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TECHNICAL SPECIFICATION

**Short Range Devices;
Low Throughput Networks (LTN);
Protocols for radio interface A;
Part 2: TS-UNB protocol**

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document is part 2 of a multi-part deliverable. Full details of the entire series can be found in part 1 [i.18].

The present document is the revision of clause 6 (i.e. TS-UNB protocol) of ETSI TS 103 357 (V1.1.1) [i.17]. It includes numerous improvements to the previous TS-UNB specifications, as follows:

- removal of flaws, inconsistencies, and typos in TS-UNB clause;
- inclusion of new functionalities: class B, class C end-points, higher symbol rates, timing flexibility, burst concatenation, guard symbols;
- inclusion of new control segments for test purpose;
- deprecation of single burst mode;
- informative annexes on TS-UNB protocol.

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the [ETSI Drafting Rules](#) (Verbal forms for the expression of provisions).

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1 Scope

The present document, which is part 2 of a multi-part document, specifies the TS-UNB protocol. It contains an implementable description of its physical and MAC/link protocol layers.

The present document is structured as follows:

- clause 2 provides references;
- clause 3 provides definitions of terms, symbols and abbreviation used;
- clause 4 specifies the TS-UNB protocol;
- informative annex A provides examples of radio profiles;
- informative annex B provides examples of MAC payload formats;
- informative annex C summarizes durations and layouts of DLB structure;
- informative annex D provides numerical examples.

TS-UNB is one of the three radio technologies specified for LTN systems, that are addressed in two overall documents:

- ETSI TR 103 249 [i.8], that describes LTN use cases and system characteristics.
- ETSI TS 103 358 [i.9], that specifies the architecture of LTN systems.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are necessary for the application of the present document.

- [1] [IEEE™ Std 802.15.4-2011](#): "IEEE Standard for Local and metropolitan area networks--Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)".
- [2] [NIST Publication 197 \(2001\)](#): "Advanced Encryption Standard (AES)".
- [3] [NIST Special Publication 800-38B \(2005\)](#): "Recommendation for Block Cipher Modes of Operation: "the CMAC Mode for Authentication".
- [4] Void.
- [5] Void.
- [6] [IEEE™ Guidelines for Use of Extended Unique Identifier \(EUI\), Organizationally Unique Identifier \(OUI\), and Company ID \(CID\)](#).

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

- [i.1] [ERC Recommendation 70-03 \(Tromsø 1997 and subsequent amendments\)](#): "Relating to the use of short range devices (SRD)", Recommendation adopted by the Frequency Management, Regulatory Affairs and Spectrum Engineering Working Groups, Version of 21 October 2016.
- [i.2] ETSI EN 300 220-1 (V2.4.1) (05-2012): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 1: Technical characteristics and test methods".
- [i.3] CFR Title 47 Part 15 section 15.247: "Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz".
- [i.4] ARIB STD-T108: "920 MHz-Band Telemeter, Telecontrol and data transmission radio equipment", Version 1.0 of February 14th 2012.
- [i.5] Void.
- [i.6] [IETF RFC 4493 \(2006\)](#): "The AES-CMAC Algorithm".
- [i.7] EN 13757-7:2018: "Communication systems for meters - Part 7: Transport and security services" (produced by CEN).
- [i.8] ETSI TR 103 249 (V1.1.1) (10-2017): "Low Throughput Network (LTN); Use Cases and System Characteristics".
- [i.9] ETSI TS 103 358 (V1.1.1) (06-2018): "Short range devices; Low Throughput Networks (LTN) Architecture; LTN Architecture".
- [i.10] EN 13757-3:2018: "Communication systems for meters - Part 3: Application protocols" (produced by CEN).
- [i.11] Void.
- [i.12] [IO-Link Interface and System Specification, Version 1.1.3, 2019](#).
- [i.13] EN 13757-8: 2023. "Communication systems for meters - Part 8: Adaptation layer" (produced by CEN).
- [i.14] EN 13757-4:2019: "Communication systems for meters - Part 4: Wireless M-Bus communication" (produced by CEN).
- [i.15] Open Metering System Specification (OMS-S), Volume 2, Annex Q, Issue 5.0.1, December 2023.
- [i.16] Void.
- [i.17] ETSI TS 103 357 (V1.1.1) (06-2018): "Short Range Devices; Low Throughput Networks (LTN); Protocols for radio interface A".
- [i.18] ETSI TS 103 357-1: "Short Range Devices; Low Throughput Networks (LTN); Protocols for radio interface A; Part 1: Lfour and DD-UNB protocol families".

3 Definitions of terms, symbols, and abbreviations

3.1 Terms

For the purposes of the present document, the following terms and definitions apply:

equivalent signal to noise ratio: signal to noise ratio (including interference) of the received message as if it was only distorted by additive noise

NOTE: The eqSNR-I is calculated based on a mutual information estimate of all radio-bursts. It is limited to +20 dB and the reception threshold is around -2 dB. For example, if in a short message with up to 10 Byte user data one radio-bursts is missed, the eqSNR decreases by app. 0,2 dB.

message signal to noise ratio: ratio of the estimated average power of the non-distorted radio-bursts over the estimated average noise power of the non-distorted radio-bursts

NOTE: Only the radio-bursts which are suspected to be free of interference, fading and which are not missed are used for the calculation.

radio-burst: radio transmission over the air which starts with a ramp up, finishes with a ramp down and which has a continuous centre frequency and constant transmission power (apart from modulation)

radio-burst signal to noise ratio: ratio of the estimated average power over the estimated average noise power

NOTE: Only the radio-bursts which are suspected to be free of interference, fading and which are not missed are used for the calculation.

radio-burst received signal strength indicator: average of the estimated power of non-interfered radio-bursts of the received message

NOTE: For the calculation only the radio-bursts are used which are suspected free of interference, fading and which are not missing.

radio-frame: area in time and frequency plane containing all radio-bursts belonging to one packet

sub-packet: fragment of a packet after telegram splitting

TSMA pattern: time and frequency transmission scheme of a radio frame

3.2 Symbols

For the purposes of the present document, the following symbols apply:

ΔT	actual symbol duration
ΔT_{dn}	Time interval between blocks of an extension frame
ΔT_{du}	maximum time window for a high priority uplink response
ΔT_{TSI}	Time interval between core frame and extension frame
ΔT_{ud}	Time interval between uplink frame and downlink frame
ΔT_{ULP}	standard symbol duration (i.e. duration of a symbol with ULP symbol rate)
B_c	Carrier spacing
B_{ch}	Channel bandwidth
C_{RB}	Radio-burst carrier number of TSMA pattern
C_{offset}	Carrier offset of radio frame
dB	decibel
$f_{0,DLB}$	lowest frequency available in a channel for DLB transmission
f_c	Channel centre frequency
f_{offset}	Additional pseudorandom radio frequency offset to the centre frequency
f_{RB}	Carrier frequency of a radio-burst
nb	Number of PSDU data bytes
n_{ts}	Timeslot offset of radio frame
pTSDL	Downlink TSMA pattern number

T_{TDN}	look-up values for the time delay in an extension frame with flexibility
S_{TOTAL}	Total number of sub-packets in a radio frame
S_C	Number of sub-packets in core frame
S_E	Number of sub-packets in extension frame
S_{RF}	Timeslot offset of radio frame
T_0	Start time of the radio frame transmission
T_{PPDU}	PPDU duration in seconds
T_{RB}	Time difference between two consecutive radio-bursts in number of symbols
T_{SB}	Sync-burst time

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ACK	Acknowledge
ADSI	Application Data Size Indicator (used in fragmentation procedure)
AES	Advanced Encryption Standard
BC	Beacon Core
BDU	Block Data Unit
BE	Beacon Extension
BRxC	Beacon receive Cycle
BS	Base Station
BSSH	Base Station Specific Hopping
BT	Bandwidth-bit period product
CIV	CMAC initialization vector
CMAC	Cipher-based Message Authentication Code
CO	Carrier Offset
CRC	Cyclic Redundancy Check
DATA_A	Data field A of a radio-burst
DATA_B	Data field B of a radio-burst
DATA_C	Data field C of a radio-burst
DC	Duty Cycle
DE	Data Extension
DL	Downlink
DLA	Downlink Class A (a transmission mode)
DLAC	DLA Core (block)
DLB	Downlink Class B (a transmission mode)
DLC	Downlink Class C (a transmission mode)
DLCC	DLC Core (block)
DLRX	Downlink Receive (status)
DL-SB	Downlink Single Burst (deprecated)
DPG	Downlink (TSMA) Pattern Group
EFI	Extension Frame Indicator
EIV	Encryption Initialization Vector
EP	End-Point
eqSNR	Equivalent Signal to Noise Ratio
ER	Extended Reach (a symbol rate)
EUI	Extended Unique Identifier
FEC	Forward Error Correction
FFB	Frame Format B (one of the variable MAC mode type for M-Bus)
FPO	Fragmentation Payload Offset
FSCNT	Fragmentation Session CouNTer
FS-ID	Fragmentation Session Identifier
FTM	Flexible Timing Mode
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
HDR	High Data Rate (a burst structure)
IA	Implicit Addressing (a flag)
IEEE	Institute of Electrical and Electronics Engineers
IPv6	Internet Protocol version 6
LFSR	Linear Feedback Shift Register

LPDE	Low Power Drain End-point Devices
LPDU	Link Layer Protocol Data Unit
LSB	Least Significant Bit
LTN	Low Throughput Network
MAC	Medium Access Control
MMODE	MAC MODE
MPAI	MAC Pres-Addressing Info
MPDU	MAC Protocol Data Unit
MPF	MAC Payload Format
MSB	Most Significant Bit
MSK	Minimum Shift Keying
PDU	Protocol Data Unit
PHR	PHY Header
PHY	Physical layer
PN9	Pseudo Noise sequence of length 9
PPDU	PHY Protocol Data Unit
PRB	Physical Resource Block
PS	Pilot Sequence
PS_A	Pilot Sequence A
PS_B	Pilot Sequence B
PS_DA	Pilot Sequence Down A (a BDU field in downlink)
PS_DB	Pilot Sequence Down B (a BDU field in downlink)
PS_DS	Pilot Sequence field of a DL Sync burst
PS_US	Pilot Sequence field of a UL Sync burst
PSDU	PHY Service Data Unit
PSI	Packet Size Indicator
RE	Resource Element
RFU	Reserved for Future Use
RSSI	Received Signal Strength Indicator
RX	Receiver
SBDU	Sync-Burst Data Unit
SBR	Single Burst Rate
SDU	Service Data Unit
SIGN	Signature field of TS burst
SNR	Signal to Noise Ratio
SRD	Short Range Device
Sync	Synchronization
TDN	Time delay between block of a downlink extension frame
TDN_F	time delay extension frame with flexibility
THB	Time delay Half Block
TS	Telegram Splitting
TSI	Transmission Start-time Indicator
TSI_F	Transmission Start-time Indicator in case of timing flexibility
TSMA	Telegram Splitting Multiple Access
TS-UNB	Telegram Splitting Ultra Narrow Band
TX	Transmitter
UL	Uplink
ULP	Ultra Low Power (a symbol rate)
ULP2	Ultra Low Power 2 (a symbol rate)
ULP8	Ultra Low Power 8 (a symbol rate)
ULZ	Uplink class Z (a transmission mode)
U-MPDU	Uplink-MPDU
UNB	Ultra Narrowband
UPG	Uplink Pattern Group
WMBUS	Wireless M-BUS
XOR	eXclusive OR

4 TS-UNB protocol description

4.1 TS-UNB in the LTN protocol families

Telegram-Splitting Ultra- Narrow Band (TS-UNB) protocol is one of the radio protocols specified for the radio interface of an LTN system; the other radio protocols for LTN systems are Lfour and DD-UNB (see ETSI TS 103 357 [i.17]).

The TS-UNB protocol is designed to operate effectively in sub-GHz frequency bands. The protocol description offers particular mechanism to allow the operation under different national or regional radio spectrum regulations (e.g. [i.1], [i.2], [i.3], [i.4]).

4.2 TS-UNB overview

The TS-UNB family is a low power wide area network with star topology based on an UNB approach using Telegram Splitting Multiple Access (TSMA). TSMA is a random channel access method wherein the radio transmission of a packet is divided into several short radio-bursts, which are sent in a non-contiguous manner over the radio channel with transmission-free time intervals in between. The radio-bursts are pseudo-randomly distributed over time and frequency within a radio frame. This method offers high interference resilience against radio transmissions of other radio devices, either from own or foreign radio systems operating in the same band, since only a part of the radio-bursts needs to be received by the base station to decode the transmitted data. Randomness is achieved by crystal reference tolerance, additional message dependent frequency offset and random channel access in time due to the asynchronous operation of the system.

The protocol supports four classes of end-points, as follows:

- Class Z end-points are unidirectional end-points, capable of uplink communication only. Class Z devices may transmit data at any time transmission data is available.
- Class A end-points are bidirectional end-points, capable of uplink communication and end-point triggered downlink communication. Upon reception of an uplink message, the base station may send a downlink message after a defined period of time, triggered by the end-point transmission.
- Class B end-points are class A end-points, also capable of scheduled downlink communication. In Class B, a base station allocates periodic opportunities for downlink transmission, which limits the maximum downlink latency.
- Class C end-points are class B end-points also capable of event-triggered downlink communication. In Class C, downlink transmission may occur at pre-defined time positions within a beacon period of a base station, resulting in a lower latency than for class B.

The end-point classes Z and A form an asynchronous network, where communication is triggered by the end-point. The end-point classes B and C form a synchronous network, where the communication is triggered by the base station. Both networks can be operated in parallel.

To further keep transmission duration short, especially for battery or energy harvesting operated end-points, channel coding together with coherent MSK or GMSK demodulation is used to increase the sensitivity in the receiver to a level of -139 dBm without narrowing the signal bandwidth too much. Hence for the transmission of application data with a size of 10 bytes, the accumulated on-air radio transmission time is less than 400 ms. Therefore TS-UNB offers ultra-low power consumption down to 10 μ Wh per message in the end-point and can be operated also in a low-duty cycle band (DC = 0,1 %). Due to the ultra-narrowband and short-time transmission as well as the high interference resilience TS-UNB can reliably handle a network capacity of more than one million messages per day and per base station within a 200 kHz spectrum.

Above the Telegram Splitting Multiple Access implemented in the PHY layer, the TS_UNB family is capable of handling two different modes:

- The Fixed-MAC Mode: in this mode, the protocol stack goes up to the Link layer and is capable of handling variable application data with a length of up to 245 bytes in uplink and up to 250 bytes in downlink. The protocol is optimized for an application data length of 10 bytes, which builds the core frame of the TS-UNB protocol. Data is encrypted with AES128. For authentication and integrity check a 32-bit Cipher-based Message Authentication Code (CMAC) is added to the MAC Protocol Data Unit. A 24-bit packet counter is used for replay protection.
- The Variable-MAC Mode: in this mode, the protocol stack has a simplified MAC layer, which allows third party protocols to leverage the TSMA PHY layer in a transparent manner. It is capable of handling variable MAC payload data with a length of up to 254 bytes in uplink and downlink. The protocol is optimized for a MAC payload length of 20 bytes, which builds the core frame of the TS-UNB protocol.

The following figures in this clause give an overview of the protocol stack and formats:

- for uplink transmission (ULZ) in Figure 4-1;
- for end-point triggered downlink transmission (DLA) in Figure 4-2;
- for scheduled downlink transmission (DLB) in Figure 4-3;
- for event-triggered downlink transmission (DLC) in Figure 4-4.

The input data at the end-point for uplink communication according to the TS-UNB protocol (see clauses 4.6.2 and 4.6.4) shall be the application data from a device application (e.g. sensor data sensed or generated by a sensor of the end-point). For downlink transmission, the application data may be data for the end-point, which can be a sensor or actuator. The input data for downlink can be e.g. configuration data for a sensor or control data to activate an actuator. On link level application data may be combined with additional link layer control segments or link layer control segments may also be put into LPDU without application data.

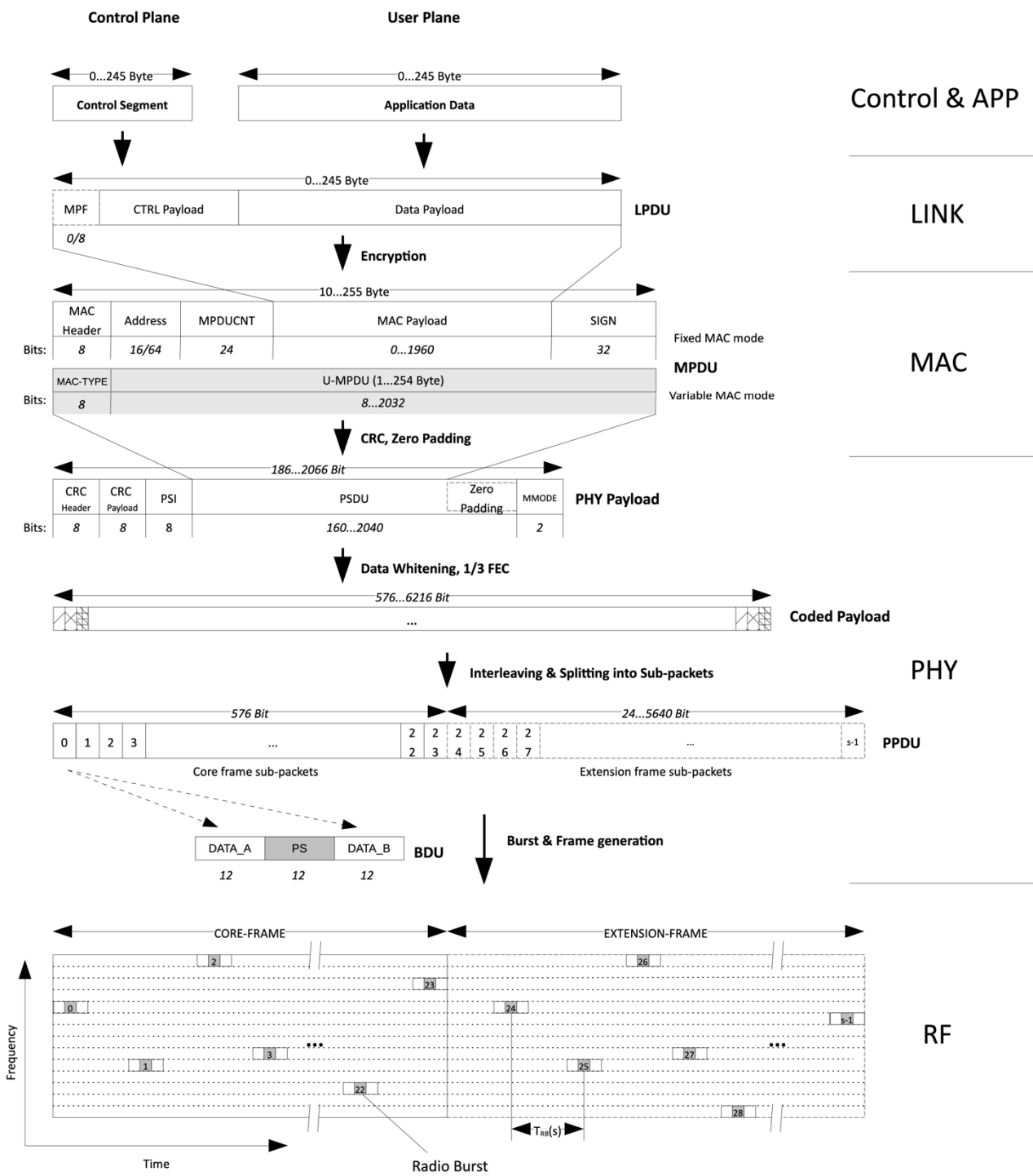


Figure 4-1: Overview of uplink Formats (ULZ transmission)

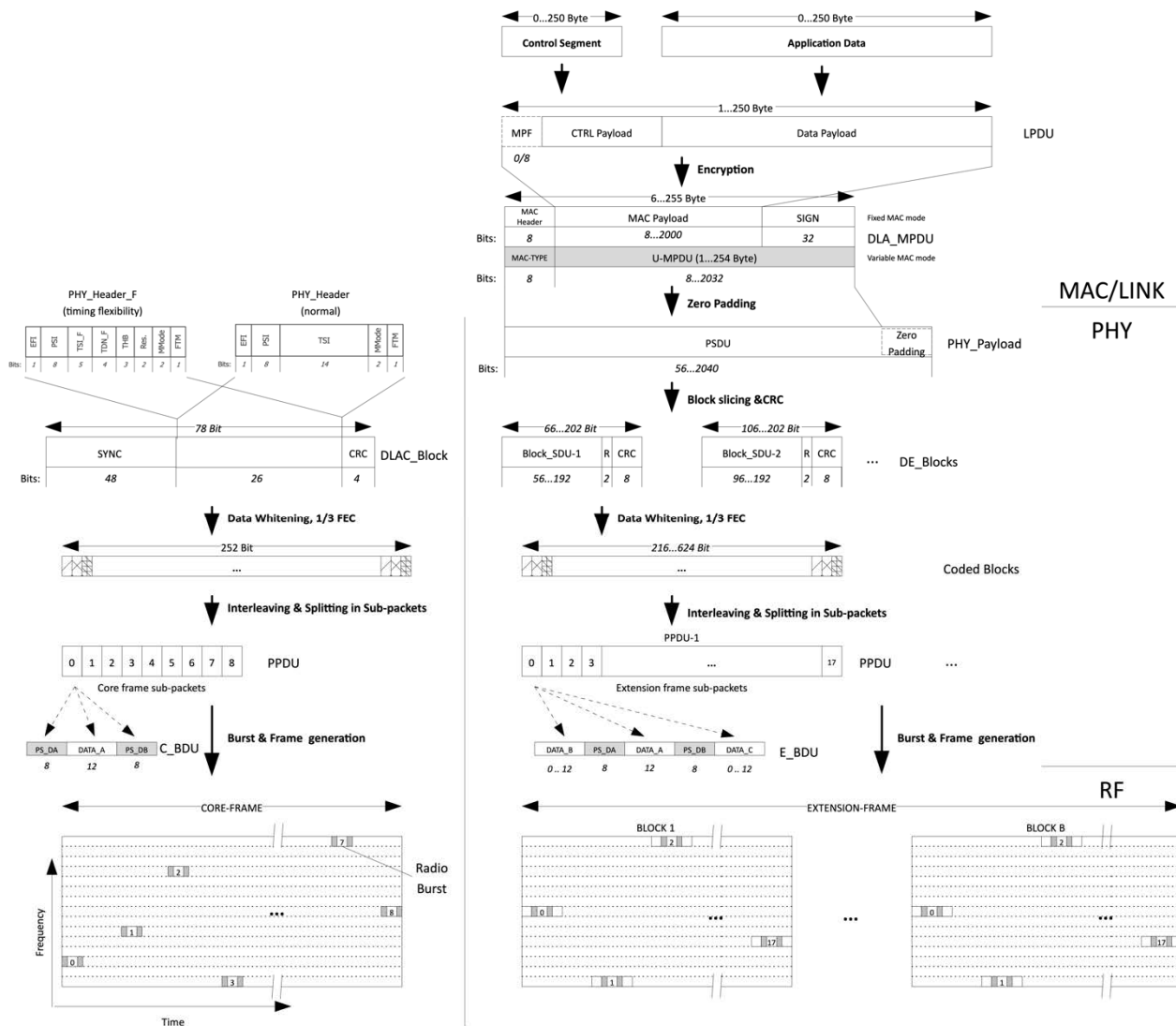


Figure 4-2: Overview of downlink formats in DLA transmissions

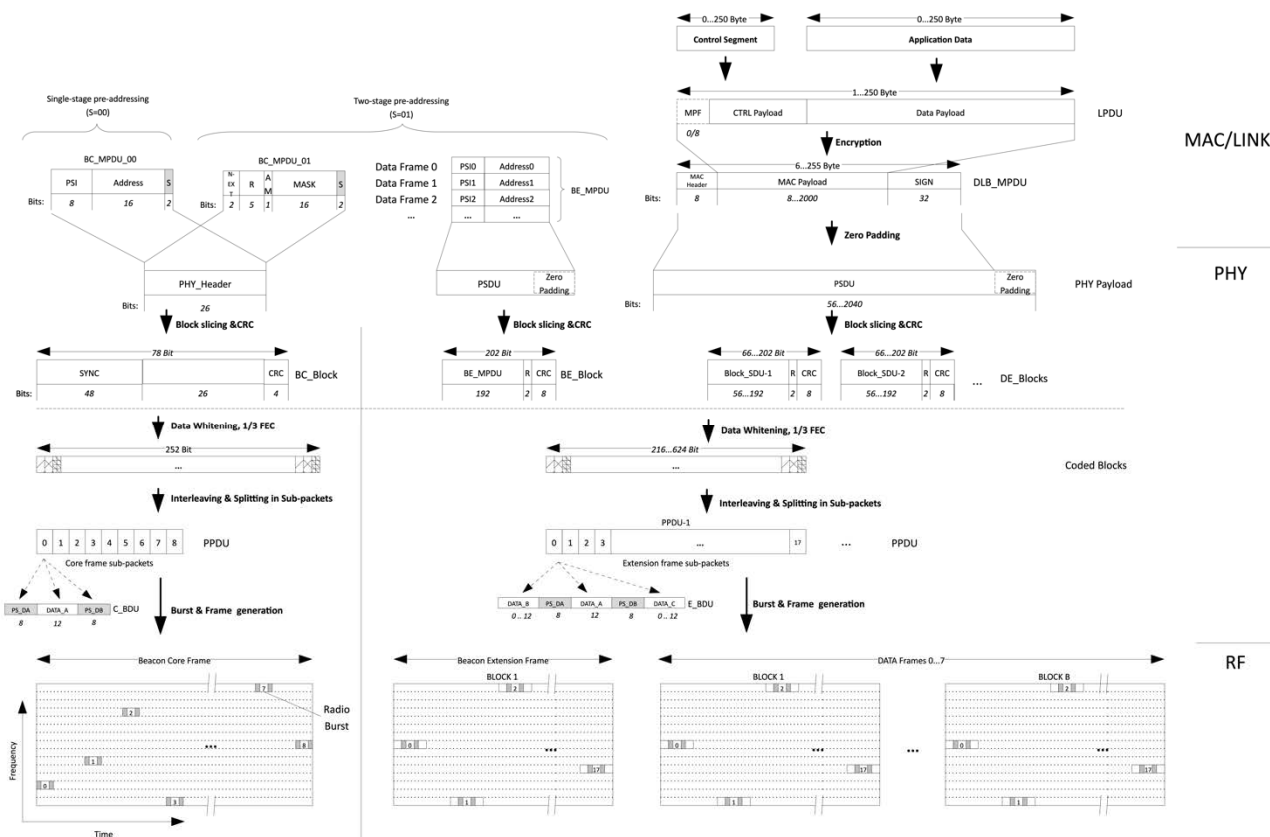


Figure 4-3: Overview of downlink formats in DLB transmission

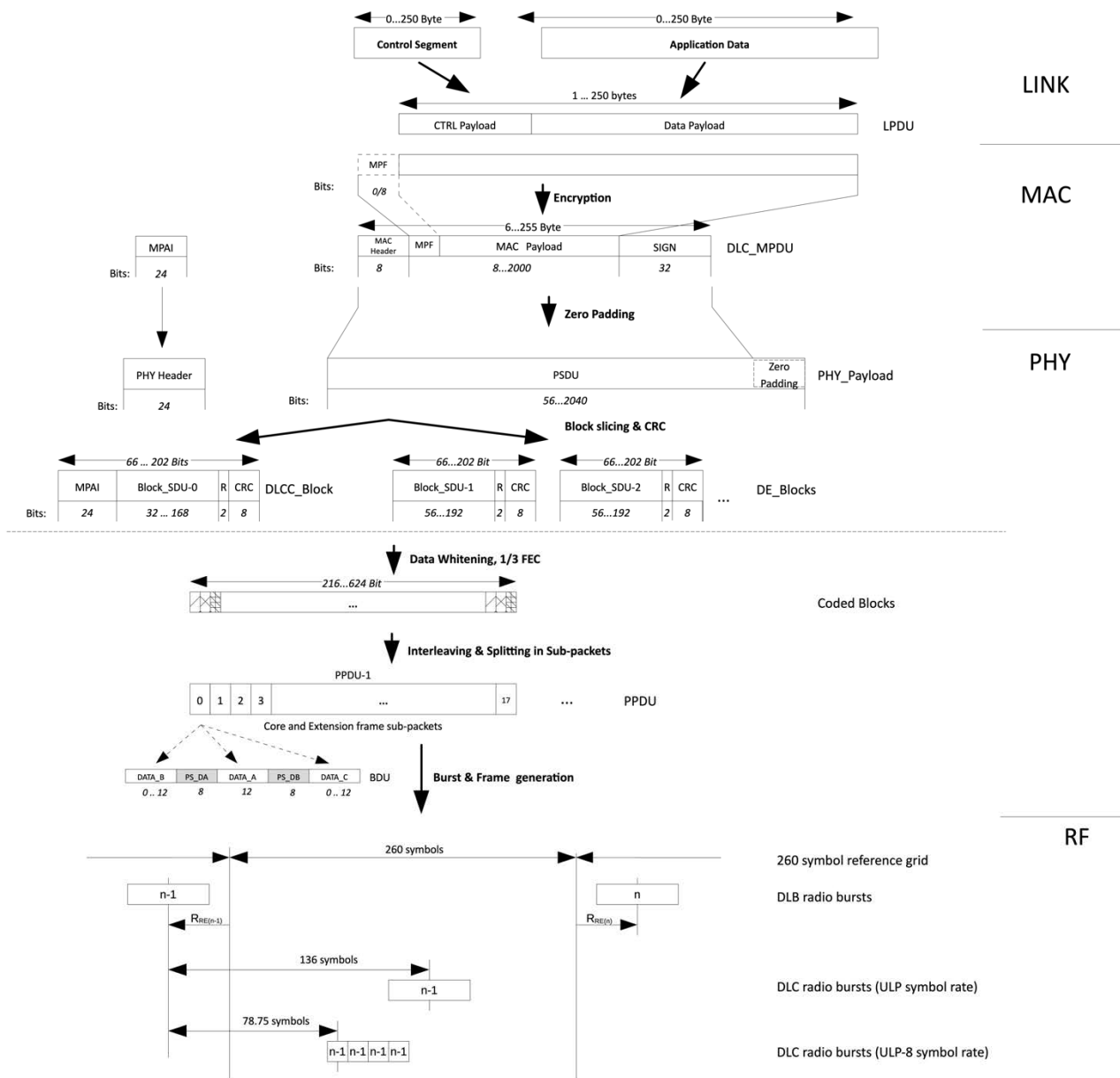


Figure 4-4: Overview of downlink formats in DLC transmission

4.3 Modes of operation

Transmission modes⁴

An LTN system using TS-UNB protocol shall support uplink-only transmission (ULZ) and may optionally also support uplink-triggered downlink transmission (DLA). In addition to ULZ and DLA transmission, an LTN system may also support scheduled downlink transmission (DLB) and event-triggered downlink transmission (DLC). A single-burst transmission mode in downlink (DL-SB), that does not use telegram splitting, is also defined, but deprecated in the present specifications.

Symbol rates

An LTN system implementing TS-UNB protocol shall support symbol rates, as defined in Table 4-2.

Radio-Burst structure

TS-UNB protocol defines different radio-burst types in uplink and downlink depending on the used symbol rate:

- Standard burst structure in uplink according to clause 4.7.1.4.1 and in downlink according to clauses 4.7.2.13.3 and 4.7.2.13.4.
- Concatenated burst structure in uplink and downlink: concatenation of three standard radio-bursts.
- HDR burst structure in downlink according to clause 4.7.2.13.6.

Combinations of symbol rates and burst structure that may be used by an LTN system implementing TS-UNB protocol are listed in Table 4-1.

Table 4-1: Possible combinations of radio-burst structures and symbol rates

		Radio-burst structure		
		Standard	Concatenated	HDR
Symbol rate	ER	ULZ	N/A	N/A
	ULP	ULZ DLA DLB DLC	N/A	N/A
	ULP2	N/A	DLA	N/A
	ULP8	N/A	ULZ DLA	DLA DLC

Class of end-points

Classes of end-points implementing TS-UNB are defined, as follows:

- class Z end-point: ULZ transmissions;
- class A end-point: ULZ and DLA transmissions;
- class B end-point: ULZ, DLA, and DLB transmissions;
- class C end-point: ULZ, DLA, DLB, and DLC transmissions.

The EP mode of operation shall be as defined in Table 4-3.

NOTE: No support of relay points is foreseen in the TS-UNB protocol.

