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5G Medium Access Control Protocol (5G-MAC) Specification (Release 1)

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Document History

Version	Date	Change	Verizon POC
0.0.1	2016-03-20	Data skeleton created	
0.0.2	2016-03-31	5G-MAC general architecture updated	
0.1	2016-05-02	Updated based on agreement of April F2F meeting	
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1.0	2016-06-29	Updated based on agreement in conf. call (Nokia's CR)	
1.1	2016-07-29	Updated based on agreement in July F2F meeting	
1.2	2016-08-31	Updated based on approved CR #3, CR#4, CR #5, CR #6	

Document Approvals

Name	Title	Company	Date of Approval

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1 Scope

The present document specifies the 5G Medium Access Control (5G-MAC) protocol of the Verizon 5G system for initial Fixed Wireless Use case.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
  For a non-specific reference, the latest version applies. In the case of a reference to a V5G document, a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1]: TS V5G.213: “5G Radio Access (5G RA); 5G Physical layer procedures”.
[2]: TS V5G.322: “5G Radio Access (5G RA); 5G Radio Link Control (5G-RLC) Protocol Specification”.
[3]: TS V5G.323: “5G Radio Access (5G RA); 5G Packet Data Convergence Protocol (5G-PDCP) Specification”.
[4]: TS V5G.212: “5G Radio Access (5G RA); 5G Multiplexing and channel coding”.
[5]: TS V5G.214: “5G Radio Access (5G RA); 5G Physical layer - Measurements”.
[6]: TS V5G.211: “5G Radio Access (5G RA); 5G Physical Channels and Modulation”.
[7]: TS V5G.331: “5G Radio Access (5G RA); 5G Radio Resource Control (5G-RRC) Protocol Specification”.

3 Definitions and abbreviations

3.1 Definitions

For the purpose of the present document, the following terms and definitions apply.

3.2 Abbreviations

For the purpose of the present document, the following abbreviations apply.

- ARQ Automatic Repeat reQuest
- BAR Beam Adjustment Request
- BI Beam Index
- BRI Beam Refinement Information
- BRRS Beam Refinement Reference Signal
- BRRS-RI Beam Refinement Reference Signal Resource Index

- BRRS-RP Beam Refinement Reference Signal Received Power
- BRS Beam Reference Signal
- BRSRP Beam Reference Signal Received Power
- BSI Beam State Information
- HARQ Hybrid ARQ
- LCG Logical Channel Group
- MAC Medium Access Control
- PCell Primary Cell
- RLC Radio Link Control
- RRC Radio Resource Control
- SCell Secondary Cell
- SDU Service Data Unit
- TB Transport Block
- xBCH 5G Broadcast Channel
- xBCCH 5G Broadcast Control Channel
- xCCCH 5G Common Control Channel
- xDCCH 5G Dedicated Control Channel
- xDL-SCH 5G Downlink Shared Channel
- xDTCH 5G Dedicated Traffic Channel
- xRACH 5G Random Access Channel
- xUL-SCH 5G Uplink Shared Channel

4 General

4.1 Introduction

The objective is to describe the 5G-MAC architecture and the 5G-MAC entity from a functional point of view.

4.2 5G-MAC architecture

The description in this sub clause is a model and does not specify or restrict implementations.

5G-RRC is in control of configuration of 5G-MAC.

4.2.1 5G-MAC Entities

5G defines two 5G-MAC entities; one in the UE and one in the 5G-RAN. These 5G-MAC entities handle the following transport channels:

- 5G Broadcast Channel (xBCH);
- 5G Downlink Shared Channel(s) (xDL-SCH);
- 5G Uplink Shared Channel(s) (xUL-SCH);
- 5G Random Access Channel(s) (xRACH).

The exact functions performed by the 5G-MAC entities are different in the UE from those performed in the 5G-RAN.

The 5G-MAC entity can be configured with multiple cells which can be aggregated up to 7 secondary cells (SCell) in addition to the primary cell (PCell). If the 5G-MAC entity is configured with one or more secondary cells, there are multiple xDL-SCH and equal amount of xUL-SCH and there may be multiple xRACH per 5G-MAC entity; one xDL-SCH and xUL-SCH on each of the PCell and SCell, zero or one xRACH for each SCell.

Figure 4.2.1-1 illustrates one possible structure for the UE side 5G-MAC entity, and it should not restrict implementation.

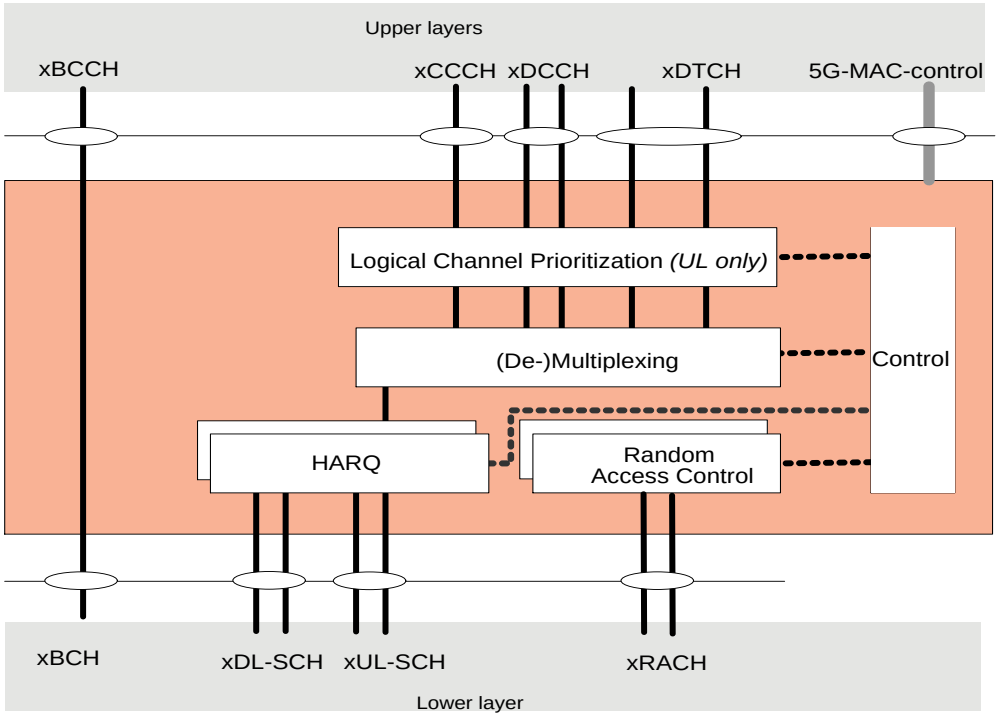


Figure 4.2.1-1: 5G-MAC structure overview, UE side

4.3 Services

4.3.1 Services provided to upper layers

This clause describes the different services provided by 5G-MAC sublayer to upper layers.

- data transfer;
- radio resource allocation.

4.3.2 Services expected from 5G physical layer

The 5G physical layer provides the following services to 5G-MAC:

- data transfer services;
- signalling of HARQ feedback;
- signalling of Scheduling Request;

- measurements (e.g. channel quality information or beam information).

The access to the data transfer services is through the use of transport channels. The characteristics of a transport channel are defined by its transport format (or format set), specifying the 5G physical layer processing to be applied to the transport channel in question, such as channel coding and interleaving, and any service-specific rate matching as needed.

4.4 Functions

The following functions are supported by 5G-MAC sublayer:

- mapping between logical channels and transport channels;
- multiplexing of 5G-MAC SDUs from one or different logical channels onto transport blocks (TB) to be delivered to the 5G physical layer on transport channels;
- demultiplexing of 5G-MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the 5G physical layer on transport channels;
- scheduling information reporting;
- error correction through HARQ;
- beam management;
- priority handling between UEs by means of dynamic scheduling;
- priority handling between logical channels of one 5G-MAC entity;
- Logical Channel prioritisation;
- transport format selection.

Table 4.4-1: 5G-MAC function location and link direction association

5G-MAC function	UE	5GNB	Downlink	Uplink
Mapping between logical channels and transport channels	X	X	X X	X X
Multiplexing	X	X	X	X
Demultiplexing	X	X	X	X
Scheduling information reporting	X			X
Error correction through HARQ	X	X	X X	X X
Beam management	X	X	X	X
Priority handling between UEs		X	X	X
Priority handling between logical channels		X	X	X
Logical channel prioritization	X			X
Transport format selection		X	X	X

4.5 Channel structure

The 5G-MAC sublayer operates on the channels defined below; transport channels are SAPs between 5G-MAC and Layer 1, logical channels are SAPs between 5G-MAC and 5G-RLC.

4.5.1 Transport Channels

The transport channels used by 5G-MAC are described in Table 4.5.1-1 below.

Table 4.5.1-1: Transport channels used by 5G-MAC

Transport channel name	Acronym	Downlink	Uplink
5G Broadcast Channel	xBCH	X	
5G Downlink Shared Channel	xDL-SCH	X	
5G Uplink Shared Channel	xUL-SCH		**X**
5G Random Access Channel	**xRACH**		**X**

4.5.2 Logical Channels

The 5G-MAC sublayer provides data transfer services on logical channels. A set of logical channel types is defined for different kinds of data transfer services as offered by 5G-MAC.

