minh-Anh Vuong, Jong-Kae Fwu
Intel Corporation

Cellular IoT in 3GPP

Since Rel.8

LTE Rel.8+
Cat.1
10 Mbps DL
20 MHz

Available in 2017

Rel.13
EC-GSM-IoT
200 kHz

Rel.13
Cat.M1
300 kbps DL
1.4 MHz

Rel.13
Cat.NB1
30 kbps DL
200 kHz

Rel.12/13
(e)D2D

2018/2019

Rel.14
FeMTC
Up to 5 MHz

Rel.14
eNB-IOT
200 kHz

Inspired by

Rel.14
V2V/V2X
Few ms
latency

Rel.15
FeD2D
Wearable

Rel.15
eV2X
Improved
latency

Rel.15
sTTI
Few ms
latency

2020+

Rel.16
5G
mMTC

Rel.16
5G URLLC
0.5ms
latency

LPWA
Wearables
Automotive
URLLC

3GPP 5G Roadmap – RAN#73 Plenary

Study phase (ongoing)

- **Requirements TR 38.913**, approved
- **New Radio (NR) framework,** ongoing
  Forward compatibility between scenarios
  - Enhanced MBB (eMBB)
  - Massive MTC (mMTC)
  - Ultra-Reliable Low Latency Communications (URLLC)

5G Work Item Phase 1:

- Specs of **NG RAN (up to 40 GHz)**: Optimized eMBB (20Gbps), TDD and FDD, licensed & unlicensed, all environments, standalone and LTE-assisted deployment

5G Work Item Phase 2:

- Specification of **NG RAN (up to 100 GHz)**
- Specification of **5G mMTC**
- Specification of **5G URLLC**

→ Full support of basic 5G requirements

Q4.16	Q1.17	Q2.17	Q3.17	Q4.17	Q1.18	Q2.18	Q3.18	Q4.18	Q1.19	Q2.19	Q3.19	Q4.19	Q1.20	Q2.20	Q3.20	Q4.20
	Rel.14					**Rel.15**						**Rel.16**				**→ Rel.17**
	5G SI New RA					**5G WI Phase 1**						**5G WI Phase 2**				**→ Evolution of 5G**

5G Massive MTC (mMTC) Key Performance Requirements[1]

10x connection density[2]

10^6 devices per sqkm in urban environment

164+ dB coverage

164dB MCL[3] @160 bps

LTE (UL): 140.7dB
Cat.M1: 155.7 dB
Benchmark[4]: NB-IOT

10+ years battery life

15 years target for 200 Byte UL and 20 Byte DL per day @164dB MCL and 5Wh stored energy capacity

Benchmark[5]: NB-IOT

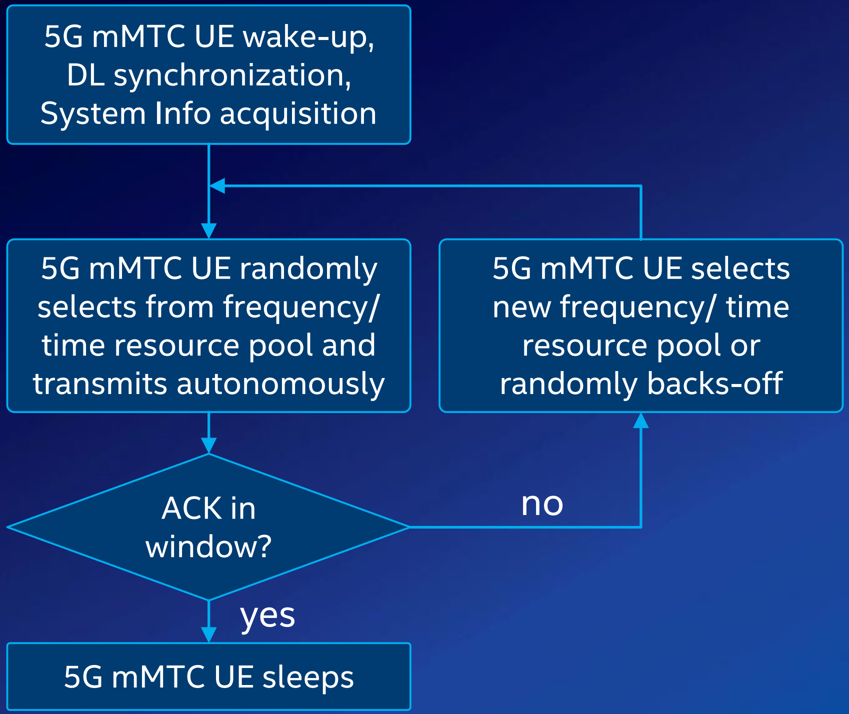
<10s latency

Infrequent small packets from most battery-efficient device state with 20 Byte UL @164dB MCL