Table 4-2: Symbol rate definition

Symbol rate acronym	ER	SBR (see NOTE)	ULP	ULP2	ULP8
Symbol rate full name	Extended Reach	Single Burst Rate	Ultra Low Power	Ultra Low Power 2	Ultra Low Power 8
Formal value (in baud)	$\frac{26 \cdot 10^6}{2^{16}}$	600	$\frac{26 \cdot 10^6 \times 3}{2^{15}}$	$\frac{26 \cdot 10^6 \times 3}{2^{14}}$	$\frac{26 \cdot 10^6 \times 3}{2^{12}}$
Approx. value (in baud)	396,7	600	2380,3	4 760,7	19 043

NOTE: SBR is a deprecated symbol rate; it should not be used in new design.

Table 4-3: TS-UNB modes of operation

End-point class	C				
	B				
	A				
Z					
Transmission	ULZ	DL-SB (deprecated)	DLA	DLB	DLC
MAC Mode	Fixed MAC Variable MAC			Fixed MAC	
PHY Mode	Telegram Splitting (TS)	Single Burst	Telegram Splitting (TS)		
TSMA pattern	normal	N/A	normal	PRB time&frequency structure	PRB time&frequency structure with additional time shift
Modulation	(G)MSK	GFSK	(G)MSK		
Symbol Rate	ER	optional	N/A	N/A	N/A
	SBR	N/A	mandatory	N/A	N/A
	ULP	mandatory	N/A	mandatory	mandatory
	ULP2	N/A	N/A	optional	N/A
	ULP8	optional	N/A	optional	N/A
MCL examples (see Note 1 & 2)	164 dB (ER) 153 dB (ULP) 144 dB (ULP8)	152 dB (SBR)	161 dB (ULP) 158 dB (ULP2) 152 dB (ULP8)		
Sync Burst	on/off	none	on/off	none	none
Retransmission	on/off	none	on/off	none	none
NOTE 1: Uplink MCL based on transmit power of $P_{TX} = 14$ dBm and noise figure of 4 dB.					
NOTE 2: Downlink MCL based on transmit power of $P_{TX} = 27$ dBm and noise figure of 8 dB.					

4.4 Drawing and writing conventions

In this clause on TS-UNB, the drawing conventions for figures of protocol data units are, as follows:

- fields to be transmitted are drawn from left to right;
- left field is transmitted first;
- right field is transmitted last.

The writing conventions for tables of protocol data units are, as follows:

- top field is transmitted first;
- bottom field is transmitted last.

The network byte order is big endian, i.e. most significant byte of a field is sent first. In a byte, the most significant bit is sent first.

When several fields are to be named according to their position in a PDU, the naming convention is to follow the serialization over the air and start with 0 (see Figure 4-5).

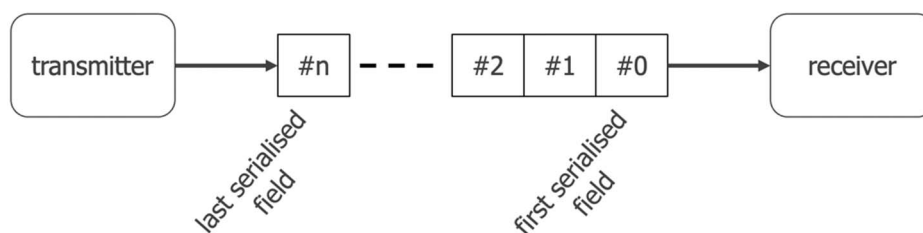


Figure 4-5: Field naming according to serialization order

4.5 Link Layer

4.5.1 Link Layer overview

The Link Layer handles control procedures required to establish and maintain a connection between an end-point and a base station (see Figure 4-6).

The link layer formats, functions and procedures, as defined in the present clause, shall be applied to the fixed MAC mode. Their usage in case of variable MAC mode depends on the MAC-TYPE definition.

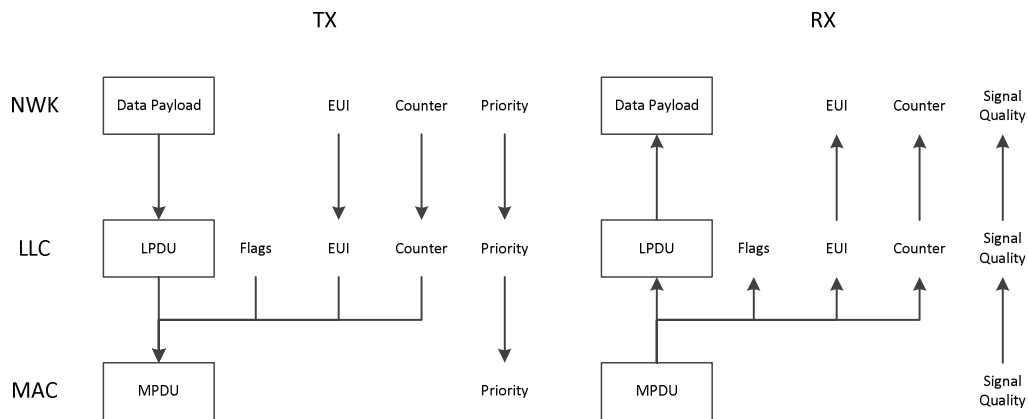


Figure 4-6: Link Layer interfaces with adjacent layers on the Base Station

4.5.2 Link Layer formats

4.5.2.1 Link Layer Protocol Data Unit (LPDU)

The link layer protocol data unit shall be as specified in Table 4-4.

Table 4-4: Link Layer Protocol Data Unit (LPDU) Format

Field length (in bytes)	1 to 245 (in UL) 1 to 250 (in DL)	0 to 245 (in UL) 0 to 250 (in DL)
Field name	Control Payload	Data Payload
Comment	Only present if MAC Header Control flag = 1	may be omitted

Table 4-5: Control payload format

Field length (in bytes)	1	0 to 244		
Field content	Control length	Control segment 1	...	Control segment n

The control flag in the MAC Header (see clause 4.6.2.3) shall determine whether a control payload is present in the packet or not. The control payload of the LPDU shall be as specified in Table 4-5. It shall comprise the control length field and one or more control segments. The control length field shall specify the total length in bytes of all control segments of the control payload.

4.5.2.2 Control Segments

4.5.2.2.1 Overview

A control segment shall consist of a control header field and zero or several additional fields. The control header value and the size of the control segment shall be as detailed in Table 4-6. Control segments shall be used only in fixed MAC mode.

Table 4-6: List of Control Segments

Control Header	Direction	Control Segment Name	Control Segment Size (in bytes)
0x10	UL	Attach Request	11
0x11	UL	Attach Request IPv6	19
0x14	DL	Attach Accept	5
0x18	UL, DL	Detach Request	5
0x1C	DL, UL	Detach Accept	5
0x20	DL	DLRX Status Query	1
0x21	UL	DLRX Status Response	3
0x22	DL	DLRX Extended Status Query	1
0x23	UL	DLRX Extended Status Response	4
0x24	DL	Link Adaptation Request	3
0x25	UL	Link Adaptation Confirm	1
0x30	UL	Sync Request	2
0x31	DL	Sync Info	36
0x32	UL	Resync Request	1
0x33	DL	Resync Info	10
0x34	DL	Desync Request	2
0x35	UL	Desync Accept	2
0x36	DL	Sync System Adaptation Notify	3
0x37	DL	Sync Request Trigger	1
0x38	DL	Sync Adpatation Request	2
0x39	UL	Sync Adaptation Confirm	1
0x3B	UL	DLB Data Ack	3
0x3C	UL	DLC Data Ack	3
0x40	DL	Group Assign Request	26
0x41	UL	Group Assign Confirm	2
0x42	DL	Group Dismiss Request	10
0x43	UL	Group Dismiss Confirm	2
0x44	UL, DL	Fragment Info	7
0x50	DL	DLRX Certification Status Query	1
0x51	UL	DLRX Certification Status Response	14
0x52	DL	DLRX Class A Statistic Query	1
0x53	UL	DLRX Class A Statistic Response	13
0x54	DL	DLRX Class B Statistic Query	1
0x55	UL	DLRX Class B Statistic Response	19
0x56	DL	DLRX Class C Statistic Query	1
0x57	UL	DLRX Class C Statistic Response	9
0xC0 to 0xFF	UL, DL	User specific	User specific (see note)
Others		Reserved	

NOTE: User specific control segments shall be placed after the listed control segments.

4.5.2.2.2 Attach Request

The attach request control segment shall be used to attach the end-point to the base station. The format, as described in Table 4-7, shall be used when an end-point does not support IPv6 addressing.

Table 4-7: Attach Request Control Segment Format

Field length (in bytes)	1	2	4	4
Field content	Control Header (0x10)	End-point Info	Nonce	User Signature

When the end-point can handle IPv6 addressing, it may use the IPv6 attach request control segment according to Table 4-8 to transmit the IPv6 subnet information to the base station.

Table 4-8: Attach Request IPv6 Control Segment Format

Field length (in bytes)	1	2	8	4	4
Field content	Control Header (0x11)	End-point Info	IPv6 subnet	Nonce	User signature

Nonce and user signature fields are user specific and should be used in the application layer to derive the network key in the end-point and the service centre from the pre-shared private key.

The end-point info field signals the end-point capabilities to the base station. The end-point info field shall have the format according to Table 4-45.

4.5.2.2.3 Attach Accept

The base station shall send a message with an attach accept control segment to answer the attach request received from the end-point. The attach accept control segment shall have the format according to Table 4-9.

Table 4-9: Attach Accept Control Segment Format

Field length (in bytes)	1	2	2
Field content	Control Header (0x14)	End-point Info	Short address

The end-point info field is used by the base station to select the actual capabilities to use from the capabilities advertised by the end-point in the attach request control segment. The bit positions are according to Table 4-45. The short address is a 16-bit address, which shall be assigned by the base station to the end-point.

4.5.2.2.4 Detach Request

If an end-point needs to disconnect from the network, the end-point shall send a message with a detach request control segment according to Table 4-10 to the base station. A base station may also send a detach request to an end-point to disconnect the end-point from the network.

Table 4-10: Detach Request Control Segment Format

Field length (in bytes)	1	4
Field content	Control Header (0x18)	User Signature

The user signature field may be used by the application to authenticate the detach request and may not be processed within the domain of the base station.

4.5.2.2.5 Detach Accept

A detach request from an end-point shall be answered with a detach accept control segment by the base station. A detach request from a base station shall be answered with a detach accept control segment by the end-point. The detach accept control segment shall have the format according to Table 4-11.

Table 4-11: Detach Accept Control Segment Format

Field length (in bytes)	1	4
Field content	Control Header (0x1C)	User Signature

The user signature field may be used by the application to authenticate the detach accept and may not be processed within the domain of the base station.

4.5.2.2.6 DLRX Status Query

The DLRX Status Query control segment shall be formatted as specified in Table 4-12. It may be sent from the base station to an EP to request a DLRX Status Response from the EP.

Table 4-12: DLRX Status Query Control Segment Format

Field length (in bytes)	1
Field content	Control Header (0x20)

4.5.2.2.7 DLRX Status Response

The DLRX Status Response control segment shall be sent by an EP after receiving a DLRX Status Query from the base station. It shall be formatted as specified in Table 4-13.

Table 4-13: DLRX Status Response Control Segment Format

Field length (in bytes)	1	1	1
Field content	Control Header (0x21)	RSSI	SNR

RSSI

Received signal strength indicator, coded as unsigned fixed point with a least significant bit value of 1 dBm and an offset of -174 dBm.

SNR

Signal to noise ratio, coded as signed fixed point with a least significant bit value of 0,5 dB.

4.5.2.2.8 DLRX Extended Status Query

The DLRX Extended Status Query control segment may be sent by the base station to request information on radio link parameters in the reception of a downlink message of either Class A, Class B or Class C. The DLRX Extended Status Query control segment shall be formatted according to Table 4-14. The end-point shall evaluate the radio link parameters over the received message, carrying the DLRX Extended Status Query control segment.

Table 4-14: DLRX Extended Status Query Format

Field length (in bytes)	1
Field content	Control Header (0x22)

4.5.2.2.9 DLRX Extended Status Response

The DLRX Extended Status Response control segment shall be sent by the end-point after the reception of a DLRX Extended Status Query control segment, sent by the base station. The DLRX Extended Status Response control segment shall be formatted according to Table 4-15.

Table 4-15: DLRX Extended Status Response Segment Format

Field length (in bytes)	1	1	1	1
Field content	Control Header (0x23)	EP eqSNR	EP SNR	EP RSSI

The fields shall contain the reception parameter values of the last block of the corresponding downlink message, which contained the DLRX Extended Status Query command:

EP eqSNR

1 byte signed integer, 0,5 dB resolution, -63,5 ... +63,5 dB, -64 representing "value not available".

EP SNR

1 byte signed integer, 0,5 dB resolution, -63,5 ... +63,5 dB, -64,0 representing "value not available".

EP RSSI

1 byte unsigned integer, 1 dBm resolution, -173 ... +81 dBm, -174 representing "value not available".

4.5.2.2.10 Link Adaptation Request

If the base station needs to change the configuration of the connection with an end-point, it shall send a Link Adaptation Request control segment, formatted as specified in Table 4-16. The requested configuration shall conform to the end-point capabilities announced during the attachment procedure.

Table 4-16: Link Adaptation Control Segment Format

Field length (in bytes)	1	2
Field content	Control Header (0x24)	End-point Info

4.5.2.2.11 Link Adaptation Confirm

If an end-point receives a Link adaptation request control segment from a base station, it shall respond with a Link adaptation confirm control segment, formatted as specified in Table 4-17.

Table 4-17: Link Adaptation Confirm Control Segment Format

Field length (in bytes)	1
Field content	Control Header (0x25)

4.5.2.2.12 Sync Request

The Sync Request control segment shall be used by the end-point to request synchronization for the DLB mode and to retrieve DLB session information. It shall consist of three fields, as detailed in Table 4-18.

Table 4-18: Sync Request Control Segment Format

Field length (in bits)	8	2	6
Field content	Control Header (0x30)	Max Beacon RX Cycle	Reserved

Max Beacon RX Cycle (BRxC)

This field shall indicate the maximum beacon RX cycle supported by the end-point.

NOTE: Actual value for BRxC is given in Sync Info control segment (see Table 4-19).

Reserved

This field shall be set to zero.

4.5.2.2.13 Sync Info

The Sync Info control segment shall be used by the base station to provide an end-point with the information for the DLB and DLC mode.

The Sync Info control segment shall consist of twelve fields, as detailed in Table 4-19.

Table 4-19: Sync Info Control Segment Format

Field length (in bits)	8	16	24	64	128	32	4	2	3	2	1	2	2
Field content	Control Header (0x31)	DLB_ FO	DLB_ TO	BS_ EUI	DLB_ KEY	BCCNT	NPRB_ IDX	BRxC_ Length	BRxC_ Offset	DLC_ SI	DLC_ D	Sync_ Frame_ Flag	Reserved (set to 0)

DLB_FO

Frequency offset of the received uplink transmission compared to the base station expected frequency in ppb - signed integer (positive values indicate an end-point frequency which is too high).

DLB_TO

Time to next beacon in 1/32 of standard symbol duration - unsigned integer (centre of first radio-burst of the DLA core frame to the grid position referencing the first resource element of the next DLB frame (see Figure 4-20).

BS_EUI

Base station unique identifier (EUI64 format).

DLB_KEY

DLB encryption key (network level).

BCCNT

Beacon Counter value of the next beacon, the DLB_TO time is referring to.

NPRB_IDX

Index to the number of physical resource blocks in the DLB structure, and the corresponding numbers of data regions. The NPRB_IDX shall be interpreted as detailed in Table 4-20. The supported number of data regions shall be one of those in Table 4-20.

NOTE: The number of data regions is dynamic. It is set by the base station for each DLB frame (see clause 4.7.2.15.1).

Table 4-20: Index to the numbers of PRBs and data regions

NPRB_IDX	Number of Physical Resource Blocks $N_{PRB,bea}$	Supported numbers of data regions
0x00	3	{1}
0x01	4	{1}
0x02	5	{1, 2}
0x03	7	{1, 2, 3}
0x04	9	{1, 2, 4}
0x05	11	{1, 2}
0x06	13	{1, 2, 3, 4}
0x07	17	{1, 2, 4}
0x08	25	{1, 2, 3, 4}
0x09	31	{1, 2, 3}
0x0A	37	{1, 2, 3, 4}
0x0B	49	{1, 2, 3, 4}
0x0C	73	{1, 2, 3, 4}
0x0D	121	{1, 2, 3, 4}
0x0E	169	{1, 2, 3, 4}
0x0F	217	{1, 2, 3, 4}

Beacon Rx Cycle Length (BRxC_Length)

This 2-bit field is the number, in powers of 2, of beacons, over which the Beacon Rx Cycle (BRxC) is defined. It determines the fraction of beacons that an EP shall receive. The BRxC_Length field shall be coded according to Table 4-21.

Table 4-21: Beacon Rx Cycle Values

BRxC_Length	Number of beacons in the BRxC	Fraction of beacons received by an EP
0x00	1	every beacon
0x01	2	every 2 nd beacon
0x02	4	every 4 th beacon
0x03	8	every 8 th beacon

Beacon Rx Cycle Offset (BRxC_Offset)

The cycle of the reception of the beacon fractions starts at the given Beacon Rx Cycle Offset, which is a 3-bit unsigned integer value.

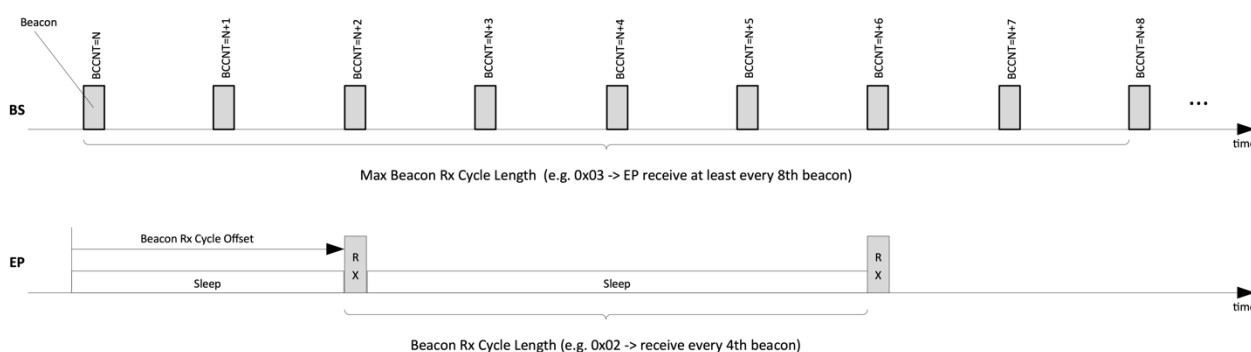


Figure 4-7: Beacon Rx Cycle Length and Offset and EP behaviour

The beacons, that shall be received (see example in Figure 4-7), are all the beacons where:

$$BCCNT \bmod (2^{BRxC_Length}) = BRxC_Offset$$

The Beacon Rx Cycle Offset shall be less than the given value 2^{BRxC_Length} .

DLC Start Index (DLC_SI)

This 2-bit field is the start index of a DLC resource element, where DLC frame transmissions can start. It shall be formatted as specified in Table 4-145.

DLC_Density (DLC_D)

This 1-bit field indicates the density of DLC transmission. It shall be set to one for high density, and shall be cleared to zero for low density.

Sync_Frame_Flag

This 2-bit field defines the presence of a synchronization frame (staircase). It shall be coded, as follows:

- 0b00: no sync frame (staircase).
- 0b01: sync frame (staircase) available (see clause 4.7.2.7).
- 0b10: sync & data frame available.
- 0b11: reserved.

4.5.2.2.14 Resync Request

The Resync Request control segment shall be used by the end-point to request resynchronization for the DLB frame, in case of a loss of synchronization (i.e. one or several beacons not received). The Resync Request control segment shall be formatted according to Table 4-22.

Table 4-22: Resync Request Control Segment Format

Field length (in bytes)	1
Field content	Control Header (0x32)

4.5.2.2.15 Resync Info

The Resync Info control segment shall be used by the base station as a response to a Resync Request from an end-point. It shall be sent in DLA transmission and shall be formatted according to in Table 4-23.

The Base Station may respond to a Resync Request with a Sync Info control segment instead of a Resync Info control segment if the Resync Info might be insufficient for a successful resynchronization.

Table 4-23: Resync Info Control Segment Format

Field length (in bits)	8	16	24	32
Field content	Control Header (0x33)	DLB_FO	DLB_TO	BCCNT
NOTE: DLB_FO, DLB_TO and BCCNT fields are detailed in clause 4.5.2.2.13				

4.5.2.2.16 Desync Request

The Desync Request control segment might be used by the end-point to explicitly request desynchronization for the DLB frame. The Desync Request control segment shall be formatted according to Table 4-24.

Table 4-24: Desync Request Control Segment Format

Field length (in bits)	8	8
Field content	Control Header (0x34)	Reserved (set to 0)

4.5.2.2.17 Desync Accept

The Desync Accept control segment might be sent by the base station as a response to a preceding Desync Request from the end-point. The Desync Accept control segment shall be formatted according to Table 4-25.

Table 4-25: Desync Accept Control Segment Format

Field length (in bits)	8	8
Field content	Control Header (0x35)	Reserved (set to 0)

4.5.2.2.18 Sync System Adaptation Notify

The Sync System Adaptation Notify control segment shall be used by the base station to notify all end-points in its coverage area about changes in the DLB structure. This control segment shall consist of four fields, as detailed in Table 4-26.

End-points shall not acknowledge a Sync System Adaptation Notify.

Table 4-26: Sync System Adaptation Notify control segment format

Field length (in bits)	8	4	4	8
Field content	Control Header (0x36)	New NPRB_IDX	Adaptation Occurrence	Reserved (set to 0)

New_ NPRB_IDX

Value of the new NPRB_IDX, after sync system adaptation.

Adaptation_Occurrence

Least significant bits of the BCCNT, when the Sync system adaptation will occur.

Reserved

Set to 0.

4.5.2.2.19 Sync Request Trigger

The Sync Request Trigger control segment shall be sent by a base station to force EP(s) to send a Sync Request. This control segment shall consist of one field, as detailed in Table 4-27.

NOTE: This control message helps EP(s) to synchronize to a different base station or to get new sync information.

Table 4-27: Sync Request Trigger control segment format

Field length (in bits)	8
Field content	Control Header (0x37)

4.5.2.2.20 Sync Adaptation Request

The Sync Adaptation Request control segment shall be used by the base station to update EP(s) with new beacon reception alignment. This control segment shall consist of four fields, as detailed in Table 4-28.

Table 4-28: Sync Adaptation Request control segment format

Field length (in bits)	8	2	3	3
Field content	Control Header (0x38)	BRxC_ Length	BRxC_ Offset	Reserved (set to 0)

4.5.2.2.21 Sync Adaptation Confirm

The Sync Adaptation Confirm control message shall be used by an end-point to confirm a Sync Adaptation Request. This control segment shall consist of one field, as detailed in Table 4-29.

Table 4-29: Sync Adaptation Confirm control segment format

Field length (in bits)	8
Field content	Control Header (0x39)

4.5.2.2.22 DLB Data Ack

The DLB Data Ack control segment shall be sent by an EP to acknowledge a DLB_Data frame, that requests an acknowledgment. This control segment shall consist of three fields, as detailed in Table 4-30.

Table 4-30: DLB Data Ack control segment format

Field length (in bits)	8	8	8
Field content	Control Header (0x3B)	DLB_Ack_Req_ Position	DLB_Data_ Frame_ Position

DLB_Ack_Req_Position

The eight LSB of the Beacon Counter of the DLB frame, in which the acknowledgment request was sent.

DLB_Data_Frame_Position

The position, in the DLB frame, where the DLB_Data frame was sent.

4.5.2.2.23 DLC Data Ack

The DLC Data Ack control segment shall be sent by an EP to acknowledge a DLC_Data frame, that requests an acknowledgment. This control segment shall consist of three fields, as detailed in Table 4-31.

Table 4-31: DLC Data Ack control segment format

Field length (in bits)	8	4	12
Field content	Control Header (0x3C)	DLC_Ack_Req_ Position	DLC_Data_ Frame_ Position

DLC_Ack_Req_Position

The 4 LSB of the Beacon Counter of the DLB frame, in which the acknowledgment request was sent.

DLC_Data_Frame_Position

The start position within the DLB structure, where the DLC_Data frame was sent. The start position is indicated by the 12 MSB of the resource element index.

4.5.2.2.24 Group Assign Request

The Group Assign Request control segment shall be used by the base station to assign an end-point to a Group EUI. Group assignment is optional and may be conducted by the base station at will. An end-point may be assigned to multiple groups. A class B or class C end-point shall support up to 8 group assignments. This control segment shall consist of three fields, as detailed in Table 4-32.

Table 4-32: Group Assign Request Control Segment Format

Field length (in bytes)	1	8	16	1
Field content	Control Header (0x40)	Group EUI	Group Key	Assignment Counter

The assignment counter is used as short identifier of the group assign request and confirm procedure and shall be incremented after each group assignment.

4.5.2.2.25 Group Assign Confirm

The Group Assign Confirm control segment shall be used by the end-point to confirm a Group Assign Request. This control segment shall consist of two fields, as detailed in Table 4-33.

Table 4-33: Group Assign Confirm control segment format

Field length (in bytes)	1	1
Field content	Control Header (0x41)	Assignment Counter

4.5.2.2.26 Group Dismiss Request

The Group Dismiss Request control segment shall be used by the base station to dismiss an end-point from a group. It shall be formatted according to Table 4-34.

Table 4-34: Group Dismiss Request control segment format

Field length (in bytes)	1	8	1
Field content	Control Header (0x42)	Group EUI	Dismissal Counter

The dismissal counter is used as short identifier of the group dismiss request and confirm procedure and shall be incremented after each group dismissal.

4.5.2.2.27 Group Dismiss Confirm

The Group Dismiss Confirm control segment shall be used by the end-point to confirm a Group Dismiss Request. This control segment shall be formatted according to Table 4-35.

Table 4-35: Group Dismiss Confirm control segment format

Field length (in bytes)	1	1
Field content	Control Header (0x43)	Dismissal Counter

4.5.2.2.28 Fragment Info

The Fragment Info control segment shall be used to signal a transmission of a fragment of a fragmented application payload. All fragment transmissions of a payload shall include the 7 byte Fragment Info control segment, as specified in Table 4-36, and a data payload with the according fragment of the complete application data payload. The fragments may be also coded in order to retrieve lost fragments.

Table 4-36: Fragment Info control segment format

Field length (in bits)	8	2	2	4	20	20
Field content	Control Header (0x44)	FS-ID	FSCNT	Coding	ADSI	FPO

FS-ID

Fragmentation Session Identifier.

FSCNT

Fragmentation Session Counter, shall be incremented after finishing of the Fragmentation Session with FS-ID.

Coding

- coding scheme of the complete payload;
- 0: uncoded;
- 1-15: reserved for future coding schemes.

ADSI

Application Data Size Indicator; length of the Application Data payload in byte before fragmentation coding (max. 1 024 kByte).

FPO

Fragmentation Payload Offset; offset byte position in steps of 2 Byte of the transmitted fragment payload in the overall fragmentation layer coded payload (max. 2 048 kByte).

4.5.2.2.29 DLRX Certification Status Query

The DLRX Certification Status Query control segment may be sent by the base station to request information on radio link parameters for the reception of the downlink message of either Class A, Class B or Class C. The DLRX Certification Status Query control segment shall be formatted according to Table 4-37.

Table 4-37: DLRX Certification Status Query Format

Field length (in bytes)	1
Field content	Control Header (0x50)

4.5.2.2.30 DLRX Certification Status Response

The DLRX Certification Status Response control segment shall be sent by the end-point after the reception of a DLRX Certification Status Query by the base station. The DLRX Certification Status Query control segment shall be formatted according to Table 4-38.

Table 4-38: DLRX Certification Status Response Segment Format

Field length (in bytes)	1	2	2	1	1	1	1	1	1	1	1	1
Field content	Control Header (0x51)	Freq. off. Core	Max. freq. off. Ext	Time off. Core	Max. time off. Ext	Min. subpack . RSSI	Max. subpack . RSSI	Min. symbol SNR	Min. symbol SNR block index	Min. symbol SNR subpacket . Index	Min. symbol SNR symbol index	Num. of missing radio-burst

The fields shall contain the values of the corresponding downlink message, which contained the DLRX Certification Status Query command:

Frequency offset of the core block

2 byte signed integer, 0,5 Hz resolution, -16 384 Hz..16 383,5 Hz, saturated on extremes.

Maximum frequency offset of any extension block

2 byte signed integer, 0,5 Hz resolution, -16 384 Hz..16 383,5 Hz, saturated on extremes.

Time offset of the core block

1 byte signed integer, value < 0 indicating early transmission, 10 μ s resolution, -1,28 ms..1,27 ms, saturated on extremes.

Maximum time offset of any extension block

1 byte signed integer, value < 0 indicating early transmission, 10 μ s resolution, -1,28 ms..1,27 ms, saturated on extremes.

Minimum radio-burst RSSI

1 byte, unsigned integer, 0,5 dBm resolution, -150 dBm offset, -150...22,5 dBm.

Maximum radio-burst RSSI

1 byte, unsigned integer, 0,5 dBm resolution, -150 dBm offset, -150...22,5 dBm.

Minimum symbol SNR

1 byte signed integer, 0,25 dB resolution, -32...31,75 dB.

Minimum symbol SNR block index

1 byte, zero based index of the block containing the symbol with the minimum SNR.

Minimum symbol SNR subpacket index

1 byte, zero based index of the subpacket containing the symbol with the minimum SNR.

Minimum symbol SNR symbol index

1 byte, zero based index of the symbol with the minimum SNR.

Number of missing radio-burst

number of radio-bursts that were not received, 1 byte unsigned integer.

4.5.2.2.31 DLRX Class A Statistic Query

The DLRX Class A Statistic Query control segment may be sent by the base station to request information on reception parameter statistics in the end-point of the corresponding and previous class A downlink messages. The DLRX Class A Statistic Query control segment shall be formatted according to Table 4-39.

Table 4-39: DLRX Class A Statistic Query

Field length (in bytes)	1
Field content	Control Header (0x52)

4.5.2.2.32 DLRX Class A Statistic Response

The DLRX Class A Statistic Response control segment shall be sent by the end-point after the reception of a DLRX Class A Statistic Query by the base station. The DLRX Class A Statistic Response control segment shall be formatted according to Table 4-40.

Table 4-40: DLRX Statistic Class A Segment Format

Field length (in bytes)	1	1	1	1	1	1	1	2	2	2
Field content	Control Header (0x53)	Min EP eqSNR	Avg EP eqSNR	Min EP SNR	Avg EP SNR	Min EP RSSI	Avg EP RSSI	Num of rec DL cores	Num of succ. rec. msg	Num of failed msg

The fields shall contain the statistics of the previous downlink messages, which were received since the last DLRX Class A Statistic Query command was issued:

Minimum and average EP eqSNR

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP SNR

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP RSSI

1 byte unsigned integer, 0,5 dBm resolution, -150..-22,5 dBm, -150 dBm representing N/A

Number of successfully received Class A DL Cores

2 byte unsigned integer, 0 .. 65 535

Number of successfully received Class A DL Messages

2 byte unsigned integer, 0 .. 65 535

Number of failed Class A DL Messages

number of messages that could not be received, 2 byte unsigned integer, 0 .. 65 535

4.5.2.2.33 DLRX Class B Statistic Query

The DLRX Class B Statistic Query control segment may be sent by the base station to request information on reception parameter statistics in the end-point of the corresponding and previous class B downlink messages. The DLRX Class B Statistic Query control segment shall be formatted according to Table 4-41.

Table 4-41: DLRX Class B Statistic Query

Field length (in bytes)	1
Field content	Control Header (0x54)

4.5.2.2.34 DLRX Class B Statistic Response

The DLRX Class B Statistic Response control segment shall be sent by the end-point after the reception of a DLRX Class B Statistic Query by the base station. The DLRX Class B Statistic Response control segment shall be formatted according to Table 4-42.

