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# PDSCH transmission latency

The parameters in email discussion [2] are used to analyze PDSCH and PUSCH latency.

* 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-trasnmission 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 = 7/14
		- Case1: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];
		- Case 1a: For the case of 14 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,1,1,1,1,1,1,1,1,1,1,1,1,1];
	+ PDSCH duration:
		- 2 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
		- Case1:7 and using the following pattern: [1,0,1,0,1,0,1,0,1,0,1,0,1,0];
		- Case1a:14 and using the following pattern: [1,1,1,1,1,1,1,1,1,1,1,1,1,1]
	+ UE decoding time for the last PDSCH: is N1 + d\_1,1

For PDSCH, case 1a are also evaluated as marked by yellow color above. For case 1a, 14 monitoring occasions per slot for PDCCH and PUCCH carrying HARQ-ACK per slot. The PDSCH transmission procedure is shown in Figure 1-1. The details of latency of one-shot and two-shot transmission for PDSCH in worst case are shown in Table 1-3 and 1-4.



Figure 1-1 PDSCH transmissions procedure

Table 1-1: Transmission latency for PDSCH in case 1 and case 1a

|  |  |  |
| --- | --- | --- |
| FDD | 30kHz worst case | 60kHz worst case |
| Case  | Case 1 | Case 1a | Case 1 | Case 1a |
| PDSCH duration1 | 2OS | 2OS | 2OS | 2OS |
| one-shot transmission | 0.51ms | 0.51ms | 0.42ms | 0.42ms |
| two-shot transmission | 1.15ms | 1.08ms | 0.94ms | 0.90ms |

Table 1-2 the parameters difference between case 1 and case 1a

|  |  |  |
| --- | --- | --- |
| parameter | Case1 (baseline) | Case 1a |
| PDCCH configuration | 7 PDCCH monitoring occasions per slot and 1 symbol PDCCH duration | 14 PDCCH monitoring occasions per slot and 1 symbol PDCCH duration |
| PUCCH configuration  | 7 PUCCH occasions for HARQ-ACK per slot and 1 symbol PUCCH duration | 14 PUCCH occasions for HARQ-ACK per slot and 1 symbol PUCCH duration |

Table 1-3 Latency of one-shot transmission for PDSCH in case 1 and case 1a

|  |  |  |
| --- | --- | --- |
|  | 30kHz | 60kHz |
| Case  | Case 1 | Case 1a | Case 1 | Case 1a |
| PDSCH duration1 | 2OS | 2OS | 2OS | 2OS |
| PDCCH/PDSCH preparation for initial Tx | 4.75 | 4.75 | 9.5 | 9.5 |
| PDCCH alignment | 2 | 2 | 2 | 2 |
| PDCCH duration | 0 | 0 | 0 | 0 |
| PDSCH duration | 2 | 2 | 2 | 2 |
| PDCCH/PDSCH decoding at UE | 5.5 | 5.5 | 10 | 10 |
| one-shot latency | 0.51ms | 0.51ms | 0.42 ms | 0.42 ms |

 1. PDCCH alignment: for 2OS PDSCH, the worst alignment time is 2 OFDM symbols.

Table 1-4 ：Latency of two-shot transmission for PDSCH in case 1 and case 1a

|  |  |  |
| --- | --- | --- |
|  | 30kHz | 60kHz |
| Case  | Case 1 | Case 1a | Case 1 | Case 1a |
| PDSCH duration | 2OS | 2OS | 2OS | 2OS |
| PDCCH/PDSCH preparation1 | 4.75 | 4.75 | 9.5 | 9.5 |
| PDCCH alignment | 2 | 2 | 2 | 2 |
| PDCCH duration | 0 | 0 | 0 | 0 |
| PDSCH duration | 2 | 2 | 2 | 2 |
| PDCCH/PDSCH decoding and PUCCH preparation | 4.5 | 4.5 | 9 | 9 |
| PUCCH alignment2 | 1.5 | 0.5 | 1 | 0 |
| PUCCH duration | 1 | 1 | 1 | 1 |
| PUCCH decoding and PDCCH/PDSCH preparation | 7.5 | 7.5 | 15 | 15 |
| PDCCH alignment3 | 1.5 | 0.5 | 1 | 0 |
| PDCCH duration | 0 | 0 | 0 | 0 |
| PDSCH duration | 2 | 2 | 2 | 2 |
| PDCCH/PDSCH decoding at UE  | 5.5 | 5.5 | 10 | 10 |
| two-shot latency | 1.15 ms | 1.08ms | 0.94 ms | 0.90ms |

1. PDCCH alignment: for 2OS PDSCH, the worst alignment time is 2 OFDM symbols.
2. In the worst case, 1.5 and 0.5 symbols are needed for PUCCH alignment with the symbol boundary for case 1 and case 1a, respectively.
3. In the worst case, 1.5 and 0.5 symbols are needed for the second PDCCH alignment with the symbol boundary for case 1 and case 1a, respectively.

