# UL Grant-Free for URLLC in 5G NR

資策會 前瞻行動通訊系統中心

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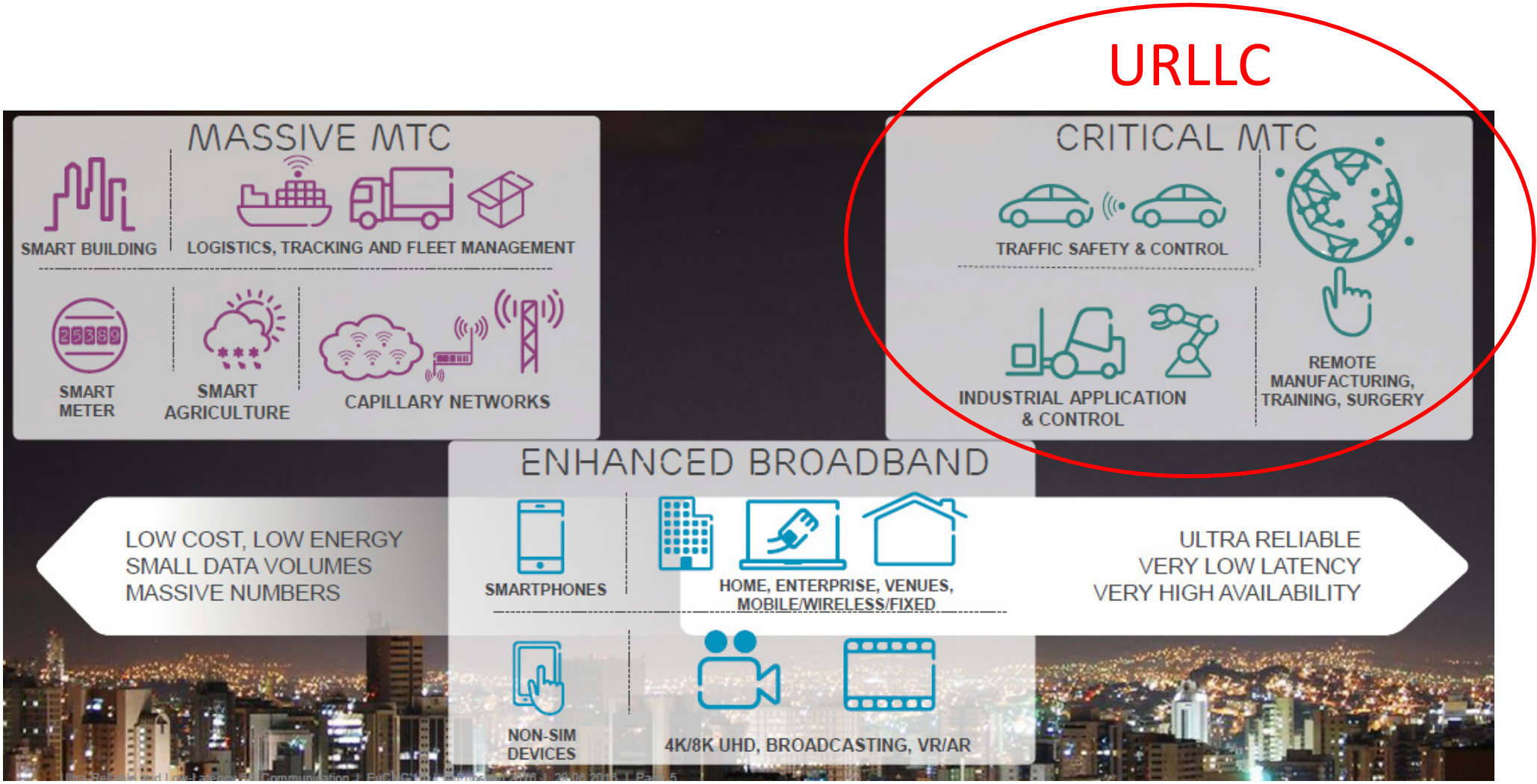
**2017.12.27**

# Agenda

- 5G 低延遲高可靠度(URLLC)應用實例
- 5G URLLC 設計需求與解決方案
- 5G URLLC UL-GF 標準制訂現況

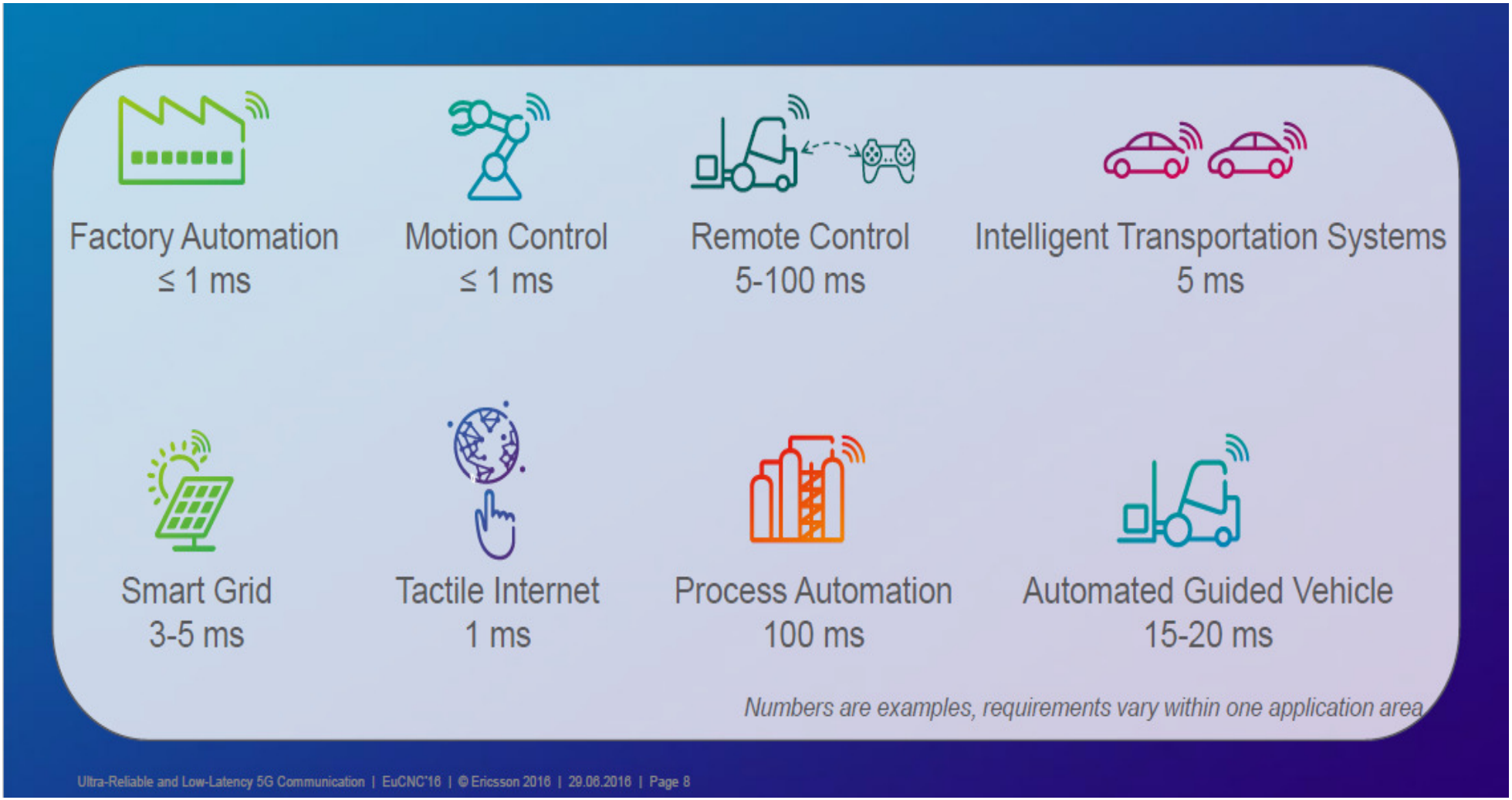
# URLLC 應用情境

# URLLC Use Cases




Ericsson

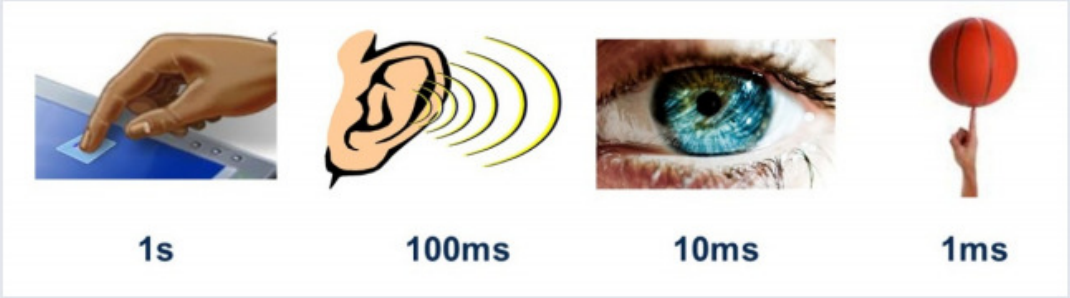
# 低時延應用




Ericsson

# 人體反應時間

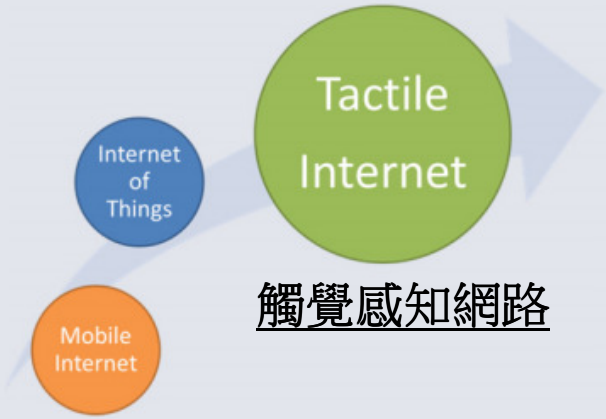
**Figure 1: Order of magnitude of human reaction times[1]**




人機互動

https://www.youtube.com/watch?v=0k3MSq6XMV8

**Figure 2: Revolutionary leap of the *Tactile Internet***




觸覺感知網路

ITU

# 數據分散服務
## (Data Distribution Service, DDS)

- A control system is based on distributed intelligence and decentralized control, to handle the rapidly expanding complexity in dynamic manufacturing environments for cooperation between robots and humans.