Each logical channel type is defined by what type of information is transferred.

5G-MAC provides the control and traffic channels listed in Table 4.5.2-1 below.

Table 4.5.2-1: Logical channels provided by 5G-MAC

Logical channel name	Acronym	Control channel	Traffic channel
5G Broadcast Control Channel	xBCCH	X	
5G Common Control Channel	xCCCH	X	
5G Dedicated Control Channel	xDCCH	X	
5G Dedicated Traffic Channel	**xDTCH**		**X**

4.5.3 Mapping of Transport Channels to Logical Channels

The mapping of logical channels on transport channels depends on the multiplexing that is configured by 5G-RRC.

4.5.3.1 Uplink mapping

The 5G-MAC entity is responsible for mapping logical channels for the uplink onto uplink transport channels. The uplink logical channels can be mapped as described in Figure 4.5.3.1-1.

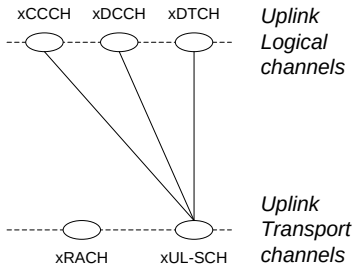


Figure 4.5.3.1-1: Mapping between uplink logical channels and uplink transport channels

In Uplink, the following connections between logical channels and transport channels exist:

- xCCCH can be mapped to xUL-SCH;
- xDCCH can be mapped to xUL-SCH;
- xDTCH can be mapped to xUL-SCH.

4.5.3.2 Downlink mapping

The 5G-MAC entity is responsible for mapping the downlink logical channels to downlink transport channels. The downlink logical channels can be mapped as described in Figure 4.5.3.2-1.

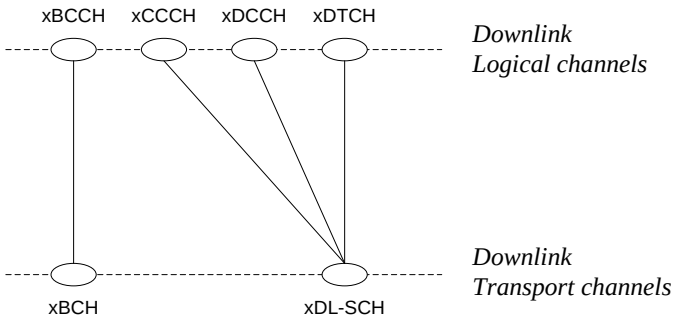


Figure 4.5.3.2-1: Mapping between downlink logical channels and downlink transport channels

In Downlink, the following connections between logical channels and transport channels exist:

- xBCCH can be mapped to xBCH;
- xCCCH can be mapped to xDL-SCH;
- xDCCH can be mapped to xDL-SCH;
- xDTCH can be mapped to xDL-SCH.

5 5G-MAC procedures

5.1 5G Random Access procedure

5.1.1 5G Random Access procedure initialization

The 5G Random Access procedure described in this subclause is initiated by a xPDCCH order [4], by the 5G-MAC sublayer itself or by the 5G-RRC sublayer. If a 5G-MAC entity receives a xPDCCH transmission consistent with a xPDCCH order masked with its C-RNTI for the Serving Cell, the 5G-MAC entity shall initiate a 5G Random Access procedure on this Serving Cell. For Random Access on the PCell a xPDCCH order or 5G-RRC optionally indicate the *ra-PreambleIndex.* For uplink timing alignment, preamble transmission on xPRACH and reception of a xPDCCH order are only supported in PCell.

Before the procedure can be initiated, the following information is assumed to be available [7]:

- the available set of xPRACH resources for the transmission of the Random Access Preamble, prach-ConfigIndex.
- the set of available Random Access Preambles;
- the RA response window size ra-ResponseWindowSize;
- the power-ramping factor powerRampingStep;
- the maximum number of preamble transmission preambleTransMax;
- the initial preamble power preambleInitialReceivedTargetPower;
- the Contention Resolution Timer mac-ContentionResolutionTimer.

NOTE: The above parameters may be updated from upper layers before each 5G Random Access procedure is initiated.

The 5G Random Access procedure shall be performed as follows:

- flush the Msg3 buffer;
- set the PREAMBLE_TRANSMISSION_COUNTER to 1;
- set the backoff parameter value to 0 ms;
- proceed to the selection of the Random Access Resource (see subclause 5.1.2).

NOTE: There is only one 5G Random Access procedure ongoing at any point in time in a 5G-MAC entity. If the 5G-MAC entity receives a request for a new 5G Random Access procedure while another is already ongoing in the 5G-MAC entity, it is up to UE implementation whether to continue with the ongoing procedure or start with the new procedure.

5.1.2 Random Access Resource selection

The Random Access Resource selection procedure shall be performed as follows:

- if ra-PreambleIndex (Random Access Preamble) has been explicitly signalled and ra-PreambleIndex is not 000000:
  - the Random Access Preamble is that explicitly signalled;
- else the Random Access Preamble shall be selected by the 5G-MAC entity as follows:
  - randomly select a Random Access Preamble. The random function shall be such that each of the allowed selections can be chosen with equal probability;
- determine the next available subframe containing xPRACH permitted by the restrictions given by the prach-ConfigIndex, and 5G physical layer timing requirements [1];
- proceed to the transmission of the Random Access Preamble (see subclause 5.1.3).

5.1.3 Random Access Preamble transmission

The random-access procedure shall be performed as follows:

- set PREAMBLE_RECEIVED_TARGET_POWER to preambleInitialReceivedTargetPower + (PREAMBLE_TRANSMISSION_COUNTER – 1) * powerRampingStep;
- instruct the 5G physical layer to transmit a preamble using the selected xPRACH, corresponding RA-RNTI, preamble index and PREAMBLE_RECEIVED_TARGET_POWER.

5.1.4 Random Access Response reception

Once the Random Access Preamble is transmitted, the 5G-MAC entity shall monitor the xPDCCH of the PCell for Random Access Response(s) identified by the RA-RNTI defined below, in the RA Response

window which starts at the subframe that contains the end of the preamble transmission [6] plus three subframes and has length *ra-ResponseWindowSize* subframes. The RA-RNTI associated with the xPRACH in which the Random Access Preamble is transmitted, is computed as:

RA-RNTI = 1 + t_id

where

t_id (0≤ t_id ≤9) is computed as m*5 + (l/2); m is the RACH subframe index in a frame (m = 0 or 1); and l is the RACH symbol index in a RACH subframe (l=0, 2, 4, 6, 8).

The 5G-MAC entity may stop monitoring for Random Access Response(s) after successful reception of a Random Access Response containing Random Access Preamble identifiers that matches the transmitted Random Access Preamble.

- if a downlink assignment for this TTI has been received on the xPDCCH for the RA-RNTI and the received TB is successfully decoded, the 5G-MAC entity shall:
  - if the Random Access Response contains a Backoff Indicator subheader:
    - set the backoff parameter value as indicated by the BI field of the Backoff Indicator subheader and Table 7.2-1.
  - else, set the backoff parameter value to 0 ms.
  - if the Random Access Response contains a Random Access Preamble identifier corresponding to the transmitted Random Access Preamble (see subclause 5.1.3), the 5G-MAC entity shall:
    - consider this Random Access Response reception successful and apply the following actions for the PCell where the Random Access Preamble was transmitted:
      - process the received Timing Advance Command (see subclause 5.2);
      - indicate the *preambleInitialReceivedTargetPower* and the amount of power ramping applied to the latest preamble transmission to lower layers (i.e., (PREAMBLE_TRANSMISSION_COUNTER – 1) * *powerRampingStep*);
      - process the received UL grant value and indicate it to the lower layers;
    - if ra-PreambleIndex was explicitly signalled and it was not 000000 (i.e., not selected by 5G-MAC):
      - consider the 5G Random Access procedure successfully completed.
    - else, if the Random Access Preamble was selected by the 5G-MAC entity:
      - set the Temporary C-RNTI to the value received in the Random Access Response message no later than at the time of the first transmission corresponding to the UL grant provided in the Random Access Response message;
      - if this is the first successfully received Random Access Response within this 5G Random Access procedure:
        - if the transmission is not being made for the xCCCH logical channel, indicate to the Multiplexing and assembly entity to include a C-RNTI MAC control element in the subsequent uplink transmission;
        - obtain the 5G-MAC PDU to transmit from the "Multiplexing and assembly" entity and store it in the Msg3 buffer.

