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Technical Report

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Study on physical layer enhancements for NR ultra-reliable and low latency case (URLLC)
(Release 16)

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Contents

Foreword

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The present document captures the results and findings from the study item "Study on physical layer enhancements for NR Ultra Reliable Low Latency Communication (URLLC)" [2][3]. The purpose of this TR is to document the baseline performance achievable with Rel-15 NR URLLC considering the prioritized URLLC use cases identified in [2][3], and to document the evaluation and findings of the potential enhancements for the prioritized URLLC use cases. However, this does not imply that NR Rel-16 URLLC is necessarily restricted to the identified use cases in [2][3].

This activity involves the Radio Access work area of the 3GPP studies and has potential impacts both on the Mobile Equipment and Access Network of the 3GPP systems.

This document is a 'living' document, i.e. it is permanently updated and presented to TSG-RAN meetings.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP RP-181477: "New SID on Physical Layer Enhancements for NR URLLC".

[3] 3GPP RP-182089: "New SID on Physical Layer Enhancements for NR Ultra-Reliable and Low Latency Communication (URLLC)".

[4] 3GPP TR 22.804: "Study on Communication for Automation in Vertical Domains".

[5] 3GPP TR 22.886: "Study on enhancement of 3GPP Support for 5G V2X Services".

[6] 3GPP TS 22.186: "Enhancement of 3GPP support for V2X scenarios".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol> <Explanation>

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

AR	Augmented Reality
ACK	Acknowledgement
CSI	Channel State Information
CCE	Control Channel Element
DCI	Downlink Control Information
eMBB	enhanced Mobile BroadBand
FDD	Frequency Division Duplex
gNB	NR Node B
HARQ	Hybrid automatic repeat request
NACK	Negative Acknowledgement
PDCCH	Physical Downlink Control Channel
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
PDSCH	Physical Downlink Shared Channel
SRI	SRS resource indicator
TDD	Time Division Duplex
URLLC	Ultra Reliable Low Latency Communication
UCI	Uplink control information
VR	Virtual Reality

4 Introduction

In Release 15 the basic support for URLLC was introduced with TTI structures for low latency as well as methods for improved reliability. Further use cases with tighter requirements have been identified as important for NR evolution, in addition to the need for enhancing the Release 15 enabled use cases.

The follow key use cases were identified to be considered:

- Release 15 enabled use case improvements
    - Such as AR/VR (Entertainment industry)
- New Release 16 use cases with higher requirements
    - Factory automation
    - Transport Industry, including the remote driving use case
    - Electrical Power Distribution

The objective of this study item is to investigate enhancements to URLLC (Ultra Reliable Low Latency Communications), considering both FR1 and FR2 as well as TDD and FDD, with the already existing solutions for NR as the baseline. The TR reports the results and findings from the study item, mainly on baseline performance achievable with Rel-15 NR URLLC, layer 1 enhancements (including PDCCH enhancements, UCI enhancements, PUSCH enhancements and enhancements to scheduling/HARQ/CSI processing timeline), UL inter UE Tx prioritization/multiplexing and enhanced UL configured grant (grant free) transmissions.

5 Baseline performance achievable with Rel-15 NR URLLC

5.1 Performance metric

The performance metric for the system level evaluations in this study item, including evaluation of the baseline performance achievable with Rel-15 NR URLLC and evaluation of the performance achievable with potential enhancement(s) for Rel-16 URLLC, is either option 1 or option 2 as below:

- **Option 1**: Percentage of users satisfying reliability and latency requirements
    - Intend for the case with fixed number of UEs and fixed traffic model per UE
- **Option 2**: URLLC capacity and URLLC/eMBB multiplexing capacity
    - Definition: URLLC system capacity is calculated as follows:
        - C(L, R) is the maximum offered cell load under which Y% of URLLC UEs in a cell operate with target link reliability R under L latency bound
        - X= (100 – Y) % is the percentage of UEs in outage
        - A UE in outage is defined as the UE cannot meet both latency L and link reliability R bound
        - Companies report their assumption on X (either ~5% or 0%)
        - Companies report their assumption on the number of eMBB UEs deployed together with the URLLC UEs
    - Intend for the case that the number of UEs and/or the data arrival rate is adjustable
        - Adjusting the number of UEs should be applied to periodic deterministic traffic model

5.2 Evaluation results and findings

One objective of this study item is to establish the baseline performance achievable with Release 15 URLLC considering the prioritized URLLC use cases (i.e. Rel-15 enabled use case, factory automation, transport industry and electrical power distribution) [3]. This section presents the evaluation results and the corresponding findings for each prioritized use case. Throughout this section, unless otherwise noted, system-level simulation assumptions in Appendix A.2 are assumed. Note that 5% Q-value (dB) is obtained by system-level simulation assuming full buffer for a given evaluation scenario.

5.2.1 Evaluation on electrical power distribution

Seven sources evaluate the baseline performance achievable with Rel-15 NR for electrical power distribution, with the evaluation results as shown in Table 5.2.1-1.

- Five sources show that the percentage of UEs satisfying the latency (i.e. 6 ms for differential protection and 3 ms for power distribution grid fault and outage management) and reliability (i.e. 99.999% for differential protection and 99.9999% for power distribution grid fault and outage management) requirements by Rel-15 NR is higher than 95% for downlink transmission for power distribution assuming up to 10 URLLC users per cell, 4 GHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 6 ms for differential protection and 3 ms for power distribution grid fault and outage management) and reliability (i.e. 99.999% for differential protection and 99.9999% for power distribution grid fault and outage management) requirements by Rel-15 NR can be lower than 95% for uplink transmission for power distribution assuming 10 URLLC users per cell, realistic channel estimation, 4 GHz and FDD.
- Two sources show that the percentage of UEs satisfying the latency (i.e. 6 ms for differential protection and 3 ms for power distribution grid fault and outage management) and reliability (i.e. 99.999% for differential protection and 99.9999% for power distribution grid fault and outage management) requirements by Rel-15 NR is higher

than 95% for uplink transmission for power distribution assuming up to 10 URLLC users per cell, ideal channel estimation, 4 GHz and FDD.

- One source shows that the percentage of UEs satisfying the latency (i.e. 6 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for both downlink and uplink transmission for differential protection (i.e. 250 bytes packet size and data arrival interval 0.833ms) assuming 10 URLLC users per cell, realistic channel estimation, 700 MHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 3 ms) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for both downlink and uplink transmission for power distribution grid fault and outage management (i.e. 100 bytes packet size and data arrival interval 100 ms) assuming 10 URLLC users per cell, ideal channel estimation, 700 MHz and FDD.
- One source (R1-1903233) shows that the percentage of UEs satisfying the latency (i.e. 6 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for downlink transmission for differential protection assuming 5 URLLC users per cell, realistic channel estimation, 4 GHz, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, and TDD with TDD UL-DL configuration {SUDSU}. The same source shows that the percentage of UEs satisfying the latency (i.e. 6 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for uplink transmission for differential protection assuming 5 URLLC users per cell, realistic channel estimation, 4 GHz, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, and TDD with TDD UL-DL configuration {SUDSU}.
- One source (R1-1901599) shows that the percentage of UEs satisfying the latency (i.e. 6 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for both downlink and uplink transmission for differential protection assuming 4 or 6 or 8 URLLC users per cell, ideal channel estimation, 4 GHz, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD.

Table 5.2.1-1: The percentage of UEs satisfying requirements for power distribution

<table>
<tr><th colspan="5">Source 1 (R1-1901248): Differential protection
Reliability of 99.999%, 6 ms air interface latency, 250 bytes, data arrival interval 0.833ms, 4 GHz, FDD, 4Tx/4Rx at gNB side and 2 Tx/4Rx at UE side, 10 users per cell, realistic channel estimation, grant based for data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>100%</td><td>27%</td><td>-2.48</td></tr>
<tr><td colspan="2">UL</td><td>52.9%</td><td>73.2%</td><td>-</td></tr>
<tr><th colspan="5">Source 1 (R1-1901248): Differential protection
Reliability of 99.999%, 6 ms air interface latency, , 250 bytes, data arrival interval 0.833ms, 700 MHz, FDD, 4Tx/4Rx at gNB side and 2Tx/4Rx at UE side, 10 users per cell, realistic channel estimation, 20 MHz, grant based for uplink data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>78.1%</td><td>64.9%</td><td>-3.1</td></tr>
<tr><td colspan="2">UL</td><td>47.1%</td><td>78.2%</td><td>-</td></tr>
<tr><th colspan="5">Source 2 (R1-1900077): Differential protection
Reliability of 99.999%, 6 ms air interface latency, 250 bytes, data arrival interval 0.833ms, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 5 users per cell, ideal channel estimation, grant based and grant free for uplink data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Offered cell load (Mbps)</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>98.1 %</td><td>11.6197</td><td>-0.06</td></tr>
<tr><td colspan="2">UL (grant based)</td><td>98.1 %</td><td>11.4572</td><td>-0.07</td></tr>
<tr><td colspan="2">UL (grant free)</td><td>96.2 %</td><td>11.4442</td><td>-0.07</td></tr>
<tr><th colspan="5">Source 3 (R1-1901350): Power Distribution Grid Fault and Outage Management
Reliability of 99.9999%, 3 ms air interface, 100 bytes, data arrival interval 100 ms, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, 10 users per cell, ideal channel estimation, grant free for data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>99.8%</td><td>-</td><td>-0.35</td></tr>
<tr><td colspan="2">UL</td><td>95.4%</td><td>-</td><td>-0.44</td></tr>
<tr><th colspan="5">Source 4 (R1-1901352): Power Distribution Grid Fault and Outage Management
Reliability of 99.9999%, 3 ms air interface, 100 bytes, data arrival interval 100 ms, 700 MHz, FDD, 4Tx/4Rx at gNB side, 2 Tx/4 Rx at UE side, 10 users per cell, ideal channel estimation, grant free for data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>99%</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">UL</td><td>95%</td><td>-</td><td>-</td></tr>
<tr><th colspan="5">Source 3 (R1-1901350): Power Distribution Grid Fault and Outage Management
Reliability of 99.9999%, 3 ms air interface, 100 bytes, data arrival interval 100 ms, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, 10 users per cell+10 eMBB users, ideal channel estimation, grant based for data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>95.8%</td><td>-</td><td>-</td></tr>
<tr><td colspan="2">UL</td><td>95.9%</td><td>-</td><td>-</td></tr>
<tr><th colspan="5">Source 5 (R1-1903233): Differential protection
Reliability of 99.999%, 6 ms air interface latency, 250 bytes, data arrival interval 0.833ms, 4 GHz, TDD with TDD UL-DL configuration {SUDSU}, 4Tx/4Rx at gNB side and 2 Tx/4Rx at UE side, 5 users per cell, realistic channel estimation, grant based for data transmission</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td colspan="2">DL</td><td>96.2%</td><td>24.8%</td><td>-2.48</td></tr>
<tr><td colspan="2">UL</td><td>38.9%</td><td>67.9%</td><td>-</td></tr>
<tr><th colspan="5">Source 6 (R1-1901599): Differential protection
Reliability of 99.999%, 6 ms air interface latency, 250 bytes, data arrival interval 0.833ms, 4 GHz, FDD, 4Tx/4Rx at gNB side, 2 Tx/4 Rx at UE side, ideal channel estimation, grant based for data transmission, single shot transmission without HARQ/repetition</th></tr>
<tr><td colspan="2"></td><td>Percentage of UEs</td><td>Resource utilization</td><td>5% Q-value</td></tr>
<tr><td rowspan="2">4 users per cell</td><td>DL</td><td>99.8%</td><td>12.5%</td><td>-</td></tr>
<tr><td>UL</td><td>96.2%</td><td>8.7%</td><td>-</td></tr>
<tr><td rowspan="2">6 users per cell</td><td>DL</td><td>99.9%</td><td>24.2%</td><td>-</td></tr>
<tr><td>UL</td><td>95.7%</td><td>16.3%</td><td>-</td></tr>
<tr><td rowspan="2">8 users per cell</td><td>DL</td><td>99.9%</td><td>24.7%</td><td>-</td></tr>
<tr><td>UL</td><td>95.2%</td><td>20.6%</td><td>-</td></tr>
</table>

10 users per cell	DL	99.9%	36.6%	-
	UL	94.4%	24.8%	-
Source 7 (R1-1903451): Power Distribution Grid Fault and Outage Management Reliability of 99.9999%, 3 ms air interface, 100 bytes, data arrival interval 100 ms, 4 GHz, FDD, 4Tx/4Rx at gNB side, 1 Tx/4 Rx at UE side, 10 users per cell, ideal channel estimation, grant based for data transmission				
		Percentage of UEs	Resource utilization	
10 users per cell	DL	100%	-	
	UL grant based	92%	-	

5.2.2 Evaluation on transport industry

Six sources evaluate the baseline performance achievable with Rel-15 NR for transport industry, with the evaluation results as shown in Table 5.2.2-1.

- Three sources show that the percentage of UEs satisfying the latency (i.e. 3 ms for remote driving and 7 ms for ITS) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for downlink transmission for transport industry assuming 2 or 6 or 10 URLLC users without any eMBB users per cell, 4 GHz/700 MHz and FDD.
- Two sources show that the percentage of UEs satisfying the latency (i.e. 3 ms for remote driving) and reliability (i.e. 99.999%) requirements by Rel-15 NR can be lower than 61% for uplink transmission for remote driving assuming 6 or 10 URLLC users per cell, 4 GHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 7 ms for ITS) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for both downlink and uplink transmission for ITS assuming 2 users per cell, 4 GHz/700 MHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 3 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for downlink transmission for remote driving assuming 6 URLLC users per cell with 30 eMBB users per 21 cells, 4 GHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 3 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for uplink transmission for remote driving assuming 10 URLLC users per cell, 4Tx/4Rx at gNB side, 2 Tx/4 Rx at UE side, realistic channel estimation, 700 MHz and FDD.
- One source (R1-1901600) shows that the percentage of UEs satisfying the latency (i.e. 7 ms for ITS) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for both downlink and uplink transmission for ITS assuming 4 or 6 or 8 or 10 users per cell, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, ideal channel estimation, 4 GHz and FDD.

Table 5.2.2-1: The percentage of UEs satisfying requirements for transport industry

Source 1 (R1-1901247): Remote driving Reliability of 99.999%, 3 ms air interface latency, 4 GHz, FDD, 4Tx/4Rx at gNB side and 2Tx/4Rx at UE side, 10 users per cell, realistic channel estimation, grant free for uplink, periodic traffic model				
		Percentage of UEs	Resource utilization	5% Q-value
DL		96.7%	10.2%	-2.2
UL		60%	91.8%	-
Source 2 (R1-1901553): Remote driving Reliability of 99.999%, 3 ms air interface latency, 700 MHz, FDD, 4Tx/4Rx at gNB side, 2Tx/4Rx at UE side, 10 users per cell, realistic channel estimation, grant free for uplink, periodic traffic model				
		Percentage of UEs	Resource utilization	5% Q-value
DL		100%	18.3%	-2.72
UL		60%	85.9%	-
Source 3 (R1-1900080): Remote driving Reliability of 99.999%, 3 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 2 users per cell, ideal channel estimation, grant based for uplink data transmission				
		Percentage of UEs	Offered cell load (Mbps)	5% Q-value (dB)
DL		97.62 %	1.9081	-0.39
UL		-	-	-6.17
Source 3 (R1-1900080): ITS Reliability of 99.999%, 7 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 2 users per cell, ideal channel estimation, grant based and grant free for uplink data transmission				
		Percentage of UEs	Offered cell load (Mbps)	5% Q-value (dB)
DL		100 %	2.092	-0.39
UL (grant based)		97.62 %	2.0918	-6.17
UL (grant free)		95.3 %	2.0876	-6.17
Source 4 (R1-1900238): Remote driving Reliability of 99.999%, 3 ms air interface latency, 700 MHz, FDD, 2Tx/2Rx at gNB side, 2 Tx/2 Rx at UE side, 2 users per cell, ideal channel estimation, grant based for uplink data transmission				
		Percentage of UEs	Offered cell load (Mbps)	5% Q-value (dB)
DL		95.2 %	1.9081	-0.44
UL		-	-	-1.54
Source 4 (R1-1900238): ITS Reliability of 99.999%, 7 ms air interface latency, 700 MHz, FDD, 2Tx/2Rx at gNB side, 2 Tx/2 Rx at UE side, 2 users per cell, ideal channel estimation, grant based for uplink data transmission				
		Percentage of UEs	Offered cell load (Mbps)	5% Q-value (dB)
DL		100 %	2.092	-0.44
UL		95.2%	2.0918	-1.54
Source 5 (R1-1901351): Remote driving Reliability of 99.999%, 3 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, 6 users per cell, ideal channel estimation, grant-free PUSCH				
		Percentage of UEs (Mean)	-	-
DL		97 %	-	-
UL		60 %	-	-
Source 5 (R1-1901351): Remote driving Reliability of 99.999%, 3 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, 6 users per cell+30 eMBB users per 21 cells, SR-based PUSCH, ideal channel estimation				
		Percentage of UEs (Mean)	-	-
DL		81 %	-	-
UL		53 %	-	-
Source 6 (R1-1901600): ITS Reliability of 99.999%, 7 ms air interface latency, 1370 bytes, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/4 Rx at UE side, ideal channel estimation, grant based for data transmission, single short transmission for uplink				
		Percentage of UEs (Mean)	Resource utilization	
4 users per cell	DL	100 %	0.6%	
	UL	99.4 %	0.6%	
6 users per cell	DL	100 %	0.7%	
	UL	99.2 %	0.7%	
8 users per cell	DL	100 %	0.7%	
	UL	98.8 %	0.8%	
10 users	DL	100 %	0.8%	

per cell	UL	98.8 %	1.0%

5.2.3 Evaluation on Rel-15 enabled use case

As shown in section A.2.4, Rel-15 enabled use case with urban macro (applicable data packet size 32 bytes and 200 bytes) and Rel-15 enabled use case with indoor hot-spot are defined.

Four sources evaluate the baseline performance achievable with Rel-15 NR for Rel-15 enabled use case with urban macro, with the evaluation results as shown in Table 5.2.3-1.

- One source shows that the percentage of UEs satisfying the latency (i.e. 1 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% with resource utilization of 3.2% or 6.4% for downlink transmission for Rel-15 enabled use case with urban macro assuming 10 URLLC users per cell, realistic channel estimation, up to 4 Tx/4 Rx at gNB size and 2 Tx/4 Rx at the UE side, 700 MHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 1 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% with resource utilization of 7.3% or 16.2% for uplink transmission for Rel-15 enabled use case with urban macro assuming 10 URLLC users per cell, realistic channel estimation, up to 4 Tx/4 Rx at gNB size and 2 Tx/4 Rx at the UE side, 700 MHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 1 ms) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for both downlink and uplink transmission for Rel-15 enabled use case with urban macro assuming 5 URLLC users per cell, ideal channel estimation, 8Tx/8Rx at the gNB size and 2Tx/2Rx at the UE side, 4 GHz and FDD.
- One source (R1-1903451) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for uplink transmission for Rel-15 enabled use case with urban macro assuming 10 URLLC users per cell, realistic channel estimation, 4Rx at the gNB size and 1Tx at the UE side, 4 GHz and FDD.
- One source (R1-1903449) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is lower than 95% for uplink transmission for Rel-15 enabled use case with urban macro assuming 10 URLLC users per cell, ideal channel estimation, 4Rx at the gNB size and 2Tx at the UE side, 4 GHz and FDD.

Table 5.2.3-1: The percentage of UEs satisfying requirements for Rel-15 enabled use case with urban macro

Source 1 (R1-1901250): Rel-15 enabled use case with urban macro (32 bytes) Reliability of 99.999%, 1 ms air interface latency, 700 MHz, FDD, 2Tx/2Rx at gNB and 2 Tx/4 Rx at UE side, 10 users per cell, realistic channel estimation, grant based for uplink, aperiodic traffic model				
λ =120 p/s		Percentage of UEs	Resource utilization	5% Q-value
	DL	81.9%	3.2%	-3.2
	UL	15.7%	7.3%	-
Source 1 (R1-1901250): Rel-15 enabled use case with urban macro (32 bytes) Reliability of 99.999%, 1 ms air interface latency, 700 MHz, FDD, 4Tx/4Rx at gNB and 2 Tx/4 Rx at UE side, 10 users per cell, realistic channel estimation, grant based for uplink, aperiodic traffic model				
λ =500 p/s		Percentage of UEs	Resource utilization	5% Q-value
	DL	91.4%	6.4%	-3.1
	UL	45.3%	16.2%	-
Source 2 (R1-1900079): Rel-15 enabled use case with urban macro (32 bytes or 200 bytes) Reliability of 99.999%, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 5 users per cell, ideal channel estimation, grant based and grant free for uplink data transmission				
32 bytes, 1 ms air interface latency λ =100 p/s		Percentage of UEs	Offered cell load (Mbps)	5% Q-value
	DL	99.05%	0.1222	-1.04
	UL (grant based)	100%	0.1221	-1.61
	UL (grant free)	100%	0.1221	-1.61
200 bytes, 1 ms air interface latency λ =100 p/s		Percentage of UEs	Offered cell load (Mbps)	5% Q-value
	DL	95.24%	0.7635	-1.04
	UL (grant based)	98.1%	0.7635	-1.61
	UL (grant free)	96.2%	0.7633	-1.61
200 bytes, 4 ms air interface latency λ =100 p/s		Percentage of UEs	Offered cell load (Mbps)	5% Q-value
	DL	98.1%	0.7635	-1.04
	UL (grant based)	100%	0.7635	-1.61
	UL (grant free)	99.0%	0.7627	-1.61
Source 3 (R1-1903451) Reliability of 99.999%, 1 ms air interface latency, 4 GHz, FDD, 4Tx/4Rx at gNB side, 1 Tx/4Rx at UE side, 10 users per cell, realistic channel estimation, grant free for uplink data transmission, 32 bytes, 7 OS TTI, aperiodic traffic model				
		Percentage of UEs	Offered cell load (Mbps)	
λ =100 p/s	DL	100%	0.2560	
	UL	89.5%	0.2560	
λ = 250 p/s	DL	99.7%	0.64	
	UL	83.5%	0.64	
λ = 400 p/s	UL	81.2%	1.024	
λ = 500 p/s	DL	99.7%	1.28	
λ = 750 p/s	DL	86.5%	1.92	
Source 4 (R1-1903449) Reliability of 99.999%, 1 ms air interface latency, 4 GHz, FDD, 4Tx/4Rx at gNB side, 2T/4Rx at UE side, ideal channel estimation, 32 bytes, 7 OS TTI, periodic traffic with packet periodicity 1 ms				
		Percentage of UEs	Resource utilization	
5 users per cell	UL (Grant based, no SR)	95.3%	5.8%	

	DL	99.3%	8.6%
10 users per cell	UL (Grant based, no SR)	90.8%	15.5%
	DL	96.3%	16.9%
Source 4 (R1-1903449) Reliability of 99.999%, 1 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2T/4Rx at UE side, ideal channel estimation, 32 bytes, 7 OS TTI, periodic traffic with packet periodicity 1 ms			
		Percentage of UEs	Resource utilization
5 users per cell	UL (Grant based, no SR)	97.7%	4.4%
	DL	98.7%	8.6%
10 users per cell	UL (Grant based, no SR)	97.3%	9.9%
	DL	95.4%	16.9%

Note: λ is the packet arrival rate

Four sources evaluate the baseline performance achievable with Rel-15 NR for Rel-15 enabled use case with indoor hot-spot, with the evaluation results as shown in Table 5.2.3-2.

- Two sources show that the percentage of UEs satisfying the latency (i.e. 7 ms) and reliability (i.e. 99.9%) requirements by Rel-15 NR is 100% for downlink transmission for Rel-15 enabled use case with indoor hot-spot assuming 5 or 10 URLLC users per cell, 4 GHz and FDD.
- Two sources show that the percentage of UEs satisfying the latency (i.e. 7 ms) and reliability (i.e. 99.9%) requirements by Rel-15 NR is lower than 95% for uplink transmission for Rel-15 enabled use case with indoor hot-spot assuming 10 users per cell, 4 GHz and FDD/TDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 7 ms) and reliability (i.e. 99.9%) requirements by Rel-15 NR is higher than 95% for uplink transmission for Rel-15 enabled use case with indoor hot-spot assuming 5 URLLC users per cell, 4 GHz and FDD.
- One source shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is 95% for uplink transmission with cell load of 1.5 Mbps for Rel-15 enabled use case with indoor hot-spot assuming 10 URLLC users per cell, 4 GHz, 32 bytes packet size, 1Tx at the UE side, 4Rx at gNB side, and FDD.

