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Ultra Reliable Low Latency Communication for 5G New Radio

IEEE Workshop on 5G Technologies for Tactical and First Responder Networks

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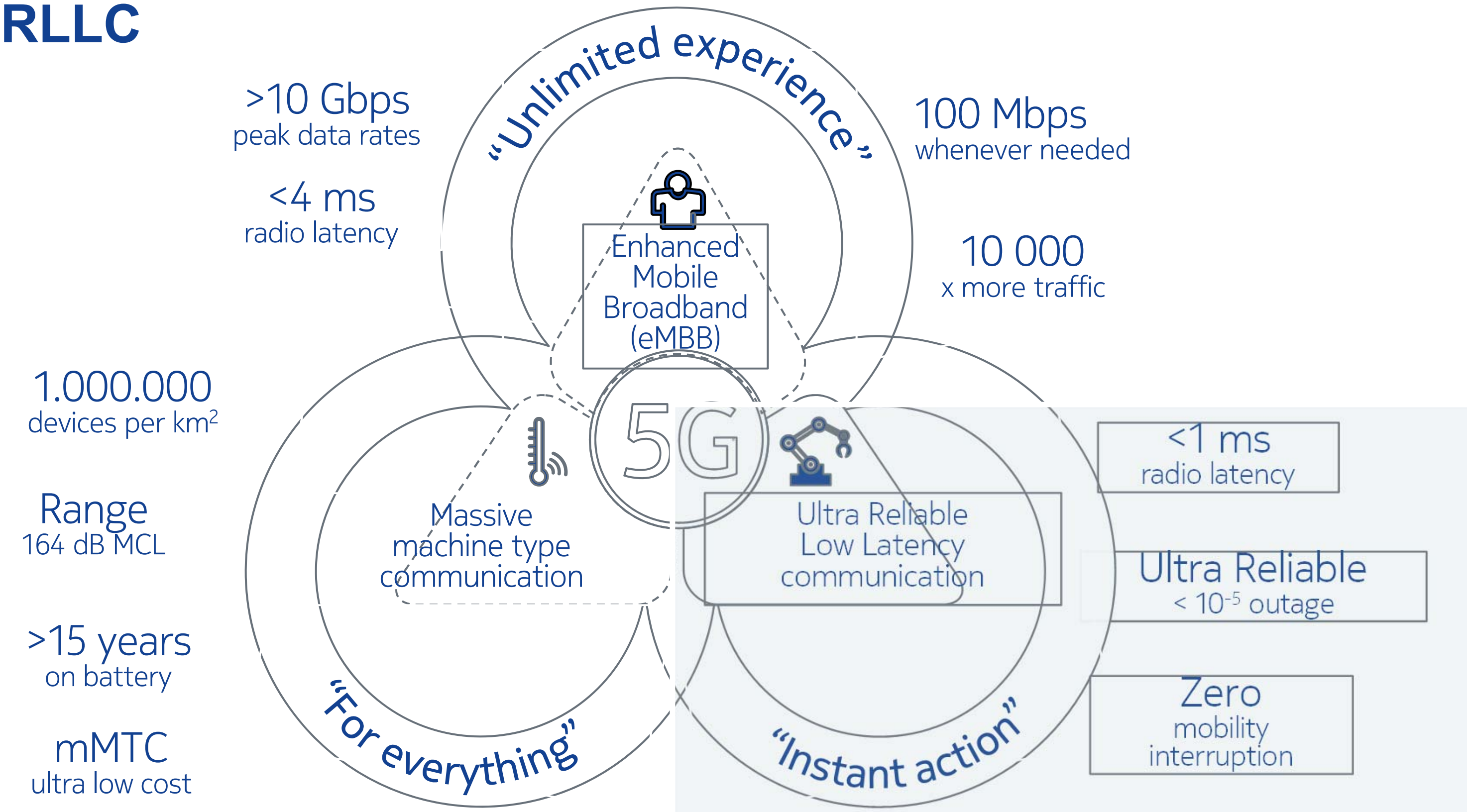
5G and URLLC



URLLC is one of the three usage scenarios identified by ITU IMT-2020

Use Cases
Selected URLLC Use Cases

Factory Automation (local area)

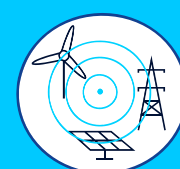
Motion Control
- Indoor
- Most stringent availability, latency, and jitter
- Limited mobility

Mobile Robots/AGVs
- Indoor & outdoor
- Stringent availability, latency, and jitter
- Ultra reliable mobility (following pre-defined paths)

Harbor Automation
- Remote control of cranes and vehicles
- Indoor & outdoor
- Mixed data traffic types
- High reliability

Smart City Automation (wide area)

Smart Grid Protection and Control
- Outdoor
- Stringent requirements on availability, latency, and jitter



Autonomous Vehicles
- Outdoor
- Stringent requirements on availability, latency
- Ultra reliable mobility (over wide area)

AGV: Automatic guided vehicle

URLLC Use Cases and Requirements (TS 22.261)

Table 7.2.2-1 Performance requirements for low-latency and high-reliability scenarios.