If no Random Access Response is received within the RA Response window, or if none of all received Random Access Responses contains a Random Access Preamble identifier corresponding to the

transmitted Random Access Preamble, the Random Access Response reception is considered not successful and the 5G-MAC entity shall:

- if the notification of power ramping suspension has not been received from lower layers:
  - increment PREAMBLE_TRANSMISSION_COUNTER by 1;
- if PREAMBLE_TRANSMISSION_COUNTER = preambleTransMax + 1:
  - indicate a Random Access problem to upper layers;
- if in this 5G Random Access procedure, the Random Access Preamble was selected by 5G-MAC:
  - based on the backoff parameter, select a random backoff time according to a uniform distribution between 0 and the Backoff Parameter Value;
  - delay the subsequent Random Access transmission by the backoff time;
  - proceed to the selection of a Random Access Resource (see subclause 5.1.2).

5.1.5 Contention Resolution

Contention Resolution is based on either C-RNTI on xPDCCH or UE Contention Resolution Identity on xDL-SCH.

Once Msg3 is transmitted, the 5G-MAC entity shall:

- start mac-ContentionResolutionTimer and restart mac-ContentionResolutionTimer at each HARQ retransmission;
- if notification of a reception of a xPDCCH transmission is received from lower layers, the 5G-MAC entity shall:
  - if the C-RNTI 5G-MAC control element was included in Msg3:
    - if the 5G Random Access procedure was initiated by the 5G-MAC sublayer itself or by the 5G-RRC sublayer and the xPDCCH transmission is addressed to the C-RNTI and contains an UL grant for a new transmission; or
    - if the 5G Random Access procedure was initiated by a xPDCCH order and the xPDCCH transmission is addressed to the C-RNTI:
      - consider this Contention Resolution successful;
      - stop mac-ContentionResolutionTimer;
      - discard the Temporary C-RNTI;
      - consider this 5G Random Access procedure successfully completed.
  - else if the xCCCH SDU was included in Msg3 and the xPDCCH transmission is addressed to its Temporary C-RNTI:
    - if the 5G-MAC PDU is successfully decoded:
      - stop mac-ContentionResolutionTimer;
      - if the 5G-MAC PDU contains a UE Contention Resolution Identity MAC control element; and if the UE Contention Resolution Identity included in the 5G-MAC control element matches the xCCCH SDU transmitted in Msg3:
        - consider this Contention Resolution successful and finish the disassembly and demultiplexing of the 5G-MAC PDU;
        - set the C-RNTI to the value of the Temporary C-RNTI;
        - discard the Temporary C-RNTI;
        - consider this 5G Random Access procedure successfully completed.
    - else
      - discard the Temporary C-RNTI;

        - consider this Contention Resolution not successful and discard the successfully decoded 5G-MAC PDU.
    - if mac-ContentionResolutionTimer expires:
        - discard the Temporary C-RNTI;
        - consider the Contention Resolution not successful.
    - if the Contention Resolution is considered not successful the 5G-MAC entity shall:
        - flush the HARQ buffer used for transmission of the 5G-MAC PDU in the Msg3 buffer;
        - if the notification of power ramping suspension has not been received from lower layers:
            - increment PREAMBLE_TRANSMISSION_COUNTER by 1;
        - if PREAMBLE_TRANSMISSION_COUNTER = *preambleTransMax* + 1:
            - indicate a Random Access problem to upper layers.
        - based on the backoff parameter, select a random backoff time according to a uniform distribution between 0 and the Backoff Parameter Value;
        - delay the subsequent Random Access transmission by the backoff time;
        - proceed to the selection of a Random Access Resource (see subclause 5.1.2).

5.1.6 Completion of the 5G Random Access procedure

At completion of the 5G Random Access procedure, the 5G-MAC entity shall:

- discard explicitly signalled ra-PreambleIndex, if any;
- flush the HARQ buffer used for transmission of the 5G-MAC PDU in the Msg3 buffer.

5.2 Maintenance of Uplink Time Alignment

The 5G-MAC entity has a configurable timer *timeAlignmentTimer*. The *timeAlignmentTimer* is used to control how long the 5G-MAC entity considers the serving cells to be uplink time aligned [7].
The 5G-MAC entity shall:

- when a Timing Advance Command MAC control element is received:
    - apply the Timing Advance Command;
    - start or restart the *timeAlignmentTimer*.
- when a Timing Advance Command is received in a Random Access Response message:
    - if the Random Access Preamble was not selected by the 5G-MAC entity:
        - apply the Timing Advance Command;
        - start or restart the *timeAlignmentTimer*.
    - else, if the *timeAlignmentTimer* is not running:
        - apply the Timing Advance Command;
        - start the *timeAlignmentTimer*;
        - when the contention resolution is considered not successful as described in subclause 5.1.5, stop *timeAlignmentTimer.*
    - else:
        - ignore the received Timing Advance Command.
- when a *timeAlignmentTimer* expires:
    - flush all HARQ buffers for all serving cells.

The 5G-MAC entity shall not perform any uplink transmission on a serving cell except the Random Access Preamble transmission on the PCell when the *timeAlignmentTimer* to which this serving cell belongs is not running.

NOTE: A 5G-MAC entity stores or maintains N_{TA} upon expiry of associated *timeAlignmentTimer*, where N_{TA} is defined in [6]. The 5G-MAC entity applies a received Timing Advance Command MAC control element and starts associated *timeAlignmentTimer* also when the *timeAlignmentTimer* is not running.

5.3 xDL-SCH data transfer

5.3.1 DL Assignment reception

Downlink assignments transmitted on the xPDCCH indicate if there is a transmission on a xDL-SCH for the 5G-MAC entity and provide the relevant HARQ information.

When the 5G-MAC entity has a C-RNTI, or Temporary C-RNTI, the 5G-MAC entity shall for each TTI during which it monitors xPDCCH and for each Serving Cell:

- if a downlink assignment for this TTI and this Serving Cell has been received on the xPDCCH for the 5G-MAC entity's C-RNTI, or Temporary C-RNTI:
  - if this is the first downlink assignment for this Temporary C-RNTI:
    - consider the New Data Indicator (NDI) to have been toggled.
  - indicate the presence of a downlink assignment and deliver the associated HARQ information to the HARQ entity for this TTI.

5.3.2 HARQ operation

5.3.2.1 HARQ Entity

There is one HARQ entity at the 5G-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 xDL-SCH to the corresponding HARQ processes (see subclause 5.3.2.2).

The number of DL HARQ processes per HARQ entity is specified in [1].

One TB is expected per subframe.

The 5G-MAC entity shall:

- If a downlink assignment has been indicated for this TTI:
  - allocate the TB received from the 5G physical layer and the associated HARQ information to the HARQ process indicated by the associated HARQ information.

5.3.2.2 HARQ process

For each subframe where a transmission takes place for the HARQ process, one TB and the associated HARQ information is received from the HARQ entity.

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

- if the NDI has been toggled compared to the value of the previous received transmission corresponding to this TB; 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 5G-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 5G-MAC entity attempted to decode was successfully decoded for this TB; or
- if the data for this TB was successfully decoded before:
  - if this is the first successful decoding of the data for this TB:
    - deliver the decoded 5G-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 5G-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 subclause 5.1.5); or
- if the *timeAlignmentTimer* is stopped or expired:
  - do not indicate the generated positive or negative acknowledgement to the 5G physical layer.
- else:
  - indicate the generated positive or negative acknowledgement for this TB to the 5G physical layer.

The 5G-MAC entity shall ignore NDI received in all downlink assignments on xPDCCH for its Temporary C-RNTI when determining if NDI on xPDCCH for its C-RNTI has been toggled compared to the value in the previous transmission.

NOTE: if the 5G-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 5G-MAC entity shall disassemble and demultiplex a 5G-MAC PDU as defined in subclause 6.1.2.

5.4 xUL-SCH data transfer

5.4.1 UL Grant reception

In order to transmit on the xUL-SCH the 5G-MAC entity must have a valid uplink grant which it may receive dynamically on the xPDCCH or in a Random Access Response. To perform requested transmissions, the 5G-MAC layer receives HARQ information from lower layers.

If the 5G-MAC entity has a C-RNTI, or a Temporary C-RNTI, the 5G-MAC entity shall for each TTI and for each serving cell that has a running *timeAlignmentTimer*:

- if an uplink grant for this TTI and this serving cell has been received on the xPDCCH for the 5G-MAC entity's C-RNTI or Temporary C-RNTI; or
- if an uplink grant for this TTI has been received in a Random Access Response:
  - deliver the uplink grant and the associated HARQ information to the HARQ entity for this TTI.

NOTE: If the 5G-MAC entity receives both a grant in a Random Access Response and a grant for its C-RNTI requiring transmissions on the PCell in the same UL subframe, the 5G-MAC entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI.

5.4.2 HARQ operation

5.4.2.1 HARQ entity

There is one HARQ entity at the 5G-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 [1].

One TB is expected per subframe.

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 NDI, MCS and resource, relayed by the 5G physical layer, to the appropriate HARQ process.

