**3GPP TSG-RAN WG2 Meeting #117 Electronic *R2-2204094***

**Electronic meeting, Feb. 21st – Mar. 3rd 2022**

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| *CR-Form-v12.2* |
| **CHANGE REQUEST** |
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|  | **38.323** | **CR** | **0087** | **rev** | **1** | **Current version:** | **16.6.0** |  |
|  |
| *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:***  |  in NR |
|  |  |
| ***Source to WG:*** | CATT, CMCC, Huawei, HiSilicon, MediaTek, Ericsson, China Unicom, China Telecom, OPPO, ZTE, Samsung, Apple, Nokia, Nokia Shanghai Bell |
| ***Source to TSG:*** | R2 |
|  |  |
| ***Work item code:*** | NR\_UDC-Core |  | ***Date:*** | 2021-12 |
|  |  |  |  |  |
| ***Category:*** | **B** |  | ***Release:*** | Rel-17 |
|  | *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-15 (Release 15)Rel-16 (Release 16)Rel-17 (Release 17)Rel-18 (Release 18) Rel-19 (Release 19)* |
|  |  |
| ***Reason for change:*** | In Rel-17, NR UDC is introduced. Therefore, to support UL data compression functionality, corresponding changes need to be introduced to the PDCP specification.  |
|  |  |
| ***Summary of change:*** | 1. Add UDC function in PDCP entities;
2. Add UDC processing into UL Data Transfer Procedures;
3. Introduce UDC related procedures: e.g. buffer reset, error handling etc.;
4. Define PDCP PDUs for UDC;
5. Define PDCP control PDU for checksum error notification;
6. Define UDC header contents;
7. Add operation of UDC Compression Buffer
 |
|  |  |
| ***Consequences if not approved:*** | Corresponding changes to support NR UDC are missing from the PDCP spec, and as a result NR UDC function would not be supported in Rel-17. |
|  |  |
| ***Clauses affected:*** | 2, 3.2, 4.2.2, 4.3.1, 4.4, 5.1.2, 5.2.1, 5.X (new clause), 5.X.1(new clause), 5.X.2(new clause), 5.X.3(new clause), 5.X.4(new clause), 5.X.5(new clause), 5.X.6(new clause), 5.X.7(new clause), 5.X.8(new clause), 6.2.3.X(new clause),6.3.X(new clause), 6.3.8, Annex X(new clause), Annex X.1(new clause), Annex X.2(new clause), Annex X.2.1(new clause), Annex X.2.2(new clause), Annex X.2.2.1(new clause), Annex X.2.2.2(new clause), Annex X.2.2.3(new clause), Annex X.2.3(new clause) |
|  |  |
|  | **Y** | **N** |  |  |
| ***Other specs*** | **X** |  |  Other core specifications  | TS 38.300 CR 0415TS 38.331 CR 2927TS 37.340 CR 0298 |
| ***affected:*** |  | **X** |  Test specifications | TS/TR ... CR ...  |
| ***(show related CRs)*** |  | **X** |  O&M Specifications | TS/TR ... CR ...  |
|  |  |
| ***Other comments:*** |  |
|  |  |
| ***This CR's revision history:*** | The first version of this CR is in R2-2203109. |

*First Change*

# 2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

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

[2] 3GPP TS 38.300: "NG Radio Access Network; Overall description".

[3] 3GPP TS 38.331: "NR Radio Resource Control (RRC); Protocol Specification".

[4] 3GPP TS 38.321: "NR Medium Access Control (MAC) protocol specification".

[5] 3GPP TS 38.322: "NR Radio Link Control (RLC) protocol specification".

[6] 3GPP TS 33.501: "Security Architecture and Procedures for 5G System ".

[7] IETF RFC 5795: "The RObust Header Compression (ROHC) Framework".

[8] IETF RFC 3095: "RObust Header Compression (ROHC): Framework and four profiles: RTP, UDP, ESP and uncompressed".

[9] IETF RFC 4815: "RObust Header Compression (ROHC): Corrections and Clarifications to RFC 3095".