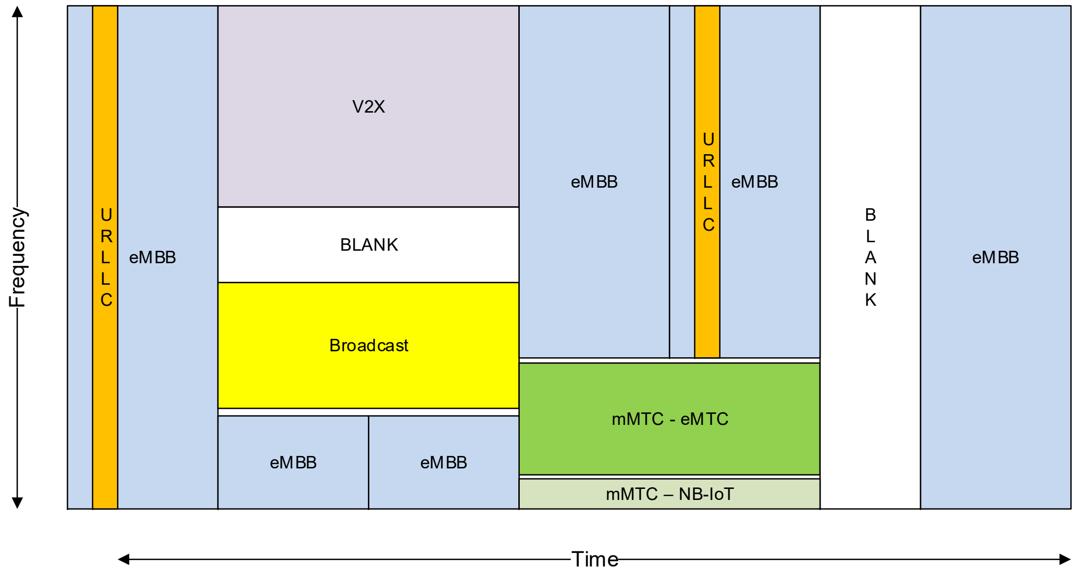
Scenario	End-to-end latency	Communication service availability	Reliability	User experienced data rate	Payload size	Traffic density	Connection density	Service area dimension
Discrete automation – motion control	1 ms	99,9999%	99,9999%	1 Mbps up to 10 Mbps	Small	1 Tbps/km^2	100 000/km^2	100 x 100 x 30 m
Discrete automation	10 ms	99,99%	99,99%	10 Mbps	Small to big	1 Tbps/km^2	100 000/km^2	1000 x 1000 x 30 m
Process automation – remote control	50 ms	99,9999%	99,9999%	1 Mbps up to 100 Mbps	Small to big	100 Gbps/km^2	1 000/km^2	300 x 300 x 50 m
Process automation – monitoring	50 ms	99,9%	99,9%	1 Mbps	Small	10 Gbps/km^2	10 000/km^2	300 x 300 x 50
Electricity distribution – medium voltage	25 ms	99,9%	99,9%	10 Mbps	Small to big	10 Gbps/km^2	1 000/km^2	100 km along power line
Electricity distribution – high voltage	5 ms	99,9999%	99,9999%	10 Mbps	Small	100 Gbps/km^2	1 000/km^2	200 km along power line
Intelligent transport systems – infrastructure backhaul	10 ms	99,9999%	99,9999%	10 Mbps	Small to big	10 Gbps/km^2	1 000/km^2	2 km along a road
Tactile interaction	0,5 ms	[99,999%]	[99,999%]	[Low]	[Small]	[Low]	[Low]	TBC
Remote control	[5 ms]	[99,999%]	[99,999%]	[From low to 10 Mbps]	[Small to big]	[Low]	[Low]	TBC

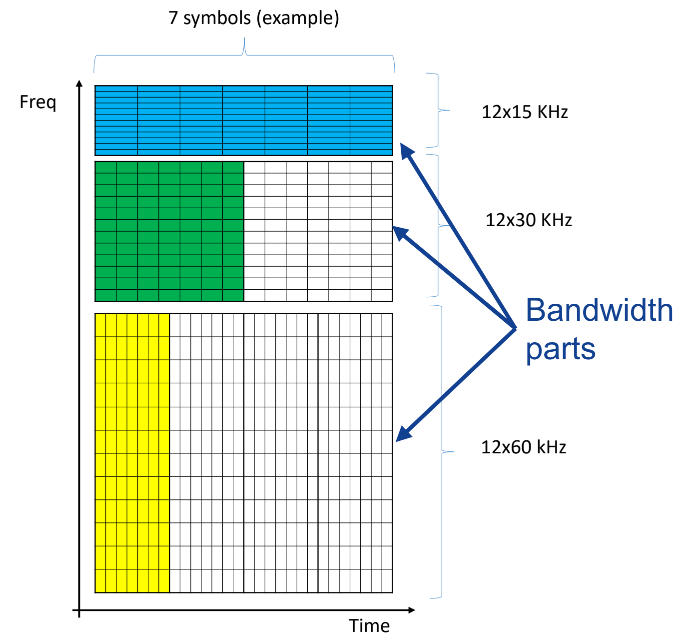
Various requirements from different URLLC services

URLLC Requirements from 3GPP RAN TR 38.913 (v14.3.0, August 2017)

Requirements	value
7.4 Control plane latency From a battery efficient state to start of continuous data transfer	10ms
7.5 User plane latency The time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions	0.5ms for both UL and DL
7.7 Mobility interruption time The shortest time duration supported by the system during which a user terminal cannot exchange user plane packets.	0ms
7.9 Reliability Reliability is defined as the success probability R of transmitting X bits within a certain delay at a certain channel quality (e.g. coverage-edge).	$1\text{-}10^{-5}$ for 32 bytes with a user plane latency of 1ms