Table 4-42: DLRX Statistic Class B Segment Format

Field length (in bytes)	1	1	1	1	1	1	1	2	2	2	2	2	2
Field content	Control Header (0x55)	Min EP eqSNR	Avg EP eqSNR	Min EP SNR	Avg EP SNR	Min EP RSSI	Avg EP RSSI	Num Rx Beacon core	Num Fail Beacon core	Num Rx Beacon Ext	Num Fail Beacon Ext	Num Rx Data Frame	Num Fail Data Frame

The fields shall contain the statistics of the previous Class B downlink beacons and data frames, which were received since the last DLRX Class B Statistic Query command was issued:

Minimum and average EP eqSNR of beacon core

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP SNR of beacon core

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP RSSI of beacon core

1 byte unsigned integer, 0,5 dBm resolution, -150..-22,5 dBm, -150 dBm representing N/A

Number of successfully received Class B Beacon Cores

2 byte unsigned integer, 0..65 535

Number of failed Class B Beacon Cores

number of beacon cores that were not received, 2 byte unsigned integer, 0..65 535

Number of successfully received Class B Beacon Extensions

2 byte unsigned integer, 0 .. 65 535

Number of failed Class B Beacon Extensions

number of beacon extensions that were not received, 2 byte unsigned integer, 0 .. 65 535

Number of successfully received Class B Data Frames

2 byte unsigned integer, 0..65 535

Number of failed Class B Data Frames

number of data frames that were not received, 2 byte unsigned integer, 0 .. 65 535

4.5.2.2.35 DLRX Class C Statistic Query

The DLRX Class C Statistic Query control segment may be sent by the base station to request information on reception parameter statistics in the end-point of the corresponding and previous class C downlink messages. The DLRX Class C Statistic Query control segment shall be formatted according to Table 4-43.

Table 4-43: DLRX Class C Statistic Query

Field length (in bytes)	1
Field content	Control Header (0x56)

4.5.2.2.36 DLRX Class C Statistic Response

The DLRX Class C Statistic Response control segment shall be sent by the end-point after the reception of a DLRX Class C Statistic Query by the base station. The DLRX Class C Statistic Response control segment shall be formatted according to Table 4-44.

Table 4-44: DLRX Statistic Class C Segment Format

Field length (in bytes)	1	1	1	1	1	1	1	2
Field content	Control Header (0x57)	Min EP eqSNR	Avg EP eqSNR	Min EP SNR	Avg EP SNR	Min EP RSSI	Avg EP RSSI	Num of rec messages

The fields shall contain the statistics of the previous Class C downlink messages, which were received since the last DLRX Class C Statistic Query command was issued:

Minimum and average EP eqSNR

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP SNR

1 byte signed integer, 0,25 dB resolution, -32,0..31,75 dB, -32,0 dB representing N/A

Minimum and average EP RSSI

1 byte unsigned integer, 0,5 dBm resolution, -150..-22,5 dBm, -150 dBm representing N/A

Number of successfully received Class C messages

2 byte unsigned integer, 0..65 535

4.5.2.3 End-point Info Field

The end-point info field is used to negotiate TS-UNB protocol settings between end-point and base station. In the attach request control segment, this field shall indicate the end-point capabilities to the base station. In the attach accept control segment the base station shall announce the configuration of the connection to the end-point via end-point info field. The end-point info field shall be formatted according to Table 4-45.

Table 4-45: End-Point Info Field Format

Serialization order	Function	Description	Comment (see note 3)
#0	Channel Use in UL	0: Single channel 1: Dual channel	deprecated
#1	Repetition in UL	Frame repetition (UPG2)	1 = supported or activate
#2	Carrier Offset value in UL	0: $n_{co} = 3$ 1: $n_{co} = 11$	deprecated
#3	DL Interblock Distance	0: short ($\Delta T_{DN} = 512$) 1: long ($\Delta T_{DN} = 7\ 168$) (see note 1)	deprecated
#4	UL-ULP	ULP symbol rate in ULZ	1 = supported or activate
#5	UL-ER	ER symbol rate in ULZ	1 = supported or activate
#6	DL-SB	Single Burst in DL	deprecated
#7	DL-ULP	ULP symbol rate in DLA	1 = supported or activate
#8	UL-HDR	ULP8 symbol rate in ULZ	1 = supported or activate
#9	DL-HDR	ULP2/ULP8 symbol rate in DLA (see note 2)	1 = supported or activate
#10	DLB	ULP symbol rate in DLB	1 = supported or activate
#11	DLC-ULP	ULP symbol rate in DLC	1 = supported or activate
#12	DLC-HDR	ULP8 symbol rate in DLC	1 = supported or activate
#13 to #15	Reserved	Reserved for future use, set to zero	

NOTE 1: ΔT_{DN} is expressed as number of actual symbols.
NOTE 2: The selection between ULP2/ULP8 and of the type of the radio-burst structure (concatenated or HDR) in downlink is done in the network management.
NOTE 3: In this column, "supported" means "function supported by the EP"; "activate" means "BS activates this function".

4.5.3 Link Layer procedures

4.5.3.1 End-point attachment procedure

4.5.3.1.1 Introduction

Before an end-point and a base station exchange data, the end-point shall be attached to the base station. The end-point attachment procedure provides a base station with information about an end-point required for servicing the end-point and provides the end-point with a short address. Bidirectional end-points may initiate an over-the-air attachment procedure. Unidirectional end-points are pre-attached by the service centre associated with the end-point.

During the attach procedure, the end-point shall use configuration parameters as specified in Table 4-46, until it is reconfigured by the base station via end-point info field.

Table 4-46: End-point protocol settings during attach procedure

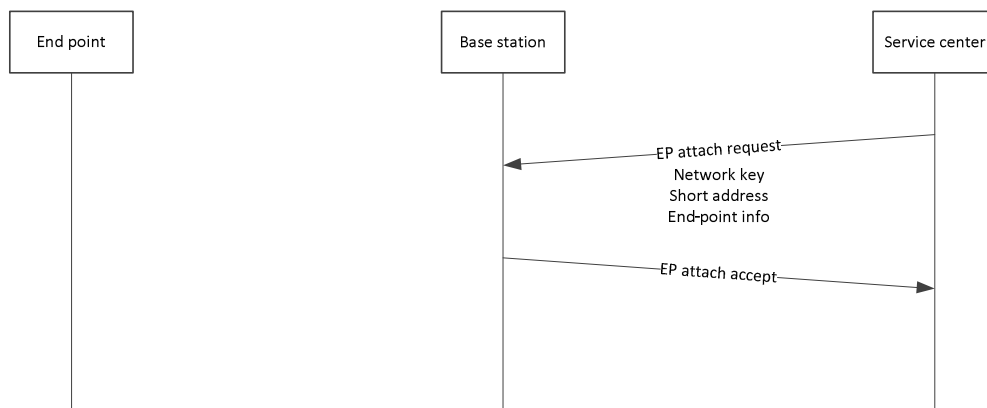
Parameter	Setting
Channel Use	Single channel use
Repetition	Repetition off
carrier offset value	$n_{co} = 3$
DL Interblock Distance	May be short or long
Symbol rate	ULP

4.5.3.1.2 End-point configuration

The end-point capabilities are advertised to the base station during the attachment procedure. The base station can then select the operational mode to be used from the advertised capabilities. For class Z devices the configuration is static, class A devices can negotiate the configuration during an over-the-air attachment procedure.

4.5.3.1.3 Class Z end-point attachment

Class Z devices are unidirectional devices and shall be pre-attached to a LTN System during manufacturing of the device. In the pre-attachment procedure the network key, the short address and the end-point info field shall be programmed in the end-point and stored in the service centre.

**Figure 4-8: Service centre based attachment procedure (Class Z devices)**

The service centre shall provide the base station with the preconfigured network key, short address and end-point info of the end-point (see Figure 4-8).

4.5.3.1.4 Class A end-point attachment

Class A devices may be attached over-the air to allow dynamic configuration by the base station (see Figure 4-9).

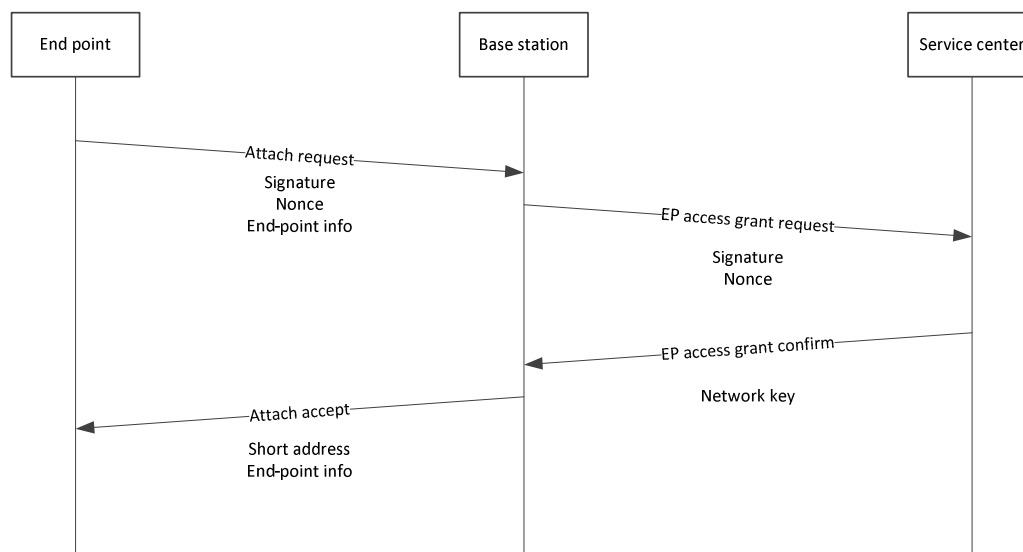


Figure 4-9: Over-the-air attachment procedure for class A devices

The over-the-air attachment procedure shall start with a message from the end-point to the base station containing an attach request control segment according to clause 4.5.2.2.2. The base station shall forward the attach request from the end-point to the service centre allowing the service centre to verify the end-point identity and to generate the network key. After successful verification the service centre shall provide the network key to the base station. The service centre may also provide a short address to the base station. If no short address is provided by the service centre, the base station shall assign a short address to the end-point. The base station shall then send a message containing an attach accept control segment to the end-point using the acquired network key for encryption. Further messages from the end-point may use the reduced addressing mode with the assigned short address and shall be encrypted with the network key.

4.5.3.2 End-point detachment procedure

The over-the-air end-point detachment procedure allows an end-point to detach from a base station in a controlled manner. It allows the base station to remove end-points from the address resolution and to inform the service centre about the end-point detachment (see Figure 4-10).

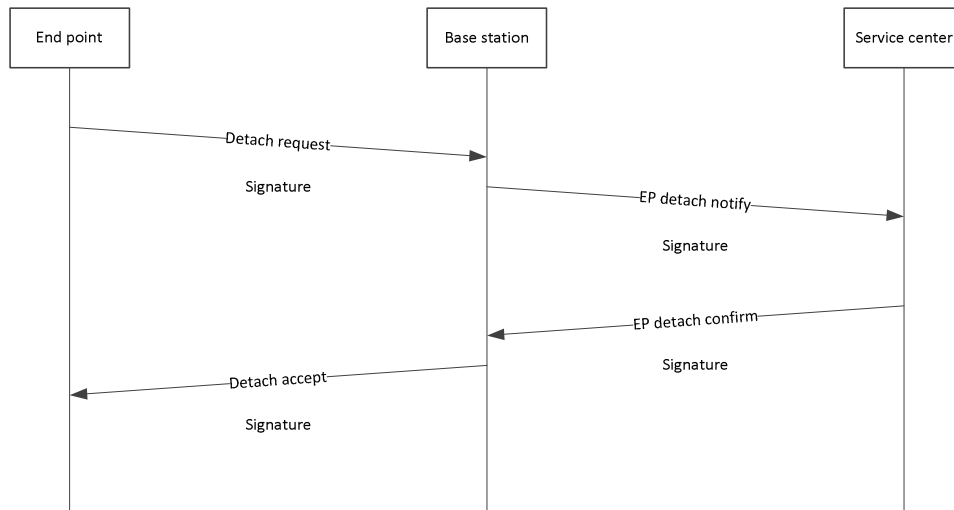


Figure 4-10: Over-the-air detachment procedure for class A devices

The service centre based detachment procedure might be used to detach class Z end-points from a base station (see Figure 4-11).

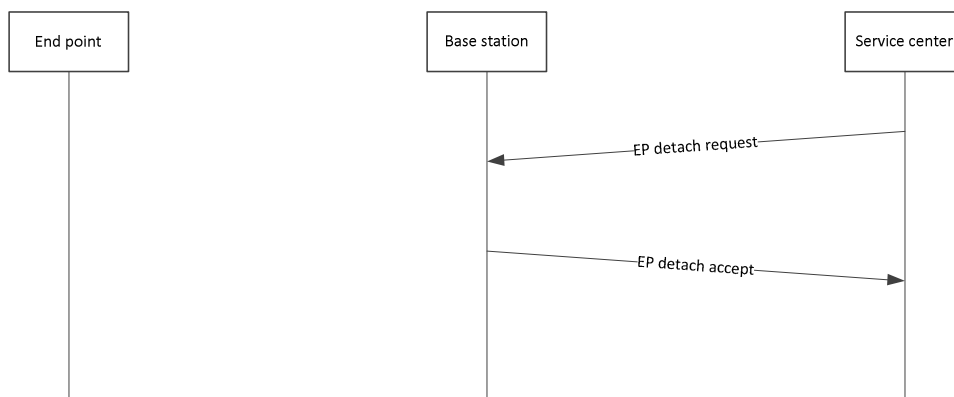


Figure 4-11: Service centre based detachment procedure for class Z devices

4.5.3.3 End-point synchronization procedure

An end-point that is attached to a base station and supports class A and class B may be synchronized to a scheduled downlink transmission (DLB) by the following synchronization procedure (see Figure 4-12).

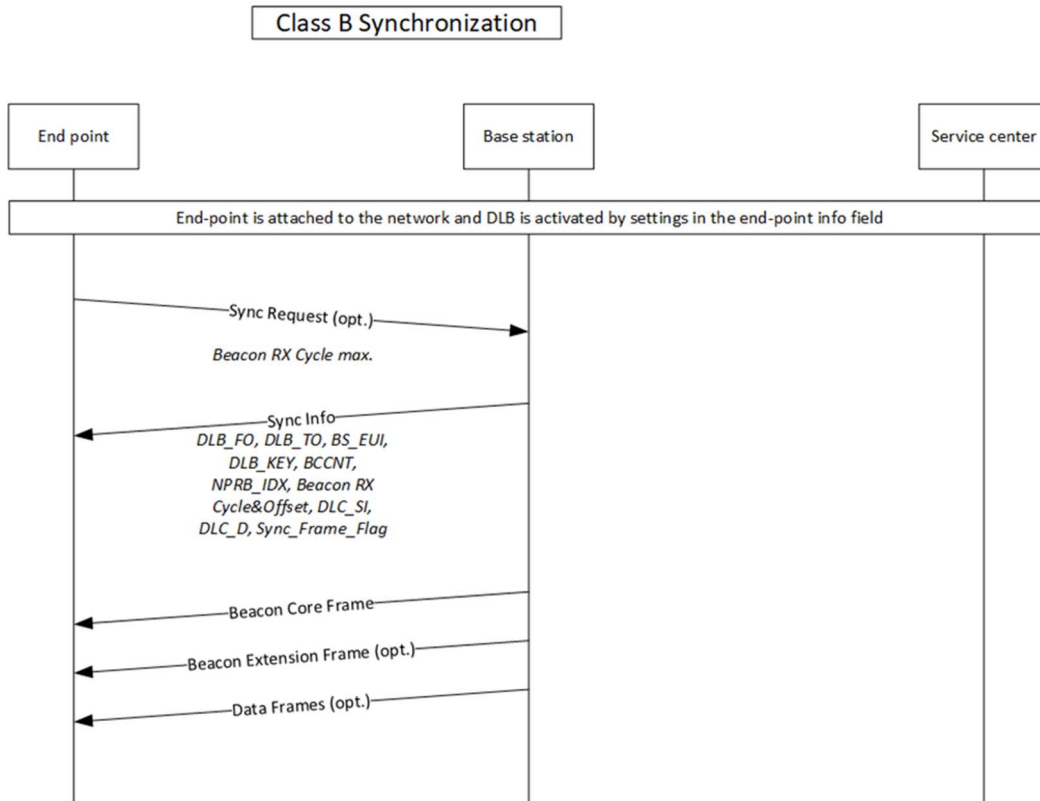


Figure 4-12: End-point synchronization procedure

A sync info control segment shall be sent from the base station in a DLA transmission in response to an optional sync request control segment sent by the end-point in ULZ transmission or unprompted alongside an attachment request or a link adaptation request sent by the base station which enables DLB mode in the end-point info field. With the provided information in the sync info control segment, the end-point is able to calculate and open the receive window for the next beacon core frame.

4.5.3.4 End-point desynchronization procedure

A base station can terminate the class B mode with an end-point by the desynchronization procedure. For a desynchronization the base station shall send a link adaptation request with the DLB_mode bit set to 0. The end-point shall then confirm with a link adaptation confirm control segment. The end-point is then only operating in class A mode anymore. Desynchronization implicitly also takes place if the end-point is detached according to clause 4.5.2.2.5.

An end-point may also request desynchronization by sending a desync request to the base station. The base station shall then respond with a desync accept to accept the desynchronization of the end-point.

4.5.3.5 Assisted resynchronization procedure

If an end-point loses synchronization to the base station, it may transmit a Resync Request control segment (see clause 4.5.2.2.14). The base station shall response with a Resync Info (see clause 4.5.2.2.15) or Sync Info control segment (see clause 4.5.2.2.13) sent in a DLA transmission. The base station may opt for the Sync Info control segment if the Resync Info is assumed to be insufficient for a successful resynchronization.

4.5.3.6 Sync System Adaptation procedure

The Sync System Adaptation procedure is used to change DLB structure parameters during runtime.

Synchronized end-points shall be informed before the DLB structure parameters are changed by sending a Sync System Adaptation Notify control segment in a broadcast message.

If end-points are present with different beacon rx cycles, the Sync System Adaptation Notify control segment shall be transmitted in all beacon cycles, where end-points are listening.

NOTE: End-points, which do not receive the Sync System Adaptation Notify control segment due to interference, being out of range, etc. are out of synchronization, once DLB structure parameters are changed. These end-points can retrieve the DLB structure parameters via the resynchronization procedure.

If a new EP requests Sync Info after the network sent a Sync System Adaptation Notify control message, it shall be provided with the Sync Info of the currently active settings and the future settings with the Sync System Adaptation Notify in the same response.

4.5.3.7 Sync Adaptation procedure

The Sync Adaptation procedure is used to change Beacon RX cycle mode and Beacon RX cycle offset.

The base station shall send a Sync Adapt Request control segment to the end-point.

The end-point shall response with a Sync Adapt Confirm control segment.

The end-point shall be assumed desynchronized until the Sync Adapt Confirm is received by the base station. If the base station does not receive the Sync Adapt Confirm control segment, it may try to resynchronize the end-point by sending Link Adaptation Request control segments in every DLA transmission opportunity, until a confirmation is received.

4.5.3.8 DLB acknowledgement procedure

Class B unicast and multicast transmissions may request an acknowledgement by setting the "response" MAC header flags (see Table 4-51).

The acknowledgement for a Class B unicast or multicast shall be done via an uplink transmission comprising the DLB Data Ack control segment.

NOTE: For multicasts, the number of addressed devices should be controlled to avoid too many simultaneous responses in uplink.

DLB messages, which are broadcast, shall not be acknowledged to avoid network congestion with a large number of uplink acknowledgement transmissions.

4.5.3.9 DLC acknowledgement procedure

Class C unicast and multicast transmissions may request an acknowledgement by setting the "response" MAC header flags (see Table 4-51).

The acknowledgement for a Class C unicast or multicast shall be done via an uplink transmission comprising the DLC Data Ack control segment.

NOTE: For multicasts, the number of addressed devices should be controlled to avoid too many simultaneous responses in uplink.

DLC messages, which are broadcast, shall not be acknowledged to avoid network congestion with a large number of uplink acknowledgement transmissions.

4.5.3.10 Grouping procedure

In class B, messages can be sent to multiple end-points at the same time (multicast). The end-points to be addressed are put together in a group. A group shall be identified by an EUI64 called group EUI and a network encryption key shall be assigned to the group called group key. An end-point may be assigned to a group by an over-the-air assignment using the link layer commands or by pre-assignment during production or installation of the end-point.

During the over-the-air assignment, an end-point is assigned to a group by sending a Group Assign Request from the base station to the end-point. The end-point shall then respond with a Group Assign Confirm. The end-point shall then receive future multicast transmissions addressed to the assigned group in addition to unicast transmission addressed to the individual end-point. The short address used for addressing the group shall be the 2 LSB of the group EUI, the multicast transmissions shall be encrypted with the group key.

For removing an end-point from a group a Group Dismiss Request command shall be sent from the base station to the end-point and responded by the end-point with a Group Dismiss Confirm control segment. The end-point shall then no longer receive future multicast messages addressed to the dismissed group. The end-point shall be removed from the group after reception of the Group Dismiss Confirm command by the base station.

4.5.3.11 Simple end-point handover procedure

A simple handover procedure shall be initiated by a Sync Request Trigger control segment, sent by the base station. The end-point shall respond with a Sync Request control segment, which will be confirmed with a Sync Info control segment, sent by the new base station (see Figure 4-13).

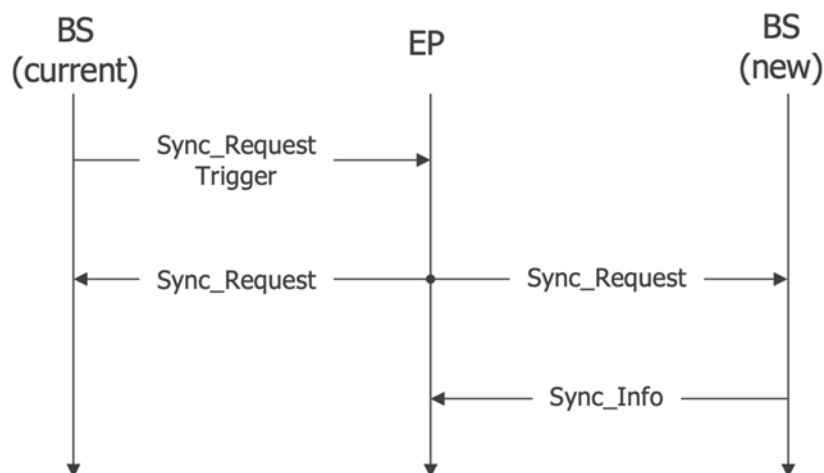


Figure 4-13: Simple handover procedure

4.5.3.12 Fragmentation procedure

The fragmentation procedure may be used to transmit application data that exceeds the maximum available MAC payload size in uplink or downlink. The application data size is indicated by the Application Data Size Indicator (ADSI). If fragmentation is used the fragmentation procedure shall cut the transmission data stream into fragments of a smaller size, that fits into the MAC payload of the transmitter. The transmitter may be an end-point in uplink or a base station in downlink. Each transmission of a fragment shall be accompanied by a fragment info control segment according to clause 4.5.2.2.28.

The transmission data stream may be the uncoded application data or coded application data with additional redundant information to retrieve lost fragments at the receiver. The size of the transmission data stream depends on the coding scheme. For uncoded transmission the size of the transmission data stream equals the application data.

The size of the fragment to be transmitted may be of variable length. The transmitter shall indicate the start position of the transmitted fragment within the transmission data stream in the Fragmentation Payload Offset (FPO) field of the Fragment Info segment.

The receiver shall collect the received fragments and combine fragments indicated by the same Fragmentation Session ID value (FS-ID) and the same Fragmentation Session Counter value (FSCNT) indicated in the Fragment Info segment to retrieve the transmission data stream. If applicable, the collected fragments may be decoded according to the coding scheme indicated in the Fragment Info segment to retrieve the application data.

Up to 4 fragmentation procedures (sessions) may be active at the same time between one transmitter and one receiver or one group of receivers. Each time a fragmentation session with Fragmentation Session ID (FS-ID) terminates the FSCNT value shall be incremented.

4.6 MAC Layer

4.6.1 Overview of MAC layer and MAC formats

The MAC layer controls the timing of transmissions and keeps track of transmission windows. Furthermore, it is responsible for address resolution and provides network level cryptography and authentication. Figure 4-14 (resp. Figure 4-15) illustrates the MAC layer exchanges with upper Link layer and lower PHY layer in a base station (resp. an end-point).

The MAC layer implements two main types of formats:

- the Fixed-MAC mode format used in uplink (see clause 4.6.2), in downlink (see clause 4.6.3);
- the Variable-MAC mode format (see clause 4.6.4) where MAC layer is transparent.

4.6.2 Fixed-MAC mode formats in UL

4.6.2.1 Overview

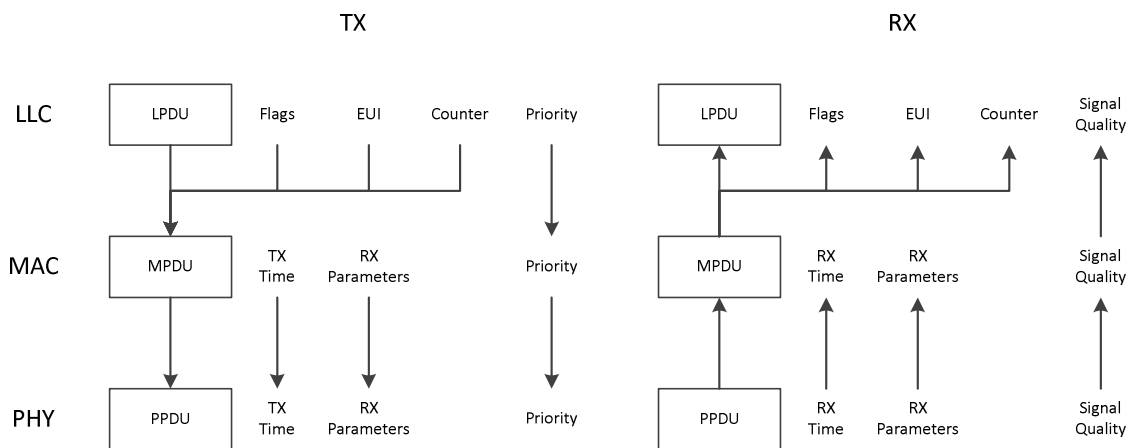


Figure 4-14: MAC layer interfaces with adjacent layers on the Base Station

In RX direction the MAC layer accepts the MPDU and associated meta information from the PHY layer. The meta information comprises the time of reception, signal quality information and a set of RX parameters. After address resolution and decryption of the LPDU, a set of flags, the end-point EUI and the packet counter are extracted from the MPDU and passed on to the link layer. The signal quality information is also forwarded to the link layer.

In TX direction the MAC layer is provided with the LPDU and associated meta information from the Link layer. The LPDU is combined with flags and addressing information and network level encryption is applied to form the MPDU. The MPDU is passed to the PHY layer with the according transmission time and the set of RX parameters of the associated uplink message. Additionally, the message priority is passed through from the link layer to the PHY layer.

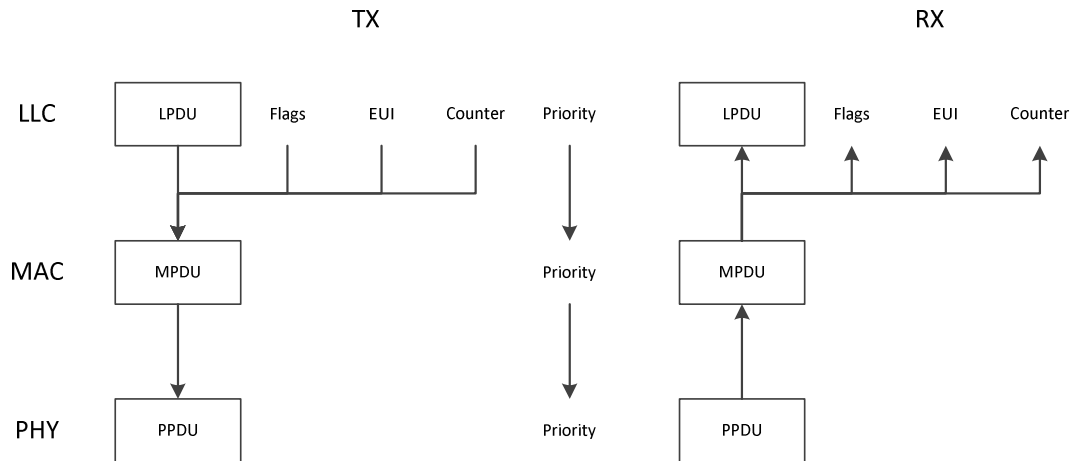


Figure 4-15: MAC Layer interfaces with adjacent layers on the end-point

4.6.2.2 UL-MPDU format description

If the LTN system using the TS-UNB protocol is operated in the fixed MAC mode, the uplink MPDU format according to Table 4-47 shall be used.

Table 4-47: Uplink MPDU Format of fixed MAC mode

Field length (in bytes)	1	2 or 8	3	0 or 1	0 to 245	4
Field content	MAC Header	Address	MPDUCNT	MPF	MAC payload	SIGN

4.6.2.3 MAC Header field in UL

The MAC header shall be a 1-byte wide field signalling different MAC options for the packet. It shall be formatted according to Table 4-48.

Table 4-48: Uplink MAC Header Format

Serialization order	Function	Description
#0	MAC version	0: Initial Version 1: Reserved
#1	MPF flag	0: No MPF field present 1: MPF field present
#2	Control flag	0: no control payload present (data only packet) 1: control payload present
#3	Response flag	0: no response expected 1: response expected
#4	RX Open flag	0: receive window for DL reception not available 1: receive window for DL reception available
#5	Addressing mode	0: short addressing mode, 16-bit short address 1: full addressing mode, 64-bit EUI
#6	Attach flag	0: regular packet 1: attachment packet, also requires addressing mode = 1, control flag = 1, RX open flag = 1 and response flag = 1
#7	ACK	0: no downlink message received since last uplink transmission 1: downlink transmission received

4.6.2.4 Address field in UL

The address field shall either contain a 16-bit short address or EUI64 of the end-point. The addressing mode bit in the MAC header determines which of these options is present in the packet.

4.6.2.5 MPDUCNT field in UL

The MPDUCNT field shall contain a 24-bit counter value according to clause 4.6.5.2. If the attach flag bit in the header is set, the attachment counter according to clause 4.6.5.3 is used instead of the packet counter.

4.6.2.6 MPF field in UL

The MPF field shall be present if the MPF flag of the MAC header is set to one. The MPF field may be used to indicate the format of the MAC Payload. The MPF values shall be used according to Table 4-49.

Table 4-49: MAC Payload Formats

MPF field value	MPF name	Description
0x00	Default	No MAC payload format specified
0x01 to 0x7F	RFU	Reserved for Future Use
0x80	M-Bus	Indicates an M-Bus format as MAC payload format, starting with CI-field (see EN 13757-7 [i.7])
0x81	M-Bus (APL only)	Indicates M-Bus APL data as MAC payload format, starting with a data information block (DIB) (see EN 13757-3 [i.10])
0x82	IO-Link	Indicates an IO-Link application layer format as next layer (see [i.12])
0x83	M-Bus Adaptation Layer (MBAL)	Indicates an M-Bus format as next layer, using adaptation Layer, starting with MBAL (see EN 13757-8 [i.13])
0x84 to 0x9F	Reserved	Reserved
0xA0 to 0xBF	Reserved	Mioty [®] Alliance MAC payload formats
0xC0 to 0xDF	Reserved	Other technology specific MAC payload formats
0xE0 to 0xFF	Custom	User specific MAC payload formats

NOTE 1: Informative details on some MPF field values are provided in Annex B.

NOTE 2: mioty[®] is a registered trademark of Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., Hansastraße 27c, 80686 München, Germany, used under license by the mioty alliance, Frauenweiherstraße 15, 91058 Erlangen, Germany (<https://mioty-alliance.com>).

4.6.2.7 MAC Payload field in UL

The MAC payload shall contain the encrypted Link Layer Protocol Data Unit (LPDU). It may have a variable size between 1 and 245 bytes. The maximum variable size is reduced accordingly when the full addressing mode and/or MPF field is used or control segments are included in the transmission. If the attach flag bit in the header is set, the Link Layer Data Unit is unencrypted.

4.6.2.8 SIGN field in UL

The SIGN field shall contain a 32-bit Cypher-based Message Authentication Code (CMAC) according to clause 4.6.5.5 cryptographically signing the content of the MAC data unit.

4.6.3 Fixed-MAC mode formats in DL

4.6.3.1 DL_MPDU format description

If the LTN system using the TS-UNB protocol is operated in the fixed MAC mode, the downlink MPDU format according to Table 4-50 shall be used for data transmission.

Table 4-50: Downlink MPDU Format of fixed MAC mode

Field length (in bytes)	1	0 or 1	1 to 250	4
Field content	MAC Header	MPF	MAC payload	SIGN

4.6.3.2 MAC Header field in DL

The MAC Header shall be a 1-byte field signalling different MAC options for the packet. The MAC Header in downlink direction supports a subset of the uplink MAC Header flags. The MAC Header shall be formatted according to Table 4-51.

