**3GPP TSG-RAN WG2 Meeting #131 R2-2506493**

**Bengaluru, India, Aug 25th – 29th, 2025**

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| *CR-Form-v12.3* |
| **CHANGE REQUEST** |
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|  | **36.321** | **CR** | **1591** | **rev** | **1** | **Current version:** | **18.4.0** |  |
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| *For* [***HE******LP***](http://www.3gpp.org/3G_Specs/CRs.htm#_blank)*on using this form: comprehensive instructions can be found at* [*http://www.3gpp.org/Change-Requests*](http://www.3gpp.org/Change-Requests)*.* |
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| ***Proposed change affects:*** | UICC apps |  | ME | **X** | Radio Access Network | **X** | Core Network |  |

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| ***Title:***  | Introduction of IoT NTN enhancements phase 3 |
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| ***Source to WG:*** | MediaTek Inc. |
| ***Source to TSG:*** | R2 |
|  |  |
| ***Work item code:*** | IoT\_NTN\_Ph3-Core |  | ***Date:*** | 2025-09-02 |
|  |  |  |  |  |
| ***Category:*** | **B** |  | ***Release:*** | Rel-19 |
|  | *Use one of the following categories:****F*** *(correction)****A*** *(mirror corresponding to a change in an earlier release)****B*** *(addition of feature),* ***C*** *(functional modification of feature)****D*** *(editorial modification)*Detailed explanations of the above categories canbe found in 3GPP [TR 21.900](http://www.3gpp.org/ftp/Specs/html-info/21900.htm). | *Use one of the following releases:Rel-8 (Release 8)Rel-9 (Release 9)Rel-10 (Release 10)Rel-11 (Release 11)…Rel-17 (Release 17)Rel-18 (Release 18)Rel-19 (Release 19)Rel-20 (Release 20)* |
|  |  |
| ***Reason for change:*** | This CR introduces the new feature from Rel-19 IoT NTN enhancement work item. The MAC SPEC is updated to support the one new feature (referred as CB-Msg3-EDT procedure).  |
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| ***Summary of change:*** | <1> A new section is added to specify the initialization, transmission, and reception for CB-Msg3 EDT procedure.<2> Update DL/UL data transfer, TA Maintenance, and MAC Reset clauses to handle CB-Msg3-EDT procedure.<3> Introduce New MAC PDU format (CB-Msg4, used for CB-Msg3-EDT procedure)<4> Introduce new RNTI (CB-RNTI) for CB-Msg4 monitoring of CB-Msg3-EDT procedure.   |
|  |  |
| ***Consequences if not approved:*** | The new feature CB-Msg3-EDT is not supported.  |
|  |  |
| ***Clauses affected:*** | 3.1, 3.2, 5.1x (new), 5.2, 5.3.1, 5.3.2.2, 5.3.3, 5.4.1, 5.4.2.1, 5.4.3.2, 5.9, 6.1.2, 6.1.x(new), 6.2.x(new), 6.2.y(new), 7.1 |
|  |  |
|  | **Y** | **N** |  |  |
| ***Other specs*** | **X** |  |  Other core specifications  | TS 36.300 CR 1425 TS 36.331 CR 5137TS 36.306 CR 1912TS 36.304 CR 0882  |
| ***affected:*** |  | **x** |  Test specifications |  |
| ***(show related CRs)*** |  | **x** |  O&M Specifications |  |
|  |  |
| ***Other comments:*** |  |
|  |  |
| ***This CR's revision history:*** | First version: R2-2505201 |

# 3 Definitions and abbreviations

## 3.1 Definitions

For the purposes of the present document, the terms and definitions given in 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 TR 21.905 [1].

**Active Time:** Time related to DRX operation, as defined in clause 5.7, during which the MAC entity monitors the PDCCH.

**CB-Msg3:** Contention based message transmitted on UL-SCH as part of a CB-Msg3-EDT procedure.

**CB-Msg3-EDT**: A procedure which allows EDT from RRC\_IDLE using contention based UL‑SCH without random access preamble transmission or random access response reception.

**CB-Msg4**: The response message to one or more CB-Msg3s.

**CB-RNTI**: The contention based RNTI used on PDCCH when CB-Msg4s are transmitted.

***CB-Msg3ResponseTimer***: Specifies the number of consecutive subframe(s) during which the MAC entity shall monitor the PDCCH after CB-Msg3(s) are transmitted.

***mac-******ContentionResolutionTimer***: Specifies the number of consecutive subframe(s) during which the MAC entity shall monitor the PDCCH after Msg3 is transmitted.

**DRX Cycle:** Specifies the periodic repetition of the On Duration followed by a possible period of inactivity (see figure 3.1-1 below).



Figure 3.1-1: DRX Cycle

***drx-InactivityTimer***: Except for NB-IoT UEs, BL UEs or UEs in enhanced coverage, it specifies the number of consecutive PDCCH-subframe(s) after the subframe in which a PDCCH indicates an initial UL, DL or SL user data transmission for this MAC entity. For NB-IoT UEs, it specifies the number of consecutive PDCCH-subframe(s), after the subframe in which the HARQ RTT timer or UL HARQ RTT timer expires, or after PDCCH indicates a new UL or DL transmission for one TB when the UE is configured with multiple HARQ processes. For BL UEs or UEs in enhanced coverage, it specifies the number of consecutive PDCCH-subframe(s) following the subframe containing the last repetition of the PDCCH reception that indicates an initial UL or DL user data transmission for this MAC entity.

***drx-RetransmissionTimer***: Specifies the maximum number of consecutive PDCCH-subframe(s) until a DL retransmission is received.

***drx-RetransmissionTimerShortTTI***: Specifies the maximum number of consecutive TTI(s) until a DL retransmission is received for HARQ processes scheduled using short TTI.

***drxShortCycleTimer***: Specifies the number of consecutive subframe(s) the MAC entity shall follow the Short DRX cycle.

***drxStartOffset***: Specifies the subframe where the DRX Cycle starts.

***drx-ULRetransmissionTimer***: Specifies the maximum number of consecutive PDCCH-subframe(s) until a grant for UL retransmission or the HARQ feedback is received.

***drx-ULRetransmissionTimeShortTTI***: Specifies the maximum number of consecutive TTI(s) until a grant for UL retransmission is received for HARQ processes scheduled using short TTI.

**Early Data Transmission**: Allows one uplink data transmission optionally followed by one downlink data transmission during the random access procedure as specified in TS 36.300 [20]. The S1 connection is established or resumed upon reception of the uplink data and may be released or suspended along with the transmission of the downlink data. Early data transmission refers to both CP-EDT and UP-EDT.

**HARQ information**: HARQ information for DL-SCH or for UL-SCH transmissions consists of New Data Indicator (NDI), Transport Block (TB) size. For DL-SCH transmissions and for asynchronous UL HARQ and for autonomous UL HARQ, the HARQ information also includes HARQ process ID, except for UEs in NB-IoT configured with a single HARQ process for which this information is not present. For UL-SCH transmission the HARQ information also includes Redundancy Version (RV). In case of spatial multiplexing on DL-SCH the HARQ information comprises a set of NDI and TB size for each transport block. HARQ information for SL-SCH and SL-DCH transmissions consists of TB size only.

**HARQ RTT Timer**: This parameter specifies the minimum amount of subframe(s) before a DL assignment for HARQ retransmission is expected by the MAC entity.

**Msg3**:Message transmitted on UL-SCH containing a C-RNTI MAC CE or a CCCH SDU optionally multiplexed with DTCH for the UP-EDT, submitted from upper layer and associated with the UE Contention Resolution Identity, as part of a random access procedure.

**NB-IoT**:NB-IoT allows access to network services via E-UTRA with a channel bandwidth limited to 200 kHz.

**NB-IoT UE**:A UE that uses NB-IoT.

**NR sidelink communication**: AS functionality enabling at least V2X Communication as defined in TS 23.287 [23], between two or more nearby UEs, using NR technology but not traversing any network node.

**Non-terrestrial networks:** An E-UTRAN consisting of eNBs, which provide non-terrestrial LTE access to UEs by means of an NTN payload embarked on a space-borne NTN vehicle and an NTN Gateway.

***onDurationTimer***: Specifies the number of consecutive PDCCH-subframe(s) at the beginning of a DRX Cycle.

**PDCCH:** Refers to the PDCCH (see TS 36.211 [7]), EPDCCH (in subframes when configured), MPDCCH (see TS 36.213 [2]), for an RN with R-PDCCH configured and not suspended, to the R-PDCCH, for NB-IoT to the NPDCCH or for short TTI to SPDCCH.

**PDCCH period (pp):** Refers to the interval between the start of two consecutive PDCCH occasions and depends on the currently used PDCCH search space, as specified in TS 36.213 [2]. A PDCCH occasion is the start of a search space and is defined by subframe k0 as specified in clause 16.6 of TS 36.213 [2]. The calculation of number of PDCCH-subframes for the timer configured in units of a PDCCH period is done by multiplying the number of PDCCH periods with *npdcch-NumRepetitions-RA* when the UE uses the common search space or by *npdcch-NumRepetitions* when the UE uses the UE specific search space. When counting a timer whose length is calculated in PDCCH-subframes, the UE shall include PDCCH-subframes that will be dropped or not required to be monitored as specified in clause 16.6 of TS 36.213 [2]. The calculation of number of subframes for the timer configured in units of a PDCCH period is done by multiplying the number of PDCCH periods with duration between two consecutive PDCCH occasions.

**PDCCH-subframe:** Refers to a subframe with PDCCH. This represents the union over PDCCH-subframes for all serving cells excluding cells configured with cross carrier scheduling for both uplink and downlink, as specified in TS 36.331 [8]; except if the UE is not capable of simultaneous reception and transmission in the aggregated cells where this instead represents the PDCCH-subframes of the SpCell.

- For FDD serving cells, all subframes represent PDCCH-subframes, unless specified otherwise in this clause.

- For TDD serving cells, all downlink subframes and subframes including DwPTS of the TDD UL/DL configuration indicated by *tdd-Config*, as specified in TS 36.331 [8] of the cell represent PDCCH-subframes, unless specified otherwise in this clause.

- For serving cells operating according to Frame structure Type 3, all subframes represent PDCCH-subframes.

- For RNs with an RN subframe configuration configured and not suspended, in its communication with the E-UTRAN, all downlink subframes configured for RN communication with the E-UTRAN represent PDCCH-subframes.

- For SC-PTM reception on an FDD cell, all subframes except MBSFN subframes represent PDCCH-subframes, unless specified otherwise in this clause.

- For SC-PTM reception on a TDD cell, all downlink subframes and subframes including DwPTS of the TDD UL/DL configuration indicated by *tdd-Config*, as specified in TS 36.331 [8] of the cell except MBSFN subframes represent PDCCH-subframes, unless specified otherwise in this clause.

- For BL UE or UE in enhanced coverage, all subframes in which the UE is required to monitor MPDCCH represent PDCCH-subframes among all valid subframes regardless of whether the subframe is dropped, see clause 9.1.5 of TS 36.213 [2].

- For NB-IoT UE, all subframes that are part of the NPDCCH search space represent PDCCH-subframes among all NB-IoT downlink subframes, including those which the UE is not required to monitor as specified in clause 16.6 of TS 36.213 [2].