Flexible NR Framework





- NR provides flexible framework to support different services and QoS requirements
  - Scalable slot duration, mini-slot and slot aggregation
  - Self-contained slot structure
  - Traffic preemption for URLLC
  - Support for different numerologies for different services

- NR transmission is well-contained in time and frequency
  - Future features can be easily accommodated

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Ultra Reliable and Low Latency Communication

It is not only about radio…

Hybrid connectivity
(e.g. multi-operator, multi-RAT)

O&M
(e.g. E2E reliability monitoring and verification, fault detection/ prediction/prevention)

NW planning & optimization
(e.g. channel prediction, deployment self-optimization)

Flexible architecture
(e.g. lower latency with MEC, SDN & VNF reliability)

5GC concepts
(e.g. admission & policy ctrl, flow based QoS, context awareness, CP decomposition)

E2E Reliability

NW Slicing
(e.g. slice provisioning, dynamic resource usage)

NR L2-3 concepts
(e.g. multi-connectivity, conditional handover, SON-MRO)

Techno-economics
(e.g. TCO analysis, e2e reliability modeling, reliability cost functions)

NR L1 concepts
(e.g. shorter TTI, multiplexing, grant based DL, grant free UL, joint transmission, control channel enhancements)

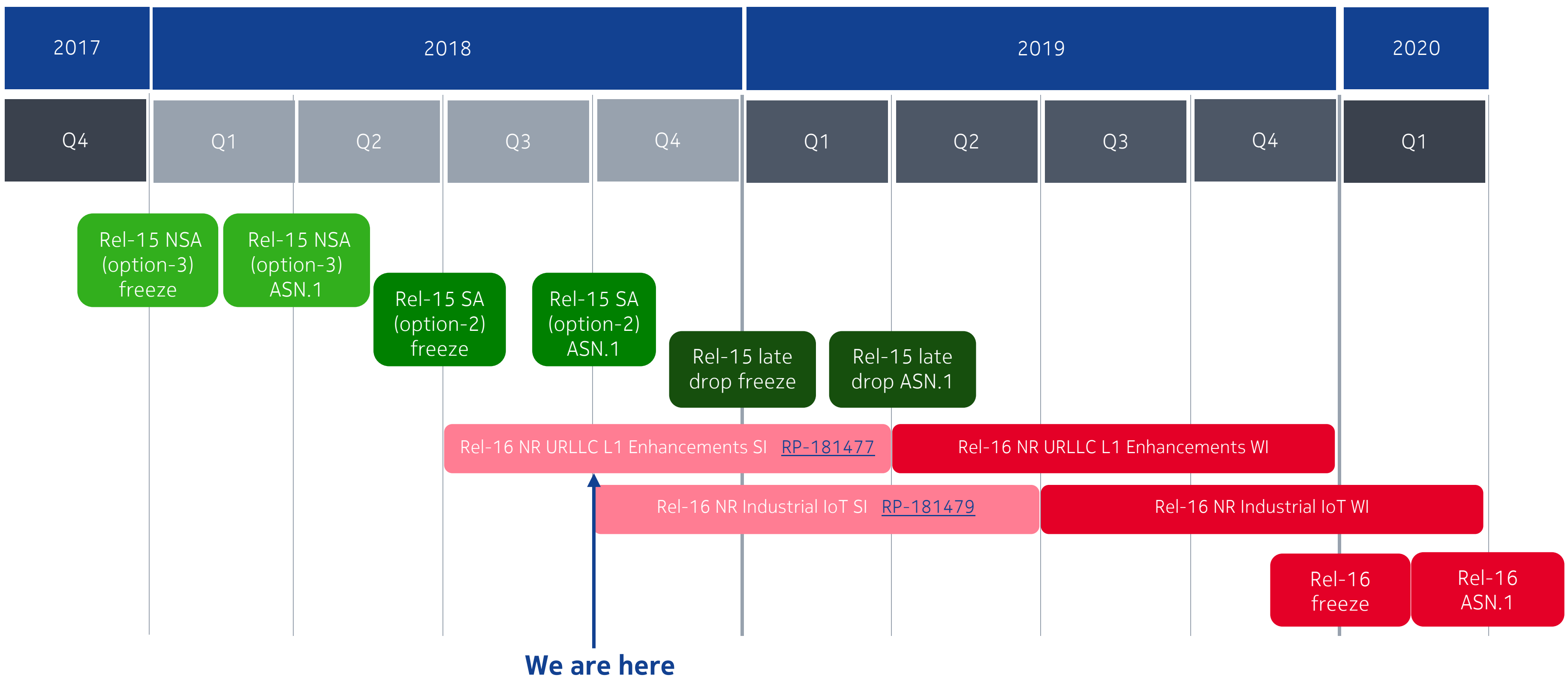
HW
(e.g. HW reliability analysis and improvements, hot swap mechanisms)

SW
(e.g. sw reliability analysis and improvements, sw maintenance breaks)

Security
(e.g. protection against cyper attacks)

Transport
(e.g. rapid rerouting, PON slicing and scheduling)

Timeline – URLLC Related Items



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Physical Channels & Physical Signals

