3GPP TSG-RAN#79
Chennai, India, March 19th - March 22nd, 2018

RP-180505

Qualcomm

# 60kHz optional for sub6 GHz in Rel15

# Executive Summary

- RAN1/RAN4 have made agreements regarding 60kHz (NCP/ECP) as optional for 1~6GHz
- 30kHz is sufficient to achieve R15 URLLC latency requirement
- 30kHz has superior/more robust LLS performance compared with 60kHz(NCP/ECP)
- 30kHz achieves URLLC requirements for both FDD/TDD

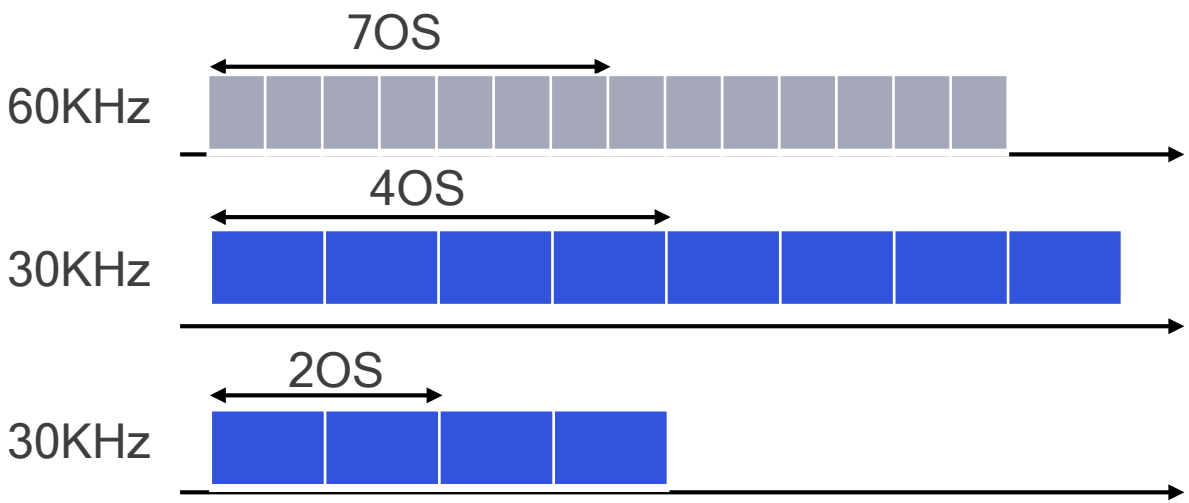
# Background

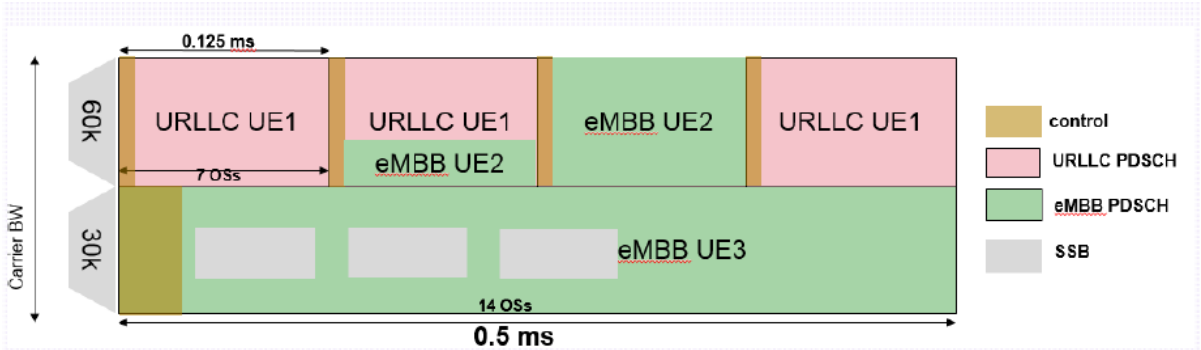
- RAN4 agreement on 60kHz as optional for 1~6GHz reached in RAN4 NR Nagoya ad-hoc in September 2017(R4-1710047)

- RAN1 agreement 60kHz ECP optional (as a compromise to support 60kHz ECP at all)

- Extensive simulation campaign already done in numerology studies to reach above agreements

