**3GPP TSG RAN WG1 Meeting #102-e R1-20xxxxx**

**E-meeting, August 17– 28, 2020**

**Agenda Item: 8.8.2**

**Source: Moderator (China Telecom)**

**Title: [102-e-Post-NR-CovEnh-02] Phase 3: initial collection of simulation results for enhancements**

**Document for: Discussion**

1. Introduction

As per the guidance of Chairman, there is following email discussion:

 [102-e-Post-NR-CovEnh-02] Email discussion/approval of link budget template, initial collection of simulation results for baseline and enhancements - Yosuke (Softbank)/Marco (Nokia)/Jianchi (CT)/Yi (Qualcomm)/Xianghui(ZTE)

· Phase 1 (9/9 to 9/29): link budget template

· Phase 2 (9/30 to 10/14): initial collection of simulation results for baseline

· Phase 3: (10/12 to 10/21): initial collection of simulation results for enhancements

This contribution is a summary of Phase 3: initial collection of simulation results for enhancements.

2. Simulation results for PUSCH enhancements

## 2.1 Time domain based solutions

Increase the number of repetitions for PUSCH repetition type A

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 |  | 3.2 dB | DDDSUDDSUU, O2I, repetitions counted on the basis of available UL slots |
|  | 4.0 dB | DDDSUDDSUU, VoIP, O2O, repetitions counted on the basis of available UL slots |
| ZTE | FR1 |  | 1~1.5 dB | Rural, O2O, 2 DMRS symbols.  Baseline scheme: 4 repetitions with maximum 1 re-transmission (Max 8 transmissions)  Enhanced scheme: 2 repetitions with maximum 3 re-transmissions (Max 8 transmissions). |
| Intel | FR1 | ~2.0dB |  | ~2dB performance gain can be observed when doubling the repetition level.  Rural 3km/h, 700MHz, FDD, TBS = 136 bits, MCS 0, 2 DMRS symbols, 12 data symbols |
| NTT DOCOMO | FR1 | 6.4 dB | 6.8 dB | Comparing w and w/o repetition (number of repetition is 4)  To support repetition for e.g. DDDSU, new mechanism is necessary |

Enhancement on PUSCH repetition Type B

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 |  | 0.8 dB | DDDSUDDSUU, O2I/O2O, across slot boundary, length > 14 OS |
| ZTE | FR1 |  | 0.8 dB | 4GHz, ‘DDDSU’ (S: 10D:2G:2U)  Baseline scheme: 14-symbol PUSCH, MCS#5  Enhanced scheme: 16-symbol PUSCH, MSC#4 |
| FR1 |  | 0.8 dB | 4GHz, ‘DDDSU’ (S: 10D:2G:2U)  Baseline scheme: PUSCH of 2 repetitions, and the length of each nominal repetition is L=8.  Enhanced scheme: Actual repetition can cross slot boundary. The duration of each actual repetition is L=8. |

TB processing at least over multi-slot PUSCH

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 |  | 1.0 dB | DDDSUDDSUU, O2I, TBS based on 4 slots |
|  | 0.6 dB | DDDSUDDSUU, O2O, TBS based on 4 slots |
| 2.7 dB |  | DDDSUDDSUU, rural, O2O, TBS based on 4 slots |
| IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | FR1 | 0.8 dB |  | 2 slots aggregation, TBS based on 2 slots, DDDSU, rural TDL-D, 30ns |
| Intel | FR1 |  | ~0.2dB | Baseline scheme 1: 4 PRBs in a slot, 14 symbols.  TB spanning multiple slots: 1 PRB spanning 4 slots  Link level simulation results for these two schemes are similar, but link budget gain of ~6dB for TB spanning 4 slots over baseline scheme can be observed.  Simulation assumption: 3km/h, 4 GHz, TDD with DDDSU |
| Qualcomm | FR1 | 1-2 dB | 1-2 dB | Baseline: 1 PRB/slot. TB sized per slot.  Proposal: Aggregate PRBs across multiple slots. Size TB for total aggregated resources.  Observation: 2 slot aggregation results in ~1 dB gain, while 4 slot aggregation results in 2 dB gain.  Additional gain due to overhead reduction is not included here. |

## 2.2 Frequency domain based solutions

Inter-slot frequency hopping

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| ZTE | FR1 | 0.5 dB |  | 4GHz, Rural, MCS#2, one DMRS per hop  Baseline scheme: 2 FH positions  Enhanced scheme: 4 FH positions |
| Intel | FR1 | 0.3dB |  | Rural 3km/h, 700MHz, FDD, TBS=136 bits, MCS 0, 8 repetitions, 2 DMRS symbols, 12 data symbols  For 4 Rx antennas, ~0.3dB performance gain can be achieved for 4 frequency hops compared to 2 frequency hops. |
| 1.5dB |  | Same simulation assumptions as above.  For 2 Rx antennas, ~1.5dB performance gain can be achieved for 4 frequency hops compared to 2 frequency hops. |
| Qualcomm | FR1 | 0 dB |  | Scenario: Urban 4GHz with 64 TXRUs.  Baseline: 4 repetitions with 2 inter-slot frequency hops.  Comparison: 4 repetitions with 4 inter-slot frequency hops. |

Inter-slot frequency hopping with inter-slot bundling to enable cross-slot channel estimation