PDSCH
DL shared channel

PBCH
Broadcast channel

PDCCH
DL control channel

gNodeB

PUSCH
UL shared channel

PUCCH
UL control channel

PRACH
Random access channel

User Equipment

DL Physical Signals

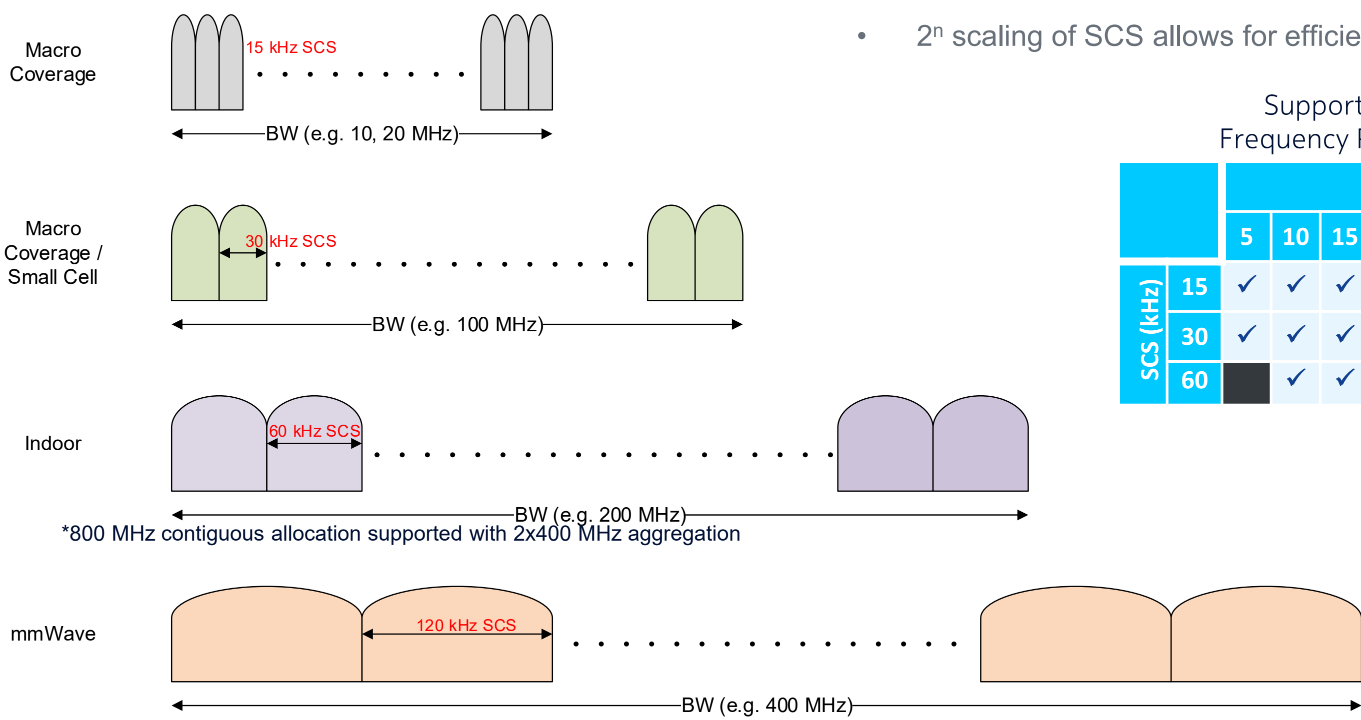
Demodulation Ref (DM-RS)
Phase-tracking Ref (PT-RS)
Ch State Inf Ref (CSI-RS)
Primary Sync (PSS)
Secondary Sync (SSS)

UL Physical Signals

Demodulation Ref (DM-RS)
Phase-tracking Ref (PT-RS)
Sounding Ref (SRS)

Scalable NR Numerology

- NR supports scalable numerology to address different spectrum, bandwidth, deployment and services
- Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channels
  - 2^n scaling of SCS allows for efficient FFT processing



Supported data numerologies in Frequency Range 1 (FR1) (below 6 GHz):

SCS (kHz)	Carrier bandwidth (MHz)											
	5	10	15	20	25	30	40	50	60	80	90	100
15	✓	✓	✓	✓	✓	✓	✓	✓				
30	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
60		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Supported data numerologies in FR2 (above 24 GHz):

SCS (kHz)	Carrier BW (MHz)			
	50	100	200	400
60	✓	✓	✓	
120	✓	✓	✓	✓

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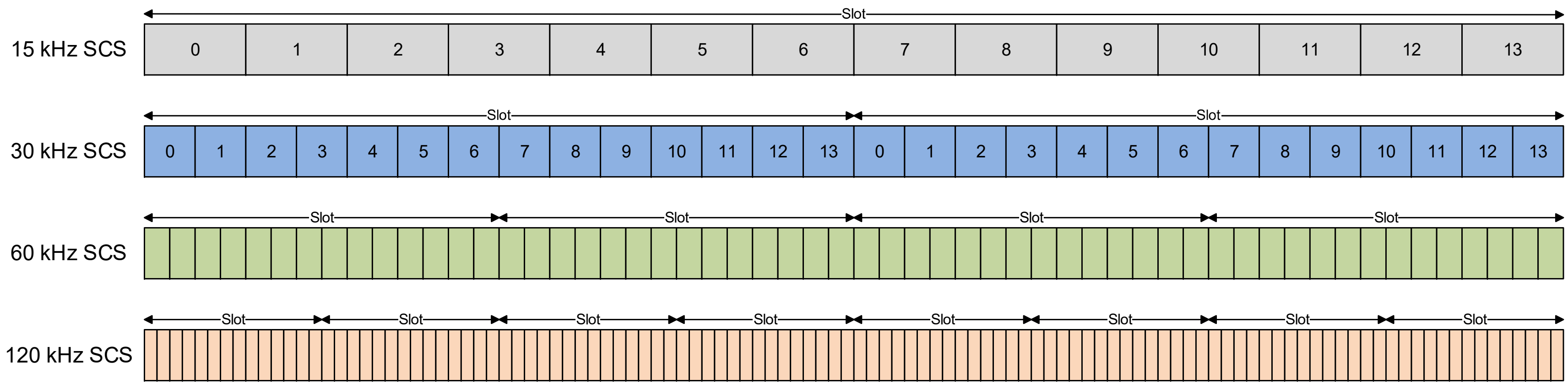
Scalable NR Slot Duration