Table 5.2.3-2: The percentage of UEs satisfying requirements for Rel-15 enabled use case with indoor hot-spot

Source 1 (R1-1901250) Reliability of 99.9%, 7 ms air interface latency, 4 GHz, FDD, 4Tx/4Rx at gNB and 4 Tx/4 Rx at UE side, 10 users per cell, realistic channel estimation, grant based for uplink, 4096 bytes				
λ =60 p/s Periodic traffic model		Percentage of UEs	Resource utilization	5% Q-value
	DL	100%	23.6%	-3.73
	UL	89.2%	38.5%	-
λ =60 p/s Aperiodic traffic model		Percentage of UEs	Resource utilization	5% Q-value
	DL	100%	20.3%	-3.73
	UL	82.5%	36.5%	-
Source 2 (R1-1900079) Reliability of 99.9%, 7 ms air interface latency, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 5 users per cell, ideal channel estimation, grant based and grant free for uplink data transmission, 4096 bytes				
λ =60 p/s Periodic traffic model		Percentage of UEs	Offered cell load (Mbps)	5% Q-value
	DL	100 %	9.3810	-1.09
	UL (grant based)	100 %	9.3810	-2.02
	UL (Grant free)	100 %	9.3727	-2.02
Source 3 (R1-1900976) Reliability of 99.9%, 7ms air interface latency, 4 GHz, TDD with TDD UL-DL configuration {SU}, S={D10, G2, U2}, 4Tx/4Rx at gNB side, 2 Tx/4 Rx at UE side, 5 users per cell, ideal channel estimation, grant based for uplink data transmission, 4096 bytes, aperiodic traffic model				
		Percentage of UEs	Resource utilization	5% Q-value
λ =185 p/s	DL	91.67 %	33.8%	-3.13
λ =145 p/s	UL	76.67 %	32.75	-2.19
Source 3 (R1-1900976) Reliability of 99.9%, 7 ms air interface latency 4 GHz, TDD with TDD UL-DL configuration {SU}, S={D10, G2, U2}, 4Tx/4Rx at gNB side, 2 Tx/4 Rx at UE side, 4 users per cell, ideal channel estimation, grant based for uplink data transmission, 4096 bytes, aperiodic traffic model				
		Percentage of UEs	Resource utilization	5% Q-value
λ =185 p/s	DL	96.43 %	26%	-3.13
λ =145 p/s	UL	97.77 %	24.93%	-2.19
Source 4 (R1-1903451) Reliability of 99.999%, 1 ms air interface latency, 4 GHz, FDD, 4Tx/4Rx at gNB side, 1 Tx/4Rx at UE side, 10 users per cell, ideal channel estimation, grant free for uplink data transmission, 32 bytes, 7 OS TTI, aperiodic traffic model				
		Percentage of UEs	Offered cell load (Mbps)	
λ = 100 p/s	DL	100%	0.2560	
λ = 250 p/s	DL	100%	0.64	
λ = 500 p/s	DL	99.5%	1.28	
λ = 750 p/s	DL	85.5%	1.92	
λ = 100 p/s	UL	100%	0.2560	
λ = 500 p/s	UL	99.8%	1.28	
λ = 750 p/s	UL	85.5%	1.92	

Note: λ is the packet arrival rate

5.2.4 Evaluation on factory automation

Six sources evaluate the baseline performance achievable with Rel-15 NR for factory automation, with the evaluation results as shown in Table 5.2.4-1.

- One source (R1-1901555) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for downlink transmission for factory automation assuming 10 or 20 users per cell, realistic channel estimation, 2 OS TTI, 4 GHz, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD. The same source shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is lower than 95% for downlink transmission for factory automation assuming 20 per cell, realistic channel estimation, 4 OS TTI, 21% DMRS and control overhead, 4 GHz and FDD.

- One source (R1-1903400) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.999%) requirements by Rel-15 NR is higher than 95% for downlink transmission for factory automation assuming 10 users per cell, ideal channel estimation, 2 OS TTI, 35% DMRS and control overhead, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, 4 GHz and FDD.
- One source (R1-1903447) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for downlink transmission for factory automation assuming 10 to 25 users per cell, realistic channel estimation, 4 OS TTI, 4 GHz, 16Tx/16Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD.
- One source (R1-1903447) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is lower than 95% for grant based uplink transmission for factory automation assuming 10 users per cell, realistic channel estimation, 4 OS TTI, 4 GHz, 16Tx/16Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD. The same source shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for grant free uplink transmission for factory automation assuming up to 30 users per cell, realistic channel estimation, 4 OS TTI, 4 GHz, 16Tx/16Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD.
- One source (R1-1903447) shows that the percentage of UE satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for both downlink and configured grant uplink transmissions for factory automation assuming up to 10 users per cell, realistic channel estimation, 4 OS TTI, 4 GHz, 16Tx/16Rx at gNB side and 2 Tx/4 Rx at UE side, and TDD.
- One source (R1-1903448) shows that the percentage of UE satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% for both downlink and configured grant uplink transmissions for factory automation assuming up to 15 users per cell, practical channel estimation, 7 OS TTI, 30 GHz, 16Tx/16Rx at gNB side and 2 Tx/2 Rx at UE side, and TDD.
- One source (R1-1901775) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is higher than 95% with cell load of 0.6108 Mbps for both downlink and uplink transmission for factory automation assuming 5 users per cell, ideal channel estimation, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 4 GHz and FDD.
- One source (R1-1901555) shows that the percentage of UEs satisfying the latency (i.e. 1 ms air interface latency) and reliability (i.e. 99.9999%) requirements by Rel-15 NR is lower than 95% with resource utilization of 50% for uplink transmission for factory automation assuming 10 users per cell, realistic channel estimation, 4 GHz, 4Tx/4Rx at gNB side and 2 Tx/4 Rx at UE side, and FDD.

Table 5.2.4-1: The percentage of UEs satisfying requirements for factory automation

Source 1 (R1-1901555): Factory automation
Reliability of 99.9999%, 1 ms air interface, 4 GHz, FDD, 4Tx/4Rx at gNB and 2Tx/4Rx at UE side, realistic channel estimation, two UE groups, grant free for uplink data transmission, ITU channel model

		Percentage of UEs	Resource utilization	5% Q-value
10 users per cell	DL: 4 OS	96.7%	6.93%	-3.32
	DL: 2 OS	100%	7.1%	-3.32
	UL: 14 OS	90.8%	50%	-
20 users per cell	DL: 4 OS	88.3%	13.2%	-3.32
	DL: 2 OS	98.2%	14.1%	-3.32
	UL: 14 OS	68.8%	50%	-
40 users per cell	DL: 4 OS	74.2%	18.4%	-3.32
	UL: 14 OS	40.8%	50%	-

Source 2 (R1-1901775): Factory automation
Reliability of 99.9999%, 1 ms air interface, 4 GHz, FDD, 8Tx/8Rx at gNB side, 2 Tx/2 Rx at UE side, 5 users per cell, ideal channel estimation, one UE group, grant based and grant free for uplink data transmission, ITU channel model

	Percentage of UEs	Offered cell load (Mbps)	5% Q-value (dB)
DL	100 %	0.6108	-1.35
Grant based UL and grant free UL	100 %	0.6108	-0.96

Source 3 (R1-1903400): Factory automation
Reliability of 99.999%, 1 ms air interface, 4 GHz, FDD, 4Tx/4Rx at gNB side, 4 Rx at UE side, 2 OS TTI, 10 users per cell, ideal channel estimation, two UE groups, ITU channel model

	Percentage of UEs	Resource utilization	5% Q-value (dB)
DL	100 %	12%	-2.5

Source 4 (R1-1903447): Factory automation
Reliability of 99.9999%, 1 ms air interface, 4 GHz, FDD, 16Tx/16Rx at gNB side and 2Tx/4Rx at UE side, 4 OS TTI, realistic channel estimation, one UE group, random offset within a slot, modified indoor hotspot LOS model with blockers

		Percentage of UEs	Resource utilization
10 users per cell	DL	100%	6.09%
	Grant based UL	74.95%	6.93%
	Grant free UL	100%	6.93%
15 users per cell	DL	99.97%	9.17%
	Grant based UL	57.71%	10.42%
	Grant free UL	100%	10.42%
20 users per cell	DL	99.58%	12.24%
	Grant based UL	43.92%	13.91%
	Grant free UL	99.96%	13.19%
25 users per cell	DL	98.05%	15.28%
	Grant based UL	35.25%	17.37%
	Grant free UL	99.61%	17.37%
30 users per cell	DL	94.73%	18.34%
	Grant based UL	29.42%	20.86%
	Grant free UL	97.65%	20.86%
35 users per cell	DL	89.46%	21.37%
	Grant based UL	25.27%	24.31%
	Grant free UL	93.16%	24.31%
40 users per cell	DL	82.22%	24.38%
	Grant based UL	22.13%	27.74%
	Grant free UL	86.72%	27.75%

Source 4 (R1-1903447): Factory automation
Reliability of 99.9999%, 1 ms air interface, 4 GHz, TDD with configuration [D D D D D D G U U U U U U U], 16Tx/16Rx at gNB side and 2Tx/4Rx at UE side, 4 OS TTI, realistic channel estimation, one UE group, random offset within a slot, modified indoor hotspot LOS model with blockers

		Percentage of UEs	Resource utilization
5 users per cell	DL	99.68%	6.56%
	Grant free UL	99.79%	6.56%
10 users per cell	DL	96.21%	13.02%
	Grant free UL	95.68%	13.02%

Source 5 (R1-1903448): Factory automation
Reliability of 99.9999%, 1 ms air interface, 30 GHz, TDD with configuration [D D D D D D F F U U U U U U], 16Tx/16Rx at gNB side and 2Tx/2Rx at UE side, 7 OS TTI, practical channel estimation, one UE group, random offset within a slot, modified indoor hotspot LOS model with blockers

		Percentage of UEs	Resource utilization
5 users per cell	DL	100%	9.02%
	Grant free UL	100%	9.02%
10 users per cell	DL	99.87%	17.14%
	Grant free UL	99.95%	17.14%
15 users per cell	DL	95.68%	25%
	Grant free UL	98.28%	25%
20 users per cell	DL	81.77%	33.05%
	Grant free UL	90.47%	33.05%
Source 6 (R1-1903451): Factory automation Reliability of 99.9999%, 1 ms air interface, 4 GHz, FDD, 4Tx/4Rx at gNB side and 1Tx/4Rx at UE side, 7 OS TTI, ideal channel estimation, random UE specific offset of traffic arrival, grant free UL, NR InH open office channel model			
		Percentage of UEs	Resource utilization
10 users per cell	DL	99.5%	-
	UL	99.1%	-
20 users per cell	DL	99.5%	-
	UL	94.4%	-

In addition, three sources (R1-1900170/R1-1900171, R1-1900976 and R1-1812996) also evaluate the baseline performance achievable with Rel-15 NR for factory automation from link level simulation perspective.

- From link-level simulation perspective, reliability requirement of 99.9999% within 1 ms one-way latency for factory automation for a single UE by Rel-15 NR URLLC can be achieved under some certain transmission configurations at carrier frequency of 4 GHz.
- From link-level simulation perspective, it seems challenging to meet the reliability requirement of 99.9999% within 1 ms one-way latency for factory automation for a single UE by Rel-15 NR URLLC with single-shot transmission at least with duration less than 8os at carrier frequency of 30 GHz.

6 Layer 1 enhancements

6.1 PDCCH enhancements

6.1.1 Rel-15 NR PDCCH evaluation

PDCCH evaluations include evaluation of PDCCH reliability and evaluation of PDCCH blocking. In order to investigate the necessity of potential PDCCH enhancements for NR Rel-16 URLLC, Rel-15 NR PDCCH evaluations were performed.

Rel-15 NR PDCCH reliability

For link-level PDCCH evaluation, the target operating BLER of DCI(s) scheduling HARQ-less PDSCH/PUSCH should be smaller than 1e-x in Rel-16 NR URLLC, at the 5%-tile SINR geometry, where x is the reliability requirement given in the table of representative use case for evaluation as shown in Table A.2-1, and the 5%-tile SINR geometry is obtained by system-level simulation assuming full buffer for a given evaluation scenario.

16 sources evaluate PDCCH reliability with evaluation results as shown in Table 6.1.1-1, where 14 sources provide the evaluation results on Rel-15 NR PDCCH reliability.

- For carrier frequency 4 GHz with antenna configuration of 4 Tx/4 Rx, channel model of TDL-C 300 ns and a CORESET with 1 or 2 symbols, 6 sources show that Rel-15 NR PDCCH (e.g. DCI payload size 40 bits and AL=16) can meet the reliability of 99.9999% at the 5%-tile SINR geometry.
- For carrier frequency 700MHz with antenna configuration of 2 Tx/2 Rx, channel model of TDL-C 300 ns, 20 MHz and a CORESET with 2 symbols, six sources show that Rel-15 NR PDCCH (e.g. DCI payload size 40 bits and AL=16) can meet the reliability of 99.9999% at the 5%-tile SINR geometry, and two sources show that Rel-15 NR PDCCH (e.g. DCI payload size 40 bits and AL=16) cannot meet the reliability of 99.9999% at the 5%-tile SINR geometry.

Table 6.1.1-1: The required SINR (dB) to achieve different target BLER

Urban Macro, carrier frequency 4 GHz, 4 Tx/4 Rx, TDL-C 300 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
1 (R1-1900043)	-7.5		-8.1	1e-6	-2.2	-4	-	-
2 (R1-1901767)	-8.1	-8.7	-9.1	1e-6	-0.06	-1.04	-	-
3 (R1-1900493)	-7.9		-8.6	1e-6	-2.282	-2.542	-	-
4 (R1-1900208)	-7.5		-8.5	1e-6	-3.1		-	-
5 (R1-1900126)	-5.829		-6.748	1e-6	-2.696		-	-
6 (R1-1901593)	-6.2	-6.5	-6.6	1e-6	0.35	1.69	-	-
6 (R1-1901593)	-6.8	-7.2	-7.4	1e-5	0.35	1.69	-	-
7 (R1-1902002)	-8.3		-8.9	1e-5	-0.3		-	-
8 (R1-1900281)	-8.2			1e-5	-2.7	-3.35	-	-
9 (R1-1902045)	-8.6		-9.4	1e-5	-3.15	-3.73	-	-
10 (R1-1900399)	-9	-9.5	-10	1e-5	-3.3		-	-
11 (R1-1900680)	-5.5		-6.2	1e-5			-	-
Urban Macro, carrier frequency 4 GHz, 4 Tx/4 Rx, TDL-C 300 ns, 30 KHz, AL=16, 60 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
1 (R1-1900043)	-7.8		-8.5	1e-6	-	-	-2	-
3 (R1-1900493)	-8.2	-8.85	-9.2	1e-5	-	-	-2.337	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-C 300 ns, 30 KHz, AL=16, 60 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
1 (R1-1900043)	-3.8		-4.5	1e-6	-	-	-2.6	-
3 (R1-1900493)	-4.3			1e-6	-	-	-2.536	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-C 100 ns, 30 KHz, AL=16, 30 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
3 (R1-1900493)	-3.75			1e-6	-	-	-2.536	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-C 300 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
1 (R1-1900043)	-3.8		-4.5	1e-6	-3.2	-3.2	-	-
2 (R1-1901767)	-5	-5.5		1e-6			-	-
3 (R1-1900493)	-3.7			1e-6	-2.595		-	-
4 (R1-190028)	-4.8		-5.7	1e-6	-3		-	-
5 (R1-1900126)	-1.693		-2.752	1e-6	-1.729		-	-
6 (R1-1901593)	-2.3	-2.7	-2.8	1e-6	-1.96	-2.3		
8 (R1-1900281)	-5			1e-6	-2.6	-2.55	-	-
6 (R1-1901593)	-3.4	-3.7	-3.9	1e-5	-1.96	-2.3		
12 (R1-1900803)			-1.6	1e-5	-3.4		-	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-C 100 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
3 (R1-1900493)	-3.3			1e-6	-2.595	-	-	-
Indoor hotspot, carrier frequency 4 GHz, 4 Tx/4 Rx, TDL-C 100 ns, 30 KHz, AL=16, 30 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4] (assuming 2Tx at gNB)
3 (R1-1900493)	-7.5			1e-6	-		-	-5
Indoor hotspot, carrier frequency 4 GHz, 4 Tx/4 Rx, TDL-C 100 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4] (assuming 2Tx at gNB)
3 (R1-1900493)	-8.25	-8.75	-9.2	1e-5	-		-	-5
Urban Macro, carrier frequency 4 GHz, 2 Tx/4 Rx, TDL-C 300 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
13 (R1-1812994)			-8.1	1e-5			-	-
14 (R1-1900896)	-8.2	-8.5		1e-5	-3		-	-

Urban Macro, carrier frequency 4 GHz, 2 Tx/4 Rx, TDL-A 30 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
14 (R1-1900896)	-7.5	-6.9		1e-5	-3	-	-	-
Urban Macro, carrier frequency 4 GHz, 2 Tx/2 Rx, TDL-C 300 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
13 (R1-1812994)			-4.7	1e-5			-	-
Urban Macro, carrier frequency 4 GHz, 2 Tx/2 Rx, TDL-D 30 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
13 (R1-1812994)			0.2	1e-5			-	-
Urban Macro, carrier frequency 4 GHz, 2 Tx/4 Rx, TDL-C 30 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
13 (R1-1812994)			-5.5	1e-5			-	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-A 30 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
15 (R1-1901557)	-1.3		-2.2	1e-6	-3.2	-3.2	-	-
Urban Macro, carrier frequency 700 MHz, 2 Tx/2 Rx, TDL-A 30 ns, 30 KHz, AL=16, 60 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
15 (R1-1901557)	-1.7		-2.7	1e-6	-	-	-2.6	-
Indoor (factory automation), carrier frequency 4 GHz, 2 Tx/4 Rx, TDL-D 30 ns, 30 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
6 (R1-1901593)	-7.6			1e-5	-	-	-	1
6 (R1-1901593)	-6.9			1e-6	-	-	-	1
Indoor (factory automation), carrier frequency 30 GHz, 2 Tx/2 Rx, CDL-A 20 ns, 120 KHz, AL=16, 3 km/h								
Source	40 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
6 (R1-1901593)	-1.3	-	-	1e-5	-	-	-	0.85
6 (R1-1901593)	-0.25	-	-	1e-6	-	-	-	0.85
Indoor (factory automation), carrier frequency 4 GHz, 4 Tx/4 Rx, TDL-D 30 ns, 30 KHz, AL=16, 3 km/h								
Source	44 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
16 (R1-1902804)	-6.5	-	-	1e-6	-	-	-	-2.8
Indoor (factory automation), carrier frequency 30 GHz, 2 Tx/2 Rx, CDL-A 20 ns, 120 KHz, AL=16, 3 km/h								
Source	44 bits	30 bits	24 bits	Target BLER	5%-tile SINR[1]	5%-tile SINR[2]	5%-tile SINR[3]	5%-tile SINR[4]
16 (R1-1902804)	-5.4	-	-	1e-6	-	-	-	8.9
Notes: **5%-tile SINR[1]**: The 5%-tile SINR for power distribution **5%-tile SINR[2]**: The 5%-tile SINR for Rel-15 enabled use case with urban Macro **5%-tile SINR[3]**: The 5%-tile SINR for transport industry **5%-tile SINR[4]**: The 5%-tile SINR for factory automation								

6.1.2 Compact DCI

A DCI format with a size potentially smaller than that of DCI formats 0_0 and 1_0 is studied for scheduling URLLC data transmissions. Several aspects are considered in this study including targeting a reduction of at least 10 to 16 bits for the DCI format size compared to the size of DCI formats 0_0 and 1_0, the link level performance gain from PDCCH reliability perspective, PDCCH resource utilization considering all UEs in the cell, PDCCH blocking probability, performance impact to PDSCH/PUSCH capacity, impact on PDCCH blind decoding and DCI size budget, and impact on PDSCH/PUSCH scheduling flexibility. Note that it is concluded that there would be no change of DCI format 0_0 and 1_0 in common search space in this study.

Link level performance gain from compact DCI

As shown in Table 6.1.1-1, 12 sources evaluate the link level performance gain from compact DCI.

- Eight sources show that compact DCI targeting a reduction of 16 bits compared to (e.g. 40 bits) Rel-15 DCI can provide 0.6dB ~ 1 dB gain for AL=16 assuming 4 GHz, 1e-5 or 1e-6 target BLER, 4 Rx at UE side, TDL-C and a CORESET with 1 or 2 symbols in time domain and 40 MHz in frequency domain.

- Three sources show that compact DCI targeting a reduction of 16 bits compared to (e.g. 40 bits) Rel-15 DCI can provide 0.7dB ~ 1 dB gain for AL=16 assuming 700 MHz, 1e-6 target BLER, 2 Rx at UE side, TDL-C and a CORESET with 2 symbols in time domain and 20 MHz in frequency domain.

Evaluation on PDCCH resource utilization

4 sources (R1-1900208, R1-1900043, R1-1900591 and R1-1900176) evaluate PDCCH resource utilization of compact DCI, where the average number of CCEs derived based on aggregation level distribution are compared between payload size of 40 and payload size of 24. The detailed evaluation results can be found in Table 6.1.2-1.

- Two sources show that compact DCI targeting a reduction of 16 bits compared to (e.g. 40 bits) Rel-15 DCI can save 14 % ~ 20% PDCCH resource used for URLLC UEs assuming 700 MHz, 1e-5 or 1e-6 target BLER for single PDCCH transmission, 2 Rx at UE side, TDL-C and a CORESET with 2 symbols in time domain, 20 MHz in frequency domain.
- Three sources show that compact DCI targeting a reduction of 16 bits compared to (e.g. 40 bits) Rel-15 DCI can save 14 % ~ 16% PDCCH resource used for URLLC UEs assuming 4 GHz, 1e-5 or 1e-6 target BLER for single PDCCH transmission, 4Tx/4Rx at gNB side and 4 Rx at UE side, TDL-C and a CORESET with 1 or 2 symbols in time domain, 40 MHz in frequency domain.
- One source shows that compact DCI targeting a reduction of 16 bits compared to (e.g. 40 bits) Rel-15 DCI can save 7 % ~ 11% PDCCH resource used for URLLC UEs assuming 4 GHz, 1e-5 target BLER for single PDCCH transmission, 16 Tx/16 Rx at gNB side and 2 Tx/4 Rx at UE side for SINR CDF geometry, 2 Tx/4 Rx for PDCCH BLER, TDL-C and a CORESET with 1 or 2 symbols in time domain, 40 MHz in frequency domain.

Table 6.1.2-1: The required SINR (dB) to achieve different target BLER

700MHz, 2Rx, 30 kHz, 2 OS CORESET, TDL-C 300ns, 3 km/h								
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-5	R1-1900208	PL40	6%	38%	24%	16%	16%	5.44	**20.22%**
		PL24	1%	29%	33%	17%	20%	4.34	
1e-6	R1-1900208	PL40	14%	41%	20%	16%	9%	6.73	**18.12%**
		PL24	7%	36%	27%	13%	17%	5.51	
	R1-1900043	PL40	14.49%	25.11%	26.10%	21.78%	12.52%	5.932	**14.22%**
		PL24	10.08%	22.75%	25.57%	21.67%	19.94%	5.08	
700MHz, 2Rx, 30 kHz, 2 OS CORESET, TDL-C 300ns, 60 km/h									
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-6	R1-1900043	PL40	13.57%	30.42%	29.18%	16.11%	10.72%	6.20	**18.29%**
		PL24	8.56%	22.76%	32.65%	21.12%	14.82%	5.07	
4GHz, 4Rx, 30 kHz, 2 OS CORESET, TDL-C 300ns, 3 km/h									
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-5	R1-1900591	PL40	0.32%	10.84%	36.04%	26.45%	26.35%	3.1524	**14.5%**
		PL24	0.14%	6.59%	30.95%	28.32%	34.00%	2.694	
1e-6	R1-1900208	PL40	0%	11%	34%	26%	29%	3.05	**14.42%**
		PL24	0%	5%	33%	27%	35%	2.61	
	R1-1900043	PL40	3.55%	4.52%	21.06%	29.31%	41.56%	2.77	**14.93%**
		PL24	2.75%	2.64%	14.63%	32.32%	47.66%	2.35	
4GHz, 4Rx, 30 kHz, 2 OS CORESET, TDL-C 300ns, 60 km/h									
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-6	R1-1900043	PL40	0%	2.58%	21.93%	35.99%	39.51%	2.20	**16.15%**
		PL24	0%	0.83%	13.07%	39.32%	46.77%	1.84	
4GHz, 2Tx/4Rx for PDCCH BLER, 16 Tx/16 Rx at gNB side and 2 Tx/4 Rx at UE side for SINR CDF geometry, 30 kHz, 1 OS CORESET, TDL-C 300ns, 3 km/h									
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-5	R1-1900176	PL40	0.44%	0.61%	6.00%	22.57%	70.23%	1.5129	
		PL30	0.43%	0.46%	5.20%	19.83%	73.98%	1.45	**4.16%**
		PL24	0.42%	0.45%	4.39%	17.80%	76.89%	1.4037	**7.22%**
4GHz, 2Tx/4Rx for PDCCH BLER, 16 Tx/16 Rx at gNB side and 2 Tx/4 Rx at UE side for SINR CDF geometry, 30 kHz, 2 OS CORESET, TDL-C 300ns, 3 km/h									
BLER	Contribution	PL	AL16	AL8	AL4	AL2	AL1	Average NR-PDCCH resources (CCE)	NR-PDCCH resources saving of PL24
1e-5	R1-1900176	PL40	0.43%	0.87%	8.48%	32.33%	57.73%	1.70	
		PL30	0.41%	0.60%	6.81%	25.73%	66.34%	1.564	**8.08%**
		PL24	0.40%	0.50%	5.85%	23.18%	69.98%	1.50	**11.76%**

Evaluation on other aspects

PDCCH evaluations on other aspects are also studied, e.g. PDCCH blocking and impact on PDCCH blind decoding and/or DCI size budget. The summary of the corresponding evaluation can be found in R1-1903532, which summarizes the views and/or evaluations from companies.