**PDSCH**: Refers to subframe-PDSCH/slot-PDSCH/subslot-PDSCH or for NB-IoT to NPDSCH.

**PRACH**: Refers to PRACH or for NB-IoT to NPRACH.

**PRACH Resource Index**: The index of a PRACH within a system frame, see TS 36.211 [7]

**Primary Timing Advance Group:** Timing Advance Group containing the SpCell.

**PUCCH SCell:** An SCell configured with PUCCH/SPUCCH.

**PUSCH**: Refers to subframe-PUSCH/slot-PUSCH/subslot-PUSCH or for NB-IoT to NPUSCH.

***ra-PRACH-MaskIndex*:** Defines in which PRACHs within a system frame the MAC entity can transmit a Random Access Preamble (see clause 7.3).

**RA-RNTI:** The Random Access RNTI is used on the PDCCH when Random Access Response messages are transmitted. It unambiguously identifies which time-frequency resource was utilized by the MAC entity to transmit the Random Access preamble.

**SC Period:** Sidelink Control period, the time period consisting of transmission of SCI and its corresponding data.

**SCI:** The Sidelink Control Information contains the sidelink scheduling information such as resource block assignment, modulation and coding scheme, Group Destination ID (for sidelink communication) and PPPP (for V2X sidelink communication), see TS 36.212 [5].

**Secondary Timing Advance Group:** Timing Advance Group not containing the SpCell. A Secondary Timing Advance Group contains at least one Serving Cell with an UL configured.

**Serving Cell:** A Primary or a Secondary Cell, see TS 36.331 [8].

**Short Processing Time**: For 1 ms TTI length, the operation with short processing time in UL data transmission and DL data reception.

**Short TTI**: TTI length based on a slot or a subslot.

**Sidelink:** UE to UE interface for sidelink communication, sidelink discovery and V2X sidelink communication. The sidelink corresponds to the PC5 interface as defined in TS 23.303 [13] for sidelink communication and sidelink discovery, and as defined in TS 23.285 [14] for V2X sidelink communication.

**Sidelink communication**: AS functionality enabling ProSe Direct Communication as defined in TS 23.303 [13], between two or more nearby UEs, using E-UTRA technology but not traversing any network node.

**Sidelink Discovery Gap for Reception:** Time period during which the UE does not receive any channels in DL from any serving cell, except during random access procedure.

**Sidelink Discovery Gap for Transmission:** Time period during which the UE prioritizes transmission of sidelink discovery and associated procedures e.g. re-tuning and synchronisation over transmission of channels in UL, if they occur in the same subframe, except during random access procedure.

**Special Cell:** For Dual Connectivity operation the term Special Cell refers to the PCell of the MCG or the PSCell of the SCG, otherwise the term Special Cell refers to the PCell.

**Timing Advance Group:** A group of Serving Cells that is configured by RRC and that, for the cells with an UL configured, using the same timing reference cell and the same Timing Advance value.

**Transmission using PUR:** Allows one uplink data transmission using preconfigured uplink resource from RRC\_IDLE mode as specified in TS 36.300 [9]. Transmission using PUR refers to both CP transmission using PUR and UP transmission using PUR.

**UE-eNB RTT:** For non-terrestrial networks, the sum of the UE's Timing Advance value (see TS 36.211 [7], clause 8.1) and *k-Mac* in units of subframe, not rounded or truncated toward an integer number of subframes.

**UL HARQ RTT Timer**: This parameter specifies the minimum amount of subframe(s) before a UL HARQ retransmission grant is expected by the MAC entity.

**V2X sidelink communication**: AS functionality enabling V2X Communication as defined in TS 23.285 [14], between nearby UEs, using E-UTRA technology but not traversing any network node.

NOTE: A timer is running once it is started, until it is stopped or until it expires; otherwise it is not running. A timer can be started if it is not running or restarted if it is running. A Timer is always started or restarted from its initial value.

## 3.2 Abbreviations

For the purposes of the present document, the abbreviations given in 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 TR 21.905 [1].

AS Access Stratum

AUL Autonomous Uplink

BL Bandwidth reduced Low complexity

BR Bandwidth Reduced

BSR Buffer Status Report

C-RNTI Cell RNTI

CB-RNTI Contention-Based RNTI

CBR Channel Busy Ratio

CC-RNTI Common Control RNTI

CG Cell Group

CQI Channel Quality Indicator

CMR Contention-based Msg3 Response

CRI CSI-RS Resource Indicator

CSI Channel State Information

DAPS Dual Active Protocol Stack

DCQR Downlink Channel Quality Report

DRB Data Radio Bearer

EDT Early Data Transmission

eIMTA Enhanced Interference Management and Traffic Adaptation

eIMTA-RNTI Enhanced Interference Management and Traffic Adaptation - RNTI

E-UTRA Evolved UMTS Terrestrial Radio Access

E-UTRAN Evolved UMTS Terrestrial Radio Access Network

G-RNTI Group RNTI

H-SFN Hyper SFN

MAC Medium Access Control

MCG Master Cell Group

M-RNTI MBMS RNTI

MPDCCH MTC Physical Downlink Control Channel

LCG Logical Channel Group

NB-IoT Narrow Band Internet of Things

NPDCCH Narrowband Physical Downlink Control Channel

NPDSCH Narrowband Physical Downlink Shared channel

NPRACH Narrowband Physical Random Access Control Channel

NPUSCH Narrowband Physical Uplink Shared channel

PCell Primary Cell

PSCell Primary Secondary Cell

PHR Power Headroom Report

PMI Precoding Matrix Index

PPPP ProSe Per-Packet Priority

P-RNTI Paging RNTI

ProSe Proximity-based Services

pTAG Primary Timing Advance Group

PTI Precoding Type Indicator

PUR Preconfigured Uplink Resource

RA-RNTI Random Access RNTI

RAI Release Assistance Indication

RI Rank Indicator

RN Relay Node

RNTI Radio Network Temporary Identifier

SCell Secondary Cell

SC-FDM Single-Carrier Frequency Division Multiplexing

SCG Secondary Cell Group

SCI Sidelink Control Information

SC-N-RNTI Single Cell Notification RNTI

SC-PTM Single Cell Point to Multipoint

SC-RNTI Single Cell RNTI

SI-RNTI System Information RNTI

SL Sidelink

SL-RNTI Sidelink RNTI

SL-V-RNTI Sidelink V2X RNTI

SR Scheduling Request

SRS Sounding Reference Symbols

SRS-TPC-RNTI Sounding Reference Symbols-Transmit Power Control-RNTI

SpCell Special Cell

sTAG Secondary Timing Advance Group

sTTI Slot or subslot TTI

TAG Timing Advance Group

TB Transport Block

TPC-PUCCH-RNTI Transmit Power Control-Physical Uplink Control Channel-RNTI

TPC-PUSCH-RNTI Transmit Power Control-Physical Uplink Shared Channel-RNTI

V2X Vehicle-to-Everything

# 5 MAC procedures

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### 5.1x CB-Msg3-EDT Procedure

#### 5.1x.1 CB-Msg3-EDT initialization

The CB-Msg3-EDT procedure is initiated by the RRC sublayer and can only be performed in a non-terrestrial network. If the UE is an NB-IoT UE, the CB-Msg3-EDT procedure is performed on the anchor carrier or one of the non-anchor carriers for which CB-Msg3-EDT resource has been configured in system information.

The following information is assumed to be available before the procedure can be initiated for NB-IoT UEs, BL UEs or UEs in CE mode A, as specified in TS 36.331 [8]:

- if the UE is a BL UE or a UE in CE mode A:

- the available set of PUSCH resources associated with one or more enhanced coverage levels for the transmission of the CB-Msg3, *cb-Msg3-ConfigSIB*.

- if the UE is an NB-IoT UE:

- the available sets of PUSCH resources on the anchor carrier, *cb-Msg3-ConfigSIB-NB* in *SystemInformationBlockType2-NB* and on the non-anchor carriers, in *ul-ConfigList*.

- the mapping of the PUSCH resources into enhanced coverage levels is determined according to the following:

- the number of enhanced coverage levels is equal to one plus the number of RSRP thresholds present in *cb-Msg3-RSRP-CE-Levels-NB*.

- each enhanced coverage level has zero or one anchor carrier PUSCH resource present in *cb-Msg3-Config-NB* and zero or one PUSCH resource for each non-anchor carrier signalled in *ul-ConfigList*.

- enhanced coverage levels are numbered from 0 and the mapping of PUSCH resources to enhanced coverage levels are done in increasing *npusch-NumRepetitionsIndex* order.

- when multiple carriers provide PUSCH resources for the same enhanced coverage level, the UE shall randomly select one of them using the following selection probabilities:

- the selection probability of the anchor carrier PUSCH resource for the given enhanced coverage level, *cb-Msg3-ProbabilityAnchor-NB* is given by the corresponding entry in *cb-Msg3-ProbabilityAnchorList-NB*.

- the selection probability is equal for all non-anchor carrier PUSCH resources and the probability of selecting one PUSCH resource on a given non-anchor carrier is (1-*cb-Msg3-ProbabilityAnchor-NB*)/(number of non-anchor PUSCH resources).

- the criteria to select PUSCH resources based on RSRP measurement per enhanced coverage level, *cb-Msg3-RSRP-CE-Level* (*cb-Msg3-RSRP-CE-Levels-NB* for NB-IoT).

- the number of replicas for CB-Msg3 transmission corresponding to the selected enhanced coverage level, *cb-Msg3-NumOfReplicas*.

- CB-Msg3 transmission window configuration corresponding to the selected enhanced coverage level, *cb-Msg3-TxWindow*, including the transmission window periodicity *windowPeriodicity*.

- *CB-Msg3ResponseTimer* corresponding to the selected enhanced coverage level, *cb-Msg3-ResponseWindow*.

- the maximum number of transmission attempts per enhanced coverage level, *cb-Msg3-MaxAttemptNum*.

- power ramping factor for CB-Msg3 transmission, *powerRampingStep*.

- initial CB-Msg3 transmission power, *cb-Msg3-InitialReceivedTargetPower*.

The CB-Msg3-EDT procedure shall be performed as follows:

- flush the Msg3 buffer;

- set the CB\_MSG3\_TRANSMISSION\_COUNTER\_CE to 1;

- if the UE is an NB-IoT UE and if the RSRP threshold of enhanced coverage level 2 configured by upper layers in *cb-Msg3-RSRP-CE-Levels-NB* and the measured RSRP is less than the RSRP threshold of enhanced coverage level 2:

- the MAC entity considers to be in enhanced coverage level 2;

- else if the measured RSRP is less than the RSRP threshold of enhanced coverage level 1 as configured by upper layers in *cb-Msg3-RSRP-CE-Level* (*cb-Msg3-RSRP-CE-Levels-NB* for NB-IoT) then:

- the MAC entity considers to be in enhanced coverage level 1;

- else:

- the MAC entity considers to be in enhanced coverage level 0;

- set the CB-Msg3-EDT backoff parameter value to 0 ms;

- set current NTA to 0;

- proceed to the transmission of the CB-Msg3 (see clause 5.1x.2).

#### 5.1x.2 CB-Msg3 transmission

Before the CB-Msg3 transmission, the MAC entity shall select *cb-Msg3-NumOfReplicas* UL grants for CB-Msg3 transmission as follows:

- select the next upcoming CB-Msg3 transmission window provided by the *cb-Msg3-TxWindow* associated with the selected enhanced coverage level;

- randomly select *cb-Msg3-NumOfReplicas* PUSCH resources in the time domain within the selected CB-Msg3 transmission window from the CB-Msg3 resources provided by *cb-Msg3-TimeResource* associated with the selected enhanced coverage level;

- randomly select a frequency domain PUSCH resource for each selected time domain resource provided by *prb-AllocationInfoSet* (*npusch-SubCarrierSetList* for NB-IoT) associated with the selected enhanced coverage level.