For each TTI, the HARQ entity shall:

- if an uplink grant has been indicated for and this TTI:
  - if the received grant was not addressed to a Temporary C-RNTI on xPDCCH 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 xPDCCH for the C-RNTI and the HARQ buffer of the identified process is empty; or
  - if the uplink grant was received in a Random Access Response:
    - if there is a 5G-MAC PDU in the Msg3 buffer and the uplink grant was received in a Random Access Response:
      - obtain the 5G-MAC PDU to transmit from the Msg3 buffer.
    - else:
      - obtain the 5G-MAC PDU to transmit from the "Multiplexing and assembly" entity;
    - deliver the 5G-MAC PDU and the uplink grant and the HARQ information to the identified HARQ process;
    - instruct the identified HARQ process to trigger a new transmission.
  - else:
    - deliver the uplink grant and the HARQ information to the identified HARQ process;
    - instruct the identified HARQ process to generate an adaptive retransmission.

When determining if NDI has been toggled compared to the value in the previous transmission the 5G-MAC entity shall ignore NDI received in all uplink grants on xPDCCH for its Temporary C-RNTI.

5.4.2.2 HARQ process

Each HARQ process is associated with a HARQ buffer.

New transmissions are performed on the resource and with the MCS indicated on xPDCCH or Random Access Response. Adaptive retransmissions are performed on the resource and, with the MCS indicated on xPDCCH.

- if the HARQ entity requests a new transmission, the HARQ process shall:
  - store the 5G-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:
  - store the uplink grant received from the HARQ entity;
  - generate a transmission as described below.

NOTE: 5G-MAC entity keeps the data in the HARQ buffer until otherwise scheduled.

To generate a transmission, the HARQ process shall:

- if the 5G-MAC PDU was obtained from the Msg3 buffer; or
- if the 5G-MAC PDU was obtained from the "Multiplexing and assembly" entity; or
- if the retransmission does not collide with a transmission for a 5G-MAC PDU obtained from the Msg3 buffer in this TTI:
  - instruct the 5G physical layer to generate a transmission according to the stored uplink grant;

5.4.3 Multiplexing and assembly

5.4.3.1 Logical channel prioritization

The Logical Channel Prioritization procedure is applied when a new transmission is performed.

5G-RRC controls the scheduling of uplink data by signalling for each logical channel: *priority* where an increasing *priority* value indicates a lower priority level, *prioritisedBitRate* which sets the Prioritized Bit Rate (PBR), *bucketSizeDuration* which sets the Bucket Size Duration (BSD).

The 5G-MAC entity shall maintain a variable Bj for each logical channel j. Bj shall be initialized to zero when the related logical channel is established, and incremented by the product PBR × TTI duration for each TTI, where PBR is Prioritized Bit Rate of logical channel j. However, the value of Bj can never exceed the bucket size and if the value of Bj is larger than the bucket size of logical channel j, it shall be set to the bucket size. The bucket size of a logical channel is equal to PBR × BSD, where PBR and BSD are configured by upper layers.

The 5G-MAC entity shall perform the following Logical Channel Prioritization procedure when a new transmission is performed:

- The 5G-MAC entity shall allocate resources to the logical channels in the following steps:

  - Step 1: All the logical channels with Bj > 0 are allocated resources in a decreasing priority order. If the PBR of a logical channel is set to “infinity”, the 5G-MAC entity shall allocate resources for all the data that is available for transmission on the logical channel before meeting the PBR of the lower priority logical channel(s);
  - Step 2: the 5G-MAC entity shall decrement Bj by the total size of 5G-MAC SDUs served to logical channel j in Step 1

NOTE: The value of Bj can be negative.

  - Step 3: if any resources remain, all the logical channels are served in a strict decreasing priority order (regardless of the value of Bj) until either the data for that logical channel or the UL grant is exhausted, whichever comes first. Logical channels configured with equal priority should be served equally.

- The UE shall also follow the rules below during the scheduling procedures above:
  - the UE should not segment an 5G-RLC PDU (or partially transmitted PDU or retransmitted 5G-RLC PDU) if the whole PDU (or partially transmitted PDU or retransmitted 5G-RLC PDU) fits into the remaining resources of the associated 5G-MAC entity.

The 5G-MAC entity shall not transmit data for a logical channel corresponding to a radio bearer that is suspended (the conditions for when a radio bearer is considered suspended are defined in [7]).

For the Logical Channel Prioritization procedure, the 5G-MAC entity shall take into account the following relative priority in decreasing order:

- 5G-MAC control element for C-RNTI or data from UL xCCCH;
- 5G-MAC control element for BSI Feedback;
- 5G-MAC control element for BAR;
- 5G-MAC control element for BSR, with exception of BSR included for padding;
- 5G-MAC control element for power headroom report;
- data from the Logical Channel, except data from UL xCCCH;
- 5G-MAC control element for BSR included for padding.

5.4.3.2 Multiplexing of 5G-MAC Control Elements and 5G-MAC SDUs

The 5G-MAC entity shall multiplex 5G-MAC control elements and 5G-MAC SDUs in a 5G-MAC PDU according to subclauses 5.4.3.1 and 6.1.2.

5.4.4 Scheduling Request

The Scheduling Request (SR) is used for requesting xUL-SCH resources for new transmission.

When an SR is triggered, it shall be considered as pending until it is cancelled. All pending SR(s) shall be cancelled when a 5G-MAC PDU is assembled and this PDU includes a BSR which contains buffer status up to (and including) the last event that triggered a BSR (see subclause 5.4.5) or when the UL grant(s) can accommodate all pending data available for transmission.

If an SR is triggered and there is no other SR pending, the 5G-MAC entity shall set the SR_COUNTER to 0.

As long as one SR is pending, the 5G-MAC entity shall for each TTI:

– if no xUL-SCH resources are available for a transmission in this TTI:
  – if the 5G-MAC entity has no valid resource for SR configured in any TTI:
    – initiate a 5G Random Access procedure (see subclause 5.1) on the Serving Cell and cancel all pending SRs;

NOTE: resources for SR configured can be either xPUCCH or xPRACH subframe (see subclauses 7.3 and 11.1.3 in [1])

  – else if the 5G-MAC entity has a valid resource for SR configured for this TTI:
    – if SR_COUNTER < *dsr-TransMax*:
      – increment SR_COUNTER by 1;
      – instruct the 5G physical layer to signal the SR on the resource for SR configured;
    – else:
      – initiate a 5G Random Access procedure (see subclause 5.1) on the Serving Cell and cancel all pending SRs.

5.4.5 Buffer Status Reporting

The Buffer Status reporting procedure is used to provide the serving 5GNB with information about the amount of data available for transmission in the UL buffers associated with the 5G-MAC entity. 5G-RRC controls BSR reporting by configuring the two timers *periodicBSR-Timer* and *retxBSR-Timer* and by, for each logical channel, optionally signalling *logicalChannelGroup* which allocates the logical channel to an LCG [7].

For the Buffer Status reporting procedure, the 5G-MAC entity shall consider all radio bearers which are not suspended and may consider radio bearers which are suspended.

A Buffer Status Report (BSR) shall be triggered if any of the following events occur:

– UL data, for a logical channel which belongs to a LCG, becomes available for transmission in the 5G-RLC entity or in the 5G-PDCP entity (the definition of what data shall be considered as available for transmission is specified in [2] and [3] respectively) and either the data belongs to a logical channel with higher priority than the priorities of the logical channels which belong to any LCG and for which data is already available for transmission, or there is no data available for transmission for any of the logical channels which belong to a LCG, in which case the BSR is referred below to as "Regular BSR";
– UL resources are allocated and number of padding bits is equal to or larger than the size of the Buffer Status Report MAC control element plus its subheader, in which case the BSR is referred below to as "Padding BSR";
– *retxBSR-Timer* expires and the 5G-MAC entity has data available for transmission for any of the logical channels which belong to a LCG, in which case the BSR is referred below to as "Regular BSR";
– *periodicBSR-Timer* expires, in which case the BSR is referred below to as "Periodic BSR".

For Regular and Periodic BSR:

– report BSR for each LCG that is configured.

For Padding BSR:

– if the number of padding bits is equal to or larger than the size of the BSR plus its subheader, report BSR for each LCG that is configured.

If the Buffer Status reporting procedure determines that at least one BSR has been triggered and not cancelled:

– if the 5G-MAC entity has UL resources allocated for new transmission for this TTI:
  – instruct the Multiplexing and Assembly procedure to generate the BSR MAC control element(s);
  – start or restart *periodicBSR-Timer*;
  – start or restart *retxBSR-Timer*.

A 5G-MAC PDU shall contain at most one MAC BSR control element, even when multiple events trigger a BSR by the time a BSR can be transmitted in which case the Regular BSR and the Periodic BSR shall have precedence over the padding BSR.

The 5G-MAC entity shall restart *retxBSR-Timer* upon indication of a grant for transmission of new data on any xUL-SCH.

All triggered BSRs shall be cancelled in case the UL grant(s) in this subframe can accommodate all pending data available for transmission but is not sufficient to additionally accommodate the BSR MAC control element plus its subheader. All triggered BSRs shall be cancelled when a BSR is included in a 5G-MAC PDU for transmission.

The 5G-MAC entity shall transmit at most one Regular/Periodic BSR in a TTI. If the 5G-MAC entity is requested to transmit multiple 5G-MAC PDUs in a TTI, it may include a padding BSR in any of the 5G-MAC PDUs which do not contain a Regular/Periodic BSR.