Design of DCI format scheduling Rel-16 NR URLLC

Design of DCI format scheduling Rel-16 NR URLLC are studied. The summary of the candidate options and corresponding pros and cons can be found in R1-1903532, which summarizes the views and/or evaluations from companies. It is observed that the support of configurable sizes for some fields can provide flexibility, enabling a DCI size target a reduction of 10~16 bits less than the DCI format size of Rel-15 fallback DCI can further ensure the requirement of PDCCH reliability and may reduce PDCCH blocking, and providing the possibility to align with the size of the Rel-15 fallback DCI (including possible zero padding if any) can reduce the impact on blind decoding and/or DCI size budget. It is concluded that for the DCI format(s) scheduling Rel-16 NR URLLC,

- Support configurable sizes for some fields, while
  - The maximum DCI size can be larger than Rel-15 fallback DCI
  - The minimum DCI size target a reduction of 10~16 bits less than the DCI format size of Rel-15 fallback DCI
  - Provide the possibility to align with the size of the Rel-15 fallback DCI (including possible zero padding if any)
- Support potential reduction of the number of bits for at least one of the following fields compared to Rel-15 DCI:
  - Frequency domain resource assignment
  - Time domain resource assignment
  - Modulation and coding scheme
  - HARQ process number
  - Redundancy version
  - PUCCH resource indicator
  - PDSCH-to-HARQ_feedback timing indicator
  - Downlink assignment index
  - Note that reduction of other fields are not precluded
- Support at least one of the following configurable fields:
  - Antenna port(s) [0~2 bits]
  - Transmission configuration indication [0~3 bits]
  - Rate matching indicator [0~2 bits]
  - SRS request [0~3 bits]
  - PRB bundling size indicator [0~1 bit]
  - Carrier indicator [0~3 bits]
  - CSI request [0~3 bit]
  - ZP CSI-RS triggering [0~2 bits]
  - Beta offset indicator [0~2 bits]
  - SRS resource indicator [0~4 bits]
  - Repetition factor [0~2 bits]
  - Priority indication [0~3 bits]
  - Note: Other field(s) can be considered if needed

Note that the DCI format scheduling Rel-16 NR URLLC may or may not be new format, which is to be finalized in the work item phase. The set of configurable field(s) including bitwidths is to be finalized in work item phase depending on DL assignment or UL grant. Note that the conclusion here on DCI format scheduling Rel-16 NR URLLC doesn't imply the necessity to increase the DCI size budget (i.e. "3+1") compared to Rel-15.

6.1.3 Increased PDCCH monitoring capability

Increased PDCCH monitoring capability is studied and identified to be beneficial. However, it may increase UE complexity and thus some restriction(s) may be needed. It is concluded to support increased PDCCH monitoring capability on at least the maximum number of non-overlapped CCEs per slot for channel estimation for Rel-16 NR URLLC for at least one SCS subject to the following restrictions:

- Explicit limitation on the maximum number of BDs/non-overlapping CCEs per monitoring occasion and/or per monitoring span, and
- The set of applicable SCS(s) to be finalized during the WI phase
- Additional restrictions (e.g. impact on the number of CCs if any, potential limitations on PDSCH/PUSCH processing, impact of wideband RS for CCE counting if any, etc.) can be considered during the WI phase

Enhancements for PDCCH monitoring capability on the maximum number of monitored PDCCH candidates per slot (with potential restrictions) for Rel-16 NR URLLC can be further considered in work item phase.

6.1.4 PDCCH repetition

PDCCH repetition is studied. The summary of analysis and evaluation on PDCCH repetition can be found in R1-1901459, which summarizes the views from companies. It is concluded that PDCCH repetition is not further considered in this study item.

6.2 UCI enhancements

6.2.1 Enhanced HARQ feedback

Enhanced HARQ feedback are studied from several aspects, including enabling more than one PUCCH for HARQ-ACK transmission within a slot and enabling enhanced reporting procedure/feedback for HARQ-ACK.

6.2.1.1 More than one PUCCH for HARQ-ACK transmission within a slot

In NR Rel-15, only one PUCCH for HARQ-ACK transmission is supported within a slot. Enabling more than one PUCCH for HARQ-ACK transmission within a slot is beneficial as it may enable fast HARQ-ACK feedback to reduce the latency and facilitate separate HARQ-ACK feedback for URLLC and eMBB. It is concluded that more than one PUCCH for HARQ-ACK transmission within a slot should be supported in Rel-16.

6.2.1.2 Enhanced reporting procedure/feedback for HARQ-ACK

Enhanced reporting procedure/feedback for HARQ-ACK are studied from several aspects, including enhanced HARQ-ACK multiplexing on PUSCH and PUCCH and finer indication for HARQ feedback timing (e.g. symbol-level or half-slot).

It is concluded that at least two HARQ-ACK codebooks can be simultaneously constructed for a Rel-16 UE, intended for supporting different service types for a UE. Rules for the two HARQ-ACK codebooks for supporting different service types should be specified in R16, if the two HARQ-ACK codebooks are due to be transmitted in resources overlapping in time. When at least two HARQ-ACK codebooks are simultaneously constructed for supporting different service types for a UE, a HARQ-ACK codebook can be identified based on some PHY indications/properties.

6.2.2 Enhanced CSI feedback

Enhanced CSI feedback are studied from several aspects, including DMRS based CSI measurement, A-CSI on PUCCH (e.g. triggering by DL assignment), enhanced CSI reporting mode.

The following options have been identified as potential candidates for A-CSI on PUCCH:

- Option 1: A-CSI report on PUCCH triggered by DL-scheduling DCI
- Option 2: A-CSI report on PUCCH based on group-common PDCCH

Regarding the benefit of A-CSI,

- One source (R1-1902297) observed that compared to link adaptation only using wideband CSI, 0.1% ~ 8.8% gain on average throughput and -0.7% ~ 20.1% gain on 5% throughput can be obtained by using A-CSI for link adaptation, depending on different cell loadings and code-book-based or ideal precoding is assumed.
- Two other sources questioned the value of A-CSI for URLLC considering reliability of CSI reception and impact of measurement and quantization.

Regarding the performance gain of DMRS/PDSCH/PDCCH-based A-CSI measurement,

- One source (R1-1901910) observed that CSI estimation based on DMRS+CSI-RS showed 15% and 45% link-level spectrum efficiency improvement at SINR=10dB over conventional CSI estimation based on CSI-RS, with 10 msec and 20 msec reporting period respectively.
- One source (R1-1903530) observed that the gain of DMRS/PDSCH/PDCCH-based is beneficial in very limited cases (it depends on specific settings of packet size, bandwidth, initial BLER, traffic pattern and load (e.g. in case of a periodic traffic pattern, requests for initial transmissions from four UE's arrive at the same OS from period to period. Each initial transmission have BLER=3%)).

Regarding the performance gain of CSI-RS-based A-CSI reporting on PUCCH triggered by DL-scheduling,

- One source (R1-1903234) observed that 12.7% (with 100p/s packet frequency) or 15.7% (with 200p/s packet frequency) more users can satisfy the 4 ms latency over R15 P-CSI reporting, and 3.1% (with 100p/s packet frequency) or 9.4% (with 200p/s packet frequency) more users can satisfy the 4ms latency requirement over R15 A-CSI reporting on PUSCH.

Regarding the benefits of the CQI report mode of wideband CQI combined with worst-M CQI, one source evaluated and observed that it leads to reduction of latency and BLER for 1st transmission over standard frequency-selective CQI.

There is no consensus in RAN1 for supporting A-CSI on PUCCH in R16.

6.3 PUSCH enhancements

Whether to allow one PUSCH transmission instance to cross the slot boundary when the remaining symbols within one slot is not enough for one PUSCH transmission instance was studied. The conclusion is that one PUSCH transmission instance is not allowed to cross the slot boundary for grant-based PUSCH.

Potential enhancements for grant-based PUSCH and configured grant based PUSCH are studied and the conclusion achieved in RAN1#95 meeting is to support at least one of the following options:

- Option 1 (Mini-slot level repetition): One UL grant scheduling two or more PUSCH repetitions that can be in one slot, or across slot boundary in consecutive available slots
- Option 2 (Multi-segment transmission): One UL grant scheduling two or more PUSCH repetitions in consecutive available slots, with one repetition in each slot with possibly different starting symbols and/or durations
- Option 3: N (N>=2) UL grants scheduling N PUSCH repetitions on consecutive available slots, with one repetition in each slot, and the i-th UL grant can be received before the end of the PUSCH transmission scheduled by the (i-1)th UL grant

7 sources evaluated the performance of mini-slot level repetition and multi-segment transmission by link level simulations for 4 GHz, with evaluation results as shown in Table 6.3-1. In addition, one source evaluated the performance of mini-slot level repetition and multi-segment transmission by link level simulations for 30 GHz, with evaluation results as shown in Table 6.3-2.

Table 6.3-1: Link level evaluation results on mini-slot level repetition (option 1) versus multi-segment transmission (option 2) assuming 4 GHz, 30 kHz, 4 Rx, 40 MHz and MMSE receiver

Source	Channel	FD-RA / TBS	PUSCH scheme incl. TD-RA	SNR 1e-3	SNR 1e-4	SNR 1e-5	SNR 1e-6	Other comments
1 (R1-1901559)	TDL-C 300ns 2TX	8PRB 36byte	1 rep. 12 OS incl. 4 DM-RS	-2,5	-1,6	NA	NA	
			2 rep 6 OS incl. 2 DM-RS	-3,5	-2,6	NA	NA	TRP cycling RV-02
			4 rep 3 OS incl. 1 DM-RS	-2,5	-1,8	-1,1	NA	TRP cycling with 2TRPs RV-0231
1 (R1-1901559)	TDL-C 300ns 2TX	8PRB 36byte	1 rep. 12 OS incl. 4 DM-RS	8	NA	NA	NA	With partial interference on the last 6 symbols (SNR_7_12=SNR+6dB)
			2 rep 6 OS incl. 2 DM-RS	0,6	NA	NA	NA	With partial interference on the second repetition only (SNR2=SNR+6dB)
2 (R1-1901694)	TDL-C 100ns 2TX	52PRB 16byte	2 rep: 2 OS incl. 1 DM-RS	-9,2	-8,2	NA	NA	No FH, no DM-RS sharing
			2 rep: 2OS, DM-RS in 1st rep	-9,6	-8,8	NA	NA	No FH, DM-RS sharing
			2rep: 2OS incl. 1 DM-RS	-8,8	NA	NA	NA	FH applied
			2 rep: 2OS, DM-RS in 1st rep	-9,6	-8,7	NA	NA	Dual-cluster PUSCH, DM-RS sharing
2 (R1-1901694)	TDL-C 100ns 2TX	47PRB 32byte	2 rep: 2 OS incl. 1 DM-RS	-6,6	NA	NA	NA	No FH, no DM-RS sharing
			2 rep: 2 OS, DM-RS in 1st rep	-7,2	-6,5	NA	NA	No FH, DM-RS sharing
			2rep: 2 OS incl. 1 DM-RS	-6,4	NA	NA	NA	FH applied
			2 rep: 2 OS, DM-RS in 1st rep	-7	NA	NA	NA	Dual-cluster PUSCH, DM-RS sharing
2 (R1-1901694)	TDL-C 100ns 2TX	26PRB 32byte	2 rep: 2 OS incl. 1 DM-RS	-2,8	NA	NA	NA	No FH, no DM-RS sharing
			2 rep: 2 OS, DM-RS in 1st rep	-3,7	NA	NA	NA	No FH, DM-RS sharing
			2rep: 2 OS incl. 1 DM-RS	-3,6	-2,6	NA	NA	FH applied
			2 rep: 2 OS, DM-RS in 1st rep	-3,9	-2,9	NA	NA	Dual-cluster PUSCH, DM-RS sharing
3 (R1-1901595)	TDL-C 300ns 2TX	8PRB 32bytes	1 rep 8 OS incl 1 DM-RS	-0,9	0,6	1,6	NA	No FH
			4 rep 2 OS, 1 DM-RS in 1st rep	0,4	1,7	2,9	NA	No FH, DM-RS sharing
3 (R1-1901595)	TDL-C 300ns 2TX	16PRB 100bytes	1 rep 8 OS incl 1 DM-RS	-1	0,1	1,3	NA	No FH

			4 rep 2 OS, 1 DM-RS in 1st rep	0,9	2	3,2	NA	No FH, DM-RS sharing
3 (R1-1901595)	TDL-C 300ns 2TX	10PRB 106bytes	2 rep. 2 OS + 6 OS 1 DM-RS in each rep	3,5	4,7	5,6	NA	RV-20 (RV0 used for the larger segment)
			4 rep 2 OS, DM-RS in 1st and 3rd rep	5,2	6,8	8,2	NA	RV-0231 DM-RS sharing between 2 repetitions
4 (R1-1903006)	TDL-C 300ns 1TX	12PRB 80bytes	1 rep 8 OS incl. 2 DMRS	-1	NA	NA	NA	QPSK
			2 rep 4 OS incl. 1 DM-RS	0,8	NA	NA	NA	16QAM RV-00 FH
			2 rep 4 OS incl. 1 DM-RS	-0,4	NA	NA	NA	16QAM RV-02 FH
4 (R1-1903006)	TDL-A 30ns 1TX	12PRB 80bytes	1 rep 8 OS incl. 2 DMRS	0,9	NA	NA	NA	QPSK
			2 rep 4 OS incl. 1 DM-RS	2,6	NA	NA	NA	16QAM RV-00 FH
			2 rep 4 OS incl. 1 DM-RS	1,4	NA	NA	NA	16QAM RV-02 FH
4 (R1-1903006)	TDL-C 300ns 1TX	12PRB 70bytes	1 rep 8 OS incl. 2 DMRS	-1,7	-1	NA	NA	QPSK
			2 rep 4 OS incl. 1 DM-RS	-0,7	NA	NA	NA	QPSK RV-00 FH
			2 rep 4 OS incl. 1 DM-RS	-1,6	NA	NA	NA	QPSK RV-02 FH
4 (R1-1903006)	TDL-A 30ns 1TX	12PRB 70bytes	1 rep 8 OS incl. 2 DMRS	-0,4	NA	NA	NA	QPSK
			2 rep 4 OS incl. 1 DM-RS	0,7	NA	NA	NA	QPSK RV-00 FH
			2 rep 4 OS incl. 1 DM-RS	-0,2	NA	NA	NA	QPSK RV-02 FH
5 (R1-1900971)	TDL-C 100ns 2TX	36PRB 32byte	1 rep 8 OS incl. 2 DM-RS	-7,7	-6,5	-5,5	-4,7	
			2 rep 4 OS incl. 1 DM-RS	-8,2	-7,3	-6,5	-6	RV-02 With precoder/QCL (or SRI)-cycling across repetitions
5 (R1-1900971)	TDL-C 100ns 2TX	8PRB 32byte	1 rep 8 OS incl. 2 DM-RS	-0,3	1,5	3,1	4,1	
			2 rep 4 OS incl. 1 DM-RS	-1,9	-0,7	0,4	NA	RV-02 With precoder/QCL (or SRI)-cycling across repetitions
6 (R1-1901915)	TDL-C 100ns 1TX	3PRBs 36byte	1 rep 12 OS incl. 2 DM-RS	6	NA	NA	NA	
			2 rep 6 OS incl. 1 DM-RS	3,2	4,6	6,1	NA	FH (2 hops) RV-02

			4 rep 3 OS incl. 1 DM-RS	3,1	4,3	5,2	NA	FH (4 hops) RV-0231
6 (R1-1901915)	TDL-C 100ns 1TX	8PRBs 36byte	1 rep 12 OS incl. 2 DM-RS	-1,5	0,1	1,3	NA	
			2 rep 6 OS incl. 1 DM-RS	-3,8	-2,5	-1,5	NA	FH (2 hops) RV-02
			4 rep 3 OS incl. 1 DM-RS	-4,5	-3,6	-2,8	NA	FH (4 hops) RV-0231
6 (R1-1901915)	TDL-C 100ns 1TX	46PRBs 36byte	1 rep 12 OS incl. 2 DM-RS	-10,5	-9,3	-8,2	NA	
			2 rep 6 OS incl. 1 DM-RS	-12,8	-12	-11,2	NA	FH (2 hops) RV-02
			4 rep 3 OS incl. 1 DM-RS	-12	-11,2	-10,3	NA	FH (2 hops) RV-0231
7 (R1-1902495)	TDL-A 30ns 1TX	16PRB 63bytes	1 rep 12 OS incl. 2 DM-RS	-1.99	-0.41	N/A	N/A	No FH
			1 rep 12 OS incl. 2 DM-RS	-2.6	-1.25	-0.33	N/A	With FH
			2 rep 6 OS incl. 1 DM-RS	-0.94	0.5	N/A	N/A	No FH RV-02
				-2.35	-1.05	N/A	N/A	With FH RV-02
			2 rep 8 OS + 4OS 1 DM-RS each	-0.98	0.68	1.9	N/A	No FH RV-02
				-1.61	-0.27	0.66	N/A	With FH RV-02
			2 rep 4 OS + 8 OS 1 DM-RS each	-0.73	1.1	N/A	N/A	No FH RV-02
				-1.54	-0.27	0.66	N/A	With FH RV-02
			3 rep 4 OS incl. 1 DMRS	-0.74	0.7	N/A	N/A	No FH RV-023
				-2.65	N/A	N/A	N/A	With FH RV-023
			4 rep 3 OS incl. 1 DMRS	0.38	0.9	2.6	N/A	No FH RV-0231
				-1.51	-0.275	N/A	N/A	With FH RV-0231
7 (R1-1902495)	TDL-C 300ns 1TX	16PRB 63bytes	1 rep 12 OS incl. 2 DM-RS	-4.65	-3.56	N/A	N/A	No FH
			1 rep 12 OS incl. 2 DM-RS	-4.66	-3.8	-3.23	N/A	With FH
			2 rep 6 OS incl. 1 DM-RS	-3.52	-2.27	N/A	N/A	No FH RV-02
				-4.32	-3.47	N/A	N/A	With FH RV-02
			2 rep 8 OS + 4 OS 1 DM-RS each	-3.6	-2.45	N/A	N/A	No FH RV-02
				-3.89	-3.03	N/A	N/A	With FH RV-02
			2 rep	-3.25	-2	N/A	N/A	No FH RV-02

			4 OS + 8 OS 1 DM-RS each	-3.82	-2.93	-2.25	N/A	With FH RV-02
			3 rep 4 OS incl. 1 DMRS	-3.6	N/A	N/A	N/A	No FH RV-023
				-4.38	-3.37	N/A	N/A	With FH RV-023
			4 rep 3 OS incl. 1 DMRS	-2.1	-1.13	N/A	N/A	No FH RV-0231
				-3.1	-2.33	N/A	N/A	With FH RV-0231
7 (R1-1902495)	TDL-A 30ns 1TX	16PRB 261bytes	1 rep 12 OS incl. 2 DM-RS	4.45	6.05	N/A	N/A	No FH
			1 rep 12 OS incl. 2 DM-RS	4.03	5.24	N/A	N/A	With FH
			2 rep 6 OS incl. 1 DM-RS	5.25	6.91	N/A	N/A	No FH RV-02
				4.31	5.47	N/A	N/A	With FH RV-02
			2 rep 8 OS + 4 OS 1 DM-RS each	4.4	6	N/A	N/A	No FH RV-02
				4.11	5.28	N/A	N/A	With FH RV-02
			2 rep 4 OS + 8 OS 1 DM-RS each	6.57	8.23	N/A	N/A	No FH RV-02
				5.82	6.88	N/A	N/A	With FH RV-02
			3 rep 4 OS incl. 1 DMRS	7.47	9.1	N/A	N/A	No FH RV-023
				5.74	6.84	N/A	N/A	With FH RV-023
			4 rep 3 OS incl. 1 DMRS	8.45	9.85	N/A	N/A	No FH RV-0231
				6.75	7.83	N/A	N/A	With FH RV-0231
7 (R1-1902495)	TDL-A 30ns 1TX	16PRB 261bytes	1 rep 12 OS incl. 2 DM-RS	2.04	2.93	N/A	N/A	No FH
			1 rep 12 OS incl. 2 DM-RS	2.02	2.72	N/A	N/A	With FH
			2 rep 6 OS incl. 1 DM-RS	2.65	3.65	N/A	N/A	No FH RV-02
				2.23	2.97	N/A	N/A	With FH RV-02
			2 rep 8 OS + 4 OS 1 DM-RS each	2.1	3.06	N/A	N/A	No FH RV-02
				1.68	2.62	N/A	N/A	With FH RV-02
			2 rep 4 OS + 8 OS 1 DM-RS each	3.73	4.77	N/A	N/A	No FH RV-02
				3.26	4.2	N/A	N/A	With FH RV-02
			3 rep 4 OS incl. 1 DMRS	4.54	5.53	N/A	N/A	No FH RV-023
				4	4.65	N/A	N/A	With FH RV-023
			4 rep 3 OS incl. 1 DMRS	5.83	6.8	N/A	N/A	No FH RV-0231
				5.02	5.98	N/A	N/A	With FH RV-0231

Table 6.3-2: Link level evaluation results on mini-slot level repetition (option 1) versus multi-segment transmission (option 2) assuming 30 GHz, 120 kHz, 2 Rx, 80 MHz and CP-OFDM

Source	Channel	FD-RA / TBS	PUSCH scheme	SNR 1e-3	SNR 1e-4	SNR 1e-5	SNR 1e-6	Other comments
1 (R1-1900971)	CDL-A 20ns	36 PRB 32byte	1 rep. 8 OS incl. 2 DM-RS	-7,6	-5,5	-3,8	NA	Without blockage
1 (R1-1900971)	CDL-A 20ns	36 PRB 32byte	1 rep. 8 OS incl. 2 DM-RS	2,4	8	14	NA	With blockage
1 (R1-1900971)	CDL-A 20ns	36 PRB 32byte	2 rep 4 OS incl. 1 DM-RS	-9,8	-8,2	-6,9	NA	Without blockage With precoder/QCL (or SRI)-cycling across repetitions RV-02
1 (R1-1900971)	CDL-A 20ns	36 PRB 32byte	2 rep 4 OS incl. 1 DM-RS	-4,5	-1,5	0,9	NA	With blockage With precoder/QCL (or SRI)-cycling across repetitions RV-02
1 (R1-1900971)	CDL-A 20ns	8 PRB 32byte	1 rep. 8 OS incl. 2 DM-RS	2,6	6	10	NA	Without blockage
1 (R1-1900971)	CDL-A 20ns	8 PRB 32byte	1 rep. 8 OS incl. 2 DM-RS	9,9	15,7	NA	NA	With blockage
1 (R1-1900971)	CDL-A 20ns	8 PRB 32byte	2 rep 4 OS incl. 1 DM-RS	-0,9	1,5	4	NA	Without blockage With precoder/QCL (or SRI)-cycling across repetitions RV-02
1 (R1-1900971)	CDL-A 20ns	8 PRB 32byte	2 rep 4 OS incl. 1 DM-RS	3,6	8	14	NA	With blockage With precoder/QCL (or SRI)-cycling across repetitions RV-02

Based on the discussion of the above option 1 and option 2, three more options (i.e. option 4, option 5 and option 6) are added. It is concluded that the details regarding how to use "option 1" vs. "option 2" is to be finalized during the WI phase using options 4, 5 and 6 as a starting point.