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 |  | 0.5 dB | FDD, O2I, 2 slots bundling |
| ZTE | FR1 | 0.5 dB |  | 4GHz, Urban, MCS#3, one DMRS per hop.  Baseline scheme: Inter-slot FH  Enhanced scheme: FH per two repetitions and cross-slot channel estimation among two repetitions per hop. |
| Intel | FR1 | ~1.0dB |  | Rural 3km/h, 700MHz, FDD, TBS=136 bits, MCS 0, 8 repetitions, 2 DMRS symbols, 12 data symbols  Enhanced inter-slot FH pattern: same frequency resource in 4 consecutive slots. Cross-slot channel estimation is employed with a fixed window size of 4 slots for both Rel-15 inter-slot FH and enhanced inter-slot FH. When employing cross-slot channel estimation, ~1.0dB performance gain can be achieved by enhanced inter-slot FH pattern, compared to Rel-15 inter-slot FH. |
| Samsung | FR1 |  | 2.5 dB | Residual BLER  DDDSUDDSUU, 4GHz with O2I, 4PRB, Delay spread: 300 ns, Max # of HARQ tx: 4, Latency: 50 ms, Frequency hopping offset: 40RBs, 1 DMRS |
| FR1 |  | 2.1 dB | Residual BLER  DDDSUDDSUU, 4GHz with O2I, 4PRB, Delay spread: 300 ns, Max # of HARQ tx: 4, Latency: 50 ms, Frequency hopping offset: 40RBs, 2 DMRS |
| FR2 |  | 1.55 dB | Residual BLER  DDDSUDDDSU, 28GHz with O2I, 4PRB, Delay spread: 100 ns, Max # of HARQ tx: 16, Latency: 50 ms, Frequency hopping offset: 40RBs, 1 DMRS |
| FR2 |  | 1 dB | Residual BLER  DDDSUDDDSU, 28GHz with O2I, 4PRB, Delay spread: 100 ns, Max # of HARQ tx: 16, Latency: 50 ms, Frequency hopping offset: 40RBs, 2 DMRS |

Enhancements on frequency hopping for PUSCH repetition type B

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
|  | FR1 |  |  |  |
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| FR2 |  |  |  |
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Sub-PRB transmission for VoIP

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 |  | 0.8 dB | DDDSUDDSUU, O2O, half PRB and 8 slots |
| NTT DOCOMO | FR1 | - | 1 dB | 2 RBs (coding rate : 60/1024)  1 RB (coding rate : 120/1024) |
| Samsung | FR1 |  | 5.6 dB | DDDSUDDSUU, TBS=80 per 5ms, 2.7 times smaller T-F resource for subPRB (4PRB\*1slot vs 0.5PRB\*3slots), TDL-A, Delay spread: 30ns, SCS=30KHz, 4Ghz  Note: Required SNR: rel-16 is better with 0.5dB;  Occupied BW (thus noise power): sub-PRB is better as 9dB; |
| 8.5dB |  | TBS=50 (per transmission), TDL-C, Delay spread: 300ns, Same T-F resource (4PRB\*1slot vs 0.5PRB\*8slots), SCS=30KHz, 4Ghz  Note: Required SNR: rel-16 is better with 3.4dB;  Occupied BW (thus noise power): sub-PRB is better as 9dB; |

## 2.3 DM-RS enhancements

Cross-slot channel estimation

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 | 0.4 dB |  | DDDSUDDSUU, rural O2I, 2 slots |
| 0.8 dB |  | FDD, rural O2I, 2 slots |
| ZTE | FR1 | 1.8 dB |  | 4GHz, MCS#5, one DMRS per repetition, 8 repetitions, No FH.  Baseline scheme: No cross-slot channel estimation  Enhanced scheme: Cross-slot channel estimation |
| Intel | FR1 | ~2.0dB |  | Rural 3km/h, 700MHz, FDD, TBS=136 bits, MCS 0, 8 repetitions, 2 DMRS symbols, 12 data symbols. Cross-slot channel estimation is employed with a fixed window size of 4 slots  For Rel-15 inter-slot FH, cross-slot channel estimation can provide ~2dB performance gain compared to the case without cross-slot channel estimation. |
| ~3.0dB |  | Same simulation assumptions as above. Enhanced inter-slot FH pattern: same frequency resource in 4 consecutive slots.  Compared to Rel-15 inter-slot FH without cross-slot channel estimation, ~3dB can be achieved by enhanced inter-slot frequency hopping with cross-slot channel estimation |
| Qualcomm | FR1 | 1-2 dB |  | Baseline: PUSCH 1RB allocation, 4 reps.  Enhancement: PUSCH 1 RB allocation, 0/2/4 reps, with cross-slot channel estimation. |
| Sharp | FR1 | 1.5 dB |  | Baseline: PUCCH, 1 RB allocation, repetition with 4 slots in FDD  Enhancement: PUCCH, 1 RB allocation, repetition with 4 slots in FDD, cross-slot channel estimation with 4 slots |
| Panasonic | FR1 | 1.0 dB |  | Rural, 4 GHz, DDDSUDDSUU, 3 km/h  4PRBs, 2 repetitions, w/o HARQ  Baseline: w/o cross-slot channel estimation  Enhancement: w/ cross-slot channel estimation |
| NTT DOCOMO | FR1 |  | 1 dB | Number of repetition is 2 for consecutive 2 UL slots assuming DDDSUDDSUU for FR1 |
| Samsung | FR1 |  | 1.3 dB | DDDSUDDSUU, 4GHz with O2I, 4PRB, Delay spread: 300 ns, Max # of HARQ tx: 4, Latency: 50 ms, 1 DMRS |
| FR1 |  | 0.9 dB | DDDSUDDSUU, 4GHz with O2I, 4PRB, Delay spread: 300 ns, Max # of HARQ tx: 4, Latency: 50 ms, 2 DMRS |
| FR2 |  | 1.1 dB | DDDSUDDDSU, 28GHz with O2I, 4PRB, Delay spread: 100 ns, Max # of HARQ tx: 16, Latency: 50 ms, 1 DMRS |
| FR2 |  | 0.85 dB | DDDSUDDDSU, 28GHz with O2I, 4PRB, Delay spread: 100 ns, Max # of HARQ tx: 16, Latency: 50 ms, 2 DMRS |