Benchmark[6]: NB-IOT

1: 3GPP TR 38.913 v0.4.0
2: NB-IOT achieves 100K – 200K w.r.t. 3GPP TR 45.820 traffic assumption of 2k reports/200kHz/hour
3: MCL: Maximum Coupling Loss
4: NB-IOT: 164dB@160 bps equiv. SNDP layer/200 bps Phy (3GPP TR 45.820)
5: NB-IOT: 10 years for 200 Byte data packet transmission per day and 5 Wh battery capacity (3GPP TR 45.820)
6: NB-IOT: 10 seconds maximum latency for exception report transmission at coverage of up to 164dB MCL (3GPP TR 45.820)

Contention-based UL Transmission for Extreme Connection Density



Autonomous/ grant-free/ contention-based UL non-orthogonal multiple access

- No need for dynamic, explicit scheduling grant from eNB
- Multiple UEs share the same frequency/ time resources
- Enables extreme connection density due to reduced overhead

Provide Extreme Coverage with 5G mMTC

Channel coding

Repetitions to allow for energy accumulation

Well-suited code(s)

Power spectral density

Power boosting

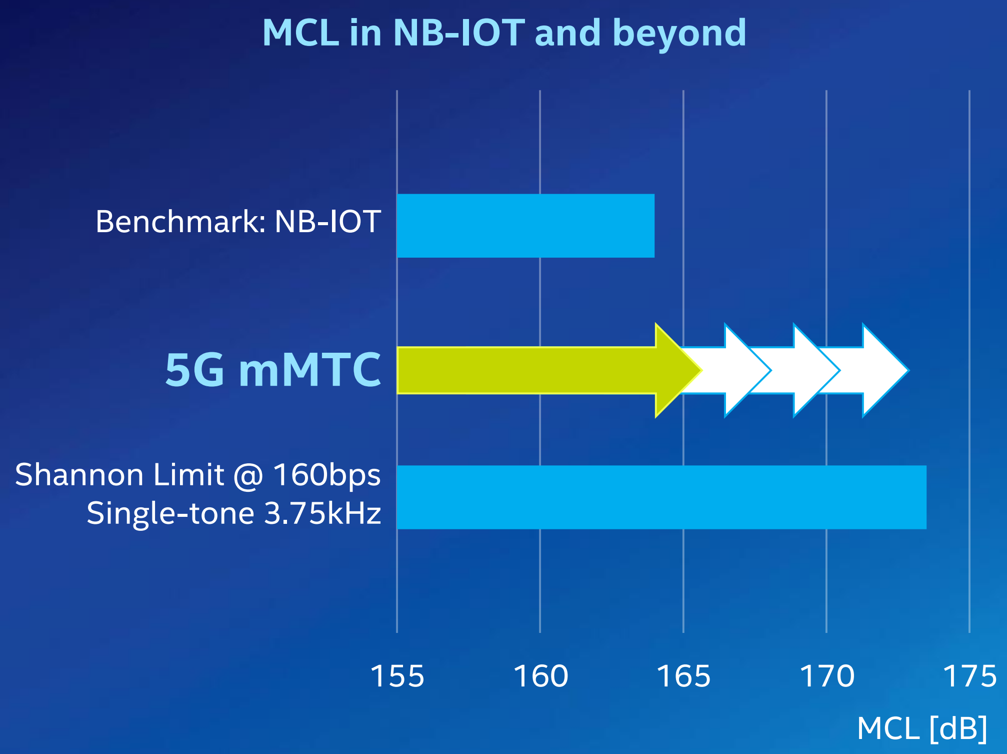
Single-tone with small subcarrier bandwidth