[10] IETF RFC 6846: "RObust Header Compression (ROHC): A Profile for TCP/IP (ROHC-TCP)".

[11] IETF RFC 5225: "RObust Header Compression (ROHC) Version 2: Profiles for RTP, UDP, IP, ESP and UDP Lite".

[12] 3GPP TS 36.321: "Evolved Universal Terrestrial Radio Access (E-UTRA) Medium Access Control (MAC) protocol specification".

[13] 3GPP TS 23.287: "Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services".

[14] 3GPP TS 33.536: "Security Aspect of 3GPP Support for Advanced V2X Services".

[15] IEEE Standard 802.3™-2018: "Ethernet".

[16] 3GPP TS 24.587: "Vehicle-to-Everything (V2X) services in 5G System (5GS), Stage 3".

[x] IETF RFC 1951: "DEFLATE Compressed Data Format Specification version 1.3".

[y] IETF RFC 3485: "The Session Initiation Protocol (SIP) and Session Description Protocol (SDP) Static Dictionary for Signaling Compression (SigComp)".

[z] IETF RFC 1979: "PPP Deflate Protocol".

*Next change*

## 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].

AM Acknowledged Mode

CID Context Identifier

DAPS Dual Active Protocol Stack

DRB Data Radio Bearer carrying user plane data

EHC Ethernet Header Compression

FIFO First In First Out

gNB NR Node B

HFN Hyper Frame Number

IETF Internet Engineering Task Force

IP Internet Protocol

MAC Medium Access Control

MAC-I Message Authentication Code for Integrity

PDCP Packet Data Convergence Protocol

PDU Protocol Data Unit

RB Radio Bearer

RFC Request For Comments

RLC Radio Link Control

ROHC RObust Header Compression

RRC Radio Resource Control

RTP Real Time Protocol

SAP Service Access Point

SCCH Sidelink Control Channel

SDU Service Data Unit

SLRB Sidelink Radio Bearer carrying NR sidelink communication

SN Sequence Number

SRB Signalling Radio Bearer carrying control plane data

STCH Sidelink Traffic Channel

TCP Transmission Control Protocol

UDC Uplink Data Compression

UDP User Datagram Protocol

UE User Equipment

UM Unacknowledged Mode

X-MAC Computed MAC-I

*Next Change*

### 4.2.2 PDCP entities

The PDCP entities are located in the PDCP sublayer. Several PDCP entities may be defined for a UE. Each PDCP entity is carrying the data of one radio bearer. A PDCP entity is associated either to the control plane or the user plane depending on which radio bearer it is carrying data for.

Figure 4.2.2.1 represents the functional view of the PDCP entity for the PDCP sublayer; it should not restrict implementation. The figure is based on the radio interface protocol architecture defined in TS 38.300 [2].

For split bearers and DAPS bearers, routing is performed in the transmitting PDCP entity.

A PDCP entity associated with DRB can be configured by upper layers TS 38.331 [3] to use header compression or uplink data compression (UDC). In this version of the specification, the robust header compression protocol (ROHC), the Ethernet header compression protocol (EHC) and UDC are supported. Each header compression protocol is independently configured for a DRB.



Figure 4.2.2-1: PDCP layer, functional view

Figure 4.2.2-2 represents the functional view of the PDCP entity associated with the DAPS bearer for the PDCP sublayer; it should not restrict implementation. The figure is based on the radio interface protocol architecture defined in TS 38.300 [2].

For DAPS bearers, the PDCP entity is configured with two sets of security functions and keys and two sets of header compression protocols.



Figure 4.2.2-2: PDCP layer associated with DAPS bearer, functional view

*Next Change*

### 4.3.1 Services provided to upper layers

The PDCP layer provides its services to the RRC or SDAP layers. The following services are provided by PDCP to upper layers:

- transfer of user plane data;

- transfer of control plane data;

- header compression;

- uplink data compression;

- ciphering;

- integrity protection.

The maximum supported size of a PDCP SDU is 9000 bytes. The maximum supported size of a PDCP Control PDU is 9000 bytes.