Lower DMRS density

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| ZTE | FR1 | 1 dB |  | 2GHz, 14-symbol PUSCH, one DMRS, DMRS type 1, one port transmission.  Baseline scheme: DMRS type 1, one port transmission, 3 dB power boosting on DMRS RE compared to data RE.  Enhanced scheme: Only mapping DMRS type 1 on even PRBs, 6 dB power boosting on DMRS RE compared to data RE. |
| Intel | FR1 | -0.2dB |  | Baseline scheme: 2 DMRS symbols in each slot  Lower DMRS density scheme: 2 DMRS symbols in even slots and no DMRS in odd slots  Rural 3km/h, 700MHz, FDD, TBS=136 bits, MCS 0, 8 repetitions, 2 DMRS symbols, 12 data symbols |
|  |  |  |  |  |

Higher DMRS density

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| China Telecom | FR1 | 0.5 dB |  | DDDSUDDSUU, urban O2I, 1-comb DM-RS |
| 1.5 dB |  | DDDSUDDSUU, rural O2O, 1-comb DM-RS |
| Intel | FR1 | -0.05dB |  | Baseline scheme: 4 DMRS symbols in each slot  Higher DMRS density: 5 or 6 DMRS symbols in each slot  Rural 3km/h, 700MHz, FDD, TBS=136 bits, MCS 0, 8 transmissions, 2 DMRS symbols, 12 data symbols. Inter-slot FH |
| NTT DOCOMO | FR1 |  | 1 dB | Symbol duration 1 or 2  Additional DMRS symbol position : pos3 |

Adaptive DMRS configuration

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| --- | --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
| Qualcomm | FR1 | 1.7 dB |  | PUSCH with 14 symbol allocation. 1 Tx, 4 Rx. Channel: TDL-C 300ns, 3 kmph. Performance gap between optimal DMRS and suboptimal DMRS choice is reported as gain. |
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DM-RS balancing among frequency hops

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| Company | Frequency Range | Performance gain | | Key Assumptions |
| eMBB | voice |
|  | FR1 |  |  |  |
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| FR2 |  |  |  |
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## 2.4 Other solutions for PUSCH coverage enhancements

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| --- | --- | --- | --- | --- | --- |
| Company | Solutions | Performance gain | | | Key Assumptions |
| eMBB | | voice |
| China Telecom | Enhanced intra-slot frequency hopping |  | | 1.8 dB | DDDSUDDSUU, O2O |
| 0.4 dB | |  | DDDSUDDSUU, rural O2I |
| IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | Power boosting for pi/2 BPSK | 3 dB for <50% UL duty cycle | | |  |
| 6 dB for <25 % UL duty cycle | | |  |
| Qualcomm | Implicit switching between DFT-S-OFDM and CP-OFDM | 2-3dB (due to change in tx power) | | | Aimed at avoiding a RRC reconfig to change waveform from CP-OFDM to DFT-S-OFDM. |
| Qualcomm | Techniques to reduce MPR in uplink transmissions | 1-1.5 dB (due to increase in tx power) | | | Aimed at increasing uplink transmit power for DFT-S-OFDM and CP-OFDM waveforms. |
| Panasonic | Symbol-level repetition | 0.4 dB |  | | Rural, 4 GHz, DDDSUDDSUU, 3 km/h  4PRBs, 2 repetitions, w/o HARQ  Baseline: w/o cross-slot channel estimation |

3. Simulation results for PUCCH enhancements

## 3.1 Prioritized solutions

DMRS-less PUCCH

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| Company | Frequency Range | Performance gain | Key Assumptions |
| ZTE | FR1 | 2~3 dB | 4GHz, 11 bits UCI  Baseline scheme: PUCCH format 3  Enhanced scheme: Sequence based PUCCH with 2^11 sequences. |
| Intel | FR1 | -1.0dB | PF3, 1Tx2Rx, FDD 700MHz, 3 UCI bits, 1% DTX to ACK, 1% ACK misdetection.  Baseline scheme: existing PF3  DMRS-less scheme: sequence based with PN sequence  For 3 UCI bits, existing PUCCH format 3 can outperform DMRS-less PUCCH schemes by >1dB, |
| 0.2dB | For 11 UCI bits, existing PUCCH format 3 can achieve similar performance compared to DMRS-less PUCCH schemes. |
| Qualcomm | FR1 & FR2 | 3 - 4 dB | Results for PUCCH with 2 bits payload:   * Baseline: NR PUCCH Format 1, 14 OFDM symbols * Enhancement: Orthogonal sequence design for non-coherent PUCCH * Perf. Target: 1% ACK🡪DTX, 0.1% NACK🡪 ACK. * Lower complexity receiver compared to R15/R16 PF3 receiver. * Robust to timing and freq errors   Results for PUCCH with 4 bits:   * Baseline: NR PUCCH Format 3, 14 OFDM symbols * Enhancement: Orthogonal sequence design for non-coherent PUCCH * Perf. Target: 1% BLER * Lower complexity receiver compared to R15/R16 PF3 receiver. * Robust to timing and freq errors   Results for PUCCH with 11 bits:   * Baseline: NR PUCCH Format 3, 4-14 OFDM symbols * Enhancement: Non-orthogonal sequence design for non-coherent PUCCH * Perf. Target: 1% BLER * Lower complexity receiver compared to R15/R16 PF3 receiver. * Robust to timing and freq errors |
| Sharp | FR1 | 3 dB | Baseline: Rel-15 PUCCH format 3 with 4 bits, ML detector, 14 symbols, 1 RB allocation  Enhancement: New PUCCH format with 4 bits for sequence selection, correlation detector, 14 symbols, 1 RB allocation |

PUSCH-repetition-Type-B like PUCCH repetition at least for UCI <=11 bits

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| --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | Key Assumptions |
|  | FR1 |  |  |
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| FR2 |  |  |
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(Explicit or implicit) Dynamic PUCCH repetition factor indication