The CB-Msg3 transmission shall be performed as follows:

- the CB-MSG3\_RECEIVED\_TARGET\_POWER is set to *cb-Msg3-InitialReceivedTargetPower* + (CB\_MSG3\_TRANSMISSION\_COUNTER\_CE – 1) \* *powerRampingStep*;

- if this is the first attempt of CB-Msg3 transmission within the selected CB-Msg3 transmission window:

- obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity and store it in the Msg3 buffer.

#### 5.1x.3 CB-Msg4 reception

Once all the CB-Msg3s of a CB-Msg3 transmission window are transmitted, the MAC entity shall monitor the PDCCH of the SpCell, while *CB-Msg3ResponseTimer* is running, for CB-Msg4(s) identified by the CB-RNTI defined below.

For BL UEs and UEs in CE mode A, the CB-RNTI associated with the CB-Msg3 transmission window in which the CB-Msg3(s) are transmitted, is computed as:

CB-RNTI = floor (SFN\_id/WP) modulo (32) + 32\*CE\_level + 2401

Where:

- SFN\_id is the first SFN of the selected CB-Msg3 transmission window.

- WP is the configured CB-Msg3 transmission window periodicity in unit of 10ms provided by *windowPeriodicity*.

- CE\_level is the selected enhanced coverage level (0 <= CE\_level < 2).

For NB-IoT UEs, the CB-RNTI associated with the CB-Msg3 transmission window in which the CB-Msg3(s) are transmitted, is computed as:

CB-RNTI = floor (SFN\_id/WP) modulo (32) + 32\*CE\_level + 96\*carrier\_id + 4097

Where:

- SFN\_id is the first SFN of the selected CB-Msg3 transmission window.

- WP is the configured CB-Msg3 transmission window periodicity in unit of 10ms provided by *windowPeriodicity*.

- CE\_level is the selected enhanced coverage level (0 <= CE\_level < 3).

- carrier\_id is the index of the UL carrier associated with the selected UL grants (0 <= carrier\_id < 16). The carrier\_id of the anchor carrier is 0.

After the CB-Msg3 transmission, the MAC entity shall:

- start the *CB-Msg3ResponseTimer* at the subframe that contains the end of selected the CB-Msg3 transmission window plus UE-eNB RTT;

- monitor the PDCCH while *CB-Msg3ResponseTimer* is running;

- if notification of a reception of a PDCCH transmission is received from lower layers; and

- if the CB-Msg4 is successfully decoded:

- if the CB-Msg4 contains a CB Backoff Indicator subheader:

- set the CB-Msg3-EDT backoff parameter value as indicated by the BI field of the CB Backoff Indicator subheader and Table 7.2-1, except for NB-IoT where the value from Table 7.2-2 is used.

- else:

- set the CB-Msg3-EDT backoff parameter value to 0 ms.

- if the CB-Msg4 contains one or more MAC CMRs; and

- if there is a UE Contention Resolution Identity in a MAC CMR that matches the 48 first bits of the CCCH SDU transmitted in CB-Msg3(s):

- consider CMR reception successful;

- discard the CB-RNTI;

- stop *CB-Msg3ResponseTimer* if running;

- flush the HARQ buffer used for transmission of the MAC PDU in the Msg3 buffer;

- if the corresponding CMR contains a Timing Advance Command field:

- process the received Timing Advance Command (see clause 5.2).

- start or restart the *timeAlignmentTimer* associated with this TAG;

- if the corresponding CMR contains a C-RNTI field:

- set the C-RNTI to the value of the C-RNTI field.

- finish the disassembly and demultiplexing of the MAC PDU;

- consider CB-Msg3 transmission successfully completed;

- if the C-RNTI field is absent in the corresponding CMR and no corresponding MAC SDU is present in CB-Msg4:

- indicate the successful completion of CB-Msg3-EDT procedure to the upper layers.

NOTE: The UE can receive CB-Msg4 after the *CB-Msg3ResponseTimer* expired if the corresponding PDCCH is received before the *CB-Msg3ResponseTimer* expired.

- if the *CB-Msg3ResponseTimer* expires:

- when MAC entity has finished decoding of all received CB-Msg4 and if CMR reception is not successful:

- flush the HARQ buffer used for transmission of the MAC PDU in the Msg3 buffer;

- increment CB\_MSG3\_TRANSMISSION\_COUNTER\_CE by 1;

- if CB\_MSG3\_TRANSMISSION\_COUNTER\_CE = *cb-Msg3-MaxAttemptNum* for the corresponding enhanced coverage level + 1:

- discard the CB-RNTI;

- consider the CB-Msg3 transmission unsuccessfully completed;

- indicate the transmission using CB-Msg3-EDT has failed to the upper layers.

- else:

- based on the CB-Msg3-EDT backoff parameter, select a random backoff time according to a uniform distribution between 0 and the CB-Msg3-EDT backoff Parameter value;

- delay the subsequent CB-Msg3 transmission by the backoff time;

- proceed to the CB-Msg3 transmission (see clause 5.1x.2).

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## 5.2 Maintenance of Uplink Time Alignment

The MAC entity has a configurable timer *timeAlignmentTimer* per TAG. The *timeAlignmentTimer* is used to control how long the MAC entity considers the Serving Cells belonging to the associated TAG to be uplink time aligned, as specified in TS 36.331 [8].

The MAC entity shall:

- when a Timing Advance Command MAC control element is received and if a NTA has been stored or maintained with the indicated TAG:

- except when the received Timing Advance Command MAC control element is addressed with a PUR-RNTI:

- apply the Timing Advance Command for the indicated TAG;

- start or restart the *timeAlignmentTimer* associated with the indicated TAG.

- when a Timing Advance Command is received in a Random Access Response message for a serving cell belonging to a TAG:

- if the UE is configured with *pur-Config* (see TS 36.331 [8]) and if a NTA has been stored or maintained and no temporary NTA has been stored:

- store current NTA as temporary NTA (see clause 5.4.7.2).

- if the Random Access Preamble was not selected by the MAC entity:

- apply the Timing Advance Command for this TAG;

- start or restart the *timeAlignmentTimer* associated with this TAG.

- else, if the *timeAlignmentTimer* associated with this TAG is not running:

- apply the Timing Advance Command for this TAG;

- start the *timeAlignmentTimer* associated with this TAG;

- when the contention resolution is considered not successful as described in clause 5.1.5, stop *timeAlignmentTimer* associated with this TAG*.*

- else:

- ignore the received Timing Advance Command.

- when a Timing Advance Command is received in a successful CMR for a serving cell belonging to a TAG:

- apply the Timing Advance Command for this TAG;

- when the MAC entity is configured with *rach-Skip* or *rach-SkipSCG*:

- apply timing advance value indicated by *targetTA* in *rach-Skip* or *rach-SkipSCG* for the pTAG;

- start the *timeAlignmentTimer* associated with this TAG.

- when a *timeAlignmentTimer* expires:

- if the *timeAlignmentTimer* is associated with the pTAG:

- flush all HARQ buffers for all serving cells;

- notify RRC to release PUCCH/SPUCCH for all serving cells;

- notify RRC to release SRS for all serving cells;

- for NB-IoT, notify RRC to release all dedicated resources for SR;

- clear any configured downlink assignments and uplink grants;

- consider all running *timeAlignmentTimer*s as expired;

- else if the *timeAlignmentTimer* isassociated with an sTAG, then for all Serving Cells belonging to this TAG*:*

- flush all HARQ buffers;

- notify RRC to release SRS;

- notify RRC to release PUCCH/SPUCCH, if configured;

- clear any configured downlink assignments and uplink grants.

- upon indication from upper layers to start *timeAlignmentTimer*, if a NTA has been stored or maintained with the indicated TAG:

- start or restart the *timeAlignmentTimer* associated with the indicated TAG.

When the MAC entity stops uplink transmissions for an SCell due to the fact that the maximum uplink transmission timing difference (as described in clause 7.9.2 of TS 36.133 [9]) or the maximum uplink transmission timing difference the UE can handle between TAGs of any MAC entity of the UE is exceeded, the MAC entity considers the *timeAlignmentTimer* associated with the SCell as expired.

The MAC entity shall not perform any uplink transmission on a Serving Cell, except the Random Access Preamble transmission and transmissions corresponding to a PUR-RNTI, when the *timeAlignmentTimer* associated with the TAG to which this Serving Cell belongs is not running. Furthermore, when the *timeAlignmentTimer* associated with the pTAG is not running, the MAC entity shall not perform any uplink transmission on any Serving Cell except the Random Access Preamble transmission on the SpCell.

The MAC entity shall not perform any sidelink transmission which is performed based on UL timing of the corresponding serving cell and any associated SCI transmissions when the corresponding *timeAlignmentTimer* is not running.

NOTE: A MAC entity stores or maintains NTA upon expiry of associated *timeAlignmentTimer*, where NTA is defined in TS 36.211 [7]. The MAC entity applies a received Timing Advance Command MAC control element and starts associated *timeAlignmentTimer* also when the *timeAlignmentTimer* is not running.

## 5.3 DL-SCH data transfer

### 5.3.1 DL Assignment reception

Downlink assignments transmitted on the PDCCH indicate if there is a transmission on a DL-SCH for a particular MAC entity and provide the relevant HARQ information.

When the MAC entity has a C-RNTI, Semi-Persistent Scheduling C-RNTI, PUR-RNTI, CB-RNTI or Temporary C-RNTI, the MAC entity shall for each TTI during which it monitors PDCCH and for each Serving Cell:

- if a downlink assignment for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI, PUR-RNTI, CB-RNTI, or Temporary C‑RNTI:

- if this is the first downlink assignment for this Temporary C-RNTI; or

- if this is the first downlink assignment corresponding to uplink transmission using previous preconfigured uplink grant for this PUR-RNTI; or

- if this is the downlink assignment for CB-RNTI:

- consider the NDI to have been toggled.

- if the downlink assignment is for the MAC entity's C-RNTI and if the previous downlink assignment indicated to the HARQ entity of the same HARQ process was either a downlink assignment received for the MAC entity's Semi-Persistent Scheduling C-RNTI or a configured downlink assignment:

- consider the NDI to have been toggled regardless of the value of the NDI.

- indicate the presence of a downlink assignment and deliver the associated HARQ information to the HARQ entity for this TTI.

- else, if a downlink assignment for this TTI has been received for this Serving Cell on the PDCCH for the MAC entity's Semi-Persistent Scheduling C-RNTI:

- if the NDI in the received HARQ information is 1:

- consider the NDI not to have been toggled;

- indicate the presence of a downlink assignment and deliver the associated HARQ information to the HARQ entity for this TTI.

- else, if the NDI in the received HARQ information is 0:

- if PDCCH contents indicate SPS release:

- clear the configured downlink assignment (if any);

- if the *timeAlignmentTimer*, associated with the TAG containing the serving cell on which the acknowledgement for the downlink SPS release is to be transmitted, is running:

- indicate a positive acknowledgement for the downlink SPS release to the physical layer.