# Latency comparison of 30kHz 2/4 OS vs. 60kHz 7 OS

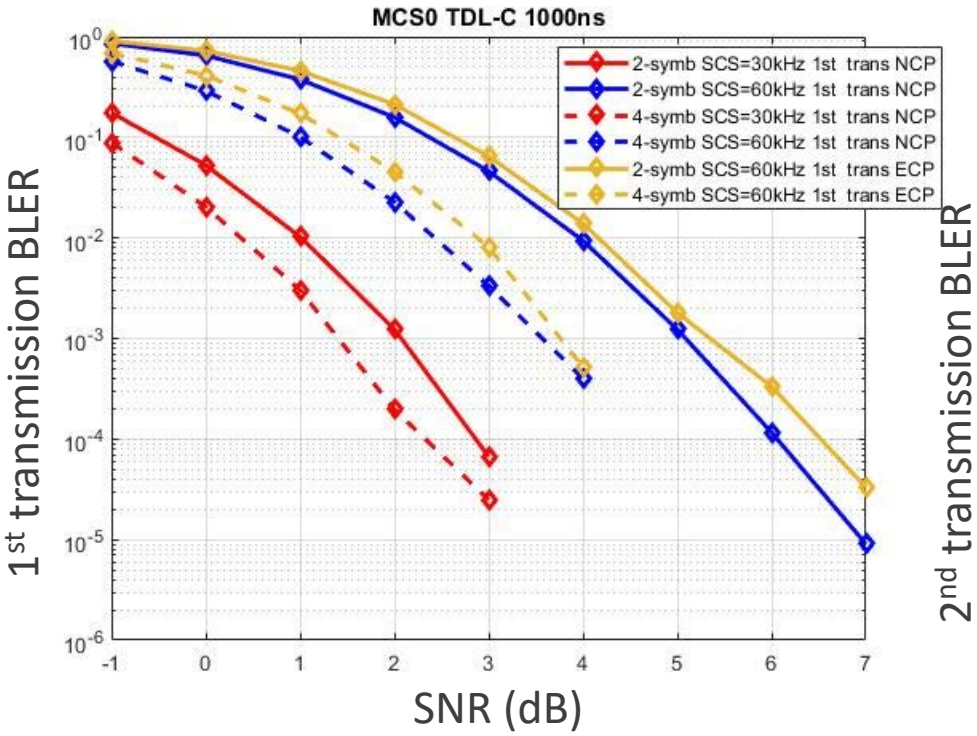


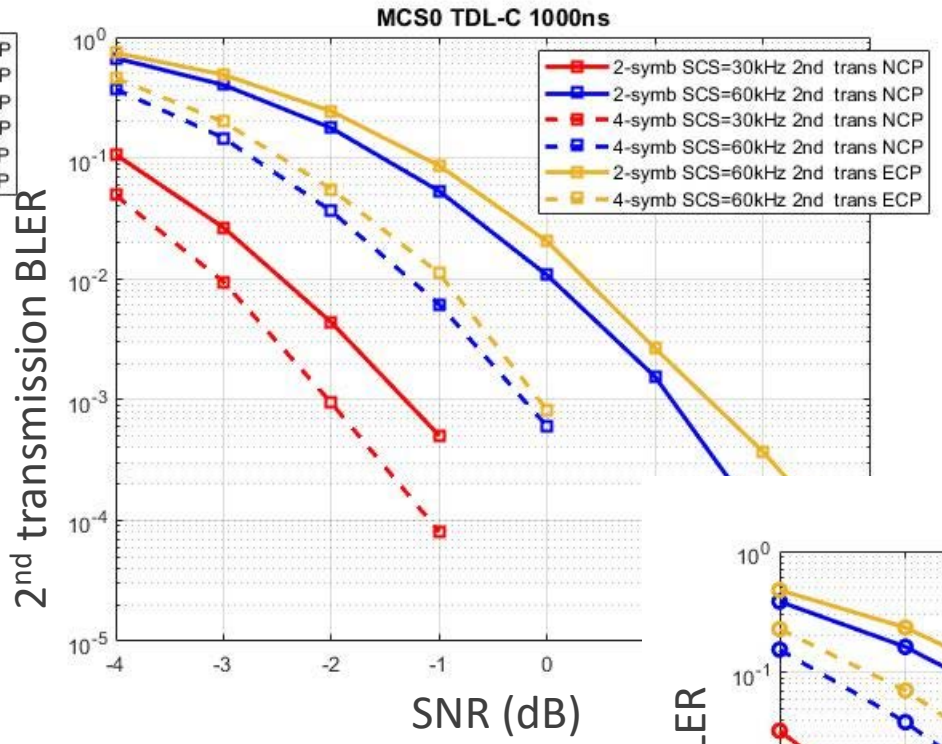



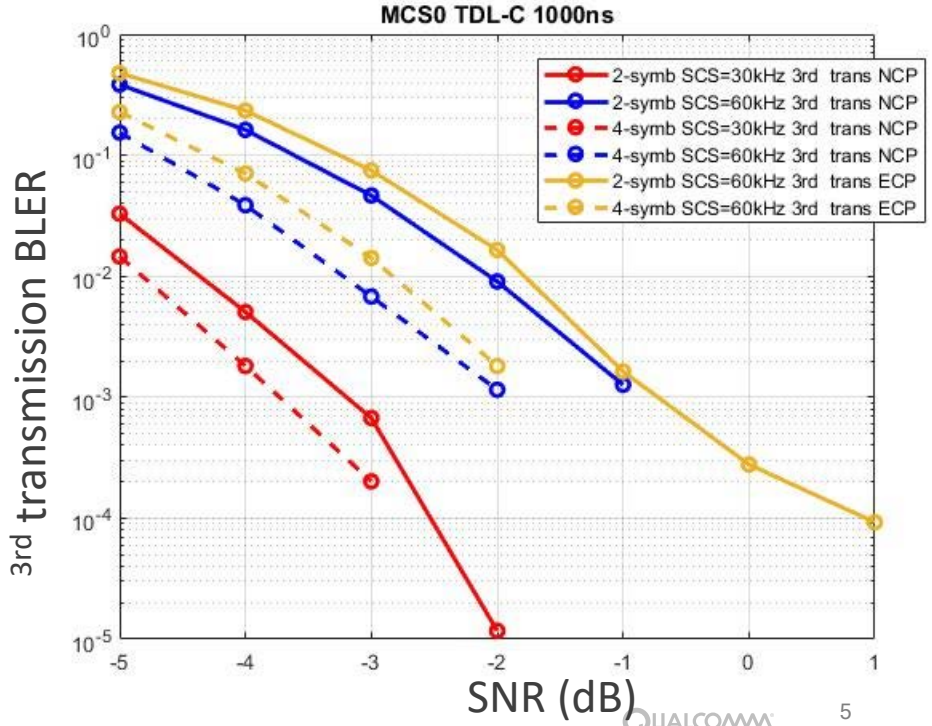

From R1-1801783

- 7 symbol 60kHz mini-slot has longer duration than 2 symbol 30kHz
- 7 symbol 60kHz mini-slot has comparable duration to 4 symbol 30kHz
- 2 symbol 30kHz mini-slot is 71us, 4 symbol 30kHz mini-slot is 143us
  - Both can be used to achieve RAN requirements
    - Mini-slot short enough to achieve 0.5ms latency without reliability requirement
    - HARQ RTT sufficient to achieve BLER = 1e-5 within 1ms with HARQ support
- 30kHz SCS is more than sufficient to achieve R15 URLLC RAN requirements