*Next Change*

## 4.4 Functions

The PDCP layer supports the following functions:

- transfer of data (user plane or control plane);

- maintenance of PDCP SNs;

- header compression and decompression using the ROHC protocol;

- header compression and decompression using the EHC protocol;

- uplink data compression and decompression using the UDC protocol;

- ciphering and deciphering;

- integrity protection and integrity verification;

- timer based SDU discard;

- for split bearers and DAPS bearer, routing;

- duplication;

- reordering and in-order delivery;

- out-of-order delivery;

- duplicate discarding.

*Next Change*

### 5.1.2 PDCP entity re-establishment

When upper layers request a PDCP entity re-establishment, the UE shall additionally perform once the procedures described in this clause for Uu or PC5 interface. After performing the procedures in this clause, the UE shall follow the procedures in clause 5.2.

When upper layers request a PDCP entity re-establishment, the transmitting PDCP entity shall:

- for UM DRBs and AM DRBs, reset the ROHC protocol for uplink and start with an IR state in U-mode (as defined in RFC 3095 [8] and RFC 4815 [9]) if *drb-ContinueROHC* is not configured in TS 38.331 [3];

- for UM DRBs and AM DRBs, reset the EHC protocol for uplink if *drb-ContinueEHC-UL* is not configured in TS 38.331 [3];

- for AM DRBs, reset the UDC compression buffer to all zeros and prefill the dictionary if *drb-ContinueUDC* is not configured in TS 38.331 [3];

- for UM DRBs and SRBs, set TX\_NEXT to the initial value;

- for SRBs, discard all stored PDCP SDUs and PDCP PDUs;

- apply the ciphering algorithm and key provided by upper layers during the PDCP entity re-establishment procedure;

- apply the integrity protection algorithm and key provided by upper layers during the PDCP entity re-establishment procedure;

- for UM DRBs, for each PDCP SDU already associated with a PDCP SN but for which a corresponding PDU has not previously been submitted to lower layers, and;

- for AM DRBs for Uu interface whose PDCP entities were suspended, from the first PDCP SDU for which the successful delivery of the corresponding PDCP Data PDU has not been confirmed by lower layers, for each PDCP SDU already associated with a PDCP SN:

- consider the PDCP SDUs as received from upper layer;

- perform transmission of the PDCP SDUs in ascending order of the COUNT value associated to the PDCP SDU prior to the PDCP re-establishment without restarting the *discardTimer*, as specified in clause 5.2.1;

- for AM DRBs whose PDCP entities were not suspended, from the first PDCP SDU for which the successful delivery of the corresponding PDCP Data PDU has not been confirmed by lower layers, perform retransmission or transmission of all the PDCP SDUs already associated with PDCP SNs in ascending order of the COUNT values associated to the PDCP SDU prior to the PDCP entity re-establishment as specified below:

- perform header compression of the PDCP SDU using ROHC as specified in the clause 5.7.4 and/or using EHC as specified in the clause 5.12.4;

- If *drb-ContinueUDC* is configured and if the PDCP SDU has been compressed before:

- submit the PDCP SDU previously compressed to integrity protection and ciphering function;

- else:

- perform uplink data compression of the PDCP SDU as specified in the subclause 5.X.4, and submit the PDCP SDU to integrity protection and ciphering function;

- perform integrity protection and ciphering of the PDCP SDU using the COUNT value associated with this PDCP SDU as specified in the clause 5.9 and 5.8;

- submit the resulting PDCP Data PDU to lower layer, as specified in clause 5.2.1.

When upper layers request a PDCP entity re-establishment, the receiving PDCP entity shall:

- process the PDCP Data PDUs that are received from lower layers due to the re-establishment of the lower layers, as specified in the clause 5.2.2.1;

- for SRBs, discard all stored PDCP SDUs and PDCP PDUs;

- for SRBs and UM DRBs, if *t-Reordering* is running:

- stop and reset *t-Reordering*;

- for UM DRBs, deliver all stored PDCP SDUs to the upper layers in ascending order of associated COUNT values after performing header decompression;

- for AM DRBs for Uu interface, perform header decompression using ROHC for all stored PDCP SDUs if *drb-ContinueROHC* is not configured in TS 38.331 [3];