More details of some of the options are provided in the following sections.

6.3.1 Option 1: Mini-slot level repetition

For time domain resource determination for mini-slot level repetition, for grant based PUSCH, the time domain resource assignment field in the DCI indicates the resource for the first repetition. The time domain resources for the remaining repetitions are derived based at least on the resources for the first repetition and the UL/DL direction of the symbols. Each repetition occupies contiguous symbols.

For frequency hopping for mini-slot level repetition, support at least inter-PUSCH-repetition hopping and inter-slot hopping.

6.3.2 Option 2: Multi-segment transmission

For time domain resource determination for multi-segment transmission, for grant based PUSCH, the time domain resource assignment field in the DCI indicates the starting symbol and the transmission duration of all the repetitions.

For the transmission within one slot for multi-segment transmission, if there are more than one UL period within a slot, where each UL period is the duration of a set of contiguous symbols within a slot for potential UL transmission as determined by the UE, one repetition is within one UL period and each repetition occupies contiguous symbols. Otherwise, a single PUSCH repetition is transmitted within a slot following Rel-15 behavior.

For frequency hopping for multi-segment transmission, support at least inter-slot frequency hopping.

6.3.3 Option 4

One or more actual PUSCH repetitions in one slot, or two or more actual PUSCH repetitions across slot boundary in consecutive available slots, is supported using one UL grant for dynamic PUSCH, and one configured grant configuration for configured grant PUSCH. It further consists of:

- The number of the repetitions signalled by gNB represents the "nominal" number of repetitions. The actual number of repetitions can be larger than the nominal number.
  - FFS dynamically or semi-statically signalled for dynamic PUSCH and type 2 configured grant PUSCH
- The time domain resource assignment (TDRA) field in the DCI or the TDRA parameter in the type 1 configured grant indicates the resource for the first "nominal" repetition.
- The time domain resources for the remaining repetitions are derived based at least on the resources for the first repetition and the UL/DL direction of the symbols.
  - FFS the detailed interaction with the procedure of UL/DL direction determination
- If a "nominal" repetition goes across the slot boundary or DL/UL switching point, this "nominal" repetition is splitted into multiple PUSCH repetitions, with one PUSCH repetition in each UL period in a slot.
  - Handling of the repetitions under some conditions, e.g., when the duration is too small due to splitting, is to be further investigated in the WI phase.
- No DMRS sharing across multiple PUSCH repetitions
- The maximum TBS size is not increased compared to Rel-15.
- FFS: L > 14
- S+L can be larger than 14
- FFS: The bitwidth for TDRA is up to 4 bits.
- Note: different repetitions may have the same or different RV.

Some examples of option 4 are shown in Figure 6.3.3-1.

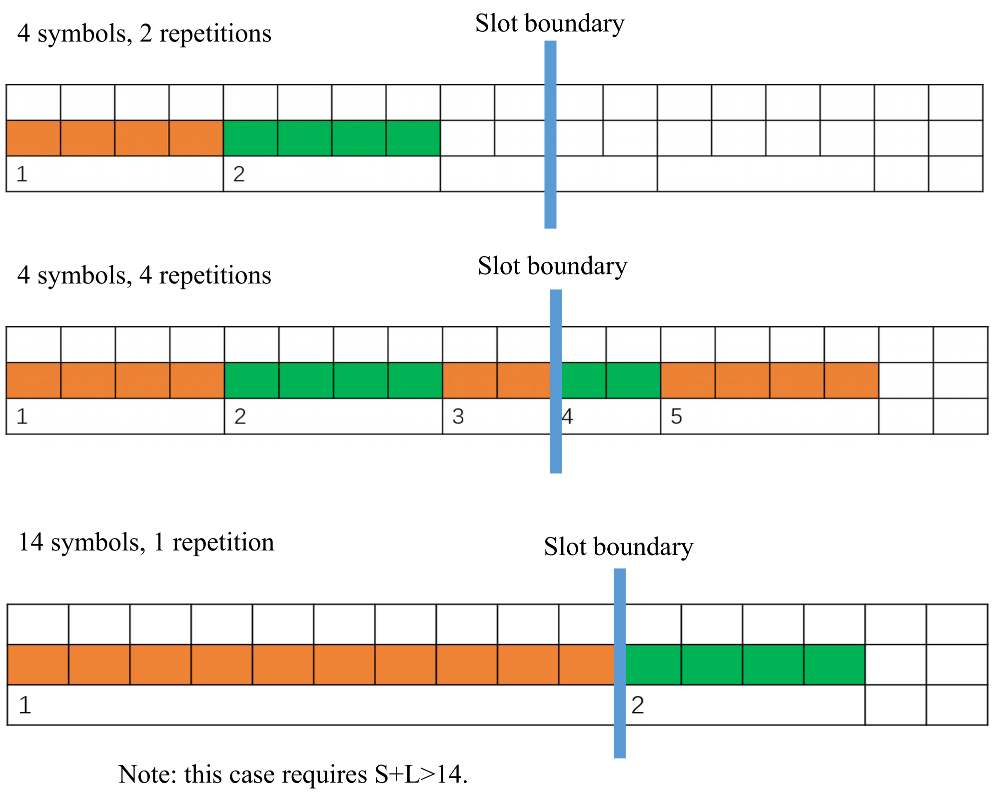


Figure 6.3.3-1: Examples of option 4 for PUSCH enhancements

6.3.4 Option 5

One or more actual PUSCH repetitions in one slot, or two or more actual PUSCH repetitions across slot boundary in consecutive available slots, is supported using one UL grant for dynamic PUSCH, and one configured grant configuration for configured grant PUSCH. It further consists of:

- The number of the repetitions signalled by gNB represents the "nominal" number of repetitions. The actual number of repetitions can be larger or smaller than the nominal number.
  - FFS dynamically or semi-statically signalled for dynamic PUSCH and type 2 configured grant PUSCH
- The time domain resource assignment (TDRA) and the number of repetitions K are used to determine the overall resources for all the repetitions (L*K).
  - If the overall resources go across the slot boundary or DL/UL switching point, one repetition is transmitted in each UL period in a slot.
  - Otherwise, the nominal number of repetitions are transmitted, each repetition with the transmission duration indicated in the TDRA.
  - The TDRA is indicated in the DCI for dynamic grant or type 2 configured grant, or RRC configured for type 1 configured grant.
- No DMRS sharing across multiple PUSCH repetitions
- No special handling of orphan symbols
- The maximum TBS size is not increased compared to Rel-15.
- L <= 14
- S+L can be larger than 14
- Note: different repetitions may have the same or different RV.

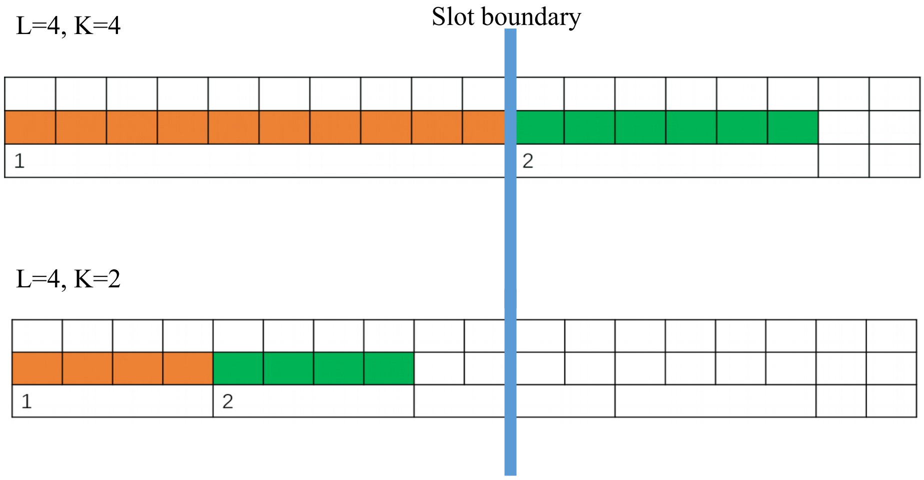


Figure 6.3.4-1: Examples of option 5 for PUSCH enhancements

6.3.5 Option 6

One or more PUSCH repetitions in one slot, or two or more PUSCH repetitions across slot boundary in consecutive available slots, is supported using one UL grant for dynamic PUSCH, and one configured grant configuration for configured grant PUSCH. It further consists of:

- The time domain resource assignment (TDRA) field in the DCI or the TDRA parameter in the type 1 configured grant indicates an entry in the higher layer configured table
    - The number of repetitions, starting symbols of each repetition, length of each repetition, and mapping of the repetitions to slots can be obtained from each entry in the table.
        - More than one repetition can be mapped to one slot
        - The resource assignment for each repetition is contained within one slot. Each transmitted repetition is contained within one UL period in a slot.
    - FFS: increasing the number of bits for TDRA field in DCI
    - FFS other details
- The maximum TBS size is not increased compared to Rel-15.

6.4 Enhancements to scheduling/HARQ/CSI processing timeline

6.4.1 Enhancements to scheduling/HARQ processing timeline

Several aspects are considered to evaluate the necessity to introduce a new N1/N2 timing capability in Rel-16 NR URLLC, including latency analysis, performance gain based on both link-level and system-level evaluations. The comparison reference point is Rel-15 NR timeline capability #2 for FR1 and Rel-15 NR timeline capability #1 for FR2. The assumed values for a set of parameters in the evaluations are as shown in A.4, including alignment latency, N1/N2 values used in the evaluations, SR periodicity in case the first PUSCH transmission is based on a dynamic grant, SR reception to initial PUSCH grant processing time at the gNB, PDCCH monitoring periodicity and the number of BDs/non-overlapping CCEs per monitoring occasion, type-B time-domain allocation length for PDSCH/PUSCH channels, time-domain allocation length for PDCCH, SR and PUCCH, UE and gNB PDSCH/PUSCH decoding time, the HARQ-ACK to re-transmission PDCCH and PUSCH to re-transmission PDCCH processing time at the gNB, the maximum number of possible PUCCH transmissions carrying HARQ-ACK per slot and the DL/UL configurations if TDD is assumed. Operation constraints (e.g., compact DCI, TB size, #RBs, #layers, #CCs, etc.) needed to enable reducing N1/N2 are also reported by companies.

6.4.1.1 Latency analysis

Latency analysis is considered in order to identify the set of scheduling configuration parameters for which the Rel-16 NR URLLC latency requirement(s) can/cannot be satisfied under the NR Rel-15 timeline capabilities. The worst-case achievable latency is considered.

Twelve sources provide the latency analysis for about 28 scenarios as defined in Table 6.4.1.1-1, Table 6.4.1.1-2 and Table 6.4.1.1-3 based on the cases defined in Annex A.4, and the results are as shown in R1-1903776. Based on the results, it was observed that:

- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1-6.
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1-6.
- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-12.
- For downlink, two HARQ transmissions can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-8.
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 9-12.
- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19 (i.e. Same as scenario 1 in Table 6.4.1.1-1 except that the gNB's processing time for the initial PDSCH is N2+X).
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19 (i.e. Same as scenario 1 in Table 6.4.1.1-1 except that the gNB's processing time for the initial PDSCH is N2+X).
- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 20 (i.e. Same as scenario 3 in Table 6.4.1.1-1 except that the gNB's processing time for the initial PDSCH is N2+X).
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 20 (i.e. Same as scenario 3 in Table 6.4.1.1-1 except that the gNB's processing time for the initial PDSCH is N2+X).
- For downlink, one source (R1-1901695) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 21 (i.e. Same as scenario 2 in Table 6.4.1.1-1 except that 14 PUCCHs and PDCCH monitoring occasions per slot are considered).
- For downlink, one source (R1-1901695) has shown that two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 21 (i.e. Same as scenario 2 in Table 6.4.1.1-1 except that 14 PUCCHs and PDCCH monitoring occasions per slot are considered).
- For downlink, one source (R1-1901695) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenario 22 (i.e. Same as scenario 8 in Table 6.4.1.1-1 except that 14 PUCCHs and PDCCH monitoring occasions per slot are considered).
- For downlink, one source (R1-1901695) has shown that two HARQ transmissions can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenario 22 (i.e. Same as scenario 8 in Table 6.4.1.1-1 except that 14 PUCCHs and PDCCH monitoring occasions per slot are considered).
- For downlink, one source (R1-1902807) has shown that a single-shot transmission cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 23-25 (i.e. Same as scenario 2/4/6 in Table 6.4.1.1-1 respectively except that TDD DL/UL configuration of {D10,G2,U2} is considered).
- For downlink, one source (R1-1902807) has shown that two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 23-25 (i.e. Same as scenario 2/4/6 in Table 6.4.1.1-1 respectively except that TDD DL/UL configuration of {D10,G2,U2} is considered).

- For downlink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 23-25 (i.e. Same as scenario 2/4/6 in Table 6.4.1.1-1 respectively except that TDD DL/UL configuration of {D10,G2,U2} is considered).
- For downlink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 23-25 (i.e. Same as scenario 2/4/6 in Table 6.4.1.1-1 respectively except that TDD DL/UL configuration of {D10,G2,U2} is considered).

- For SR-based uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1, 2 and 4.
- For SR-based uplink, a single-shot transmission cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 3, 5 and 6.
- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1-6.
- For SR-based uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-12.
- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-12.
- For SR-based uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For SR-based uplink, a single source (R1-1902807) has shown that a single-shot transmission cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19-21.
- For SR-based uplink, a single source (R1-1902807) has shown that a two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19-21.
- For SR-based uplink, a single source (R1-1902807) has shown that a single-shot transmission cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 19-21.
- For SR-based uplink, a single source (R1-1902807) has shown that a two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 19-21.

- For GF uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1-6.
- For GF uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenarios 1-6.
- For GF uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-12.
- For GF uplink, two HARQ transmissions can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 7-10.
- For GF uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenarios 11-12.
- For GF uplink, a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For GF uplink, two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenarios 13-18.
- For GF uplink, a single source (R1-1901695) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19.
- For GF uplink, a single source (R1-1901695) has shown that two HARQ transmissions can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 19.

- For GF uplink, a single source (R1-1901695) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenario 20.
- For GF uplink, a single source (R1-1901695) has shown that two HARQ transmissions can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 60 KHz in scenario 20.
- For GF uplink, a single source (R1-1902807) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 21.
- For GF uplink, a single source (R1-1902807) has shown that a single-shot transmission cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 22-23.
- For GF uplink, a single source (R1-1902807) has shown that a two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 30 KHz in scenario 21-23.
- For GF uplink, a single source (R1-1902807) has shown that a single-shot transmission can be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 24-26.
- For GF uplink, a single source (R1-1902807) has shown that a two HARQ transmissions cannot be completed within 1ms by considering the Rel. 15 timing capability for SCS = 120 KHz in scenario 24-26.

Table 6.4.1.1-1: Scenarios defined for latency analysis for downlink

	SCS	# PDCCH monitoring occasions per slot	PDSCH Duration
Scenario 1	30	4	2
Scenario 2	30	7	2
Scenario 3	30	4	4
Scenario 4	30	7	4
Scenario 5	30	4	7
Scenario 6	30	7	7
Scenario 7	60	4	2
Scenario 8	60	7	2
Scenario 9	60	4	4
Scenario 10	60	7	4
Scenario 11	60	4	7
Scenario 12	60	7	7
Scenario 13	120**	4	2
Scenario 14	120**	7	2
Scenario 15	120**	4	4
Scenario 16	120**	7	4
Scenario 17	120**	4	7
Scenario 18	120**	7	7
Scenario 19	same as scenario 1 except that the gNB's processing time for the initial PDSCH is N2 + X		
Scenario 20	same as scenario 3 except that the gNB's processing time for the initial PDSCH is N2 + X		
Scenario 21	same as scenario 2, but 14 PUCCHs and PDCCH MOs per slot are considered		
Scenario 22	same as scenario 8, but 14 PUCCHs and PDCCH MOs per slot are considered		
Scenario 23	same as scenario 2, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 24	same as scenario 4, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 25	same as scenario 6, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 26	same as scenario 14, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 27	same as scenario 16, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 28	same as scenario 18, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Note**: For Scenario 13-18, the assumed TDD UL/DL configuration is [D,D,D,D,D,D,F,F,U,U,U,U,U,U]			

Table 6.4.1.1-2: Scenarios defined for latency analysis for uplink with SR-based PUSCH

	SCS	# PDCCH monitoring occasions per slot	PUSCH Duration
Scenario 1	30	4	2
Scenario 2	30	7	2
Scenario 3	30	4	4
Scenario 4	30	7	4
Scenario 5	30	4	7
Scenario 6	30	7	7
Scenario 7	60	4	2
Scenario 8	60	7	2
Scenario 9	60	4	4
Scenario 10	60	7	4
Scenario 11	60	4	7
Scenario 12	60	7	7
Scenario 13	120**	4	2
Scenario 14	120**	7	2
Scenario 15	120**	4	4
Scenario 16	120**	7	4
Scenario 17	120**	4	7
Scenario 18	120**	7	7
Scenario 19	same as scenario 2, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Scenario 20	same as scenario 4, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Scenario 21	same as scenario 6, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Scenario 22	same as scenario 14, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Scenario 23	same as scenario 16, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Scenario 24	same as scenario 18, but TDD DL/UL configuration of {D10,G2,U2} is considered		
Note**: For Scenario 13-18, the assumed TDD UL/DL configuration is [D,D,D,D,D,D,F,F,U,U,U,U,U,U]			

Table 6.4.1.1-3: Scenarios defined for latency analysis for uplink with grant free based PUSCH

	SCS	# PDCCH monitoring occasions per slot	PUSCH Duration
Scenario 1	30	4	2
Scenario 2	30	7	2
Scenario 3	30	4	4
Scenario 4	30	7	4
Scenario 5	30	4	7
Scenario 6	30	7	7
Scenario 7	60	4	2
Scenario 8	60	7	2
Scenario 9	60	4	4
Scenario 10	60	7	4
Scenario 11	60	4	7
Scenario 12	60	7	7
Scenario 13	120**	4	2
Scenario 14	120**	7	2
Scenario 15	120**	4	4
Scenario 16	120**	7	4
Scenario 17	120**	4	7
Scenario 18	120**	7	7
Scenario 19	same as scenario 2, but GF-PUSCH duration and periodicity of 1 symbol and 14 PDCCH MOs per slot are assumed		
Scenario 20	same as scenario 8, but GF-PUSCH duration and periodicity of 1 symbol and 14 PDCCH MOs per slot are assumed		
Scenario 21	same as scenario 2, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 22	same as scenario 4, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 23	same as scenario 6, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 24	same as scenario 14, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 25	same as scenario 16, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Scenario 26	same as scenario 18, but TDD DL/UL configuration of {D10, G2, U2} is considered		
Note**: For Scenario 13-18, the assumed TDD UL/DL configuration is [D,D,D,D,D,D,F,F,U,U,U,U,U,U]			

Note that the possible latency reduction is evaluated by allowing the PDSCH/PUSCH to cross the slot boundary in R1-1903706.

6.4.1.2 Performance gain based on link-level evaluation

Link-level evaluations are considered in order to investigate the gains brought by reducing N1/N2 and allowing for more (re-)transmissions within the latency budget. Resource efficiency, i.e., the average number of REs used for completing the transmission of a TB, is reported. The number of transmissions for successfully decoding a TB and the target BLER for each transmission are also reported.

No any observation and/or conclusion on this aspect was made in this study item.

6.4.1.3 Performance gain based on system-level evaluation

System-level evaluations are considered in order to investigate the gains brought by reducing N1/N2 and allowing for more (re-)transmissions within the latency budget.

No any observation and/or conclusion on this aspect was made in this study item.

6.4.1.4 Conclusion

It is concluded that in Rel-16 NR there is no PDSCH and PUSCH processing timing enhancement as compared to Rel-15 NR for SCS = 15 kHz.

For downlink, the following conclusions are made:

- For downlink, two HARQ transmissions cannot be completed within 1ms under any of the considered scenarios for SCS = 30 KHz and FDD.
- For downlink, single-shot transmission can be completed within 1ms under all of the considered scenarios for SCS = 30 KHz and FDD.
- For downlink, under some considered FDD scenarios, two HARQ transmissions can be completed within 1ms for SCS = 60 KHz.
- For downlink, under all considered FDD scenarios, a single-shot transmission can be completed within 1ms for SCS = 60 KHz.
- For downlink, two HARQ transmissions cannot be completed within 1ms under any of the considered TDD scenarios for SCS = 120 KHz.
- For downlink, a single-shot transmission can be completed within 1ms under all of the considered TDD scenarios for SCS = 120 KHz.

For uplink, the following conclusions are made:

- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms under any of the considered scenarios for SCS = 30 KHz and FDD.
- For SR-based uplink, a single-shot transmission can be completed within 1ms under some of the considered scenarios for SCS = 30 KHz and FDD.
- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms under any of the considered scenarios for SCS = 60 KHz and FDD.
- For SR-based uplink, under all considered FDD scenarios, a single-shot transmission can be completed within 1ms for SCS = 60 KHz.
- For SR-based uplink, two HARQ transmissions cannot be completed within 1ms under any of the considered TDD scenarios for SCS = 120 KHz
- For SR-based uplink a single-shot transmission can be completed within 1ms under any of the considered TDD scenarios for SCS = 120 KHz.
- For GF uplink, a single-shot transmission can be completed within 1ms under all of the considered scenarios for SCS = 30 KHz and FDD.
- For GF uplink, two HARQ transmissions can be completed within 1ms under some of the considered scenarios for SCS = 60 KHz and FDD.

- For GF uplink, under all considered FDD scenarios, a single-shot transmission can be completed within 1ms for SCS = 60 KHz.
- For GF uplink, two HARQ transmissions cannot be completed within 1ms under any of the considered TDD scenarios for SCS = 120 KHz.
- For GF uplink a single-shot transmission can be completed within 1ms under some of the considered TDD scenarios for SCS = 120 KHz.

6.4.2 Out-of-order HARQ-ACK and PUSCH scheduling

In Rel-15, out-of-order HARQ-ACK and PUSCH scheduling are not supported as defined in section 5.1 and section 6.1 in TS 38.214. Out-of-order HARQ-ACK and PUSCH scheduling are studied in this study item and is identified to be beneficial. It is concluded to support out-of-order HARQ-ACK and out-of-order PUSCH scheduling as below.

Out-of-order HARQ-ACK

For a Rel-16 URLLC UE and dynamic downlink scheduling, on the active BWP of a given serving cell, the HARQ-ACK associated with the second PDSCH with HARQ process ID x received after the first PDSCH with HARQ process ID y (x != y) can be sent before the HARQ-ACK of the first PDSCH. Out-of-order HARQ-ACK is to be specified based on the following solutions:

- Solution 1: The UE always processes the second PDSCH. The UE may or may not drop the processing of the first channel.
- Solution 2: The UE processes both the first and second PDSCHs as a UE capability with no condition.
- Solution 3: The UE processes both the first and second channels under some conditions, e.g. using the CA capability. The conditions are reported as a UE capability. If the conditions are not satisfied, the UE behavior is not defined.
  - FFS: The details of the UE capability
- Solution 4:
  - A UE drops (terminates) the processing of the first PDSCH.
    - Alt1: The UE always drops the first PDSCH
    - Alt2: Some scheduling conditions should be defined. If not satisfied, the UE drops the processing of the first channel
    - FFS how to define the scheduling conditions, e.g., based on the number of RBs, TBS, number of layers, the gap between the first and second PDSCHs, the gap between the two PUCCHs carrying HARQ-ACK, etc.
  - The UE behavior, e.g., decision on dropping the first channel and timing capability associated with the second channel, is determined, and is fixed, after decoding the PDCCH associated with the first and the second PDSCH.
  - When the UE drops the processing of the first channel, increasing the minimum PDSCH processing procedure time (N1) of the second PDSCH by d symbols can be considered.
    - FFS the value of d
  - Dropping the processing of the first PDSCH can be done in one of the two ways
    - Alt1: dropping the processing of the first PDSCH on the same serving cell
    - Alt2: dropping the processing of a PDSCH(s) on the same cell or a different serving cell
- The UE only expects a maximum of one OOO PDSCH-to-HARQ-ACK flow on the active BWP of a given serving cell when applicable
- FFS whether or not, out-of-order operation is allowed across PDSCHs with PDSCH-to-HARQ gap compatible with PDSCH processing time (N1) for capability X.