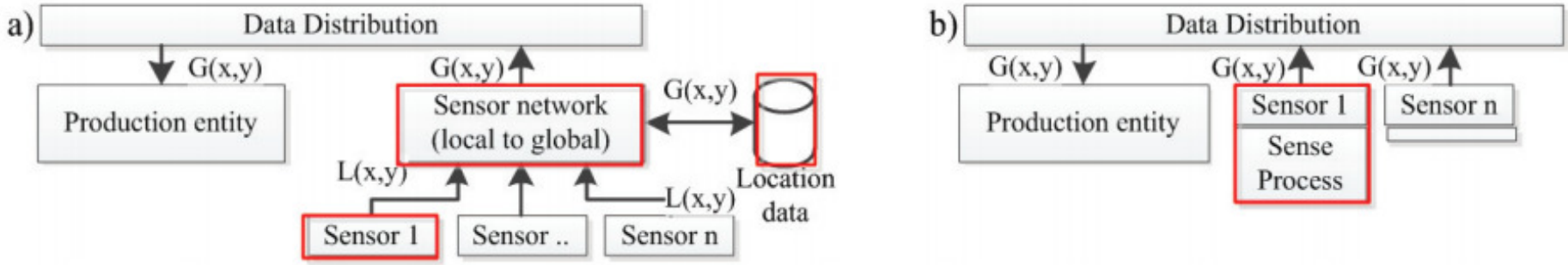



Fig. 1. (a) The difference between a hierarchical system and (b) a heterarchical system.

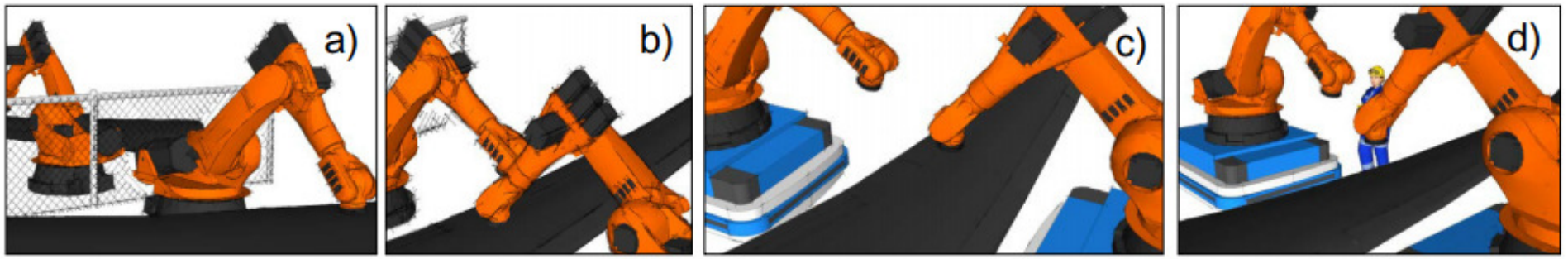
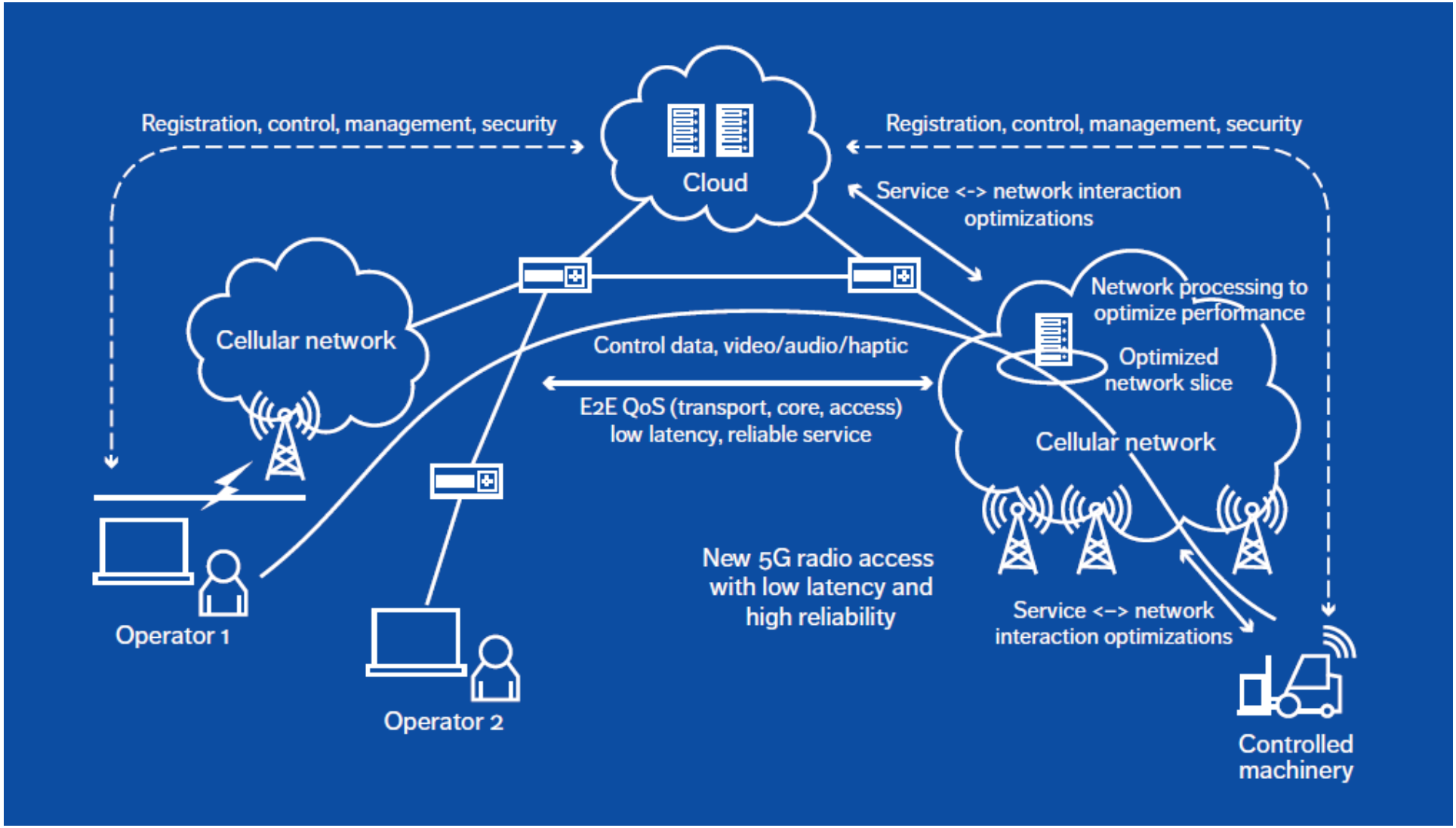



Fig. 2. (a-d) Industrial robot production planning paradigms.

Evaluating a data distribution service system for dynamic manufacturing environments: a case study, Elsvier 2014.

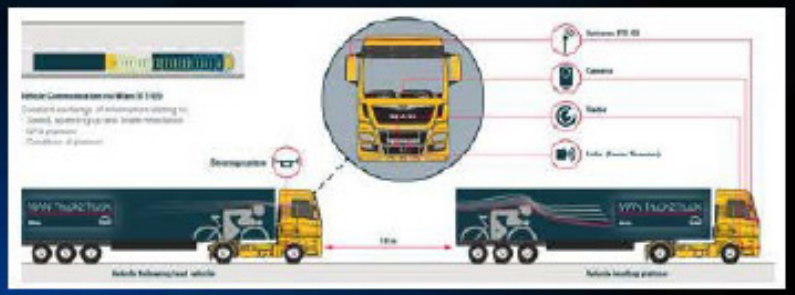
# 遠端控制




Ericsson

# 運輸車隊

## Hot use case for today – Truck platooning

Online business has significantly increased the transport of goods.

Platooning can reduce transportation cost:

- 15 to 20 meters 5 to 7 % less
- 5 meters 15 to 20 % less diesel
- semi-automatic driving changes driver time

For high speeds and short distance low latency radio control with 99.999% is needed to keep platoon oscillations to a minimum level

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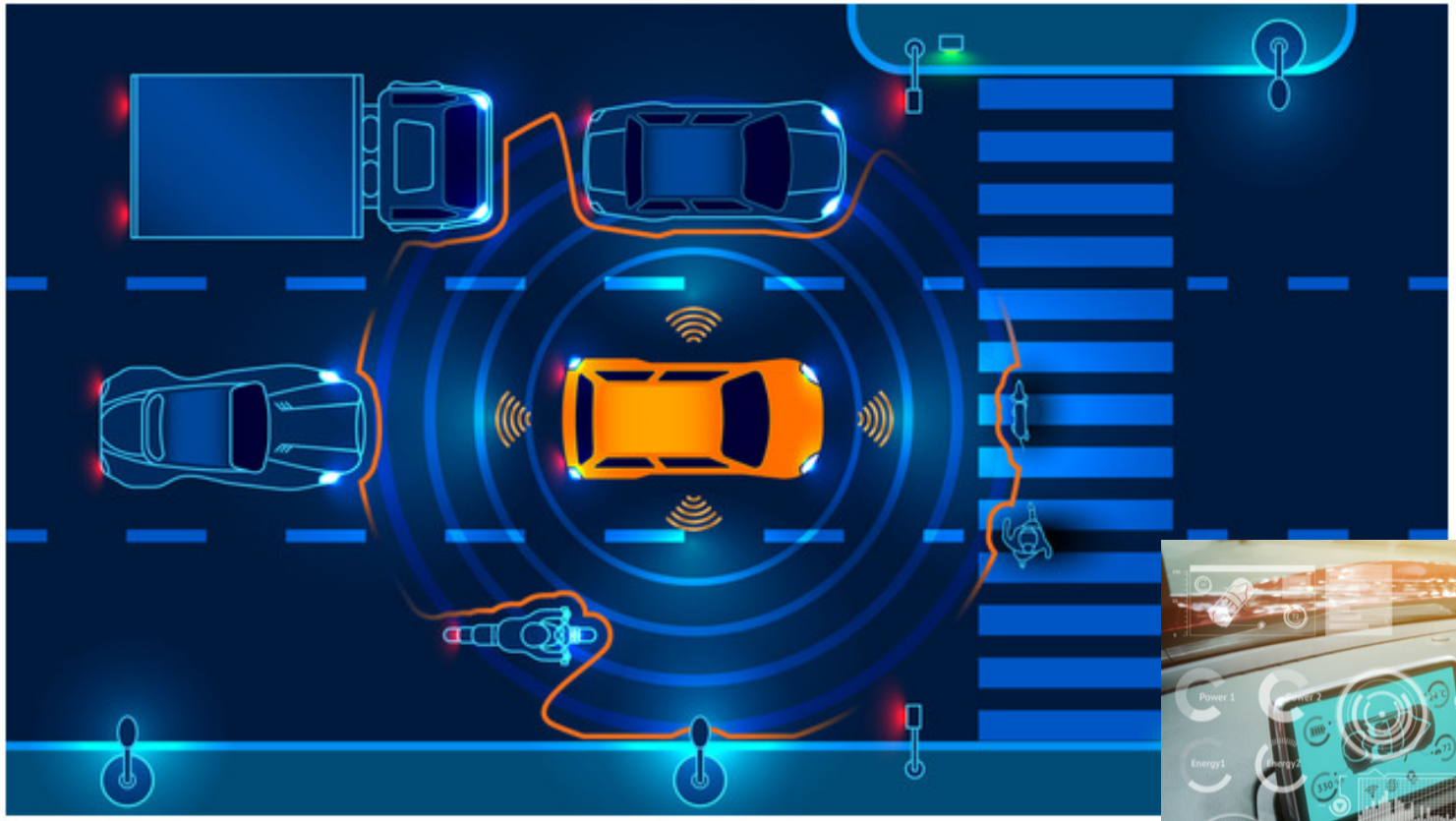
HUAWEI