- One slot is comprised of 14 symbols
  - Slot length depends on SCS – 1ms for 15 kHz SCS to 0.125ms for 120 kHz SCS
- Mini-slot (2, 4, or 7 symbols) can be allocated for shorter transmissions
- Slots can also be aggregated for longer transmissions
- A frame (10 ms) and sub-frame (1 ms) provide an SCS-agnostic time reference

3GPP Rel-15 URLLC Toolbox

Low latency

- New numerology/slot/mini-slot/bi-directional structure
- Non-slot (i.e. mini-slot) based scheduling
- Downlink multiplexing between URLLC and eMBB services: pre-emptive scheduling
- Uplink grant free transmission
- Reduced processing time
- Short PUCCH (one or two symbols)

Reliability

- Blind repetitions (i.e. K-repetition)
- Micro-diversity (e.g. Rank-1 MIMO)
- Slot-aggregation for PDSCH and PUSCH
- Multi-slot PUCCH
- Configurable BLER targets for CQI report
- URLLC MCS/CQI table
- PDCP layer data duplication: allows a packet to be transmitted on two different carriers

Basic URLLC framework specified in 5G NR Rel-15

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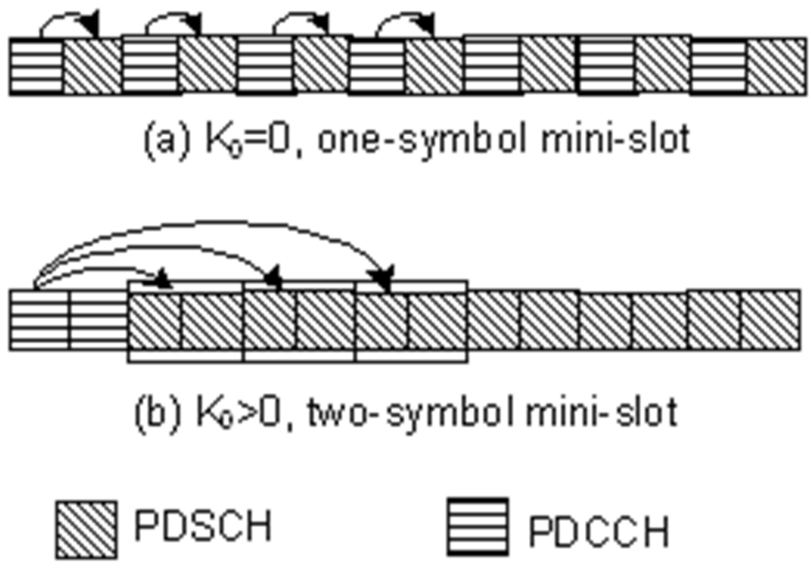
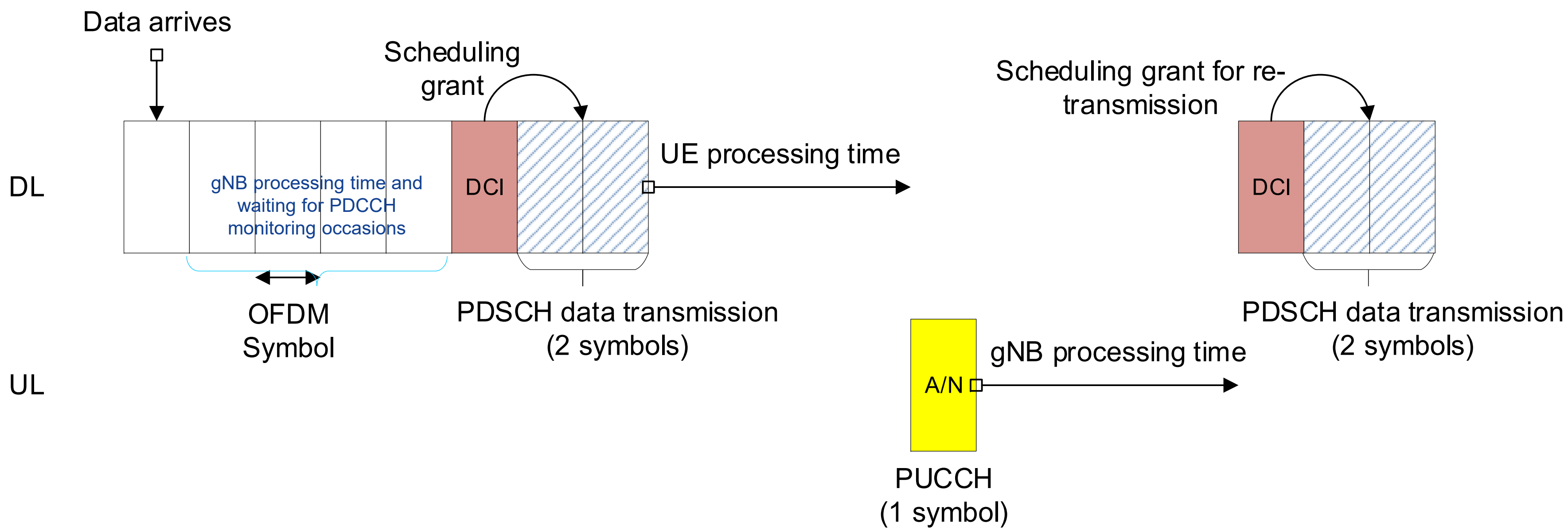
Mini-slot Scheduling (Non-slot based Scheduling)