Out-of-order PUSCH scheduling

For a Rel-16 UE, on the active BWP of a given serving cell, the UE can be scheduled with a second PUSCH associated with HARQ process x starting earlier than the ending symbol of the first PUSCH associated with HARQ process y (x != y) with a PDCCH that does not end earlier than the ending symbol of first scheduling PDCCH. Out-of-order PUSCH scheduling is to be specified based on the following solutions:

- Solution 1: The UE always processes the second scheduled PUSCH. The UE may or may not drop the processing of the first scheduled PUSCH.
- If the first scheduled and second scheduled PUSCHs are not colliding in the time domain:
  - Solution 2: The UE processes both the first scheduled and second scheduled PUSCHs as a UE capability with no condition.
  - Solution 3: The UE processes both the first scheduled and second scheduled PUSCHs under some conditions. The conditions are reported as a UE capability.
    - FFS: The details of the UE capability
  - Solution 4:
    - A UE drops (terminates) the processing of the first scheduled PUSCH
      - Alt1: The UE always drops the first scheduled PUSCH
      - Alt2: Some scheduling conditions should be defined. If not satisfied, the UE drops the processing of the first scheduled PUSCH
        - FFS how to define the scheduling conditions, e.g., based on the number of RBs, TBS, number of layers, the gap between the first and the second PUSCHs, etc
  - The UE behavior, e.g., decision on dropping the first scheduled PUSCH and timing capability associated with the second scheduled PUSCH, is determined, and is fixed, after decoding the PDCCH associated with first and the second scheduled PUSCHs
  - When the UE drops the processing the UE behavior, e.g., decision on dropping the first scheduled PUSCH and timing capability associated with the second scheduled PUSCH, is determined, and is fixed, after decoding the PDCCH associated with the first and the second scheduled PUSCHs, of the first scheduled PUSCH, increasing the minimum PUSCH preparation procedure time (N2) of the second PUSCH by d symbols can be considered
      - FFS the value of d.
  - Dropping the processing of the first scheduled PUSCH can be done in one of the two ways:
      - Alt1: dropping the processing of the first scheduled PUSCH on the same serving cell
      - Alt2: dropping the processing of a PUSCH(s) on the same cell or different serving cell
- The UE only expects a maximum of one OOO PDCCH-to-PUSCH flow on the active BWP of a given serving cell when applicable
- FFS whether or not out-of-order operation is allowed across PUSCHs with PDCCH-to-PUSCH gap compatible with PUSCH processing time (N2) for capability X
- If the first scheduled PUSCH and the second scheduled PUSCH are colliding in the time domain, the UE drops the processing and the transmission of the first scheduled PUSCH.
  - For dropping, the scheduling limitations do not apply. The UE always drops the first scheduled PUSCH
  - Other details of dropping are as those of the solution 4

6.4.3 Non-periodic SR enhancement

A non-periodic SR scheme has been discussed in R1-1901589 and R1-1900015 for latency reduction and overhead reduction.

7 UL inter UE Tx prioritization/multiplexing

7.1 Performance evaluation

Performance evaluations are performed to evaluate the enhanced UL inter UE Tx prioritization/multiplexing mechanisms using Rel-15 mechanisms as the performance benchmark. Requirements and assumptions given in Annex A are considered for the evaluation of UL inter UE Tx prioritization/multiplexing unless otherwise noted. Other factors such as overhead and capability are also considered.

7.1.1 Link level simulation

3 sources evaluated the required SNR for single URLLC transmission with 1e-4 BLER target with evaluation results as shown in Table 7.1.1-1. Note that 1e-4 BLER target used here is only for evaluation comparison purpose because the requirement of reliability is higher than 99.99% for most cases as shown in Annex A.

- For URLLC with low MCS level
  - Three sources (source 1/2/3 in Table 7.1.1-1) show 0.2dB~1dB required SNR loss for URLLC BLER target 1e-4 when URLLC PUSCH uses MCS#0 and collides with another eMBB PUSCH transmission, compared to the baseline with URLLC only PUSCH transmission using MCS#0, assuming MMSE-IRC receiver is used at the gNB and 0dB power offset.
    - Two sources (source 2/3 in Table 7.1.1-1) show that the loss can be reduced to 0.2dB~0.5dB, when URLLC power is 3dB higher than eMBB
    - One source (source 1 in Table 7.1.1-1) shows that the loss can be negligible if MMSE-SIC receiver is used at the gNB (eMBB and URLLC are decoded with two hypothesis) and 0 dB power offset assuming orthogonal DMRS between eMBB and URLLC
  - One source (source 5 in Table 7.1.1-1) observed 1.5dB required SNR loss for URLLC BLER target 10^{-4} when URLLC PUSCH uses MCS#3 and collides with another eMBB PUSCH transmission, compared to the baseline with URLLC only PUSCH transmission using MCS#3, assuming MMSE-IRC receiver is used at the gNB and 0dB power offset, and the loss can be reduced to 0.7dB when URLLC power is 3dB higher than eMBB.
- For URLLC with medium MCS level
  - Three sources (source 2/3/4 in Table 7.1.1-1) show 1.8dB~6dB required SNR loss for URLLC BLER target 1e-4 when URLLC PUSCH uses MCS#6 and collides with another eMBB PUSCH transmission, compared to the baseline with URLLC only PUSCH transmission using MCS#6, assuming MMSE-IRC receiver (source 2/3 in Table 7.1.1-1) or MMSE receiver (source 4 in Table 7.1.1-1) is used at the gNB
    - Two sources (source 2/3 in Table 7.1.1-1) show that the loss can be reduced to 0.4dB~2dB, when URLLC power is 3dB higher than eMBB
    - One source (source 4 in Table 7.1.1-1) observed the loss cannot be reduced if MMSE-SIC receiver is used assuming case 1 DMRS assumption between eMBB and URLLC.
- For URLLC with higher MCS level
  - One source (source 1 in Table 7.1.1-1) shows about 3.2dB required SNR loss for URLLC BLER target 1e-4 when URLLC PUSCH uses MCS#14 and collides with another eMBB PUSCH transmission using MCS#14 or 23 (for the higher SE table), compared to the baseline with URLLC only PUSCH transmission using MCS#14, assuming MMSE receiver is used at the gNB and 0dB power offset
  - One source (source 1 in Table 7.1.1-1) shows that when no power offset is applied to the URLLC, if MMSE-SIC receiver is used at the gNB (eMBB and URLLC are decoded with two hypothesis), the loss can be reduced to 0.5dB for the case with URLLC MCS#14 and eMBB MCS#14, assuming orthogonal DMRS between eMBB and URLLC. However, the loss cannot be reduced by MMSE-SIC receiver for the case with URLLC MCS#14 and eMBB MCS#23
  - Two sources (source 3/5 in Table 7.1.1-1) shows that URLLC error floor at 10^{-1}~10^{-3} when URLLC PUSCH uses MCS#10 or 14 and collides with another eMBB PUSCH transmission using 16QAM or 64 QAM, compared to the baseline with URLLC only PUSCH transmission using MCS#10 or 14, assuming MMSE-IRC receiver is used at the gNB and 0dB or 3dB power offset between URLLC and eMBB

Note that for SIC receiver, if eMBB transmission ends later than URLLC, the latency performance of URLLC may be impacted if the eMBB is decoded first. In Table 7.1.1-1 and Table 7.1.1-2, case-1 DMRS assumption means orthogonal DMRS for the collided users and no interference on DMRS of one UE caused by data from another colliding UE, case-2 DMRS assumption means there is interference on DMRS of one UE caused by data from another colliding UE.

3 sources evaluated the required SNR for single eMBB transmission with 1e-1 BLER target with evaluation results as shown in Table 7.1.1-2.

- For eMBB with low MCS level (QPSK modulation)
  - Two sources (source 1/3 in Table 7.1.1-2) show up to 0.5dB required SNR loss for eMBB BLER target 1e-1 when eMBB PUSCH uses MCS#0 or 2 and collides with another URLLC PUSCH transmission, compared to the baseline with eMBB only PUSCH transmission assuming MMSE-IRC (source 1 in Table 7.1.1-2) or MMSE (source 3 in Table 7.1.1-2) receiver is used at the gNB and 0dB power offset.
    - One source (source 1 in Table 7.1.1-2) shows that the loss can be negligible, if MMSE-SIC receiver (eMBB and URLLC are decoded with two hypothesis) is used assuming case-1 DMRS between eMBB and URLLC.
  - One source (source 3 in Table 7.1.1-2) shows that 0.3dB~2dB required SNR loss for eMBB BLER target 1e-1 when eMBB PUSCH uses MCS#6 and collides with another URLLC PUSCH transmission, compared to the baseline with eMBB only PUSCH transmission assuming MMSE receiver is used at the gNB and 0dB power offset.
- For eMBB with higher MCS level (16QAM or 64QAM)
  - Three sources (source 1/13/19 in Table 7.1.1-2) show that 0.9dB~1.6dB required SNR loss for eMBB BLER target 1e-1 when eMBB PUSCH uses MCS#10, 12, 14 or 23 and collides with another URLLC PUSCH transmission, compared to the baseline with eMBB only PUSCH transmission assuming MMSE-IRC receiver (source 1/19 in Table 7.1.1-2) or MMSE receiver (source 13 in Table 7.1.1-2) is used at the gNB and 0dB power offset. Another source (source 2 in Table 7.1.1-2) observed 8dB loss. One source (source 19 in Table 7.1.1-2) observed 2.5dB loss for eMBB when URLLC has 3dB higher power than eMBB. One source (source 19 in Table 7.1.1-2) observed eMBB error floor, (i.e. 10^{-1} BLER cannot be reached) when eMBB using MCS#12 has a full bandwidth collision with URLLC using MCS#3 during 2 OFDM symbols.
    - Two sources (source 1/13 in Table 7.2.1-2) show that the loss can be reduced to 0.2~0.3dB, if MMSE-SIC receiver is used at the gNB (eMBB and URLLC are decoded with two hypothesis), assuming case-1 DMRS between eMBB and URLLC.

Table 7.1.1-1: Comparison of required SNR for single URLLC transmission with 1e-4 BLER target

	Required SNR for URLLC 1e-4 BLER (URLLC only, baseline)	Required SNR for URLLC 1e-4 BLER when colliding with eMBB (0dB power offset)	Required SNR for URLLC 1e-4 BLER when colliding with eMBB (3dB power offset)	Key Assumptions
Source 1 (R1-1901303)	-10dB	-9.8dB (0.2dB loss)	N/A	URLLC MCS#0(30/1024,2) eMBB MCS#0 (30/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-10dB	-10dB (0 loss)	N/A	URLLC MCS#0(30/1024,2) eMBB MCS#0 (30/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-10dB	-9.8dB (0.2dB loss)	N/A	URLLC MCS#0 (30/1024,2) eMBB MCS#0 (120/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-10dB	-10dB (0 loss)	N/A	URLLC MCS#0 (30/1024,2) eMBB MCS#0 (120/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	11dB (3.2dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS#14(602/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	8.3dB (0.5dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS#14(602/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	8.3 dB (0.5dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS #12 (434/1024,4) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	8.3 dB (0.5dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS #12 (434/1024,4) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	11dB (3.2dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS #23(772/1024,6) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	7.8dB	11dB (3.2dB loss)	N/A	URLLC MCS#14(602/1024,2) eMBB MCS #23(772/1024,6) MMSE-SIC receiver Case-1 DMRS assumption
Source 2 (R1-1900131)	-8.8dB	-8.3dB (0.5dB loss)	-8.6dB (0.2 dB loss)	URLLC MCS#0, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 2 (R1-1900131)	-3.5dB	-1.7dB (1.8 dB loss)	-3.1dB (0.4 dB loss)	URLLC MCS#6, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 3 (R1-1900131)	-6.5 dB	-5.5 dB (1dB loss)	-6 dB (0.5 dB loss)	URLLC MCS#0, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 3 (R1-1812161)	-1 dB	5dB (6dB loss)	1dB (2dB loss)	URLLC MCS#6, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 3 (R1-1812161)	4dB	Error floor	Error floor	URLLC MCS#10, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 3 (R1-1812161)	11dB	Error floor	Error floor	URLLC MCS#14, eMBB 16QAM MMSE-IRC receiver Case-2 DMRS assumption
Source 4 (R1-1902006)	-4dB	-2dB (2dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE receiver Case-1 DMRS assumption
Source 4 (R1-1902006)	-4dB	1.7dB (5.7dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE receiver Case-2 DMRS assumption
Source 4 (R1-1902006)	-4dB	-2.2dB (1.8 dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE-SIC receiver (CRC-based hard IC)

				Case-1 DMRS assumption
Source 5 (R1-1903243)	-7.2dB	-5.7dB (1.5dB loss)	-6.5dB (0.7dB loss)	URLLC MCS #3 (64/1024, QPSK) eMBB MCS#12 of existing 64QAM table MMSE-IRC receiver Case-2 DMRS assumption
Source 5 (R1-1903243)	1.3dB	Error floor	Error floor	URLLC MCS #10 (308/1024, QPSK) eMBB MCS#12 of existing 64QAM table MMSE-IRC receiver Case-2 DMRS assumption

Table 7.1.1-2: Comparison of required SNR for single eMBB transmission with 1e-1 BLER target

	Required SNR for eMBB 1e-1 BLER (eMBB only, baseline)	Required SNR for eMBB 1e-1 BLER when colliding with URLLC (0dB power offset)	Key Assumptions
Source 1 (R1-1901303)	-14.4dB	-14.3dB (0.1dB loss)	URLLC MCS#0(30/1024,2) eMBB MCS#0 (30/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-14.4dB	-14.4dB (0dB loss)	URLLC MCS#0(30/1024,2) eMBB MCS#0 (30/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-9.3dB	-8.8dB (0.5dB loss)	URLLC MCS#0 (30/1024,2) eMBB MCS#0 (120/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	-9.3dB	-9.3dB (0dB loss)	URLLC MCS#0 (30/1024,2) eMBB MCS#0 (120/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	0dB	1.6dB (1.6dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS#14(602/1024,2) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	0dB	0.3dB (0.3dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS#14(602/1024,2) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	2.7dB	3.2dB (0.5dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS #12 (434/1024,4) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	2.7dB	3dB (0.3dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS #12 (434/1024,4) MMSE-SIC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	13dB	14dB (1dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS #23(772/1024,6) MMSE-IRC receiver Case-1 DMRS assumption
Source 1 (R1-1901303)	13dB	11.5dB (0.5dB loss)	URLLC MCS#14(602/1024,2) eMBB MCS #23(772/1024,6) MMSE-SIC receiver Case-1 DMRS assumption
Source 2 (R1-1813328)	2dB	10dB (8dB loss) (-0.12dB power offset)	eMBB MCS#12, 14 symbol, URLLC MCS#7, 2 symbol MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	-3dB	-3dB (0dB loss)	eMBB MCS#2, 14 symbols eMBB interfered by 1 symbol and 50% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	-3dB	-3dB (0dB loss)	eMBB MCS#2, 14 symbols eMBB interfered by 2 symbol and 50% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	1.3dB	1.6dB (0.3dB loss)	eMBB MCS#6, 14 symbols eMBB interfered by 1 symbol and 50% BW MMSE receiver Case-2 DMRS assumption
Source3 (R1-1901284)	1.3dB	1.9dB (0.6dB loss)	eMBB MCS#6, 14 symbols eMBB interfered by 2 symbol and 50% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	-3dB	-2.9dB (0.1dB loss)	eMBB MCS#2, 14 symbols eMBB interfered by 1 symbol and 100% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-	-3dB	-2.8dB	eMBB MCS#2, 14 symbols

1901284)			(0.2dB loss)	eMBB interfered by 2 symbol and 100% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	1.3dB		2.1dB (0.8dB loss)	eMBB MCS#6, 14 symbols eMBB interfered by 1 symbol and 100% BW MMSE receiver Case-2 DMRS assumption
Source 3 (R1-1901284)	1.3dB		around 2dB loss	eMBB MCS#6, 14 symbols eMBB interfered by 2 symbol and 100% BW MMSE receiver Case-2 DMRS assumption
Source 4 (R1-1902006)	0.9dB	1.9dB (1dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE receiver Case-1 DMRS assumption
Source 4 (R1-1902006)	0.9dB	2dB (1.1dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE receiver Case-2 DMRS assumption
Source 4 (R1-1902006)	0.9dB	1.1dB (0.2dB loss)	N/A	URLLC MCS#6(120/1024, QPSK) eMBB MCS#10 (340/1024,16QAM) MMSE-SIC receiver (CRC-based hard IC) Case-1 DMRS assumption
Source 5 (R1-1903243)	2.5dB	3.4 dB (0.9 dB loss)	5dB (2.5 dB loss)	URLLC MCS #10 (308/1024, QPSK) eMBB MCS#12 of existing 64QAM table MMSE-IRC receiver Case-2 DMRS assumption
Source 5 (R1-1903243)	2.5dB	Error floor	Error floor	URLLC MCS #3 (64/1024, QPSK) eMBB MCS#12 of existing 64QAM table MMSE-IRC receiver Case-2 DMRS assumption

In addition, three sources (R1-1902129, R1-1902420 and R1-1903008) provided the link level evaluation for the signalling of UL cancelation.

7.1.2 System level simulation

8 sources performed system-level simulation on the potential enhancements with evaluation results as shown in Table 7.1.2-1.

- From URLLC perspective
    - Comparing the potential enhancements with Rel-15 baseline scheme
        - Two sources (source 2/7 in Table 7.1.2-1) show better URLLC performance (URLLC capacity or percentage of URLLC UEs satisfying the requirement) in UMa scenario for UL cancelation scheme, compared to a Rel-15 baseline scheme using semi-static power setting of eMBB and URLLC. One source (source 5 in Table 7.1.2-1) shows almost the same performance between the two cases. One source (source 7 in Table 7.1.2-1) shows degraded URLLC performance (percentage of URLLC UEs satisfying the requirement) in InH scenario for UL cancelation scheme, compared to a Rel-15 baseline case where URLLC has 8dB higher power than eMBB using semi-static power setting.
        - One source(source 3 in Table 7.1.2-1) shows better URLLC performance (URLLC capacity or percentage of URLLC UEs satisfying the requirement) for the potential enhanced schemes (i.e. UL cancellation and enhanced dynamic power control), compared to a Rel-15 baseline scheme using orthogonal scheduling of eMBB and URLLC in UMa scenario. One source (source 1 in Table 7.1.2-1) shows almost the same URLLC performance for enhanced schemes compared to a Rel-15 baseline scheme using orthogonal scheduling of eMBB and URLL in UMa scenario.
        - Two sources (source 6/7 in Table 7.1.2-1) show that 100% URLLC UE satisfying the requirement can only be achieved when the URLLC traffic load is low and the colliding eMBB transmission power is 5dB or 8dB lower than URLLC using semi-static power setting, while for higher URLLC traffic loads, source

6 shows that it is not possible to reach the URLLC performance requirement without removing the colliding eMBB transmission.

- One source (source 4 in Table 7.1.2-1) shows almost the same URLLC performance for enhanced schemes, compared to a Rel-15 baseline using TPC. The percentage of packets satisfying reliability and latency requirements is used as the URLLC performance metric, which is different from the agreed URLLC performance metric option 1 or option 2 as shown in section 5.1.

- Comparing UL cancelation scheme and enhanced power control scheme
    - One source (source 3 in Table 7.1.2-1) shows better URLLC performance (URLLC capacity or percentage of URLLC UEs satisfying the requirement) for UL cancelation scheme than enhanced dynamic power control scheme using enhanced TPC range of up to 6 dB. The URLLC performance metric include throughput or percentage of URLLC UEs fulfilling the requirement.
    - One source (source 1 in Table 7.1.2-1) shows almost the same URLLC performance (percentage of URLLC UEs satisfying the requirement) between UL cancelation scheme and enhanced UL power control scheme. In the evaluation by source 1, the enhanced UL power control is such that URLLC is always power boosted by 6dB higher than eMBB since eMBB and URLLC are assumed to always collide in the evaluation.

- From eMBB perspective
    - Comparing the potential enhancements with Rel-15 baseline scheme
        - Two sources (source 1/3/7 in Table 7.1.2-1) show degraded eMBB throughput in UMa scenario for UL cancelation, compared to orthogonal scheduling of eMBB and URLLC when TB-level retransmission is used for eMBB.
        - One (source 3 in Table 7.1.2-1) shows degraded eMBB throughput in UMa scenario for enhanced dynamic power control using enhanced TPC range of up to 6 dB, compared to Rel-15 baseline.
        - One source (source 7 in Table 7.1.2-1) shows improved eMBB throughput in InH scenario for UL cancelation with CBG-level retransmission, compared to Rel-15 baseline using orthogonal scheduling of eMBB and URLLC, or semi-static power setting.
        - One source (source 7 in Table 7.1.2-1) shows improved eMBB throughput in UMa scenario for UL cancelation with CBG-level retransmission, compared to semi-static power setting.
    - Comparing UL cancelation scheme and enhanced power control scheme
        - One sources (source 1 in Table 7.1.2-1) shows better eMBB throughput for enhanced dynamic power control, compared to UL cancelation. In the evaluation by source 1, then enhanced UL power control is such that URLLC is always power boosted by 6 dB higher than eMBB since eMBB and URLLC are assumed to always collide in the evaluation.
        - One source (source 3 in Table 7.1.2-1) shows better eMBB throughput for UL cancelation, compared to enhanced dynamic power control, using enhanced TPC range of up to 6 dB.

Note that in the above observations, the corresponding additional overhead to support the enhanced scheme(s) was not reported.