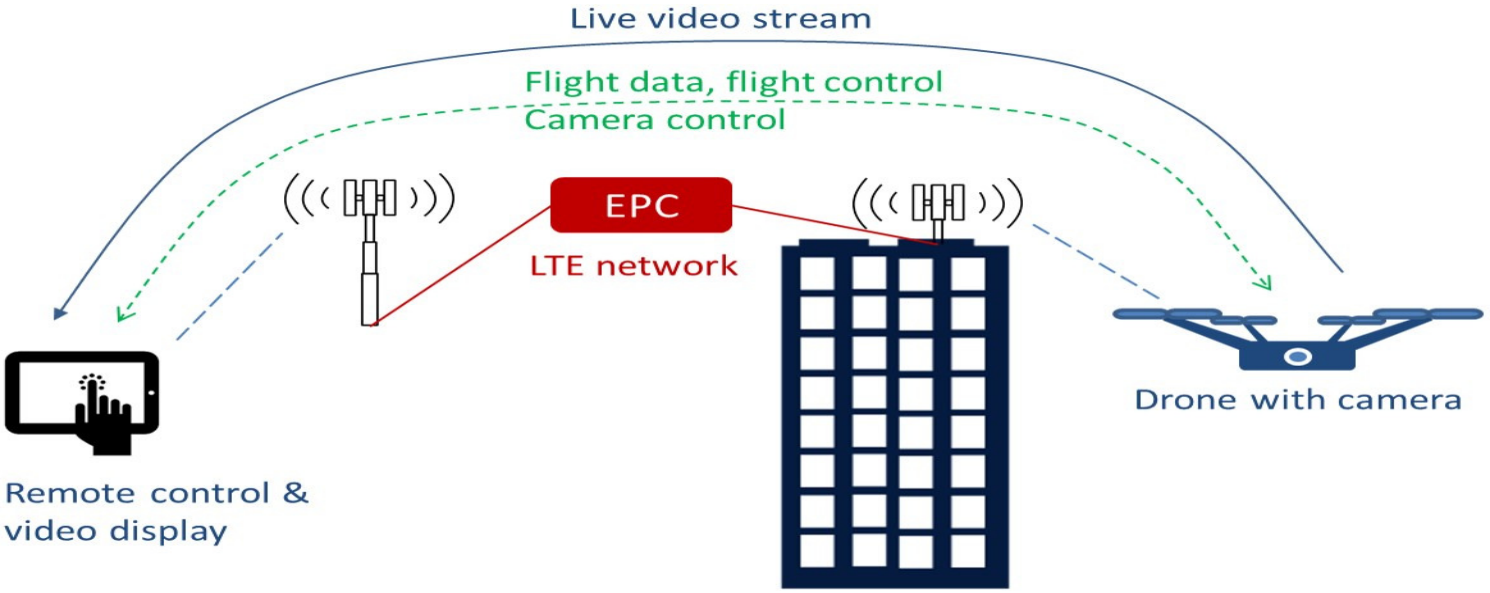
**Safety, Efficiency (同時起步), Cost-Saver (等速, 風阻)**

# 自動車駕駛




Shutterstock

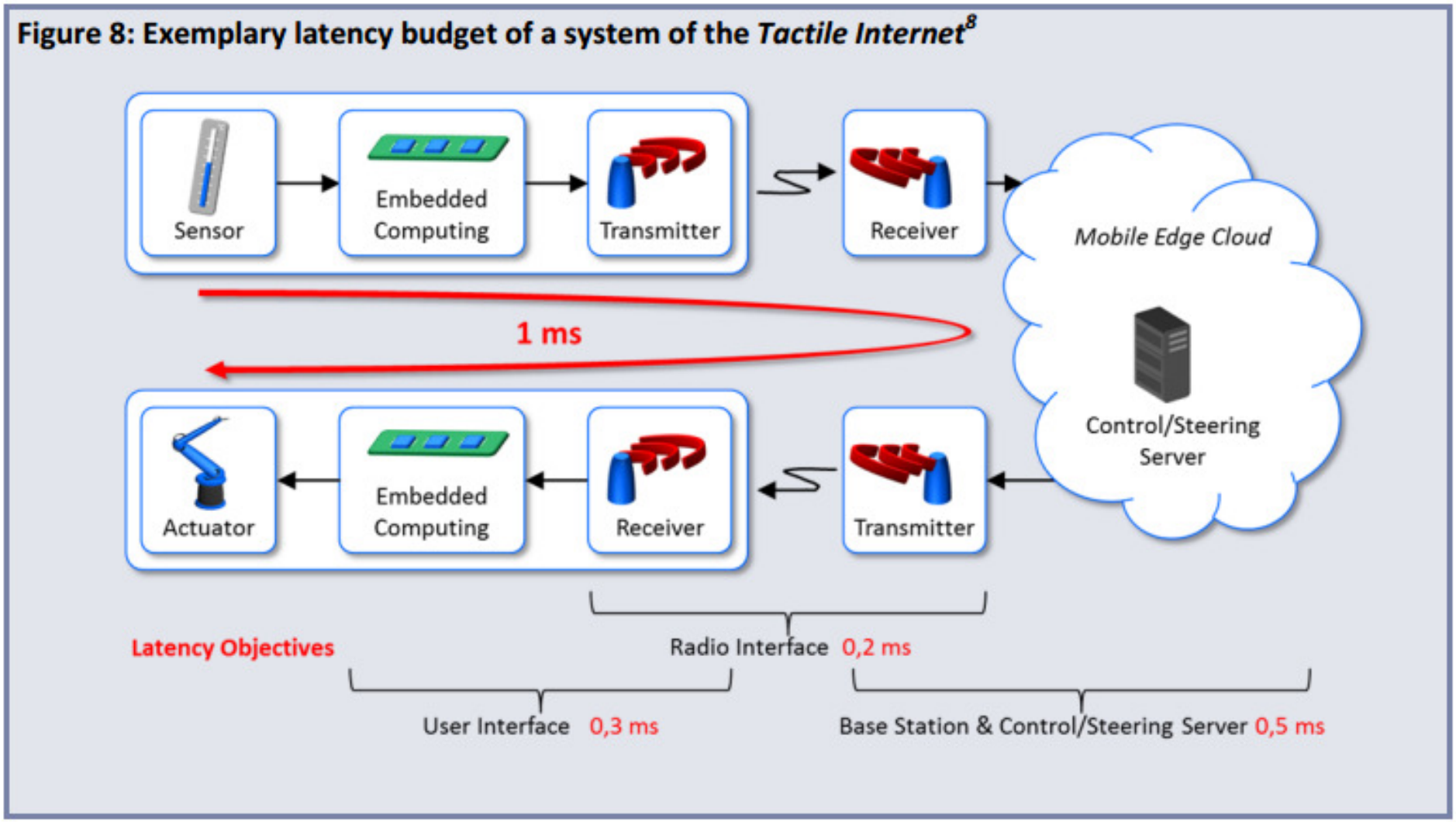
# 無人機遠端控制




# Requirements for URLLC in 3GPP RAN

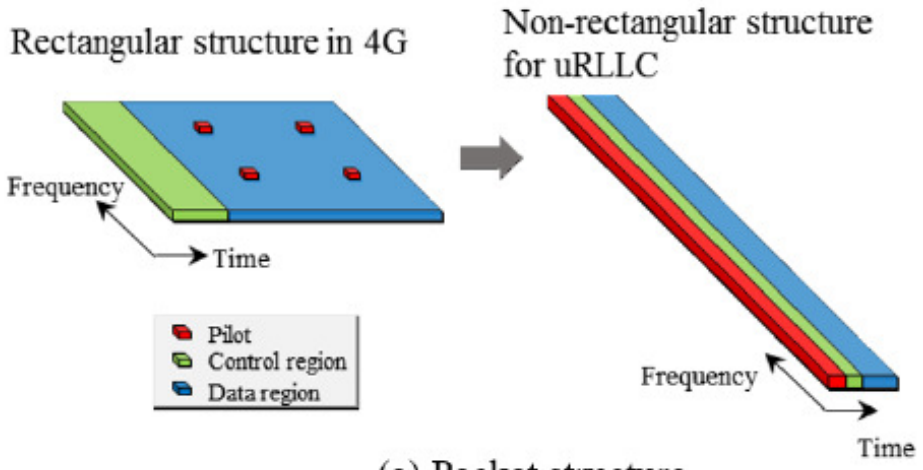
- Latency definition:
  - User Plane
    - Deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by DRX.
  - Control Plane
    - Control plane latency refers to the time to move from a battery efficient state (e.g., IDLE) to start of continuous data transfer (e.g., ACTIVE).
- Latency requirement
  - User plane
    - UL : 0.5ms , DL : 0.5ms
  - Control plane
    - 10ms
- Reliability requirement for one transmission
  - $1\text{-}10^{-5}$ (99.999%) for 32 bytes with 1ms latency