- for AM DRBs for PC5 interface, perform header decompression using ROHC for all stored PDCP IP SDUs;

- for AM DRBs for Uu interface, perform header decompression using EHC for all stored PDCP SDUs if *drb-ContinueEHC-DL* is not configured in TS 38.331 [3];

- for UM DRBs and AM DRBs, reset the ROHC protocol for downlink and start with NC state in U-mode (as defined in RFC 3095 [8] and RFC 4815 [9]) if *drb-ContinueROHC* is not configured in TS 38.331 [3];

- for UM DRBs and AM DRBs, reset the EHC protocol for downlink if *drb-ContinueEHC-DL* is not configured in TS 38.331 [3];

- for UM DRBs and SRBs, set RX\_NEXT and RX\_DELIV to the initial value;

- apply the ciphering algorithm and key provided by upper layers during the PDCP entity re-establishment procedure;

- apply the integrity protection algorithm and key provided by upper layers during the PDCP entity re-establishment procedure.

NOTE: After PDCP re-establishment on a sidelink ‎SRB/DRB, UE determines when to transmit and receive with the new key and discard the old key as specified in TS ‎‎33.536 [14].‎

*Next Change*

### 5.2.1 Transmit operation

At reception of a PDCP SDU from upper layers, the transmitting PDCP entity shall:

- start the *discardTimer* associated with this PDCP SDU (if configured).

For a PDCP SDU received from upper layers, the transmitting PDCP entity shall:

- associate the COUNT value corresponding to TX\_NEXT to this PDCP SDU;

NOTE 1: Associating more than half of the PDCP SN space of contiguous PDCP SDUs with PDCP SNs, when e.g., the PDCP SDUs are discarded or transmitted without acknowledgement, may cause HFN desynchronization problem. How to prevent HFN desynchronization problem is left up to UE implementation.

- perform header compression of the PDCP SDU using ROHC as specified in the clause 5.7.4 and/or using EHC as specified in the clause 5.12.4;

- perform uplink data compression of the PDCP SDU as specified in the subclause 5.X.4;

- perform integrity protection, and ciphering using the TX\_NEXT as specified in the clause 5.9 and 5.8, respectively;

- set the PDCP SN of the PDCP Data PDU to TX\_NEXT modulo 2[*pdcp-SN-SizeUL*];

- increment TX\_NEXT by one;

- submit the resulting PDCP Data PDU to lower layer as specified below.

When submitting a PDCP PDU to lower layer, the transmitting PDCP entity shall:

- if the transmitting PDCP entity is associated with one RLC entity:

- submit the PDCP PDU to the associated RLC entity;

- else, if the transmitting PDCP entity is associated with at least two RLC entities:

- if the PDCP duplication is activated for the RB:

- if the PDCP PDU is a PDCP Data PDU:

- duplicate the PDCP Data PDU and submit the PDCP Data PDU to the associated RLC entities activated for PDCP duplication;

- else:

- submit the PDCP Control PDU to the primary RLC entity;

- else (i.e. the PDCP duplication is deactivated for the RB or the RB is a DAPS bearer):

- if the split secondary RLC entity is configured; and

- if the total amount of PDCP data volume and RLC data volume pending for initial transmission (as specified in TS 38.322 [5]) in the primary RLC entity and the split secondary RLC entity is equal to or larger than *ul-DataSplitThreshold*:

- submit the PDCP PDU to either the primary RLC entity or the split secondary RLC entity;

- else, if the transmitting PDCP entity is associated with the DAPS bearer:

- if the uplink data switching has not been requested:

- submit the PDCP PDU to the RLC entity associated with the source cell;

- else:

- if the PDCP PDU is a PDCP Data PDU:

- submit the PDCP Data PDU to the RLC entity associated with the target cell;

- else:

- if the PDCP Control PDU is associated with source cell:

- submit the PDCP Control PDU to the RLC entity associated with the source cell;

- else:

- submit the PDCP Control PDU to the RLC entity associated with the target cell;

- else:

- submit the PDCP PDU to the primary RLC entity.