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| --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | Key Assumptions |
| ZTE | FR1 | Reducing the number of PUCCH repetitions for more than 70% cases. | Set the SNR at the required SNR for the case with 11bits UCI and 4 PUCCH repetitions. Collect the instantaneous SNR on each PRB.  More than 70% of instantaneous SNR on the RBs can satisfy the required SNR of 2 repetitions. |
| Qualcomm | FR2 | Helps robust beam switching (L1 beam report reliability increased) | In FR2, incorrect beam switching can lead to link failure. Building robustness around the beam switching procedure is desirable. |
|  |  |  |  |

DMRS bundling cross PUCCH repetitions

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| --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | Key Assumptions |
| ZTE | FR1 | 1 dB | Urban, 4GHz, 4 PUCCH repetitions.  Baseline scheme: Inter-slot FH for PUCCH repetition.  Enhanced scheme: FH per two repetitions and cross-slot channel estimation among two repetitions per hop. |
| Intel | FR1 | ~1.2dB | PF3, 1Tx2Rx, FDD 700MHz, 22 UCI bits, 8 repetitions  Enhanced inter-slot FH pattern: same frequency resource in 4 consecutive slots. Cross-slot channel estimation is employed with a fixed window size of 4 slots.  For Rel-15 inter-slot FH, cross-slot channel estimation can provide ~1.2dB performance gain compared to the case without cross-slot channel estimation. |
| ~2.8dB | PF3, 1Tx2Rx, FDD 700MHz, 22 UCI bits, 8 repetitions  Enhanced inter-slot FH pattern: same frequency resource in 4 consecutive slots.  Compared to Rel-15 inter-slot FH without cross-slot channel estimation, ~2.8dB can be achieved by enhanced inter-slot FH with cross-slot channel estimation. |

## 3.2 Other solutions for PUCCH coverage enhancements

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| Company | Solutions | Performance gain | Key Assumptions |
| CATT | One antenna precoder cycling | 1 dB | Two precoders are applied to consecutive resources in a cycling manner. One antenna port is assumed. |
| IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | Power boosting for pi/2 BPSK | 3 dB for <50% UL duty cycle |  |
| 6 dB for <25 % UL duty cycle |
| Qualcomm | UCI payload compression (FR2 L1 beam report) | Helps increase reliability of beam switching procedure | PUCCH carrying larger payloads can be a coverage bottleneck. Payload size reduction helps improve reliability. |
| NTT DOCOMO | Repetition for PUCCH format 2 | 1.5 dB | Number of repetition : 2 |

4. Simulation results for enhancements on other channels / signals

Msg3 PUSCH repetition

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| --- | --- | --- | --- |
| Company | Frequency Range | Performance gain | Key Assumptions |
| ZTE | FR1 | 2.6dB | Rural, 700MHz, O2O, No FH  Baseline scheme: Msg3 PUSCH with one repetition.  Enhanced scheme: Msg3 PUSCH with two repetitions. |
| 2.4 dB | Urban, 4GHz, O2I, No FH  Baseline scheme: Msg3 PUSCH with one repetition.  Enhanced scheme: Msg3 PUSCH with two repetitions. |
| 5.2 dB | Rural, 700MHz, O2O, No FH  Baseline scheme: Msg3 PUSCH with one repetition.  Enhanced scheme: Msg3 PUSCH with four repetitions. |
| 4.7 dB | Urban, 4GHz, O2I, No FH  Baseline scheme: Msg3 PUSCH with one repetition.  Enhanced scheme: Msg3 PUSCH with four repetitions. |
| 0.5dB~ 1.07dB | Urban, 4GHz, O2I  Baseline scheme: Msg3 PUSCH with 4 repetitions.  Enhanced scheme: Msg3 PUSCH with 4 repetitions and cross-slot channel estimation. |
| Intel | FR1 | ~2dB | TBS = 56, MCS = 0, 3 DMRS symbols that are allocated in each slot and UE moving speed of 3km/h  ~2dB performance gain can be observed with doubling the repetition levels for Msg3 PUSCH |
| NTT DOCOMO | FR1 | 3.46 dB (2 repetition) | Channel: Urban  Center frequency: 2.6 GHz  RV: 0,0 |
| 6.27 dB (4 repetition) | Channel: Urban  Center frequency: 2.6 GHz  RV: 0,0,0,0 |

For evaluation results of other enhancements for Msg3 other than Msg3 repetition or enhancements for other channels/signals including PBCH, unicast/broadcast PDCCH, PDSCH, PRACH, A-CSI and PUCCH with HARQ-ACK for Msg4 etc., please include in the following table:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Company | Channels/Signals | Solutions | Performance gain | Key Assumptions |
| ZTE | SSB | Increasing the number of SSBs | 1.84 dB | Rural, 700MHz  Baseline scheme: 4 SSBs  Enhanced scheme: 8 SSBs |
| PRACH | PRACH repetition | 3.7 dB | Urban, 4GHz, O2I  Baseline scheme: one PRACH transmission  Enhanced scheme: PRACH with 2 repetitions |
| 5.2 dB | Urban, 4GHz, O2I  Baseline scheme: one PRACH transmission  Enhanced scheme: PRACH with 4 repetitions |
| 1.7 dB | Urban, 28GHz, O2I  Baseline scheme: one PRACH transmission  Enhanced scheme: PRACH with 2 repetitions |
| 3.7 dB | Urban, 28GHz, O2I  Baseline scheme: one PRACH transmission  Enhanced scheme: PRACH with 4 repetitions |
| PRACH beam sweeping | 2.5 dB | Rural, 2GHz  Baseline scheme: 1 PRACH transmission  Enhanced scheme: 2 PRACH transmission with different beam |
| PUCCH with Msg4 HARQ-ACK | PUCCH repetition | 3 dB | Rural, 2GHz, 2Rx, PUCCH format 1, 1 bit  Baseline scheme: one PUCCH transmission  Enhanced scheme: PUCCH with 2 repetitions |
| 6 dB | Rural, 2GHz, 2Rx, PUCCH format 1, 1 bit  Baseline scheme: one PUCCH transmission  Enhanced scheme: PUCCH with 4 repetitions |
| PDCCH | PDCCH repetition | 2.8~3.1 dB | Rural, 2GHz, 2Tx-2Rx, AL=16  Baseline scheme: one PDCCH transmission  Enhanced scheme: PDCCH with 2 repetitions with separate decoding or joint decoding among 2 repetitions. |
| 4~5.8 dB | Urban, 4GHz, 4Tx-4Rx, AL=16  Baseline scheme: one PDCCH transmission  Enhanced scheme: PDCCH with 4 repetitions with separate decoding or joint decoding among 2 repetitions. |
| IITH, IITM, CEWIT, Reliance Jio, Tejas Networks | Msg3 | Power boosting using pi/2 BPSK waveform | 3 dB for <50% UL duty cycle |  |
| 6 dB for <25% UL duty cycle |
| NTT DOCOMO | PDCCH | Aggregation for time domain | 2 dB | Number of PDCCH symbol = 2 and 4 |
| NTT DOCOMO | PDCCH | Compact DCI | 1.5 dB | Payload size = 40 bits and 20 bits |