# URLLC 時間延遲

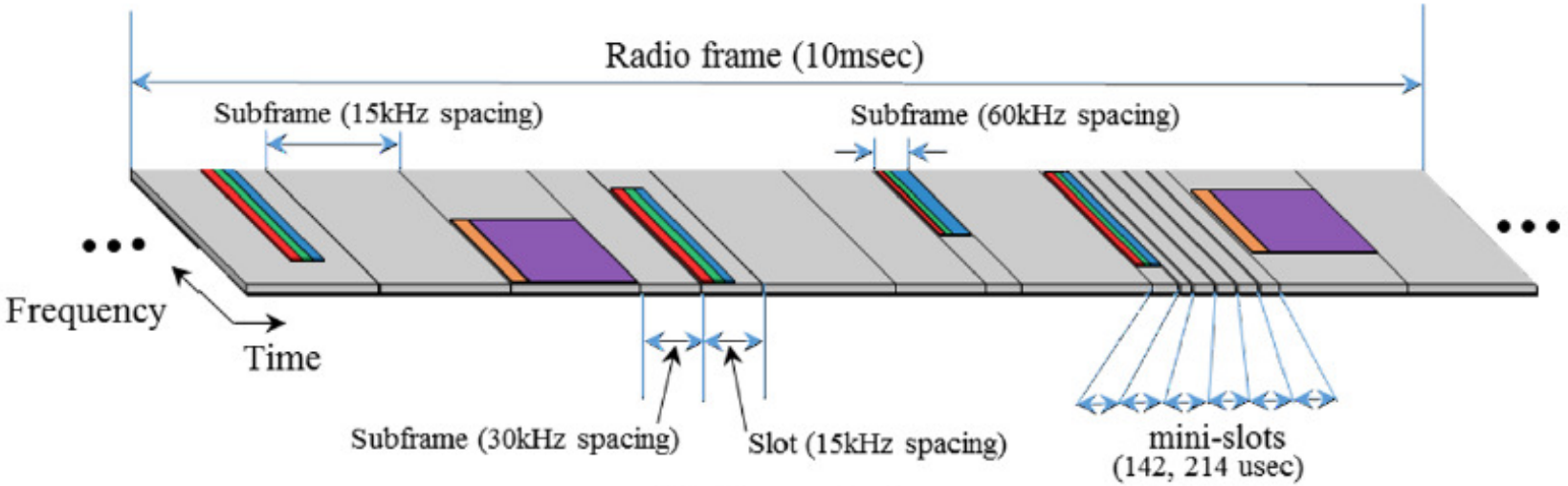



ITU

# URLLC 訊框結構



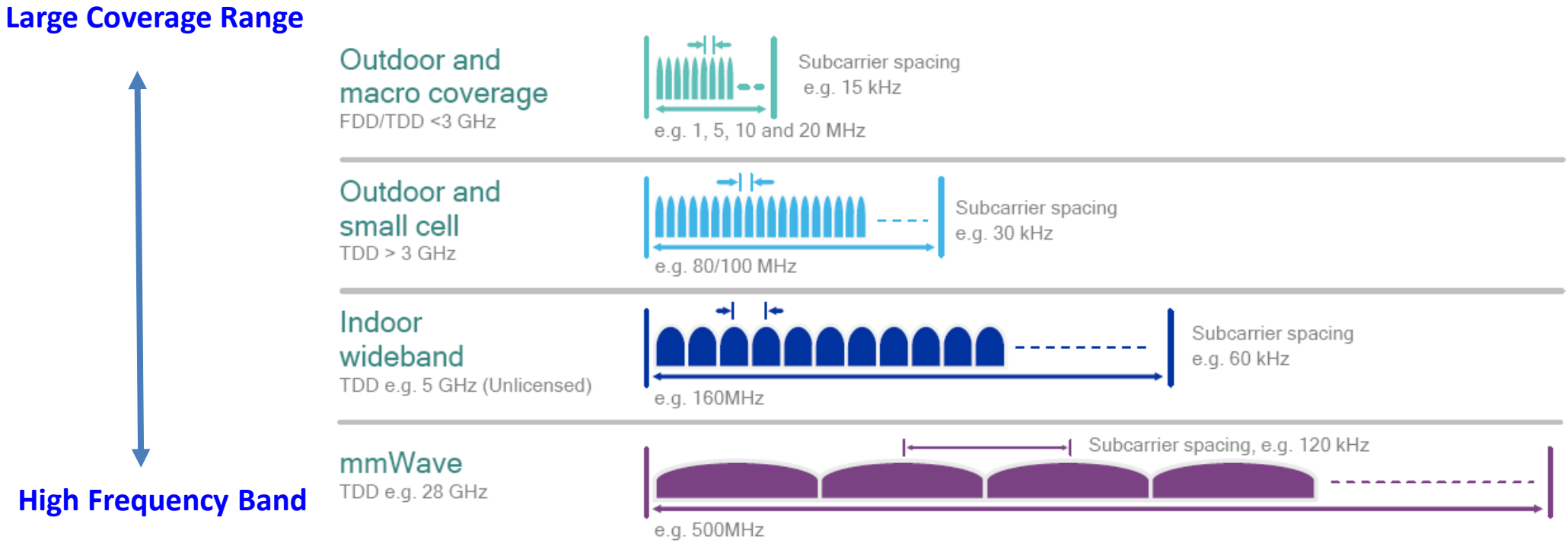

(a) Packet structure




(b) Frame structure

Samsung

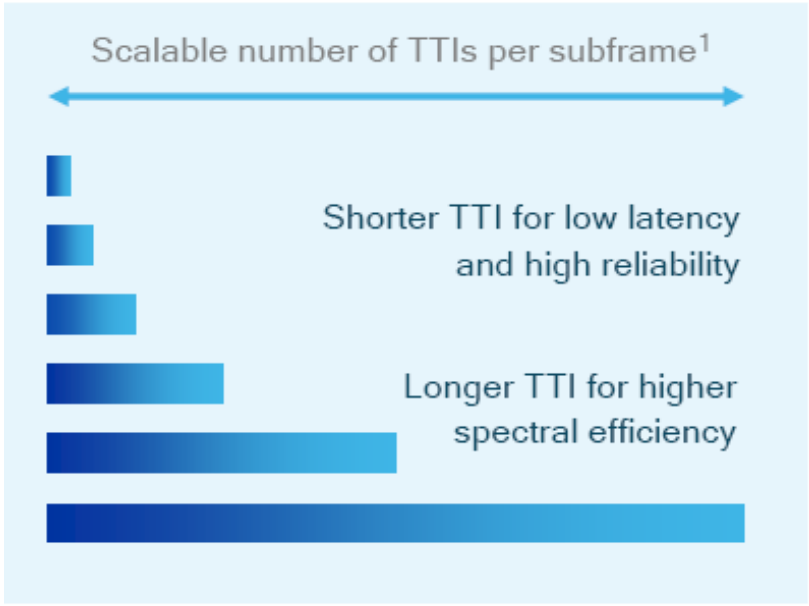
# 載波間距可調



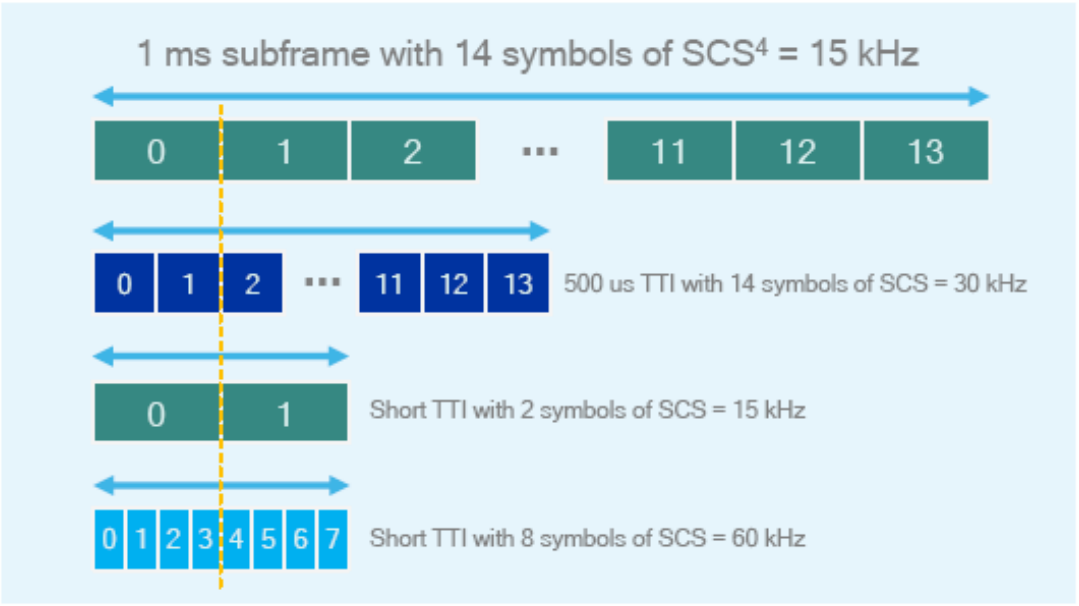

Qualcomm

# 排程單元間隔
## (Transmission Time Interval, TTI)

### Scalable TTI for diverse latency and QoS requirements




### Efficient multiplexing of long & short TTIs to allow transmissions to start on symbol boundaries[2,3]

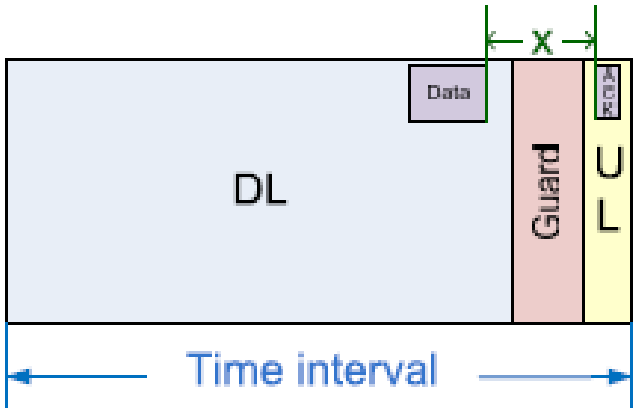


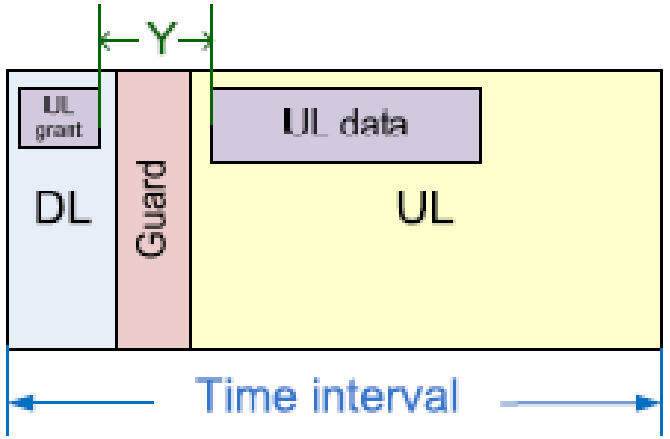

Qualcomm

# NR SCS Table

| | Item | <6GHz | >6GHz | Note |
|---|---|---|---|---|
| **Initial Access** | SS Block (NPSS, NSSS, NPBCH) | 15kHz/30kHz | 120kHz/240kHz | Default value in each RAN4 specified band |
| **Random Access Procedure** | PRACH (Preamble, Msg. 1) | 1.25kHz/5kHz (L= 839) 15kHz/30KHz (L=139) | 60KHz/120kHz (L=139) | Configured in the RMSI |
| | Random Access Response (RAR, Msg. 2) | 15kHz/30kHz | 60kHz/120kHz | Same as the numerology of RMSI |
| | Msg. 3 | 15kHz/30kHz | 60kHz/120kHz | Configured in the RMSI |
| | Msg. 4 | 15kHz/30kHz | 60kHz/120kHz | Same as Msg.2 |
| **RMSI (Remaining Minimum System Info.)** | RMSI PDCCH | 15kHz/30kHz | 60kHz/120kHz | PBCH Indication |
| | RMSI PDSCH | 15kHz/30kHz | 60kHz/120kHz | Same as RMSI PDCCH |
| **OSI (Other System Info.)** | OSI PDCCH | 15kHz/30kHz | 60kHz/120kHz | PBCH Indication |
| | OSI PDSCH | 15kHz/30kHz | 60kHz/120kHz | Same as OSI PDCCH |
| **Paging** | Paging PDCCH | 15kHz/30kHz | 60kHz/120kHz | Same as RMSI |
| | Paging PDSCH | 15kHz/30kHz | 60kHz/120kHz | Same as RMSI |
| **Data part in general** | | 15kHz/30kHz/60kHz | 60kHz/120kHz/240kHz/480kHz(FFS) | As per RAN4 TR 38.803 |
| | | | | |