Table 4-51: Downlink MAC Header Format

Serialization order	Function	Description
#0	MAC version	0: Initial Version 1: Reserved
#1	MPF Flag	0: No MPF field present 1: MPF field present
#2	Control flag	0: no control payload present (data only packet) 1: control payload present
#3	Response flag	0: no response expected 1: response expected
#4	RX Open flag	0: no further EP receive window required 1: Request to EP for further DL receive window after next uplink
#5	Response Priority flag	0: EP response expected within regular time window 1: EP response expected within priority time window
#6 to #7	Reserved	Reserved, shall be set to 0

4.6.3.3 MPF field in DL

The MPF field shall be present if the MPF Flag of the MAC header is set to 1. The MPF field may be used to indicate the format of the MAC Payload according to Table 4-49 in clause 4.6.2.6.

4.6.3.4 MAC Payload field in DL

The MAC Payload shall contain the encrypted Link Layer Protocol Data Unit (LPDU). It shall have a variable size between 1 and 250 bytes. The maximum size is reduced accordingly when control segments are included in the packet.

4.6.3.5 SIGN field in DL

The SIGN field shall contain a 32-bit Cypher-based Message Authentication Code (CMAC) according to clause 4.6.6.6 cryptographically signing the content of the MAC data unit.

4.6.3.6 DLB mode MPDU formats

4.6.3.6.1 Introduction

At MAC level, the DLB transmission mode implements five types of PDUs:

- A Sync frame format for standalone resynchronization.
- A beacon core frame format in case of single-stage pre-addressing.
- A beacon core frame format in case of two-stage pre-addressing.
- A beacon extension frame format.

- A DLB_Data frame format.

4.6.3.6.2 Sync Frame MPDU format

The sync frame MPDU shall contain three fields, as detailed in Table 4-52.

Table 4-52: Sync Frame MPDU format

Field length (in bits)	16	24	8
Field content	BS-EUI [48-63]	BCCNT [0-23]	Sync CMAC

BS-EUI [48-63]

16 least significant bit of Base station EUI

BCCNT [0-23]

24 most significant bits of Beacon Counter value

Sync CMAC

8-bit CMAC for transmission error detection and authentication (see clause 4.6.6.6.4)

4.6.3.6.3 Single-stage Beacon Core MPDU format

This beacon core MPDU format shall be used for signalling the transmission of one DLB_Data frame, in single-stage pre-addressing (i.e. with no beacon extension frame). It shall be formatted as in Table 4-53.

Table 4-53: Single-stage beacon core MPDU format

Field length (in bits)	24	2
Field content	Pre-addressing Info	S (0b00)

Pre-addressing Info

a 24-bit field describing type, size and destination short address of the DLB_Data MPDU. The pre-addressing info shall be formatted as in Table 4-62.

S

2-bit field set to 0b00 (single-stage pre-addressing)

4.6.3.6.4 Two-stage Beacon Core MPDU format

This beacon core MPDU format shall be used for signalling the transmission of DLB_Data frames, with two-stage pre-addressing (i.e. with beacon extensions). It shall be formatted according to Table 4-54.

Table 4-54: Two-stage beacon core MPDU format

Field length (in bits)	2	5	1	16	2
Field content	BE_N	Reserved	IA	Mask	S (0b01)

BE_N

a 2-bit field coding the number of Beacon Extension frames (BE_N) in the DLB frame (0b00 = 1, 0b01 = 2, 0b10 = 3, 0b11 = 4)

Reserved

Set to 0

IA

A flag set to 1 in case of implicit addressing (see clause 4.6.6.2.3)

Mask

A 16-bit field indicating the short address ranges used by the DLB_Data frames. Mask shall be coded according to Table 4-55

S

2-bit field set to 0b01 (two-stage pre-addressing)

Table 4-55: Mask for short address ranges in use

Serialization order	Short address range
0	0xF000 - 0xFFFF
1	0xE000 - 0xEFFF
2	0xD000 - 0xDFFF
3	0xC000 - 0xCFFF
4	0xB000 - 0xBFFF
5	0xA000 - 0xAFFF
6	0x9000 - 0x9FFF
7	0x8000 - 0x8FFF
8	0x7000 - 0x7FFF
9	0x6000 - 0x6FFF
10	0x5000 - 0x5FFF
11	0x4000 - 0x4FFF
12	0x3000 - 0x3FFF
13	0x2000 - 0x2FFF
14	0x1000 - 0x1FFF
15	0x0000 - 0x0FFF

4.6.3.6.5 Beacon Extension MPDU format

The Beacon Extension MPDU shall consist of eight fields. Each field shall contain, in order, the pre-addressing info for the eight DLB_Data frames, that may follow a Beacon Extension frame. Figure 4-16 illustrates the BE_MPDU format.

A pre-addressing info in a BE_MPDU shall be formatted according to Table 4-62.

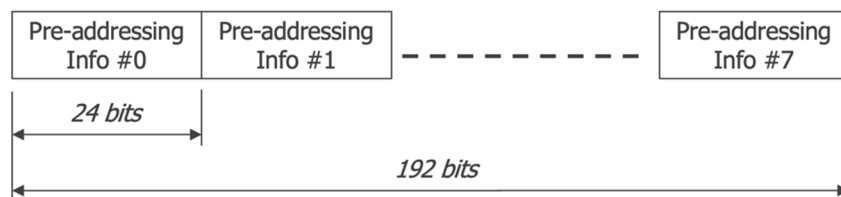


Figure 4-16: BE_MPDU format

4.6.3.6.6 DLB_Data frame MPDU format

The format of a DLB_Data frame MPDU shall be equivalent to the format of a DL_MPDU, in fixed MAC mode (see clause 4.6.3.1), but a different encryption and authentication procedures shall be used (see clauses 4.6.6.5.2 and 4.6.6.6.2).

4.6.3.7 DLC mode MPDU formats

4.6.3.7.1 DLC frame MPDU format

The format of a DLC frame MPDU shall be equivalent to the format of a DL_MPDU, in fixed MAC mode (see clause 4.6.3.1), but a different encryption and authentication procedures shall be used (see clauses 4.6.6.5.3 and 4.6.6.6.3).

4.6.4 Variable MAC mode formats

4.6.4.1 Overview

A LTN system using TS-UNB protocol can run user specific MAC/LINK layer, when operated in the variable MAC mode. If a LTN system using TS-UNB protocol is operated in variable MAC mode, the MMODE field in the PHY layer shall be set according to clause 4.7.1.2.6.

4.6.4.2 MPDU format in variable MAC mode

In the variable MAC mode, the MPDU format in uplink and downlink shall be formatted according to Table 4-56.

Table 4-56: Uplink and downlink MPDU Format of variable MAC mode

Field length (in bytes)	1	1 to 254
Field content	MAC-TYPE	U-MPDU (Variable MAC according to MAC-TYPE)

A custom specific MAC Payload field U-MPDU shall be preceded by a MAC-TYPE field indicating the MAC/LINK layer used in the variable MAC Mode. Table 4-57 lists possible MAC-TYPES.

Table 4-57: List of MAC-TYPES

MAC-TYPE field value	MAC-TYPE name	Description
0x00 (see note)	WMBUS	MAC/LINK Layer optimized for metering applications according to clause 4.6.4.3
0x01	MBUS FFB	Introducing a wireless M-Bus frame with Frame Format B (FFB), according to [i.14], clause 12.4
0x02	MBUS MAC	Introducing a M-Bus frame that starts with a wireless M-Bus MAC according to OMS-S Volume 2, Annex Q (see [i.15])
0x03 to 0x09	mioty	Mioty® Alliance MAC/LINK layers
0x30 to 0x3F	Custom	User specific MAC/LINK layer
Others	Reserved	Reserved

NOTE: This value is deprecated and shall not be used for future development.

4.6.4.3 Details on Variable MAC-TYPE 0x00 (WMBUS)

4.6.4.3.1 Overview

If the variable MAC mode with MAC-TYPE WMBUS is used, the same MAC/LINK layer as for the fixed MAC mode described in clause 4.6 shall be used with adaptations according to the following clauses.

As variable MAC-TYPE 0x00 is deprecated; it should not be used in new design.

4.6.4.3.2 MAC format in uplink (WMBUS)

The uplink U-MPDU format shall be formatted according to Table 4-58.

Table 4-58: Uplink U-MPDU Format of variable MAC with MAC-TYPE WMBUS

Field length (in bytes)	1	8	3	1	0 or 1	1 to 238	4
Field content	MAC Header	WMBUS Address	MPDUCNT	CI	MPF	MAC Payload	SIGN

An 8-Byte WMBUS Addressing shall be used instead of EUI64 as shown in Table 4-59.

Table 4-59: WMBUS Address format

Field length (in bytes)	2	4	1	1
Field content	Manufacturer	Identification number	Version	Device type
NOTE: All multi byte fields are most significant byte first in contradiction to "normal M-Bus usage".				

An additional Control Information (CI) field shall be used according to EN 13757-7 [i.7]. The CI field declares the structure of the upper layers for metering applications. All other fields of the MPDU shall be the same as in clause 4.6.2.1.

4.6.4.3.3 MAC format in downlink (WMBUS)

The same U-MPDU format as in fixed MAC mode downlink MPDU shall be used.

4.6.4.3.4 MAC functions (WMBUS)

The MAC functions according to clauses 4.6.4 and 4.6.6 shall be used.

4.6.4.3.5 MAC procedures (WMBUS)

The MAC procedures according to clause 4.6.8 shall be used.

4.6.5 Fixed-MAC functions in UL

4.6.5.1 Addressing function in UL

Every end-point shall uniquely be identified by a lifetime assigned IEEE EUI64 [6]. Additionally, an end-point may be associated with a 16-bit, non-unique, short address via the attachment procedure, as described in clause 4.5.3.1.

Packets using the full addressing mode shall explicitly include the EUI64 of the corresponding end-point. No further address resolution is required in this case.

The reduced addressing mode shall be based on 16-bit explicit addressing using the short address assigned by the base station and 32-bit implicit addressing via the CMAC. Hence packets using the reduced addressing mode require the end-point identity to be derived from the included short address and the cryptographic signature contained in the CMAC.

4.6.5.2 Packet Counter function in UL

A 32-bit packet counter shall be used to track the number of transmitted uplink packets in the end-point and the base station. The packet counter shall be formatted as specified in Table 4-60.

Table 4-60: Packet Counter Format

Field length (in bytes)	8	24
Field Name	Extended Counter	MPDUCNT
Comment	8 most significant bits Used, with the remaining 24 bits, in encryption function (see clause 4.6.7)	24 least significant bits Transmitted in uplink packets (see clause 4.6.2.1)
NOTE: Packet Counter is concatenation of Extended Counter and MPDUCNT.		

Uplink packets, except attachment packets, shall contain the 24 least significant bits of the packet counter in the MPDUCNT field. The packet counter shall only be reset when a new network key is generated during the attachment procedure and shall be incremented after each packet transmission.

4.6.5.3 Attachment Counter function in UL

A 24-bit attachment counter shall be used in the end-point and service centre to count the number of attachment procedures initiated by the end-point. The attach counter shall be incremented after each attach request message by the end-point. The MPDUCNT field of the MPDU shall be filled with the attach counter in attach request packets. The packet counter shall implicitly be defined as 0 for attach request packets.

4.6.5.4 MAC Payload encryption function in UL

The MAC payload and the optional MPF field in uplink shall be encrypted according to clause 4.6.7.1.

4.6.5.5 Authentication function in UL

Uplink MPDU is authenticated with a 32-bit SIGN field. The SIGN field shall be the four most significant bytes of the result of a CMAC algorithm (see clause 4.6.7.2).

The CMAC algorithm shall be generated over the following fields (see Table 4-61): CMAC Initialization Vector (CIV), MAC Header, Address, MPDUCNT, the optional MPF field (if available) and the MAC payload after encrypting the MAC payload (i.e. encrypt then MAC).

Table 4-61: Input Data of CMAC generation in uplink (SIGN field)

Field length (in bytes)	16	1	2 or 8	3	0 or 1	0 to 245
Field content	CIV	MAC Header	Address	MDPUCNT	MPF	MAC Payload

The CMAC initialization vector according to Table 4-68 shall be used with the block counter set to a fixed value of 0xFFFF.

4.6.6 Fixed-MAC functions in DL

4.6.6.1 Addressing function in a DLA transmission

In DLA mode, addressing is done implicitly via the time of transmission and the CMAC included in the SYNC field of the downlink core frame. The end-point shall only accept transmissions at the defined time offset ΔT_{ud} after the previous uplink transmission, as described in clause 4.6.8.1. The comparison of the contained CMAC against the expected CMAC of the end-point rejects packets for other end-points accidentally transmitted simultaneously. Before transmission, the base station shall ensure that a CMAC in a downlink transmission is not considered valid by any other end-points than the intended one with simultaneously opened downlink windows.

4.6.6.2 Addressing function in a DLB transmission

4.6.6.2.1 Pre-addressing Info for DLB_Data frame

In a DLB transmission, addressing is done via pre-addressing info, inserted either in the beacon core frame as single-stage addressing (see clause 4.6.3.6.3) or in the beacon extension frame(s) (see clause 4.6.3.6.5) with a preceding beacon core frame containing information about beacon extension frame(s) (see clause 4.6.3.6.4) as two-stage addressing. The pre-addressing info shall be formatted according to Table 4-62.

Table 4-62: Pre-addressing info format

Field length (in bits)	Fields			Usage
	8	16		
Field content	PSI	Address		
Field length (in bits)	8	8	8	Pre-addressing info for broadcast DLB_Data Frame
Field content	set to 0	PSI	Reserved (set to 0)	
Field length (in bits)	8	8	8	Null Pre-addressing info (see note)
Field content	set to 0	set to 0	Reserved (set to 0)	
NOTE: Putting 0 in the PSI field is equivalent to broadcasting a zero-size message.				

PSI

size of the DLB_Data MPDU. This field shall be an 8-bit unsigned integer, strictly greater than zero

Address

destination short address of the DLB_Data MPDU, in case of unicast or multicast (i.e. non-broadcast).

Null pre-addressing info shall be used, as follows:

- in single-stage BC_MPDU, to indicate a DLB frame with no data;
- in BE_MDPDU, to indicate unused pre-addressing info positions.

4.6.6.2.2 Complete addressing for DLB_Data frames

The complete addressing shall use 32-bit implicit addressing via the CMAC. Hence DLB packets require the end-point identity to be derived from the short address in the beacon core or beacon extension pre-addressing info and the cryptographic signature contained in the CMAC of the DLB_Data frame MPDU.

4.6.6.2.3 Implicit addressing for DLB_Data frames

In a DLB frame with two or more beacon extension frames (i.e. two or more data regions), the implicit addressing may be used to distribute DLB_Data frames between data regions.

When IA flag is set (i.e. IA=1), DLB_Data frame shall be transmitted in the data region which number is, as follows:

$$Number_{DataRegion} = short\ address \bmod (BE_N + 1)$$

Figure 4-17 illustrates implicit addressing in case of three data regions.

When IA flag is reset (i.e. IA=0), DLB_Data frames may be transmitted in any data region, irrespective of their address.

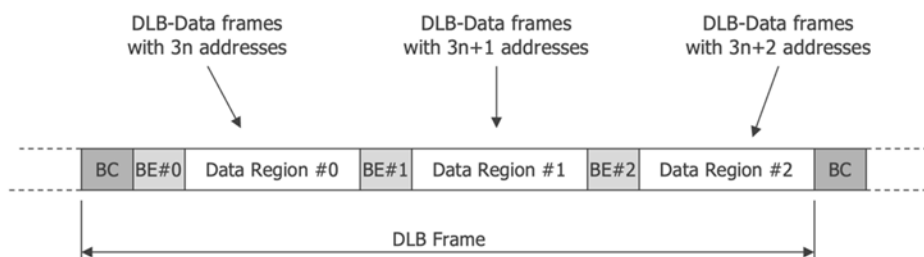


Figure 4-17: Example of implicit address with three data regions

4.6.6.3 Addressing function in a DLC transmission

In a DLC transmission, pre-addressing is done via the MAC Pre-Addressing Info Field (MPAI) inserted before the MPDU. The MPAI field shall be formatted according to Table 4-62 (pre-addressing in DLB).

The complete addressing shall use 32-bit implicit addressing via the CMAC. Hence DLC packets require the end-point identity to be derived from the included short address in the pre-addressing info and the cryptographic signature contained in the CMAC of the DLC_frame MPDU.

4.6.6.4 Packet Counter function in DLA

The packet counter of the associated uplink shall be implicitly used as packet counter in the downlink transmission. If the associated uplink uses the attach format and therefore includes the attach counter instead of the packet counter, the packet counter for encryption and signature generation shall be implicitly defined as 0.

4.6.6.5 MAC payload encryption function in DL

4.6.6.5.1 MAC Payload encryption function in DLA

The MAC payload and the optional MPF field in class A downlink shall be encrypted according to clause 4.6.7.1. The network key shall be used as cryptographic key for the generation of the encryption Initialization vector.

4.6.6.5.2 MAC payload encryption function in DLB

The MAC payload and the optional MPF field in class B downlink shall be encrypted according to clause 4.6.7.1.

The beacon counter BCCNT shall be used as encryption counter.

For a data frame, the frame counter shall be the potential data frame number within the DLB frame, considering the 8 possible data packets in all the data region in a DLB frame are used.

NOTE: As an example, the values 0 to 7 are used for the first data region, 8 to 15 for the second data region, etc.

The beacon core frame shall use frame counter value of 0, the beacon extension frame shall use increasing frame counters from 1 upwards in order of transmission.

Unicast DLB_Data frames shall be encrypted with a network sync session key specific to a given end-point in the system. This network sync session key shall be generated, as follows:

- Upon synchronization of the end-point to the base station, the seed vector shall be as in Table 4-63.
- Then, the seed vector is processed as one block in a first AES128 ECB step using the network session key.
- The resulting ciphertext is then processed in a second AES128 ECB step using the system key to get the network sync session key.

Table 4-63: Seed vector format for network sync session key generation

Field length (in bytes)	8	8
Field content	EP_EUI	BS_EUI

Broadcast DLB_Data frames shall be encrypted with the system key instead of the device specific network sync session key. The Crypto_Flags are ensuring different initialization vectors for the beacon frames and broadcast data frames.

Multicast DLB_Data frames shall be encrypted with the specific group key as provided in the group assignment procedure.

4.6.6.5.3 MAC payload encryption function in DLC

The MAC payload and the optional MPF field in class C downlink shall be encrypted according to clause 4.6.7.1.

4.6.6.5.4 MPAI encryption function in DLC

The MPAI field of the DLC core frame shall be encrypted separately according to clause 4.6.7.1. For the encryption the data direction flag, DL mode flag, DLC mode flag and beacon flag are set in the initialization vector and the system key is used.

The beacon counter BCCNT shall be used as encryption counter.

Block counter shall consist of a 12-bit crypto resource element counter and 4-bit crypto block counter for DLC transmission. The crypto resource element counter shall consist of the 12 most significant bits of the resource element index within a beacon period where the class C transmissions starts. It shall be incremented for every second resource element.

The crypto block counter value shall be 0.

4.6.6.6 Authentication function in DL

4.6.6.6.1 Authentication function in DLA

Downlink MPDU is authenticated with a 32-bit SIGN field. The SIGN field shall be the four most significant bytes of the result of a CMAC algorithm (see clause 4.6.7.2).

The CMAC algorithm shall be generated over the following fields (see Table 4-64): CMAC Initialization Vector (CIV), MAC Header, the optional MPF field (if available), and the MAC payload after encrypting the MAC payload (encrypt then MAC).

Table 4-64: Input Data for CMAC Generation in downlink (SIGN field)

Field length (in bytes)	16	1	0 or 1	1 to 250
Field content	CIV	MAC Header	MPF	MAC Payload

4.6.6.6.2 Authentication function in DLB

MPDU in DLB transmission is authenticated with a 32-bit SIGN field. The SIGN field shall be the four most significant bytes of the result of a CMAC algorithm (see clause 4.6.7.2).

The CMAC algorithm shall be generated over the same fields as in DLA (see Table 4-64). The CMAC initialization vector according to Table 4-68 shall be used. For CMAC generation, the frame counter is set to the data frame number, the signature is computed for. The remaining 8 bits of the block counter in the initialization vector shall be set to 0xFF.

For unicast messages the network sync session key shall be used for CMAC generation. For multicast messages the group key shall be used and for broadcast messages the system key shall be used for CMAC generation.

4.6.6.6.3 Authentication function in DLC

MPDU in DLC transmission is authenticated with a 32-bit SIGN field. The SIGN field shall be the four most significant bytes of the result of a CMAC algorithm (see clause 4.6.7.2).

The CMAC algorithm shall be generated over the same fields as in DLA (see Table 4-64). The CMAC initialization vector according to Table 4-68 shall be used. For CMAC generation, the 12-bit crypto resource element counter of the block counter shall be set to the resource element index within the beacon period where the DLC frame starts. The remaining 4 bits of the block counter in the initialization vector shall be set to 0xFF.

For unicast messages the network sync session key shall be used for CMAC generation. For multicast messages the group key shall be used and for broadcast messages the system key shall be used for CMAC generation.

4.6.6.6.4 Authentication function for Sync Frame

The sync frame MPDU (see clause 4.6.3.6.2) contains a CMAC to authenticate the class B parameters of the beacon which the sync frame belongs to. In this case, the authentication function shall use a CMAC computation based on the initialization vector as specified in Table 4-65 and the system key.

The MSB of the CMAC result shall be copied in the sync authentication.

Table 4-65: Sync assist authentication initialization vector

Field length (in bytes)	8	4	4
Field content	BS_EUI	BCCNT	0x00000000

4.6.7 Common Fixed-MAC functions

4.6.7.1 Network level encryption function

The MAC layer handles the network level encryption of the MAC payload. The network level encryption shall be used for all packets, except for the Attach_Request packet and the Attach_Request_IPv6 packet. Network level cryptography shall be based on the 128-bit network key provided through the attachment procedure described in clause 4.5.3.1 and the AES128 algorithm in counter mode of operation [2] and [i.15].

The Encryption Initialization Vector (EIV) for each block shall be formatted as described in Table 4-66.

Table 4-66: Encryption Initialization Vector (EIV) format

Field length (in bytes)	8	1	1	4	2
Field content	EUI64	0x00	Encryption Flags	Encryption counter	Block counter

Where:

EUI64

Unique 64-bit identifier as an identifier of an end-point (unicast), or a group of end-points (multicast). In the case of beacon/broadcast (resp. group transmissions), the end-point EUI in the initialization vector shall be substituted with the base station EUI (resp. the group EUI)

Encryption_Flags

A set of flags, coded according to Table 4-67

Encryption Counter

Counter value individual for each packet:

- packet counter shall be used as encryption counter for ULZ and DLA transmission;
- BCCNT value of the DLB frame in which the packet is transmitted shall be used as encryption counter for DLB transmissions.

Block Counter

Counter value individual for each block in the AES encryption and each frame of a downlink transmission:

- Block counter shall consist of a 16-bit crypto block counter for ULZ and DLA transmission.
- Block counter shall consist of a 8-bit frame counter (MSB) and 8-bit Crypto block counter (LSB) for DLB transmission.
- Block counter shall consist of a 12-bit crypto resource element counter and 4-bit crypto block counter for DLC transmission.

The crypto block counter shall be reset to 0 at the beginning of every packet, and shall be incremented for every consecutive 16-byte AES128 block within the packet.

Each initialization vector shall only be used once to ensure the security of the encrypted data. Thus, the extended counter value of the packet counter increases the usable initialization vector range before a new network key is required due to a counter wrap. The extended counter needs to be synchronized between base station and end-point. If no extended counter is tracked the extended counter field shall be set to 0. The 24-bit packet counter grants a resynchronization window of 16 777 216 packets. Within this window the extended counter shall be implicitly resynchronized at reception. If the number of consecutively lost packets exceeds the window length, the synchronization between end-point and base station shall be recovered. Recovery should be achieved via probing a range of extended counters against the packet authentication. In the case of bidirectional end-points a reattachment, resetting the packet counter and extended counter, also recovers synchronization.

The encryption flags field contains several flags for payload encryption, which differ for different uplink and downlink modes.

Table 4-67: Encryption Flags format

Serialization order	Function	Description
#0 to #3	RFU	Set to 0
#4	DLC mode flag	0: non DLC 1: DLC
#5	Beacon flag	0: data frame 1: beacon frame
#6	DL mode flag	0: DLA 1: DLB/DLC
#7	Data direction flag	0: uplink 1: downlink
NOTE 1: DLA, DLB and DLC frames shall be encrypted with the Data direction flag set to one in their respective initialization vectors.		
NOTE 2: DLB Data frames, beacon frames, and beacon extension frames shall be encrypted with the DL mode flag set to one (i.e. DLB mode) in their respective initialization vector.		
NOTE 3: Beacon frames and beacon extension frames shall be encrypted with the Beacon flag set to one in their respective initialization vector.		
NOTE 4: DLC frames shall be encrypted with the DL mode flag and the DLC mode flag set to one in their respective initialization vector.		

The Encryption Initialization Vector (EIV) shall be AES encrypted with the corresponding cryptographic key. The encrypted initialization vector IV^* shall be truncated to the payload length if the remaining block is shorter than 16 bytes. The payload plaintext block P shall be combined with the encrypted and truncated initialization vector via an exclusive or operation to create the payload cipher text C .

$$IV^* = AES128(EIV)$$

$$C = IV^* \oplus P$$

The procedure shall be repeated after incrementing the block counter within the initialization vector until the entire MAC payload has been processed.

4.6.7.2 CMAC generation function

A Cypher-based Message Authentication Code (CMAC) [3] and [i.6] shall be used to verify the integrity and authenticity of an uplink or downlink packet. AES128 shall be employed as the block cipher algorithm required within the CMAC procedure. The network key provided through the attachment procedure (see clause 4.5.3.1) shall be used as the cryptographic key for the AES128 algorithm to authenticate messages in ULZ and DLA transmission. If the attachment flag is set in the MAC header, the cryptographic key shall be substituted with all zeros. The function of the CMAC is then reduced to verification of the packet integrity. For DLB transmission the cryptographic key shall be selected according to clause 4.6.6.6.2. The CMAC Initialization Vector (CIV) shall be formatted according to Table 4-68.

Table 4-68: CMAC Initialization Vector (CIV) format

Field length (in bytes)	8	1	1	4	2
Field content	EUI64	0x00	Encryption Flags	Encryption counter	Block counter

Where:

EUI64

Unique 64-bit identifier as an identifier of an end-point (unicast), or a group of end-points (multicast). In the case of beacon/broadcast, the end-point EUI in the initialization vector shall be substituted with the base station EUI

Encryption_Flags

A set of flags, coded according to Table 4-67

Encryption Counter

Counter value individual for each packet:

- packet counter shall be used as encryption counter for ULZ and DLA transmission;
- BCCNT value of the DLB frame in which the packet is transmitted shall be used as encryption counter for DLB and DLC transmissions.

Block Counter

Counter value individual for each block in the AES encryption and each frame of a downlink transmission:

- Block counter shall consist of a 16-bit Crypto Block Counter for ULZ and DLA transmission and shall be set to 0xFFFF.
- Block counter shall consist of a 8-bit Frame counter (MSB). The remaining 8 bits (LSB) shall be set to 0xFF for DLB transmission.
- Block counter shall consist of a 12-bit crypto resource element counter (MSB). The remaining 4 bits (LSB) shall be set to 0xF for DLC transmission.

The frame counter value corresponds to the data frame number within the beacon period, the CMAC is computed for. Accordingly the values 0 to 7 shall be used for the first data region, 8 to 15 for the second data region, values 16 to 23 for the third data region and 24 to 31 for the last data region.

After processing the input data with the CMAC generation procedure, the resulting value shall be truncated according to the description in clauses 4.6.5.5, 4.6.6.6, 4.7.2.3, 4.7.2.5 and 4.7.2.8.

Verification by the recipient shall be done by generating the CMAC for the received packet with the expected initialization vector and cryptographic key and comparing it against the CMAC transmitted with the packet.

4.6.8 MAC procedures

4.6.8.1 Introduction to MAC procedure section

The MAC procedures, that are performed between an end-point and a base station, are, as follows:

- EP-triggered downlink transmission (i.e. DLA).
- Uplink message acknowledgement.
- Downlink message acknowledgement.
- EP synchronization to DLB frames of a base station, for DLB and DLC communication.

NOTE: Procedures and timings for downlink transmissions are specified in PHY level section.

4.6.8.2 EP-triggered downlink transmission procedure (DLA)

Downlink data in DLA shall only be transmitted after the reception of an uplink transmission. Hence every downlink transmission needs to be preceded by an uplink transmission of an end-point. After sending an uplink packet to the base station, an end-point may open a downlink window for the reception of a downlink transmission from the base station (see Figure 4-18).

The downlink transmission shall start after a predefined duration ΔT_{ud} after reception of the uplink transmission. This duration is defined as the time between last radio-burst of last transmitted radio frame of the uplink transmission to the first radio-burst of the downlink transmission and is measured from the middle of the pilot sequence of the two radio-bursts. It is expressed as number of symbols, and shall be linked with the uplink TSMA pattern group, as follows:

- for UPG1, UPG2, and UPG6 patterns, ΔT_{ud} shall be 16 384 standard symbols;
- for UPG3 and UPG5 patterns, ΔT_{ud} shall be 2 048 actual symbols;
- for UPG4 pattern, ΔT_{ud} shall be 16 384 actual symbols.

The downlink window shall be announced in the preceding uplink message via the response flag in the MAC Header (see clause 4.6.2.3). The MAC layer shall track the time of arrival for uplink transmissions and schedule the corresponding downlink response to meet the time offset and the corresponding time intervals for DLA, as specified in Table 4-69.

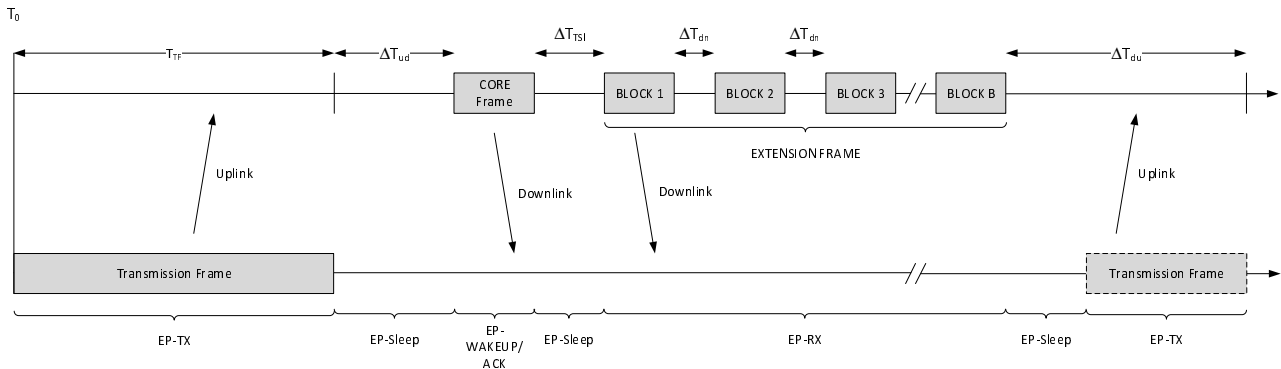


Figure 4-18: Uplink/Downlink Scheduling

Table 4-69: Downlink time intervals for DLA

Parameter	Range of values	Default value	Description
ΔT_{TSI}	84 ... 65 532	512	Time interval between core frame and extension frame, expressed as number of actual symbols
ΔT_{dn}	512 or 7 168	512	Time interval between blocks of extension frame, expressed as number of actual symbols
ΔT_{du}	5 ... 1 024 s	120 s	Maximum time window for a high priority uplink response (Response priority flag = 1), expressed in seconds

The time reference shall be the end-point time starting with the transmission of the first radio-burst at T_0 . The base station estimates the symbol rate offset of the end-point based on the received carrier frequency offset:

$$\Delta f_{sym} \sim \frac{f_{c,RX} - f_{c,expected}}{f_{c,expected}}$$

or based on the timing offset of the received radio-bursts. Based on the estimated symbol rate offset the downlink symbol rate and carrier frequency may be adapted.

If the base station expects an uplink message (e.g. for acknowledgment of downlink) it shall set the response flag in the MAC header (see clause 4.6.3.2) of the downlink transmission. If the base station expects the end-point uplink response within a limited time, it shall set the response priority flag in the MAC header of the downlink transmission.

If an end-point is ready to receive a downlink transmission from the base station, the end-point shall set the RX open flag in the MAC header field (see clause 4.6.2.3). After the predefined time ΔT_{ud} after the UL frame, the end-point shall open its receive window for the reception of a DL frame from the base station.