5. Reference

1. RAN1 Chairman’s Notes of RAN1#102-e

6. Agreements

**Agreements:**

* Capture the following updated structure in TR 38.830.

6.1 PUSCH coverage enhancements

6.1.1 Time-domain based solutions

6.1.2 Frequency-domain based solutions

6.1.3 DM-RS enhancements

6.1.4 Power-domain based solutions

6.1.5 Spatial-domain based solutions

6.1.6 Others

**Agreements:**

* Prioritize the study on the performance and specification impacts on time domain based solutions for PUSCH enhancements, including
  + Increase the number of repetitions for PUSCH repetition  type A
    - PUSCH repetition with non-consecutive slots/on the basis of available slots for TDD
    - Note: whether increasing the number of PUSCH repetition for FDD depends on the outcome of AI 8.8.1.1.
  + Enhancement on PUSCH repetition Type B
    - E.g., actual repetition across the slot boundary, or the length of actual repetition larger than 14 symbols, etc.
  + TB processing at least over multi-slot PUSCH
    - e.g., single TB, sized for a single slot, but transmitted in parts over multiple slots; or single TB, sized for multiple slots, transmitted over multiple slots, and in conjunction with repetition, etc.
* FFS
  + OCC spreading based repetition
  + Symbol-level repetition
  + TB interleaving
  + RV repetition
  + Early termination of PUSCH repetitions

**Agreements:**

* Following solutions are not considered for PUSCH enhancements in this study item in RAN1:
  + Enhancements to improve spherical coverage / beam correspondence
  + Reflective arrays
  + Polarization aspects of the UL and/or DL reference signals

**Agreements:**

* Prioritize the study on the performance and specification impacts on DM-RS enhancements for PUSCH, including
  + Cross-slot channel estimation
  + With a lower priority compared with cross-slot channel estimation (i.e., companies are encouraged to study it)
    - Lower density
      * E.g., DM-RS sharing among multiple PUSCH transmissions **or lower DMRS density in the frequency domain.**
    - Higher density
      * E.g., in time or frequency domain, e.g., 1-comb pattern
    - Adaptive configuration
    - DM-RS balancing among frequency hops

**Agreements:**

* Multiple layer PUSCH transmission with DFT-S-OFDM for PUSCH enhancements can be studied with low priority.
* Study open-loop/closed loop Tx diversity for PUSCH enhancements with low priority.

**Agreements:**

* Study the performance and specification impacts on frequency domain based solutions for PUSCH, including
  + Inter-slot frequency hopping
    - with more frequency offsets
    - with more frequency hopping positions.
  + Inter-slot frequency hopping with inter-slot bundling to enable cross-slot channel estimation
  + Enhancements on frequency hopping for PUSCH repetition type B
    - Note that the above inter-slot frequency hopping enhancement can apply for PUSCH repetition type B
  + Sub-PRB transmission for VoIP
    - FFS: details, e.g., number of tones, multi-slot aggregation
* FFS
  + Intra-slot frequency hopping
    - with more frequency offsets
    - with more frequency hopping positions.

[Note: Appropriate simulation assumptions are expected.]

**Agreements:**

* Study following power domain based solution for PUSCH enhancements
  + Waveform design to optimize MPR/A-MPR
  + [FDD high power UE]
  + Power boosting for pi/2 BPSK

Note: if a LS to RAN4 (for the last two bullets) is deemed necessary, target sending the LS in the 1st week of RAN1#103-e

**Agreements:**

Contingent on all of the outcome of sub-agenda 8.8.1 regarding PUCCH enhancements, prioritize the study of the following schemes for PUCCH coverage enhancement,

* DMRS-less PUCCH
  + FFS: design detail for DMRS-less PUCCH, e.g., sequence based PUCCH transmission, v.s. reuse Rel-15 scheme to transmit UCI without DMRS
* Rel-16 PUSCH-repetition-Type-B like PUCCH repetition at least for UCI <=11 bits.
* (Explicit or implicit) Dynamic PUCCH repetition factor indication
* DMRS bundling cross PUCCH repetitions
  + Including study of transmitting a subset of PUCCH repetitions without DMRS, at least for UCI<=11 bits

Note 1: other schemes are not excluded.

Note 2: the study on DMRS bundling for PUCCH repetition can be a joint study with DMRS bundling for PUSCH repetition studied under 8.8.2.1.

Note 3: Companies are invited to report details of the receivers used in the evaluation. Advanced receiver can be included (not mandatory) in performance evaluations. Performance and receiver complexity are discussed respect to a baseline Rel-15/16 PUCCH scheme.

Note 4: proposed PUCCH repetitions scheme shall account for the resources used by PUSCH to meet the throughput target and should be compared against Rel-15/16 PUCCH repetition framework.