# Self-Contained Frame Structure

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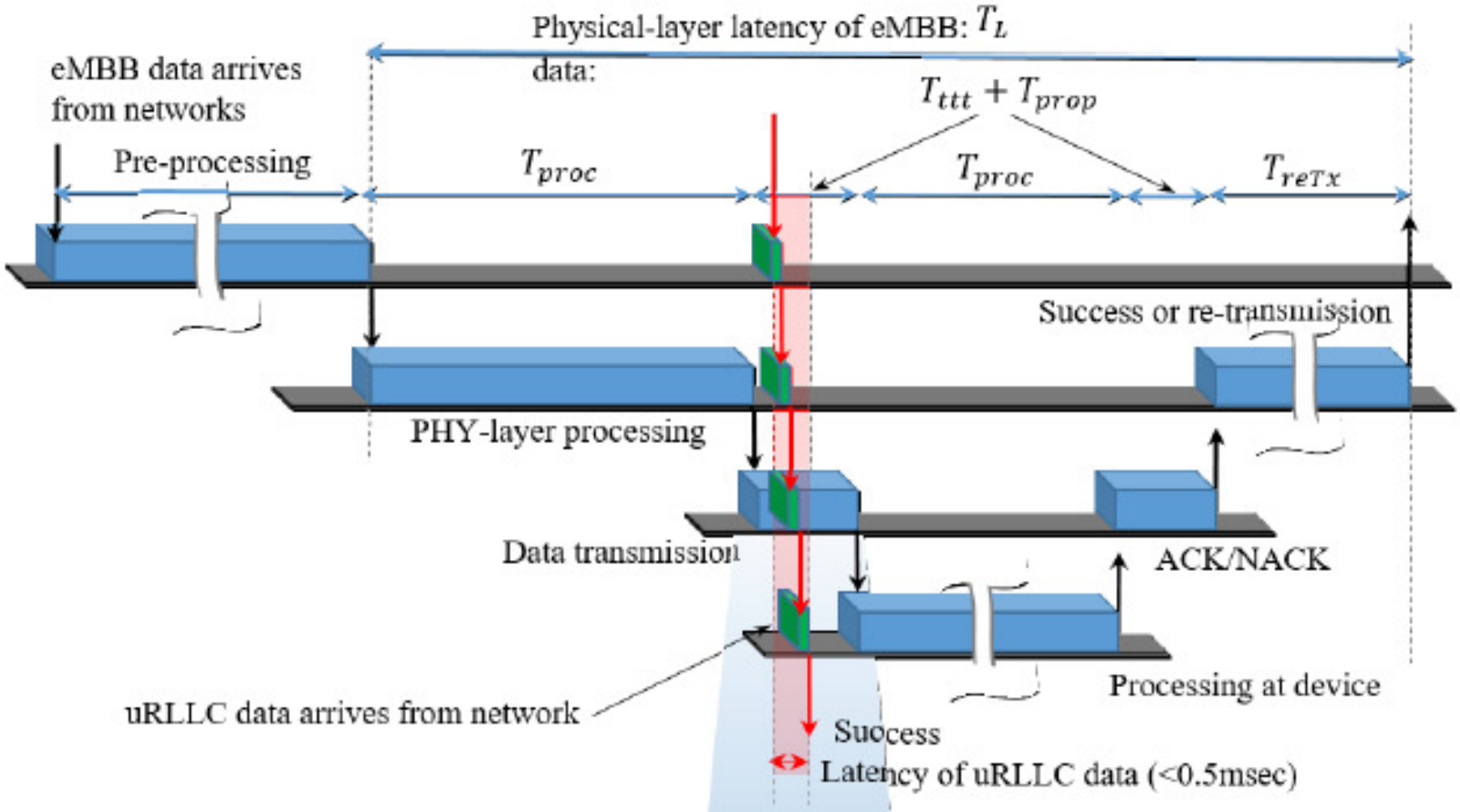
| Configuration | HARQ Timing Parameter | Units | 15 KHz SCS | 30 KHz SCS | 60 KHz SCS | 120 KHz SCS |
|---|---|---|---|---|---|---|
| Front-loaded DMRS only | N1 | Symbols | 8 | 10 | 17 | 20 |
| Front-loaded + additional DMRS | N1 | Symbols | 13 | 13 | 20 | 24 |
| Frequency-first RE-mapping | N2[1] | Symbols | 10 | 12 | 23 | 36 |

**UE Processing Time and HARQ Timing (Capability #1)**

| Configuration | HARQ Timing Parameter | Units | 15 KHz SCS | 30 KHz SCS |
|---|---|---|---|---|
| Front-loaded DMRS only | N1 | Symbols | 3 | 5 |
| | | us | 214 | 178 |
| Front-loaded + additional DMRS | N1 | Symbols | 12 | 12 |
| | | us | 214 | 178 |
| Frequency-first RE-mapping | N2[1] | Symbols | [4][2] | 6 |
| | | us | 285 | 214 |

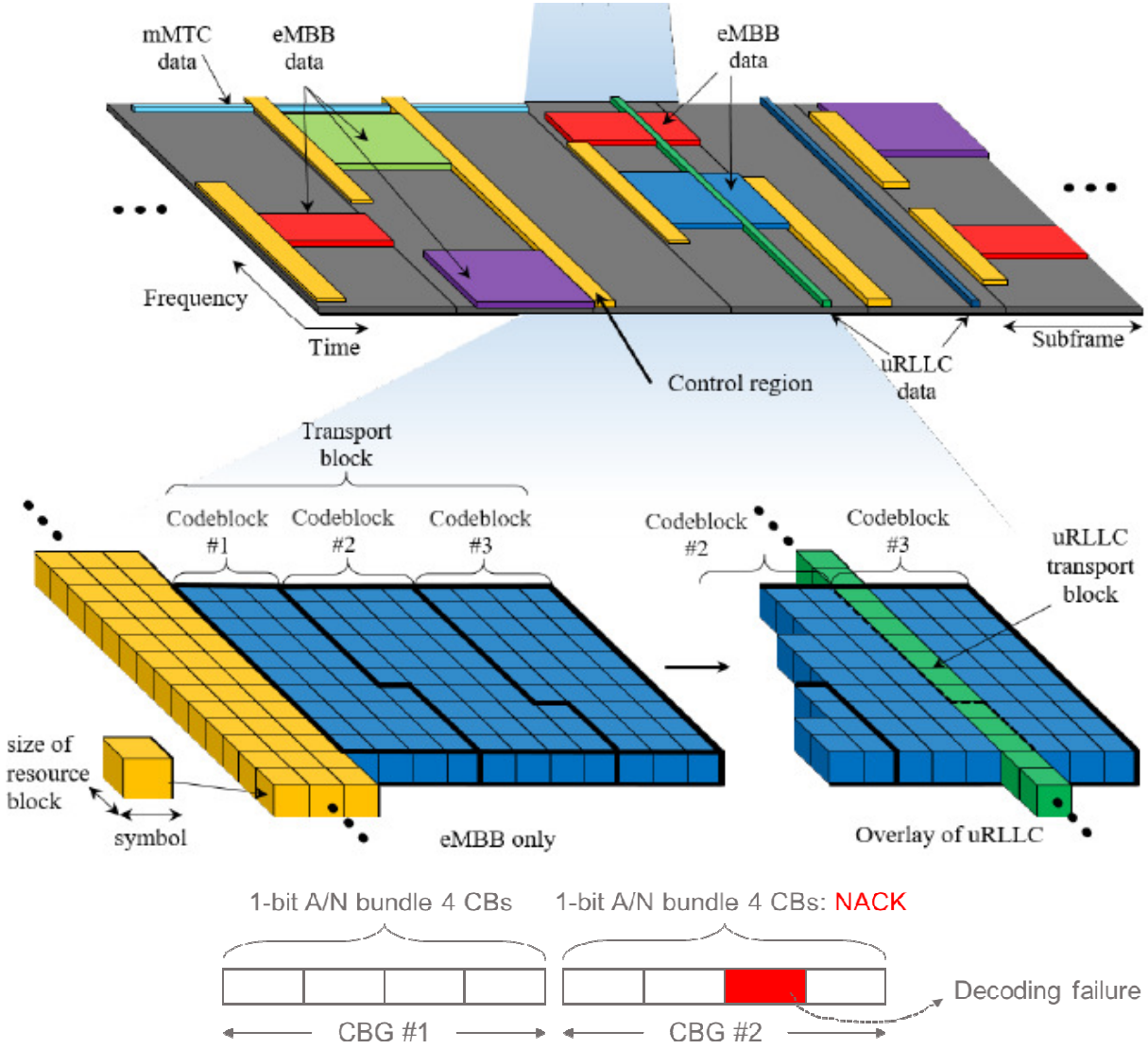
**UE Processing Time and HARQ Timing (Capability #2)**