# LLS of URLLC 30kHz vs. 60kHz Comparison (TDL-C 1000ns)

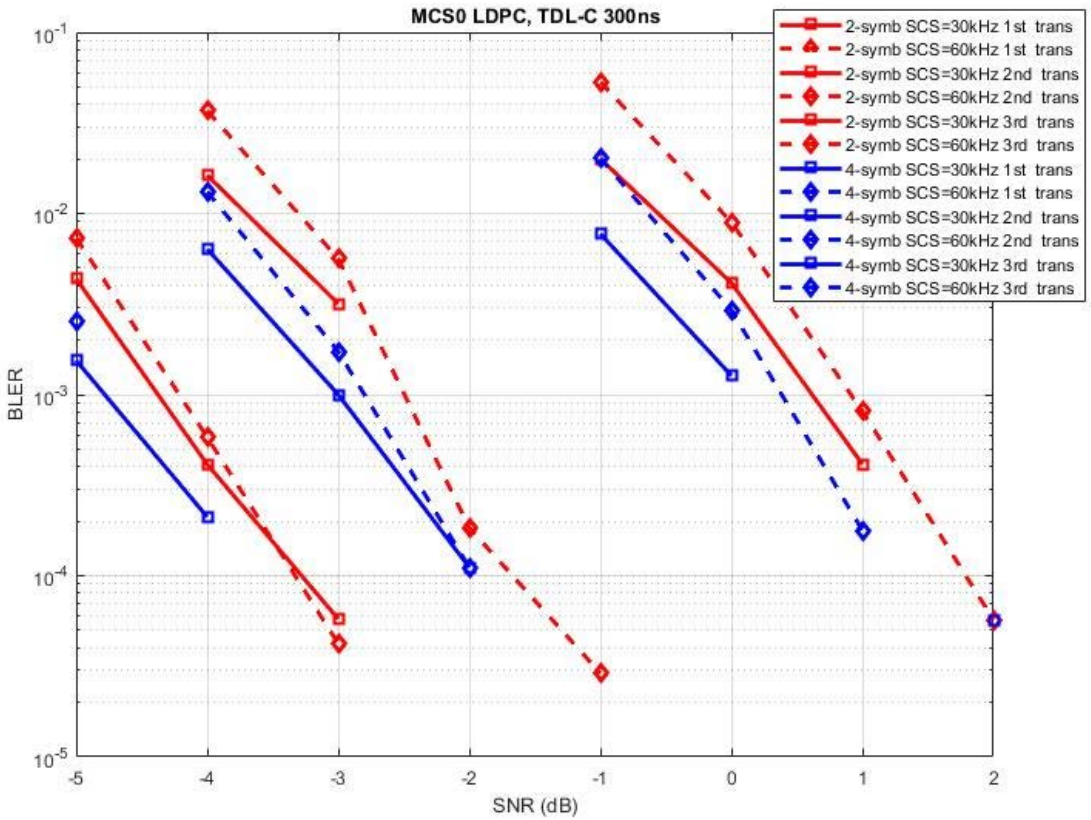



- Over long DS (TDL-C1000), 60kHz has worse performance
  - 60kHz NCP link-level performance is much worse than 30kHz due to insufficient DMRS density (for 60kHz) and ISI
  - Despite longer CP, 60kHz ECP is even worse than 60kHz NCP due to excessive CP overhead (20%) and insufficient DMRS density (for 60kHz)

# LLS of URLLC 30kHz vs. 60kHz Comparison (TDL-C 300ns)




- 30kHz and 60kHz mini-slot have similar link-level performance over TDL-C 300ns for URLLC
  - 30kHz has robust performance (sufficient DMRS density in frequency)
  - 60kHz ECP over TDL-C 300ns (not simulated here) is expected even worse than 60kHz NCP due to excessive CP overhead under moderate DS channel

# Processing Timeline of 30kHz vs. 60kHz

Processing timeline of 60kHz is not linear scale of 30kHz (Table from 38.214)

Table 5.3-1: PDSCH processing time for PDSCH processing capability 1

| $\mu_{DL}$ | PDSCH decoding time $N_1$ [symbols] | |
|---|---|---|
| | No additional PDSCH DM-RS configured | Additional PDSCH DM-RS configured |
| 0 | 8 | 13 |
| 1 | 10 | 13 |
| 2 | 17 | 20 |
| 3 | 20 | 24 |

Table 6.4-1: PUSCH preparation time for PUSCH timing capability 1

| $\mu_{DL}$ | PUSCH preparation time $N_2$ [symbols] |
|---|---|
| 0 | 10 |
| 1 | 12 |
| 2 | 23 |
| 3 | 36 |

Table 5.3-2: PDSCH processing time for PDSCH processing capability 2

| $\mu_{DL}$ | PDSCH decoding time $N_1$ [symbols] | |
|---|---|---|
| | No additional PDSCH DM-RS configured | Additional PDSCH DM-RS configured |
| 0 | [2.5 - 4] | [12] |
| 1 | [2.5 - 6] | [12] |