If a base station needs to transmit further downlink messages to the end-point, it shall set the RX open flag in the MAC header of the downlink transmission to indicate to the end-point that it shall open its receive window after the next uplink transmission.

4.6.8.3 Uplink message acknowledgement procedure

If an end-point requires a downlink response from the base station after its uplink communication, e.g. for acknowledgment of the uplink message, it shall set the response flag in the MAC header field. Due to the limited duty cycle in the base station transmission, the base station may refuse the downlink transmission.

4.6.8.4 Downlink message acknowledgment procedure (in DLA mode)

If a base station expects an acknowledgment of a message transmitted in DLA mode, the base station shall set the response flag of the MAC header field in downlink. The end-point shall then send a separate uplink transmission to acknowledge the reception of the preceding downlink transmission.

NOTE 1: An EP may send a DL message acknowledgment, even if the base station had not set the response flag in its DL transmission.

NOTE 2: If a base station requires a DL message acknowledgment in a shorter time than the regular transmission period of the EP, it can use the response priority flag to indicate the EP to use a short response time (i.e. time window of ΔT_{du}).

4.6.8.5 Synchronization procedures for scheduled downlink transmission mode (DLB)

4.6.8.5.1 Introduction

For scheduled downlink transmission, an end-point is synchronized to a base station to receive data at a point in time and frequency, scheduled by the base station. The base station sends a periodic beacon signal to span a time window in between called beacon period divided into discrete time slots called physical resource blocks. Additional scheduling information (beacon extension) and data are transmitted in blocks consisting of a set of radio-bursts, which are distributed over the physical resource blocks (see Figure 4-19).

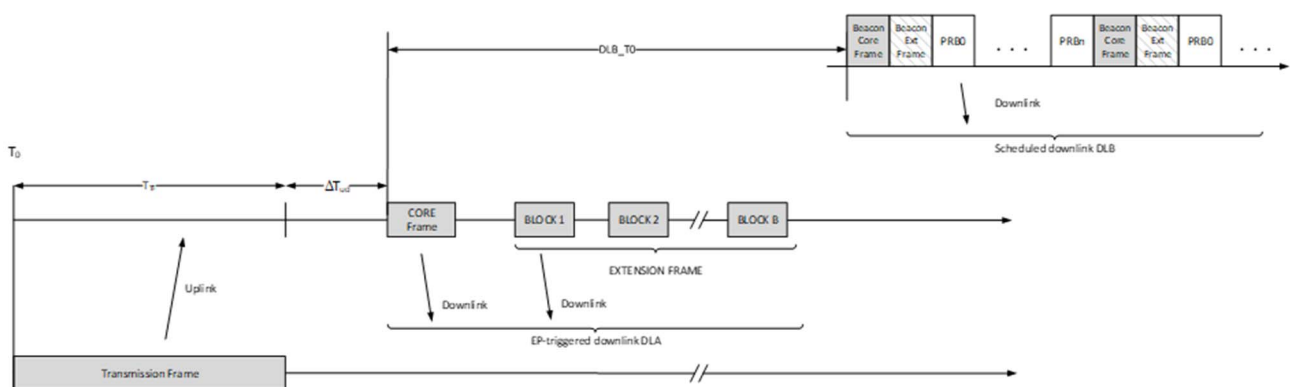


Figure 4-19: Transition from end-point triggered to scheduled downlink transmission

The time and frequency offset to the beacon core frame of the next beacon period is indicated to the end-point via link layer command during synchronization procedure. After reception of the beacon core frame, the end-point keeps synchronization by continuously receiving beacon core frames. Every beacon core frame and optional additional beacon extension frame is carrying scheduling information for which devices or group of devices data is transmitted within the DLB frame.

4.6.8.5.2 Time synchronization to DLB mode

Before switching to DLB mode, an end-point shall receive, via DLA mode from the base station, a Sync Info control segment with time synchronization parameters (see clause 4.5.2.2.13). The base station may send this Sync Info control segment either after an Attach Accept control segment, or in response to a Sync Request control segment sent by the end-point.

The MAC layer of the base station shall provide information to the end-point on the transmission time of the first radio-burst of the beacon core frame in the next beacon period following the Sync Info control segment. This is done by the field DLB_TO of the Sync Info control segment.

The value DLB_TO represents the time offset in 1/32 of a standard symbol duration between the center of the first radio-burst of the core frame of the DLA transmission containing the Sync Info control segment and the grid position related to the first resource element (n=0) of the PRB, which contains the beacon core frame of the next beacon period, as illustrated in Figure 4-20.

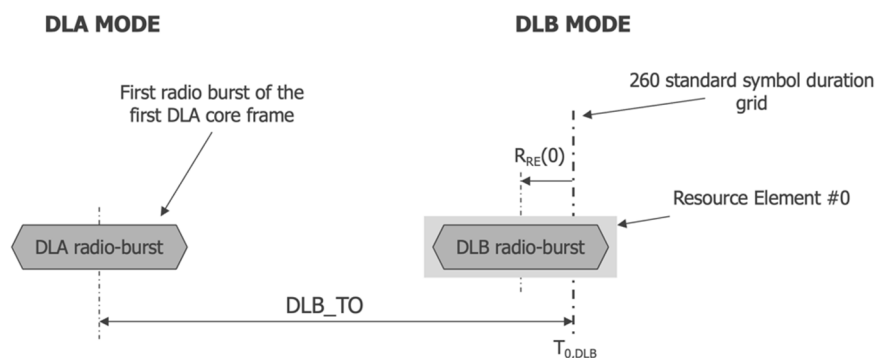


Figure 4-20: Time offset evaluation between DLA and DLB mode grid

NOTE: In this context, the centre of a radio-burst is defined as the midpoint, in the time domain, of the transmit signal associated to data field DATA_A (see clause 4.7.2.13.3).

4.6.8.5.3 Frequency offset correction procedure

The frequency offset correction procedure is used to compensate inaccuracies of local oscillators in base stations and end-points. It is performed before switching to DLB mode and uses signalling from the base station to the end-point.

The frequency offset correction procedure shall be, as follows:

- The EP may send a Sync Request control segment (see clause 4.5.2.2.12) using its local oscillator for radio-burst frequency setting.
- The base station shall measure the actual centre frequencies of the radio-bursts received from the end-point to be synchronized.
- The base station shall compute the average difference between actual and expected radio-burst frequencies in Hz. This value, that shall be rounded to the nearest signed integer number, is named DLB_FO (see clause 4.5.2.2.13). A positive (resp. negative) value means that the local oscillator frequency of the end-point is too high (resp. too low) relative to the base station local oscillator.
- The base station shall send a Sync Info control segment to the end-point
- With the received DLB_FO parameter, the end-point will be able to align its carrier frequency grid to the base station carrier frequency grid.

4.6.8.5.4 Stand-alone Resynchronization procedure

For easier synchronization or for resynchronization after a beacon was not correctly received, an optional sync frame (staircase) may be transmitted by the base station prior to each beacon core frame (see Figure 4-21) with only three radio-bursts distributed over a subset of neighbouring carriers to limit the occupied bandwidth. Whether the sync frame is transmitted, is signalled during the end-point synchronization procedure in the Sync Info control segment. The end-point can use the optional sync frame to synchronize or resynchronize to the base station without exchanging synchronization information.

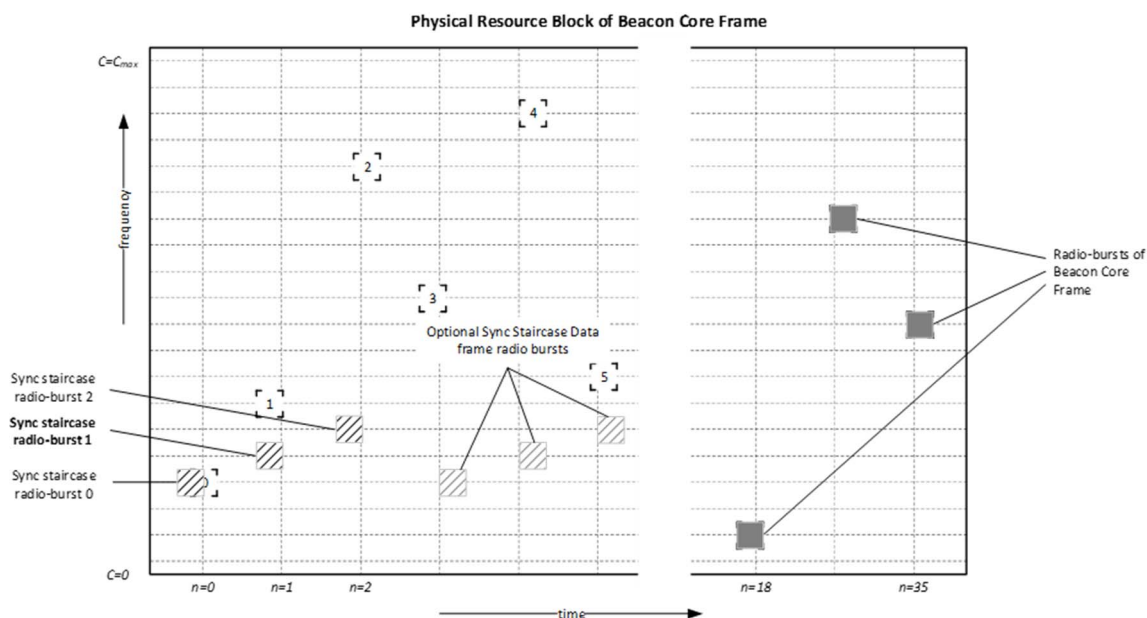


Figure 4-21: Sync frame radio-burst location within the physical resource block of a beacon core frame

4.7 PHY Layer

4.7.1 PHY formats in UL

4.7.1.1 Overview in uplink

In TS-UNB, the transmission of a message is split into several radio-bursts, which are distributed over time and frequency to form a radio frame. Figure 4-22 illustrates the various processing steps that are implemented in the PHY layer of an end-point, in order to get the radio-bursts out of a message MPDU.

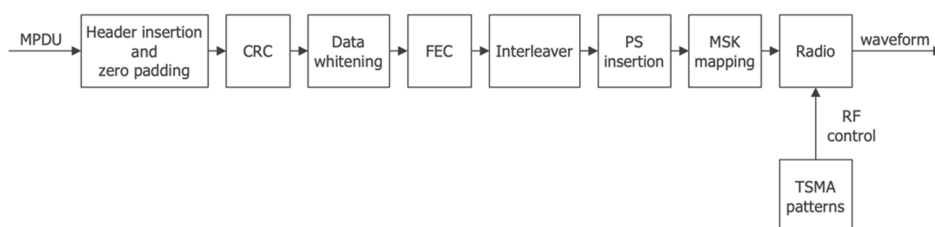


Figure 4-22: Block Diagram of PHY waveform generation in uplink

4.7.1.2 PHY Payload format in UL

4.7.1.2.1 Introduction

The PHY Payload in uplink shall consist of the five fields, as specified in Table 4-70.

Table 4-70: PHY_Payload format in uplink

Field length (in bits)	8	8	8	160 to 2040	2
Field content	Header_CRC	Payload_CRC	PSI	PSDU	MMode
NOTE: The three fields Header_CRC, Payload_CRC, and PSI together form the PHY_Header (PHR).					

4.7.1.2.2 Header_CRC field in UL

The Header_CRC shall be 8 bits and calculated according to clause 4.7.3.4.1.

4.7.1.2.3 Payload CRC field in UL

The Payload CRC shall be 8 bits and calculated according to clause 4.7.3.4.2.

4.7.1.2.4 Packet Size Indicator (PSI) in UL

The Packet Size Indicator (PSI) field shall be 8-bit long and shall indicate the length in bytes of the MPDU (i.e. PSDU length without zero padding). Valid values range from 1 to 255 bytes.

4.7.1.2.5 PHY Service Data Unit (PSDU) in UL

The physical layer service data unit (PSDU) may hold a variable length of up to 255 bytes of data. The minimum PSDU length shall be 20 bytes and shall be covered by the core frame.

The PSDU shall be filled with the MAC Protocol Data Unit (MPDU). If the MPDU size is below 20 bytes, the PSDU shall be filled up to 20 bytes by zero padding after the MPDU. Therefore, a minimum number of 20 bytes is always transmitted, regardless of the actual MPDU size. For CRC calculation, the padded zeroes shall be omitted.

4.7.1.2.6 MMode field in UL

The 2-bit long field MMODE shall indicate if fixed MAC or variable MAC is used. The MMODE field shall be formatted according to Table 4-71.

Table 4-71: MMODE field format

MMode value	Description
0b00	Fixed MAC Mode (see clause 4.6.2)
0b01	Variable MAC Mode (see clause 4.6.4)
0b10	Reserved
0b11	Reserved

4.7.1.3 Radio Frame formats in UL

4.7.1.3.1 Overview

The uplink transmission shall consist of a core frame and shall comprise an additional extension frame, if the PHY payload length exceeds 186 bits.

4.7.1.3.2 Core Frame format in UL

The uplink core frame shall consist of 24 radio-bursts, transmitting the minimum PHY payload length of 186 bits.

4.7.1.3.3 Extension Frame format in UL

The uplink extension frame structure shall be derived from the information of the core frame according to clause 4.7.6.1.7. For each additional byte in the PHY payload, the frame shall be extended by one radio-burst.

4.7.1.4 Radio-burst formats in UL

4.7.1.4.1 Burst Data Unit (BDU) in UL

The uplink transmission consists of several radio-bursts. Each radio-burst shall consist of one 12-bit long pilot sequence PS field and two accompanying 12-bit long data fields DATA_A and DATA_B according to Table 4-72.

Table 4-72: Uplink Burst Data Unit format

Field length (in bits)	12	12	12
Field content	DATA_A	PS	DATA_B

A 36-byte long synchronization sequence is split into 24 pilot sequences of 12 bits, distributed over the core frame and recombined in the base station for proper receiver synchronization. The PS field shall be filled with the resulting 12-bit pilot sequence (0, 1, 1, 1, 0, 1, 0, 0, 0, 0, 1, 0).

The PS field of each radio-bursts in the extension frame (clause 4.7.1.3.3) shall be filled with the sequence (0, 1, 0, 0, 1, 1, 1, 1, 0, 1, 0).

DATA_A and DATA_B fields shall be filled with the uplink interleaver output described in clause 4.7.3.6.

4.7.1.4.2 Sync Burst Data Unit (SBDU) in UL

For easier synchronization in the receiver (e.g. for low complexity receivers) an optional synchronization radio-burst may be used before the core frame. The synchronization burst data unit shall consist of fields according to Table 4-73.

Table 4-73: Uplink Sync-Burst Data Unit format

Field length (in bits)	12	8	1	3	8	2	2
Field content	Preamble_S	PS_US	TSMA Group Subset	Uplink TSMA Pattern Index p_i	LSB Short Address	Uplink TSMA Pattern Group	Sync CRC

The fields are defined as:

- The Preamble_S field shall be filled with (0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1).
- The pilot sequence field PS_US shall be filled with (1, 1, 0, 1, 0, 0, 1, 1).
- TSMA Group Subset: cleared to 0 for UPG group 1, 2, 3, and 6; set to 1 for UPG group 4 and 5.
- The field Uplink TSMA Pattern Number index p_i shall indicate the TSMA pattern number p used for this transmission.
- The LSB Short Address shall be the eight least significant bits of the short address as described in clause 4.5.3.1.

The uplink TSMA Pattern Group shall indicate the TSMA pattern group used for this transmission as described in Table 4-74: Uplink TSMA Pattern Group

Name	Abbreviation	TSMA Group Subset	Pattern Group	Pattern number index p_i	Pattern number p
Uplink TSMA Pattern Group 1	UPG1	0	(0, 0)	0...7	1-8
Uplink TSMA Pattern Group 2	UPG2	0	(0, 1)	0...7	1-8
Uplink TSMA Pattern Group 3	UPG3	0	(1, 0)	0	1
Uplink TSMA Pattern Group 6	UPG6	0	(1, 1)	0...7	1-8
Uplink TSMA Pattern Group 4	UPG4	1	(0,0)	0...7	1-8
Uplink TSMA Pattern Group 4	UPG4	1	(0,1)	0..3	9-12
Uplink TSMA Pattern Group 5	UPG5	1	(1,0)	0..2	1-3

- .
- Sync CRC shall be 2-bit long and calculated over the bits 20 to 33 of the SBDU according to clause 4.7.5.2.

Table 4-74: Uplink TSMA Pattern Group

Name	Abbreviation	TSMA Group Subset	Pattern Group	Pattern number index p_i	Pattern number p
Uplink TSMA Pattern Group 1	UPG1	0	(0, 0)	0...7	1-8
Uplink TSMA Pattern Group 2	UPG2	0	(0, 1)	0...7	1-8
Uplink TSMA Pattern Group 3	UPG3	0	(1, 0)	0	1
Uplink TSMA Pattern Group 6	UPG6	0	(1, 1)	0...7	1-8
Uplink TSMA Pattern Group 4	UPG4	1	(0,0)	0...7	1-8
Uplink TSMA Pattern Group 4	UPG4	1	(0,1)	0..3	9-12
Uplink TSMA Pattern Group 5	UPG5	1	(1,0)	0..2	1-3

4.7.2 PHY formats in DL

4.7.2.1 Overview in downlink

In TS-UNB, the transmission of a message in downlink is split into several radio-bursts, which are distributed over time and frequency. Radio-bursts are combined to a block, one or more blocks are combined to a radio frame.

In the TS-UNB protocol stack, the downlink PHY layer contains two main steps:

- The generation of blocks from PHY_Payload (see Figure 4-23).
- The generation of radio-bursts from blocks (see Figure 4-24).

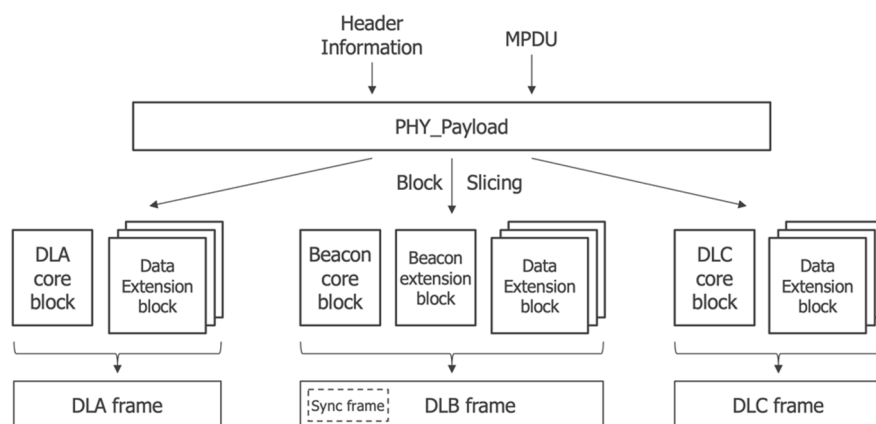


Figure 4-23: Block generation overview in DL

Figure 4-24 illustrates the various processing steps that are implemented in the PHY layer of a base station, in order to get the radio-bursts out of a PSDU block.

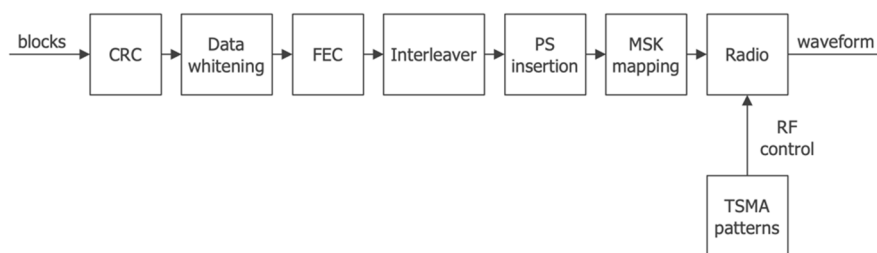


Figure 4-24: Radio-burst generation overview in DL

4.7.2.2 PHY Payload format in DL

The PHY Payload format in downlink shall consist of several fields, as illustrated in Figure 4-25:

- a PHY header;
- PSDU fields (one for DLA and DLC, one or several for DLB), each PSDU field containing a downlink MPDU to be transmitted.

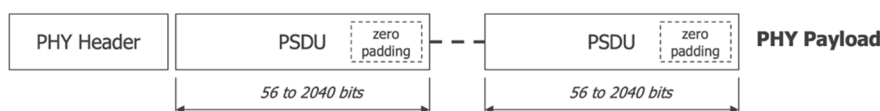


Figure 4-25: PHY_Payload format in downlink transmission

The PHY header shall be build, as follows:

- in DLA transmission mode with no timing flexibility, the five fields as defined in Table 4-75;
- in DLA transmission mode with timing flexibility activated, the eight fields as defined in Table 4-77;
- in DLA transmission mode with HDR burst structure, the six fields as defined in Table 4-80;
- in DLB transmission mode, the beacon core (see clause 4.6.3.6.3 for single stage pre-addressing, and clause 4.6.3.6.4 for two-stage pre-addressing);
- in DLC transmission mode, the MPAI field (see clause 4.7.2.11).

The PHY payload is sliced into blocks according to clause 4.7.4.1; the block formats depending on the transmission mode.

4.7.2.3 DLA Core (DLAC) block format (no timing flexibility)

When timing flexibility is not used, the DLA core block format shall consist of seven fields, as detailed in Table 4-75

Table 4-75: DLA core block format (no timing flexibility)

Field length (in bits)	48	1	8	14	2	1	4
Field content	Sync	EFI	PSI	TSI	MMode	FTM	CRC

NOTE: The five fields EFI, PSI, TSI, MMode, and FTM together form the PHY_Header field.

Sync

If fixed MAC mode is used, the Sync field shall contain a 48-bit cypher-based Message Authentication Code (CMAC) cryptographically signing the counter of the uplink MAC Data Unit received from the end-point. The CMAC is generated according to clause 4.6.7.2 with the CMAC initialization vector for downlink direction as input data. The 48 most significant bits of the result of the CMAC generation shall be used as Sync field.

If the variable MAC mode of the TS-UNB protocol is used, the Sync field shall be filled with the pilot sequences PS_A and PS_B (see Table 4-91) according to Table 4-76.

Table 4-76: Sync field in variable MAC mode

Field length (in bits)	8	8	8	8	8	8
Field content	PS_A	PS_B	PS_A	PS_B	PS_A	PS_B

Extension frame Indicator (EFI)

The Extension Frame Indicator (EFI) field indicates if the core frame is followed by an extension frame. EFI shall be set to one, if an extension frame follows. If EFI is set to one, PSI, TSI and MMODE fields shall be used. If EFI is zero, PSI, TSI and MMODE are reserved and shall be set to (0).

Packet Size Indicator (PSI)

The packet size indicator (PSI) shall indicate the size of the downlink MPDU in bytes. Valid values range from 1 to 255 bytes.

Transmission Start Time Indicator (TSI)

The transmission start time indicator (TSI) indicates the time interval between core frame and extension frame. The time interval is measured from the last radio-burst of the repeated core frame to the first radio-burst of the first block of the extension frame and is measured from the middle of the pilot sequence of the two radio-bursts. The time interval ΔT_{TSI} (Table 4-69 in clause 4.6.8.1) shall be calculated from the TSI value according to the following formula:

$$\Delta T_{TSI} = TSI * 4 * \Delta T$$

The TSI value ranges from 21 to 16 383. The default TSI value shall be 128. ΔT is the actual symbol duration of DLA mode.

If the core frame is not repeated, the time of the last radio-burst of a core frame with 18 radio-bursts shall be used.

MMode

The same MMode field shall be used as in uplink (see clause 4.7.1.2).

Flexible Timing Mode (FTM)

This 1-bit field shall be set to zero, when a downlink transmission does not use timing flexibility (see clause 4.7.2.4).

Downlink Core frame CRC

A 4-bit CRC checksum shall be calculated over the 26 bits of the PHY Header (see Table 4-75) and placed at the end of the core frame.

4.7.2.4 DLA Core (DLAC) block format (timing flexibility activated)

When timing flexibility is activated, the DLA core block format shall consist of ten fields, as detailed in Table 4-77.

Table 4-77: DLA core block format (timing flexibility activated)

Field length (in bits)	48	1	8	5	4	3	2	2	1	4
Field content	Sync	EFI	PSI	TSI_F	TDN_F	THB	Reserved	MMode	FTM	CRC
NOTE:	The eight fields EFI, PSI, TSI_F, TDN_F, THB, Reserved, MMode, and FTM together form the PHY_Header_F field.									

Sync

As in clause 4.7.2.3.

EFI

The Extension Frame Indicator (EFI) shall be set to one, when an extension frame follows the core frame. It shall be cleared to zero, when there is no extension frame.

When EFI is set to one, PSI, TSI_F, TDN_F, THB and MMode fields shall be used.

When EFI is cleared to zero, PSI, TSI_F, TDN_F, THB and MMode are reserved and shall be cleared to zero.

PSI

As in clause 4.7.2.3.

TSI_F

The transmission start time indicator with flexibility (TSI_F) shall be a 5-bit unsigned integer.

When timing flexibility is activated, TSI_F shall be used to calculate the time interval ΔT_{TSI} between the core frame and the extension frame (see Table 4-69), according to the following formula:

$$\Delta T_{TSI} = N_{TAF} \cdot 512 \cdot r_{TSI} \cdot \Delta T$$

Where:

- N_{TAF} is the timing adaptation factor, as specified in clause 4.7.6.1.11:

$$r_{TSI} = \begin{cases} 1 & \text{for } TSI_F = 0 \\ (4 \cdot TSI_F) & \text{for } TSI_F > 0 \end{cases}$$

- ΔT is the actual symbol duration.

TDN_F

The time delay extension frame with flexibility (TDN_F) shall be a 4-bit field. It indicates the time interval between blocks of a DLA extension frame transmitted with timing flexibility activated.

TDN_F shall be used to calculate the time offset ΔT_{dn} (see Table 4-69), according to the following formula:

$$\Delta T_{dn} = N_{TAF} \cdot 512 \cdot r_{TDN} \cdot \Delta T$$

Where:

- N_{TAF} is the timing adaptation factor, as specified in clause 4.7.6.1.11
- r_{TDN} shall be defined by TDN_F, as specified in Table 4-78
- ΔT is the actual symbol duration

Table 4-78: Look-up table for r_{TDN} values

TDN_F	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
r_{TDN}	1	6	10	14	18	26	34	42	50	58	70	82	94	106	118	130

THB

The Time delay Half Block (THB) shall be a 3-bit field. It indicates the additional time delay between the two radio-bursts with index s=8 and index s=9, in the blocks of a DLA extension frame with timing flexibility activated.

THB shall be used to calculate the additional time delay ΔT_{hb} (see clause 4.7.6.1.11), according to the following formula:

$$\Delta T_{hb} = 2\,048 \cdot r_{THB} \cdot \Delta T$$

Where:

- r_{THB} shall be defined by THB, as specified in Table 4-79
- ΔT is the actual symbol duration.

Table 4-79: Look-up table for r_{THB} values

THB	0	1	2	3	4	5	6	7
r_{THB}	0	4	7	10	13	16	19	31

Reserved

This 2-bit field shall be set to 0b00.

MMode

The same MMode field shall be used as in uplink (see clause 4.7.1.2).

Flexible Timing Mode (FTM)

This 1-bit field shall be set to one, when a DLA frame is transmitted with timing flexibility activated (see clause 4.7.6.1.11).

Downlink Core frame CRC

A 4-bit CRC checksum shall be calculated over the 26 bits of the PHY_Header_F (see Table 4-77) and placed at the end of the core frame.

4.7.2.5 DLA Core (DLAC) block format for HDR burst structure

For HDR burst structure the DLA Core block format shall be formatted as detailed in Table 4-80. This block format shall be only used in fixed MAC mode.

Table 4-80: DLA core block format for high data rate burst structure

Field length (in bits)	48	1	8	14	2	1	20	8
Field content	SYNC	EFI	PSI	TSI	MMode	FTM	Reserved	CRC
NOTE:	The six fields EFI, PSI, TSI, MMode, FTM, and Reserved together form the PHY_Header field.							

SYNC

The SYNC field shall contain a 48-bit cypher-based Message Authentication Code (CMAC) cryptographically signing the counter of the uplink MAC Data Unit received from the end-point. The CMAC is generated according to clause 4.6.7.2 with the CMAC initialization vector for downlink direction as input data. The 48 most significant bits of the result of the CMAC generation shall be used as SYNC field. The SYNC field is separately FEC coded, resulting in 162 coded bits (including tail bits), where the first 160 bits are used as pilot sequences for the five core frame radio-bursts.

Extension frame Indicator (EFI)

The Extension Frame Indicator (EFI) field indicates if the core frame is followed by an extension frame. EFI shall be set to one, if an extension frame follows. If EFI is set to one PSI, TSI and MMODE fields shall be used. If EFI is zero, PSI, TSI and MMODE are reserved and shall be set to zero.

Packet Size Indicator (PSI)

The packet size indicator (PSI) shall indicate the size of the downlink PSDU of the extension frame before zero padding in bytes. Valid values range from 1 to 255 bytes.

Transmission Start time Indicator (TSI)

The Transmission Start time Indicator (TSI) indicates the time interval between core frame and extension frame. The time interval is measured from the last radio-burst of the core frame to the first radio-burst of the first block of the extension frame and is measured from the middle of the pilot sequence of the two radio-bursts. The time offset ΔT_{TSI} (see Table 4-69) shall be calculated from the TSI value according to the following formula:

$$\Delta T_{TSI} = TSI * 4 * \Delta T$$

The TSI value ranges from 40 to 16 383. The default TSI value shall be 128. ΔT is the actual symbol duration of DLA mode.

MMode

The same MMode field shall be used as in uplink (see clause 4.7.1.2.6).

Flexible Timing Mode (FTM)

Timing flexibility is not used in HDR burst structure, therefore this field shall be cleared to zero.

Downlink Core frame CRC

A 8-bit CRC checksum shall be calculated over bits of the PHY Header according to clause 4.7.5.2 and placed at the end of the core frame.

4.7.2.6 Data Extension block format for HDR burst structure

In the case of HDR burst structure, the Data Extension (DE) block format shall consist of four fields, as detailed in Table 4-81.

Table 4-81: Format of a Data Extension block

Field length (in bits)	40...160	4	2	8
Field content	Block_SDU	Custom Block Info	Reserved	Block_CRC

Block_SDU

A variable size field that shall contain an MPDU slice, resulting from the block slicing function (see clause 4.7.4.1).

Custom Block Info

A 4-bit field that can be filled with customer specific information about Data Extension block. If unused, these bits shall be cleared to zero.

Reserved

A 2-bit field that shall be set to zero.

Block_CRC

An 8-bit field that shall contain a CRC calculated, according to clause 4.7.5.2, over the up to 166 bits of the concatenation of Block_SDU field and Custom Block Info field and Reserved field. For CRC calculation, the padded zeroes, if any, shall be omitted.

The DE Block format is used within DLA and DLC extension frames with ULP8 data rate and HDR burst structure.

4.7.2.7 DLB Sync frame (staircase) format

For easier synchronization or resynchronization after a not-received beacon, an optional DLB Sync frame (staircase) may be transmitted prior to each beacon core frame.

The DLB Sync frame shall consist of three radio-bursts, with no data (i.e. pure pilot sequences) followed by an optional DLB Sync data frame. Each radio-burst shall be a series of 52 symbols, all set to zero.

NOTE: With the defined (G)MSK modulation scheme, this is equivalent to the transmission of three pure sine waves at three different frequencies, which give several options for simple detection algorithms in the receiver.

The availability of a DLB Sync frame shall be indicated in the Sync_Frame_Flag field (see Table 4-19).

Radio-bursts of the DLB Sync frame shall be mapped to specific time & frequency patterns, as specified in clauses 4.7.6.2.5 and 4.7.6.2.6.

If an optional DLB Sync data frame is transmitted, it shall be signalled during the sync attachment procedure in the Sync_Frame_Flag field (see Table 4-19).

The optional DLB Sync data frame contains additional information for end-points which have not been connected in DLB to the base station before or if an end-point was disconnected for a long time.

The DLB Sync data frame format shall be as specified in Table 4-82.

Table 4-82: Sync data frame format

Field name	BS EUI [48-63]	Beacon counter BCCNT [0-23]	Sync CMAC
Field size (in bytes)	2	3	1

The BS-EUI and the beacon counter value from the DLB Sync data frame may be used by the end-point to calculate the TSMA pattern of the following beacon core frame using the DLB system key of the base station. Therefore no sync request via DLA is required. The Sync CMAC shall be used to detect transmission errors and for data authentication.

The 6 byte shall be encoded by a 1/2 forward-error correction according to clause 4.7.5.4.