# eMBB 與 URLLC DL 共存




Samsung

# 資源破壞性共存

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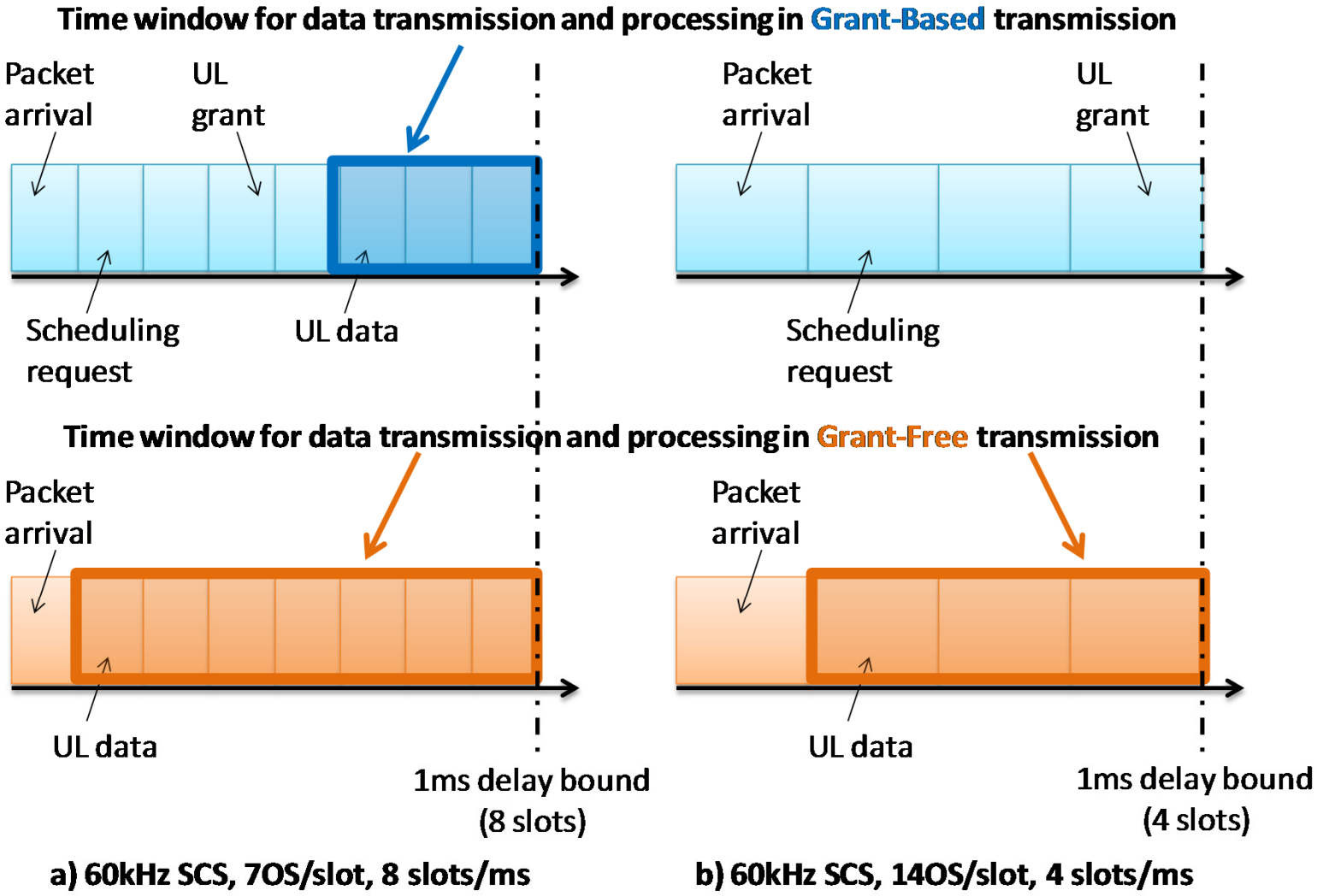
# Grant-based v.s. Grant Free Transmission



# UL-GF Types

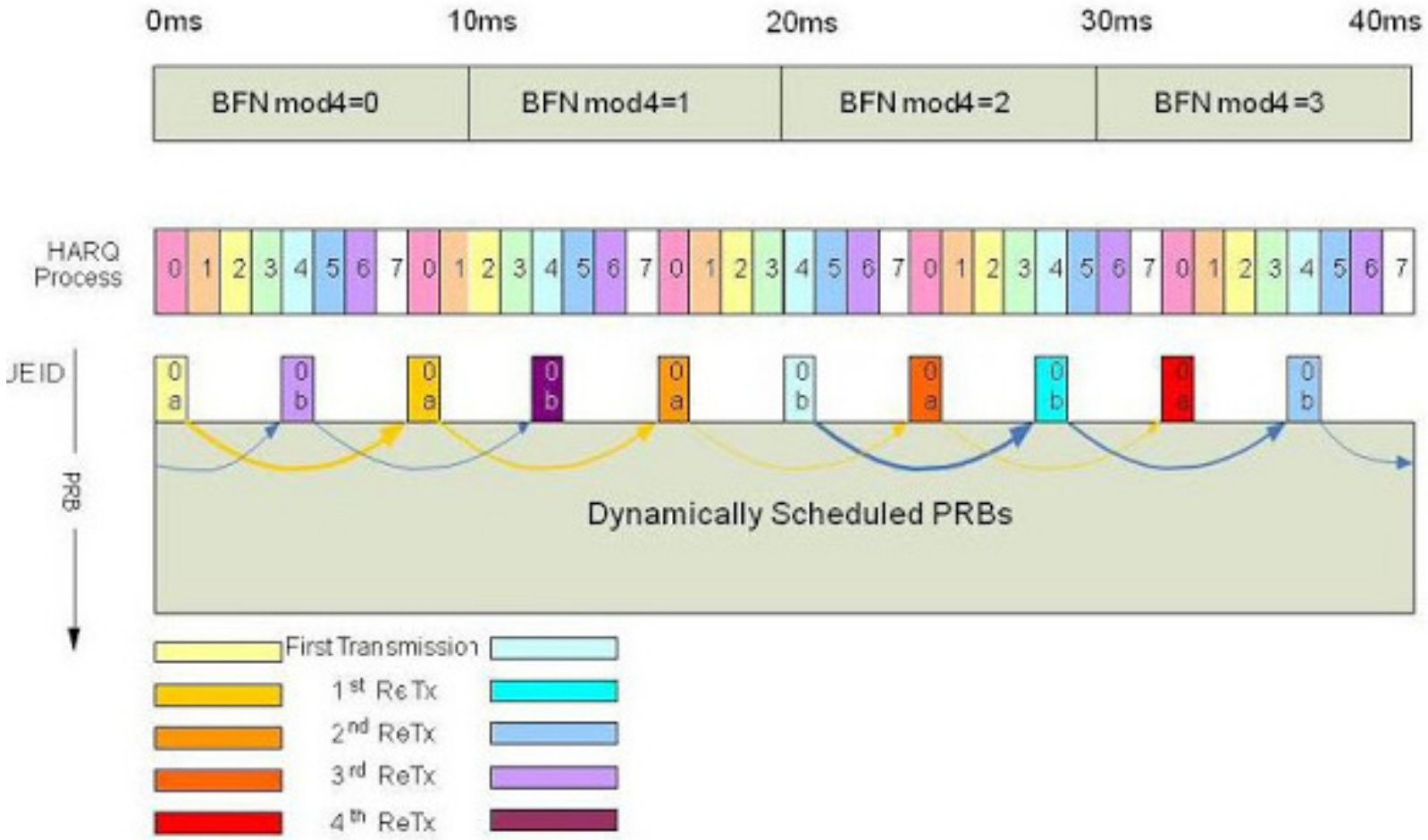
**RAN1 AH#2 Agreements:**

- Type of UL data transmission without grant
  - **Type 1:** UL data transmission without grant is only based on RRC (re)configuration without any L1 signalling
  - **Type 2:** UL data transmission without grant is based on both RRC configuration and L1 signalling to activation/deactivation for UL data transmission without grant
    - Note: functionality of modification is achieved the L1 signalling by activation
  - **Type 3:** UL data transmission without grant is based on RRC configuration, and allows L1 signalling to modify some parameters configured by RRC but no L1 signalling for activation

**RAN1 AH#3 Agreements:**

- Type 3 UL transmission without UL grant is not supported in Rel.15.

# LTE Semi-Persistent Scheduling (SPS)->Type2

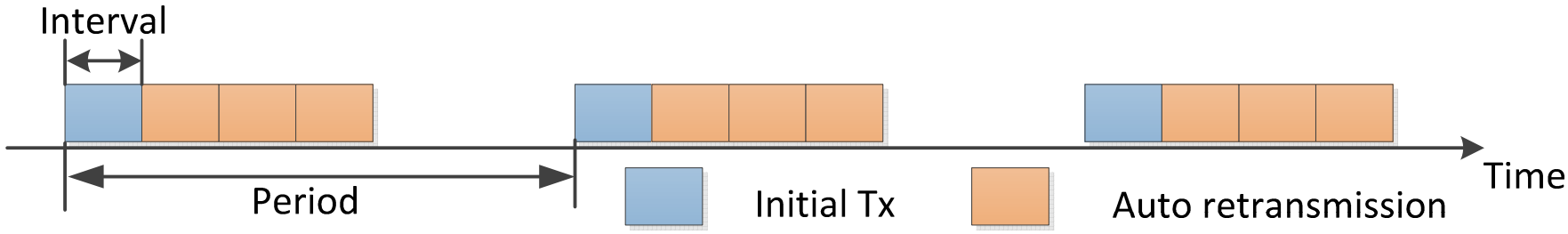


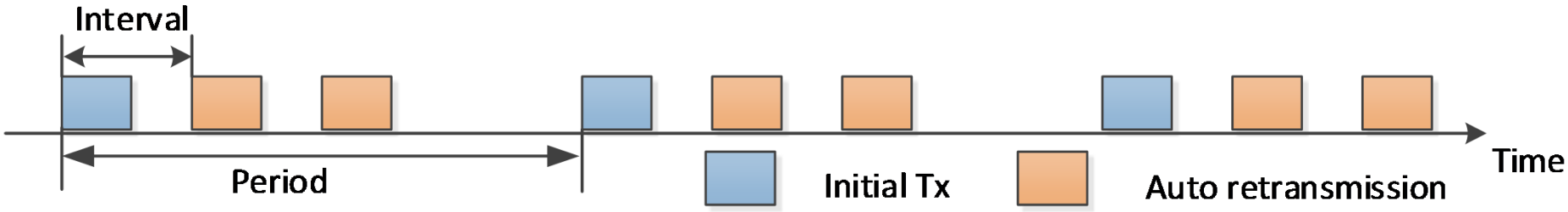

**Example of Semi-Persistent Scheduling.**

# Type1/Type2 RRC Parameters

| UL GR Type | Parameter name in text | Description |
|---|---|---|
| Type1/Type2 | UL-TWG-periodicity | Periodicity for UL transmission without UL grant |
| Type1 | UL-TWG-offset | Offset for UL transmission without UL grant |
| Type1/Type2 | UL-TWG-power-control | Set of power control related parameters for UL transmission without UL grant |
| Type1 | UL-TWG-tim-dom | Time domain resource allocation for UL transmission without UL grant |
| Type1 | UL-TWG-freq-dom | Frequency domain resource allocation for UL transmission without UL grant |
| Type1 | UL-TWG-DMRS | UE-specific DMRS configuration for UL transmission without UL grant |
| Type1 | UL-TWG-MCS-TBS | MCS/TBS for UL transmission without UL grant |
| Type1 | UL-TWG-repK | The number or repetitions of K for UL transmission without UL grant |