NOTE 2: If the transmitting PDCP entity is associated with two RLC entities, the UE should minimize the amount of PDCP PDUs submitted to lower layers before receiving request from lower layers and minimize the PDCP SN gap between PDCP PDUs submitted to two associated RLC entities to minimize PDCP reordering delay in the receiving PDCP entity.

*Next Change*

5.X Uplink Data compression and decompression

5.X.1 UDC protocol

The UDC protocol is based on IETF RFC 1951 (DEFLATE Compressed Data Format Specification) [x].

Static Huffman coding tree defined in [x] is used as the DEFLATE compression strategy.

UDC Data Block should be byte-alignment. Z\_SYNC\_FLUSH is used as the DEFLATE byte-alignment with corresponding reference [z], wherein the fixed last four bytes, 0x00 0x00 0xFF 0xFF, are removed before transmission.

5.X.2 Configuration of UDC

The PDCP entities associated with DRBs can be configured by upper layers, see TS 38.331 [3], to use UDC. If UDC is configured, the UE shall apply UDC compression function (details see subclause X.1) to process the received PDCP SDU from upper layers corresponding to the configured DRB. The size of compression buffer is configured by upper layer via *bufferSize*. If pre-defined dictionary is configured by upper layers, the UE shall first set the compression buffer to all zeros and then prefill the configured pre-defined dictionary in the compression buffer upon configuration of UDC. If pre-defined dictionary is not configured by upper layers, UE shall set the compression buffer to all zeros.

5.X.3 UDC header

UDC header (1 byte) is added in UDC compression function followed by UDC data block. The UDC header contains the information about whether the current PDCP SDU is compressed by UDC protocol or not. Only the compressed packets are stored in the buffer. The UDC header also contains a reset bit to inform the decompressor that the compression buffer has been reset. The validation bits (checksum) of the compression buffer are also contained in UDC header. Checksum mechanism could be used to resolve miss-match (if any) between the compression and de-compression buffers. If both SDAP and UDC are configured for a DRB, the UDC header shall be located after the SDAP header. Figure 5.X.3-1 shows the location of the UDC header in a PDCP data PDU.

Figure 5.X.3-1: Location of UDC header in a PDCP Data PDU

5.X.4 Uplink data compression

The UDC protocol generates UDC packets, each associated with one PDCP SDU.

A UDC packet is associated with the same PDCP SN and COUNT values as the related PDCP SDU. The uplink data compression is not applicable to the SDAP header and the SDAP Control PDU if included in the PDCP Data PDU.

### 5.X.5 PDCP Control PDU for UDC feedback

At reception of a PDCP Control PDU for UDC feedback from lower layers, the receiving PDCP entity shall:

- deliver the corresponding UDC feedback to the UDC protocol without performing deciphering/integrity verification.

5.X.6 Pre-defined dictionary

One standard dictionary for SIP and SDP and one operator defined dictionary can be used as pre-defined dictionaries in UDC. The standard dictionary for SIP and SDP consists of the first 3468 bytes of the dictionary for SigComp defined in RFC 3485 [y]. When UDC is configured, at most one dictionary, configured by upper layers, is put into the tail of the compression buffer. Also, the compression buffer acts as a FIFO and hence the content of the dictionary is to be totally pushed out of the compression buffer after the size of transmitted uncompressed packets compressed by UDC exceeds the compression buffer size. If the size of dictionary is larger than the compression buffer size, only the tail of the dictionary is inserted in the compression buffer.

5.X.7 UDC buffer reset procedure

UDC works on the condition that compression buffer and de-compression buffer are synchronized. UDC buffer reset mechanism is to resynchronize buffer when error is detected. For resynchronization, UE shall reset the compression buffer to all zeros.

5.X.8 UDC checksum error handling

UDC checksum error notification PDCP control PDU indicates the compression buffer and de-compression buffer are out of synchronization. When receiving the notification, the UE shall trigger UDC buffer reset procedure to resynchonize the compression buffer.

*Next Change*

#### 6.2.3.X PDCP Control PDU for UDC feedback packet

Figure 6.2.3.X-1 shows the format of the PDCP Control PDU carrying one UDC feedback. This format is applicable for AM DRBs.