- else:

- store the downlink assignment and the associated HARQ information as configured downlink assignment;

- initialise (if not active) or re-initialise (if already active) the configured downlink assignment to start in this TTI, or in TTI according to N=0 in clause 5.10.1 for short TTI, and to recur according to rules in clause 5.10.1;

- set the HARQ Process ID to the HARQ Process ID associated with this TTI;

- consider the NDI bit to have been toggled;

- indicate the presence of a configured downlink assignment and deliver the stored HARQ information to the HARQ entity for this TTI.

- else, if a downlink assignment for this TTI has been configured for this Serving Cell and there is no measurement gap in this TTI and there is no Sidelink Discovery Gap for Reception in this TTI; and

- if this TTI is not an MBSFN subframe or the MAC entity is configured with transmission mode *tm9* or *tm10*:

- instruct the physical layer to receive, in this TTI, transport block on the DL-SCH according to the configured downlink assignment and to deliver it to the HARQ entity;

- set the HARQ Process ID to the HARQ Process ID associated with this TTI;

- consider the NDI bit to have been toggled;

- indicate the presence of a configured downlink assignment and deliver the stored HARQ information to the HARQ entity for this TTI.

- if the MAC entity is configured with *rach-Skip* or *rach-SkipSCG* and a UE Contention Resolution Identity MAC control element for this TTI has been received on the PDSCH indicated by the PDCCH of the SpCell addressed to the C-RNTI:

- indicate to upper layer the successful reception of a PDCCH transmission addressed to the C-RNTI.

For configured downlink assignments, the HARQ Process ID associated with this TTI is derived from the following equation:

- if the TTI is a subframe TTI:

- HARQ Process ID = [floor(CURRENT\_TTI/*semiPersistSchedIntervalDL*)] modulo *numberOfConfSPS-Processes*,

where CURRENT\_TTI=[(SFN \* 10) + subframe number].

- else:

- HARQ Process ID = [floor(C*URRENT\_TTI/semiPersistSchedIntervalDL-sTTI*)] modulo *numberOfConfSPS-Processes-sTTI*,

where CURRENT\_TTI = [(SFN \* 10 \* sTTI\_Number\_Per\_Subframe) + subframe number \* sTTI\_Number\_Per\_Subframe + sTTI\_number]. Refer to 5.10.1 for sTTI\_Number\_Per\_Subframe and sTTI\_number.

For BL UEs or UEs in enhanced coverage, CURRENT\_TTI refers to the TTI where first transmission of repetition bundle takes place.

When the MAC entity needs to read BCCH or BR-BCCH, the MAC entity may, based on the scheduling information from RRC:

- if the UE is a BL UE or a UE in enhanced coverage:

- the redundancy version of the received downlink assignment for this TTI is determined by *RVK* = ceiling(3/2\**k*) modulo 4, where *k* depends on the type of system information message.

- for *SystemInformationBlockType1-BR*

- if number of repetitions for PDSCH carrying *SystemInformationBlockType1-BR* is 4, *k* = floor(SFN/2) modulo 4, where SFN is the system frame number.

- else if number of repetitions for PDSCH carrying *SystemInformationBlockType1-BR* is 8, *k* = SFN modulo 4, where SFN is the system frame number.

- else if number of repetitions for PDSCH carrying *SystemInformationBlockType1-BR* is 16, *k* = (SFN\*10+i) modulo 4, where SFN is the system frame number, and *i* denotes the subframe within the SFN.

NOTE: the set of subframes for *SystemInformationBlockType1-BR* when number of repetitions for PDSCH is 16 are given by Table 6.4.1-2 in TS 36.211 [7].

- for *SystemInformation-BR* messages, *k*=*i* modulo 4, *i* =0,1,…, *nsw*–1, where *i* denotes the subframe number within the SI window *nsw*;

- indicate a downlink assignment and redundancy version for the dedicated broadcast HARQ process to the HARQ entity for this TTI.

- else if a downlink assignment for this TTI has been received on the PDCCH for the SI-RNTI, except for NB-IoT;

- if the redundancy version is not defined in the PDCCH format:

- the redundancy version of the received downlink assignment for this TTI is determined by *RVK* = ceiling(3/2\**k*) modulo 4, where *k* depends on the type of system information message: for *SystemInformationBlockType1* message, *k* = (SFN/2) modulo 4, where SFN is the system frame number; for *SystemInformation* messages, *k*=*i* modulo 4, *i* =0,1,…, *nsw*–1, where *i* denotes the subframe number within the SI window *nsw*;

- indicate a downlink assignment and redundancy version for the dedicated broadcast HARQ process to the HARQ entity for this TTI.

When the MAC entity has SC-RNTI and/or G-RNTI, the MAC entity shall for each TTI during which it monitors PDCCH for SC-RNTI as specified in TS 36.331 [8] for UEs other than NB-IoT UEs, BL UEs or UEs in enhanced coverage and in clause 5.7a for NB-IoT UEs, BL UEs or UEs in enhanced coverage and for G-RNTI as specified in clause 5.7a and for each Serving Cell and cell that may be additionally configured as a Serving Cell according to the UE capabilities:

- if a downlink assignment for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's SC-RNTI or G-RNTI:

- attempt to decode the received data.

- if the data which the MAC entity attempted to decode was successfully decoded for this TB:

- deliver the decoded MAC PDU to the disassembly and demultiplexing entity.

### 5.3.2 HARQ operation

#### 5.3.2.1 HARQ Entity

There is one HARQ entity at the MAC entity for each Serving Cell which maintains a number of parallel HARQ processes. Each HARQ process is associated with a HARQ process identifier. The HARQ entity directs HARQ information and associated TBs received on the DL-SCH to the corresponding HARQ processes (see clause 5.3.2.2).

The number of DL HARQ processes per HARQ entity is specified in TS 36.213 [2], clause 7.

When the physical layer is configured for downlink spatial multiplexing, as specified in TS 36.213 [2], one or two TBs are expected per TTI and they are associated with the same HARQ process. Otherwise, one TB is expected per TTI.

For NB-IoT UEs or BL UEs or UEs in enhanced coverage, the parameter DL\_REPETITION\_NUMBER provides the number of transmissions repeated in a bundle. For each bundle, DL\_REPETITION\_NUMBER is set to a value provided by lower layers. Within a bundle, after the initial (re)transmission, DL\_REPETITION\_NUMBER-1 HARQ retransmissions follow. The HARQ feedback is transmitted for the bundle and a downlink assignment corresponding to a new transmission or a retransmission of the bundle is received after the last repetition of the bundle. A retransmission of a bundle is also a bundle. HARQ feedback may be disabled per HARQ process by configuring *downlinkHARQ-FeedbackDisabledBitmap(-NB)* and/or by indication from lower layers.

If the MAC entity is configured with *blindSlotSubslotPDSCH-Repetitions* or *blindSubframePDSCH-Repetitions* on a serving cell (TS 36.331 [8]), the parameter DL\_REPETITION\_NUMBER provides the number of transmissions repeated in a bundle for a downlink assignment received on that serving cell. For each bundle, DL\_REPETITION\_NUMBER and the redundancy version for each transmission within a bundle are set to values provided by lower layers. Within a bundle, after the initial (re-)transmission, DL\_REPETITION\_NUMBER-1 HARQ retransmissions follow. The HARQ feedback is sent only one time for the bundle and after the last transmission of the bundle.

In addition to the broadcast HARQ process, NB-IoT has one or two DL HARQ processes.

The MAC entity shall:

- If a downlink assignment has been indicated for this TTI; or

- If this TTI is for a retransmission within a bundle:

- allocate the TB(s) received from the physical layer and the associated HARQ information to the HARQ process indicated by the associated HARQ information.

- If a downlink assignment has been indicated for the broadcast HARQ process:

- allocate the received TB to the broadcast HARQ process.

NOTE: In case of BCCH and BR-BCCH a dedicated broadcast HARQ process is used.

#### 5.3.2.2 HARQ process

For each TTI where a transmission takes place for the HARQ process, one or two (in case of downlink spatial multiplexing) TBs and the associated HARQ information are received from the HARQ entity.

For each received TB and associated HARQ information, the HARQ process shall:

- if the NDI, when provided, has been toggled compared to the value of the previous received transmission corresponding to this TB; or

- if the HARQ process is equal to the broadcast process and if this is the first received transmission for the TB according to the system information schedule indicated by RRC; or

- if this is the very first received transmission for this TB (i.e. there is no previous NDI for this TB):

- consider this transmission to be a new transmission.

- else:

- consider this transmission to be a retransmission.

The MAC entity then shall:

- if this is a new transmission:

- attempt to decode the received data.

- else if this is a retransmission:

- if the data for this TB has not yet been successfully decoded:

- combine the received data with the data currently in the soft buffer for this TB and attempt to decode the combined data.

- if the data which the MAC entity attempted to decode was successfully decoded for this TB; or

- if the data for this TB was successfully decoded before:

- if the HARQ process is equal to the broadcast process:

- deliver the decoded MAC PDU to upper layers.

- else if this is the first successful decoding of the data for this TB:

- deliver the decoded MAC PDU to the disassembly and demultiplexing entity.

- generate a positive acknowledgement (ACK) of the data in this TB.

- else:

- replace the data in the soft buffer for this TB with the data which the MAC entity attempted to decode.

- generate a negative acknowledgement (NACK) of the data in this TB.

- if the HARQ process is associated with a transmission indicated with a Temporary C-RNTI and the Contention Resolution is not yet successful (see clause 5.1.5); or

- if the HARQ process is equal to the broadcast process; or

- if the HARQ process is not associated with a transmission indicated with a PUR-RNTI or CB-RNTI, and the *timeAlignmentTimer*, associated with the TAG containing the serving cell on which the HARQ feedback is to be transmitted, is stopped or expired:

- do not indicate the generated positive or negative acknowledgement to the physical layer.

- else if the HARQ process is associated with a transmission indicated with a CB-RNTI:

- if the CMR reception is successful (see clause 5.1x. 3); and

- if the HARQ ACK resource field is present in the associated CMR:

- indicate to the physical layer the generated positive acknowledgement together with the HARQ ACK resource.

- else:

- do not indicate the generated positive or negative acknowledgement to the physical layer.

- else if the HARQ feedback is disabled for the corresponding HARQ process:

- if *harq-FeedbackEnablingforSPSactive* is configured and the transmission is the first SPS PDSCH transmission after SPS activation:

- indicate the generated positive or negative acknowledgement for this TB to the physical layer.

- else:

- do not indicate the generated positive or negative acknowledgement to the physical layer.

- else:

- indicate the generated positive or negative acknowledgement for this TB to the physical layer.

The MAC entity shall ignore NDI received in all downlink assignments on PDCCH for its Temporary C-RNTI when determining if NDI on PDCCH for its C-RNTI has been toggled compared to the value in the previous transmission.

NOTE 1: When the MAC entity is configured with more than one serving cell, UE behaviors for storing data to the soft buffer is specified in TS 36.213 [2].

NOTE 2: If the MAC entity receives a retransmission with a TB size different from the last valid TB size signalled for this TB, the UE behavior is left up to UE implementation.

### 5.3.3 Disassembly and demultiplexing

The MAC entity shall disassemble and demultiplex a MAC PDU as defined in clause 6.1.2 (when CB-RNTI is not used) and in clause 6.1.x (when the CB-RNTI is used).

## 5.4 UL-SCH data transfer

### 5.4.1 UL Grant reception

In order to transmit on the UL-SCH the MAC entity must have a valid uplink grant (except for non-adaptive HARQ retransmissions) which it may receive dynamically on the PDCCH or in a Random Access Response or which may be configured semi-persistently or preallocated by RRC or provided by RRC for transmission using PUR (see clause 5.4.7). To perform requested transmissions, the MAC layer receives HARQ information from lower layers. When the physical layer is configured for uplink spatial multiplexing, the MAC layer can receive up to two grants (one per HARQ process) for the same TTI from lower layers.