- **Main use cases:**
  - **Low latency** when using small SCS (e.g. 15 kHz)
  - Supporting **TDM within slot** when operating at high carrier frequencies and with RF beamforming
- **Design principles for mini-slot:**
  - Mini-slot is a shortened version of the slot
    - *Common DMRS structures between slot and mini-slot*
    - *Common control channel structures*
  - Flexible HARQ/scheduling timing with symbol level granularity
  - Supported mini-slot lengths
    - *2, 4, 7 OFDM symbols will have high priority*
    - *Other lengths can be considered later*



Mini-slot plays a key role for latency reduction especially for smaller subcarrier spacing.

Example Latency Analysis with Mini-Slot Scheduling



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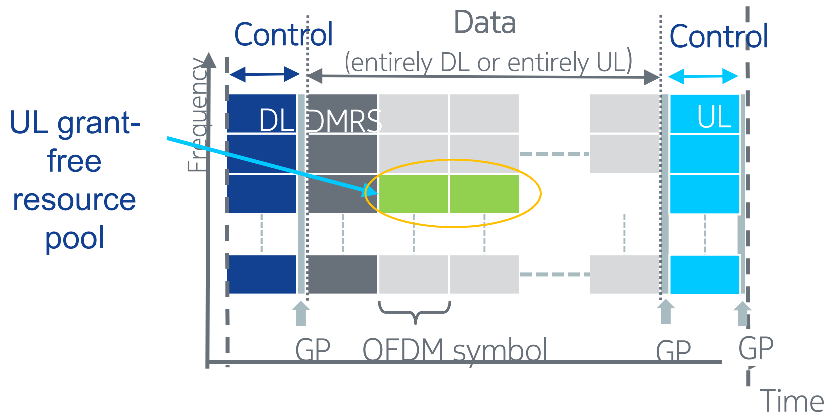
UL Grant-free Transmission

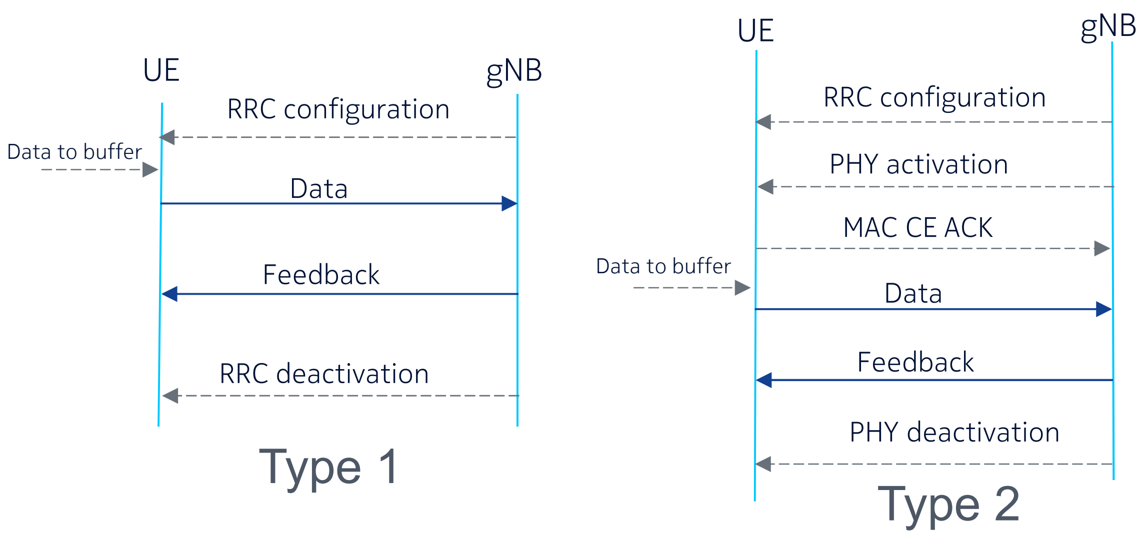
- 5G network can configure dedicated SPS resource to one UE or a shared SPS resource allocation pattern to a group of user devices with similar characteristics
- In case of **dedicated resource per URLLC UE**, no collision and similar operation as in LTE.
- In case of shared SPS resource:
  - Multiple users share the same SPS resource allocation pattern and use **contention based access** with load control at base station



SCS(kHz)	Supported periodicities [ms]
15	2 symbols, 7 symbols, 1, 2, 5, 10, 20, 32, 40, 64, 80, 128, 160, 320, 640
30	2 symbols, 7 symbols, 0.5, 1, 2, 5, 10, 20, 32, 40, 64, 80, 128, 160, 320, 640
60	2 symbols, 7 symbols (6 symbols for ECP), 0.25,0.5,1,2,5,10,20, , 32, 40, 64, 80, 128, 160, 320, 640
120	2 symbols, 7 symbols, 0.125,0.25,0.5,1,2,5,10,20, 32, 40, 64, 80, 128, 160, 320, 640