Very low data rates

Service allows for lowest data rates

Relaying and D2D support

Multi-hop to reach deep indoor or wide area cell edge



Extend Battery Life in NB-IOT and beyond

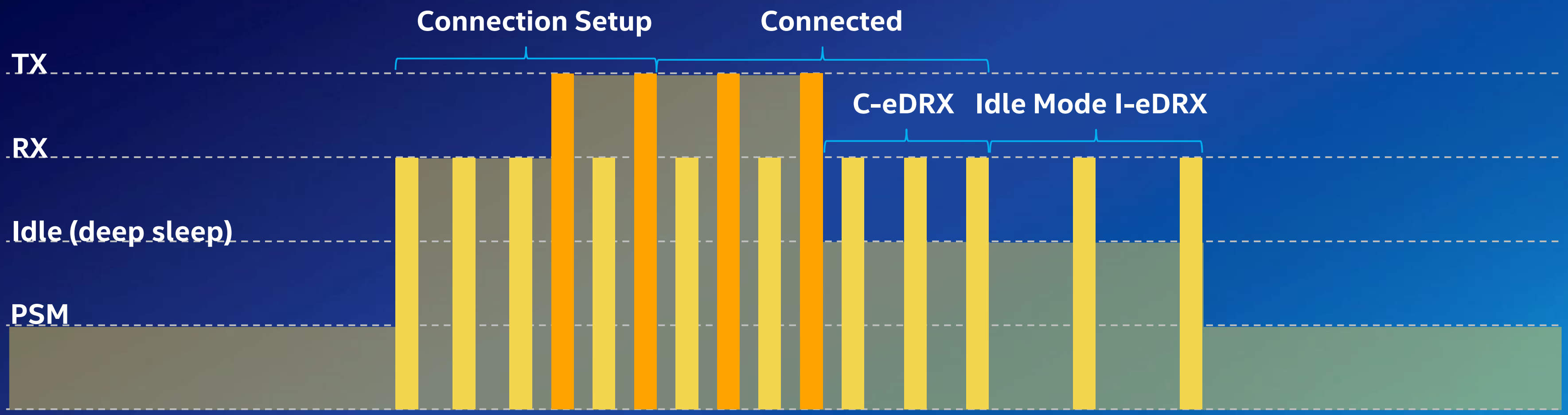
Rel.12 PSM Max time in Power Saving Mode/ device unreachable by network: ~13days

Relaxed reachability for Mobile Terminated (MT) traffic

Rel.13 I-eDRX Max Idle Mode eDRX: ~3hrs

Strict reachability delay requirements for MT traffic

Rel.13 C-eDRX Max Connected Mode extended Discontinuous RX (eDRX) cycle: ~9sec



Illustrative, power consumption levels (Y axis) and durations (X axis) not in realistic proportions

Additional 5G IOT, mainly 5G Ultra-Reliable Low Latency Comms (URLLC), Key Performance Requirements[1]

0.5ms U-plane latency[2]

Successful delivery of DL or UL packet from L2/L3 SDU ingress point to L2/L3 SDU egress point (no DRX)

99.999% reliability[2,3]

$1 - 10^{-5}$ reliability within 1ms U-plane latency targeted

$1 - 10^{-5}$ eV2V (sidelink) reliability @3-10ms U-plane latency

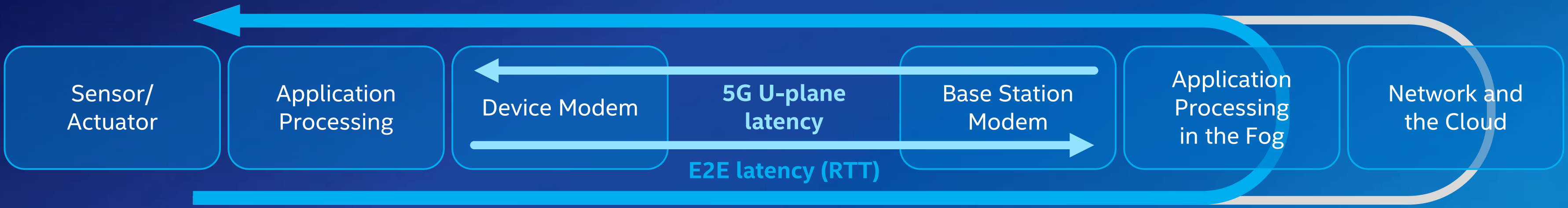
accurate position[4]

Beyond state-of-the art based on RAN-embedded (including Cell-ID, OTDOA, UTDOA) and RAN-external (including GNSS, Bluetooth*, Wi-Fi*, terrestrial beacons) methods

1: 3GPP TR 38.913 v0.4.0
2: Percentage of #packets successfully delivered out of #packets sent and within a service-specific time constraint
U-plane: user plane, DRX: discontinuous reception, SDU: Service Data Unit
3: For URLLC (= Ultra-Reliable Low Latency Communications) use cases; eV2V: enhanced Vehicle-to-Vehicle
4: For mMTC and URLLC use cases; GNSS: Global Navigation Satellite Systems, OTDOA/UTDOA: Observed/ Uplink Time Difference of Arrival