If the MAC entity has a C-RNTI, a Semi-Persistent Scheduling C-RNTI, a UL Semi-Persistent Scheduling V-RNTI, a AUL C-RNTI, or a Temporary C-RNTI, the MAC entity shall for each TTI and for each Serving Cell belonging to a TAG that has a running *timeAlignmentTimer* and for each grant received for this TTI and for each SPS configuration that is indicated by the PDCCH addressed to UL Semi-Persistent Scheduling V-RNTI; or if the MAC entity has Preconfigured Uplink Resource RNTI, the MAC entity shall for each TTI and for each grant received for this TTI; or if the MAC entity has CB-RNTI, the MAC entity shall for each TTI and for the uplink grant selected for this TTI:

- if an uplink grant for this TTI and this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI, Preconfigured Uplink Resource RNTI or Temporary C-RNTI; or

- if an uplink grant for this TTI has been received in a Random Access Response; or

- if the uplink grant was selected by MAC for CB-Msg3-EDT:

- if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's Semi-Persistent Scheduling C-RNTI, for the MAC entity's UL Semi-Persistent Scheduling V-RNTI, or a configured uplink grant for which the UL HARQ operation was not autonomous; or

- if the uplink grant is for MAC entity’s CB-RNTI:

- consider the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI.

- deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else, if an uplink grant for this TTI has been received for this Serving Cell on the PDCCH for the MAC entity's Semi-Persistent Scheduling C-RNTI or for the MAC entity's UL Semi-Persistent Scheduling V-RNTI; or if an uplink grant for this TTI has been received for this Serving Cell on the PDCCH for the MAC entity's AUL C-RNTI:

- if the NDI in the received HARQ information is 1:

- consider the NDI for the corresponding HARQ process not to have been toggled;

- deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else if the NDI in the received HARQ information is 0:

- if PDCCH contents indicate AUL release:

- trigger an AUL confirmation;

- if an uplink grant for this TTI has been configured:

- consider the NDI bit for the corresponding HARQ process to have been toggled;

- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI;

- else if PDCCH contents indicate AUL activation:

- trigger an AUL confirmation;

- store the uplink grant and the associated HARQ information as configured uplink grant;

- initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI and to recur according to rules in clause 5.23;

- consider the NDI bit for the corresponding HARQ process to have been toggled;

- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else if PDCCH contents indicate SPS release:

- if the MAC entity is configured with *skipUplinkTxSPS*:

- trigger an SPS confirmation;

- if an uplink grant for this TTI has been configured:

- consider the NDI bit for the corresponding HARQ process to have been toggled;

- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI;

- else:

- clear the corresponding configured uplink grant (if any).

- else:

- if the MAC entity is configured with *skipUplinkTxSPS*:

- trigger an SPS confirmation;

- store the uplink grant and the associated HARQ information as configured uplink grant;

- initialise (if not active) or re-initialise (if already active) the configured uplink grant to start in this TTI, or in TTI according to N=0 in clause 5.10.2 for short TTI, and to recur according to rules in clause 5.10.2;

- if UL HARQ operation is asynchronous, set the HARQ Process ID to the HARQ Process ID associated with this TTI;

- consider the NDI bit for the corresponding HARQ process to have been toggled;

- deliver the configured uplink grant and the associated HARQ information to the HARQ entity for this TTI.

- else, if an uplink grant for this TTI has been configured for the Serving Cell and if UL HARQ operation is autonomous for the corresponding HARQ process:

- if the HARQ\_FEEDBACK is set to ACK for the corresponding HARQ process or if there is no uplink grant previously delivered to the HARQ entity for the same HARQ process:

- consider the NDI bit for the corresponding HARQ process to have been toggled.

- if the *aul-RetransmissionTimer* is not running:

- if there is no uplink grant previously delivered to the HARQ entity for the same HARQ process; or

- if the previous uplink grant delivered to the HARQ entity for the same HARQ process was not an uplink grant received for the MAC entity's C-RNTI; or

- if the HARQ\_FEEDBACK is set to ACK for the corresponding HARQ process:

- deliver the configured uplink grant, and the associated HARQ information to the HARQ entity for this TTI.

- else:

- if this Serving Cell is the SpCell and an uplink grant for this TTI has been preallocated for the SpCell; or

- except for preconfigured uplink grant for PUR, if an uplink grant for this TTI has been configured for this Serving Cell:

- if UL HARQ operation is asynchronous, set the HARQ Process ID to the HARQ Process ID associated with this TTI;

- consider the NDI bit for the corresponding HARQ process to have been toggled;

- deliver the configured or preallocated uplink grant, and the associated HARQ information to the HARQ entity for this TTI.

NOTE 1: The period of configured uplink grants is expressed in TTIs.

NOTE 2: If the MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI or Semi persistent scheduling C-RNTI requiring transmissions on the SpCell in the same UL subframe, the MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or Semi persistent scheduling C-RNTI.

NOTE 3: When a configured uplink grant is indicated during a measurement gap and indicates an UL-SCH transmission during a measurement gap, the MAC entity processes the grant but does not transmit on UL-SCH. When a configured uplink grant is indicated during a Sidelink Discovery gap for reception and indicates an UL-SCH transmission during a Sidelink Discovery gap for transmission with a SL-DCH transmission, the MAC entity processes the grant but does not transmit on UL-SCH. When a configured uplink grant indicates an UL-SCH transmission during a V2X sidelink communication transmission and transmission of V2X sidelink communication is prioritized as described in clause 5.14.1.2.2, the MAC entity processes the grant but does not transmit on UL-SCH.

NOTE 4: The NDI transmitted in the PDCCH for the MAC entity's AUL C-RNTI is set to '0' (TS 36.212 [5]).

Except for NB-IoT, for configured uplink grants without *harq-ProcID-offset*, if UL HARQ operation is not autonomous, the HARQ Process ID associated with this TTI is derived from the following equation for asynchronous UL HARQ operation:

- if the TTI is a subframe TTI:

- HARQ Process ID = [floor(CURRENT\_TTI/semiPersistSchedIntervalUL)] modulo numberOfConfUlSPS-Processes,

where CURRENT\_TTI=[(SFN \* 10) + subframe number] and it refers to the subframe where the first transmission of a bundle takes place.

- else:

- HARQ Process ID = [floor(CURRENT\_TTI/*semiPersistSchedIntervalUL-sTTI*)] modulo *numberOfConfUlSPS-Processes-sTTI*,

where CURRENT\_TTI = [(SFN \* 10 \* sTTI\_Number\_Per\_Subframe) + subframe number \* sTTI\_Number\_Per\_Subframe + sTTI\_number] and it refers to the short TTI occasion where the first transmission of a bundle takes place. Refer to 5.10.2 for sTTI\_Number\_Per\_Subframe and sTTI\_number.

For preallocated uplink grants the HARQ Process ID associated with this TTI is derived from the following equation for asynchronous UL HARQ operation:

HARQ Process ID = [floor(CURRENT\_TTI/*ul-SchedInterval*)] modulo *numberOfConfUL-Processes*,

where CURRENT\_TTI=subframe number and it refers to the subframe where the first transmission of a bundle takes place.

For configured uplink grants, if UL HARQ operation is autonomous, the HARQ Process ID associated with this TTI for transmission on this Serving Cell is selected by the UE implementation from the HARQ process IDs that are configured for autonomous UL HARQ operation by upper layers in *aul-HARQ-Processes* (TS 36.331 [8]).

For configured uplink grants with *harq-ProcID-offset*, the HARQ Process ID associated with this TTI is derived from the following equation for asynchronous UL HARQ operation:

- if the TTI is a subframe TTI:

- HARQ Process ID = [floor(CURRENT\_TTI/*semiPersistSchedIntervalUL*)] modulo *numberOfConfUlSPS-Processes* + *harq-ProcID-offset*,

where CURRENT\_TTI = [(SFN \* 10) + subframe number] and it refers to the subframe where the first transmission of a bundle takes place.

- else:

- HARQ Process ID = [floor(CURRENT\_TTI/*semiPersistSchedIntervalUL-sTTI*)] modulo *numberOfConfUlSPS-Processes-sTTI* + harq-ProcID-offset,

where CURRENT\_TTI = [(SFN \* 10 \* sTTI\_Number\_Per\_Subframe) + subframe number \* sTTI\_Number\_Per\_Subframe + sTTI\_number] and it refers to the short TTI occasion where the first transmission of a bundle takes place. Refer to 5.10.2 for sTTI\_Number\_Per\_Subframe and sTTI\_number. For NB-IoT, for configured uplink grants for BSR, the HARQ Process ID is set to 0.

If the MAC entity is configured with Short Processing Time or short TTI and if current\_TTI is a subframe TTI, the HARQ Process ID associated with this TTI is derived from the following equation for synchronous UL HARQ operation:

HARQ Process ID = [SFN \* number\_of\_UL\_PUSCH\_SFs\_per\_radio\_frame + index\_of\_UL\_PUSCH\_SF] modulo number\_of\_UL\_HARQ\_processes.

where number\_of\_UL\_PUSCH\_SFs\_per\_radio\_frame is the number of subframes that can be used for PUSCH (UL PUSCH subframe) per radio frame:

- For FDD serving cells and serving cells operating according to Frame structure Type 3, all 10 subframes in a radio frame represent UL PUSCH subframes;

- For TDD serving cells, all uplink subframes of the TDD UL/DL configuration indicated by *tdd-Config*, as specified in TS 36.331 [8] of the cell represent UL PUSCH subframes and additionally the subframes including UpPTS if the cell is configured with *symPUSCH-UpPts-r14*;

and index\_of\_UL\_PUSCH\_SF is the index of a subframe that can be used for PUSCH within the radio frame, and number\_of\_UL\_HARQ\_processes is the number of parallel HARQ processes per HARQ entity for subframe TTI as specified in TS 36.213 [2], clause 8.

### 5.4.2 HARQ operation

#### 5.4.2.1 HARQ entity

There is one HARQ entity at the MAC entity for each Serving Cell with configured uplink, which maintains a number of parallel HARQ processes allowing transmissions to take place continuously while waiting for the HARQ feedback on the successful or unsuccessful reception of previous transmissions.

The number of parallel HARQ processes per HARQ entity is specified in TS 36.213 [2], clause 8. NB-IoT has one or two UL HARQ processes.

When the physical layer is configured for uplink spatial multiplexing, as specified in TS 36.213 [2], there are two HARQ processes associated with a given TTI. Otherwise there is one HARQ process associated with a given TTI.

At a given TTI, if an uplink grant is indicated for the TTI, the HARQ entity identifies the HARQ process(es) for which a transmission should take place. It also routes the received HARQ feedback (ACK/NACK information), MCS and resource, relayed by the physical layer, to the appropriate HARQ process(es).

In asynchronous HARQ operation, a HARQ process is associated with a TTI based on the received UL grant except for UL grant in RAR. Except for NB-IoT UE configured with a single HARQ process, each asynchronous HARQ process is associated with a HARQ process identifier. For UL transmission with UL grant in RAR, for transmission using PUR and for CB-Msg3-EDT transmission, HARQ process identifier 0 is used. HARQ feedback is not applicable for asynchronous UL HARQ except if *mpdcch-UL-HARQ-ACK-FeedbackConfig* is configured.