Table 7.1.2-1: Comparison of system level evaluations for UL inter-UE prioritization/multiplexing

Source	Simulated cases/schemes	URLLC performance	eMBB performance	Resource utilization	Simulated scenario and key assumptions	Observations
Source 1 (R1-1901561)	Case 1: Orthogonal scheduling (Rel-15 baseline) eMBB 4OS, URLLC 4OS	Ratio of URLLC users fulfilling URLLC requirements =0.70202	1.7867 bps/Hz	URLLC RU =0.034	R15 enabled use case, Urban macro with 500m ISD 40MHz BW@ 4GHz, 30 kHz SCS URLLC: Low URLLC traffic arriving rate, FTP model 3 with 120	No evident gain for UL cancelation
	Case 2 UL cancelation for Embb eMBB 12OS URLLC 4OS	Ratio of URLLC users fulfilling URLLC requirements =0.71728	1.6939 bps/Hz	URLLC RU=0.033		

	Case 3 Dynamic URLLC power boosting eMBB 12OS URLLC 4OS	Ratio of URLLC users fulfilling URLLC requirements =0.70000	1.7959bps/Hz	URLLC RU=0.033	p/s arrival rate, 32Bytes URLLC target:_ 1ms, 99.999% eMBB: Full buffer No retransmissions BS receiver: MMSE Number of generated packets per URLLC user in the simulation is 10^6	
Source 2 (R1-1903008)	Case 1 UL cancelation for eMBB	100% packets fulfills URLLC requirements, URLLC throughput : 16.13Mbps for 20MHz BW 5.38Mbps for 10MHz BW 1.08Mbps for 5MHz BW	N/A	URLLC RU 63.9% for 20MHz BW 41.7% for 10MHz BW 17.3% for 5MHz BW	Macro with 200m ISD 20MHz / 10MHz/5MHz@2 GHz 30KHz/NCP Retransmission: IR Target URLLC requirement : 1e-5 with 1ms latency bound URLLC traffic arrival: Poisson with 32-byte packets (FTP3), swept over a wide range to find the largest one that is supported in the network eMBB: full buffer BS receiver: L-MMSE eMBB 14OS URLLC 2OS Number of generated packets per URLLC user in the simulation is 4.5x10^5	1. Semi-static power control of eMBB UEs significantly degrades the URLLC performance, unless the target received data SNR of eMBB is very low, resulting in significantly degraded eMBB performance. 2. FDM-ing URLLC and eMBB is also not a good idea as the capacity drops super-linearly as the URLLC frequency resources are reduced.
	Case 2 Semi-static power control with 18dB offset between URLLC and eMBB	100% packets fulfills URLLC requirements, URLLC throughput : 15.05Mbps for 20MHz BW 5.38Mbps for 10MHz BW 1.08Mbps for 5MHz BW	N/A	URLLC RU 63.8% for 20MHz BW 44.5% for 10MHz BW 18.6%for 5MHz BW		
	Case 3: Semi-static power control with 12dB offset between URLLC and eMBB	100% packets fulfills URLLC requirements, URLLC throughput : 11.83Mbps for 20MHz BW 4.3Mbps for 10MHz BW 0Mbps for 5MHz BW	N/A	URLLC RU 58.8% for 20MHz BW 41.3% for 10MHz BW 0% for 5MHz BW		
	Case 4: Semi-static power control with 6dB offset between URLLC and eMBB	100% packets fulfills URLLC requirements, URLLC throughput : 5.38Mbps for 20MHz BW 2.15Mbps for 10MHz BW 0Mbps for 5MHz BW	N/A	URLLC RU 39.4%for 20MHz BW 28.1% for 10MHz BW 0% for 5MHz BW		
	Case 5: Semi-static power control with 0dB offset between URLLC and eMBB	100% packets fulfills URLLC requirements, URLLC throughput : 2.15Mbps for 20MHz BW 0Mbps for 10/5MHz BW	N/A	URLLC RU 25.4% for 20MHz BW 0% for 10/5MHz BW		
Source 2 (R1-1903008)	Case 1: UL cancellation for URLLC	95% of the users satisfying the requirements: URLLC per UE packet arrival rate per second at capacity: 4100	N/A	40MHz BW: URLLC RU 21% @1500 arrival rate, 24% @1700 arrival rate, and 58% @4100 arrival rate	R15 enabled use case, Urban macro with 500m ISD, 40MHZ @4GHz and SCS = 30KHz eMBB traffic: full buffer, BS receiver: MMSE eMBB 14OS URLLC 2OS Number of generated packets per URLLC user in the simulation is around 4.5x10^{5}	ULPI gain over TPC ranges from 2.41x to 2.73x. It is observed that RU for URLLC with ULPI is much less than that of with power control. For example, at the same arrival rate, URLLC's RU with ULPI is almost half of that with power boosting. This shows ULPI not only benefits URLLC but also eMBB UE, as more resources will be left for eMBB utilization
	Case 2: TPC without power boosting and the same target SNR for both eMBB and URLLC	95% of the users satisfying the requirements: URLLC per UE packet arrival rate per second at capacity: 1500	N/A	40MHz BW: URLLC RU 43% @1500 arrival rate		
	Case 3: TPC with power boosting; URLLC has 3dB higher target SNR than eMBB	95% of the users satisfying the requirements: URLLC per UE packet arrival rate per second at capacity: 1700	N/A	40MHz BW: URLLC RU 44% @1700 arrival rate		

Source 3 (R1-1901772)	Case 1: Rel-15 baseline	% of URLLC UEs fulfil the latency and reliability requirement =87.14%	Mean UPT = 0.3143Mbps 5% UPT = 0.0773 Mbps 50% UPT = 0.3288Mbps 95% UPT = 0.5490Mbps	eMBB RU =0.8092	Macro with 500m ISD 80% of users are outdoors and 20% of users are indoors 40MHz @ 4GHz, 30 kHz SCS 1ms (air interface delay)/99.999 eMBB: FTP Model 3 with Poisson arrival $\lambda = 1800$ - Packet size: 50~600 bytes Pareto distribution, with shaping parameter alpha = 1.5. URLLC: - Periodic with arrival rate of 1 packet per 2ms - Packet size: 32bytes BS receiver: MMSE-IRC eMBB 14OS URLLC 4OS Number of generated packets per URLLC user in the simulation is around 5x10^5	1. UL cancelation mechanism with resuming and group common signaling has a better performance compared to UL cancelation mechanism with UE-specific rescheduling signaling. 2. UL cancelation mechanism with resuming and group common signaling has a better performance compared to UL power control mechanism.
	Case 2: UL cancelation with UE-specific re-scheduling	% of URLLC UEs fulfil the latency and reliability requirement =93.81%	Mean UPT = 0.2258Mbps 5% UPT = 0.0732 Mbps 50% UPT = 0.1857Mbps 95% UPT = 0.4605Mbps	eMBB RU =0.7465		
	Case 3: UL cancelation with resuming and GC-PDCCH	% of URLLC UEs fulfil the latency and reliability requirement =95.24%	Mean UPT = 0.3086Mbps 5% UPT = 0.0762 Mbps 50% UPT = 0.3191Mbps 95% UPT = 0.5352Mbps	eMBB RU =0.7648		
	Case 4: Dynamic power control for URLLC (+6dB power boosting for URLLC)	% of URLLC UEs fulfil the latency and reliability requirement =89.05%	Mean UPT = 0.2900Mbps 5% UPT = 0.0760 Mbps 50% UPT = 0.2722Mbps 95% UPT = 0.5212Mbps	eMBB RU =0.8141		
Source 4 (R1-1901826)	Case 1: No enhanced scheme	% of URLLC packets fulfil the latency and reliability requirement =94.42% Note: The used metric is not aligned with the agreed metric option 1 and 2	N/A	> 80%	Power distribution 100 MHz @ 4 GHz, 30KHz SCS URLLC: ftp model 3 with 2ms arrival interval, 100 bytes eMBB: ftp model 3 with 1ms arrival interval, 1500 bytes Retransmisison: Chase combining URLLC latency requirement: 2ms BS receiver: MRC Power control for URLLC: absolute only with TPC steps [-3, -1, 1, 3] dB Simulation time: 5s eMBB 14OS URLLC 4OS Number of generated packets per URLLC user in the simulation is 2500	Power control solution achieves better latency performance than PI.
	Case 2: Dynamic power control for URLLC	% of URLLC packets fulfil the latency and reliability requirement =99.55% Note: The used metric is not aligned with the agreed metric option 1 and 2	N/A	> 80%		
	Case 3: UL cancelation for eMBB	% of URLLC packets fulfil the latency and reliability requirement =99.01% Note: The used metric is not aligned with the agreed metric option 1 and 2	N/A	> 80%		
Source 5 (R1-1901284)	Case 1: Dynamic power control	% of URLLC UEs fulfil the latency and reliability requirement =90.3%	Average eMBB SE 0.7751 bps/Hz	52%	Power distribution, 500m ISD	1. Power control shows improved average eMBB

	Case 2: UL cancelation (ideal)	% of URLLC UEs fulfil the latency and reliability requirement =92.5%	Average eMBB SE 0.6571 bps/Hz	52%	40MHz BW@4GHz, 30KHz SCS URLLC: 100 bytes, FTP model 3 with arrival interval 100 ms, Generated URLLC packets: 1500 eMBB: FTP model 3 with 0.5 Mbytes URLLC requirement: 99.9999%, 2ms latency BS receiver: MMSE-IRC eMBB 14OS URLLC 2OS Number of generated packets per URLLC user in the simulation is around 1500	spectral efficiency relative to UL cancelation indication by about 15% 2. Power control shows a slightly worse performance than UL cancelation indication by about 2% regarding percentage of UEs satisfying reliability and latency requirements under ideal assumptions for UL cancelation indication.
Source 6 (R1-1900931)	Case 1: URLLC only, low URLLC load	URLLC outage = 0	N/A	1.5%	Macro, 500m ISD 10 MHz @ 4GHz, 15KHz FTP Model 3 with average arrival interval of 100 ms for each URLLC UE, 32 bytes Full-buffer for eMBB UEs Number of URLLC UEs per cell: 10 for low URLLC load, and 300 for high URLLC load Number of eMBB UEs per cell: 0 (no eMBB interference baseline), 1 (single UE) and 2 (simultaneous MU-MIMO streams) Open loop power control with full path-loss compensation for URLLC (α=1), and fractional path-loss compensation for eMBB (α=0.7 or α=1) BS receiver: MMSE-IRC eMBB 14OS URLLC 2OS Number of generated packets per URLLC user in the simulation is around 5x10^5 for high load and ~1.7x10^4 for low load	1. Having colliding URLLC and eMBB transmission is only feasible for low URLLC loads with at maximum one co-scheduled eMBB user, when using 5 dB lower Po value for eMBB, and accepting the eMBB performance loss from this. 2. For higher URLLC loads, or if more than one eMBB user is (MU-MIMO) co-scheduled, the URLLC targets are only achieved when not colliding with eMBB. 3. Presented performance results therefore confirm our hypothesis that it is beneficial to avoid eMBB transmission to overlap with URLLC transmissions.
	Case 2: URLLC and 1 eMBB user, low URLLC load	URLLC outage = 0 when eMBB α=1, P0=-113; URLLC outage = 2.5e-5 when eMBB α=1, P0=-108; URLLC outage = 2.4e-5 when eMBB α=0.7, P0=-78;	N/A	100%		
	Case 3: URLLC and 1 eMBB user, low URLLC load	URLLC outage = 2.6e-5 when eMBB α=1, P0=-113; URLLC outage = 2.6e-4 when eMBB α=1, P0=-108; URLLC outage = 3e-4 when eMBB α=0.7, P0=-78;	N/A	100%		
	Case 4: URLLC only, High URLLC load	URLLC outage = 1.2e-5	N/A	35%		
	Case 5: URLLC and 1 eMBB user, High URLLC load	URLLC outage = 8e-5 when eMBB α=1, P0=-113; URLLC outage = 2.6e-4 when eMBB α=1, P0=-108; URLLC outage = 2.3e-4 when eMBB α=0.7, P0=-78;	N/A	100%		
	Case 6: URLLC and 2 eMBB user, High URLLC load	URLLC outage = 2e-4 when eMBB α=1, P0=-113; URLLC outage = 1.1e-3 when eMBB α=1, P0=-108; URLLC outage = 1.2e-3 when eMBB α=0.7, P0=-78;	N/A	100%		
Source 7 (R1-1902497)	Case 1 URLLC Only	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 100% @ 1.2Mbps URLLC load, Ratio of satisfied URLLC UEs is 100%	N/A	@ 0.4Mbps URLLC RU = 10.8%, @1.2Mbps URLLC RU = 32.3%	Rel 15 InH BS: 4 Rx UE: 1 Tx, 20MHz, SCS = 30kHz, NCP Resource granularity: 7OS Link adaptation: URLLC (fixed low	From URLLC performance perspective, in InH scenario 1. In case of dynamic scheduling, URLLC capacity is worse than URLLC-only scenario and is
	Case 2 eMBB only	N/A	14.3Mbps	eMBB full buffer		

	Case 3: No overlap. This case includes Case 3-1) dynamic scheduling with same scheduling granularity (both 7 OS), Case 3-2) UL cancellation by PI. eMBB transmission is dropped for the overlapping part. For Case 3-2), eMBB retransmission can be Case 3-2-1) TB-based or Case 3-2-2) CBG-based.	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 95% @ 1.2Mbps URLLC load, Ratio of satisfied URLLC UEs is 94%	Case 3-1) @ 0.4Mbps eMBB throughput = 11.8 Mbps @ 1.2Mbps eMBB throughput = 7.8Mbps Case 3-2-1) @ 0.4Mbps eMBB throughput = 8 Mbps @ 1.2Mbps eMBB throughput = 3.7 Mbps Case 3-2-2) @ 0.4Mbps eMBB throughput = 12 Mbps @ 1.2Mbps eMBB throughput = 8.1 Mbps	@ 0.4Mbps URLLC RU = 10.8%, @1.2Mbps URLLC RU = 32.3%	MCS), eMBB (LA with outer loop) Retransmission: TB/CBG-based. Target URLLC requirement : 1e-4 with 1ms latency bound URLLC traffic arrival: Poisson with 32-byte packets (FTP3), 10 URLLC UEs eMBB: full buffer, 2 eMBB UEs BS receiver: L-MMSE URLLC: P0 to achieve target SNR = 20 dB, alpha = 0.8. Power boost of 0, 4, 8 dB eMBB: P0 to achieve target SNR = 20 dB, alpha = 0.8 eMBB 7OS URLLC 7OS Number of generated packets per URLLC user in the simulation is 10^5	limited by inter-cell interference from full-buffer eMBB transmissions 2. Overlapped transmissions with same power control setting drops URLLC performance significantly. 3. Moderate power boosting (4 dB) restores URLLC performance to similar level as non-overlapped scheduling. 4. High power boosting (8 dB) results in URLLC capacity similar to URLLC-only scenario by overcoming inter-cell interference limitation from full buffer eMBB transmissions **From eMBB performance perspective, in InH scenario** **1.** Usage of UL cancellation indication together with TB-based retransmissions provides worst performance among the considered schemes due to resource wastage when only a part of a TB was cancelled 2.Usage of UL cancellation indication together with CBG-based retransmissions provides performance comparable / better than dynamic scheduling with same timescale 3. Overlapped transmissions with same power control setting leads to eMBB performance comparable to dynamic scheduling and UL cancellation 4. Power boosting of URLLC degrades eMBB performance down to the case of cancellation with TB-based retransmissions
	Case 4: Overlap with same power setting	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 75% @ 1.2Mbps URLLC load, Ratio of satisfied URLLC UEs is 71%	@ 0.4Mbps eMBB throughput = 11.8 Mbps @ 1.2Mbps eMBB throughput = 9 Mbps	@ 0.4Mbps URLLC RU = 10.8%, @1.2Mbps URLLC RU = 32.3%		
	Case 5: Semi-static power control with 4dB offset between eMBB and URLLC	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 96% @ 1.2Mbps URLLC load, Ratio of satisfied URLLC UEs is 93%	@ 0.4Mbps eMBB throughput = 10 Mbps @ 1.2Mbps eMBB throughput = 6 Mbps	@ 0.4Mbps URLLC RU = 10.8%, @1.2Mbps URLLC RU = 32.3%		
	Case 6: Semi-static power control with 8dB offset between eMBB and URLLC	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 100% @ 1.2Mbps URLLC load, Ratio of satisfied URLLC UEs is 98%	@ 0.4Mbps eMBB throughput = 8 Mbps @ 1.2Mbps eMBB throughput = 3.9 Mbps	@ 0.4Mbps URLLC RU = 10.8%, @1.2Mbps URLLC RU = 32.3%		

Source 7 (R1-1902497)	Case 1 URLLC Only	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 88% @ 1.0Mbps URLLC load, Ratio of satisfied URLLC UEs is 77%	N/A	@ 0.4Mbps URLLC RU = 6.3%, @1.0Mbps URLLC RU = 25.9%	**Rel 15 UMa** BS: 4 Rx UE: 1 Tx, 40MHz, SCS = 30kHz, NCP Resource granularity: 7OS Link adaptation: URLLC (fixed low MCS), eMBB (LA with outer loop) Retransmission: TB/CBG-based. Target URLLC requirement : 1e-4 with 1ms latency bound URLLC traffic arrival: Poisson with 32-byte packets (FTP3), 10 URLLC UEs eMBB: full buffer, 2 eMBB UEs BS receiver: L-MMSE URLLC: P0 to achieve target SNR = 20 dB, alpha = 0.8. Power boost of 0, 4, 8 dB eMBB: P0 to achieve target SNR = 20 dB, alpha = 0.8 eMBB 7OS URLLC 7OS Number of generated packets per URLLC user in the simulation is 10^{5}	**From URLLC performance perspective, in UMa scenario** 1. In case of dynamic scheduling, URLLC capacity is worse than in URLLC-only scenario and is limited by inter-cell interference from full-buffer eMBB transmissions 2. Overlapped transmissions with same power control setting and even with power boosting degrades URLLC performance significantly due to significant power limitation in UMa compared to InH 3. High power boosting (8 dB) only slightly improves URLLC capacity and but still quite inferior to orthogonal URLLC transmission in URLLC-only and No overlap cases. **From eMBB performance perspective, in UMa scenario** 1. Usage of UL cancellation indication together with TB-based retransmissions provides worst performance among the considered schemes due to resource wastage when only a part of a TB was cancelled 2. Dynamic
	Case 2 eMBB only	N/A	51.8 Mbps	eMBB full buffer		
	Case 3) No overlap. This case includes Case 3-1) dynamic scheduling with same scheduling granularity (both 7 OS), Case 3-2) UL cancellation by PI. eMBB transmission is dropped for the overlapping part. For Case 3-2), eMBB retransmission can be Case 3-2-1) TB-based or Case 3-2-2) CBG-based.	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 76% @ 1.0Mbps URLLC load, Ratio of satisfied URLLC UEs is 67.5%	Case 3-1) @ 0.4Mbps eMBB throughput = 44 Mbps @ 1.0Mbps eMBB throughput = 35 Mbps Case 3-2-1) @ 0.4Mbps eMBB throughput = 27 Mbps @ 1.0Mbps eMBB throughput = 12.5 Mbps Case 3-2-2) @ 0.4Mbps eMBB throughput = 40 Mbps @ 1.0Mbps eMBB throughput = 28 Mbps	@ 0.4Mbps URLLC RU = 6.7%, @1.0Mbps URLLC RU = 26.6%		
	Case 4: Overlap with same power setting	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 57% @ 1.0Mbps URLLC load, Ratio of satisfied URLLC UEs is 54%	@ 0.4Mbps eMBB throughput = 39 Mbps @ 1.0Mbps eMBB throughput = 28 Mbps	@ 0.4Mbps URLLC RU = 7.2%, @1.0Mbps URLLC RU = 28.7%		
	Case 5: Semi-static power control with 4dB offset between eMBB and URLLC	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 61.5% @ 1.0Mbps URLLC load, Ratio of satisfied URLLC UEs is 59.2%	@ 0.4Mbps eMBB throughput = 37.5 Mbps @ 1.0Mbps eMBB throughput =27 Mbps	@ 0.4Mbps URLLC RU = 7.1%, @1.0Mbps URLLC RU = 28.5%		

	Case 6: Semi-static power control with 8dB offset between eMBB and URLLC	@ 0.4Mbps URLLC load, Ratio of satisfied URLLC UEs is 63 % @ 1.0Mbps URLLC load, Ratio of satisfied URLLC UEs is 61 %	@ 0.4Mbps eMBB throughput = 36.8 Mbps @ 1.0Mbps eMBB throughput = 24.8 Mbps	@ 0.4Mbps URLLC RU = 7.1%, @1.0Mbps URLLC RU = 28.5%		scheduling with same time scale as URLLC provides better performance compared to both PI-based and overlapped transmission. 3. PI with CBG-based retransmissions provide performance better than overlapped transmission with URLLC power boosting and PI with TB-based retransmission, and comparable performance to overlapped transmission with same power setting. 4. Overlapped transmissions leads to eMBB performance improvement compared to PI with TB-based retransmission.

7.2 Potential enhancements

In the following sub-sections, potential enhancements for UL inter UE Tx prioritization/multiplexing are presented. It is recommended to specify both UL cancelation scheme and enhanced UL power control scheme in the work item phase.

7.2.1 UE UL cancelation mechanisms

UE UL cancelation mechanisms are considered as one potential enhancement for UL inter-UE Tx prioritization/multiplexing and are studied from several aspects, including the potential mechanisms (e.g. UE UL cancelation/pausing indication, UL continuation indication, UL re-scheduling indication), physical channel/signal used for the UL cancelation indication, UE processing timeline for the UL cancelation indication, UE monitoring behaviours for the UL cancelation indication, UE PDCCH monitoring capability if the UL cancelation indication is by PDCCH, methods to ensure the reliability of the indication for UE UL cancelation.

Either PDCCH or sequence can be considered as potential options for the UL cancelation indication. If PDCCH is used, either group common DCI or UE-specific DCI can be considered as potential options. If sequence is used, either group common sequence or UE-specific sequence can be considered.

The monitoring periodicity for the UL cancelation indication should be configurable by the gNB and UE supporting UL cancelation indication should be able to support more than one monitoring occasions for the UL cancelation indication in a slot. If PDCCH is used, whether the UE PDCCH monitoring capability (number of CCEs/BDs per slot) should be increased is to be further investigated.

The UE processing time for UL cancelation indication should be equal or shorter than N2 defined in Rel-15 UE capability#2.

Upon detecting an UL cancelation indication, UE cancels the corresponding UL transmission. The corresponding UL transmission may include an on-going UL transmission, or an UL transmission that has not been started. After cancelation, the UE may resume the transmission afterwards as one option, or may not resume the transmission afterwards as another option.

7.2.2 Enhanced UL power control

Enhanced UL power control is considered as one potential enhancement for UL inter-UE Tx prioritization/multiplexing and the study mainly focuses on enhanced dynamic power boost for URLLC UE, including dynamic change of power control parameters (e.g. P0 and alpha without SRI configured) and enhanced TPC (e.g. increased TPC range and finer granularity). The need of URLLC UE power change during one transmission instance is not envisioned. It is assumed that there is no change of eMBB UE power control scheme in this study item.

Enhanced dynamic power boost for URLLC UE are studied from several aspects, including feasibility of boosting UE power in power limited or interference limited scenarios, physical channel/signal used for the signalling, UE processing timeline for the signalling, UE monitoring behaviours for the signalling, UE PDCCH monitoring capability if the signalling is by PDCCH and methods to ensure the reliability of the signalling.

It is concluded that the potential enhanced UL power control may include UE determining the power control parameter set (e.g. P0, alpha) based on scheduling DCI indication without using SRI, or based on group-common DCI indication. Increased TPC range compared to Rel-15 may also be considered. Power boosting is not applicable to power limited UEs.

8 Enhanced UL configured grant (grant free) transmissions

8.1 Performance evaluation

Requirements and assumptions given in Annex A are considered for the evaluation of enhanced UL configured grant (grant free) transmissions.

As discussed in section 8.2.4, link-level simulation evaluations are performed to evaluate gNB's missed detection performance, with evaluation results as shown in Table 8.1-1 below. The corresponding observations can be found in section 8.2.4.