# Repetition Behavior



# Resource for both Initial & Repetition

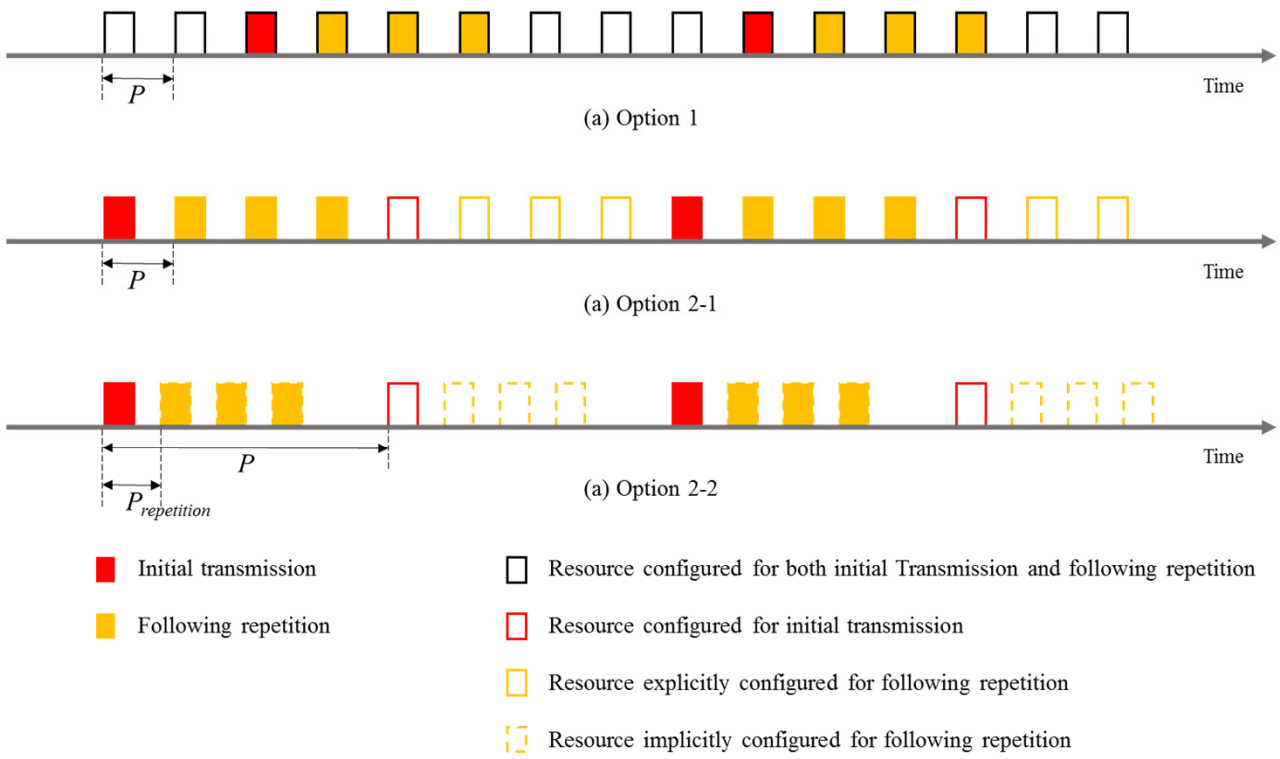
(R1-1715888, LG)

Alt 1: Configured resource are used for both initial and repetition

Alt 2: Resource for initial and following repetition(s) are configured separately

Alt 2-1: Resource(s) for following repetition(s) is/are configured explicitly

Alt 2-2: Resource(s) for following repetition(s) is/are configured implicitly

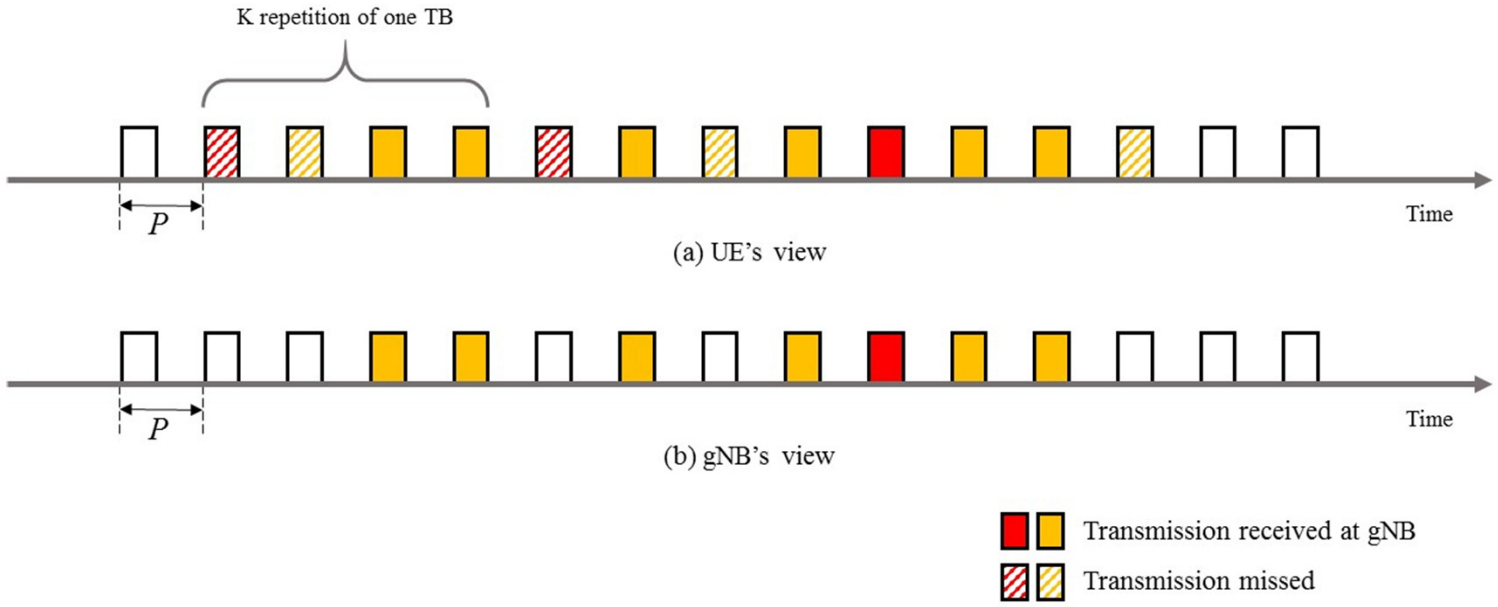



| Complexity | Latency | Reliability |
|---|---|---|
| ✗ | ☺ | ☺ |
| ☺ | ✗ | ✗ |
| ☺ | ✗ | ✗ |

Figure 1 Possible options of resource configuration for K repetitions

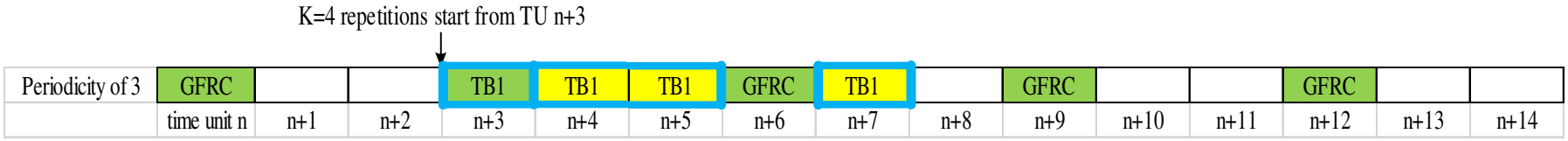
# Issue of Option 1

- Ambiguity at gNB
- Additional indication for different repetition

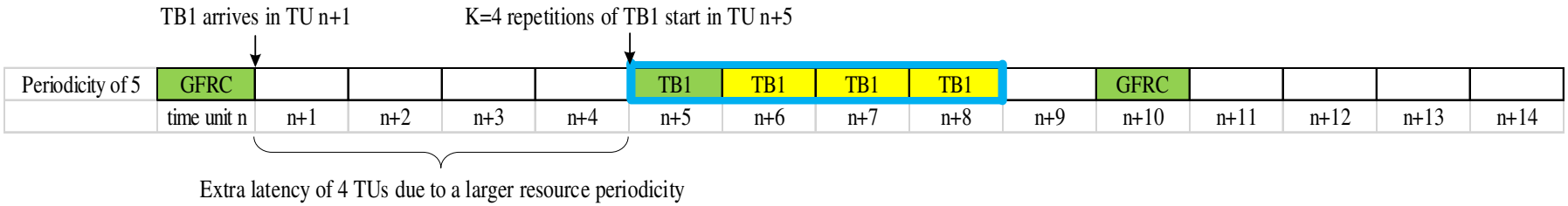


# Issue of Option2

- Repetition longer than resource period




- Larger resource period induce additional latency

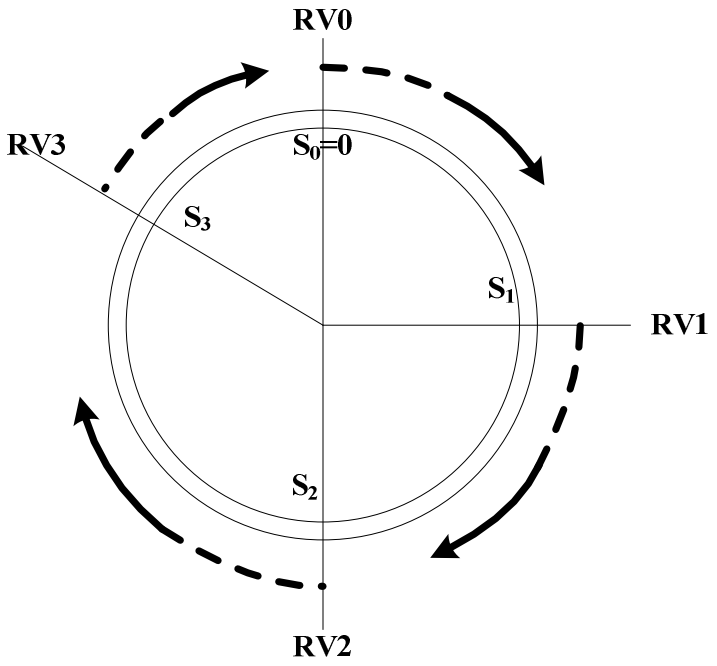


# RV pattern

**RAN1#90bis E-Mail Working Assumption:**

- For UL transmission without UL grant, for a TB transmission with K repetitions
  - The repetitions follow an RV sequence and it is configured by UE-specific RRC signalling to be one of the following:
    - Sequence 1: {0, 2, 3, 1}
    - Sequence 2: {0, 3, 0, 3}
    - Sequence 3: {0, 0, 0, 0}

- 10Z -> Encode -> 52Z -> Puncture -> 50Z (circular buffer)
  - 50/4 = 12.5
- 50Z bits are in the circular buffer
- The first 8Z in the circular buffer are systematic bits




3GPP R1-1718409 (ZTE)

# Latest Agreement on RV Pattern

**RAN1#91 E-Mail Agreements:**

- For UL transmission without UL grant,
  - The n-th transmission occasion of a K repetitions is associated with the (mod(n-1,4)+1)-th value in the configured RV sequence **{RV1, RV2, RV3, RV4},** where n=1, 2, …, K.
  - For RV sequence {0, 2, 3, 1},
    - The initial transmission of a TB shall start at the first transmission occasion of the K repetitions.
  - For RV sequence {0, 3, 0, 3},
    - The initial transmission of a TB can start at any of the transmission occasions of the K repetitions that are associated with RV=0.
  - (working assumption) For RV sequence {0, 0, 0, 0},
    - The initial transmission of a TB can start at any of the transmission occasions of the K repetitions when K=1, 2 or 4;
    - The initial transmission of a TB can start at any of the transmission occasions of the K repetitions, except-the last transmission occasion when K=8.
  - For any RV sequence, repetition end at the last transmission occasion within the period P.