5G specifications[1] will enable low E2E latency

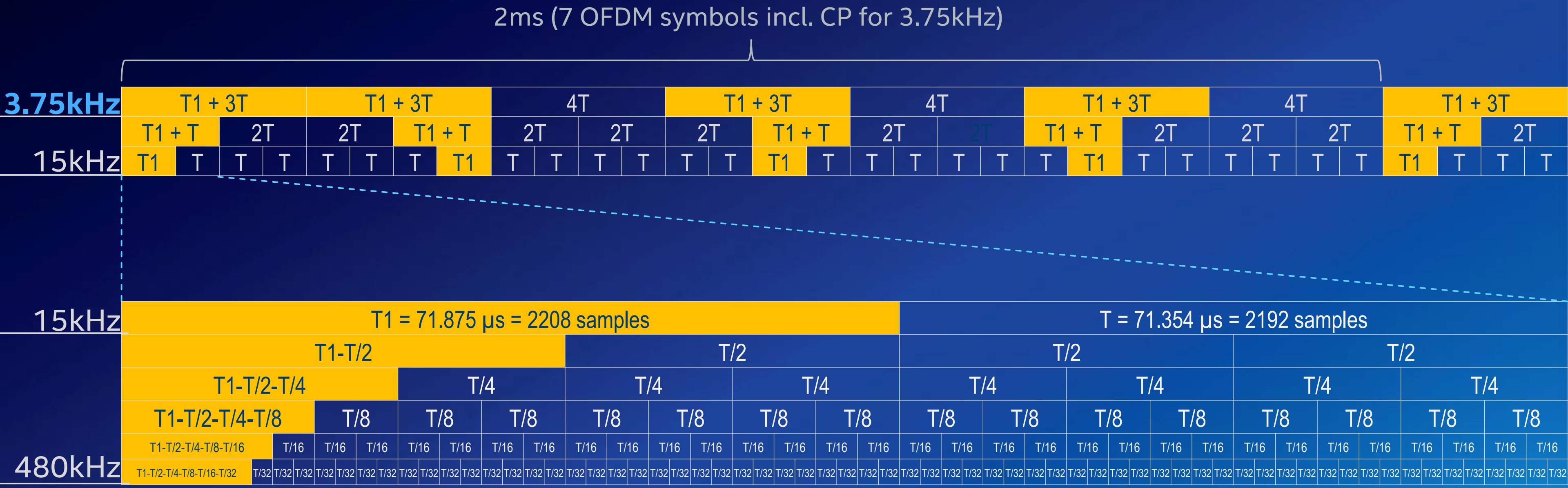
E2E latency (RTT)	U-plane latency	Quality measure	5G URLLC Use Cases
< 1ms		packet loss $<10^{-4}$	Smart grid substation control for power outage avoidance[2]
< 2ms	< 1ms	reliability $1 - 10^{-5}$	Tactile Internet, eHealth@300Mbps data rate[2]
< 2ms		transport loss $<10^{-9}$	Industrial factory automation, industrial control[2]
	< 2ms	reliability $1 - 10^{-5}$	eV2X packet of 300 Byte relayed via infrastructure[3]
	< 8ms	reliability $1 - 10^{-5}$	Smart grid of distributed sensors: critical event detection[2]
< 20ms			LTE Rel.14 V2X pre-crash sensing[4]
< 100ms			Drone, Unmanned Aerial Vehicle (UAV)[2]



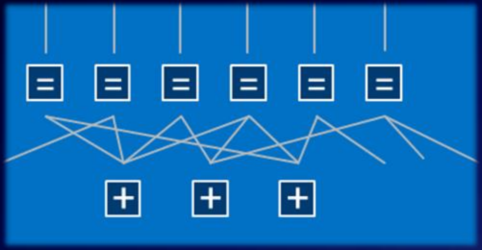
(1) 3GPP work in progress, Rel.15 to start in H2.2017 – (2) 3GPP TR 22.862 – (3) 3GPP TR 38.913 v0.4.0 – (4) 3GPP TR 22.185

Flexible NR framework (1/2)