UL Grant-free Transmission Types

- Two types of operation
  - Type 1: only based on RRC (re)configuration without any L1 signaling (released also by RRC).
  - Type 2: based on both RRC configuration and L1 signaling for activation/deactivation, LTE SPS-alike

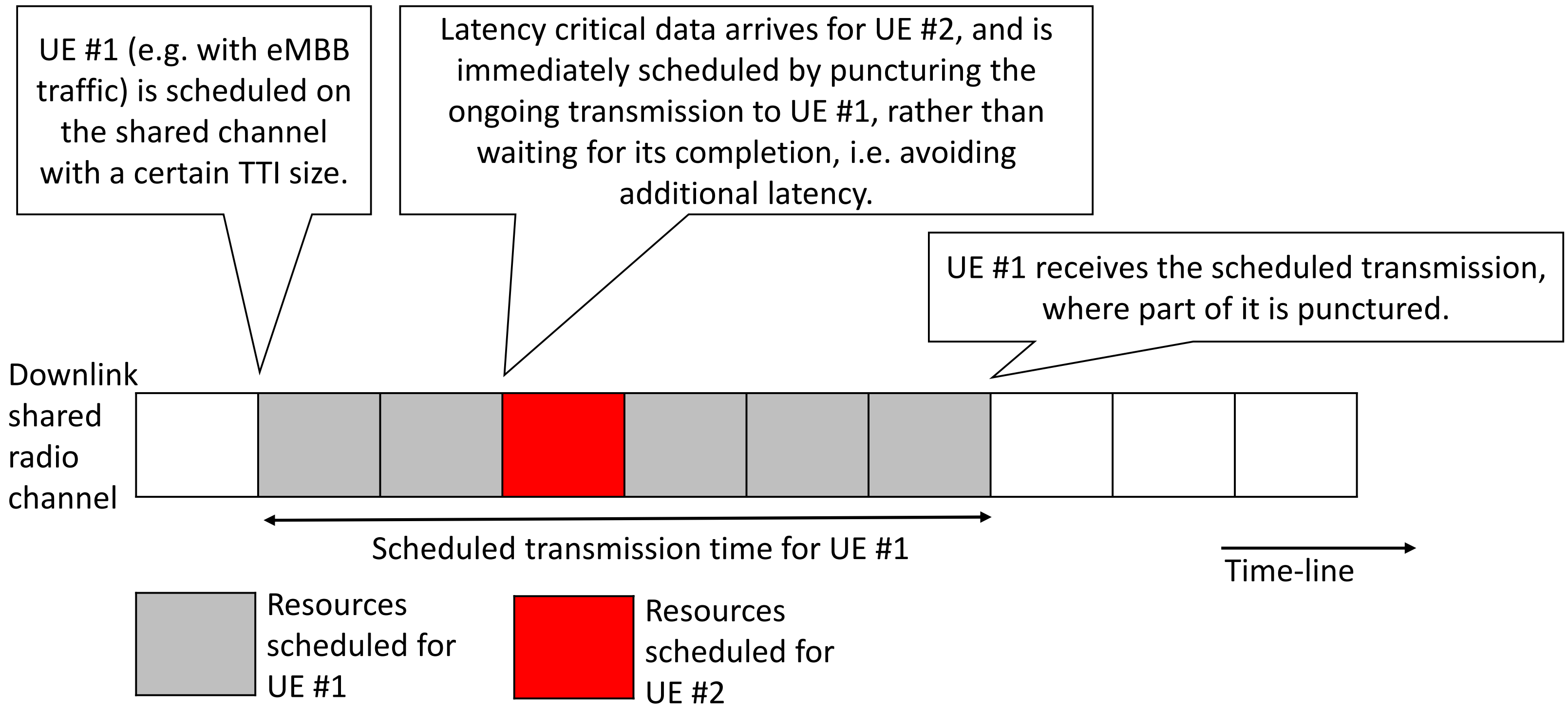


UEs are pre-allocated with resources and other necessary parameters before grant-free transmission

Using MAC CE to acknowledge PHY control → minimizing misunderstanding on the configuration.

UL grant-free transmission reducing overall latency by removing the scheduling process

DL Multiplexing: Pre-emptive Scheduling



Effective scheduling to reduce DL latency

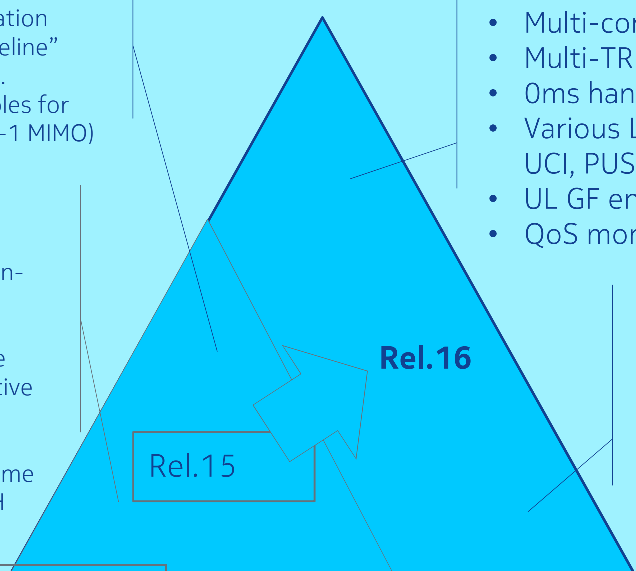
Enhancements for latency and reliability in Radio and E2E