Table 8.1-1: Required SNR for achieving 1e-4 or 1e-5 gNB's miss detection probability

	Required SNR for		Key Assumptions
	10^{-4} Miss detection probability	10^{-5} Miss detection probability	
Source 1 (R1-1901562)	-1dB	~ 1dB	Target FA rate = 0.01, w/o collision 6 UEs with only one active UE and Freq. domain RA (RBs) = 8 1-symbol front-loaded DMRS with Type 2 and Case-2 DMRS assumption*2 Carrier frequency = 4GHz 1T4R
Source 1 (R1-1901562)	0dB	1.3dB	Target FA rate = 0.001, w/o collision 6 UEs with only one active UE and Case-2 DMRS assumption*2 Freq. domain RA (RBs) = 8 1-symbol front-loaded DMRS with Type 2 Carrier frequency = 4GHz 1T4R
Source 1 (R1-1901562)	5dB	Error floor	Target FA rate = 0.01, with collision 6 UEs with only one active UE and Case-2 DMRS assumption*2 Freq. domain RA (RBs) = 8 1-symbol front-loaded DMRS with Type 2 Carrier frequency = 4GHz 1T4R
Source 1 (R1-1901562)	Error floor	Error floor	Target FA rate = 0.001, with collision 6 UEs with only one active UE and Case-2 DMRS assumption*2 Freq. domain RA (RBs) = 8 1-symbol front-loaded DMRS with Type 2 Carrier frequency = 4GHz 1T4R
Source 2 (R1-1902007)	-8.2dB	-7dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 16 1-symbol front-loaded DMRS with Type 1 Length of PUSCH=7OS Carrier frequency = 4GHz 1T4R
Source 3 (R1-1900075)	0dB	N/A	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 20 1-symbol front-loaded DMRS with Type 1 Length of PUSCH=4OS Carrier frequency = 4GHz 1T4R
Source 4 (R1-1900132)	-3dB for 1DMRS, -5dB for 2DMRS	-1.9 dB for 1DMRS -4dB for 2DMRS	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 12 DMRS with Type 1 Carrier frequency = 4GHz 1T4R
Source 4 (R1-1900132)	-6.5 for 1DMRS -8.5 dB 2DMRS	-5.6 dB for 1DMRS -7.5dB for 2DMRS	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 32 DMRS with Type 1 Carrier frequency = 4GHz 1T4R
Source 5 (R1-1902421)	-5.3dB	N/A	Number of UE= 1 Freq. domain RA (RBs) = 32 1 symbol DMRS with Type 1 Carrier frequency = 4GHz 1T4R
Source 5 (R1-1902421)	-3.2dB	N/A	Number of UE= 1 Freq. domain RA (RBs) = 16 1 symbol DMRS with Type 1 Carrier frequency = 4GHz 1T4R
Source 5 (R1-	-1.3dB	N/A	Number of UE= 1

1902421)			Freq. domain RA (RBs) = 8 1 symbol DMRS with Type 1 Carrier frequency = 4GHz 1T4R
Source 6 (R1-1902396)	-13.9dB	-13dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 70 1 symbol DMRS with Type 1 Length of PUSCH=2OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-12.4dB	N/A	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) = 70 1 symbol DMRS with Type 1 Length of PUSCH=2OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-9.8dB	-9dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 24 1 symbol DMRS with Type 1 Length of PUSCH=4OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-7.8dB	-7dB	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) = 24 1 symbol DMRS with Type 1 Length of PUSCH=4OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-6 dB w 1DMRS; -7.9dB w 2DMRS	-5.2dB w 1DMRS; -6.8dB w 2DMRS	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) =10 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-3.6dB w 1DMRS; -5.4dB w 2DMRS	-2dB w 1DMRS; -3.8dB w 2DMRS	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =10 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-5 dB w 1DMRS; -7.3 dB w 2DMRS	-3.5dB w 1DMRS; -6.3dB w 2DMRS	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =8 DMRS with Type 1 Length of PUSCH=10OS Carrier frequency = 4GHz 2T4R
Source 6 (R1-1902396)	-2.6 dB w 1DMRS; -4.6 dB w 2DMRS	-0.7dB w 1DMRS; -2.4dB w 2DMRS	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =8 DMRS with Type 1 Length of PUSCH=10OS Carrier frequency = 4GHz 2T4R
Source 7 (R1-1903009)	-5.3 dB w 1DMRS; -8.7 dB w 2DMRS	-4.5dB w 1DMRS; -7.5dB w 2DMRS	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =12 DMRS with Type 1 Length of PUSCH=7OS Carrier frequency = 4GHz 1T4R
Source 7 (R1-	-5.3 dB w 1DMRS;	-4.5 dB w 1DMRS;	Target FA rate = 0.001,

1903009)	-8.7 dB w 2DMRS	-7.5 dB w 2DMRS	Number of UE= 1 Freq. domain RA (RBs) =12 DMRS with Type 1 Length of PUSCH=4OS Carrier frequency = 4GHz 1T4R
Source 7 (R1-1903009)	-5.3 dB w 1DMRS; -8.7 dB w 2DMRS	-4.5 dB w 1DMRS; -7.5 dB w 2DMRS	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =12 DMRS with Type 1 Length of PUSCH=2OS Carrier frequency = 4GHz 1T4R
Source 7 (R1-1903009)	-5dB w 1DMRS, -7.5dB w 2DMRS	-6.5dB w 1DMRS -3dB w 2DMRS	Target FA rate = 0.001, Number of UE= 2 Freq. domain RA (RBs) =8 DMRS with Type 1 Length of PUSCH=7OS Carrier frequency = 4GHz 1T4R
Source 8 (R1-1903502)	-0.9 dB	0.9 dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 16 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 30ns 1T4R
Source 8 (R1-1903502)	-4.2 dB	-2.2 dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 32 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 30ns 1T4R
Source 8 (R1-1903502)	-6.9 dB	-5.2 dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 64 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 30ns 1T4R
Source 8 (R1-1903502)	-1.7dB	0dB	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 16 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 300ns 1T4R
Source 8 (R1-1903502)	-4.1dB	-2.8	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 32 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 300ns 1T4R
Source 8 (R1-1903502)	-6.6dB	-5.5	Target FA rate = 0.01, Number of UE= 1 Freq. domain RA (RBs) = 64 1-symbol DMRS with Type 1 Carrier frequency = 4GHz TDL-C 300ns 1T4R
Source 9 (R1-1900974)	-2.4 dB	-0.8 dB	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =8 1 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz

			2T4R
Source 9 (R1-1900974)	-1.8 dB	0 dB	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =8 1 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz 2T4R
Source 9 (R1-1900974)	-6.8 dB	-5.6 dB	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =36 2 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz 2T4R
Source 9 (R1-1900974)	-6 dB	-4.8 dB	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =36 2 DMRS with Type 1 Length of PUSCH=8OS Carrier frequency = 4GHz 2T4R
Source 9 (R1-1900974)	0 dB	2.5 dB	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =8 1 DMRS with Type 1 Length of PUSCH=4OS with 2 repetitions Carrier frequency = 30GHz 2T2R
Source 9 (R1-1900974)	-1 dB	1 dB	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =8 1 DMRS with Type 1 Length of PUSCH=4OS with 2 repetitions Carrier frequency = 30GHz 2T2R
Source 9 (R1-1900974)	-4 dB	-1.5 dB	Target FA rate = 0.001, Number of UE= 1 Freq. domain RA (RBs) =36 1 DMRS with Type 1 Length of PUSCH=4OS With 2 repetitions Carrier frequency = 30GHz 2T2R
Source 9 (R1-1900974)	-3 dB	0 dB	Target FA rate = 0.00001, Number of UE= 1 Freq. domain RA (RBs) =36 1 DMRS with Type 1 Length of PUSCH=4OS with 2 repetitions Carrier frequency = 30GHz 2T2R

8.2 Potential enhancements

In the following sub-sections, potential enhancements for UL configured grant (grant free) transmissions are presented.

Whether to allow one PUSCH transmission instance to cross the slot boundary when the remaining symbols within one slot is not enough for one PUSCH transmission instance was studied. The conclusion is that one PUSCH transmission instance is not allowed to cross the slot boundary for UL configured grant transmission.

8.2.1 Multiple active configured grants

Multiple active configured grants for a BWP of a serving cell are studied. It is concluded that multiple active configured grant configurations for a given BWP of a serving cell should be supported at least for different services/traffic types and/or for enhancing reliability and reducing latency. Potential specification impacts for both type 1 and type 2 grant free transmission are studied from several aspects, including activation/deactivation mechanism for type 2 grant free transmission, support of repetitions with multiple configurations for a BWP of a serving cell.

As to repetitions with multiple configurations for a BWP of a serving cell, it is concluded that in Rel-16, for both Type 1 and Type 2 configured grant and when multiple active configurations are configured in a BWP, transmission of a TB based on the configured grant is associated with a single active configuration, even if the transmission is repeated.

8.2.2 Enhancing reliability and reducing latency

Mechanisms to ensure a sufficient number of repetitions to meet the latency and reliability requirements were studied, including multiple active configured grant configurations for a BWP of a serving cell and repetition(s) across the boundary of a period P. Multiple configured grant configurations has been considered to be used for enhancing reliability and reducing latency. In addition, using single configured grant configuration to enhance reliability and reduce latency was discussed and may be further considered.

8.2.3 PUSCH repetitions within a slot for grant free transmission

It is understood that the potential enhancements for dynamically scheduled PUSCH and configured grant PUSCH should be studied jointly. Details can be found in section 6.3.

8.2.4 Explicit HARQ-ACK for UL configured grant transmission

gNB's missed detection performance of the PUSCH under configured grant is considered as one aspect for evaluating whether to support explicit HARQ-ACK for UL configured grant transmission, with a set of parameters to be reported by companies for the study, including false alarm target, DMRS configuration assumptions, the number of Tx/Rx and the number of UEs sharing the time/frequency-domain grant free resource. The simulation results are shown in section 8.1.

It is observed that PUSCH miss detection performance highly depends on the PUSCH configurations such as DMRS configuration, resource allocation and false-alarm target setting.

If a configured grant PUSCH resource is not shared by multiple UEs, 8 sources (R1-1900075, R1-1902007, R1-1900132, R1-1902396, R1-1900498, R1-1903009, R1-1900974, R1-1903502) show that if the reliability requirement is to be met by a single transmission, PUSCH miss detection probability is lower than the PUSCH target BLER under the respective evaluation assumptions (e.g. MCS levels, etc.).

If the overall PUSCH BLER target requirement is to be met by uplink grant based HARQ re-transmission for the configured grant PUSCH, the BLER of the configured grant PUSCH transmission can be higher than the overall PUSCH BLER target such that the residual BLER after the re-transmission achieves the overall PUSCH BLER target. However, even in this case, miss detection probability for configured grant PUSCH should not be higher than the overall PUSCH BLER target.

It is concluded that there is no consensus on the necessity of explicit HARQ-ACK for configured grant PUSCH for this study item.

9 Conclusion and recommendation

9.1 Conclusion

PDCCH enhancements

For the DCI format(s) scheduling Rel-16 NR URLLC, it is identified to be beneficial to support configurable sizes for some fields and potential reduction of the number of bits for some field(s) compared to Rel-15 DCI, to enable a minimum DCI size target a reduction of 10~16 bits less than the DCI format size of Rel-15 fallback DCI, and to provide the possibility to align with the size of the Rel-15 fallback DCI. The maximum DCI size can be larger than Rel-15 fallback DCI. It is also concluded on the potential list of fields with reduction of the number of bits and the potential list of configurable fields.

Increased PDCCH monitoring capability is identified to be beneficial while it may increase UE complexity. It is concluded to support increased PDCCH monitoring capability on at least the maximum number of non-overlapped CCEs per slot for channel estimation for Rel-16 NR URLLC for at least one SCS subject to some restrictions as shown in section 6.1.3. Enhancements for PDCCH monitoring capability on the maximum number of monitored PDCCH candidates per slot (with potential restrictions) for Rel-16 NR URLLC can be further considered in work item phase.

It is concluded that PDCCH repetition is not further considered in this study item.

UCI enhancements

Enabling more than one PUCCH for HARQ-ACK transmission within a slot is identified to be beneficial and it is concluded that more than one PUCCH for HARQ-ACK transmission within a slot should be supported in Rel-16.

Intended for supporting different service types for a UE, it is concluded that at least two HARQ-ACK codebooks can be simultaneously constructed for a Rel-16 UE. Rules for the HARQ-ACK codebooks for supporting different service types should be specified in Rel-16, if at least two HARQ-ACK codebooks are due to be transmitted in resources overlapping in time. When at least two HARQ-ACK codebooks are simultaneously constructed for supporting different service types for a UE, a HARQ-ACK codebook can be identified based on some PHY indications/properties.

Enhanced CSI feedback is studied with observations as shown in section 6.2.2. There is no consensus in RAN1 for supporting A-CSI on PUCCH in Rel-16.

PUSCH enhancements

It is identified to be beneficial to support enhancements for both grant-based PUSCH and configured grant based PUSCH in Rel-16, to enable one UL grant scheduling two or more PUSCH repetitions that can be in one slot, or across slot boundary in consecutive available slots. Candidate solutions are as shown in section 6.3. It is concluded to finalize the details regarding how to use "option 1" vs. "option 2" during the work item phase using option 4, 5 and 6 as shown in section 6.3 as a starting point.

Enhancements to scheduling/HARQ/CSI processing timeline

Enhancements to scheduling/HARQ processing timeline are studied with conclusions as provided in section 6.4.1.4.

Out-of-order HARQ and scheduling is studied and is identified to be beneficial. It is concluded to support out-of-order HARQ-ACK and out-of-order PUSCH scheduling as defined in section 6.4.2.

Inter UE Tx prioritization/multiplexing

It is identified to be beneficial to support enhancements for inter UE Tx prioritization/multiplexing, and it is recommended to support UL cancelation scheme and enhanced UL power control scheme in Rel-16.

Configured grant transmission

Multiple active configured grants for a BWP of a serving cell is identified to be beneficial. It is concluded that multiple active configured grant configurations for a given BWP of a serving cell should be supported at least for different services/traffic types and/or for enhancing reliability and reducing latency. As to repetitions with multiple configurations for a BWP of a serving cell, it is concluded that transmission of a TB based on the configured grant is associated with a single active configuration for both Type 1 and Type 2 configured grant and when multiple active configurations are configured in a BWP in Rel-16, even if the transmission is repeated.

It is concluded that there is no consensus on the necessity of explicit HARQ-ACK for configured grant PUSCH for this study item.

9.2 Recommendation

For PDCCH enhancement, it is recommended to support the following in Rel-16:

- DCI format(s) with configurable sizes for some fields and potential reduction of the number of bits for some field(s) compared to Rel-15 DCI, while enabling the minimum DCI size target a reduction of 10~16 bits less than the DCI format size of Rel-15 fallback DCI and the maximum DCI size can be larger than Rel-15 fallback DCI, and provide the possibility to align with the size of the Rel-15 fallback DCI (including possible zero padding if any).

- Increased PDCCH monitoring capability on at least the maximum number of non-overlapped CCEs per slot for channel estimation for Rel-16 NR URLLC for at least one SCS subject to some restrictions, including at least explicit limitation on the maximum number of BDs/non-overlapping CCEs per monitoring occasion and/or per monitoring span, and the set of applicable SCS(s).

For UCI enhancement, it is recommended to support the followings in Rel-16:

- More than one PUCCH for HARQ-ACK transmission within a slot.

- At least two HARQ-ACK codebooks can be simultaneously constructed for a Rel-16 UE, intended for supporting different service types for a UE.

For PUSCH enhancements, it is recommended to support enhancements for both grant-based PUSCH and configured grant based PUSCH in Rel-16, to enable one UL grant scheduling two or more PUSCH repetitions that can be in one slot, or across slot boundary in consecutive available slots.

For enhancements to scheduling/HARQ, it is recommended to support the following in Rel-16:

- Out-of-order HARQ-ACK: HARQ-ACK associated with the second PDSCH with HARQ process ID x received after the first PDSCH with HARQ process ID y (x != y) can be sent before the HARQ-ACK of the first PDSCH on the active BWP of a given serving cell

- Out-of-order PUSCH scheduling: A UE can be scheduled with a second PUSCH associated with HARQ process x starting earlier than the ending symbol of the first PUSCH associated with HARQ process y (x != y) with a PDCCH that does not end earlier than the ending symbol of first scheduling PDCCH on the active BWP of a given serving cell

For inter UE Tx prioritization/multiplexing, it is recommended to support UL cancelation scheme and enhanced UL power control scheme in Rel-16.

For enhanced UL configured grant transmission, it is recommended to support multiple active configured grant type 1 and type 2 configurations for a given BWP of a serving cell in Rel-16.

Annex A: Requirements and simulation assumptions

A.1 Requirements

According to the SID [3], the identified use cases for Rel-16 URLLC include factory automation, transport industry, electrical power distribution and Rel-15 enabled use case. The detailed use case and requirements for the identified use cases can refer to TR 22.804, TS 22.104, TS 22.186 and TS 22.261.

This Annex offers some examples of detailed use case and requirements for the identified use case, from TR 22.804 v16.2.0 for electrical power distribution and factory automation, from TS 22.186 v16.1.0 for remote driving, from TS 22.261 v16.6.0 for intelligent transport system, from TR 22.804 v16.2.0 for AR and from TS 22.261 v16.6.0 for VR. However, this does not imply that Rel-16 NR URLLC is necessarily restricted to the use cases provided in this Annex.

A.1.1 Examples of use case and requirements for electrical power distribution

The following use cases for electrical power distribution from Appendix F in TR 22.804 v16.2.0 can be the potential use cases for Rel-16 NR URLLC:

Use case (Clause #)	Characteristic parameter (KPI)				Influence quantity						Related requirement	Remark
	Communication service availability	End-to-end latency: target value	End-to-end latency: jitter	Service bit rate: user-experienced data rate (note)	Message size [byte]	Transfer interval: target value	Survival time	UE speed	# of UEs	Service area		
5.6.4	≥ 99,9999%	< 5 ms									*Electric Power Distribution 3.1, 3.2*	Power distribution grid fault and outage management: distributed automated switching for isolation and service restoration for overhead lines; peer-to-peer (here: UE to UE)
5.6.6		< transfer interval	< 50% of transfer interval		250	0,8 ms					*Electric Power Distribution 5.1, 5.2, 5.4*	Differential protection; peer-to-peer communication
5.6.6		< 15 ms									*Electric Power Distribution 5.3*	Differential protection; peer-to-peer communication

Note that the detailed requirements for power distribution grid fault and outage management can also refer to TS 22.104 v16.0.0.

A.1.2 Examples of use case and requirements for factory automation

The following use cases for factory automation from Appendix F in TR 22.804 v16.2.0 can be the potential use cases for Rel-16 NR URLLC:

Use case (Clause #)	Characteristic parameter (KPI)				Influence quantity						Related requirement	Remark
	Communication service availability	End-to-end latency: target value	End-to-end latency: jitter	Service bit rate: user-experienced data rate (note)	Message size [byte]	Transfer interval: target value	Survival time	UE speed	# of UEs	Service area		
5.3.2	99,9999 % to 99,999999%	< transfer interval			20	2 ms	2 ms	≤ 20 m/s	≤ 100	50m x 10 m x 10 m	*Factories of the Future 2.3, 2.8, 2.10*	Motion control; cyclic interaction

Note that the detailed requirements for the above detailed use case for factory automation can also refer to TS 22.104 v16.0.0, where there might be update on a few parameters.

A.1.3 Examples of use case and requirements for transport industry

The following performance requirements for remote driving are defined in Table 5.5-1 in TS 22.186 v16.1.0:

Communication scenario description	Req #	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)
Information exchange between a UE supporting V2X application and a V2X Application Server	[R.5.5-002]	5	99.999	UL: 25 DL: 1

The following performance requirements for intelligent transport system are defined in Table 7.2.3.2-1 in TS 22.261 v16.6.0:

Scenario	Maximum allowed end-to-end latency	Survival time	Communication service availability	Reliability	User experienced data rate	Payload size	Traffic density	Connection density	Service area dimension (note 8)
Wireless road-side infrastructure backhaul	30 ms	100 ms	99,9999%	99,999%	10 Mbps	Small to big	10 Gbps/km^2	1 000/km^2	2 km along a road

A.1.4 Examples of use case and requirements for Rel-15 enabled use case (e.g. AR/VR)

The following performance requirements for augmented reality (AR) are defined in section 8.1.3 in TR 22.804 v16.2.0:

Characteristic parameter (KPI)				Influence quantity		Related requirement	Remark
Communication service availability	End-to-end latency: target value	End-to-end latency: jitter (note)	Service bit rate: user-experienced data rate	UE speed	# of UEs		
> 99,9%	< 10 ms					*Factories of the Future 10.2, 10.3*	Augmented reality; bi-directional transmission; support at least 3 devices in the same radio cell

The following performance requirements for VR are defined in section 7.2.3 in TS 22.261:

To support VR environments with low motion-to-photon capabilities, the 5G system shall support:

- motion-to-photon latency in the range of 7-15ms while maintaining the required user data rate of [1Gbps] and
- motion-to-sound delay of [<20ms].

NOTE: The motion-to-photon latency is defined as the latency between the physical movement of a user's head and the updated picture in the VR headset. The motion-to-sound latency is the latency between the physical movement of a user's head and updated sound waves from a head mounted speaker reaching their ears.

The following requirement for Rel-15 URLLC use case are defined in ITU-R M. [IMT-2020.TECH PERF REQ]:

The minimum requirement for the reliability is $1\text{-}10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead).

Proponents are encouraged to consider larger packet sizes, e.g. layer 2 PDU size of up to 100 bytes.

A.2 System level simulation assumptions

According to the SID [3], the identified use cases for Rel-16 URLLC include factory automation, transport industry, electrical power distribution and Rel-15 enabled use case. Evaluations are performed for the representative use cases for the identified use cases. Table A.2-1 shows the representative use cases for Rel-16 NR URLLC evaluation.

Table A.2-1: Representative use cases for Rel-16 NR URLLC evaluation

Use case	Reliability (%)	Latency	Data packet size and traffic model	Description
Power distribution	99.9999	5 ms (end to end latency) Note: 2-3 ms air interface latency	DL & UL: 100 bytes ftp model 3 with arrival interval 100 ms	Power distribution grid fault and outage management (TR 22.804:5.6.4)
	99.999	15 ms (end to end latency) Note: 6-7 ms air interface latency	DL & UL: 250 bytes Periodic and deterministic with arrival interval 0.833 ms Random offset between UEs	Differential protection (TR 22.804:5.6.6)
Factory automation	99.9999	2 ms (end to end latency) Note: 1 ms air interface latency	DL & UL: 32 bytes Periodic deterministic traffic model with data arrival interval 2 ms	Motion control
Rel-15 enabled use case (e.g. AR/VR)	99.999	1 ms (air interface delay) for 32 bytes 1 ms and 4 ms (air interface delay) for 200 bytes	DL & UL: 32 and 200 bytes FTP model 3 or periodic with different arrival rates	
	99.9	7 ms (air interface delay)	DL & UL: 4096 and 10 K bytes FTP model 3 or periodic with different arrival rates	
Transport Industry	99.999	5 ms (end to end latency) Note: 3 ms air interface latency	UL: 2.5 Mpbs; Packet size 5220 bytes DL: 1Mbps; Packet size 2083 bytes Note: Data arrival rate 60 packets per second for periodic traffic model	Remote driving (TS 22.186: 5.5)
	99.999	10 ms (end to end latency) Note: 7ms air interface latency	UL&DL: 1.1 Mbps; Packet size 1370 bytes Note: Data arrival rate 100 packets per second for periodic traffic model	Intelligent transport system (ITS) (TS 23.501, TS 22.261)

For periodic traffic model for factory automation, the following assumptions are adopted in the evaluations:

- Data for UEs in a group will arrive simultaneously in the evaluations
- Data for UEs in different groups can arrive at different time either in a random manner or in a pre-planned manner
  - Companies report what manner used in the evaluations

- Companies can report the number of groups and the number of users in each group used in the evaluations
    - The number of users in a group can be one or more, up to companies to report

Evaluate aperiodic traffic model (FTP model 3) for DL for remote driving and ITS.

PDCP duplication, which may be applicable for improving reliability but not always available/applicable, is not evaluated in this study item.

In addition to the assumptions provided in the following sections, companies should describe the following assumptions for evaluation:

- Overhead modeling (e.g. PDCCH overhead) used in the simulation
- CDF of UE geometry
- Duplex mode: FDD or TDD (DL/UL configuration)
- Blockage due to moving metal parts for channel model for factory automation
- Detailed assumptions for carrier frequency 700 MHz and 2 GHz if evaluation is performed based on these carrier frequencies
- If any, details on re-dropping or discarding UEs which do not satisfy certain channel quality
- Other assumptions like TTI size, gNB/UE processing time, CSI measurement and reporting

A.2.1 Simulation assumption for electrical power distribution

This subclause describes the simulation assumptions for evaluating electrical power distribution. Table A.2.1-1 shows the evaluation assumptions at 4 GHz for some basic parameters for urban macro. Table A.2.1-2 shows the evaluation assumptions at 700 MHz for power distribution with urban macro scenario, assumptions for the remaining parameters are the same as that at 4 GHz as shown in Table A.2.1-1 Note that this does not imply that Rel-16 NR URLLC is necessarily restricted to urban macro scenario for electrical power distribution. Rural scenario is also applicable.

Table A.2.1-1: System-level simulation assumptions at 4 GHz for urban macro for power distribution

Parameters	Value
Layout	Single layer - Macro layer: Hex. Grid
Inter-BS distance	500m Note: Other value (e.g. 150 m) is not precluded
Carrier frequency	4 GHz
Channel model	UMa in TR 38.901
UE Tx power	23dBm
BS antenna configurations	4 Tx/4 Rx antenna ports and 8 Tx/8 Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (8, 4, 2, 1, 1; 1, 2) for 4 Tx/4 Rx antenna ports; (M, N, P, Mg, Ng; Mp, Np) = (8, 4, 2, 1, 1; 1, 4) for 8 Tx/8 Rx antenna ports; dH = 0.5λ, dV = 0.8λ; Companies report the antenna tilt Note: Other BS antenna configurations (e.g. 16 Tx/16 Rx) for evaluation are not precluded. If 16 Tx/16 Rx is used, (M, N, P, Mg, Ng; Mp, Np) = (8, 8, 2, 1, 1; 1, 8)
BS antenna height	25m
BS antenna element gain + connector loss	8 dBi
BS receiver noise figure	5dB
UE antenna configuration	2 Tx/4 Rx antenna ports Panel model 1: Mg=1, Ng=1, P=2, d_H=0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx; Note: Other UE antenna configurations for evaluation are not precluded
UE antenna height	Follow the modelling of TR 38.901 (e.g. 1.5m)
UE antenna gain	0dBi as starting point
UE receiver noise figure	9 dB
Total transmit power per TRxP	49 dBm
BS receiver	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.
Number of UEs per cell	Up to 10 Note: Example of the number of users for evaluation can be 5 and 10. The number of users per cell in this table is the number of pure URLLC UEs.
Simulation bandwidth	40 MHz Note: For FDD, 40 MHz for DL and 40 MHz for UL. Note that this is for evaluation purpose because there is no FDD bands identified at 4 GHz currently. For TDD, 40 MHz for DL/UL.
SCS	30 kHz Note: Other values for evaluation are not precluded.
UE distribution	100% of users are outdoors Use 3 km/h for modeling fading channel
UE power control	Companies report the PC mechanisms used for URLLC.
HARQ/repetition	Companies report (including HARQ mechanisms).
Channel estimation	Realistic

Table A.2.1-2: System-level simulation assumptions at 700 MHz for urban macro for power distribution

Parameters	Value
BS antenna configurations	2 Tx/2 Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (8,1,2,1,1;1,1) (dH, dV) = (N/A, 0.8)λ +45°, -45° polarization Note: 4 Tx/4 Rx as agreed for 4 GHz should be evaluated also
UE antenna configuration	2Tx/2 Rx antenna ports (M, N, P, Mg, Ng) = (1,1,2,1,1) 2 Tx/4 Rx antenna ports Panel model 1: Mg=1, Ng=1, P=2, d_H=0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx; 0°, 90° polarization
Simulation bandwidth	10 MHz, 20 MHz Note: 10 MHz for DL and 10 MHz for UL for simulation bandwidth of 10 MHz; 20 MHz for DL and 20 MHz for UL for simulation bandwidth of 20 MHz
Other parameters	As shown in Table A.2.1-1 for 4 GHz

A.2.2 Simulation assumption for factory automation

This subclause describes the simulation assumptions for evaluating factory automation. Table A.2.2-1 shows the evaluation assumptions at 4 GHz for factory automation.