Table 6.4-2: PUSCH preparation time for PUSCH timing capability 2

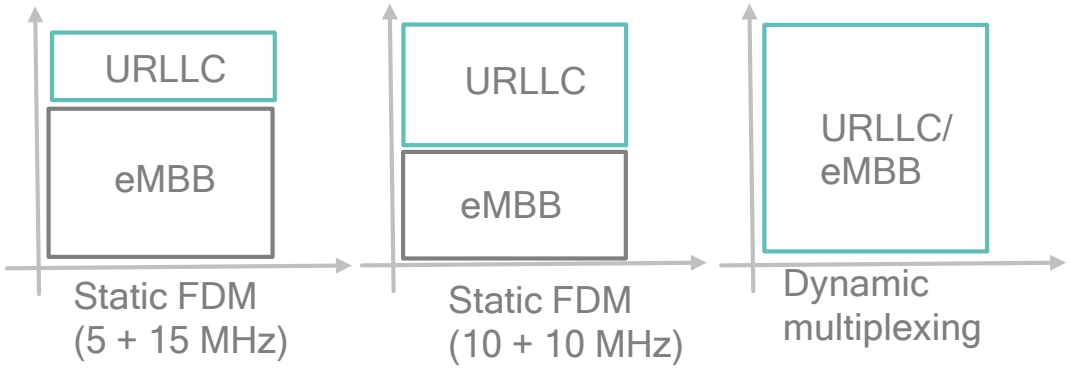
| $\mu_{DL}$ | PUSCH preparation time $N_2$ [symbols] |
|---|---|
| 0 | [2.5-6] |
| 1 | [2.5-6] |

- Processing time 60kHz ($\mu_{DL} = 2$) (capability 1) are close to that for 30kHz ($\mu_{DL} = 1$) (capability 1) and is worse than 30kHz ($\mu_{DL} = 1$) (capability 2):
  - Processing time for 30kHz (capability 1): PDSCH = 0.357ms, PUSCH – 0.41ms
  - Processing time for 60kHz (capability 1): PDSCH = 0.303ms, PUSCH – 0.429ms
  - Processing time for 30kHz (capability 2): PDSCH = [0.089, 0.214] ms, PUSCH = [0.089, 0.214] ms
  - Processing time for 60kHz (capability 2) is undefined and not even actively discussed in RAN1
- Processing timeline gain for 60kHz vs 30kHz is marginal if at all (at least for Rel15)
  - 30kHz (Capability 2) is better than 60kHz

# Problem of 60kHz URLLC and 30kHz eMBB under static FDM

sysim assumptions

## Poor performance of static FDM URLLC (60kHz) and eMBB (30kHz)




Deadline requirement

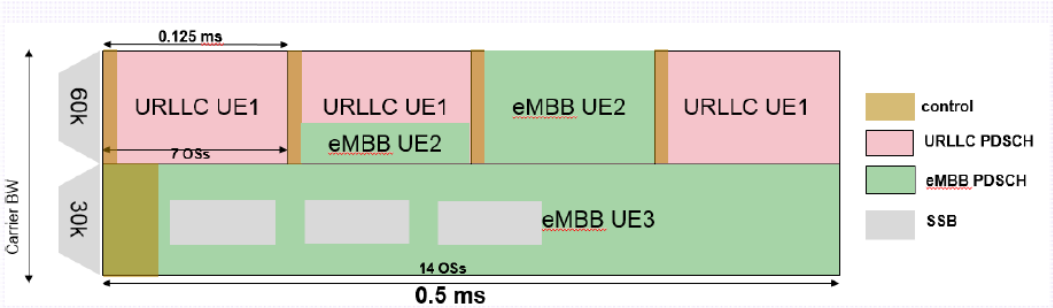
| Frequency resources | 500us | 750us | 1000us |
|---|---|---|---|
| 5MHz | ~0 | ~0 | ~0 |
| 10MHz | 0.3 | 3.9 | 6.2 |
| 20MHz | 10.8 | 15.8 | 17.0 |

URLLC outage capacity (Mbps)
1e-5 reliability

Deadline requirement

| Frequency resources | 500us | 750us | 1000us |
|---|---|---|---|
| 5MHz | -- | -- | -- |
| 10MHz | 2.3% | 32.4% | 50.9% |
| 20MHz | 43.3% | 64% | 68.6% |