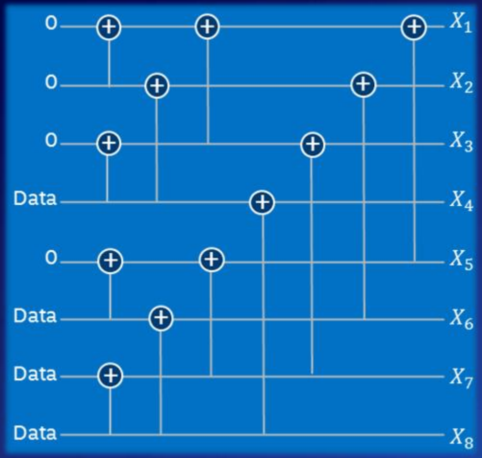
Subcarrier spacing and OFDM symbol alignment for coexistence (Scaled CP)



Channel Coding status in NR



LDPC: agreed for DL eMBB data channels for all block sizes, working assumption in UL eMBB



Polar coding: agreed for UL eMBB control information (except for extremely small block sizes where block/repetition coding will be applied), working assumption for DL eMBB

Low latency status in 3GPP (Nov 2016)

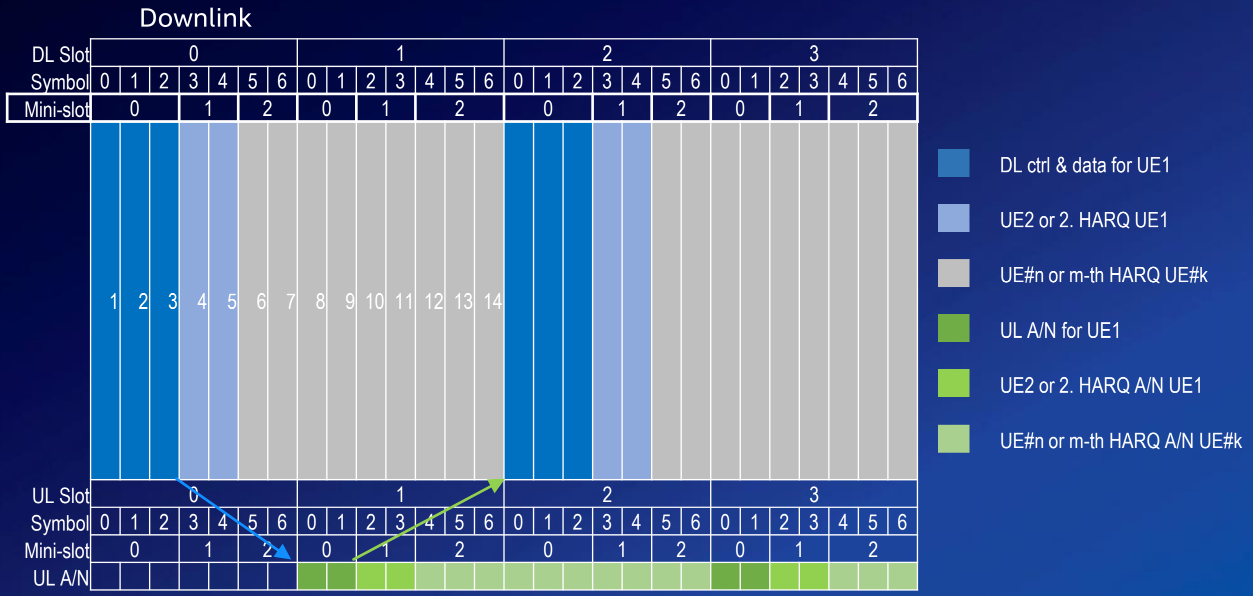
Rel.14 shortened TTI

- Support of the mini-slot configs: {2 DL, 2 UL} , {7 DL, 7 UL} OFDM symbols
- Special case mini-slot with 3 OFDM symbols may have flexible position within subframe