# Grant-free PUSCH transmission latency

* 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 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 symbols
		- Case 1a:1 symbol
	+ 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 = 7/14
		- Case1: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];
		- Case 1a: For the case of 14 monitoring occasions per slot, PDCCH monitoring occasions are given as [1,1,1,1,1,1,1,1,1,1,1,1,1,1];
	+ For GF-PUSCH:
		- The re-transmission is triggered by a dynamic grant.
		- The number of PUSCH transmission occasions per slot:
			* Case1:7 for the case of 2-symb PUSCH (i.e., the UL pattern is [2,2,2,2,2,2,2].)
			* Case 1a:14 for the case of 1-symbol PUSCH (i.e., the UL pattern is [1,1,1,1,1,1,1,1,1,1,1,1,1,1].)

For grant free PUSCH, case 1a are also evaluated as marked by yellow color above. For case 1a, 14 monitoring occasions per slot for PDCCH and PUCCH carrying HARQ-ACK per slot. On the other hand, grant free PUSCH with 1 OS priority configuration is also evaluated for case 1a to achieve the shorter latency. The grant free PUSCH transmission procedure is shown in Figure 2-1.



Fig 2-1 Grant-free PUSCH transmission procedure

The details of latency of one-shot and two-shot transmission for grant-free PUSCH in worst case are shown in Table 2-3 and 2-4.

**Table 2-1 Transmission latency for grant free PUSCH in case 1 and case 1a**

|  |  |  |
| --- | --- | --- |
| **FDD** | **30kHz worst case** | **60kHz worst case** |
| **Case**  | **Case 1** | **Case 1a** | **Case 1** | **Case 1a** |
| PDSCH duration | 2OS | 1OS | 2OS | 1OS |
| one-shot transmission | 0.39ms | 0.32ms | 0.34ms | 0.30ms |
| two-shot transmission | 1.04ms | 0.86ms | 0.84ms | 0.75ms |

**Table 2-2 the parameters difference between case 1 and case 1a**

|  |  |  |
| --- | --- | --- |
| **parameter** | **Case1 (baseline)** | **Case 1a** |
| PDCCH configuration | 7 PDCCH monitoring occasions per slot and 1 symbol PDCCH duration | 14 PDCCH monitoring occasions per slot and 1 symbol PDCCH duration |
| PUSCH configuration  | grant free PUSCH with 2 OS duration and 2 symbol periodicity  | grant free PUSCH with 1 OS duration and 1 symbol periodicity  |

Table 2-3 Latency of one-shot transmission for grant-free PUSCH in case 1 and case 1a

|  |  |  |
| --- | --- | --- |
|  | **30kHz** | **60kHz** |
| **case** | **Case1** | **Case 1a** | **Case1** | **Case 1a** |
| PUSCH duration | 2OS | 1OS | 2OS | 1OS |
| PUSCH preparation | 2.75 | 2.75 | 5.5 | 5.5 |
| PUSCH alignment | 2 | 1 | 2 | 1 |
| PUSCH duration | 2 | 1 | 2 | 1 |
| PUSCH decoding | 4.25 | 4.25 | 9.5 | 9.5 |
| one-shot latency | 0.39ms | 0.32ms | 0.34ms | 0.30ms |

Table 2-4 Latency of two-shot transmission for grant-free PUSCH in worst case

|  |  |  |
| --- | --- | --- |
|  | **30kHz** | **60kHz** |
| **case** | **Case1** | **Case 1a** | **Case1** | **Case 1a** |
| PUSCH duration | 2OS | 1OS | 2OS | 1OS |
| PUSCH preparation | 2.75 | 2.75 | 5.5 | 5.5 |
| PUSCH alignment1 | 2 | 1 | 2 | 1 |
| PUSCH duration | 2 | 1 | 2 | 1 |
| PUSCH decoding and PDDCH preparation | 6.5 | 6.5 | 13 | 13 |
| PDCCH alignment2 | 1.5 | 0.5 | 1 | 0 |
| PDCCH duration | 1 | 1 | 1 | 1 |
| PDCCH decoding PUSCH preparation at UE2 | 5.5 | 5.5 | 11 | 11 |
| PUSCH alignment3 | 1.5 | 0.5 | 1 | 0 |
| PUSCH duration | 2 | 1 | 2 | 1 |
| PUSCH decoding | 4.25 | 4.25 | 8.5 | 8.5 |
| two-shot latency  | 1.04ms | 0.86ms | 0.84ms | 0.75ms |

1. PUSCH alignment: for case 1 and case 1a, the worst alignment symbol s are 2 and 1 OS, respectively.
2. In the worst case, 1.5 and 0.5 symbols are needed for PDCCH alignment with the symbol boundary for case 1 and case 1a, respectively.
3. In the worst case, 1.5 and 0.5 symbols are needed for the second PUSCH alignment with the symbol boundary for case 1 and case 1a, respectively.