**Figure 6.2.3.X-1: PDCP Control PDU format for UDC feedback**

*Next Change*

#### 6.3.X FE

Length: 1 bit

Indication of whether checksum error is detected or not. Value '1' means checksum error is detected and the UE shall reset the compression buffer.

**Table 6.3.X-1: FE field**

|  |  |
| --- | --- |
| **Bit** | **Description** |
| 0 | No Error |
| 1 | Checksum Error Notification |

*Next Change*

### 6.3.8 PDU type

Length: 3 bits

This field indicates the type of control information included in the corresponding PDCP Control PDU.

Table 6.3.8-1: PDU type

|  |  |
| --- | --- |
| Bit | Description |
| 000 | PDCP status report |
| 001 | Interspersed ROHC feedback |
| 010 | EHC feedback |
| 011 | UDC feedback |
| 100-111 | Reserved |

*Next Change*

Annex X (normative):

Uplink Data Compression Protocol

X.1 UDC general description

A UDC packet consists of a UDC header and a UDC data block. A UDC data block contains either DEFLATE compressed blocks generated by UDC protocol or original PDCP SDU for SDU not compressed by UDC protocol; the type is specified in FU field (details see subclause X.2.2.1) in UDC header. The FR field (details see subclause X.2.2.2) and the Checksum field (details see subclause X.2.2.3) in UDC header are used only if FU field is set to 1.

If reset procedure is triggered, after performing the reset, the FR field in UDC header of the first compressed PDU shall be set to 1.

NOTE: UE is allowed not to compress the PDCP SDUs if the UL data rate before compression is higher than what the UE is capable of.

X.2 UDC packet format and parameters

### X.2.1 UDC Header and UDC Data Block format

Figure X.2.1-1 shows the format of UDC Header and UDC Data Block.



**Figure X.2.1-1: UDC header format**

### X.2.2 UDC parameters

#### X.2.2.1 FU

Length: 1 bit

Indication of whether this packet is compressed by UDC protocol or not. Value '1' means the packet is compressed by UDC protocol.

**Table X.2.2.1-1: FU field**

|  |  |
| --- | --- |
| **Bit** | **Description** |
| 0 | Packet is not compressed using UDC protocol |
| 1 | Packet is compressed using UDC protocol |

#### X.2.2.2 FR

Length: 1 bit

Indication of whether UDC compression buffer is reset or not. Value '1' means this is the first compressed packet after UDC buffer reset.

**Table X.2.2.2-1: FR field**

|  |  |
| --- | --- |
| **Bit** | **Description** |
| 0 | Compression buffer is not reset. |
| 1 | Compression buffer has been reset. |

#### X.2.2.3 Checksum

Length: 4 bits

This field contains the validation bits for the compression buffer content: The checksum is calculated by the content of current compression buffer before the current packet is put into buffer.

The checksum is derived from the values of the first 4 bytes and the last 4 bytes in the whole compression buffer. The calculation is described as follows:

- Each byte is divided into two 4-bit numbers.

- The 16 4-bit numbers are added together to obtain a sum;

- The checksum is one's complement of the right-most 4 bits (i.e. 4 LSB) of the sum.

An example of checksum calculation is shown in Annex X.2.3.

### X.2.3 An example of UDC Checksum calculation

The current UDC compression/decompression buffer has the following binary values for example:

Header <1,1,0,0,0,1,0,1,0,0,1,1,1,1,1,1,0,0,0,1,1,0,0,1,0,1,0,1,0,0,0,1, ……, 0,1,1,1,1,1,0,1,1,0,0,0,1,0,1,0,1,0,0,1,1,1,1,1,1,0,0,1,1,1,0,0> Tail

The sum of the first 4 bytes and the last 4 bytes can be calculated:

1100+0101+0011+1111+0001+1001+0101+0001+0111+1101+1000+1010+1001+1111+1001+1100 = 10000110;

And checksum value will be one's complement of the right-most 4 bits (i.e. 4 LSB) of the above sum. Hence checksum is 1001.

*End of Change*