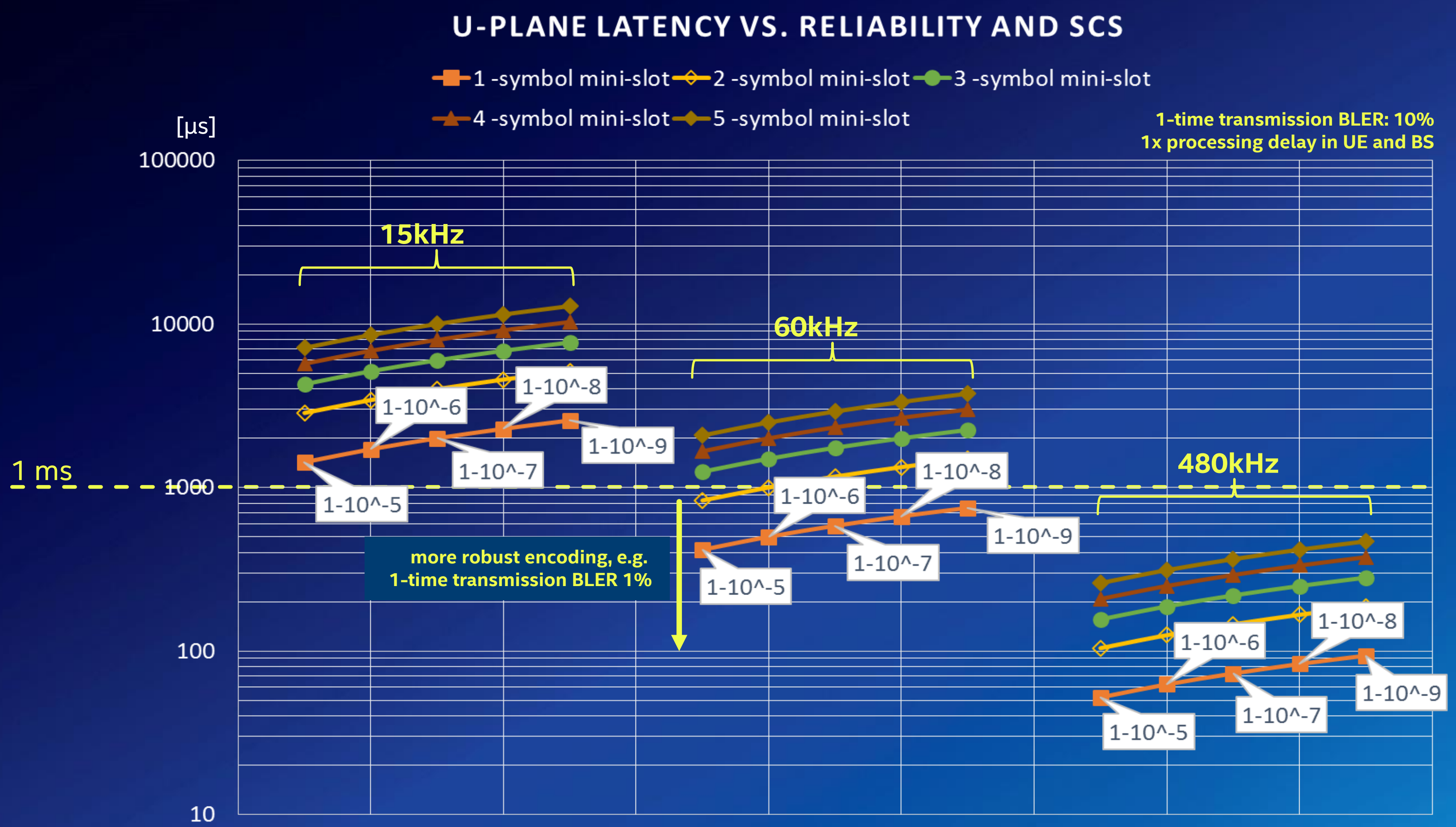
NR status relevant to low latency

- At least >6 GHz, mini-slot with length 1 symbol
  (FFS: <6 GHz for unlicensed FFS, all bands for URLLC)
- FFS: DL control within one mini-slot of length 1
- NR-PDCCH monitoring for single-stage DCI design at least every other OFDM symbol in mini-slot
- Mini-slot lengths from 2 to Slot Length -1
  (FFS on restrictions of mini-slot length due to starting position)
- For URLLC, 2 OFDM symbols in mini-slot supported
  (FFS other values)
- At least >6GHz, mini-slot can start at any OFDM symbol
  (FFS <6 GHz for unlicensed, FFS for URLLC all bands)
- URLLC UL grant-free multiple access

Possible 5G low latency design based on mini-slots Compliant to 5G NR agreements (Nov 2016)



Parameters	Value (80 MHz)
Subcarrier spacing	60kHz
Mini-slot configuration	2 OFDM-symbol configuration
DL & UL HARQ_RTT	14 OFDM symbols ~ 250µs[1]
Est. average HARQ latency for effective BLER 10^{-5} when operating at BLER 10^{-1}	~278µs
U-plane latency for 1-10^{-5} reliability when operating at BLER 10^{-1}	1 ms
Max TBS[2] DL (Est. for 2OS mini-slot)	~7.3 Kb
Max TBS[3] UL (Est. for 2OS mini-slot)	~5.1 Kb
DL & UL processing delay	2x mini-slot
Est. DL peak per 2OS HARQ (average over HARQ ReTx)	~28Mbps
Est. UL peak per 2OS HARQ (average over HARQ ReTx)	~19 Mbps
1: URLLC Scaled Normal CP 2: Max TBS DL (Estimated) < 66% RE per mini-slot*6*0.8 3: Max TBS UL (Estimated) < 66% RE per mini-slot*4*0.8	