The output bit size is afterwards app. two times higher than the input size, the following formula applies:

$$nBit_{out} = nBit_{in} \cdot 2 + 12$$

4.7.2.8 DLB Beacon Core (BC) block format

The Beacon core block format shall consist of three fields, as detailed in Table 4-83.

Table 4-83: Beacon core block format

Field length (in bits)	48	26	4
Field content	BC_Sync	BC_MPDU	BC_CRC

BC_Sync

a 48-bit field that shall contain the 48 most significant bits of a CMAC computed according to clause 4.6.7.2 with the initialization vector as the only input.

The initialization vector is formed by setting the Data_direction_flag, the DL_transmission_flag and the Beacon_flag according to Table 4-67.

BC_MPDU

a 26-bit field that shall be loaded with a BC_MPDU (see clause 4.6.3.6.3 (resp. clause 4.6.3.6.4) for single-stage (resp. two-stage) beacon core MPDU format).

BC_CRC

A 4-bit field that shall contain a CRC calculated over the BC_MPDU field, according to clause 4.7.5.2.

4.7.2.9 DLB Beacon Extension (BE) block format

The Beacon extension block format shall consist of three fields, as detailed in Table 4-84.

Table 4-84: Beacon extension block format

Field length (in bits)	192	2	8
Field content	BE_MPDU	Reserved	BE_CRC

BE_MPDU

A 192-bit field that shall be loaded with a BE_MPDU (see clause 4.6.3.6.5)

Reserved

A 2-bit field that shall be set to zero

BE_CRC

An 8-bit field that shall contain a CRC calculated, according to clause 4.7.5.2, over the 194 bits of the concatenation of BC_MPDU field and Reserved field

4.7.2.10 Data Extension block format

When present in DLA, DLB, or DLC transmission mode, the Data extension block format shall consist of three fields, as detailed in Table 4-85.

Table 4-85: Format of a Data Extension block (DE_Block)

Field length (in bits)	56...192	2	8
Field content	Block_SDU	Reserved	Block_CRC

Block_SDU

A variable size field that shall contain the result of the block slicing function (see clause 4.7.4.1).

Reserved

A 2-bit field that shall be set to zero.

Block_CRC

An 8-bit field that shall contain a CRC calculated, according to clause 4.7.5.2, over the maximum 194 bits of the concatenation of Block_SDU field and Reserved field. For CRC calculation, the padded zeroes, if any, shall be omitted.

This DE_Block format is used within DLA and DLC extension frames and DLB data frames.

4.7.2.11 DLC Core Block format

First block of a DLC transmission, the DLC Core Block (DLCC_Block) shall be formatted with four fields, as detailed in Table 4-86.

Table 4-86: Format of a DLC Core block

Field length (in bits)	24	32...168	2	8
Field content	MPAI	Block_SDU	Reserved	Block_CRC

MPAI

MAC Pre-addressing Info Field formatted according to Table 4-62 and encrypted separately.

Block_SDU

A variable size field that shall contain the result of the block slicing function (see clause 4.7.4.1).

Reserved

A 2-bit field that shall be set to zero.

Block_CRC

An 8-bit field that shall contain a CRC calculated, according to clause 4.7.5.2, over the 194 bits of the concatenation of MPAI, Block_SDU field and Reserved field. For CRC calculation, the padded zeroes, if any, shall be omitted.

4.7.2.12 DLC Core Block format for HDR burst structure

First block in a DLC transmission with HDR burst structure, the DLC Core Block shall be formatted with four fields, as detailed in Table 4-87.

Table 4-87: Format of DLC core block for HDR burst structure

Field length (in bits)	24	16 to 136	4	2	8
Field content	MPAI	Block SDU	Custom Block Info	Reserved	CRC

MPAI

MAC Pre-addressing Info Field formatted according to Table 4-62 and encrypted separately.

Block_SDU

A variable size field that shall contain an MPDU slice, resulting from the block slicing function (see clause 4.7.4.1).

Custom Block Info

A 4-bit field that can be filled with customer specific information about Data Extension Block. If unused, these bits shall be cleared to zero.

Reserved

A 2-bit field that shall be set to zero.

Block_CRC

An 8-bit field that shall contain a CRC calculated, according to clause 4.7.5.2, over the 166 bits of the concatenation of MPAAI, Block_SDU field, Custom Block Info field and Reserved field. For CRC calculation, the padded zeroes, if any, shall be omitted.

4.7.2.13 Radio-burst formats in DL**4.7.2.13.1 Introduction**

In downlink, the radio-bursts are of five types:

- Sync Burst Data Unit (S_BDU): radio-bursts that are transmitted before a core frame and before each block of the extension frame.
- Core frame Burst Data Unit (C_BDU): radio-bursts that are part of a DLA core frame or a Beacon Core frame.
- Extension frame Burst Data Unit (E_BDU): radio-bursts that are part of a DLA or DLB Data frame, a Beacon Extension frame or DLC core and extension frame.
- Single Burst mode Burst Data Unit (SB_BDU): radio-burst in a DL-SB transmission (deprecated).
- High data rate Burst data Unit (H_BDU): radio-bursts that are part of a DLA or DLC core frame or extension frame with ULP8 symbol rate.

4.7.2.13.2 S_BDU format in DLA

For easier synchronization in the receiver (e. g. for low performance receivers), an optional additional synchronization radio-burst may be sent for transmissions with standard or concatenated burst structure. If an additional synchronization burst is sent, it shall be sent before the core frame and before each block of the extension frame. The synchronization burst data unit (S_BDU) shall be formatted according to Table 4-88.

Table 4-88: S_BDU format

Field length (in bits)	14	12	13
Field content	PS_Ext_A	PS_DS	PS_Ext_B

The pilot sequence field PS_DS shall be filled with (0, 1, 1, 1, 0, 1, 0, 0, 0, 0, 1, 0), the PS_Ext_A field shall be filled with (0, 1, 0, 1, 0, 0, 1, 1, 1, 1, 0, 1, 0) and the PS_Ext_B field shall be filled with (0, 1, 0, 0, 1, 1, 1, 1, 0, 1, 0, 0).

As the number and the size of the radio-bursts in downlink are dependent on the PHY payload length, the length of the synchronization radio-burst also differs.

In the core frame, the size of the Sync-burst data unit (n_{sb}) shall be always 21 symbols. In the extension frame, the size of the Sync-burst data unit shall be calculated according to the following formula:

$$n_{sb} = \begin{cases} 21 & \text{for } n_b \leq 7 \\ 21 + (n_b - 7) & \text{for } n_b > 7 \end{cases}$$

where n_b is the number of PSDU data bytes in the block.

If the size of the Sync-burst data unit is lower than the maximum defined size of 39 Symbols in Table 4-88, the PS_Ext_A and PS_Ext_B field shall be truncated. The number of symbols in the fields are calculated according to the following formula:

$$n_{PS_{Ext_A}} = \lceil (n_{sb} - 12) / 2 \rceil$$

$$n_{PS_{Ext_B}} = \lfloor (n_{sb} - 12) / 2 \rfloor$$

In case of truncation the outer symbols of the PS_Ext_A and PS_Ext_B fields shall be omitted. The PS_DS field shall always indicate the middle of the synchronization radio-burst.

4.7.2.13.3 C_BDU format in DL

In DLA and DLB transmission modes, the Burst Data Units in the Core frame (C_BDU) shall be formatted according to Table 4-89.

Table 4-89: C_BDU format in DLA and DLB transmission modes

Field length (in bits)	8	12	8
Field name	PS_DA	DATA_A	PS_DB

Content of the three fields in a C_BDU shall be according to clause 4.7.4.5 (i.e. interleaving function in downlink).

4.7.2.13.4 E_BDU format in DL

In DLA and DLB transmission modes, the Burst Data Units in an Extension frame (E_BDU) shall be formatted according to Table 4-90.

Table 4-90: E_BDU format in DLA and DLB transmission modes

Field length (in bits)	0 ... 12	8	12	8	0 ... 12 (see note)
Field name	DATA_B	PS_DA	DATA_A	PS_DB	DATA_C
NOTE: The maximum size of DATA_C field is 12 bits, but the interleaver uses a maximum of 11 bits only.					

The E_BDU shall consist of at least one 12-bit DATA_A field, accompanied by the 8-bit PS_DA (resp. PS_DB) field, carrying PS_A (resp. PS_B) pilot sequence, as specified in Table 4-91.

Table 4-91: Pilot sequences values in E_BDU

Pilot sequence name	Pilot sequence value
PS_A	(0, 1, 0, 0, 0, 0, 1, 0)
PS_B	(1, 1, 1, 0, 1, 0, 0, 0)

DATA_B and DATA_C fields shall be added and loaded depending on the PSDU length (see clause 4.7.2.14.2).

4.7.2.13.5 SB_BDU format in DL (deprecated)

In DL-SB transmission mode, telegram splitting shall not be used. Therefore, the PHY payload shall be transmitted in one or two continuous radio-bursts, depending on the length of the PHY payload. The BDUs shall be formatted, as follows:

- a fixed length of 78 symbols for the core frame BDU, as specified in Table 4-92;
- a variable length between 66 and 202 symbols for the extension frame BDU, as specified in Table 4-93.

Table 4-92: Burst Data Unit format of DL-SB Mode (core frame)

Field length (in symbols)	32	32	14
Field content	Preamble	Sync	PHY Payload

Table 4-93: Burst Data Unit format of DL-SB Mode (extension frame)

Field length (in symbols)	32	32	2 to 138
Field content	Preamble	Sync	PHY Payload

Preamble

The preamble field of the radio-burst shall be 32 bits, filled with (0,1,0,1....).

Sync Field

The Sync field of the radio-burst shall be 32 bits, with a value of 0x930B51DE.

NOTE: DL-SB is a deprecated transmission mode; it should not be used in new design.

4.7.2.13.6 H_BDU format in DL for HDR burst structure

In DLA and DLC transmission modes at ULP8 symbol rate, the Burst Data Units in the Core frame and extension frame (H_BDU) shall be formatted according to Table 4-94.

Table 4-94: H_BDU format in DLA and DLC transmission modes at ULP8 data rate

Field length (in bits)	0...36	16	36	16	0...36
Field name	DATA_B	PS_DA	DATA_A	PS_DB	DATA_C

Content of the five fields in a H_BDU shall be according to clause 4.7.4.5.9 (i.e. interleaving function in downlink).

The pilot sequences PS_DA and PS_DB are different for the core frame (first block) and the extension frame (remaining blocks).

Pilot sequence for the Core frame of DLA ULP8

In core frame of DLA the 48-bit SYNC field according to clause 4.7.2.5 is used to derive the pilot sequence. The end-point may skip the reception after the core frame, if the SYNC field does not match.

The SYNC field is encoded separately from the remaining Physical Layer Core Payload according to clause 4.7.2.5.

The 48 Bit SYNC result in a size of $(48 \text{ Bit} * 3 + 18 \text{ Bit}) = 162 \text{ Bits}$ after the encoding is done. The size of the pilot sequence in all subpackets equals $5 * 32 \text{ Bit} = 160 \text{ Bit}$. Therefore the last two bits provided by the encoding shall be omitted in the pilot sequences.

Table 4-95 shows the mapping of the bits after the encoding to the sub-packet pilot sequences, where the first 16 bits of each subpacket are mapped to the PS_DA part and the remaining 16 bits to the PS_DB part.

Table 4-95: DLA-ULP8 core frame mapping of coded bits onto pilot sequence

m \ s	0	1	2	3	4	Mapping
0	0	1	2	3	4	PS_DA
1	6	7	8	9	5	PS_DA
2	12	13	14	10	11	PS_DA
3	18	19	15	16	17	PS_DA
4	24	20	21	22	23	PS_DA
5	25	26	27	28	29	PS_DA
6	31	32	33	34	30	PS_DA
7	37	38	39	35	36	PS_DA
8	43	44	40	41	42	PS_DA
9	49	45	46	47	48	PS_DA
10	50	51	52	53	54	PS_DA
11	56	57	58	59	55	PS_DA
12	62	63	64	60	61	PS_DA
13	68	69	65	66	67	PS_DA
14	74	70	71	72	73	PS_DB
15	75	76	77	78	79	PS_DB
16	81	82	83	84	80	PS_DB
17	87	88	89	85	86	PS_DB
18	93	94	90	91	92	PS_DB
19	99	95	96	97	98	PS_DB
20	100	101	102	103	104	PS_DB
21	106	107	108	109	105	PS_DB
22	112	113	114	110	111	PS_DB
23	118	119	115	116	117	PS_DB
24	124	120	121	122	123	PS_DB
25	125	126	127	128	129	PS_DB
26	131	132	133	134	130	PS_DB
27	137	138	139	135	136	PS_DB
28	143	144	140	141	142	PS_DB
29	149	145	146	147	148	PS_DB
30	150	151	152	153	154	PS_DB
31	156	157	158	159	155	PS_DB

The pilot sequence for the extension frame of a DLA ULP8 and for all frames of DLC ULP8 shall be chosen according to Table 4-96 for all following blocks, whereby the sub-packet index equals the radio-burst number.

Table 4-96: Pilot sequences values in H_BDU

s	PS A	PS B
0	(0, 0, 0, 0, 1, 0, 1, 0, 0, 0, 1, 1, 0, 1, 1, 1)	(1, 0, 1, 0, 0, 0, 0, 0, 1, 0, 0, 1, 1, 1, 0, 1)
1	(1, 1, 0, 1, 0, 0, 0, 1, 1, 0, 0, 0, 0, 1, 0, 0)	(1, 1, 1, 1, 0, 1, 0, 1, 1, 1, 0, 1, 1, 0, 0, 0)
2	(1, 0, 1, 0, 0, 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 1)	(0, 0, 0, 0, 1, 0, 1, 0, 0, 1, 0, 0, 1, 1, 1, 1)
3	(1, 1, 1, 1, 0, 1, 0, 1, 1, 1, 1, 0, 1, 1, 0, 0)	(0, 1, 0, 1, 1, 0, 0, 1, 1, 1, 1, 1, 1, 1, 0, 1, 0)
4	(0, 1, 0, 0, 1, 1, 1, 0, 1, 1, 1, 1, 1, 0, 1, 0)	(0, 0, 0, 0, 1, 0, 1, 0, 0, 1, 0, 0, 1, 0, 0, 0, 1, 1, 1)

4.7.2.14 Radio frame formats in DLA mode

4.7.2.14.1 Core frame format in DLA mode

The core frame is used as authenticated wakeup and acknowledgment of the previous end-point uplink transmission. Every downlink transmission shall consist of a core frame and may be followed by an optional extension frame. The succeeding extension frame shall be indicated in the core frame.

The core frame shall consist of 9 radio-bursts according to the structure described in clause 4.7.2.1, which may be repeated to fill the 18 radio-bursts of the downlink TSMA pattern. The base station should decide upon the signal strength of the uplink transmission if the same core frame is repeated.

For synchronization purpose an additional Sync-burst may be transmitted before the start of the core frame. If an additional Sync-burst is used in front of the core frame an additional Sync-burst shall also be used in front of each block of the extension frame.

4.7.2.14.2 Extension frame format in DLA mode

The extension frame is an optional transmission frame to transmit user data. The extension frame contains a minimum of 56 bits (7 bytes) and a maximum 2 040 bits (255 bytes) of PSDU data. The PSDU contains the MPDU data with additional zero padding if needed. The extension frame shall be split into blocks of at most 24 bytes of PSDU data per block. If the overall PSDU size is more than 24 bytes, multiple blocks shall be used for transmission. Each block of the extension frame shall comprise 18 radio-bursts according to clause 4.7.2.1. If an additional Sync-burst is used in the core frame, then an additional Sync-burst shall be transmitted also for each block of the extension frame.

The number of optional data symbols in data fields DATA_B and DATA_C utilized for data transmission is dependent on the number of symbols transmitted in the respective block of the extension frame.

The PSDU data shall be spread byte-wise evenly over the number of extension frame blocks required to accommodate for the whole packet, according to clause 4.7.4.1.1.

4.7.2.14.3 DLA Frame format for HDR burst structure

Figure 4-26 illustrates the DLA frame construction with HDR burst structure.

The core frame of DLA with HDR burst structure shall be used in the same way as in clause 4.7.2.14.1 and shall consist of 5 radio-bursts. PS_DA field and PS_DB field of each radio-burst in the core frame shall be filled with symbols derived from the channel coded SYNC field, which is encoded separately from the remaining PHY Payload. DATA_B and DATA_C fields shall not be used for transmission of the core frame.

The extension frame is an optional transmission frame to transmit user data, containing the MPDU data with additional zero padding if needed. The extension frame shall be split into blocks of at most 20 bytes of PSDU data per block. If the overall PSDU size is more than 20 bytes, multiple blocks shall be used for transmission. Each block of the extension frame shall comprise 5 radio-bursts.

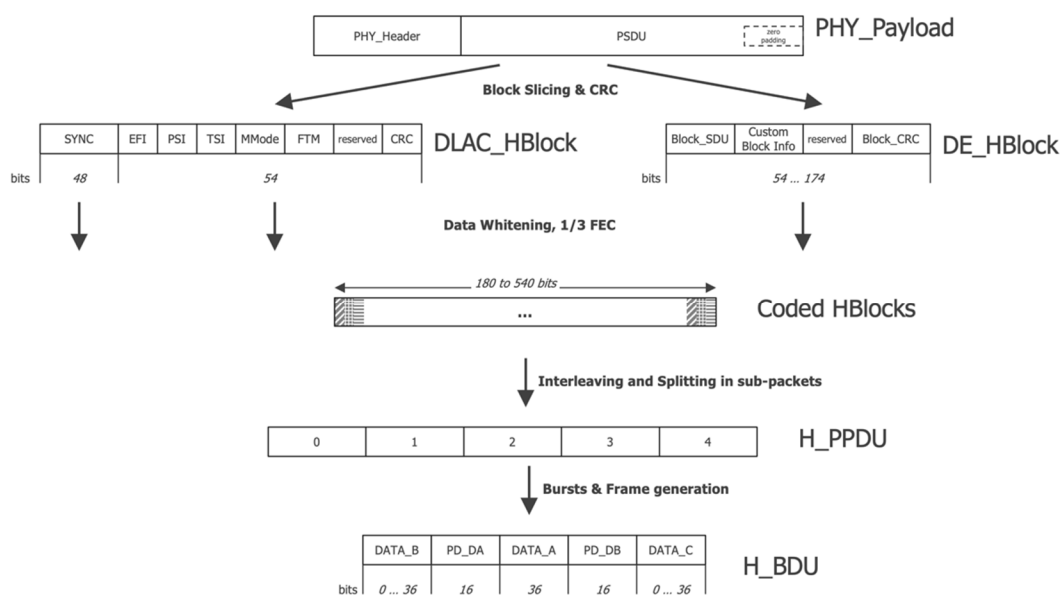


Figure 4-26: Overview of DLA frame construction with HDR burst structure

4.7.2.15 Radio frame formats in DLB mode

4.7.2.15.1 Overview of a DLB frame

In DLB transmission mode, emission of bursts occurs within a time & frequency structure, named DLB structure. A DLB structure consists of a number of Physical Resource Blocks (PRB). Each PRB consists of 36 Resource Elements (RE), where a radio-burst may be transmitted.

$N_{RBL,bea}$ is the length of a DLB structure, expressed in numbers of physical resource blocks and called beacon period. This number is given by the PRB allocation index (see Table 4-20), which is signalled to the end-point during the synchronization procedure.

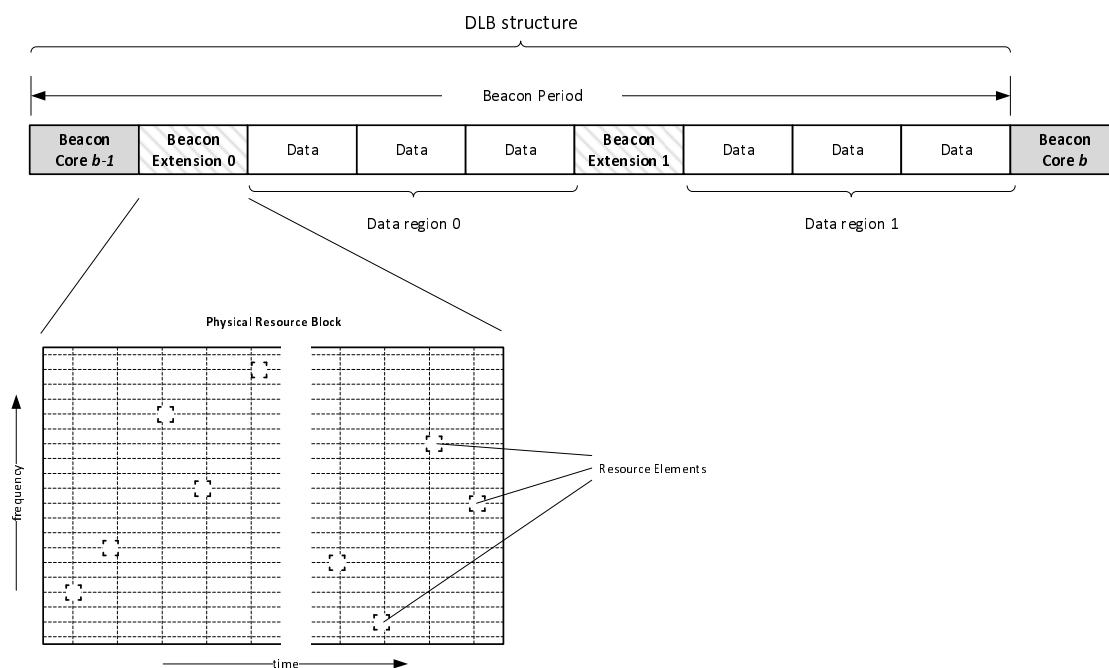


Figure 4-27: DLB structure (example with two BE frame regions)

A DLB frame is a sequence of radio-bursts transmitted at resource elements of the DLB structure. Not all resources of a DLB structure may be used by a DLB frame. Within a DLB frame, there are three different types of regions:

- The beacon core frame region, which defines the beginning of a DLB frame. It is always located in PRB0 and contains a beacon core frame.
- The beacon extension frame region, which contains a beacon extension frame. The Number of beacon extension frame region varies from zero to four and is signalled in the beacon core frame.
- The Data region, which contains DLB data frames. Number of data region varies from one to four.

The remaining part, that follows the beacon core frame region in a DLB frame, is dynamically configured by the base station from DLB frame to DLB frame to cope with the downlink data traffic. Each beacon extension frame region, if any, is followed by an associated data region. If there are several data regions in a DLB frame, their lengths are identical. Data frame positions are counted from zero, starting from the first Data frame position after the beacon core frame, and irrespective of the number of Data regions.

Figure 4-27 depicts an example with two beacon extension frame regions and accordingly two data regions. Informative annex C gives possible durations and layouts of a DLB structure.

A base station, which implements DLB mode, can schedule downlink transmissions independently of any previous uplink transmissions by end-points.

NOTE: The beacon period, $N_{RBL,bea}$, stays constant for long period of time, as there is no fast-signalling mechanism for its reconfiguration.

4.7.2.15.2 Physical Resource Blocks and Resource Elements definitions

Each region of a DLB frame shall be divided, in the time domain, into Physical Resource Blocks (PRBs).

The beacon core frame region shall consist of one physical resource block.

Each beacon extension frame region shall consist of one physical resource block.

Each data region shall consist of $N_{RBL,data}$ physical resource blocks.

Each physical resource block shall contain 36 Resource Elements (RE).

All resource elements in a DLB frame shall be numbered from zero (first RE in the PRB carrying the beacon core frame) to $(N_{RE,bea} - 1)$.

NOTE 1: REs can be considered as radio-burst transmission occasions in frequency and time, which are prescheduled by the base station. They are defined and indexed whether or not they are used by a radio-burst transmission.

The duration of a resource element shall be 52 standard symbol durations.

In the time domain, resource elements shall be arranged according to (see Figure 4-27):

- a time grid with a raster spacing of 260 standard symbol durations, in average; and
- an additional pseudo-random time offset relative to this time grid, that shall be calculated according to clause 4.7.6.2.3.

In the frequency domain, resource elements shall be arranged according to clause 4.7.6.2.2.

When transmitted in a resource element, a radio-burst shall be centred to the resource element in time and frequency.

NOTE 2: Per definition, each physical resource block has a fixed duration of $36 \times 260 = 9360$ standard symbol duration, irrespective of the specific pseudo-random time offsets R_{RE} of the first and last resource element in the physical resource block.

The total number of resource elements $N_{RE,bea}$ in a DLB frame shall be calculated, as follows:

$$N_{RE,bea} = 36 * N_{RBL,bea}$$

The DLB frame length in standard symbol duration $N_{sym,bea}$ shall be calculated, as follows:

$$N_{sym,bea} = 260 * N_{RE,bea}$$

The number of physical resource blocks in each data region $N_{RBL,data}$ shall be calculated, as follows:

$$N_{RBL,data} = \frac{(N_{RBL,bea} - 1)}{N_{ext,bea}} - 1$$

where $N_{ext,bea}$ is the number of beacon extension frames.

4.7.2.15.3 Density of PRBs

Resource blocks can either be used in a low- or high-density configuration depending on the amount of data to be transmitted in the resource block.

In low-density, only the 18 even-indexed resource elements in a PRB shall be used for radio-burst transmission.

In high-density, the 36 resource elements in a PRB shall be used for radio-burst transmission.

Beacon core frame and beacon extension frames shall be transmitted in low-density configuration only.

DLB Data frames shall use low-density configuration by default. They may use high-density configuration, to get additional capacity.

4.7.2.16 Radio frame formats in DLC mode

A radio frame in DLC mode shall consist of a core frame and may be followed by one or several extension frame blocks, depending on the payload size to be transmitted. A maximum of 255 bytes can be transmitted in a MAC payload. The core frame shall be either formatted as DLC Core Block with 18 radio-bursts according to clause 4.7.2.11 (if ULP symbol rate is used) or as DLC Core Block for HDR burst structure with 5 radio-bursts according to clause 4.7.2.12 (if ULP8 symbol rate is used). The optional extension frame blocks shall be formatted accordingly as defined in clauses 4.7.2.3 and 4.7.2.10 with 18 radio-bursts or clause 4.7.2.6 with 5 radio-bursts, if ULP8 symbol rate is used.

The blocks shall be generated according to clauses 4.7.4.1.3 and 4.7.4.1.5.

4.7.2.17 Radio frame formats in DL-SB mode (deprecated)

In DL-SB, a radio frame shall consist of a core frame and an optional extension frame, depending on the PHY payload length (see clause 4.7.2.13.5). The core frame shall be transmitted in one radio-burst. The extension frame, if any, shall be transmitted in one radio-burst, on the same centre frequency as the core frame radio-burst and separated by ΔT_{TSI} .

4.7.3 PHY functions in UL

4.7.3.1 Modulation in UL

A LTN system using TS-UNB protocol shall use MSK Modulation or GMSK Modulation with $BT = 1.0$ in the uplink.

4.7.3.2 Symbol mapping in UL

4.7.3.2.1 Overview

The bits of the Burst Data Unit and Sync-burst Data Unit shall be mapped according to the symbol representation of Figure 4-28.

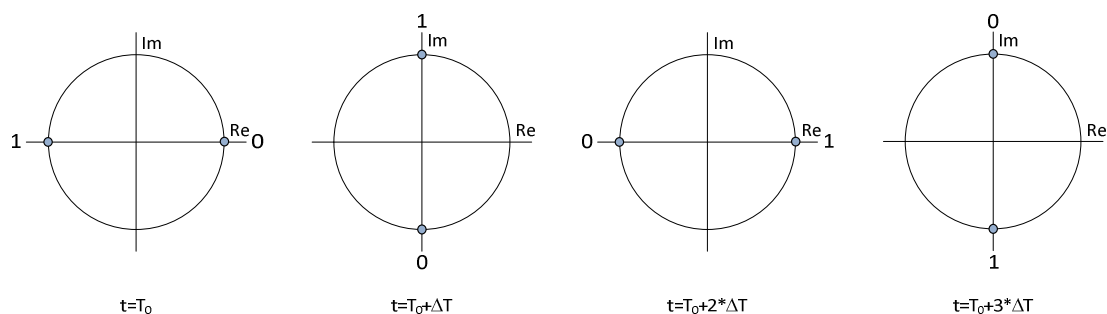


Figure 4-28: Symbol mapping for MSK/GMSK with absolute phase

The representation shall be repeated after 4 symbols. T_0 is the start time of the PHY transmission with a symbol duration of ΔT .

4.7.3.2.2 Symbol rates in uplink

The symbol rate of the (G)MSK modulation in ULZ transmission mode shall be selected according to the definitions in Table 4-2 and the allowances in Table 4-3. The tolerance of the symbol rate shall be kept within the range defined in Table 4-155.

4.7.3.3 Data Whitening function in UL

The complete PHY Payload (see clause 4.7.1.2 and Figure 4-22) shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

4.7.3.4 CRC functions in UL

4.7.3.4.1 Payload CRC in UL

An 8-bit Cyclic Redundancy Check (CRC) according to clause 4.7.5.2 shall be used.

The payload CRC shall be calculated over MPDU and MMODE field according to clause 4.7.5.2. In case of zero padding the padded zeros shall be omitted for the CRC calculation (see Figure 4-29).

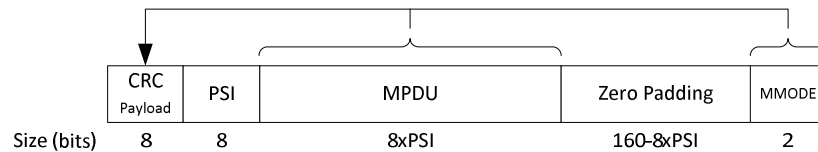


Figure 4-29: Calculation of Payload CRC

4.7.3.4.2 Header CRC in UL

An 8-bit cyclic redundancy check (CRC) according to clause 4.7.5.2 shall be used.

The additional Header CRC shall be calculated over Payload CRC and PSI according to clause 4.7.5.2 (see Figure 4-30).

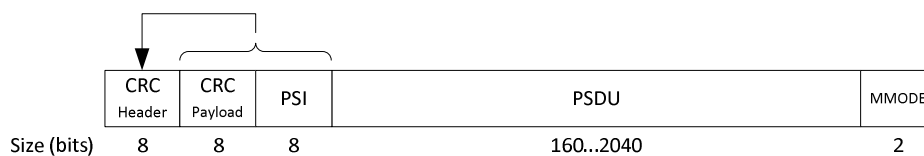


Figure 4-30: Calculation of Header CRC

4.7.3.5 Forward Error Correction function in UL

A Forward Error Correction code (FEC) according to clause 4.7.5.3 shall be calculated over the complete PHY payload after data whitening. The FEC extends the original series of 186 - 826 uncoded bits to a series of 576 - 2 496 encoded bits.

4.7.3.6 Interleaving function in UL

4.7.3.6.1 Introduction

After data whitening and FEC, the FEC coded bit-stream of the PHY payload shall be distributed to sub-packets of the core and extension frame by the interleaver in a way, that the information of the PHR field (see clause 4.7.1.4) required to receive the extension frame are contained in the core frame.

The length of the bit-stream n_s determines how many sub-packets in the extension frame are used. If less or equal than 576 bits are transmitted, the extension frame shall be omitted completely. Otherwise, the number of sub-packets in the extension frame S_E is given by $S_E = \left\lceil \frac{(n_s - 576)}{24} \right\rceil$.

The number of sub-packets in the core frame shall always be $S_C = 24$.

For the interleaving, the coded PHY payload is shifted cyclically by 48 symbols; hence the 48 last bits become the 48 first bits.

Interleaving is done in two steps:

- Assign bits of the coded PHY payload to a sub-packet.
- Place the bits in the right order within the burst data unit.

4.7.3.6.2 Bit assignment to sub-packets

The stream of cyclically shifted bits shall be indexed in ascending order with $i \in \{0, 1, 2 \dots (n_s - 1)\}$, where $i = 0$ represents the first bit. These bits shall be placed into the $S_{TOTAL} = S_C + S_E$ sub-packets.

The sub-packet index $s \in \{0, 1, 2, \dots, (S - 1)\}$ gives the index of the sub-packet a symbol will be placed in after interleaving.