In autonomous HARQ operation, HARQ feedback is applicable.

When TTI bundling is configured, the parameter TTI\_BUNDLE\_SIZE provides the number of TTIs of a TTI bundle. TTI bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and triggered without waiting for feedback from previous transmissions according to TTI\_BUNDLE\_SIZE. The HARQ feedback of a bundle is only received for the last TTI of the bundle (i.e the TTI corresponding to TTI\_BUNDLE\_SIZE), regardless of whether a transmission in that TTI takes place or not (e.g. when a measurement gap occurs). A retransmission of a TTI bundle is also a TTI bundle. TTI bundling is not supported when the MAC entity is configured with one or more SCells with configured uplink.

Uplink HARQ operation is asynchronous for NB-IoT UEs, BL UEs or UEs in enhanced coverage except for the repetitions within a bundle, in serving cells configured with *pusch-EnhancementsConfig*, serving cells operating according to Frame Structure Type 3, for HARQ processes scheduled using short TTI, for HARQ processes scheduled using Short Processing Time, and for HARQ processes associated with an SPS configuration with *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* exceptfor the repetitions within a bundle.

For serving cells configured with *pusch-EnhancementsConfig*, NB-IoT UEs, BL UEs or UEs in enhanced coverage, the parameter UL\_REPETITION\_NUMBER provides the number of transmission repetitions within a bundle. For each bundle, UL\_REPETITION\_NUMBER is set to a value provided by lower layers. Bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and are triggered without waiting for feedback from previous transmissions according to UL\_REPETITION\_NUMBER. An uplink grant corresponding to a new transmission of the bundle is only received after the last repetiton of the bundle if *mpdcch-UL-HARQ-ACK-FeedbackConfig* is not configured. An uplink grant corresponding to a retransmission of the bundle is only received after the last repetition of the bundle. For UEs configured with *mpdcch-UL-HARQ-ACK-FeedbackConfig*, repetitions within a bundle are stopped if an UL HARQ-ACK feedback or an uplink grant corresponding to a new transmission of the bundle is received on PDCCH during the bundle transmission. A retransmission of a bundle is also a bundle.

For a SPS configuration with *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* (TS 36.331 [8]), the parameter *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* provides the number of transmission repetitions within a configured grant bundle. Bundling operation relies on the HARQ entity invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle HARQ retransmissions are non-adaptive and are triggered without waiting for feedback from previous transmissions.

TTI bundling is not supported for RN communication with the E-UTRAN in combination with an RN subframe configuration.

For transmission of Msg3 during Random Access (see clause 5.1.5) TTI bundling does not apply. For UEs configured with *pusch-EnhancementsConfig* performing contention free Random Access, NB-IoT UEs, BL UEs or UEs in enhanced coverage, uplink repetition bundling is used for transmission of Msg3.

For each TTI, the HARQ entity shall:

- identify the HARQ process(es) associated with this TTI, and for each identified HARQ process:

- if an uplink grant has been indicated for this process and this TTI:

- if the received grant was addressed neither to a Temporary C-RNTI nor to a PUR-RNTI on PDCCH and if the NDI provided in the associated HARQ information has been toggled compared to the value in the previous transmission of this HARQ process; or

- if the uplink grant was received on PDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or

- if the uplink grant was provided by RRC for transmission using PUR; or

- if the uplink grant was received in a Random Access Response; or

- if the uplink grant was selected by MAC for CB-Msg3-EDT:

- if there is a MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response or selected by MAC for CB-Msg3-EDT:

- if the MAC PDU in the Msg3 buffer contains the Data Volume and Power Headroom Report MAC control element:

- the MAC entity shall update the Data Volume and Power Headroom Report MAC control element in the MAC PDU in the Msg3 buffer.

- if the UE is an NB-IoT UE and *cqi-Reporting* is configured by upper layers:

- the MAC entity shall update the MAC PDU in the Msg3 buffer in accordance with the DL channel quality measurement result.

- obtain the MAC PDU to transmit from the Msg3 buffer.

- else if the uplink grant is a configured grant with *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* and if a retransmission within a bundle is triggered for another configured grant with *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* in this TTI:

- ignore the uplink grant.

- else if the MAC entity is configured with *semiPersistSchedIntervalUL* shorter than 10 subframes and if the uplink grant is a configured grant, and if the HARQ buffer of the identified HARQ process is not empty, and if HARQ\_FEEDBACK of the identified HARQ process is NACK; or if the MAC entity is configured with *ul-SchedInterval* shorter than 10 subframes and if the uplink grant is a preallocated uplink grant, and if the HARQ buffer of the identified HARQ process is not empty, and if HARQ\_FEEDBACK of the identified HARQ process is NACK:

- instruct the identified HARQ process to generate a non-adaptive retransmission.

- else:

- if the UL HARQ operation is synchronous, and the uplink grant is a preallocated uplink grant, and a MAC PDU has previously been obtained from the "Multiplexing and assembly" entity during this handover attempt:

- ignore the uplink grant;

- else:

- obtain the MAC PDU to transmit from the "Multiplexing and assembly" entity, if any;

- if a MAC PDU to transmit has been obtained:

- deliver the MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;

- if the UL grant is selected by MAC for CB-Msg3-EDT:

- instruct the physical layer to set the transmit power in according with the CB-MSG3\_RECEIVED\_TARGET\_POWER.

- instruct the identified HARQ process to trigger a new transmission.

- else:

- flush the HARQ buffer of the identified HARQ process.

- else:

- if the MAC entity is configured with *skipUplinkTxSPS* and if the uplink grant received on PDCCH was addressed to the Semi-Persistent Scheduling C-RNTI or to the UL Semi-Persistent Scheduling V-RNTI and if the HARQ buffer of the identified process is empty; or

- if UL HARQ operation is autonomous for the identified HARQ process and if the uplink grant is a configured UL grant and if the HARQ buffer of the identified process is empty; or

- if the previous uplink grant delivered to the HARQ entity for the same HARQ process was a configured uplink grant for which the UL HARQ operation was autonomous, and if the corresponding UL grant size was different from the UL grant size indicated by the uplink grant for this TTI:

- ignore the uplink grant;

- else:

- deliver the uplink grant and the HARQ information (redundancy version) to the identified HARQ process;

- if UL HARQ operation is autonomous for the identified HARQ process and if the uplink grant is a configured UL grant:

- instruct the identified HARQ process to generate a non adaptive retransmission.

- else:

- instruct the identified HARQ process to generate an adaptive retransmission.

- else, if the HARQ buffer of this HARQ process is not empty:

- instruct the identified HARQ process to generate a non-adaptive retransmission;

- if the non-adaptive retransmission collides with a transmission of another HARQ process scheduled using Short Processing Time:

- instruct the identified HARQ process to generate a positive acknowledgement (ACK) of the data in the corresponding TB.

When determining if NDI has been toggled compared to the value in the previous transmission the MAC entity shall ignore NDI received in all uplink grants on PDCCH for its Temporary C-RNTI and PUR-RNTI.

#### 5.4.2.2 HARQ process

Each HARQ process is associated with a HARQ buffer.

For synchronous HARQ, each HARQ process shall maintain a state variable CURRENT\_TX\_NB, which indicates the number of transmissions that have taken place for the MAC PDU currently in the buffer, and a state variable HARQ\_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer. When the HARQ process is established, CURRENT\_TX\_NB shall be initialized to 0.

The sequence of redundancy versions is 0, 2, 3, 1. The variable CURRENT\_IRV is an index into the sequence of redundancy versions. This variable is up-dated modulo 4. For serving cells configured with *pusch-EnhancementsConfig*, BL UEs or UEs in enhanced coverage see clause 8.6.1 in TS 36.213 [2] for the sequence of redundancy versions and redundancy version determination. For NB-IoT UEs see clause 16.5.1.2 in TS 36.213 [2] for the sequence of redundancy versions and redundancy version determination. For an SPS configuration with *totalNumberPUSCH-SPS-STTI-UL-Repetitions* or *totalNumberPUSCH-SPS-UL-Repetitions* (TS 36.331 [8]), the redundancy version for each transmission within a bundle are determined by *rv-SPS-STTI-UL-Repetitions* or *rv-SPS-UL-Repetitions* in the SPS configuration (TS 36.331 [8]).

For NB-IoT UEs, BL UEs or UEs in enhanced coverage for UL\_REPETITION\_NUMBER for Mode B operation, the same redundancy version is used multiple times before cycling to the next redundancy version as specified in clauses 16.5.1.2, 8.6.1 and 7.1.7.1 in TS 36.213 [2].

New transmissions are performed on the resource and with the MCS indicated on PDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, if provided, with the MCS indicated on PDCCH. Non-adaptive retransmission is performed on the same resource and with the same MCS as was used for the last made transmission attempt.

For synchronous HARQ, the MAC entity is configured with a maximum number of HARQ transmissions and a maximum number of Msg3 HARQ transmissions by RRC: *maxHARQ-Tx* and *maxHARQ-Msg3Tx* respectively. For transmissions on all HARQ processes and all logical channels except for transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Tx*. For transmission of a MAC PDU stored in the Msg3 buffer, the maximum number of transmissions shall be set to *maxHARQ-Msg3Tx*.

For autonomous HARQ, each HARQ process shall maintain a state variable HARQ\_FEEDBACK, which indicates the HARQ feedback for the MAC PDU currently in the buffer, and a timer *aul-RetransmissionTimer* which prohibits new transmission or retransmission for the same HARQ process on the configured autonomous uplink when the timer is running.

When the HARQ feedback is received for this TB, the HARQ process shall:

- set HARQ\_FEEDBACK to the received value;

- if running, stop the *aul-RetransmissionTimer*.

When an uplink grant addressed to C-RNTI is received for this HARQ process and if the UL HARQ operation is autonomous, the HARQ process shall:

- if running, stop the *aul-RetransmissionTimer*.

When PUSCH transmission is performed for this TB and if the uplink grant is a configured grant for the MAC entity's AUL C-RNTI, the HARQ process shall:

- start or restart the *aul-RetransmissionTimer*.

If the HARQ entity requests a new transmission, the HARQ process shall:

- if UL HARQ operation is synchronous:

- set CURRENT\_TX\_NB to 0;

- set HARQ\_FEEDBACK to NACK;

- set CURRENT\_IRV to 0;

- else:

- if UL HARQ operation is autonomous asychronous:

- set HARQ\_FEEDBACK to NACK.

- if the uplink grant was addressed to the AUL C-RNTI:

- set CURRENT\_IRV to 0.

- else:

- set CURRENT\_IRV to the index corresponding to the redundancy version value provided in the HARQ information;

- store the MAC PDU in the associated HARQ buffer;

- store the uplink grant received from the HARQ entity;

- generate a transmission as described below.

If the HARQ entity requests a retransmission, the HARQ process shall:

- if UL HARQ operation is synchronous:

- increment CURRENT\_TX\_NB by 1;

- if the HARQ entity requests an adaptive retransmission:

- store the uplink grant received from the HARQ entity;

- set CURRENT\_IRV to the index corresponding to the redundancy version value provided in the HARQ information;

- if UL HARQ operation is synchronous; or

- if UL HARQ operation is autonomous:

- set HARQ\_FEEDBACK to NACK;

- generate a transmission as described below.