All BSRs transmitted in a TTI always reflect the buffer status after all 5G-MAC PDUs have been built for this TTI. Each LCG shall report at the most one buffer status value per TTI and this value shall be reported in all BSRs reporting buffer status for this LCG.

NOTE: A Padding BSR is not allowed to cancel a triggered Regular/Periodic BSR. A Padding BSR is triggered for a specific 5G-MAC PDU only and the trigger is cancelled when this 5G-MAC PDU has been built.

5.4.6 Power Headroom Reporting

The Power Headroom reporting procedure is used to provide the serving 5G-NB with information about the difference between the nominal UE maximum transmit power and the estimated power for xUL-SCH transmission per Serving Cell.

The reporting period, delay and mapping of Power Headroom are defined in [FFS, TS 36.133 or TS V5G.133]. 5G-RRC controls Power Headroom reporting by configuring the two timers *periodicPHR-Timer* and *prohibitPHR-Timer*, and by signalling *dl-PathlossChange* which sets the change in measured downlink pathloss and the required power backoff due to power management (as allowed by $P\text{-}MPR_c$ [FFS, TS 36.101 or TS V5G.101]) to trigger a PHR [6].

A Power Headroom Report (PHR) shall be triggered if any of the following events occur:

– *prohibitPHR-Timer* expires or has expired and the path loss has changed more than *dl-PathlossChange* dB for at least one activated Serving Cell which is used as a pathloss reference

since the last transmission of a PHR in the 5G-MAC entity when the 5G-MAC entity has UL resources for new transmission;
– *periodicPHR-Timer* expires;
– upon configuration or reconfiguration of the power headroom reporting functionality by upper layers [8], which is not used to disable the function;
– activation of an SCell.
– *prohibitPHR-Timer* expires or has expired, when the 5G-MAC entity has UL resources for new transmission, and the following is true in this TTI for any of the activated Serving Cells:
  – there are UL resources allocated for transmission or there is a xPUCCH transmission on this cell, and the required power backoff due to power management (as allowed by $P\text{-}MPR_c$ [FFS, TS 36.101 or TS V5G.101]) for this cell has changed more than *dl-PathlossChange* dB since the last transmission of a PHR when the 5G-MAC entity had UL resources allocated for transmission or xPUCCH transmission on this cell.

NOTE: The 5G-MAC entity should avoid triggering a PHR when the required power backoff due to power management decreases only temporarily (e.g. for up to a few tens of milliseconds) and it should avoid reflecting such temporary decrease in the values of $P_{CMAX,c}$/PH when a PHR is triggered by other triggering conditions.

If the 5G-MAC entity has UL resources allocated for new transmission for this TTI the 5G-MAC entity shall:

– if it is the first UL resource allocated for a new transmission since the last 5G-MAC reset, start *periodicPHR-Timer*;
– if the Power Headroom reporting procedure determines that at least one PHR has been triggered and not cancelled, and;
– if the allocated UL resources can accommodate a PHR MAC control element plus its subheader
  – obtain the value of the power headroom from the 5G-physical layer;
  – instruct the Multiplexing and Assembly procedure to generate and transmit a PHR MAC control element as defined in subclause 6.1.3.5 based on the value reported by the 5G-physical layer;
– start or restart *periodicPHR-Timer*;
– start or restart *prohibitPHR-Timer*;
– cancel all triggered PHR(s).

5.5 Beam management

5.5.1 Beam feedback procedure

The beam feedback procedure is used to report beam measurement results to the serving cell.

There are two beam feedback procedures defined one based on measurement of beam reference signal (BRS), beam state information reporting below, and one based on measurement of beam refinement reference signal (BRRS), beam refinement information reporting below.

5.5.1.1 Beam state information reporting

The beam state information (BSI) reports initiated by xPDCCH order are transmitted through UCI on xPUCCH/xPUSCH as scheduled by the corresponding DCI [1]; event triggered BSI reports are transmitted through BSI Feedback MAC Control Element defined in subclause 6.1.3.9 using normal SR or

contention-based RACH procedure, where a BSI consists of beam index (BI) and beam reference signal received power (BRSRP). BSI reports are based on BRS transmitted by the serving cell.

5.5.1.1.1 BSI reporting initiated by xPDCCH order

The BSI reports initiated by xPDCCH order are sent on xPUCCH or xPUSCH as specified in subclauses 5.1 and 8.3 in [1].

5.5.1.1.2 BSI reporting initiated by MAC

The BSI reports initiated by MAC are based on an event trigger.

- if the BRSRP of the best beam is higher than *beamTriggeringRSRPoffset* dB + the BRSRP of the serving beam and:
  - if the UE is uplink synchronized (i.e., when *timeAlignmentTimer* is not expired):
    - if the 5G-MAC entity has UL resources allocated for new transmission for this TTI:
      - instruct the Multiplexing and Assembly procedure to generate and transmit a BSI Feedback MAC Control Element as defined in 6.1.3.9;
    - else if the 5G-MAC entity has a valid resource for normal SR configured for this TTI:
      - instruct the 5G physical layer to transmit the normal SR;
  - else:
    - UE transmits BSI Feedback MAC Control Element on the UL resource for Msg3 granted through contention-based random access procedure;

5.5.1.2 Beam refinement information reporting

The beam refinement information (BRI) reports are initiated by xPDCCH order and reported on xPUCCH/xPUSCH as specified in subclauses 5.2 and 8.4 in [1].

NOTE: event-triggered BRI feedback is not supported

NOTE: BSI/BRI feedback requested by xPDCCH order do not affect on the 5G-MAC layer reporting procedures.

5.5.2 Beam change procedure

The beam change procedure is used by the serving cell to change the serving beam for the UE. The serving cell initiates the procedure by xPDCCH order, by BRRS Beam Change Indication MAC Control Element, or by BRS Beam Change Indication MAC Control Element.

The UE shall, upon receiving the BRS Beam Change Indication MAC Control Element as defined in 6.1.3.7, switch the serving beam at the UE to match the beam indicated by the BRS Beam Change Indication MAC Control Element, following the procedure defined in subclause 5.1.1 in [1].

The UE shall, upon receiving the BRRS Beam Change Indication MAC Control Element as defined in 6.1.3.8, switch the serving beam at the UE to match the beam indicated by the BRRS Beam Change Indication MAC Control Element, following the procedure defined in subclause 5.2.1 in [1].

5.5.3 Beam adjustment request procedure

If configured, the Beam Adjustment Request (BAR) is used to request the serving cell to transmit BRRS (Beam Refinement Reference Signal). UE measures the BRRS in the scheduled subframe(s) to determine the best beam of the serving cell.

5G-RRC controls the BAR by configuring the timer *prohibitBAR-Timer*, which limits the interval between two consecutive BARs.

NOTE: UE can trigger BAR based on any UE implementation specific conditions.
A BAR shall be triggered if prohibitBAR-Timer is not running and any UE implementation specific condition is met.

- As long as the BAR procedure determines that a BAR has been triggered:
  - if the 5G-MAC entity has UL resources allocated for new transmission for this TTI
    - instruct the Multiplexing and Assembly procedure to generate and transmit a BAR MAC Control Element as defined in 6.1.3.6;
    - start or restart the *prohibitBAR-Timer*;
  - else if the 5G-MAC entity has a valid resource for SR configured for this TTI:
    - if a dedicated SR for BRRS request is configured to the UE:
      - instruct the 5G physical layer to transmit the dedicated SR;
      - start or restart the *prohibitBAR-Timer*;
    - else:
      - a Scheduling Requset shall be triggered to transmit a BAR MAC Control Element.

5.6 xBCH reception

When the 5G-MAC entity needs to receive xBCH, the 5G-MAC entity shall:

- receive and attempt to decode the xBCH;
- if a TB on the xBCH has been successfully decoded:
  - deliver the decoded 5G-MAC PDU to upper layers.

5.7 5G-MAC reconfiguration

When a reconfiguration of the 5G-MAC entity is requested by upper layers, the 5G-MAC entity shall:

- upon addition of an SCell, initialize the corresponding HARQ entity;
- upon removal of an SCell, remove the corresponding HARQ entity;
- for timers apply the new value when the timer is (re)started;
- when counters are initialized apply the new maximum parameter value;
- for other parameters, apply immediately the configurations received from upper layers.

5.8 5G-MAC Reset

If a reset of the 5G-MAC entity is requested by upper layers, the 5G-MAC entity shall:

- initialize Bj for each logical channel to zero;
- stop (if running) all timers;
- consider *timeAlignmentTimer* as expired and perform the corresponding actions in subclause 5.3;

– set the NDIs for all uplink HARQ processes to the value 0;
– stop, if any, ongoing 5G Random Access procedure (see subclause 5.1);
– flush Msg3 buffer;
– cancel, if any, triggered Scheduling Request procedure;
– cancel, if any, triggered Buffer Status Reporting procedure;
– cancel, if any, triggered Beam Feedback procedure;
– cancel, if any, triggered Beam Adjustment Request 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.