URLLC resource utilization

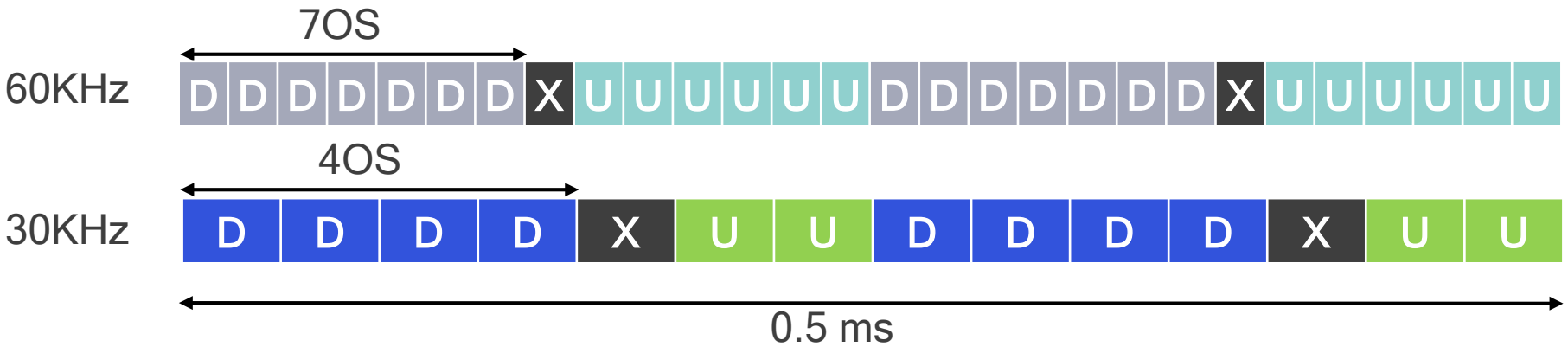



From R1-1801783

- 60kHz 7 symbol mini-slot has worse latency than 30kHz 2-symb and similar latency as 30kHz 4-symb
- Static FDM of 30kHz eMBB and 60kHz URLLC:
  - Low URLLC capacity and low resource utilization
- 30kHz URLLC achieves efficient multiplexing with eMBB

- FDM-ing URLLC and eMBB incurs significant capacity loss
  - The whole system bandwidth should be made available to URLLC (with 30kHz SCS, this is easier to achieve
- eMBB and URLLC should be dynamic multiplexed for efficiency
- There is no forward compatible issues introducing 60kHz. However, some 60kHz based URLLC designs are inferior!

# Optimized URLLC TDD DL/UL configuration under different SCS

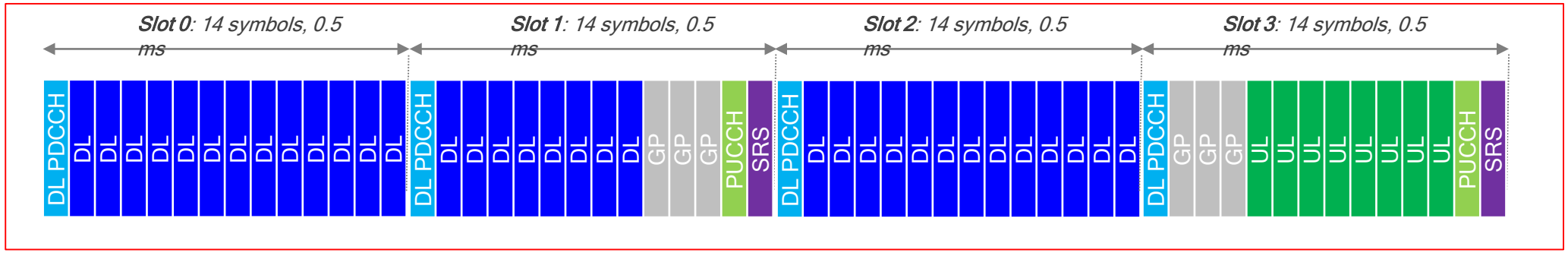



- NR supports very flexible DL/UL partitioning (via flexible symbols)
  - PDCCH can flexibly schedule DL/UL data on the desired DL/UL symbols
  - Multiple DL/UL transmission opportunities can be achieved via gNB flexible scheduling
- For efficient TDD URLLC design, 30kHz can achieve DL/UL 2-switch within 0.5
  - Latency is similar to 60kHz 7-symbol UL/DL switch design
  - Example shown in diagram above (different DL/UL ratio can be configured as needed)
- Even over TDD, both 30kHz and 60kHz can be configured to achieve URLLC R15 requirement
  - Config can be found in SFI table, but scheduling location is signaled in DCI, no need to monitor SFI