U-PLANE LATENCY VS. RELIABILITY AND SCS
1 -symbol mini-slot
2 -symbol mini-slot
3 -symbol mini-slot
4 -symbol mini-slot
5 -symbol mini-slot
1-time transmission BLER: 10%
1x processing delay in UE and BS
[µs]
100000
10000
1000
100
10
1 ms
15kHz
60kHz
480kHz
1-10^-5
1-10^-6
1-10^-7
1-10^-8
1-10^-9
more robust encoding, e.g.
1-time transmission BLER 1%

Summary of URLLC* for sub-6GHz Cellular IoT

*: Ultra-Reliable Low Latency Communications

Key performance requirements

- 0.5ms U-plane latency[1]
- 99.999% reliability[2] @1ms U-plane latency
- Varying latency requirements for different URLLC applications

Possible sub-6GHz (UR)LLC design

- Subcarrier spacing: 60kHz
- Bandwidth: (up to) 80MHz

Characteristic features

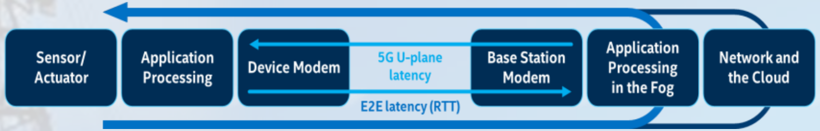
- Low latency by mini-slot design together with wider subcarrier spacing
- Ultra-reliability by Phy channel design and robust channel coding

Moderate data rate URLLC use cases

- Smart Grid: teleprotection, secondary substation control
- Safety features in V2X: collision avoidance
- Industrial Control
- Augmented Reality in Verticals

Latency reduction

- E2E latency reduction by optimal network slicing
- 5G air i/f definition for reduced U-plane latency



1) Successful delivery of DL or UL packet from L2/L3 SDU ingress point to L2/L3 SDU egress point (no DRX); U-plane: user plane, DRX: discontinuous reception, SDU: Service Data Unit
2) Percentage of #packets successfully delivered out of #packets sent and within a service-specific time constraint

Wrap-Up and Conclusion

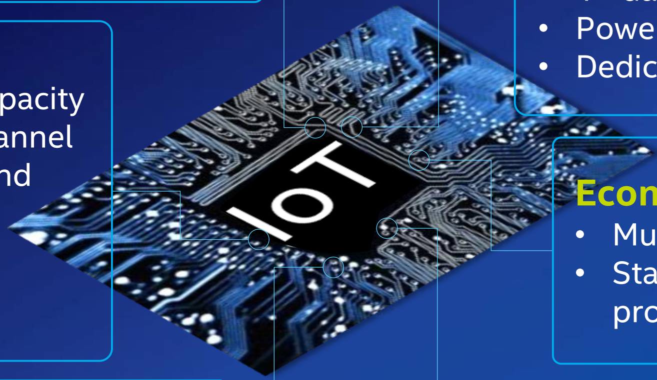
Sabine Roessel & Stefania Sesia

Key Challenges of Modem and SoC Design for Massive IoT

Key performance requirements
- 10^6 connections in 1 km^2 urban environment
- 10 years battery lifetime[1]
- 164dB MCL@160bps[2]
- <10s latency[3]

Signal processing
- Close-to-Shannon channel capacity
- Advanced, low-complexity channel coding for small packet size and extreme coverage
- Optimal signal processing for synchronization and channel estimation in narrowband

Special requirements
- Accurate positioning, how to avoid costly GNSS integration via native mMTC methods?