5.9 Handling of unknown, unforeseen and erroneous protocol data

When a 5G-MAC entity receives a 5G-MAC PDU for the 5G-MAC entity's C-RNTI or by the configured downlink assignment, containing reserved or invalid values, the 5G-MAC entity shall:

– discard the received 5G-MAC PDU.

6 Protocol data units, formats and parameters

6.1 Protocol data units

6.1.1 General

A 5G-MAC PDU is a bit string that is byte aligned (i.e. multiple of 8 bits) in length. In the figures in subclause 6.1, bit strings are represented by tables in which the most significant bit is the leftmost bit of the first line of the table, the least significant bit is the rightmost bit on the last line of the table, and more generally the bit string is to be read from left to right and then in the reading order of the lines. The bit order of each parameter field within a 5G-MAC PDU is represented with the first and most significant bit in the leftmost bit and the last and least significant bit in the rightmost bit.

5G-MAC SDUs are bit strings that are byte aligned (i.e. multiple of 8 bits) in length. A 5G-MAC SDU is included into a 5G-MAC PDU from the first bit onward.

The 5G-MAC entity shall ignore the value of Reserved bits in downlink 5G-MAC PDUs.

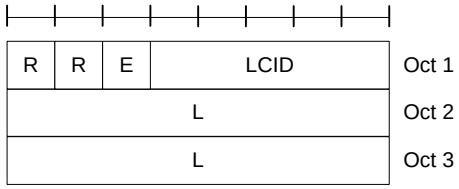
6.1.2 5G-MAC PDU (xDL-SCH and xUL-SCH except transparent MAC and Random Access Response)

A 5G-MAC PDU consists of a 5G-MAC header, zero or more 5G-MAC Service Data Units (5G-MAC SDU), zero, or more 5G-MAC control elements, and optionally padding; as described in Figure 6.1.2-3.

Both the 5G-MAC header and the 5G-MAC SDUs are of variable sizes.

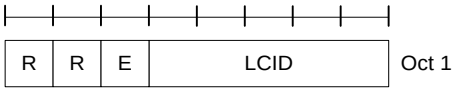
A 5G-MAC PDU header consists of one or more 5G-MAC PDU subheaders; each subheader corresponds to either a 5G-MAC SDU, a 5G-MAC control element or padding.

A 5G-MAC PDU subheader consists of the five header fields R/R/E/LCID/L but for the last subheader in the 5G-MAC PDU and for fixed sized 5G-MAC control elements. The last subheader in the 5G-MAC PDU and subheaders for fixed sized 5G-MAC control elements consist solely of the four header fields R/R/E/LCID. A 5G-MAC PDU subheader corresponding to padding consists of the four header fields R/R/E/LCID.



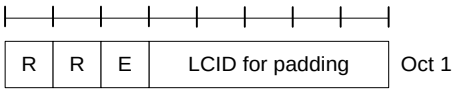
R/R/E/LCID/L sub-header with 16-bit L field

Figure 6.1.2-1: R/R/E/LCID/L 5G-MAC subheader



R/R/E/LCID sub-header

Figure 6.1.2-2: R/R/E/LCID 5G-MAC subheader for 5G-MAC CE



R/R/E/LCID sub-header

Figure 6.1.2-3: R/R/E/LCID 5G-MAC subheader for Padding

5G-MAC PDU subheaders have the same order as the corresponding 5G-MAC SDUs, 5G-MAC control elements and padding.

5G-MAC control elements are always placed before any 5G-MAC SDU.

Padding occurs at the end of the 5G-MAC PDU, except when single-byte or two-byte padding is required. Padding may have any value and the 5G-MAC entity shall ignore it. When padding is performed at the end of the 5G-MAC PDU, zero or more padding bytes are allowed.

When single-byte or two-byte padding is required, one or two 5G-MAC PDU subheaders corresponding to padding are placed at the beginning of the 5G-MAC PDU before any other 5G-MAC PDU subheader.

A maximum of one 5G-MAC PDU can be transmitted per TB per 5G-MAC entity.

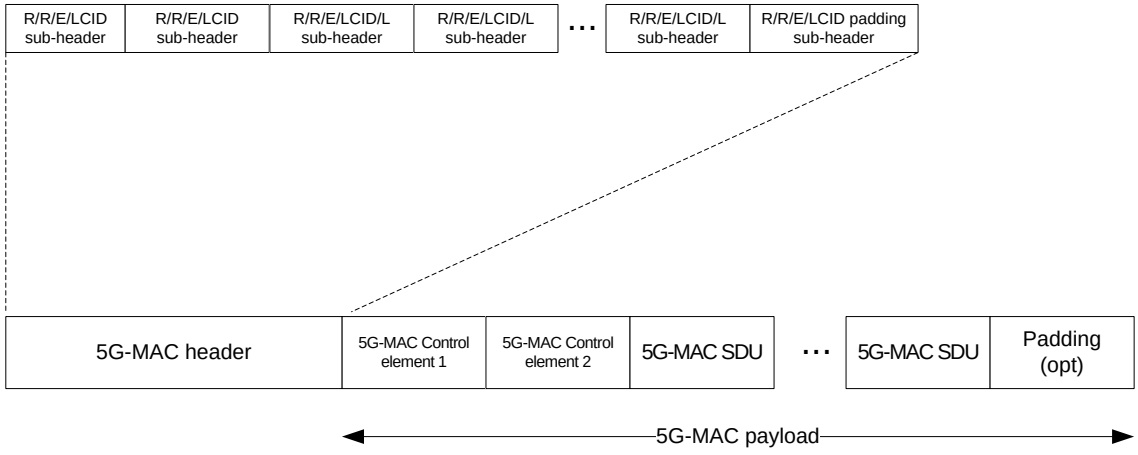


Figure 6.1.2-4: Example of 5G-MAC PDU consisting of 5G-MAC header, 5G-MAC Control Elements, 5G-MAC SDUs and padding

6.1.3 5G-MAC Control Elements

6.1.3.1 Buffer Status Report MAC Control Element

The Buffer Status Report (BSR) MAC control element is identified by 5G-MAC PDU subheader with LCID as specified in Table 6.2.1-2.

The BSR MAC control element consist of:

- N Buffer Size fields, corresponding to N LCGs (figure 6.1.3.1-1). The N is equal to 4.

The fields Buffer Size are defined as follow:

– Buffer Size: The Buffer Size field identifies the total amount of data available across all logical channels of a logical channel group after all 5G-MAC PDUs for the TTI have been built. The amount of data is indicated in number of bytes. It shall include all data that is available for transmission in the 5G-RLC layer and in the 5G-PDCP layer; the definition of what data shall be considered as available for transmission is specified in [2] and [3] respectively. The size of the 5G-RLC and 5G-MAC headers are not considered in the buffer size computation. The length of this field is 6 bits. The values taken by the Buffer Size field are shown in Table 6.1.3.1-1.

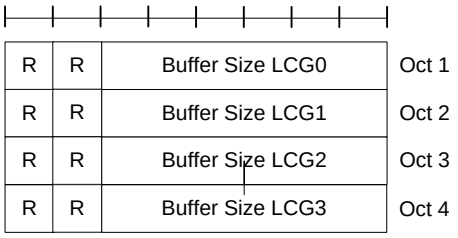


Figure 6.1.3.1-1: BSR MAC control element

Table 6.1.3.1-1: Buffer size levels for BSR

Index	Buffer Size (BS) value [bytes]	Index	Buffer Size (BS) value [bytes]
0	BS = 0	32	**4940 < BS <= 6074**
1	0 < BS <= 10	33	**6074 < BS <= 7469**
2	10 < BS <= 13	34	**7469 < BS <= 9185**
3	13 < BS <= 16	35	**9185 < BS <= 11294**
4	16 < BS <= 19	36	**11294 < BS <= 13888**
5	19 < BS <= 23	37	**13888 < BS <= 17077**
6	23 < BS <= 29	38	**17077 < BS <= 20999**
7	29 < BS <= 35	39	**20999 < BS <= 25822**
8	35 < BS <= 43	40	**25822 < BS <= 31752**
9	43 < BS <= 53	41	**31752 < BS <= 39045**
10	53 < BS <= 65	42	**39045 < BS <= 48012**
11	65 < BS <= 80	43	**48012 < BS <= 59039**
12	80 < BS <= 98	44	**59039 < BS <= 72598**
13	98 < BS <= 120	45	**72598 < BS <= 89272**
14	120 < BS <= 147	46	**89272 < BS <= 109774**
15	147 < BS <= 181	47	**109774 < BS <= 134986**
16	181 < BS <= 223	48	**134986 < BS <= 165989**
17	223 < BS <= 274	49	**165989 < BS <= 204111**
18	274 < BS <= 337	50	**204111 < BS <= 250990**
19	337 < BS <= 414	51	**250990 < BS <= 308634**
20	414 < BS <= 509	52	**308634 < BS <= 379519**
21	509 < BS <= 625	53	**379519 < BS <= 466683**
22	625 < BS <= 769	54	**466683 < BS <= 573866**
23	769 < BS <= 945	55	**573866 < BS <= 705666**
24	945 < BS <= 1162	56	**705666 < BS <= 867737**
25	1162 < BS <= 1429	57	**867737 < BS <= 1067031**

26	1429 < BS <= 1757	58	**1067031 < BS <= 1312097**
27	1757 < BS <= 2161	59	**1312097 < BS <= 1613447**
28	2161 < BS <= 2657	60	**1613447 < BS <= 1984009**
29	2657 < BS <= 3267	61	**1984009 < BS <= 2439678**
30	3267 < BS <= 4017	62	**2439678 < BS <= 3000000**
31	**4017 < BS <=4940**	**63**	**BS > 3000000**

6.1.3.2 C-RNTI MAC Control Element

The C-RNTI MAC control element is identified by 5G-MAC PDU subheader with LCID as specified in table 6.2.1-2.