[Note 5: enhancement on one or more PUCCH formats/UCI types may or may not be needed, depends on the outcome of sub-agenda 8.8.1]

**Agreements:**

Deprioritize the study of the following schemes for PUCCH coverage enhancement

* UE Antenna configuration enhancement for FR2
* Relay (including sidelink relay)
* Reflective arrays

**Agreements:**

Contingent on all of the outcome of sub-agenda 8.8.1 regarding PUCCH enhancements, the following schemes for PUCCH coverage enhancement can be further studied

* Sequence based PF 0/1 with Pi/2 BPSK
* Pre-DFT data-RS multiplexing for PF2 with Pi/2 BPSK
* UCI size reduction
* Freq hopping enhancement for PUCCH
* Short/mini-slot PUCCH repetition
* Power control enhancement for PUCCH (including power boost for pi/2 BPSK)
* Increase maximum # allowed repetitions for PUCCH
* PUCCH Transmit diversity scheme
* Symbol-level repetition for long PUCCH
* Split UCI payload on short and long PUCCH on adjacent S and U slots
* Potential higher DMRS density for PUCCH with repetitions

**Conclusion:**

For the performance evaluation of PUCCH coverage enhancement schemes under 8.8.2.2, use PUCCH simulation assumptions agreed under 8.4.1 in RAN1#101e as a baseline. Companies are encouraged to report additional simulation parameters/assumptions particular to their proposed schemes together with the simulations results in RAN1 #103e.

**Agreements:**

* Study Msg3 PUSCH enhancement in NR coverage enhancement SI
  + Study at least Msg3 PUSCH repetition
    - FFS the aspects to be enhanced, e.g., signaling indication, repetition pattern, interplay between Msg1 and Msg3, DM-RS enhancements related to repetition etc.
  + FFS multiple-antenna techniques.

**Agreements:**

* Study whether or how to enhance MsgA PUSCH in NR coverage enhancement SI

**Agreements:**

If PRACH enhancement is needed, study it in NR coverage enhancement SI, e.g. multiple PRACH transmissions.

**Agreements:**

Study whether/how to enable potential techniques for early CSI and/or beam refinement for physical channels during initial/random access procedure.

**Agreements:**

* If PDCCH enhancement is needed based on evaluation, study PDCCH enhancement for NR coverage enhancement
  + Study at least for broadcast PDCCH
    - For broadcast PDCCH, it includes a PDCCH monitored in a Type0/0A/1/2-PDCCH CSS set.
  + FFS unicast PDCCH
  + Study the aspects to be enhanced, e.g., PDCCH repetition.

**Agreements:**

Further discuss the evaluation of PDSCH and discuss whether/how to enhance PDSCH in NR coverage enhancement SI.

**Agreements:**

Enhancement to PUSCH scheduled by RAR UL grant will not consider the optimization specific for CFRA case in NR coverage SI.

**Agreements:**

* Capture the following structure in TR 38.830.

6.3 Coverage enhancements for channels other than PUSCH and PUCCH

6.3.1 Enhancements for Msg3 PUSCH

* Note: The above structure can be further updated by adding more sections under section 6.3 for other enhancements if justified.

7. Appendix

## 7.1 Detailed simulation results for PUSCH enhancements

Companies can provide the detailed simulations results with figures/curves in the appendix.