Rel.16 URLLC aims for higher reliability and better efficiency

High Reliability (>99.9999%)

- K-repetition
- PDCP duplication
- Various “baseline” features (e.g. CQI/MCS tables for URLLC, Rank-1 MIMO)

- Multi-connectivity enhancements
- Multi-TRP
- 0ms handover interruption
- Various L1 enhancements (PDCCH, UCI, PUSCH, processing time line, …)
- UL GF enhancements
- QoS monitoring support for URLLC



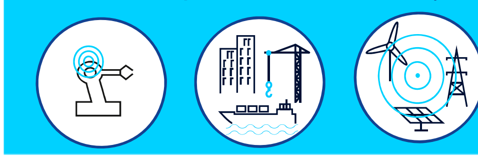
- Flexible architecture
- Short TTI/non-slot based scheduling
- UL grant free
- DL pre-emptive scheduling
- Reduced processing time
- Short PUCCH

- Data duplication enhancements
- Scheduling enhancements for intra- and inter-UE mux of eMBB and URLLC
- …

Low Latency (<1ms)

URLLC Efficiency [bps/Hz]

- R15 use case improvements (e.g. AR/VR)
- New use cases with higher requirements (e.g. factory automation, transport industry, electrical power distribution)



Key Rel.16 SI/WIs	Primary WG
FS_5G_URLLC (SP-180118)	SA2
NR_IIoT (RP-181479)	RAN2
NR_Mob_enh (RP-181433)	RAN2
NR_eURLLC_L1 (RP-181477)	RAN1
NR eMIMO (RP-181453)	RAN1

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Industrial IoT with 5G and NR

5G Time Sensitive Communications (TSC)

Support for Wireless Industrial Ethernet (IEEE TSN) and Multi-hop/Internet deterministic communications (aka IETF DetNet)

New R16 enablers on top of enhanced URLLC

i. Common understanding of global time among devices and network

ii. Network to support bounded latencies and error rates for packet transport (both min and max latency)

iii. More detailed service descriptors for TSC flows (condition for deterministic forwarding in TSN/DetNet)

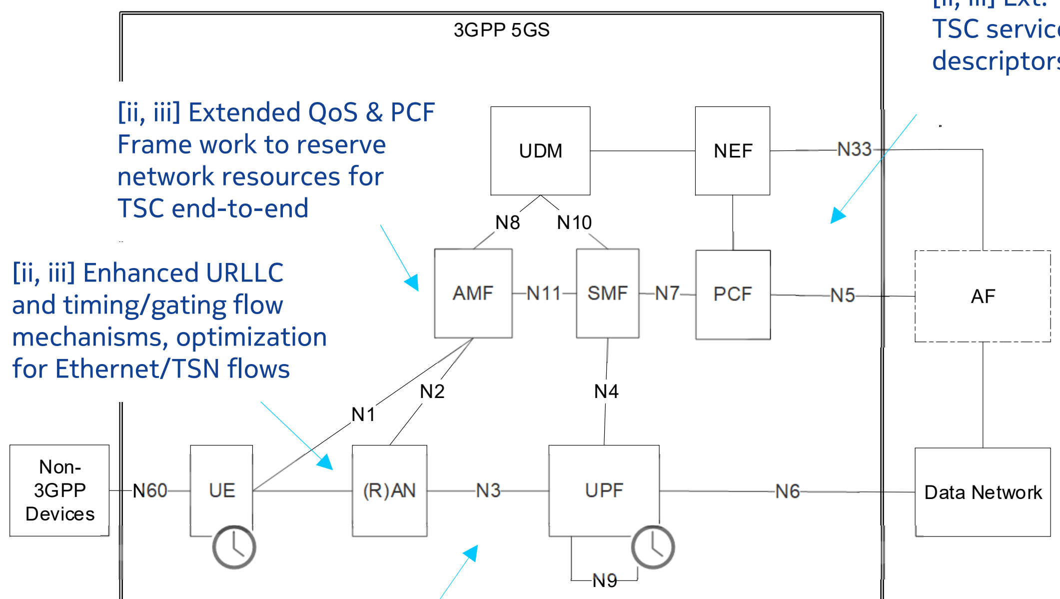
Key Rel.16 SI/WIs	Primary WG
NR_IIoT (RP-181479)	RAN2
FS_Vertical_LAN (SP-180507)	SA2

TSC defined on U-Plane between N6 and new reference point N60

[ii, iii] Ext. TSC service descriptors

[ii, iii] Extended QoS & PCF Frame work to reserve network resources for TSC end-to-end

[ii, iii] Enhanced URLLC and timing/gating flow mechanisms, optimization for Ethernet/TSN flows



[iii] Absolute E2E time synchronization to grand master clock (5GS internal or external) and sync capability for connected NEs via gPTP (both UE and UPF side)

Summary

- Diverse requirements expected from different URLLC use cases.
- 5G URLLC is one of the strong enablers of expansion to newly emerging vertical markets.
- Basic URLLC frame work has been specified in NR Rel-15. In the studied scenario, URLLC requirement of 10^{-5} within 1ms can be achieved.
- The coming Rel-16 will further enhance URLLC features especially e.g. supporting industrial wireless Ethernet.

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Q&A

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