It has a fixed size and consists of a single field defined as follows (figure 6.1.3.2-1):

– C-RNTI: This field contains the C-RNTI of the 5G-MAC entity. The length of the field is 16 bits.

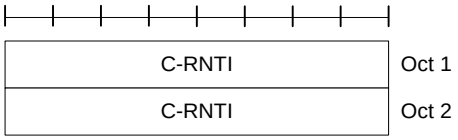


Figure 6.1.3.2-1: C-RNTI MAC control element

6.1.3.3 UE Contention Resolution Identity MAC Control Element

The UE Contention Resolution Identity MAC control element is identified by 5G-MAC PDU subheader with LCID as specified in table 6.2.1-1.

This control element has a fixed 48-bit size and consists of a single field defined as follows (figure 6.1.3.3-1)

– UE Contention Resolution Identity: This field contains the uplink xCCCH SDU.

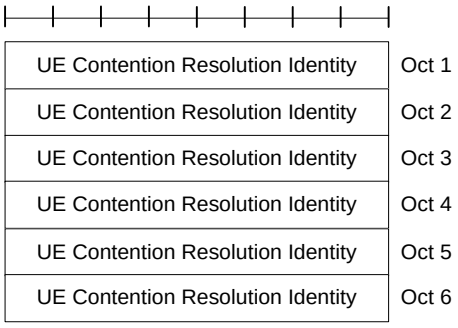


Figure 6.1.3.3-1: UE Contention Resolution Identity MAC control element

6.1.3.4 Timing Advance Command MAC Control Element

The Timing Advance Command MAC control element is identified by 5G-MAC PDU subheader with LCID as specified in table 6.2.1-1.

It has a fixed size and consists of a single octet defined as follows (figure 6.1.3.4-1):

– Timing Advance Command: This field indicates the index value T_A (0, 1, 2… 63) used to control the amount of timing adjustment that 5G-MAC entity has to apply (see [1]). The length of the field is 6 bits.

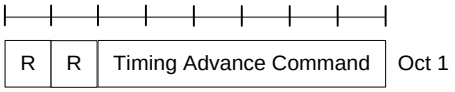


Figure 6.1.3.4-1: Timing Advance Command MAC control element

6.1.3.5 Power Headroom Report MAC Control Element

The Power Headroom Report (PHR) MAC control element is identified by a 5G-MAC PDU subheader with LCID as specified in table 6.2.1-2.

It has a fixed size and consists of a single octet defined as follows (figure 6.1.3.5-1):

– R: reserved bit, set to "0";
– Power Headroom (PH): this field indicates the power headroom level. The length of the field is 6 bits. The reported PH and the corresponding power headroom levels are shown in Table 6.1.3.5-1 below (the corresponding measured values in dB can be found in [FFS, TS 36.133 or TS V5G.133]).

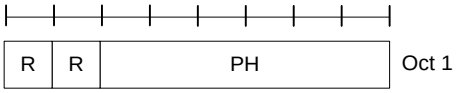


Figure 6.1.3.5-1: PHR MAC control element

Table 6.1.3.5-1: Power Headroom levels for PHR

PH	Power Headroom Level
0	POWER_HEADROOM_0
1	POWER_HEADROOM_1
2	POWER_HEADROOM_2
3	POWER_HEADROOM_3
…	…
60	POWER_HEADROOM_60
61	POWER_HEADROOM_61
62	POWER_HEADROOM_62
63	POWER_HEADROOM_63

6.1.3.6 Beam Adjustment Request MAC Control Element

The Beam Adjustment Request (BAR) MAC control element is identified by a 5G-MAC PDU subheader with LCID as specified in table 6.2.1-2. It has a fixed size and consists of a single octet containing seven C-fields and one P-field. The BAR MAC control element is defined as follows (figure 6.1.3.6-1).

– C_i: if there is an SCell configured with *SCellIndex* i as specified in [7], this field indicates the beam adjustment request is for the SCell with *SCellIndex* i, else the 5G-MAC entity shall ignore the C_i field. The C_i field is set to “1” to indicate that the UE requests the BRRS (Beam Refinement Referene Signal) transmission via the SCell with *SCellIndex* i. The Ci field is set to “0” to indicate that the UE does not request the BRRS transmission via the SCell with *SCellIndex* i.
– P: this field indicates the beam adjustment request status of the PCell. The P field is set to “1” to indicate that the UE requests the BRRS transmission via the PCell. The P field is set to “0” to indicate that the UE does not request the BRRS transmission via the PCell.

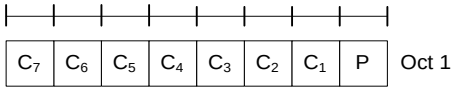


Figure 6.1.3.6-1: Beam Adjustment Request MAC control element

6.1.3.7 BRS Beam Change Indication MAC Control Element

The BRS Beam Change Indication MAC control element is identified by a 5G-MAC PDU subheader with LCID as specified in table 6.2.1-1. It has a fixed size and consists of a 9-bit BI field. The BRS Beam Change Indication MAC control element is defined as follows (figure 6.1.3.7-1).

– BI (9-bit) : this field indicates the beam index;
– R : reserved bit, set to “0”.

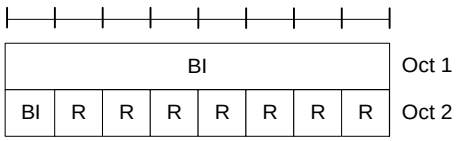


Figure 6.1.3.7-1: BRS Beam Change Indication MAC control element

6.1.3.8 BRRS Beam Change Indication MAC Control Element

The BRRS Beam Change Indication MAC control element is identified by a 5G-MAC PDU subheader with LCID as specified in table 6.2.1-1. It has a fixed size and consists of a 3-bit BRRS-RI field and a 2-bit BR process index field. The BRRS Beam Change Indication MAC control element is defined as follows (figure 6.1.3.8-1).

– BRRS-RI (3-bit) : this field indicates the beam index;
– BR process index (2-bit) : this field indicates the BRRS process index;
– R : reserved bit, set to “0”.

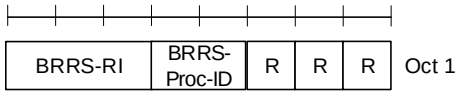


Figure 6.1.3.8-1: BRRS Beam Change Indication MAC control element

6.1.3.9 BSI Feedback MAC Control Element

The Beam State Information (BSI) Feedback MAC control element is identified by a 5G-MAC PDU subheader with LCID as specified in table 6.2.1-2. It consists of 4 BSI fields, corresponding to 4 beams.The BSI field is defined as follows:

– BI (9-bit) : this field indicates the beam index;
– BRSRP (7-bit): this field indicates the beam reference signal received power of the beam.

The BSI Feedback MAC control element is defined as follows (figure 6.1.3.9-1).

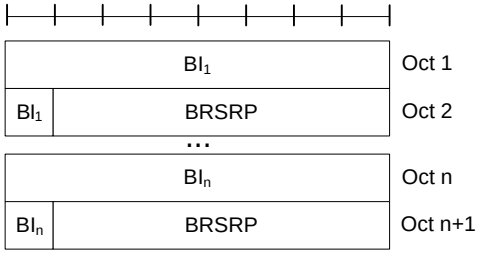


Figure 6.1.3.9-1: BSI Feedback MAC control element

6.1.4 5G-MAC PDU (Transparent MAC)

A 5G-MAC PDU consists solely of a 5G-MAC Service Data Unit (5G-MAC SDU) whose size is aligned to a TB; as described in Figure 6.1.4-1. This 5G-MAC PDU is used for transmissions on xBCH.

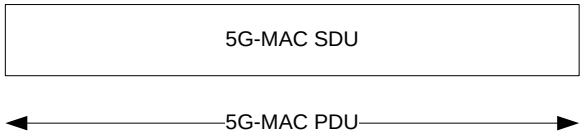


Figure 6.1.4-1: Example of 5G-MAC PDU (transparent MAC)

6.1.5 5G-MAC PDU (Random Access Response)

A 5G-MAC PDU consists of a 5G-MAC header and zero or more 5G-MAC Random Access Responses (5G-MAC RAR) and optionally padding as described in Figure 6.1.5-4.