|  |  |  |
| --- | --- | --- |
| Company | Solution | Detailed simulation results |
| China Telecom | Repetitions counted on the basis of available UL slots | Fig.1-1 O2I    Fig.1-2 O2O |
| Enhanced repetition type B: PUSCH transmission can across the slot boundary and the length of PUSCH transmission can be larger than 14 symbols | Fig.2-1 O2I    Fig.2-2 O2O |
| TBS is determined based on multiple slots, different segment is transmitted in each slot | Fig.3-1 O2I    Fig.3-2 O2O    Fig.4 eMBB |
| Enhanced intra-slot frequency hopping | Fig.5-1 eMBB    Fig.5-2 VoIP |
| Inter-bundle frequency hopping | Fig.6 |
| Sub-PRB transmission | Fig.7 |
| Cross-slot channel estimation | Fig.8-1 TDD (DDDSUDDSUU)    Fig.8-2 FDD |
| Higher DM-RS density, 1-comb DM-RS | Fig.9-1 Urban scenario    Fig.9-2 Rural scenario |
| ZTE | Increase the number of repetitions for PUSCH repetition type A | Figure. Simulation results for VoIP with different number of repetitions and HARQ re-transmissions  For PUSCH repetition type A in NR Rel-15/Rel-16, in case of collision with DL slots for TDD or BWP switching, the collided PUSCH transmission shall be canceled. So, the actual number of PUSCH repetitions is less than the nominal indicated number of repetitions. Take TDD configuration ‘DDDDDDDSUU’ for instance, only two repetitions can be transmitted even the number of indicated repetitions is 4 or 8. Therefore, the following two schemes are compared, and 1~1.5 dB gain is observed for the enhanced scheme.   * Baseline scheme: 4 repetitions with maximum 1 re-transmission (Max 8 transmissions) * Enhanced scheme: 2 repetitions with maximum 3 re-transmissions (Max 8 transmissions). |
| Enhancement on PUSCH repetition Type B | Figure. Cases for PUSCH type B scheduling in frame structure ‘DDDSU’ (S: 10D:2G:2U)  D:\repetition-RV.jpgrepetition-RV  Figure. Simulation results for above four scheduling cases in frame structure ‘DDDSU’ (S: 10D:2G:2U)  The performance of the enhanced Case 3 and Case 4 is similar and both can provide about 0.8 dB gain over the baseline schemes (Case 1 and Case 2). |
| Inter-slot FH | Figure. Simulation results for inter-slot frequency hopping  The case with 4 hopping positions can provide additional 0.5 dB gain over inter-slot hopping in Rel-15 at target BLER 0.1. The performance gain is expected to be larger at a lower BLER target. |
| Inter-slot frequency hopping with inter-slot bundling to enable cross-slot channel estimation | Figure 6. Performance of PUSCH with cross-slot channel estimation and frequency hopping  As can be observed, cross-slot channel estimation could provide about 0.5 dB gain for PUSCH with 4 repetitions in urban 4GHz scenario. |
| Cross-slot channel estimation | Figure. Performance comparison of PUSCH w/ or w/o DMRS sharing in case frequency hopping is disabled  The case with cross-slot channel estimation can provide additional 1.8 dB gain over the baseline case with 8 inter-slot repetitions at target BLER 0.1 in urban scenario. |
| Lower DMRS density | TDL-A-100 BLER2  Figure. Performance results for lower DMRS density  About 1 dB gain can be obtained by the enhanced scheme with only mapping DMRS on even PRBs. |
| Intel | Number of repetitions | From the figure, it can be observed that link level performance for PUSCH can be improved by increasing the number of repetitions. More specifically, ~2dB performance gain can be observed when doubling the repetition levels for PUSCH. |
| TB spanning multiple slots | For single slot transmission, 4 PRBs and 14 symbols with 2 DMRS symbols were used. Further, for a TB spanning multiple slots, 4 slots were used with 1 PRB in each slot. From the figure, it can be observed that these two schemes deliver similar link level simulation performance. However, given that only 1 PRB is occupied for TB spanning 4 slots, ~6dB performance gain can be achieved in term of link budget. |
| Enhancement on inter-slot frequency hopping and cross-slot channel estimation | 8 repetitions are used for PUSCH transmission with 1) intra-slot FH, 2) inter-slot FH and 3) enhanced inter-slot FH pattern with same frequency resource in 4 consecutive slots. Further, cross-slot channel estimation is employed with a fixed window size of 4 slots. From the figure, it can be observed that   * For Rel-15 inter-slot frequency hopping pattern, cross-slot channel estimation can provide ~2dB performance gain compared to the case without cross-slot channel estimation. * When employing cross-slot channel estimation, ~1.0dB performance gain can be achieved by enhanced inter-slot frequency hopping pattern, compared to Rel-15 intra-slot and inter-slot frequency hopping pattern. * Compared to Rel-15 inter-slot frequency hopping without cross-slot channel estimation, substantial performance gain, i.e., ~3dB can be achieved by enhanced inter-slot frequency hopping with cross-slot channel estimation. |
| Number of frequency hops | It is assumed TBS = 136, MCS = 0, 2 and 4 Rx antennas, and 2 DMRS symbols are allocated in each slot. From the figure, it can be observed that when 2 Rx antennas are used, ~1.5dB performance gain can be achieved for 4 frequency hops compared to 2 frequency hops. However, when 4 Rx antennas are used, ~0.3dB performance gain can be achieved for 4 frequency hops compared to 2 frequency hops. |
| Higher DMRS density | it is assumed TBS = 136, MCS = 0 and inter-slot frequency hopping. From the figure, it can be observed that for 8 repetitions, 4 DMRS symbols can achieve better link level performance than 5 and 6 DMRS symbols. |
| lower DMRS density | Two cases were considered for comparison: 1) 2 DMRS symbols are allocated in each slot, 2) 2 DMRS symbols are allocated in even slot while DMRS symbols are not allocated in odd slots. In addition, cross-slot channel estimation is employed with a fixed window size of 4 slots  From the figure, it can be observed that for 8 repetitions with intra-slot frequency hopping, performance difference is small for the cases when DMRS symbols are not allocated in odd slots and when DMRS symbols are allocated in every slot. |
| Sharp | Cross-slot channel estimation | N means the number of slots for cross-slot channel estimation. |
| Samsung | 2.2 Inter-slot frequency hopping with inter-slot bundling to enable cross-slot channel estimation  2.3 Cross-slot channel estimation | Fig. 1-1 FR1    Fig. 1-2 FR2 |
| Sub-PRB transmission for eMBB and VoIP | cid:image003.png@01D6A6E9.3E162DC0  Fig. 2-1 eMBB  cid:image005.png@01D6A6E9.3E162DC0  Fig. 2-2 VoIP |
|  |  |  |

## 7.2 Detailed simulation results for PUCCH enhancements

Companies can provide the detailed simulations results with figures/curves in the appendix.