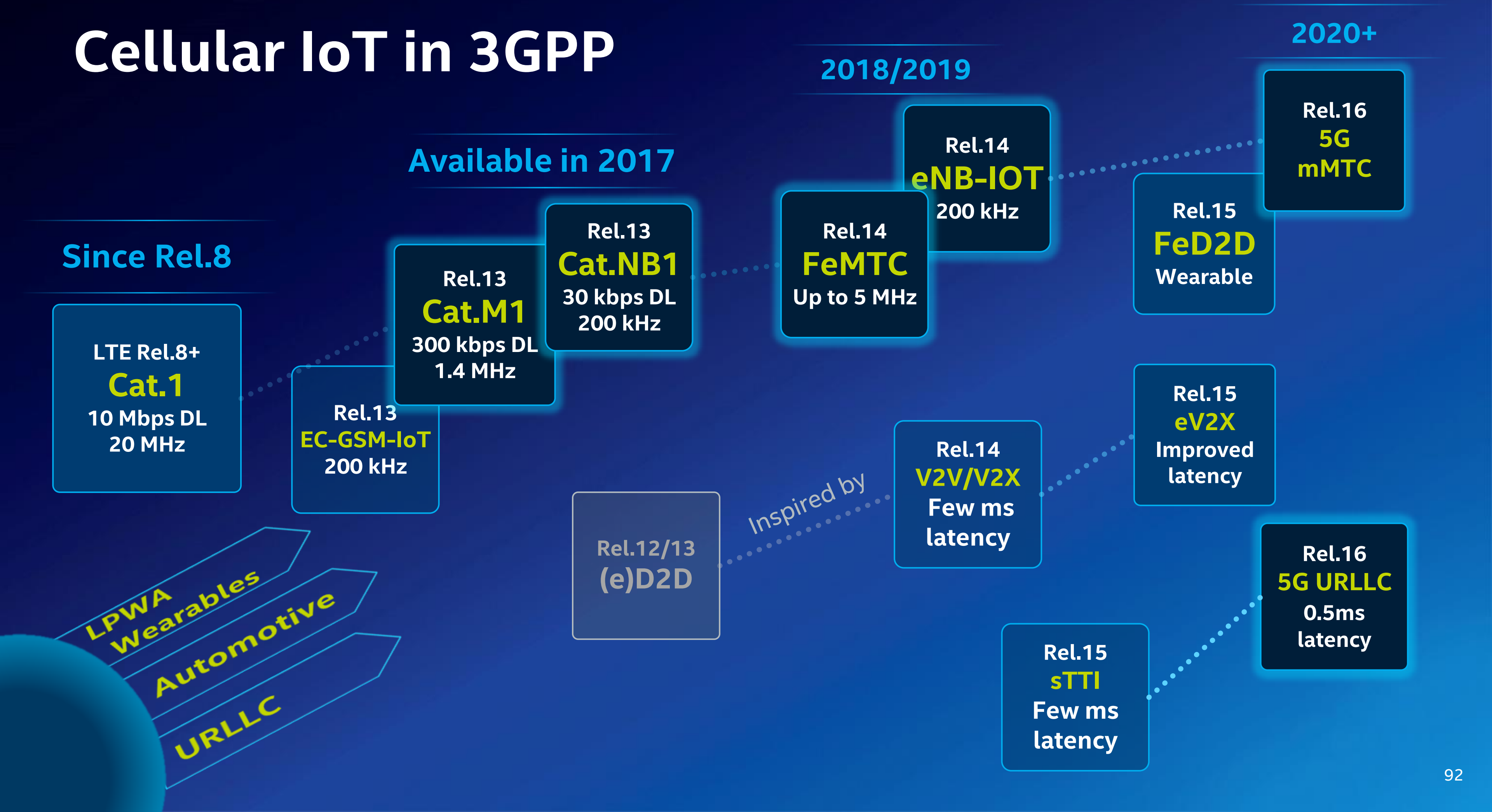
Cross-system design of application, modem, network for lowest power
- Communications system design for 10+ years battery lifetime[1] in mMTC and 1+ day battery lifetime[2] of high-end Wearables
- Power-saving SoC HW/ SW/ memory architecture
- Dedicated optimizations for Idle mode and Paging

Economy of scale in fragmented market
- Multiple use cases with a single-digit-$ SoC
- Standardized solutions preferred over proprietary ones – also in unlicensed spectrum

Fundamental prerequisites
- Security and privacy
- Device management and provisioning

1) 5000 mAh, 2xAA, 200 Byte UL and 20 Byte DL per day at 164dB MCL
2) NB-IOT is benchmark: 164dB@160 bps equiv. SNDP layer/200 bps Phy (3GPP TR 45.820)
3) Infrequent small packets from most battery-efficient device state with 20 Byte UL @164dB MCL
4) 250 mAh, high end use cases including voice, browsing, audio streaming

Cellular IoT in 3GPP



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