Table A.2.2-1: System-level simulation assumptions at 4 GHz for factory automation

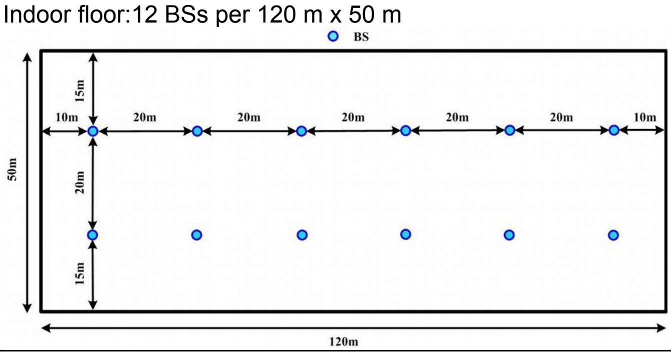
Parameters	Value
Inter-BS distance	20m
Carrier frequency	4 GHz
UE Tx power	23dBm
BS antenna element gain + connector loss	5 dBi
BS receiver noise figure	5dB
BS antenna configurations	4 Tx/4 Rx antenna ports and 8 Tx/8 Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Tx/4 Rx antenna ports; (M, N, P, Mg, Ng; Mp, Np) = (2, 2, 2, 1, 1; 2, 2) for 8 Tx/8 Rx antenna ports; dH = dV = 0.5 λ Note: Other values are not precluded for evaluation
BS antenna height	10 m Note: Other value (e.g. 3 m) is not precluded for evaluation
UE antenna configuration	2 Tx/4 Rx antenna ports Panel model 1: Mg = 1, Ng = 1, P = 2, dH = 0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx; Note: Other UE antenna configurations for evaluation are not precluded
UE antenna height	Follow the modelling of TR 38.901 (e.g. 1.5m) Note: Companies report the modification of the layout
UE antenna gain	0dBi as starting point
BS Tx power	24 dBm per 20 MHz
BS receiver	MMSE-IRC as the baseline receiver Note: Advanced receiver is not precluded.
UE receiver noise figure	9 dB
SCS	30 kHz Note: Other values for evaluation are not precluded.
Simulation bandwidth	40 MHz Note: For FDD, 40 MHz for DL and 40 MHz for UL. Note that this is for evaluation purpose because there is no FDD bands identified at 4 GHz currently. For TDD, 40 MHz for DL/UL.
Layout	Single layer as defined in 38.802 Indoor floor:12 BSs per 120 m x 50 m 
Channel model	ITU InH for 4 GHz Companies report the modification of the channel model
Number of UEs per cell	Up to 40 Note: Example of the number of users for evaluation can be 5, 10, 20, 30 and 40. The number of users per cell in this table is the number of pure URLLC UEs.
UE distribution	100% of users are indoor: 3 km/h and/or 30 km/h UE-speed Note: which one to use is up to companies and other value(s) are not precluded
UE power control	Companies report the PC mechanisms used for URLLC.
HARQ/repetition	Companies report (including HARQ mechanisms).
Channel estimation	Realistic

Table A.2.2-2 shows the evaluation assumptions at 30 GHz for factory automation. Assumptions for the remaining parameters are the same as that at 4 GHz as shown in Table A.2.2-1.

Table A.2.2-2: System-level simulation assumptions at 30 GHz for factory automation

Parameters	Value
Carrier frequency	30 GHz
BS receiver noise figure	7dB as defined in TR 38.802
BS antenna configurations	2 Tx/Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (4, 4, 2, 1, 1; 1, 1) dH = dV = 0.5 λ Note: Other antenna configurations are not precluded
UE antenna configuration	2 Tx/Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (2, 4, 2, 1, 2; 1, 1) (dH, dV) = (0.5, 0.5) λ Static panel selection Note: Other antenna configurations are not precluded
UE antenna gain	5dBi
BS Tx power	23 dBm for 80 MHz bandwidth
UE receiver noise figure	10 dB
SCS	120 kHz Note: Other values for evaluation are not precluded.
Simulation bandwidth	160 MHz Note: For TDD, 160 MHz for DL/UL. No FDD bands identified at 30 GHz currently.
Channel model	5GCM office for 30 GHz Companies report the modification of the channel model

1 ms air interface latency is assumed for evaluation for factory automation, with the assumption of 1 ms CN delay in 2 ms end-to-end latency. Other values for evaluation can also be considered.

A.2.3 Simulation assumption for transport industry

This subclause describes the simulation assumptions for evaluating transport industry, including remote driving and intelligent transport system (ITS). For evaluating urban macro scenario for transport industry, simulation assumptions at 4 GHz are provided in Table A.2.3-1 and simulation assumptions at 700 MHz are provided in Table A.2.3-2.

Table A.2.3-1: System-level simulation assumptions at 4 GHz for urban macro for transport industry

Parameters	Value
Layout	Single layer - Macro layer: Road configuration in Figure 6.1.9-1 in 38.913 and BS placement as depicted in Figure A.1.3-1 in 36.885.
UE antenna height	3.0 m
Number of UEs per cell	Up to 10 Note: Examples for evaluation 2, 6, 10. The number of users per cell in this table is the number of pure URLLC UEs.
UE distribution	100% of users are outdoors UE speed of 60 km/h
Other parameters	As shown in Table A.2.1-1 for power distribution

Table A.2.3 -2: System-level simulation assumptions at 700 MHz for urban macro for transport industry

Parameters	Value
BS antenna configurations	2 Tx/2 Rx antenna ports (M, N, P, Mg, Ng; Mp, Np) = (8,1,2,1,1;1,1) (dH, dV) = (N/A, 0.8)λ +45°, -45° polarization Note: 4 Tx/4 Rx as agreed for 4 GHz should be evaluated also
UE antenna configuration	2Tx/2 Rx antenna ports (M, N, P, Mg, Ng) = (1,1,2,1,1) 2 Tx/4 Rx antenna ports Panel model 1: Mg=1, Ng=1, P=2, d_H=0.5 (M, N, P, Mg, Ng; Mp, Np) = (1, 2, 2, 1, 1; 1, 2) for 4 Rx; (M, N, P, Mg, Ng; Mp, Np) = (1, 1, 2, 1, 1; 1, 1) for 2 Tx; 0°, 90° polarization
Simulation bandwidth	10 MHz, 20 MHz Note: 10 MHz for DL and 10 MHz for UL for simulation bandwidth of 10 MHz; 20 MHz for DL and 20 MHz for UL for simulation bandwidth of 20 MHz
Other parameters	As shown in Table A.2.3-1 for 4 GHz

A.2.4 Simulation assumption for Rel-15 enabled use case

This subclause describes the simulation assumptions for evaluating Rel-15 enabled use case (e.g. AR/VR). For evaluating Rel-15 enabled use case with urban macro (applicable data packet size 32 bytes and 200 bytes), simulation assumptions are provided in Table A.2.4-1.

Table A.2.4-1: System-level simulation assumptions at 4 GHz for Rel-15 enabled use case with urban macro (applicable data packet size 32 bytes and 200 bytes)

Parameters	Value
Number of UEs per cell	Up to 20 Companies to report the value used in the evaluations Note: Example of the number of users can be 5, 10, 15 and 20. The number of users per cell in this table is the number of pure URLLC UEs
UE distribution	80% of users are outdoors and 20% of users are indoors Indoor penetration loss is modelled according to low loss model
Other parameters	As shown in Table A.2.1-1 for power distribution

For evaluating Rel-15 enabled use case with indoor hot-spot, simulation assumptions are provided in Table A.2.4-2.

Table A.2.4-2: System-level simulation assumptions at 4 GHz for Rel-15 enabled use case with indoor hot-spot

Parameters	Value
Number of UEs per cell	Up to 20 Companies to report the value used in the evaluations Note: Example of the number of users can be 5, 10, 15 and 20. The number of users per cell in this table is the number of pure URLLC UEs.
UE distribution	100% of users are indoors: 3 km/h UE-speed
BS antenna height	3 m
Channel model	ITU InH for 4 GHz
Other parameters	As shown in Table A.2.2-1 for factory automation

A.2.5 Simulation assumption for evaluating multiplexing of eMBB and URLLC UEs sharing the same carrier

This subclause describes the simulation assumptions for evaluating multiplexing of eMBB and URLLC UEs sharing the same carrier. The simulation assumptions provided in Table A.2-1, Table A.2.1-1, Table A.2.2-1, Table A.2.2-2, Table A.2.3-1, Table A.2.4-1 and Table A.2.4-2 are reused with the following additional assumptions:

- Rel-15 enabled use case with 1 ms air interface delay and 32 bytes packet size is evaluated as the baseline. Rel-15 enabled use case with 1 ms or 4 ms air interface delay and 200 bytes packet size, and power distribution (e.g. Power distribution grid fault and outage management) with 2 ms air interface delay should be considered, if provided.
- Either full buffer with 2 eMBB UEs per cell, or FTP model 3 with 10 eMBB UEs per cell with medium to high cell load for eMBB traffic, can be used in the evaluations. 10 URLLC UEs per cell is assumed in the evaluations.
- If full buffer is used for eMBB, cell throughput is evaluated for eMBB. If FTP model 3 is used for eMBB, UE perceived throughput is evaluated for eMBB.
- Performance metrics as shown in section 5.1 are used for evaluating URLLC performance. Company shall report whether maximum URLLC capacity has been reached.
- Rel-15 processing timeline capability #2 is used for URLLC UEs.- A certain ratio(s) of UEs that is not capable of the enhanced schemes can be assumed in the evaluation and company should report the ratio(s)
- eMBB UEs and URLLC UEs have the same subcarrier spacing (for evaluation purpose only)
- Companies shall report the following parameters
  - Resource utilization
  - Number of packets generated per URLLC user in the simulation
  - Coupling loss CDFs of URLLC and eMBB UEs
  - Percentage of UEs in outage, i.e. ~5% if re-dropping is not used, 0% if re-dropping is used
- Companies can optionally report the following parameters
  - PDCCH overhead, for example the number of cancelation indications in the simulation
- Detailed modelling shall be described, including at least the following
  - For UL cancelation indication: UE monitoring periodicity, processing timeline, cancelation with or without resuming
  - For power control: exact power control scheme, e.g. semi-static or dynamic power control with details
  - Retransmission modelling

A.3 Link level simulation assumptions

This subclause describes the link level simulation assumptions used for evaluating Rel-16 NR URLLC. The link level simulation assumptions at the carrier frequencies of 4 GHz for all cases (e.g. power distribution, transport industry and Rel-15 enabled use case) with urban macro are provided in Table A.3-1. The link level simulation assumptions at the carrier frequencies of 4 GHz for all cases with indoor hot-spot (e.g. Rel-15 enabled use case with indoor hot-spot) and factory automation are provided in Table A.3-2. The link level simulation assumptions at the carrier frequencies of 30 GHz for all cases with indoor hot-spot (e.g. Rel-15 enabled use case with indoor hot-spot) and factory automation are provided in Table A.3-2.

Table A.3-1: Link-level simulation assumptions at 4 GHz for all cases with urban macro

Parameter	Value
Carrier frequency for evaluation	4 GHz
Channel model	TDL-C (delay spread: 300ns) as in 38.901
UE speed	3 km/h for power distribution and Rel-15 enabled use case; 60 km/h for remote driving and ITS;
BS antenna configuration	4 Tx/4 Rx antenna ports and 8 Tx/8 Rx antenna ports Higher BS antenna configurations for evaluation are not precluded
UE antenna configuration	2 Tx/4 Rx antenna ports Higher UE antenna configurations for evaluation are not precluded
System bandwidth	40 MHz Note: For FDD, 40 MHz for DL and 40 MHz for UL. Note that this is for evaluation purpose because there is no FDD bands identified at 4 GHz currently. For TDD, 40 MHz for DL/UL.
Sub-carrier spacing	30 kHz Note: Other values for evaluation are not precluded.
Channel estimation	Practical
Receiver type	MMSE
Q value (i.e. SINR range)	Companies report the 5% Q value

- Evaluation of 700 MHz and 2 GHz carrier frequency are not precluded.

Table A.3-2: Link-level simulation assumptions at 4 GHz for all cases with indoor hot-spot and factory automation

Parameter	Value
Carrier frequency for evaluation	4 GHz
Channel model	TDL-D (delay spread: 30ns) as in 38.901 TDL-C (delay spread: 100ns) as in 38.901 Note: Companies report the modification of the channel model if any
UE speed	3 km/h, 30 km/h
BS antenna configuration	4 Tx/4 Rx antenna ports and 8 Tx/8 Rx antenna ports Higher BS antenna configurations for evaluation are not precluded
UE antenna configuration	2 Tx/4 Rx antenna ports Higher UE antenna configurations for evaluation are not precluded
System bandwidth	40 MHz Note: For FDD, 40 MHz for DL and 40 MHz for UL. Note that this is for evaluation purpose because there is no FDD bands identified at 4 GHz currently. For TDD, 40 MHz for DL/UL.
Sub-carrier spacing	30 kHz Note: Other values for evaluation are not precluded.
Channel estimation	Practical
Receiver type	MMSE
Q value (i.e. SINR range)	Companies report the 5% Q value

Table A.3-3: Link-level simulation assumptions at 30 GHz for all cases with indoor hot-spot and factory automation

Parameter	Value
Carrier frequency for evaluation	30 GHz
Channel model	CDL-A (delay spread: 20 ns) as in 38.901
UE speed	3 km/h, 30 km/h
BS antenna configuration	2 Tx/2 Rx antenna ports
UE antenna configuration	2 Tx/2 Rx antenna ports
System bandwidth	160 MHz Note: For TDD, 160 MHz for DL/UL. No FDD bands identified at 30 GHz currently.
Sub-carrier spacing	120 kHz Note: Other values for evaluation are not precluded.
Channel estimation	Practical
Receiver type	MMSE
Q value (i.e. SINR range)	Companies report the 5% Q value

Table A.3-1: Link-level simulation assumptions at 700 MHz for all cases with urban macro

Parameter	Value
Carrier frequency for evaluation	700 MHz
BS antenna configuration	2 Tx/2 Rx antenna ports
UE antenna configuration	2 Tx/2 Rx antenna ports and 2 Tx/4 Rx antenna ports
System bandwidth	10 MHz, 20 MHz Note: 10 MHz for DL and 10 MHz for UL for simulation bandwidth of 10 MHz; 20 MHz for DL and 20 MHz for UL for simulation bandwidth of 20 MHz
Other parameters	As shown in Table A.3-1 for 4 GHz

A.4 Cases used for calibration of the latency results in section 6.4.1.1

To study the need for introducing a new PDSCH and PUSCH processing timelines, the following cases are used for calibration of the results amongst the companies:

- For evaluating the impact of processing times on downlink latency:
  - The latency of the initial transmission must include the gNB processing time after receiving a packet from the higher layers and the alignment delay.
    - The alignment delay includes the gap between the two consecutive PDCCH monitoring occasions for FDD, the PDCCH transmission latency due to the UL/DL configuration for TDD, and the scheduling constraint due to the slot boundaries.
    - The alignment delay should also be considered for scheduling the later PDSCHs.
  - gNB's processing time for transmission of the initial PDSCH and gNB's PUCCH-to-PDCCH processing time for re-transmission of the PDSCH:
    - Case1: UE's N2/2 + X for scheduling the initial PDSCH and UE's N2 + X for re-transmission.
      - X = 2/4/8 symbols for SCS = 30/60/120KHz, respectively.
  - PDCCH duration = 1 symbol
  - 1-symbol overlap between PDCCH and PDSCH
  - Number of PDCCH monitoring occasions per slot = 4/7
    - For the case of 4 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,0,0,0,1,0,0,0,1,0,0,0,1,0];

        - For the case of 7 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,0,1,0,1,0,1,0,1,0,1,0,1,0];
    - PDSCH duration:
        - 2 symbols
        - 4 symbols
        - 7 symbols
    - PDSCH with front-loaded DMRS is assumed.
    - PDSCH of mapping type B is assumed.
    - PUCCH duration = 1 symbol
    - Number of PUCCH carrying HARQ-ACK for URLLC per slot is 7 and using the following pattern: [1,0,1,0,1,0,1,0,1,0,1,0,1,0];
    - UE decoding time for the last PDSCH: is N1 + d_1,1

- For evaluating the impact of processing times on uplink latency:
    - The latency of the initial transmission must include the alignment delay.
        - For the case of SR-based PUSCH, the alignment delay includes the gap between the two consecutive SR occasions for FDD, the SR transmission latency due to the UL/DL configuration for TDD, and the scheduling constraint due to the slot boundaries.
        - For the case of grant-free PUSCH, the alignment delay includes the transmission constraint due to the grant-free UL occasions for the initial transmission, and the scheduling constraint due to the slot boundaries for the grant-based re-transmission.
        - For both SR-based PUSCH and grant-free PUSCH, the alignment delay should also be considered for PUSCH re-transmission triggered by a dynamic grant.
        - The first symbol of PUSCH consists of only DMRS.
        - PUSCH with type-B mapping and no additional DMRS is assumed.
    - For the case of grant-free PUSCH, the latency of the initial transmission must also include the UE's processing time given as UE's N2/2
    - gNB's PUSCH-to-PDCCH processing time (note that PDCCH alignment has to be included separately) is UE's N1 + X
        - X = 2/4/8 symbols for SCS = 30/60/120KHz, respectively.
    - gNB's decoding time for the last PUSCH is UE's N1/2 + X
        - X = 2/4/8 symbols for SCS = 30/60/120KHz, respectively.
    - PUSCH duration:
        - Case 1: 2
        - Case 2: 4
        - Case 3: 7
    - For dynamic PUSCH, it is assumed that the TB cannot be repeated across the slot boundary.
    - PDCCH duration: 1 symbol
    - Number of PDCCH monitoring occasions per slot = 4/7

        - For the case of 4 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,0,0,0,1,0,0,0,1,0,0,0,1,0];
        - For the case of 7 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,0,1,0,1,0,1,0,1,0,1,0,1,0];
    - For GF-PUSCH:
        - The re-transmission is triggered by a dynamic grant.
        - The number of PUSCH transmission occasions per slot:
            - 7 for the case of 2-symb PUSCH (i.e., the UL pattern is [2, 2, 2, 2, 2, 2, 2].)
            - 3 for the case of 4-symbol PUSCH (i.e., the UL pattern is [4, 4, 4, 0].)
            - 2 for the case of 7-symb PUSCH (i.e., the UL pattern is [7, 7].)
    - For SR-based PUSCH:
        - gNB's processing time for SR is UE's N1
        - Duration of the PUCCH for SR: 1 symbol
        - Number of SR occasions per slot: 7 with [1,0,1,0,1,0,1,0,1,0,1,0,1,0] configuration.

- For SCS = 30/60 KHz, FDD is assumed.
    - The companies can additionally consider TDD; the assumed TDD UL/DL configuration should be reported.
- For SCS = 120KHz, the companies report the considered TDD UL/DL configuration (e.g., [D,D,D,D,D,D,F,F,U,U,U,U,U,U] can be assumed, where 'F' indicates the semi-static flexible symbol.)
- In this study, a timing advance is assumed to be 0.
- The gNB processing times assumed in here are only for the purpose of this study, and are not necessarily indicative of actual gNB processing capabilities.

- For each scenario, the following parameters are reported:
    1) The worst-case latency for completing a single-shot transmission under NR Rel. 15 N1/N2 capabilities.
        - Cap#2 for SCS = 30/60 KHz and Cap#1 for SCS = 120KHz are assumed.
    2) The worst-case latency for completing two transmissions (i.e., the initial transmission and one HARQ-based re-transmission) under NR Rel. 15 N1/N2 capabilities.
        - Cap#2 for SCS = 30/60 KHz and Cap#1 for SCS = 120KHz are assumed.
    3) In case a single-shot transmission cannot be completed under (1), companies report the maximum required N1/N2 (smaller than those of the NR Rel. 15) to complete a single-shot transmission within 1ms.
        - Also, the latency reduction gains as compared to (1) above.
    4) In case two transmissions cannot be completed under (2), companies report the maximum required N1/N2 (smaller than those of the NR Rel. 15) to complete two transmissions (i.e., the initial transmission and one HARQ-based re-transmission) within 1ms.
        - Also, the latency reduction gains as compared to (2) above.
    5) Support/No support for introducing new processing timing capabilities for Rel. 16 eURLLC.

- For the DL study, it is assumed that N2=N1 when calculating gNB processing time. This assumption applies only to the Rel. 16 based analysis.
- For the UL study, it is assumed that N2=N1 when calculating gNB processing time. This assumption applies only to the Rel. 16 based analysis.
- Besides the above mentioned values, the companies can consider other values for gNB's processing time for transmission of the initial PDSCH and gNB's PUCCH-to-PDCCH processing time for re-trasnmission of the PDSCH, gNB's PUSCH-to-PDCCH processing time, and gNB's decoding time for the last PUSCH. In case other values are considered, the assumption of N2 = N1 when calculating the gNB processing time for the Rel. 16 analysis is not required.
- For the UL study, a solution with N2 of Rel. 15 > N2 of Rel. 16 = N1 of Rel. 16 > N1 of Rel. 15 is not valid.
- The LLS and SLS evaluation results can be reported under the methodology agreed in RAN1 #95 for the scenarios identified above.

Annex B: Change history

Change history							
Date	**Meeting**	**TDoc**	**CR**	**Rev**	**Cat**	**Subject/Comment**	**New version**
2018-08	RAN1#94	R1-1809861				Skeleton TR	0.0.0
2018-10	RAN1#94 bis	R1-1811105				Inclusion of agreements made at RAN1#94 on system-level simulation assumptions	0.0.1
2018-10	RAN1#94 bis	R1-1811909				Updated based on R1-1811105 by removing section 7.2.3	0.0.2
2018-11	RAN1#95	R1-1813469				Inclusion of agreements made at RAN1#94bis	0.0.3
2018-11	RAN1#95	R1-1814025				Updated based R1-1813469 with some editorial changes	0.0.4
2018-11	RAN1#95	R1-1814036				Updated based R1-1814025 with some editorial changes	0.0.5
2018-11	RAN1#95	R1-1814401				Updated based R1-1814036 with inclusion of agreements made at RAN1#95	0.0.6
2018-11	RAN1#95	R1-1814402				MCC clean-up – version for information to plenary	1.0.0
2019-02	RAN1#96	R1-1902932				Updated based R1-1814402 with inclusion of agreements made at RAN1#AH 1901.	1.0.1
2019-02	RAN1#96	R1-1903438				Updated based on R1-1902932 with some editorial changes.	1.0.2
2019-02	RAN1#96	R1-1903798				Updated based on R1-1903438 with inclusion of agreements made at RAN1#96.	1.1.0
2019-03	RAN1#96	R1-1903829				Updated based on R1-1903798 with inclusion of more agreements made at RAN1#96.	1.2.0
2019-03	RAN#83	RP-190423				For approval by RAN plenary – includes MCC clean-up	2.0.0
2019-03	RAN#83	RP-190621				Additional clean-up and reformating of tables under 6.4.1.1	2.0.1
2019-03	RAN#83					TR under change control further to RAN decision and approval	16.0.0