|  |  |  |
| --- | --- | --- |
| Company | Solution | Detailed simulation results |
| ZTE | DMRS-less PUCCH | Figure. Performance comparison of sequence based PUCCH and PUCCH format 3  For UCI of 11 bits, sequence based PUCCH can provide about 2~3 dB gain over legacy PUCCH format 3. |
| Dynamic PUCCH repetition factor indication | Figure. Distribution of instantaneous SNR on each RB  A simulation is conducted at an SNR of -12.8dB, which is the required SNR for the case with 11bits UCI and RP=4. The simulation is to get the distribution of instantaneous received SNR at certain RBs (which are assumed to be configured for PUCCH transmission) and to see the percentage of instantaneous received SNR higher than the required SNR for RP=4. From Figure-3, we find that at least 90% of the instantaneous SNR on the RBs assumed to be configured for PUCCH transmission exceed the required SNR and more than 70% cases can be indicated to 2 repetitions instead. Therefore, dynamic repetition should be considered if the instantaneous SNR can be obtained by gNB. |
| DMRS bundling cross PUCCH repetitions | Figure. Simulation results for different DMRS patterns with 4 repetitions.  Enhanced scheme: FH per two repetitions and cross-slot channel estimation among two repetitions per DMRS bundle.  For PUCCH with four repetitions, support of both frequency hopping and DMRS bundling can provide 1 dB gain compared with inter-slot frequency hopping only. |
| Intel | DMRS-less PUCCH design | 3 schemes were considered:   * Existing PUCCH format 3: a DTX threshold is determined based on DMRS symbols. Further, coherent decoding is employed for ACK decoding. * Option 1 with modified scrambling sequence: as mentioned above, two scrambling sequences are used depending on first UCI bit. A DTX threshold is determined based on sequence symbols. Further, non-coherent detection based receiver is employed. * Option 2: PN sequence is used. Similar to Option 1, a DTX threshold is determined based on sequence symbols and non-coherent detection based receiver is employed.   From the figures, it can be observed that   * For 3 UCI bits, existing PUCCH format 3 can outperform DMRS-less PUCCH schemes by >1dB, including Option 1 with modified scrambling sequence and Option 2. * For 11 UCI bits, existing PUCCH format 3 can achieve similar performance compared to DMRS-less PUCCH schemes. * Performance difference between Option 1 with modified scrambling sequence and Option 2 is negligible for both 3 and 11 UCI bits. |
| Intel | DMRS bundling and enhanced inter-slot frequency hopping | It is assumed 22 bit UCI payload and 8 repetitions for PUCCH transmission with 1) intra-slot FH, 2) inter-slot FH and 3) enhanced inter-slot FH pattern with 4 consecutive slots in a same frequency resource. Further, cross-slot channel estimation is employed with a fixed window size of 4 slots. From the figure, it can be observed that   * For Rel-15 inter-slot frequency hopping, cross-slot channel estimation can provide ~1.2dB performance gain compared to the case without cross-slot channel estimation. * When employing cross-slot channel estimation, ~1.6dB performance gain can be achieved for enhanced inter-slot frequency hopping pattern, compared to Rel-15 intra-slot and inter-slot frequency hopping pattern. * Compared to Rel-15 inter-slot frequency hopping without cross-slot channel estimation, substantial performance gain, i.e., ~2.8dB can be achieved by enhanced inter-slot frequency hopping with cross-slot channel estimation. |
| Intel | Higher DMRS density | In the simulation, it is assumed 22 bit UCI payload and inter-slot frequency hopping. From the figure, it can be observed that for 8 repetitions, 4 DMRS symbols can achieve slightly better link level performance than 5 and 6 DMRS symbols. |
| Intel | number of repetitions | It is assumed 22 bit UCI payload and intra-slot frequency hopping for PUCCH format 3. In addition, it is assumed 2 DMRS symbols are allocated for each slot. From the figure, it can be observed that link level performance for PUCCH format 3 can be improved by increasing the number of repetitions. Further, ~2dB gain can be observed when doubling the repetition levels for PUCCH format 3. |
| Sharp | DMRS-less PUCCH design | The above figure shows BLER performance comparison of DMRS-less scheme and Rel-15 PUCCH format 3. As shown, DMRS-less scheme has gain of about 3 dB compared to Rel-15 PUCCH format 3. |

## 7.3 Detailed simulation results for enhancements on other channels / signals

Companies can provide the detailed simulations results with figures/curves in the appendix.

|  |  |  |  |
| --- | --- | --- | --- |
| Company | Channel | Solution | Detailed simulation results |
| ZTE | Msg3 | Msg3 repetition | Figure. Performance of Msg3 w/ or w/o repetition.  Msg3 PUSCH with 2 and 4 repetitions can provide about 2.6 and 5.2 dB gain respectively compared to one repetition in rural 700MHz scenario. In urban 4GHz scenario, the respective gain is of Msg3 PUSCH with 2 and 4 repetitions is about 2.4 and 4.7 dB. |
| Msg3 | Msg3 repetition and cross-slot channel estimation | Figure. Performance of Msg3 with cross-slot channel estimation  In case inter-slot frequency hopping is disabled, cross-slot channel estimation can be conducted among all 4 repetitions. As can be observed, cross-slot channel estimation could provide 0.88 dB and 1.07 dB gain for Msg3 PUSCH at target BLER 0.1 and 0.01 respectively. |
| SSB | Increasing the number of SSBs | Figure: Simulation result of beamforming gain for different number of SSBs in 700MHz rural scenario  Beamforming gain under 8 SSBs case has an average 1.84 dB improvement comparing with that 4 SSBs case. |
| PRACH | PRACH repetition | Figure: Simulation results of PRACH repetition  The performance of PRACH with 2 and 4 repetitions is about 3.7dB and 5.2dB better than one PRACH transmission respectively in 4GHz urban O2I scenario. For 28GHz urban O2I scenario, about 1.7dB and 3.7dB gain is observed for PRACH with 2 and 4 repetitions respectively. |
|  | PRACH beam sweeping | Figure: Simulation result of PRACH sweeping  By PRACH sweeping with 2 times, average gain with 2.5dB can be obtained comparing with baseline case (i.e., without sweeping). |
| PUCCH with Msg4 HARQ-ACK | PUCCH repetition | About 3 dB and 6dB gain can be obtained by employing 2 repetitions and 4 repetitions respectively. This could be an effective way for coverage enhancement of PUCCH with Msg4 HARQ-ACK. |
| PDCCH | PDCCH repetition | Figure. Simulation results for PDCCH repetition  For PDCCH repetition with separate decoding, average gains with 2.8 dB for 2 repetitions and 4.0 dB for 4 repetitions can be obtained comparing to the baseline case (i.e., without repetition) in rural and urban scenarios. For PDCCH repetition with joint decoding among multiple repetitions, average gains with 3.1 dB for 2 repetitions and 5.8 dB for 4 repetitions can be obtained comparing with baseline case (i.e., without repetition) in rural and urban scenarios. |
| Intel | Msg3 PUSCH | Repetitions | It is assumed TBS = 56, MCS = 0, 3 DMRS symbols that are allocated in each slot and UE moving speed of 3km/h. From the figure, it can be observed that link level performance for Msg3 PUSCH can be improved by increasing the number of repetitions. More specifically, ~2dB performance gain can be observed with doubling the repetition levels for Msg3 PUSCH. |
|  |  |  |  |