- else if the HARQ entity requests a non-adaptive retransmission:

- if UL HARQ operation is asynchronous or HARQ\_FEEDBACK = NACK:

- if both *skipUplinkTxSPS* and *fixedRV-NonAdaptive* are configured and the uplink grant of the initial transmission of this HARQ process was performed on a configured grant and UL HARQ operation is not autonomous; or

- if the uplink grant is a preallocated uplink grant:

- set CURRENT\_IRV to 0;

- else if UL HARQ operation is autonomous:

- set CURRENT\_IRV to the index corresponding to the redundancy version value selected by the UE implementation.

- generate a transmission as described below.

NOTE 1: When receiving a HARQ ACK alone, the MAC entity keeps the data in the HARQ buffer.

NOTE 2: When no UL-SCH transmission can be made due to the occurrence of a measurement gap or a Sidelink Discovery Gap for Transmission, or prioritization of V2X sidelink communication transmission described in clause 5.14.1.2.2, no HARQ feedback can be received and a non-adaptive retransmission follows.

NOTE 3: For asynchronous HARQ operation, UL retransmissions are triggered only by adaptive retransmission grants, except for retransmissions within a bundle.

To generate a transmission, the HARQ process shall:

- if the MAC PDU was obtained from the Msg3 buffer; or

- if Sidelink Discovery Gaps for Transmission are not configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer in this TTI; or

- if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is no Sidelink Discovery Gap for Transmission in this TTI; or

- if Sidelink Discovery Gaps for Transmission are configured by upper layers, and there is no measurement gap at the time of the transmission and, in case of retransmission, the retransmission does not collide with a transmission for a MAC PDU obtained from the Msg3 buffer, and there is a Sidelink Discovery Gap for Transmission, and there is no configured grant for transmission on SL-DCH in this TTI:

- if there is neither transmission of V2X sidelink communication on SL-SCH nor transmission of NR sidelink communication in this TTI; or

- if the transmission of the MAC PDU is prioritized over sidelink transmission:

- instruct the physical layer to generate a transmission according to the stored uplink grant with the redundancy version corresponding to the CURRENT\_IRV value;

- increment CURRENT\_IRV by 1 if UL HARQ operation is not autonomous;

- if UL HARQ operation is synchronous and there is a measurement gap or Sidelink Discovery Gap for Reception at the time of the HARQ feedback reception for this transmission and if the MAC PDU was not obtained from the Msg3 buffer:

- set HARQ\_FEEDBACK to ACK at the time of the HARQ feedback reception for this transmission.

After performing above actions, if UL HARQ operation is synchronous the HARQ process then shall:

- if CURRENT\_TX\_NB = maximum number of transmissions – 1:

- flush the HARQ buffer;

The transmission of the MAC PDU is prioritized over sidelink transmission or can be performed simultaneously with sidelink transmission if one of the following conditions is met:

- if there are both a configured grant for transmission of V2X sidelink communication on SL-SCH in this TTI and a sidelink grant for transmission of NR sidelink communication as described in clause 5.22.1.1 of TS 38.321 [24] at the time of the transmission, and neither the transmissions of V2X sidelink communication is prioritized as described in clause 5.14.1.2.2 nor the transmission of NR sidelink communication is prioritized as described in clause 5.22.1.3.1a of TS 38.321 [24]; or

- if there are both a configured grant for transmission of V2X sidelink communication on SL-SCH in this TTI and a sidelink grant for transmission of NR sidelink communication as described in clause 5.22.1.1 of TS 38.321 [24] at the time of the transmission, and the MAC entity is able to perform this UL transmission simultaneously with the transmissions of V2X sidelink communication and/or the transmission of NR sidelink communication; or

- if there is only configured grant(s) for transmission of V2X sidelink communication on SL-SCH in this TTI, and either none of the transmissions of V2X sidelink communication is prioritized or the MAC entity is able to perform this UL transmission and the transmissions of V2X sidelink communication simultaneously; or

- if there is only a sidelink grant for transmission of NR sidelink communication in this TTI as described in clause 5.22.1.1 of TS 38.321 [24], and either no transmission of NR sidelink communication is prioritized as described in clause 5.22.1.3.1a of TS 38.321 [24] or the MAC entity is able to perform this UL transmission simultaneously with the transmission of NR sidelink communication; or

- if there are both a configured grant for transmission of V2X sidelink communication on SL-SCH in this TTI and a sidelink grant for transmission of NR sidelink communication as described in clause 5.22.1.1 of TS 38.321 [24] at the time of the transmission, and either only the transmissions of V2X sidelink communication is prioritized as described in clause 5.14.1.2.2 or only the transmission of NR sidelink communication is prioritized as described in clause 5.22.1.3.1a of TS 38.321 [24] and the MAC entity is able to perform this UL transmission simultaneously with the prioritized transmission of V2X sidelink communication or NR sidelink communication.

NOTE 4: Among the UL transmissions where the MAC entity is able to perform all transmissions of V2X sidelink communication prioritized simultaneously, if there are more than one UL transmission which the MAC entity is not able to perform simultaneously, it is up to UE implementation whether this UL transmission is performed.

NOTE 5: Among the UL transmissions that the MAC entity is able to perform simultaneously with the transmission of NR sidelink communication prioritized, if there are more than one UL transmission which the MAC entity is not able to perform simultaneously, it is up to UE implementation whether this UL transmission is performed.

NOTE 6: Among the UL transmissions where the MAC entity is able to perform all transmissions of V2X sidelink communication prioritized simultaneously with the transmission of NR sidelink communication prioritized, if there are more than one UL transmission which the MAC entity is not able to perform simultaneously, it is up to UE implementation whether this UL transmission is performed.

NOTE 7: If there is a sidelink grant for transmission of NR sidelink communication in this TTI as described in clause 5.22.1.1 of TS 38.321 [24] and the MAC entity is not able to perform this UL transmission simultaneously with the transmission of NR sidelink communication, and prioritization-related information is not available prior to the time of the transmission due to processing time restriction, it is up to UE implementation whether this UL transmission is performed.

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### 5.4.3 Multiplexing and assembly

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#### 5.4.3.2 Multiplexing of MAC Control Elements and MAC SDUs

The MAC entity shall multiplex MAC control elements and MAC SDUs in a MAC PDU according to clauses 5.4.3.1 , 6.1.2 and 6.1.x.

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## 5.9 MAC Reset

If a reset of the MAC entity is requested by upper layers, the MAC entity shall:

- initialize Bj for each logical channel to zero;

- except for *pur-TimeAlignmentTimer,* if configured*,* stop (if running) all timers;

- except for *pur-TimeAlignmentTimer,* if configured*,* consider all *timeAlignmentTimer*sas expired and perform the corresponding actions in clause 5.2;

- set the NDIs for all uplink HARQ processes to the value 0;

- stop, if any, ongoing RACH procedure;

- discard explicitly signalled *ra-PreambleIndex* and *ra-PRACH-MaskIndex*, if any;

- flush Msg3 buffer;

- cancel, if any, triggered Scheduling Request procedure;

- cancel, if any, triggered Buffer Status Reporting procedure;

- cancel, if any, triggered Power Headroom Reporting procedure;

- cancel, if any, triggered Recommended bit rate query procedure;

- cancel, if any, triggered Timing Advance Reporting procedure;

- cancel, if any, triggered GNSS Validity Duration Reporting procedure;

- cancel, if any, triggered CB-Msg3-EDT procedure;

- flush the soft buffers for all DL HARQ processes;

- for each DL HARQ process, consider the next received transmission for a TB as the very first transmission;

- release, if any, Temporary C-RNTI;

- release, if any, CB-RNTI;

- clear, if any, Differential Koffset.

If a partial reset of the MAC entity is requested by upper layers, for a serving cell, the MAC entity shall for the serving cell:

- set the NDIs for all uplink HARQ processes to the value 0;

- flush all UL HARQ buffers;

- stop all running *drx-ULRetransmissionTimers*;

- stop all running UL HARQ RTT timers;

- stop, if any, ongoing RACH procedure;

- discard explicitly signalled *ra-PreambleIndex* and *ra-PRACH-MaskIndex*, if any;

- flush Msg3 buffer;

- release, if any, Temporary C-RNTI.

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# 6 Protocol Data Units, formats and parameters

## 6.1 Protocol Data Units

### 6.1.2 MAC PDU (DL-SCH and UL-SCH except transparent MAC and Random Access Response, MCH, CB-Msg4)

A MAC PDU consists of a MAC header, zero or more MAC Service Data Units (MAC SDU), zero, or more MAC control elements, and optionally padding; as described in Figure 6.1.2-3.

Both the MAC header and the MAC SDUs are of variable sizes.

A MAC PDU header consists of one or more MAC PDU subheaders; each subheader corresponds to either a MAC SDU, a MAC control element or padding.

A MAC PDU subheader consists of the header fields R/F2/E/LCID/(R/R/eLCID)/(F)/(L). The L field is present in the MAC PDU subheader except for the last subheader in the MAC PDU and fixed sized MAC control elements. The last subheader in the MAC PDU and subheaders for fixed sized MAC control elements consist of the header fields R/F2/E/LCID/(R/R/eLCID). A MAC PDU subheader corresponding to padding consists of the four header fields R/F2/E/LCID.





Figure 6.1.2-1: R/F2/E/LCID/(R/R/eLCID)/F/L MAC subheader with 7-bits and 15-bits L field



Figure 6.1.2-1a: R/F2/E/LCID/(R/R/eLCID)/L MAC subheader with 16-bits L field



Figure 6.1.2-2: R/F2/E/LCID/(R/R/eLCID) MAC subheader

MAC PDU subheaders have the same order as the corresponding MAC SDUs, MAC control elements and padding.

MAC control elements are always placed before any MAC SDU.

Padding occurs at the end of the MAC PDU, except when single-byte or two-byte padding is required. Padding may have any value and the MAC entity shall ignore it. When padding is performed at the end of the MAC PDU, zero or more padding bytes are allowed.

When single-byte or two-byte padding is required, one or two MAC PDU subheaders corresponding to padding are placed at the beginning of the MAC PDU before any other MAC PDU subheader.

A maximum of one MAC PDU can be transmitted per TB per MAC entity. A maximum of one MCH MAC PDU can be transmitted per TTI.



Figure 6.1.2-3: Example of MAC PDU consisting of MAC header, MAC control elements, MAC SDUs and padding

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### 6.1.x MAC PDU (CB-Msg4)

A MAC PDU consists of a MAC header, zero or more MAC CB-Msg3-EDT Responses (MAC CMR), zero or more optional MAC SDUs, and optional padding as described in figure 6.1.x-5. Each MAC SDU is associated with the UE identified by the preceding MAC CMR.

The MAC header is of variable size.

A MAC PDU header consists of one or more MAC PDU subheaders; each subheader except for the CB Backoff Indicator subheader corresponding to a MAC CMR, MAC SDU, or padding. If included, the CB Backoff Indicator subheader is only included once and is the first subheader included within the MAC PDU header except when single-byte or two-byte padding is required.

The CB Backoff Indicator subheader consists of the four header fields E/T/R/BI (as described in figure 6.1.x-1).

A CMR subheader consists of the seven header fields E/T/R/R/H/TA/C (as described in figure 6.1.x-2).

A MAC PDU subheader corresponding to the MAC SDU consists of the header fields E/T/LCID/(F)/(L). The L field is present in the MAC PDU subheader corresponding to the MAC SDU except for the last subheader in the MAC PDU (as described in figure 6.1.x-3). A MAC PDU subheader corresponding to padding consists of the three header fields E/T/LCID.