# RV Pattern for Repetition

- The transmission occasion (TO)
  - time domain resource allocation of one repetition in an aggregation with factor K where the aggregated transmission occasions start in resources configured by the offset and the period.

| RV Pattern {RV1, RV2, RV3, RV4} | Initial Transmission | Supported Repetition Number (K) | Note |
|---|---|---|---|
| {0, 2, 3, 1} | First TO | K = 1, 2, 4, 8 | Agreed |
| {0, 3, 0, 3} | Any TO at RV = 0 | K = 1, 2, 4, 8 | Agreed |
| {0, 0, 0, 0} | Any TO | K = 1, 2, 4 | Working Assumption |
| | Any TO except last TO | K = 8 | Working Assumption |

# Repetition Termination Conditions

**RAN1#88 Agreement:**

- For UE configured with K repetitions for a TB transmission with/without grant, the UE can continue repetitions for the TB until one of the following conditions is met
  - If an UL grant is successfully received for a slot/mini-slot for the same TB
  - FFS: An acknowledgement/indication of successful receiving of that TB from gNB
  - The number of repetitions for that TB reaches K
  - Note that this does not assume that UL grant is scheduled based on the slot whereas grant free allocation is based on mini-slot (vice versa)

# GF Resource Periodicity

| Subcarrier spacing (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 |

**RAN1#91 Agreements:**

- For grant-free UL transmission, the UE is not expected to be configured with the time duration for the transmission of K repetitions larger than the time duration derived by the periodicity P.

# Multiple Grant-free Resource Configuration (for Type 1)

- Different Periodicity

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency | GFRC2 | | | | | GFRC2 | | | | | GFRC2 | | | | | Periodicity of 5 |
| | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | Periodicity of 1 |
| | time unit n | n+1 | n+2 | n+3 | n+4 | n+5 | n+6 | n+7 | n+8 | n+9 | n+10 | n+11 | n+12 | n+13 | n+14 | |

a) Multiple GF resource with different periodicity

- Different MCS/TBS

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency | GFRC2 | | GFRC2 | | GFRC2 | | GFRC2 | | GFRC2 | | GFRC2 | | GFRC2 | | GFRC2 | MCS/TBS2 |
| | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | GFRC1 | MCS/TBS1 |

a) Multiple GF resource with different MCS/TBS

**RAN1 AH#3 Agreements:**

- Multiple resource configurations for UL tx without UL grant can be configured to a UE
- For UL tx without UL grant, the same resource configuration is used for K repetitions for a TB including the initial transmission

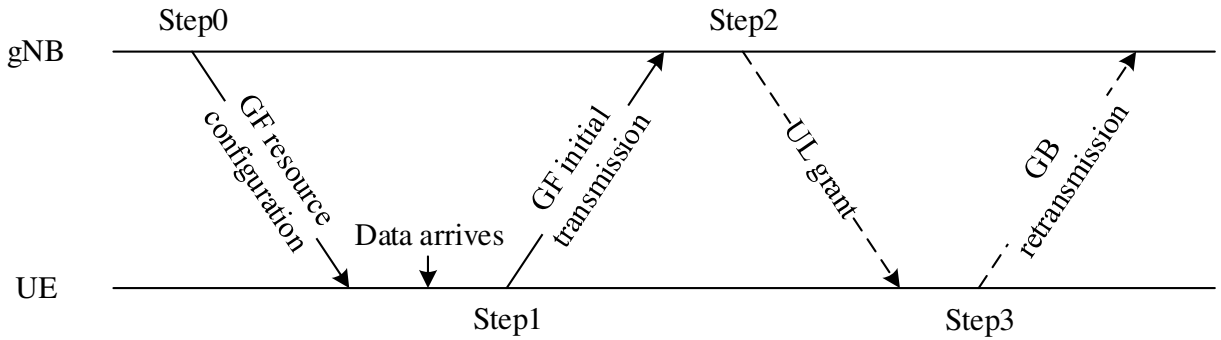
# HARQ Feedback

**RAN1#90 Agreement:**

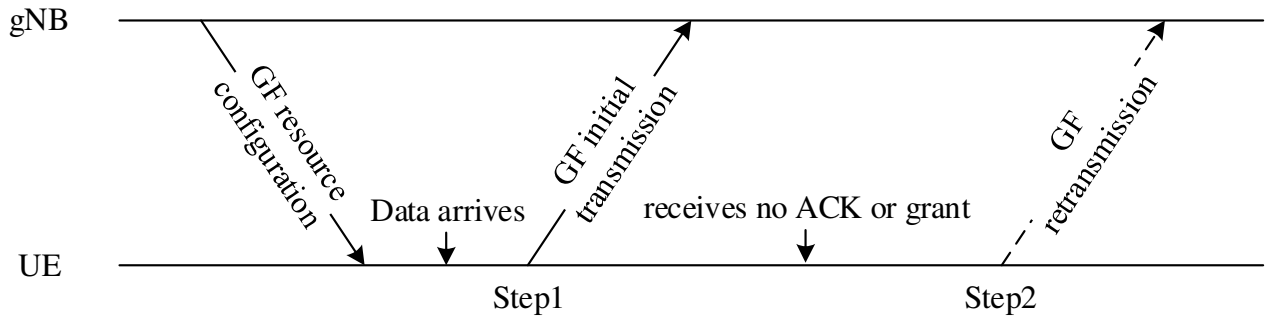
- If HARQ feedback is supported, to indicate HARQ feedback of UL transmission without grant, following options and related UE behavior should be further studied.
  - Option 1: Based on UL grant to indicate "ACK"
  - Option 2: Group-common DCI
    - 2-1: Only ACK
    - 2-2: ACK and NACK
  - Option 3: Define a Timer, UE assumes following, when the Timer expires
    - 3-1: ACK if an NACK is not received after the K repetitions
    - 3-2: NACK if an ACK is not received
- Note: UL grant for the same TB initially transmitted without grant can indicate "NACK"

# Re-transmission Behavior

- GF2GB retransmission




- GF2GF retransmission




**(R1-1709992,Huawei)**

# HARQ Process ID

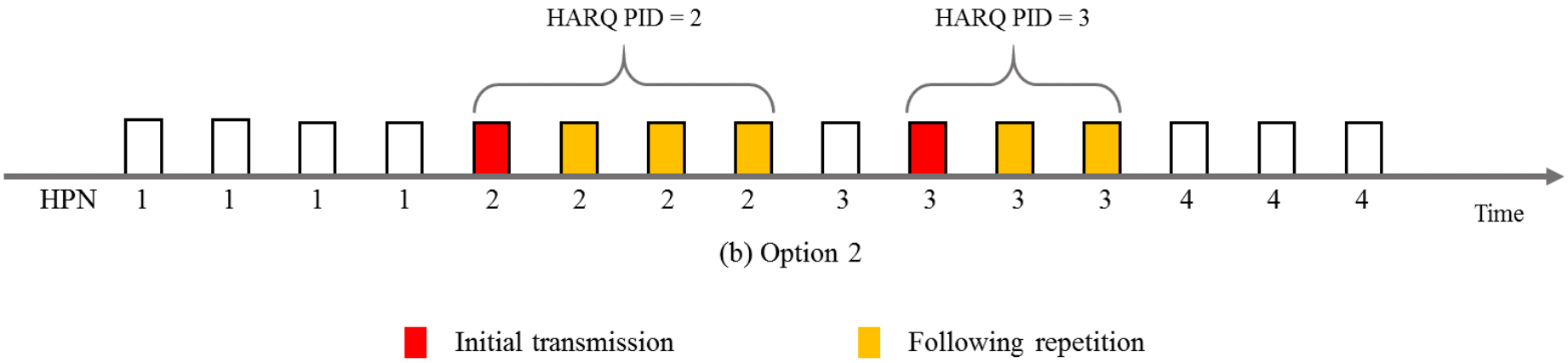
**RAN1#90bis E-Mail Agreements:**

- For UL transmission without UL grant, for each configuration
  - The number of configured HARQ processes is explicitly configured by RRC
  - Each configuration can have multiple HARQ processes
    - The value range is {1, 2, …, M}, where M value is FFS
- For UL transmission without UL grant,
  - The HARQ ID for a TB should be the same during the repetitions and retransmissions if any.

**RAN1#91 Agreements:**

- For UL transmission without UL grant, the HARQ ID associated with the K repetitions of a TB is derived from the following equation:
  - HARQ Process ID = floor (X / UL-TWG-periodicity) mod UL-TWG-numbHARQproc
    - Where X= (SFN * SlotPerFrame * SymbolPerSlot + Slot_index_In_SF * SymbolPerSlot + Symbol_Index_In_Slot)
    - X refers to the symbol index of the first transmission occasion of repetition bundle that takes place.

# HARQ Process ID Determination



# UE Identification

**RAN2# 97bis Agreements**

- From RAN2 point of view it would be beneficial to be able to share "SPS/grant free" UL resources amongst different UE.
- Mechanism to identify the UE for collision resolution purpose may be needed.
- The details can be discussed in RAN1.

**Agreements:**

- RAN1 considers that UE transmitting UL transmission without UL grant can be identified based on time/frequency resources and RS parameter(s).

# UE Identification Scheme

**Scheme 1: fixed RS**

UE1 with CS_index=0

UE2 with CS_index=3

…

UE7 with CS_index=21

UE8 with CS_index=24