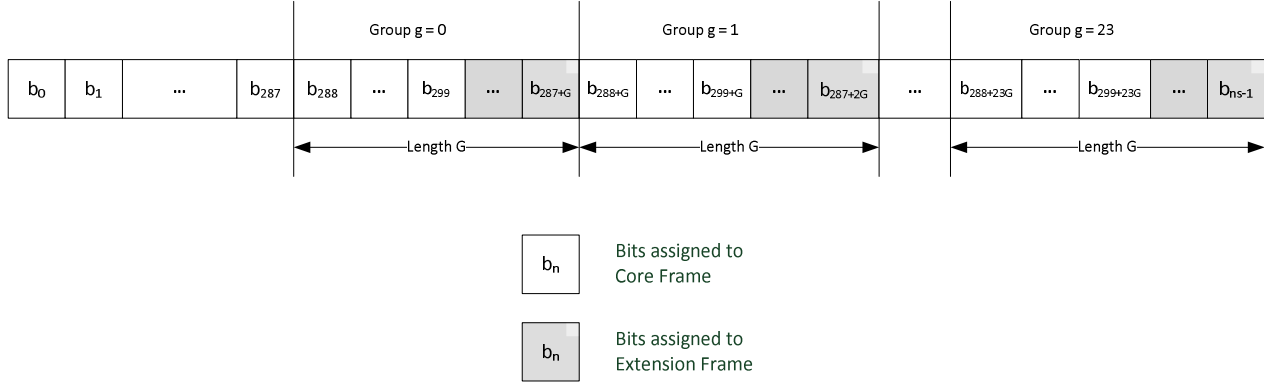


Figure 4-31: Bit order of coded PHY payload before interleaving

The bits $i \in \{0, 1, 2 \dots 287\}$ shall be placed in the sub-packets of the core frame with starting by placing the first bit $i = 0$ in sub-packet $s = 0$; the next bit $i + 1$ shall be placed in the next sub-packet $s + 1$ and so on. This scheme shall be repeated until $s = S_C - 1$, where the assignment cycle starts again at $s = 0$.

This is represented by the following formula:

$$s(i) = i \text{ modulo } S_C \text{ for } i \in \{0, 1, 2, \dots 287\}.$$

The remaining unassigned bits are placed in every other sub-packet of the core frame and in every sub-packet of the extension frame. To achieve this, the remaining bit stream starting from $i = 288$ shall be segmented in groups of length $G = S_E + \frac{S_C}{2}$ bits (see Figure 4-31).

The group index g for the current index i is given by:

$$g(i) = \left\lfloor \frac{(i-288)}{G} \right\rfloor.$$

The number of groups is always:

$$n_G = 24$$

The group symbol index $i_g(i) \in \{0, 1 \dots (G - 1)\}$ gives the index of a symbol i within the group and is used to determine whether the symbol is part of the core sub-packets or the extension sub-packets. It is given by:

$$i_g(i) = (i - 288) - (g(i) * G).$$

For every group, the first $\frac{S_C}{2}$ bits shall be placed in core sub-packets, hence bits with a group symbol index $i_g(i)$ smaller than $\frac{S_C}{2}$, shall be assigned to core sub-packets. Dependent on the group index, these bits shall be placed in either the even indexed core sub-packets for even group indices or the odd indexed core sub-packets for odd group indices. These assignments are represented by the following two formulas:

$$s(i) = i_g(i) * 2 \text{ for } i_g(i) < \frac{S_C}{2} \text{ and } g(i) = \text{even}$$

$$s(i) = i_g(i) * 2 + 1 \text{ for } i_g(i) < \frac{S_C}{2} \text{ and } g(i) = \text{odd}.$$

The remaining S_E bits of the group shall be assigned to extension sub-packets without distinguishing between even and odd groups:

$$s(i) = i_g(i) + \frac{S_C}{2} \text{ for } i_g(i) \geq \frac{S_C}{2}.$$

4.7.3.6.3 Bit placing within Burst Data Unit

Once all bits are assigned to a sub-packet, the bits shall be interleaved within a sub-packet and assigned to their position on the burst data unit. Bits with a lower index i shall be mapped to symbols around the pilot sequence and bits with a higher index shall be mapped to symbols closer to the start and the end of the radio-burst.

The set $I_s[o]$ holds all indices assigned to the same sub-packet s in ascending order, where $o = 0$ denotes the lowest bit index assigned to sub-packet s and $o = 23$ denotes the highest bit index assigned to sub-packet s .

The bits shall then be mapped to the symbols in the radio-burst according to Table 4-97, where $m = 0$ denotes the first symbol to be transmitted in a radio-burst.

Table 4-97: UL-ULP sub-packet bit to burst data unit symbol mapping

Index o	0	1	2	3	4	5	6	7	8	9	10	11
m when s is even	11	24	10	25	9	26	8	27	7	28	6	29
m when s is odd	24	11	25	10	26	9	27	8	28	7	29	6
Index o	12	13	14	15	16	17	18	19	20	21	22	23
m when s is even	5	30	4	31	3	32	2	33	1	34	0	35
m when s is odd	30	5	31	4	32	3	33	2	34	1	35	0

The 12 symbols $m \in \{12, 13, 14 \dots 23\}$ shall be occupied by the symbols of the pilot sequence.

4.7.4 PHY functions in DL

4.7.4.1 Block slicing

4.7.4.1.1 Overview

The block slicing function shall be used in the extension frame in DLA and DLC mode and for data frames in DLB mode. It cuts the PHY_Payload into one or several Block_SDU(s) (see Figure 4-32). The maximum size of a Block_SDU shall be 192 bits for standard burst structure and 160 bits for HDR burst structure. The minimum size of a Block_SDU shall be 56 bits for standard burst structure and 40 bits for HDR burst structure. If the PSDU is shorter than the minimum size, the remaining payload shall be zero padded.

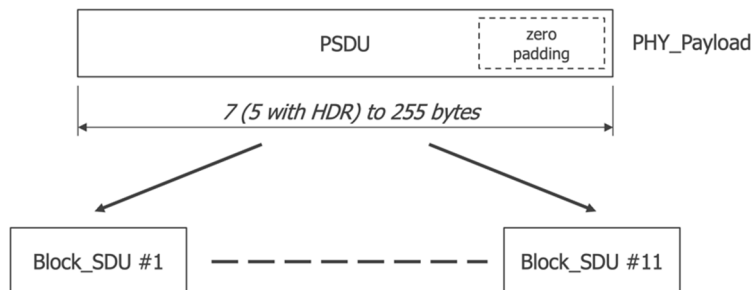


Figure 4-32: Block slicing function

For DLC an additional MPAI field is used in the DLC Core Block reducing the size of the first Block_SDU by 24 bits.

4.7.4.1.2 Block slicing in DLA

The number of blocks B that shall be used for the transmission shall be determined according to the following formula:

$$B = \left\lceil \frac{P}{24} \right\rceil,$$

where $P \in \{1, 2 \dots 255\}$, shall be the PSDU size in byte.

The extension frame blocks shall be numbered in ascending order to their respective transmission time. Block $b = 1$ shall be the block directly transmitted after the core frame, block $b + 1$ shall be transmitted after block b .

The number of PSDU data bytes n_b assigned to one block is a result of spreading the data evenly over all blocks. In case the number of bytes is not a multiple of the number of blocks, the remaining bytes $n_r = P - \left\lfloor \frac{P}{B} \right\rfloor * B$ shall be assigned to the blocks in ascending order:

$$n_b = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor, & \text{for } b > n_r \\ \left\lfloor \frac{P}{B} \right\rfloor + 1, & \text{for } b \leq n_r \end{cases}.$$

The data bits assigned to one block shall be spread over the radio-bursts by filling the field DATA_A of all bursts first and then consecutively filling the optional data fields DATA_B and DATA_C of all radio-bursts evenly. The procedure is described in detail in clause 4.7.4.5.2.

4.7.4.1.3 Block slicing in DLC

In DLC the core frame already carries up to 21 byte of PSDU. The number of blocks B in the extension frame is then calculated according to:

$$B = \left\lceil \frac{P-21}{24} \right\rceil,$$

The first 21 bytes are assigned to the core block, the following bytes are evenly spread over all blocks in the extension frame. In case the number of bytes is not a multiple of the number of blocks, the remaining byte:

$$n_r = P - \left\lfloor \frac{P-21}{24} \right\rfloor,$$

are assigned to the blocks in ascending order.

$$n_b = \begin{cases} \left\lfloor \frac{P-21}{B} \right\rfloor, & \text{for } b > n_r \\ \left\lfloor \frac{P-21}{B} \right\rfloor + 1, & \text{for } 1 \leq b \leq n_r \end{cases}.$$

The data bits assigned to the core block and the blocks of the extension frame shall be spread over the radio-bursts by filling the field DATA_A of all bursts first and then consecutively filling the optional data fields DATA_B and DATA_C of all radio-bursts evenly. The procedure is described in detail in clause 4.7.4.5.8.

4.7.4.1.4 Block slicing in DLA for high data rate burst structure

For high data rate burst structure with only 5 radio-bursts, the maximum size of a Block_SDU shall be 160 bits. The minimum size of a Block_SDU shall be 40 bits.

The number of blocks B that shall be used for the transmission shall be determined according to the following formula:

$$B = \left\lceil \frac{P}{20} \right\rceil,$$

where $P \in \{1, 2 \dots 255\}$, shall be the PSDU size in byte.

The number of PSDU data bytes n_b assigned to one block is determined according to the following formula:

$$n_b = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor, & \text{for } b > n_r \\ \left\lfloor \frac{P}{B} \right\rfloor + 1, & \text{for } b \leq n_r \end{cases}$$

with:

$$n_r = P - \left\lfloor \frac{P}{20} \right\rfloor$$

The data bits assigned to one block shall be spread over the radio-bursts by filling the field DATA_A of all bursts first and then consecutively filling the optional data fields DATA_B and DATA_C of all radio-bursts evenly as described in detail in clause 4.7.4.5.4.

4.7.4.1.5 Block slicing in DLC for high data rate burst structure

For DLC, an additional MPAI field is used in the DLC Core Block reducing the size of the Block_SDU by 24 bits. Therefore in DLC for high data rate burst structure the core frame already carries up to 17 byte of PSDU.

The number of blocks B that shall be used for the extension frame shall be determined according to the following formula:

$$B = \left\lceil \frac{P-17}{20} \right\rceil$$

where $P \in \{1,2 \dots 255\}$, shall be the PSDU size in byte.

The first 17 bytes are assigned to the core block, the following bytes are evenly spread over all blocks in the extension frame. In case the number of bytes is not a multiple of the number of blocks, the remaining byte:

$$n_r = P - \left\lfloor \frac{P-17}{20} \right\rfloor$$

are assigned to the blocks in ascending order.

The number of PSDU data bytes n_b assigned to one block is determined according to the following formula:

$$n_b = \begin{cases} \left\lfloor \frac{P-17}{B} \right\rfloor, & \text{for } b > n_r \\ \left\lfloor \frac{P-17}{B} \right\rfloor + 1, & \text{for } 1 \leq b \leq n_r \end{cases}$$

The data bits assigned to the core block and the blocks of the extension frame shall be spread over the radio-bursts by filling the field DATA_A of all bursts first and then consecutively filling the optional data fields DATA_B and DATA_C of all radio-bursts evenly. The procedure is described in detail in clause 4.7.4.5.9.

4.7.4.2 CRC function in DL

4.7.4.2.1 Core frame case

A 4-bit CRC, according to clause 4.7.5.2, shall be used for the downlink core frame. The same CRC shall be used for DL-SB and DLA Mode.

4.7.4.2.2 Extension frame

An 8-bit CRC, according to clause 4.7.5.2, shall be used for the downlink extension frame. The same CRC shall be used for DL-SB and DLA Mode.

4.7.4.2.3 Beacon core frame case

A 4-bit CRC, according to clause 4.7.5.2, shall be used for the beacon core frame.

4.7.4.2.4 Beacon extension frame case

An 8-bit CRC, according to clause 4.7.5.2, shall be used for the beacon extension frame.

4.7.4.2.5 DLB_Data frame case

An 8-bit CRC, according to clause 4.7.5.2, shall be used for the DLB_Data frame.

4.7.4.2.6 DLC core and extension frame case

An 8-bit CRC, according to clause 4.7.5.2, shall be used for the DLC core and extension frame.

4.7.4.3 Data Whitening function in DL

4.7.4.3.1 Core block case

The complete DLA Core block (see clause 4.7.2.3 (no timing flexibility) or clause 4.7.2.4 (timing flexibility activated)) shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

In the same way, the complete DLC Core Block (see clause 4.7.2.11) shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

4.7.4.3.2 Data Extension block case

The DE_Blocks of a DLA extension frame (see clause 4.7.2.10), the DLB data frame, and the DLC extension frame shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

4.7.4.3.3 Beacon core block case

The content of the Beacon core block (BC_Block) shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

4.7.4.3.4 Beacon extension block case

The content of the Beacon extension block (BE_Block) shall be whitened using the PN9 sequence defined in IEEE 802.15.4 [1].

4.7.4.4 Forward Error Correction function in DL

4.7.4.4.1 Core frame case in DLA mode

A forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the DLAC Block of the downlink core frame.

The FEC shall be calculated over all bits of the DLAC Block after data whitening. After FEC, the sequence of 78 bits results in 252 encoded bits, named a coded block.

4.7.4.4.2 Extension frame case in DLA mode

A forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the DE_Blocks of the downlink extension frame block. Each DE_Block shall be encoded separately.

The FEC shall be calculated over all bits of the Data Extension block after data whitening. One block can transmit 66 to 202 uncoded bits, which results in a coded block of 216 to 624 bits after the FEC.

4.7.4.4.3 Beacon core block case

After whitening, a forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the Beacon Core Block. The result is a code block of 216 bits.

4.7.4.4.4 Beacon extension block case

After whitening, a forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the Beacon Extension Block. The result is a coded block of 216 to 624 bits.

4.7.4.4.5 DE_Block of a DLB frame

After whitening, a forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the DE Block of a DLB frame. The result is a coded block of 216 to 624 bits.

4.7.4.4.6 DL-SB mode case (deprecated)

No forward error correction shall be used in DL-SB Mode.

4.7.4.4.7 DE Blocks of a DLC frame

After whitening, a forward error correction, calculated according to clause 4.7.5.3, shall be used to protect the DE_Blocks of a DLC frame. The result is a coded block of 216 to 624 bits.

4.7.4.5 Interleaving function in DL

4.7.4.5.1 Core frame case in DLA mode

The coded PHY payload shall be interleaved according to Table 4-98, whereas:

- s = sub-packet index 0 ... S-1
- m = symbol index in radio-burst
- the numbers in the table represent the bit number of the PHY payload of the core frame

Table 4-98: DLA core frame interleaver mapping of coded bits onto radio-bursts

$m \setminus s$	0	1	2	3	4	5	6	7	8
0	90	93	96	91	94	97	92	95	98
1	0	3	6	1	4	7	2	5	8
2	54	57	60	55	58	61	56	59	62
3	126	129	132	127	130	133	128	131	134
4	72	75	78	73	76	79	74	77	80
5	18	21	24	19	22	25	20	23	26
6	108	111	114	109	112	115	110	113	116
7	36	39	42	37	40	43	38	41	44
8	144	147	150	145	148	151	146	149	152
9	171	174	177	172	175	178	173	176	179
10	198	201	204	199	202	205	200	203	206
11	225	228	231	226	229	232	227	230	233
12	153	156	159	154	157	160	155	158	161
13	180	183	186	181	184	187	182	185	188
14	207	210	213	208	211	214	209	212	215
15	234	237	240	235	238	241	236	239	242
16	162	165	168	163	166	169	164	167	170
17	189	192	195	190	193	196	191	194	197
18	216	219	222	217	220	223	218	221	224
19	243	246	249	244	247	250	245	248	251
20	99	102	105	100	103	106	101	104	107
21	9	12	15	10	13	16	11	14	17
22	63	66	69	64	67	70	65	68	71
23	135	138	141	136	139	142	137	140	143
24	81	84	87	82	85	88	83	86	89
25	27	30	33	28	31	34	29	32	35
26	117	120	123	118	121	124	119	122	125
27	45	48	51	46	49	52	47	50	53

The interleaved bits of a sub-packet shall then be directly mapped to the symbols of the radio-burst:

- $m = 0 \dots 7$, are mapped to the symbols in PS_DA field

- $m = 8 \dots 19$, are mapped to the symbols in DATA_A field
- $m = 20 \dots 27$, are mapped to the symbols in PS_DB field

The DATA_B and DATA_C fields are not used.

4.7.4.5.2 Extension frame case in DLA mode

Interleaving of the extension frame shall also be done block-wise. The minimal input length of the interleaver is 216 bits which corresponds to the number of required data bits in one coded block of the extension frame. The maximum input length per block is 624 bits, thus not all symbols of the data fields in the radio-bursts are used.

Table 4-99 shall be used by the interleaver for mapping coded bits into the radio-burst, whereas:

- $s =$ sub-packet index $0 \dots S-1$
- $m =$ symbol index in radio-burst
- the numbers in the table represent the bit number of the PPDU (coded bits) of the extension frame

Table 4-99: DLA extension frame interleaver symbol mapping

m/s	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0	612	615	618	621	624	627	613	616	619	622	625	628	614	617	620	623	626	629
1	576	579	582	585	588	591	577	580	583	586	589	592	578	581	584	587	590	593
2	540	543	546	549	552	555	541	544	547	550	553	556	542	545	548	551	554	557
3	504	507	510	513	516	519	505	508	511	514	517	520	506	509	512	515	518	521
4	468	471	474	477	480	483	469	472	475	478	481	484	470	473	476	479	482	485
5	432	435	438	441	444	447	433	436	439	442	445	448	434	437	440	443	446	449
6	396	399	402	405	408	411	397	400	403	406	409	412	398	401	404	407	410	413
7	360	363	366	369	372	375	361	364	367	370	373	376	362	365	368	371	374	377
8	324	327	330	333	336	339	325	328	331	334	337	340	326	329	332	335	338	341
9	288	291	294	297	300	303	289	292	295	298	301	304	290	293	296	299	302	305
10	252	255	258	261	264	267	253	256	259	262	265	268	254	257	260	263	266	269
11	216	219	222	225	228	231	217	220	223	226	229	232	218	221	224	227	230	233
12 ... 19 PS_DA field																		
20	0	3	6	9	12	15	1	4	7	10	13	16	2	5	8	11	14	17
21	36	39	42	45	48	51	37	40	43	46	49	52	38	41	44	47	50	53
22	72	75	78	81	84	87	73	76	79	82	85	88	74	77	80	83	86	89
23	108	111	114	117	120	123	109	112	115	118	121	124	110	113	116	119	122	125
24	144	147	150	153	156	159	145	148	151	154	157	160	146	149	152	155	158	161
25	180	183	186	189	192	195	181	184	187	190	193	196	182	185	188	191	194	197
26	198	201	204	207	210	213	199	202	205	208	211	214	200	203	206	209	212	215
27	162	165	168	171	174	177	163	166	169	172	175	178	164	167	170	173	176	179
28	126	129	132	135	138	141	127	130	133	136	139	142	128	131	134	137	140	143
29	90	93	96	99	102	105	91	94	97	100	103	106	92	95	98	101	104	107
30	54	57	60	63	66	69	55	58	61	64	67	70	56	59	62	65	68	71
31	18	21	24	27	30	33	19	22	25	28	31	34	20	23	26	29	32	35
32 ... 39 PS_DB field																		
40	234	237	240	243	246	249	235	238	241	244	247	250	236	239	242	245	248	251
41	270	273	276	279	282	285	271	274	277	280	283	286	272	275	278	281	284	287
42	306	309	312	315	318	321	307	310	313	316	319	322	308	311	314	317	320	323
43	342	345	348	351	354	357	343	346	349	352	355	358	344	347	350	353	356	359
44	378	381	384	387	390	393	379	382	385	388	391	394	380	383	386	389	392	395
45	414	417	420	423	426	429	415	418	421	424	427	430	416	419	422	425	428	431
46	450	453	456	459	462	465	451	454	457	460	463	466	452	455	458	461	464	467
47	486	489	492	495	498	501	487	490	493	496	499	502	488	491	494	497	500	503
48	522	525	528	531	534	537	523	526	529	532	535	538	524	527	530	533	536	539
49	558	561	564	567	570	573	559	562	565	568	571	574	560	563	566	569	572	575
50	594	597	600	603	606	609	595	598	601	604	607	610	596	599	602	605	608	611
51	630	633	636	639	642	645	631	634	637	640	643	646	632	635	638	641	644	647

NOTE: Grey boxes are not used.

The interleaved bits of a sub-packet shall then be directly mapped to the symbols of the radio-burst:

- $m = 0 \dots 11$, are mapped to the symbols in data field DATA_B
- $m = 12 \dots 19$, are reserved for PS_DA field
- $m = 20 \dots 31$, are mapped to the symbols in data field DATA_A
- $m = 32 \dots 39$, are reserved for PS_DB field
- $m = 40 \dots 51$, are mapped to the symbols in data field DATA_C

If the number of bits is not a multiple of the number of sub-packets in the block, the sizes of the sub-packets differ inside of one block.

4.7.4.5.3 Sync data frame interleaving

After FEC, the coded block of the sync data frame shall be interleaved and assigned to the three sub-packets of the sync data frame according to Table 4-100.

Table 4-100: Sync Data frame interleaving and mapping

m/s	0	1	2		m/s	0	1	2		m/s	0	1	2
0	102	103	104		20	2	0	1		40	40	41	39
1	97	98	96		21	3	4	5		41	47	45	46
2	92	90	91		22	7	8	6		42	51	52	53
3	84	85	86		23	11	9	10		43	58	59	57
4	79	80	78		24	12	13	14		44	65	63	64
5	74	72	73		25	16	17	15		45	69	70	71
6	66	67	68		26	20	18	19		46	76	77	75
7	61	62	60		27	21	22	23		47	83	81	82
8	56	54	55		28	25	26	24		48	87	88	89
9	48	49	50		29	29	27	28		49	94	95	93
10	43	44	42		30	30	31	32		50	101	99	100
11	38	36	37		31	34	35	33		51	105	106	107
12...19	PS_A field				32...39	PS_B field							

The interleaved bits of a sub-packet shall then be directly mapped to the symbols of the radio-burst. PS_A and PS_B field of each radio-burst shall be filled with the pilot sequences according to Table 4-91.

4.7.4.5.4 Data Extension block interleaving for HDR burst structure

The coded blocks of an Extension frame in HDR burst structure shall be interleaved as for DLC DE coded blocks of a DLC frame with HDR burst structure (see clause 4.7.4.5.9).

4.7.4.5.5 Beacon core block interleaving

After whitening and FEC, the coded block of a beacon core shall be processed by the interleaving function, as specified in clause 4.7.4.5.1.

4.7.4.5.6 Beacon extension block interleaving

After whitening and FEC, the coded blocks of a beacon extension shall be processed by the interleaving function, as specified in clause 4.7.4.5.2.

4.7.4.5.7 Data Extension block interleaving of a DLB frame

After whitening and FEC, the coded blocks of a DLB frame shall be processed by the interleaving function, as specified in clause 4.7.4.5.2.

4.7.4.5.8 Data Extension block interleaving of a DLC frame

After whitening and FEC, the coded blocks of an extension frame in DLC shall be processed by the interleaving function, as specified in clause 4.7.4.5.2.

4.7.4.5.9 Data Extension block interleaving for DLC with HDR burst structure

The coded blocks of a DLC extension frame shall be interleaved according to Table 4-101, whereas:

- s = sub-packet index 0 ... S-1
- m = symbol index in radio-burst
- the numbers in the table represent the bit number of the coded blocks.

Table 4-101: DLC frame interleaver symbol mapping

m/s	0	1	2	3	4		m/s	0	1	2	3	4		m/s	0	1	2	3	4	
0	530	531	532	533	534		52	2	3	4	0	1		104	189	185	186	187	188	
1	521	522	523	524	520		53	13	14	10	11	12		105	195	196	197	198	199	
2	512	513	514	510	511		54	24	20	21	22	23		106	206	207	208	209	205	
3	503	504	500	501	502		55	30	31	32	33	34		107	217	218	219	215	216	
4	494	490	491	492	493		56	41	42	43	44	40		108	228	229	225	226	227	
5	480	481	482	483	484		57	52	53	54	50	51		109	239	235	236	237	238	
6	471	472	473	474	470		58	63	64	60	61	62		110	245	246	247	248	249	
7	462	463	464	460	461		59	74	70	71	72	73		111	256	257	258	259	255	
8	453	454	450	451	452		60	80	81	82	83	84		112	267	268	269	265	266	
9	444	440	441	442	443		61	91	92	93	94	90		113	278	279	275	276	277	
10	430	431	432	433	434		62	102	103	104	100	101		114	289	285	286	287	288	
11	421	422	423	424	420		63	113	114	110	111	112		115	295	296	297	298	299	
12	412	413	414	410	411		64	124	120	121	122	123		116	306	307	308	309	305	
13	403	404	400	401	402		65	130	131	132	133	134		117	317	318	319	315	316	
14	394	390	391	392	393		66	141	142	143	144	140		118	328	329	325	326	327	
15	380	381	382	383	384		67	152	153	154	150	151		119	339	335	336	337	338	
16	371	372	373	374	370		68	163	164	160	161	162		120	345	346	347	348	349	
17	362	363	364	360	361		69	174	170	171	172	173		121	356	357	358	359	355	
18	353	354	350	351	352		70	175	176	177	178	179		122	367	368	369	365	366	
19	344	340	341	342	343		71	166	167	168	169	165		123	378	379	375	376	377	
20	330	331	332	333	334		72	157	158	159	155	156		124	389	385	386	387	388	
21	321	322	323	324	320		73	148	149	145	146	147		125	395	396	397	398	399	
22	312	313	314	310	311		74	139	135	136	137	138		126	406	407	408	409	405	
23	303	304	300	301	302		75	125	126	127	128	129		127	417	418	419	415	416	
24	294	290	291	292	293		76	116	117	118	119	115		128	428	429	425	426	427	
25	280	281	282	283	284		77	107	108	109	105	106		129	439	435	436	437	438	
26	271	272	273	274	270		78	98	99	95	96	97		130	445	446	447	448	449	
27	262	263	264	260	261		79	89	85	86	87	88		131	456	457	458	459	455	
28	253	254	250	251	252		80	75	76	77	78	79		132	467	468	469	465	466	
29	244	240	241	242	243		81	66	67	68	69	65		133	478	479	475	476	477	
30	230	231	232	233	234		82	57	58	59	55	56		134	489	485	486	487	488	
31	221	222	223	224	220		83	48	49	45	46	47		135	495	496	497	498	499	
32	212	213	214	210	211		84	39	35	36	37	38		136	506	507	508	509	505	
33	203	204	200	201	202		85	25	26	27	28	29		137	517	518	519	515	516	
34	194	190	191	192	193		86	16	17	18	19	15		138	528	529	525	526	527	
35	180	181	182	183	184		87	7	8	9	5	6		139	539	535	536	537	538	
36 ... 51 PS_DA field							88 ... 103 PS_DB field													

The interleaved bits of a sub-packet shall then be directly mapped to the symbols of the radio-burst:

- $m = 0 \dots 35$, are mapped to the symbols in data field DATA_B
- $m = 36 \dots 51$, are reserved for PS_DA field
- $m = 52 \dots 87$, are mapped to the symbols in data field DATA_A

- $m = 88 \dots 103$, are reserved for PS_DB field
- $m = 104 \dots 139$, are mapped to the symbols in data field DATA_C

If the number of bits is not a multiple of the number of sub-packets in the block, the sizes of the sub-packets differ inside of one block.

4.7.4.5.10 DL-SB Mode (deprecated)

No interleaving is used in DL-SB Mode.

4.7.4.6 Modulation in downlink

4.7.4.6.1 DLA, DLB, and DLC modes

For DLA, DLB, and DLC modes, an MSK modulation or a GMSK modulation, with $BT = 1,0$ shall be used.

4.7.4.6.2 Modulation in DL-SB mode (deprecated)

For the DL-SB mode, a GFSK modulation with a symbol rate of 600 Baud and modulation index $h = 1$ (deviation 300 Hz) shall be used.

4.7.4.7 Symbol mapping in downlink

4.7.4.7.1 Symbol mapping in DLA, DLB, and DLC modes

The same symbol mapping as in uplink shall be used.

4.7.4.7.2 Symbol mapping in DL-SB mode (deprecated)

In DL-SB transmission mode, the BDU bits shall be mapped one bit per symbol (GFSK modulation).

4.7.4.8 Symbol rates in DLA, DLB, and DLC modes

The symbol rates of the (G)MSK modulation in DLA, DLB, and DLC modes shall be selected according to the definitions in Table 4-2 and the allowances in Table 4-3. The tolerance of the symbol rate shall be kept within a range defined in Table 4-157.

4.7.5 Common PHY functions

4.7.5.1 Introduction

There are common PHY functions which are used in different sections of the physical layer. They are described here to be referenced in the appropriate sections.

4.7.5.2 CRC

All 2-bit CRCs shall be calculated with the following parameters:

- 2-bit length (CRC-2)
- Polynomial: 0x3
- Initial value: 0x3
- No XOR

All 4-bit CRCs shall be calculated with the following parameters:

- 4-bit length (CRC-4)

- Polynomial: 0x3
- Initial value: 0xF
- No XOR

All 8-bit CRCs shall be calculated with the following parameters:

- 8-bit length (CRC-8)
- Polynomial: 0x9B
- Initial value for calculation: 0xFF
- No XOR

All 32-bit CRCs shall be calculated with the following parameters:

- 32-bit length (CRC-32)
- Polynomial: 0x4C11DB7
- Initial value for calculation: 0xFFFFFFFF
- No XOR

4.7.5.3 FEC

All FECs shall be calculated with the following parameters:

- Convolutional code
- Rate: 1/3
- Polynomials (0155, 0123, 0137) (octal), (0x6D, 0x53, 0x5F) (hex)
- Constraint length: 7
- Zero-tailing

4.7.5.4 FEC for staircase

FEC for the sync staircase data frame shall be calculated with the following parameters:

- Convolutional code
- Code rate: 1/2
- Polynomials (0171, 0133) (octal), (0x79, 0x5B) (hex)
- Constraint length: 7
- Zero-tailing

4.7.6 PHY procedures

4.7.6.1 TSMA schemes for ULZ and DLA transmission mode

4.7.6.1.1 Overview on ULZ and DLA

In the TS-UNB protocol, the application message is not transmitted in one radio-burst. The PPDU of the TS-UNB protocol in ULZ and DLA transmission modes shall be split into several radio-bursts, which are distributed over time and frequency (see Figure 4-33). The set of radio-bursts belonging to one message is called radio-frame. A radio frame is further divided into a core frame and an extension frame. The radio-bursts within a radio frame are spread over 24 or 25 carriers with a carrier spacing step size of B_c .

In the uplink core frame and the downlink core and extension frame, the way the radio-bursts are distributed over time and frequency is called TSMA pattern. A TSMA pattern consists of a set of carrier numbers and time spacings defining the transmission time and frequency of the radio-bursts within the radio-frame. The carrier numbers are chosen from a set of 24 carriers ($C=0\dots23$) with a carrier spacing of B_c . Carrier number $C=24$ shall be used only for the transmission of an optional Sync-Burst before the radio frames.

In the uplink extension frame, all 25 carriers are used for the transmission of a radio-burst. The carrier numbers and time spacings are derived from the CRC (see clause 4.7.6.1.7).

In uplink, the following TSMA pattern groups are possible:

- Uplink Pattern Group 1 (UPG1) with 8 patterns using 24 carriers ($C=0\dots23$), which shall be used if a radio-frame is transmitted once.
- Uplink Pattern Group 2 (UPG2) with 8 patterns using 24 carriers ($C=0\dots23$), which shall be used if the radio frame is repeated. The pattern group shall be used for both the initial transmission and repetition.
- Uplink Pattern Group 3 (UPG3) with 1 pattern using 24 carriers ($C=0\dots23$), which shall be used if a radio-frame is transmitted with low latency requirement. Repetition shall not be used with pattern of this group.
- Uplink Pattern Group 4 (UPG4) with 12 patterns using 8 carriers ($C=0\dots7$) for 200 kHz channel bandwidth and 24 carriers ($C=0\dots23$) otherwise, which shall be used if a radio-frame is transmitted at ULP8 symbol rate and concatenated radio-bursts. Repetition shall not be used with pattern of this group.
- Uplink Pattern Group 5 (UPG5) with 3 patterns using 8 carriers ($C=0\dots7$) for 200 kHz channel bandwidth and 24 carriers ($C=0\dots23$) otherwise, which shall be used if a radio-frame is transmitted at ULP8 symbol rate and concatenated radio-bursts and with low latency requirement. Repetition shall not be used with pattern of this group.
- Uplink Pattern Group 6 (UPG6) with 8 patterns using 24 carriers ($C=0\dots23$) shall be used for Low Power Drain End-point devices (LPDE). Repetition shall not be used with pattern of this group.

In downlink, one Downlink Pattern Group (DPG) is available for DLA transmission with standard radio-bursts and one pattern group for concatenated radio-bursts. For DLA transmission with HDR bursts, the carrier numbers and time spacings shall be calculated as defined in clause 4.7.6.1.13.