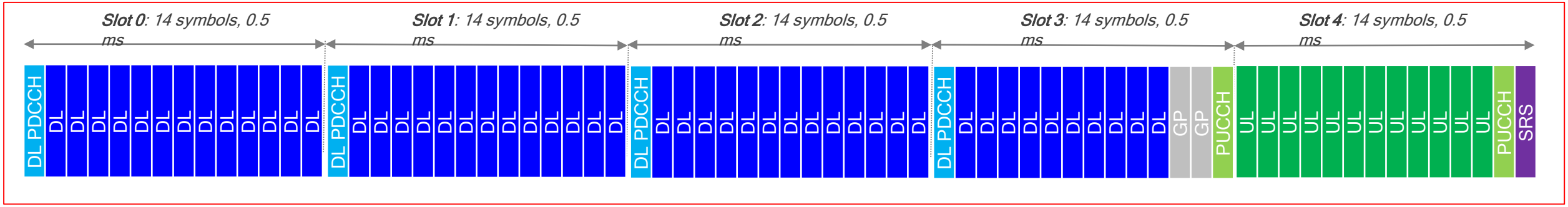
# URLLC Multiplexed in existing eMBB TDD network

- URLLC latency is determined by the UL/DL configuration of eMBB deployed spectrum
  - Latency dominated by UL/DL configuration, impact from numerology (30kHz vs. 60kHz) is negligible for URLLC
  - More important thing is to adopt a ULDL config that supports low latency (e.g., DSDU 1ms DL/UL switch)
  - DDDSU TDD configuration has fundamental limits to support URLLC in eMBB TDD network

- DSDU TDD Configuration
  - 1 ms DL/UL switching time




- DDDSU TDD Configuration
  - 2.5 ms DL/UL switching time



# Summary

- 30kHz is sufficient to achieve R15 URLLC latency requirement
- 30kHz has superior/more robust LLS performance compared with 60kHz(NCP/ECP)
- 30kHz achieves URLLC requirements for both FDD/TDD
  - When multiplexed with existing eMBB TDD network, the key is to make sure the eMBB UL/DL configure supports low latency
- RAN1 and RAN4 made the right agreement to have 60kHz optional for 1~6GHz
  - Many performance evaluations have been done already
  - These agreements shall be honored

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# Network Evaluation assumptions for DL URLLC

| Parameters | Rural |
|---|---|
| Layout | Single macro layer. Hex. Grid, 21 cells wrap around |
| Inter-BS distance | 1732m |
| Carrier frequency | 2GHz |
| System bandwidth | 5, 10, 20MHz |
| Channel model | 3D UMa |
| Transmission power | BS: 49dBm PA scaled with simulation bandwidth. UE: 23dBm |
| Antenna config | 2 Tx / 2 Rx (X-pol) |
| BS antenna height | 35m |
| BS antenna element gain+connector loss | 8dBi |
| BS/UE receiver noise figure | 5/9 dB |
| Traffic model | eMBB: full-buffer. URLLC: Poisson with 32-byte packets (FTP3) |
| UE distribution | 22 URLLC UEs in the serving cell. Uniformly random drop in a cell with 50% indoor and 50% outdoor. 20 eMBB neighboring cells, each has one eMBB UE. |
| Scheduling algorithm | URLLC: delay-based subband 2x2 SU-MIMO |
| Intercell interference | Fully captured with beamforming |
| Tone spacing/cyclic prefix | 60KHz/NCP |
| Minislot/RTT durations | 2-symbol minislot, 6-symbol RTT |
| HARQ | Incremental redundancy |
| Target reliability | Tx missed deadline + Rx HARQ failure <= 1e-5 |
| Hard latency bound | 500us, 750us, 1ms |

# Link-level Evaluation assumptions for DL URLLC

| Parameters | |
|---|---|
| Antenna config | 1 Tx / 2 Rx |
| MCS | MCS0, NR LDPC, SBPM interleaver |
| Minislot/numerology | 2/4-symbol; 30/60 kHz, NCP/ECP |
| Target reliability | Tx missed deadline + Rx HARQ failure <= 1e-5 |
| Channel profile | TDL-C 1000ns and TDL-C 300ns with 70Hz Doppler |
| Channel estimation | Realistic |
| # of Layer | 1 |
| PRG | 2RB |
| Allocation | 80 RB (ECP normalized to 68RB) |
| DMRS | 2-comb front loaded; single layer DMRS FDMed with PDSCH |