The 5G-MAC header is of variable size.

A 5G-MAC PDU header consists of one or more 5G-MAC PDU subheaders; each subheader corresponding to a 5G-MAC RAR except for the Backoff Indicator subheader. If included, the Backoff Indicator subheader is only included once and is the first subheader included within the 5G-MAC PDU header.

A 5G-MAC PDU subheader consists of the three header fields E/T/RAPID (as described in figure 6.1.5-1) but for the Backoff Indicator subheader which consists of the five header field E/T/R/R/BI (as described in figure 6.1.5-2).

A 5G-MAC RAR consists of the four fields R/Timing Advance Command/UL Grant/Temporary C-RNTI (as described in figure 6.1.5-3).

Padding may occur after the last 5G-MAC RAR. Presence and length of padding is implicit based on TB size, size of 5G-MAC header and number of RARs.

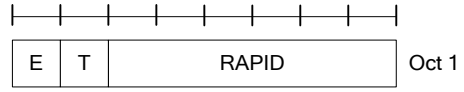


Figure 6.1.5-1: E/T/RAPID 5G-MAC subheader

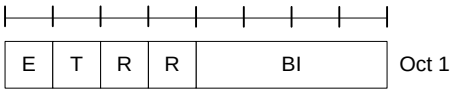


Figure 6.1.5-2: E/T/R/R/BI 5G-MAC subheader

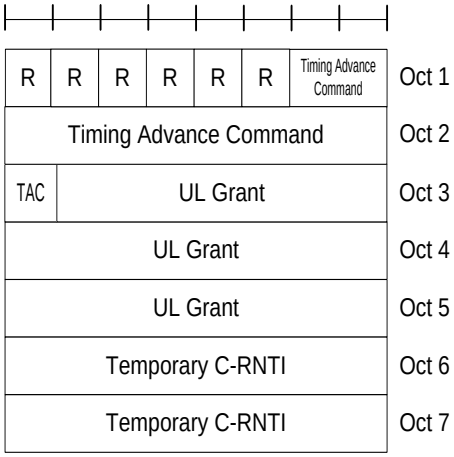


Figure 6.1.5-3: 5G-MAC RAR

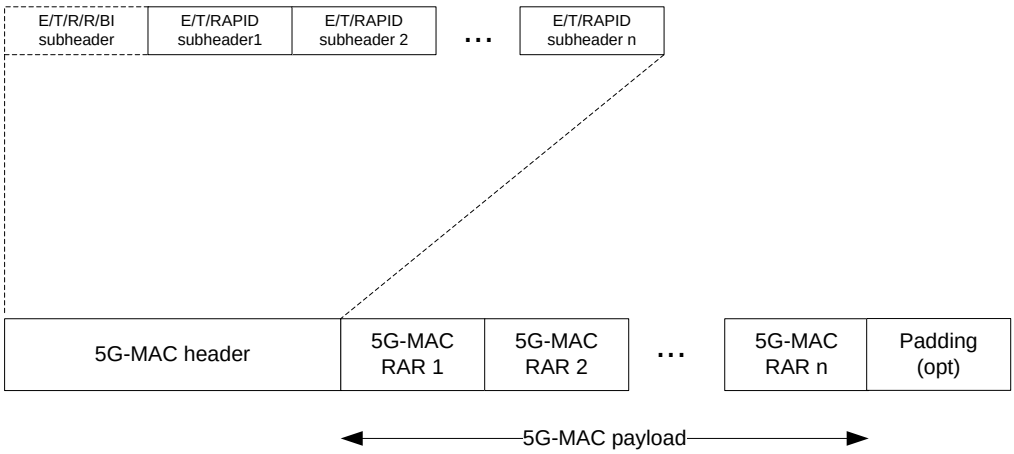


Figure 6.1.5-4: Example of 5G-MAC PDU consisting of a 5G-MAC header and 5G-MAC RARs

6.2 Formats and parameters

6.2.1 5G-MAC header for xDL-SCH and xUL-SCH

The 5G-MAC header is of variable size and consists of the following fields:

– LCID: The Logical Channel ID field identifies the logical channel instance of the corresponding 5G-MAC SDU or the type of the corresponding 5G-MAC control element or padding as described in tables 6.2.1-1 and 6.2.1-2 for the xDL-SCH and xUL-SCH respectively. There is one LCID field for each 5G-MAC SDU, 5G-MAC control element or padding included in the 5G-MAC PDU. In addition to that, one or two additional LCID fields are included in the 5G-MAC PDU, when single-byte or two-byte padding is required but cannot be achieved by padding at the end of the 5G-MAC PDU. The LCID field size is 5-bit;
– L: The Length field indicates the length of the corresponding 5G-MAC SDU or variable-sized 5G-MAC control element in bytes. There is one L field per 5G-MAC PDU subheader except for the last subheader and subheaders corresponding to fixed-sized 5G-MAC control elements. The size of the L field is 16-bit;
– E: The Extension field is a flag indicating if more fields are present in the 5G-MAC header or not. The E field is set to "1" to indicate another set of at least R/R/E/LCID fields. The E field is set to "0" to indicate that either a 5G-MAC SDU, a 5G-MAC control element or padding starts at the next byte;
– R: Reserved bit, set to "0".

The 5G-MAC header and subheaders are octet aligned.

Table 6.2.1-1 Values of LCID for xDL-SCH

Index	LCID values
00000	xCCCH
00001- 01010	Identity of the logical channel
01011	BRS Beam Change Indication
01100	BRRS Beam Change Indication
01101 - 11011	Reserved
11100	UE Contention Resolution Identity
11101	Timing Advance Command
11110	Reserved
11111	Padding

Table 6.2.1-2 Values of LCID for xUL-SCH

Index	LCID values
00000	xCCCH
00001 - 01010	Identity of the logical channel
01011	Reserved
01100	Beam Adjustment Request
01101	BSI Feedback
01110 - 11001	Reserved
11010	Power Headroom Report
11011	C-RNTI
11100	Reserved
11101	Buffer Status Report
11110	Reserved
11111	Padding

6.2.2 5G-MAC header for Random Access Response

The 5G-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 5G-MAC header or not. The E field is set to "1" to indicate at least another set of E/T/RAPID fields follows. The E field is set to "0" to indicate that a 5G-MAC RAR or padding starts at the next byte;
- T: The Type field is a flag indicating whether the 5G-MAC subheader contains a Random Access ID or a Backoff Indicator. The T field is set to “0” to indicate the presence of a Backoff Indicator field in the subheader (BI). The T field is set to “1” to indicate the presence of a Random Access Preamble ID field in the subheader (RAPID);
- 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;

– RAPID: The Random Access Preamble IDentitfier field identifies the transmitted Random Access Preamble (see subclause 5.1). The size of the RAPID field is 6 bits.

6.2.3 5G-MAC payload for Random Access Response

The 5G-MAC RAR is of fixed size and consists of the following fields:

– R: Reserved bit, set to "0";
– Timing Advance Command: The Timing Advance Command field indicates the index value T_A (0, 1, 2… 1282) used to control the amount of timing adjustment that the 5G-MAC entity has to apply (see [1]). The size of the Timing Advance Command field is 11 bits;
– UL Grant: The UpLink Grant field indicates the resources to be used on the uplink (see subclause 7.2 in [1]). The size of the UL Grant field is 23 bits;
– Temporary C-RNTI: The Temporary C-RNTI field indicates the temporary identity that is used by the 5G-MAC entity during Random Access. The size of the Temporary C-RNTI field is 16 bits.

The 5G-MAC RAR is octet aligned.

7 Variables, constants and timers

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**
0001-003C	**RA-RNTI, C-RNTI, Temporary C-RNTI**
003D-FFF3	**C-RNTI, Temporary C-RNTI**
FFF4-FFFF	**Reserved**

NOTE: A 5G-MAC entity uses the same C-RNTI on all Serving Cells.

Table 7.1-2: RNTI usage

RNTI	Usage	Transport Channel	Logical Channel
Temporary C-RNTI	Contention Resolution (when no valid C-RNTI is available)	xDL-SCH	**xCCCH**
Temporary C-RNTI	Msg3 transmission	xUL-SCH	**xCCCH, xDCCH, xDTCH**
C-RNTI	Dynamically scheduled unicast transmission	xUL-SCH	**xDCCH, xDTCH**
C-RNTI	Dynamically scheduled unicast transmission	xDL-SCH	**xCCCH, xDCCH, xDTCH**
C-RNTI	**Triggering of xPDCCH ordered random access**	**N/A**	**N/A**

7.2 Backoff Parameter values

Backoff Parameter values are presented in Table 7.2-1.

Table 7.2-1: Backoff Parameter values.

Index	Backoff Parameter value (ms)
0	**0**
1	**10**
2	**20**
3	**30**
4	**40**
5	**60**
6	**80**
7	**120**
8	**160**
9	**240**
10	**320**
11	**480**
12	**960**
13	**Reserved**
14	**Reserved**
15	**Reserved**

The reserved values of the backoff parameter if received by the current release version UEs shall be taken as 960 ms.