For BL UEs and UEs in CE mode A, a MAC CMR consists of the following fields: UE Contention Resolution Identity/(Timing Advance Command)/(HARQ ACK resource)/(C-RNTI) (as described in figures 6.1.x-4a). For NB-IoT UEs, a MAC CMR consists of the following fields: UE Contention Resolution Identity/(R)/(HARQ ACK resource) /(R)/(Timing Advance Command)/(C-RNTI) (as described in figures 6.1.x-4b).

Padding occurs at the end of the MAC PDU, except when single-byte or two-byte padding is required. Padding may have any value and the MAC entity shall ignore it. When padding is performed at the end of the MAC PDU, zero or more padding bytes are allowed.

When single-byte or two-byte padding is required, one or two MAC PDU subheaders corresponding to padding are placed at the beginning of the MAC PDU before any other MAC PDU subheader.



Figure 6.1.x-1: E/T/R/BI MAC subheader



Figure 6.1.x-2: E/T/R/R/H/TA/C MAC subheader



Figure 6.1.x-3:E/T/LCID/(F)/(L) MAC subheader



Figure 6.1.x-4a: MAC CMR for BL UEs and UEs in CE mode A



Figure 6.1.x-4b: MAC CMR for NB-IoT UEs



Figure 6.1.x-5: Example of MAC PDU consisting of a MAC header, MAC CMRs, MAC SDUs and padding

## 6.2 Formats and parameters

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### 6.2.x MAC header for CB-Msg4

The MAC header is of variable size and consists of the following fields:

- E: The Extension field is a flag indicating if more fields are present in the MAC header or not. The E field is set to "1" to indicate at least another subheader follows. The subsequent subheader can be E/T/R/BI MAC subheader, E/T/R/R/H/TA/C MAC subheader or E/T/LCID/(F)/(L) MAC subheader. The E field is set to "0" to indicate that either a MAC CMR, a MAC SDU, or padding starts at the next byte;

- T: The Type field is a flag indicating the type of the MAC subheader. The T field is set to "00" to indicate the presence of a Backoff Indicator field in the subheader (BI). The T field is set to "01" to indicate the presence of a CMR in the subheader. The T field is set to "10" to indicate the presence of a Logical Channel ID (LCID) field in the subheader. The value "11" is reserved for future use. The size of the Type field is 2 bits;

- H: The H field is a flag indicating the presence of the HARQ ACK resource field in the corresponding MAC CMR. For NB-IoT, it also indicates the presence of the 4-bit R fields preceding the HARQ ACK resource field in the same MAC CMR;

- TA: The TA field is a flag indicating the presence of the Timing Advance Command field in the corresponding MAC CMR. For NB-IoT, it also indicates the presence of the 2-bit R fields preceding the Timing Advance Command field in the same MAC CMR;

- C: The C field is a flag indicating the presence of the C-RNTI field in the corresponding MAC CMR;

- R: Reserved bit, set to "0";

- BI: The Backoff Indicator field identifies the overload condition in the cell. The size of the BI field is 4 bits;

- LCID: The Logical Channel ID field identifies the logical channel instance of the corresponding MAC SDU or padding as described in table 6.2.1-1 for the DL-SCH. There is one LCID field for each MAC SDU, or padding included in the MAC PDU. In addition to that, one or two additional LCID fields are included in the MAC PDU, when single-byte or two-byte padding is required but cannot be achieved by padding at the end of the MAC PDU. The LCID field size is 5 bits;

- L: The Length field indicates the length of the corresponding MAC SDU in bytes. There is one L field per MAC PDU subheader corresponding to the MAC SDU except for the last subheader. The size of the L field is indicated by the F field;

- F: The Format field indicates the size of the Length field. There is one F field per MAC PDU subheader except for the last subheader. The size of the F field is 1 bit. If the F field is included; if the size of the MAC SDU is less than 128 bytes, the value of the F field is set to 0, otherwise it is set to 1.

The MAC header and subheaders are octet aligned.

### 6.2.y MAC payload for CB-Msg4

The MAC CMR is of variable size and consists of the following fields:

- UE Contention Resolution Identity: This field contains the first 48 bits of the uplink CCCH SDU;

- R: Reserved bit, set to "0";

- HARQ ACK resource: This field indicates the resource used to transmit the HARQ ACK for this MAC CMR. For BL UEs and UEs in CE mode A, the size of this field is 2 bits (see HARQ-ACK resource offset in clause 5.3.3.1.13 of TS 36.212 [5]). For NB-IoT UEs, the size of this field is 4 bits (see HARQ-ACK resource in clause 6.4.3.2 of TS 36.212 [5]). For BL UEs and UEs in CE mode A, if this field is not present as indicated in the corresponding MAC CMR subheader and the Timing Advance Command field is present, set these bits to "0";

- Timing Advance Command: The Timing Advance Command field indicates the index value *TA* (0, 1, 2… 63) used to control the amount of timing adjustment that the MAC entity has to apply (see clause 4.2.3 of TS 36.213 [2]). The size of the Timing Advance Command field is 6 bits. For BL UEs and UEs in CE mode A, if this field is not present as indicated in the corresponding MAC CMR subheader and the HARQ ACK resource field is present, set these bits to "0";

- C-RNTI: This field contains the C-RNTI. The length of the field is 16 bits.

The MAC CMR is octet aligned.

The size of the MAC CMR is determined based on its corresponding MAC CMR subheader. It is consist of a mandatory 6 octets UE contention resolution identify field follow by one or more optionally fields for C-RNTI, Timing Advance Command, and HARQ ACK resource. If the C-RNTI is present, the 2 octets C-RNTI field is included. For BL UEs and UEs in CE mode A, if the HARQ ACK resource, the Timing Advance Command, or both are present, the 1 octects field for Timing Advance Command and HARQ ACK resource is included. For NB-IoT UEs, if the HARQ ACK resource is present, the 1 octects field for HARQ ACK resource is included; if the Timing Advance Command is present, the 1 octects field for Timing Advance Command is included.

# 7 Variables and constants

## 7.1 RNTI values

RNTI values are presented in Table 7.1-1 and their usage and associated Transport Channels and Logical Channels are presented in Table 7.1-2.

Table 7.1-1: RNTI values.

|  |  |
| --- | --- |
| Value (hexa-decimal) | RNTI |
| 0000 | N/A |
| 0001-09600001-1000 (Note 3) | RA-RNTI, C-RNTI, Semi-Persistent Scheduling C-RNTI, Temporary C-RNTI, eIMTA-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, SL-RNTI (see note), G-RNTI, SL-V-RNTI, UL Semi-Persistent Scheduling V-RNTI, SL Semi-Persistent Scheduling V-RNTI, SRS-TPC-RNTI, AUL C-RNTI, and PUR-RNTI |
| 0961-FFF31001-FFF3 (Note 3) | C-RNTI, Semi-Persistent Scheduling C-RNTI, eIMTA-RNTI, Temporary C-RNTI, TPC-PUCCH-RNTI, TPC-PUSCH-RNTI, SL-RNTI, G-RNTI, SL-V-RNTI, UL Semi-Persistent Scheduling V-RNTI, SL Semi-Persistent Scheduling V-RNTI, SRS-TPC-RNTI, AUL C-RNTI, CB-RNTI, and PUR-RNTI |
| FFF4-FFF8 | Reserved for future use |
| FFF9 | SI-RNTI |
| FFFA | SC-N-RNTI |
| FFFB | SC-RNTI |
| FFFC | CC-RNTI |
| FFFD | M-RNTI |
| FFFE | P-RNTI |
| FFFF | SI-RNTI |

NOTE 1: A MAC entity uses the same C-RNTI on all Serving Cells.

NOTE 2: SI-RNTI value FFFF may be used for MBMS-dedicated carrier. SI-RNTI value FFF9 is only used for MBMS-dedicated carrier.

NOTE 3: Range applicable for NB-IoT.

Table 7.1-2: RNTI usage.

|  |  |  |  |
| --- | --- | --- | --- |
| RNTI | Usage | Transport Channel | Logical Channel |
| P-RNTI | Paging and System Information change notification | PCH | PCCH |
| SI-RNTI | Broadcast of System Information | DL-SCH | BCCH, BR-BCCH |
| M-RNTI | MCCH Information change notification | N/A | N/A |
| RA-RNTI | Random Access Response | DL-SCH | N/A |
| eIMTA-RNTI | eIMTA TDD UL/DL configuration notification | N/A | N/A |
| Temporary C-RNTI | Contention Resolution(when no valid C-RNTI is available) | DL-SCH | CCCH, DCCH |
| Temporary C-RNTI | Msg3 transmission | UL-SCH | CCCH, DCCH, DTCH |
| C-RNTI | Dynamically scheduled unicast transmission | UL-SCH | DCCH, DTCH |
| C-RNTI | Dynamically scheduled unicast transmission | DL-SCH | CCCH, DCCH, DTCH |
| C-RNTI | Triggering of PDCCH ordered random access | N/A | N/A |
| Semi-Persistent Scheduling C-RNTI | Semi-Persistently scheduled unicast transmission(activation, reactivation and retransmission) | DL-SCH, UL-SCH | DCCH, DTCH |
| Semi-Persistent Scheduling C-RNTI | Semi-Persistently scheduled unicast transmission(deactivation) | N/A | N/A |
| TPC-PUCCH-RNTI | Physical layer Uplink power control | N/A | N/A |
| TPC-PUSCH-RNTI | Physical layer Uplink power control | N/A | N/A |
| SL-RNTI | Dynamically scheduled sidelink transmission for sidelink communication | SL-SCH | STCH |
| SC-RNTI | Dynamically scheduled SC-PTM control information | DL-SCH | SC-MCCH |
| G-RNTI | Dynamically scheduled SC-PTM transmission | DL-SCH | SC-MTCH |
| SC-N-RNTI | SC-MCCH Information change notification | N/A | N/A |
| CC-RNTI | Providing common control PDCCH information | N/A | N/A |
| SL-V-RNTI | Dynamically scheduled sidelink transmission for V2X sidelink communication | SL-SCH | STCH |
| UL Semi-Persistent Scheduling V-RNTI | Semi-Persistently scheduled uplink transmission for V2X communication(activation, reactivation and retransmission) | UL-SCH | DCCH, DTCH |
| UL Semi-Persistent Scheduling V-RNTI | Semi-Persistently scheduled uplink transmission for V2X communication(deactivation) | N/A | N/A |
| SL Semi-Persistent Scheduling V-RNTI | Semi-Persistently scheduled sidelink transmission for V2X sidelink communication(activation, reactivation and retransmission) | SL-SCH | STCH |
| SL Semi-Persistent Scheduling V-RNTI | Semi-Persistently scheduled sidelink transmission for V2X sidelink communication(deactivation) | N/A | N/A |
| SRS-TPC-RNTI | SRS and TPC for the PUSCH-less SCells | N/A | N/A |
| AUL C-RNTI | Autonomous Uplink C-RNTI unicast transmission (activation and reactivation) | UL-SCH | DCCH, DTCH |
| AUL C-RNTI | Autonomous Uplink C-RNTI unicast transmission (deactivation) | N/A | N/A |
| PUR-RNTI | Transmission using Preconfigured Uplink Resource | DL-SCH, UL-SCH | CCCH, DCCH, DTCH |
| PUR-RNTI | Transmission using Preconfigured Uplink Resource (L1 ACK or fallback indication) | N/A | N/A |
| CB-RNTI | CB-Msg4 | DL-SCH | CCCH, DCCH,DTCH |