For the transmission of a radio-frame, one TSMA pattern of the pattern group shall be selected. The TSMA pattern shall vary from radio frame to radio frame. The start time T_0 and the start frequency f_0 of the TSMA pattern are varying between end-points. Individual radio-bursts of a TSMA pattern may be discarded.

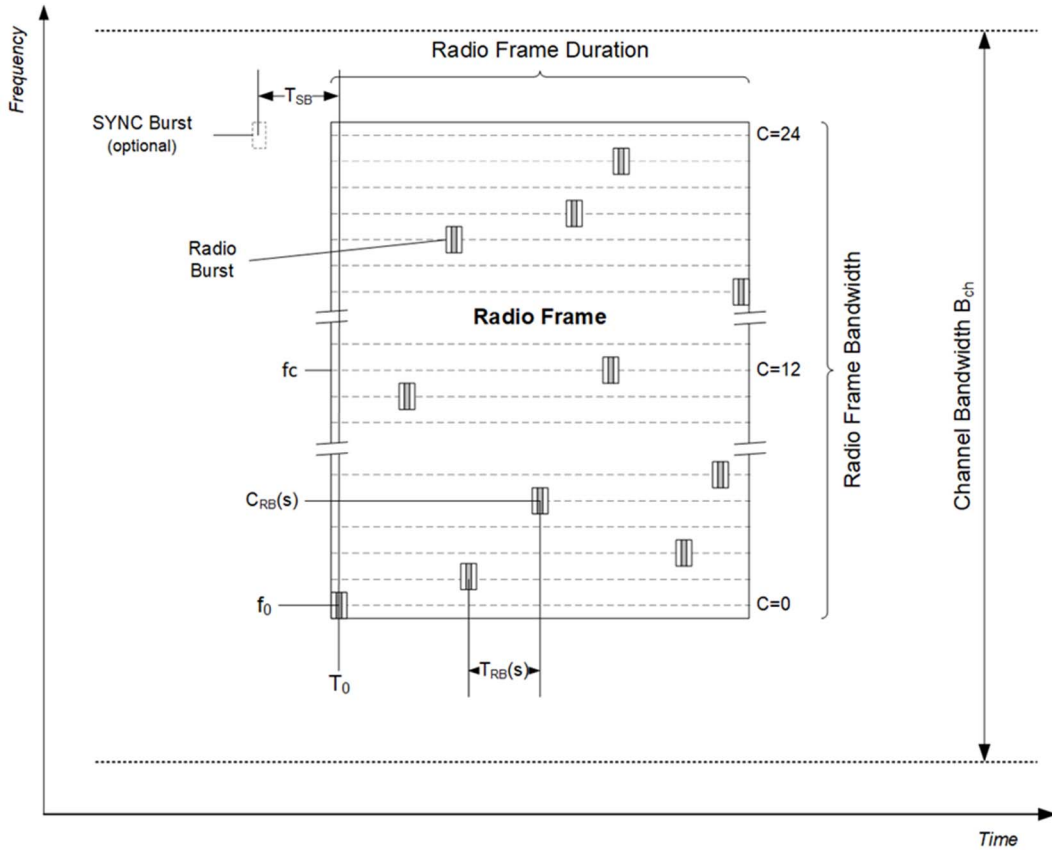


Figure 4-33: TSMA scheme of a radio frame

The radio frame shall be transmitted within the bandwidth B_{ch} of a channel with the channel centre frequency f_c taking crystal tolerances and pseudorandom carrier offset into account.

NOTE: If no frequency offset applies the nominal carrier frequency of carrier 12 is the centre frequency f_c of the channel.

The start frequency f_0 is the carrier frequency of carrier zero of the 24 carriers used by the TSMA pattern. It is derived from the channel centre frequency by:

$$f_0 = f_c - 12 * B_c + f_{offset}$$

The frequency offset f_{offset} is a variable radio-frame offset, which is calculated according to the following formula:

$$f_{offset} = C_{RF} * B_{C0}$$

where:

- B_{C0} is the frequency offset step of 2 380,371 Hz;
- C_{RF} is an additional frequency offset in number of frequency offset steps B_{C0} selected by the end-point and set for every radio-frame depending on the payload CRC.

The transmission frequency f_{RB} of a radio-burst (Radio-burst Frequency) is defined as:

$$f_{RB}(s) = f_0 + C_{RB}(s) * B_c + f_{middle}(s)$$

where:

- C_{RB} is the radio-burst carrier number according to the TSMA pattern chosen for the transmission of the radio-frame,
- B_c is the actual carrier spacing step size and defined as $B_c = N_{St} * B_{C0}$

The frequency offset $f_{Middle}(s)$ is a variable radio-frame offset, which is calculated according to the following formulae:

$$f_{Middle}(s) = \begin{cases} f_m(s) & \text{for TSMA mode} = \text{Medium} \\ 0 \text{ Hz} & \text{for all other TSMA modes} \end{cases}$$

$$f_m(s) = 12 * B_c + f_{RBoffset}(s)$$

$$f_{RBoffset}(s) = \begin{cases} -71\,411,130 \text{ Hz} & \text{for } 0 \leq C_{RB}(s) \leq 3 \\ -28\,564,452 \text{ Hz} & \text{for } 4 \leq C_{RB}(s) \leq 7 \end{cases}$$

Five different carrier spacing step sizes B_c according to Table 4-147 are available to address different radio regulations.

The carrier spacing accuracy shall be according to the tolerances given in clause 4.8.3.2.1.

If two radio channels A and B are used, the frame transmissions shall be alternated between the two channels. The channel to be used for transmission shall be derived from the least significant bit of the payload CRC according to Table 4-105.

4.7.6.1.2 Frame Repetition in UL

For performance improvement, a radio frame consisting of a core frame and extension frame may be repeated. The repeated radio frame rFRAME shall have the identical data format as the initial radio frame iFRAME. Both transmissions, iFRAME and rFRAME shall use the same TSMA pattern of the uplink TSMA pattern group UPG2 with a timeslot offset S_{RF} (see Figure 4-34).

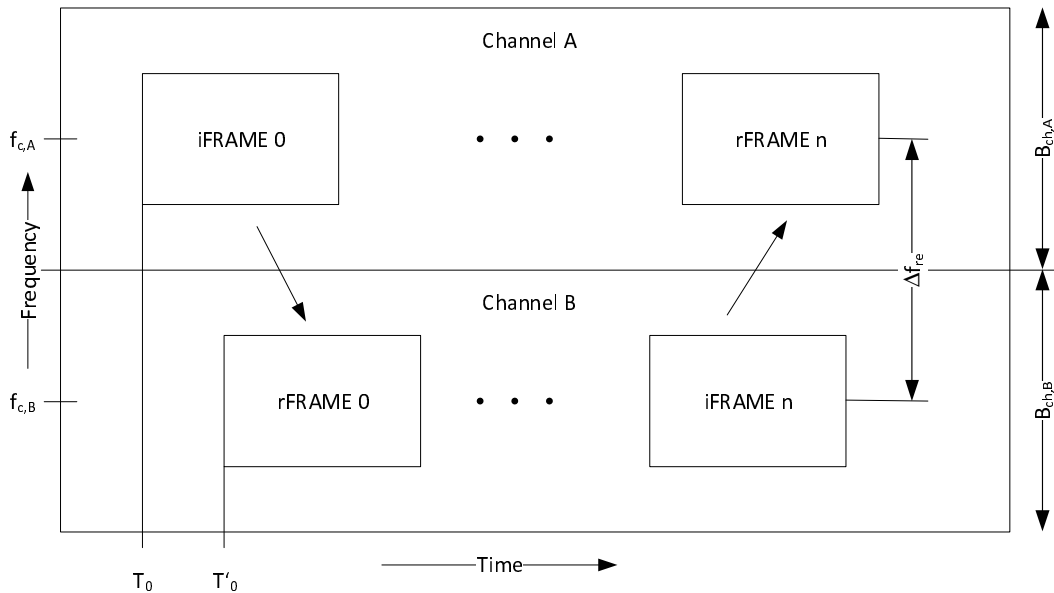


Figure 4-34: Frame transmission and repetition

Repetitions may be used in single and dual channel transmission mode. The repeated radio frame rFRAME shall have a fixed frequency offset Δf_{re} and a variable time offset $T'_0 - T_0$ according to clause 4.7.6.1.5 from the initial radio frame transmission. If single channel transmission is used Δf_{re} shall be (0).

If dual channel mode is used, the repetition shall always be transmitted in the frequency channel opposite to the initial iFRAME transmission with a frequency offset of:

$$\Delta f_{re} = N_{re} * B_c$$

where:

- N_{re} is the number of carrier frequency offset steps and is adjusted to the radio regulations (see profiles in annex B).

The base station may configure the end-point to repetition mode when attaching the end-point to the LTN network.

4.7.6.1.3 Frame repetition in DL

In DLA mode, only the core frame may be repeated. The downlink extension frame shall not be repeated. The repetition of the downlink core frame uses the second half of the downlink TSMA pattern.

NOTE: There is no repetition in DLB or DLC transmission mode.

4.7.6.1.4 Radio-burst timing in TSMA patterns

The start time T_0 of the first radio-burst $s=0$ of a radio frame is randomly chosen by the end-point.

T_0 shall be the middle point of the radio-burst, i.e. the middle of the pilot sequence in uplink, or the middle of the Data Field 0a in downlink.

The transmission time of radio-burst s is defined by $D_{RB}(s)$, the actual time distance between the middle point of radio-burst $s-1$ to the middle point of radio-burst s (see Figure 4-35).

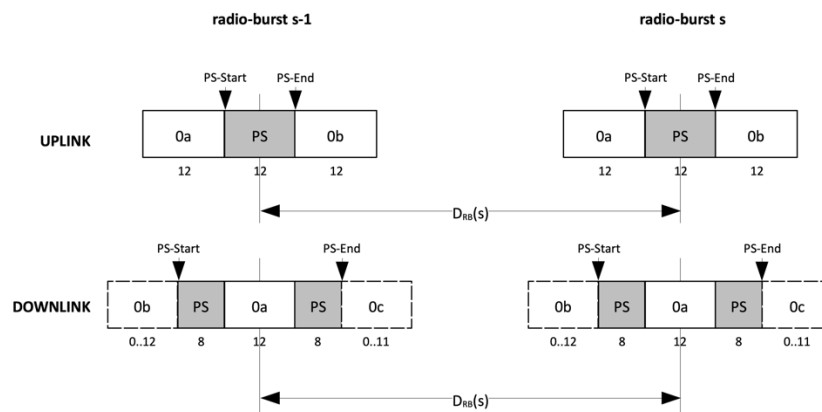


Figure 4-35: Definition of $D_{RB}(s)$, the actual time distance between consecutive radio-bursts

$D_{RB}(s)$ shall be expressed in number of symbols, according to formula:

$$D_{RB}(s) = T_{RB}(s) + D_{HB}(s)$$

where:

- $T_{RB}(s)$ is the TSMA radio-burst time distance, expressed as number of symbols, corresponding to the TSMA pattern chosen for ULZ transmission (see clauses 4.7.6.1.6 and 4.7.6.1.7), or for DLA transmission (see clauses 4.7.6.1.10 and 4.7.6.1.12),
- $D_{HB}(s)$ is an additional time distance, expressed as number of symbols, that implements timing flexibility in the half block, as specified in Table 4-102.

Table 4-102: Additional time distance for half-block timing flexibility

Transmission direction	Radio-burst number	$D_{HB}(s)$	Comment
uplink	$s \in \{1, 2, \dots, 23\}$	0	No half-block delay in UL
downlink	$s \neq 9$	0	
downlink	$s = 9$	ΔT_{hb}	Extra distance (see clause 4.7.6.1.11)

NOTE: $D_{RB}(s)$ is named $TD_{RB}(s)$ and $D_{HB}(s)$ is named $T_{offset}(s)$ in [i.15]

If an additional Sync-burst is used, it shall be transmitted one carrier spacing above the highest carrier ($C=24$) of the carrier group and T_{SB} symbols before radio-burst 0 of the uplink and downlink core frame (see Figure 4-36), as well as before radio-burst 0 of each block of the downlink extension frame. In that case, the time spacings T_{UPG1-6} in Table 4-103 shall be used for T_{SB} in ULZ and DLA mode.

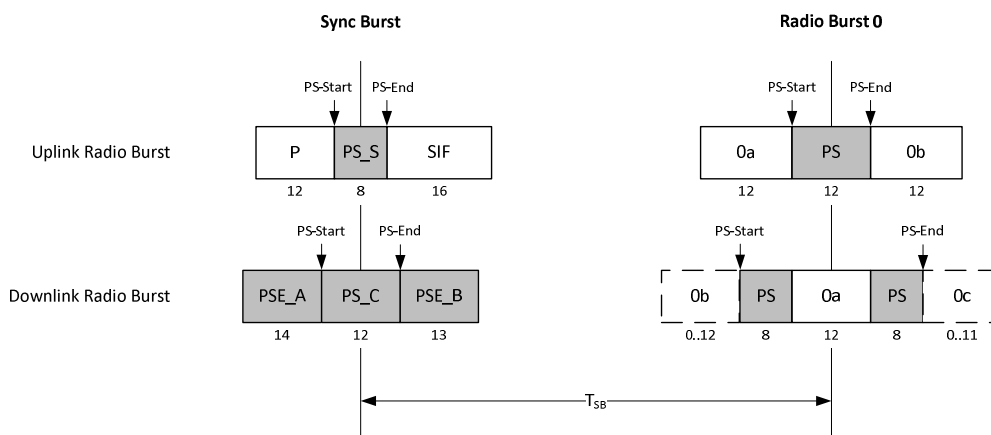


Figure 4-36: Definition of Sync-burst Time T_{SB}

The time spacing in Table 4-103 shall also be used for the calculation of radio-burst time in the uplink extension frame (see clause 4.7.6.1.7).

Table 4-103: Time spacings of Uplink Pattern Groups

Name	Time spacing
Uplink Pattern Group 1	$T_{UPG1} = 337$ symbols
Uplink Pattern Group 2	$T_{UPG2} = 337$ symbols
Uplink Pattern Group 3	$T_{UPG3} = 66$ symbols
Uplink Pattern Group 4	$T_{UPG4} = 1\,993$ symbols
Uplink Pattern Group 5	$T_{UPG5} = 419$ symbols
Uplink Pattern Group 6	$T_{UPG6} = 1\,904$ symbols

The end-point shall keep the radio-burst timing within a tolerance given in cause 4.8.3.

4.7.6.1.5 Time and frequency random offsets

Pseudo-random offsets in time and frequency derived from the header and payload CRC shall be added to the selected TSMA pattern start time and start frequency, as illustrated in Figure 4-37.

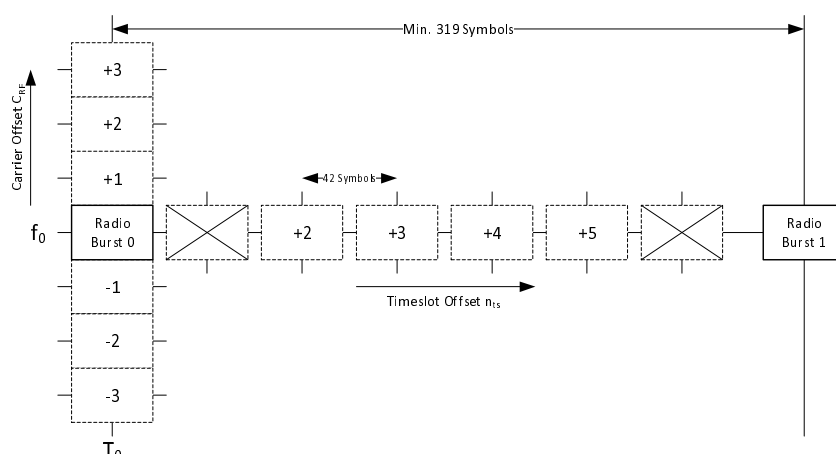


Figure 4-37: Definition of frame start offset parameter

The timeslot offset n_{ts} is given in an integer number of timeslots, where the timeslot duration is 42 actual symbols. The timeslot offset n_{ts} is calculated with the following formula:

$$n_{ts} = v_{ts} + 2$$

where:

- v_{ts} shall be derived from the header CRC, as specified in Table 4-104.

For the initial frame, the timeslot offset n_{ts} shall be 0 since the timeslot offset is used only for repetitions in uplink. For the repetition frame, the shifted start time T'_0 of the first radio-burst shall be calculated with the following formula:

$$T'_0 = T_0 + n_{ts} * 42 * \Delta T$$

Table 4-104: Use of Header CRC bits

Field length (in bits)	4	2	2
Value	0...15	/	0...3
Comment	the four most significant bits, used as downlink TSMA pattern selection value v_{TSDL}	not used	the two least significant bits, used as timeslot offset value v_{ts}

A frequency offset shall be added to the start frequency f_0 of the selected TSMA pattern for every frame transmission. The same frequency offset shall be used for initial frame and repetition frame. This frequency offset, expressed in integer multiples of the frequency offset steps B_{co} , is named carrier offset C_{RF} . It shall be calculated according to the following formula:

$$C_{RF} = (v_{co} \text{ modulo } n_{co}) - \lfloor n_{co}/2 \rfloor$$

where:

- v_{co} shall be derived from the payload CRC, as specified in Table 4-105
- n_{co} shall be selected according to Table 4-106 for ULZ and Table 4-107 for DLA

Table 4-105: Use of the Payload CRC bits

Field length (in bits)	7	1
Value	0...127	0 or 1
Comment	The seven most significant bits, used as v_{co} value	the least significant bit, used as channel selection for frame transmission (in two channel operation only) 0: channel A 1: channel B

Table 4-106: n_{co} selection table for ULZ

Symbol rate	ULP and ER	ULP and ER	ULP8	ULP8
Burst structure	standard	standard	concatenated	concatenated
Center frequency tolerance of end-point	above 10 ppm	equal or below 10 ppm	above 10 ppm	equal or below 10 ppm
n_{co}	3	11	1	5
Comment: (resulting carrier offset range)	$C_{RF} \in \{-1, 0, \dots, 1\}$	$C_{RF} \in \{-5, -4, \dots, 5\}$	$C_{RF} \in \{0\}$	$C_{RF} \in \{-2, -1, \dots, 2\}$

Table 4-107: n_{CO} selection table for DLA

Symbol rate	ULP and ER	ULP and ER	ULP2&	ULP8	ULP8	ULP8
Burst structure	standard	standard	concatenated	concatenated	HDR	HDR
Center frequency tolerance of end-point	above 10 ppm	equal or below 10 ppm	all values	all values	above 10 ppm	equal or below 10 ppm
n_{CO}	3	11	19	5	1	5
Comment: (resulting carrier offset range)	$C_{RF} \in \{-1, 0, \dots, 1\}$	$C_{RF} \in \{-5, -4, \dots, 5\}$	$C_{RF} \in \{-9, -8, \dots, 9\}$	$C_{RF} \in \{-2, -1, \dots, 2\}$	$C_{RF} \in \{0\}$	$C_{RF} \in \{-2, -1, \dots, 2\}$

NOTE: The carrier offset range is defined so that, together with the radio frame bandwidth and the centre frequency tolerance according to Table 4-155, the emission does not exceed the channel bandwidth.

At the beginning of the attach process (i.e. before the carrier offset range negotiation), the end-point shall use the lower carrier offset range, i.e. $n_{CO} = 3$.

Downlink TSMA pattern selection: the base station shall select the downlink TSMA pattern p_{TSDL} , according to the following formula:

$$p_{TSDL} = (v_{TSDL} \text{ modulo } (PGsize)) + 1$$

where:

- v_{TSDL} shall be derived from the header CRC of the received uplink transmission, as described in Table 4-104
- $PGsize$ is the number of patterns of the downlink pattern group.

Channel selection: If dual channel is used, the least significant bit of the Payload CRC shall be used for the selection of the channel, as described in Table 4-105.

4.7.6.1.6 Uplink TSMA pattern for core frame

The sets of radio-burst carrier $C_{RB}(s)$ and radio-burst time $T_{RB}(s)$ of the uplink TSMA pattern shall be according to Table 4-108, Table 4-109, Table 4-110, Table 4-111, Table 4-112, Table 4-113, Table 4-114, and Table 4-115, where s is the sub-packet index, as defined in clause 4.7.4.5, and p is the pattern number in the TSMA pattern group.

Table 4-108: Radio-burst carrier set of Uplink TSMA Pattern Group 1 (UPG1)

p \ s	$C_{RB}(s)$											
	0	1	2	3	4	5	6	7	8	9	10	11
1	5	21	13	6	22	14	1	17	9	0	16	8
2	4	20	12	1	17	9	0	16	8	6	22	14
3	4	20	12	3	19	11	6	22	14	7	23	15
4	6	22	14	2	18	10	7	23	15	0	16	8
5	7	23	15	4	20	12	3	19	11	2	18	10
6	3	19	11	6	22	14	2	18	10	0	16	8
7	3	19	11	1	17	9	5	21	13	7	23	15
8	0	16	8	6	22	14	3	19	11	2	18	10
p \ s	$C_{RB}(s)$											
	12	13	14	15	16	17	18	19	20	21	22	23
1	7	23	15	4	20	12	3	19	11	2	18	10
2	7	23	15	2	18	10	5	21	13	3	19	11
3	0	16	8	5	21	13	2	18	10	1	17	9
4	1	17	9	4	20	12	5	21	13	3	19	11
5	6	22	14	0	16	8	1	17	9	5	21	13
6	7	23	15	1	17	9	4	20	12	5	21	13
7	0	16	8	2	18	10	6	22	14	4	20	12
8	4	20	12	7	23	15	5	21	13	1	17	9

Table 4-109: Radio-burst time set of Uplink TSMA Pattern Group 1 (UPG1)

p \ s	$T_{RB}(s)$											
	1	2	3	4	5	6	7	8	9	10	11	12
1	330	387	388	330	387	354	330	387	356	330	387	432
2	330	387	435	330	387	409	330	387	398	330	387	370
3	330	387	356	330	387	439	330	387	413	330	387	352
4	330	387	352	330	387	382	330	387	381	330	387	365
5	330	387	380	330	387	634	330	387	360	330	387	393
6	330	387	364	330	387	375	330	387	474	330	387	355
7	330	387	472	330	387	546	330	387	501	330	387	356
8	330	387	391	330	387	468	330	387	512	330	387	543
p \ s	$T_{RB}(s)$											
	13	14	15	16	17	18	19	20	21	22	23	
1	330	387	352	330	387	467	330	387	620	330	387	
2	330	387	361	330	387	472	330	387	522	330	387	
3	330	387	485	330	387	397	330	387	444	330	387	
4	330	387	595	330	387	604	330	387	352	330	387	
5	330	387	352	330	387	373	330	387	490	330	387	
6	330	387	478	330	387	464	330	387	513	330	387	
7	330	387	359	330	387	359	330	387	364	330	387	
8	330	387	354	330	387	391	330	387	368	330	387	

Table 4-110: Radio-burst carrier set of Uplink TSMA Pattern Group 2 (UPG2)

p \ s	$C_{RB}(s)$											
	0	1	2	3	4	5	6	7	8	9	10	11
1	4	20	12	0	16	8	3	19	11	5	21	13
2	3	19	11	7	23	15	2	18	10	5	21	13
3	6	22	14	0	16	8	1	17	9	4	20	12
4	3	19	11	1	17	9	4	20	12	5	21	13
5	5	21	13	2	18	10	0	16	8	6	22	14
6	1	17	9	3	19	11	4	20	12	6	22	14
7	5	21	13	1	17	9	2	18	10	4	20	12
8	3	19	11	6	22	14	5	21	13	1	17	9

p \ s	$C_{RB}(s)$											
	12	13	14	15	16	17	18	19	20	21	22	23
1	1	17	9	7	23	15	2	18	10	6	22	14
2	4	20	12	0	16	8	1	17	9	6	22	14
3	3	19	11	5	21	13	2	18	10	7	23	15
4	2	18	10	7	23	15	6	22	14	0	16	8
5	7	23	15	1	17	9	4	20	12	3	19	11
6	7	23	15	5	21	13	2	18	10	0	16	8
7	3	19	11	0	16	8	6	22	14	7	23	15
8	7	23	15	2	18	10	0	16	8	4	20	12

Table 4-111: Radio-burst time set of Uplink TSMA Pattern Group 2 (UPG2)

p \ s	$T_{RB}(s)$											
	1	2	3	4	5	6	7	8	9	10	11	12
1	373	319	545	373	319	443	373	319	349	373	319	454
2	373	319	371	373	319	410	373	319	363	373	319	354
3	373	319	414	373	319	502	373	319	433	373	319	540
4	373	319	396	373	319	516	373	319	631	373	319	471
5	373	319	655	373	319	416	373	319	367	373	319	400
6	373	319	370	373	319	451	373	319	465	373	319	593
7	373	319	393	373	319	374	373	319	344	373	319	353
8	373	319	367	373	319	346	373	319	584	373	319	579

p \ s	$T_{RB}(s)$											
	13	14	15	16	17	18	19	20	21	22	23	
1	373	319	578	373	319	436	373	319	398	373	319	
2	373	319	379	373	319	657	373	319	376	373	319	
3	373	319	428	373	319	467	373	319	409	373	319	
4	373	319	457	373	319	416	373	319	354	373	319	
5	373	319	415	373	319	342	373	319	560	373	319	
6	373	319	545	373	319	380	373	319	365	373	319	
7	373	319	620	373	319	503	373	319	546	373	319	
8	373	319	519	373	319	351	373	319	486	373	319	

Table 4-112: Radio-burst carrier set of Uplink TSMA Pattern Group 3 (UPG3)

p \ s	$C_{RB}(s)$											
	0	1	2	3	4	5	6	7	8	9	10	11
1	1	5	4	3	2	17	21	20	19	18	9	13

p \ s	$C_{RB}(s)$											
	12	13	14	15	16	17	18	19	20	21	22	23
1	12	11	10	6	0	7	22	16	23	14	8	15

Table 4-113: Radio-burst time set of Uplink TSMA Pattern Group 3 (UPG3)

p	s	$T_{RB}(s)$											
		1	2	3	4	5	6	7	8	9	10	11	12
1		66	66	66	66	66	66	66	66	66	123	66	66
p	s	$T_{RB}(s)$											
		13	14	15	16	17	18	19	20	21	22	23	
1		66	66	60	66	66	198	66	66	255	66	66	

Table 4-114: Radio-burst carrier set of Uplink TSMA Pattern Group 6 (UPG6)

p	s	$C_{RB}(s)$											
		0	1	2	3	4	5	6	7	8	9	10	11
1		5	21	13	6	22	14	1	17	9	0	16	8
2		4	20	12	1	17	9	0	16	8	6	22	14
3		4	20	12	3	19	11	6	22	14	7	23	15
4		6	22	14	2	18	10	7	23	15	0	16	8
5		7	23	15	4	20	12	3	19	11	2	18	10
6		3	19	11	6	22	14	2	18	10	0	16	8
7		3	19	11	1	17	9	5	21	13	7	23	15
8		0	16	8	6	22	14	3	19	11	2	18	10
p	s	$C_{RB}(s)$											
		12	13	14	15	16	17	18	19	20	21	22	23
1		7	23	15	4	20	12	3	19	11	2	18	10
2		7	23	15	2	18	10	5	21	13	3	19	11
3		0	16	8	5	21	13	2	18	10	1	17	9
4		1	17	9	4	20	12	5	21	13	3	19	11
5		6	22	14	0	16	8	1	17	9	5	21	13
6		7	23	15	1	17	9	4	20	12	5	21	13
7		0	16	8	2	18	10	6	22	14	4	20	12
8		4	20	12	7	23	15	5	21	13	1	17	9

Table 4-115: Radio-burst time set of Uplink TSMA Pattern Group 6 (UPG6)

p	s	$T_{RB}(s)$											
		1	2	3	4	5	6	7	8	9	10	11	12
1		1 483	1 683	1 670	1 483	1 683	1 446	1 483	1 683	1 744	1 483	1 683	1 644
2		1 483	1 683	1 659	1 483	1 683	1 681	1 483	1 683	1 745	1 483	1 683	1 464
3		1 483	1 683	1 604	1 483	1 683	1 756	1 483	1 683	1 782	1 483	1 683	1 697
4		1 483	1 683	1 734	1 483	1 683	1 519	1 483	1 683	1 403	1 483	1 683	1 397
5		1 483	1 683	1 803	1 483	1 683	1 473	1 483	1 683	1 796	1 483	1 683	1 464
6		1 483	1 683	1 481	1 483	1 683	1 528	1 483	1 683	1 582	1 483	1 683	1 511
7		1 483	1 683	1 524	1 483	1 683	1 555	1 483	1 683	1 481	1 483	1 683	1 350
8		1 483	1 683	1 358	1 483	1 683	1 546	1 483	1 683	1 379	1 483	1 683	1 680
p	s	$T_{RB}(s)$											
		13	14	15	16	17	18	19	20	21	22	23	
1		1 483	1 683	1 409	1 483	1 683	1 444	1 483	1 683	1 634	1 483	1 683	
2		1 483	1 683	1 753	1 483	1 683	1 368	1 483	1 683	1 439	1 483	1 683	
3		1 483	1 683	1 441	1 483	1 683	1 450	1 483	1 683	1 349	1 483	1 683	
4		1 483	1 683	1 571	1 483	1 683	1 539	1 483	1 683	1 350	1 483	1 683	
5		1 483	1 683	1 399	1 483	1 683	1 491	1 483	1 683	1 372	1 483	1 683	
6		1 483	1 683	1 645	1 483	1 683	1 677	1 483	1 683	1 605	1 483	1 683	
7		1 483	1 683	1 389	1 483	1 683	1 754	1 483	1 683	1 762	1 483	1 683	
8		1 483	1 683	1 427	1 483	1 683	1 476	1 483	1 683	1 404	1 483	1 683	

For UPG1 or UPG2 an end-point shall use at least six patterns of a TSMA pattern group and may use all eight patterns over multiple transmissions.

Pattern Group UPG3 shall be used only for the transmission of a radio frame with low latency.

Pattern group UPG4 and UPG5 are used for transmissions with ULP8 symbol rate. An end-point shall use all TSMA pattern of a pattern group.

Pattern Group UPG6 shall be used for Low Power Drain End-point devices (LPDE).

4.7.6.1.7 Uplink TSMA pattern for extension frame

The TSMA pattern for the extension frame is derived from information of the core frame. The TSMA pattern of the extension frame is generated using a pseudo random number derived from the core frame information.

A 16-bit Linear Feedback Shift Register (LFSR) shall be used to generate a random number $R[s_e]$ for every s_e -th radio-burst of the extension frame. The initial 16-bit seed for this LFSR $R[0]$ shall be as specified in Table 4-116.

Table 4-116: LFSR Seed R[0]

Field length (in bits)	1	7	8
Field content	1	the seven least significant bits of the Header CRC	Payload CRC

The polynomial for the Galois-LFSR in hexadecimal notation shall be (0xB4F3). For every radio-burst of the extension frame, the LFSR shall be applied to derive the next 16-bit number. For radio-burst s_e of the extension frame, the number is given by:

$$R[s_e] = LFSR(R[s_e - 1])$$

Where s_e shall be (1) for the first radio-burst of the extension frame. The radio-burst time of radio-burst s_e in the extension frame shall be calculated by:

$$T_{RB}[s_e] = (T_{UPGx} + (R[s_e] \text{ modulo } 128)) * T_{symUL-ULP}$$

where:

- T_{UPGx} shall be the time spacing of the selected uplink pattern group x, the transmitted core was part of, according to Table 4-103

For the first radio-burst in the extension frame, this time denotes the delay between the centre of the pilot symbols of the last radio-burst of the core frame and the centre of the pilot symbols of the first radio-burst of the extension frame. The radio-burst carrier number for deriving the transmission frequency of the radio-burst of the extension frame shall be calculated by:

$$C_{RB}[s_e] = [(R[s_e]/256)] \text{ modulo } 25$$

For repetition the same values are used for initial transmission and repetition of the frame.

4.7.6.1.8 Specific case of TSMA pattern for DL-SB mode (deprecated)

In DL-SB Mode, no telegram splitting shall be used. Hence for the transmission of a radio-burst the carrier offset $C_{RF}(s = 0)$ from the selected pattern of TSMA pattern group shall be used for core and extension frame.

4.7.6.1.9 Uplink TSMA Pattern for ULP8 symbol rate

For ULP8 symbol rate, the occupied bandwidth of the transmitted signal is broader compared to ULP symbol rate, thus to realize non overlapping radio-burst transmission, the carrier spacing is increased according to Table 4-147. For the standard channel bandwidth of 200 kHz, only 8 carriers are available.

For transmission in ULP8 symbol rate, three radio-bursts are concatenated. The T_{RB} time shall then refer to the centre of the second radio-burst of the set of three concatenated radio-bursts (see Figure 4-38).

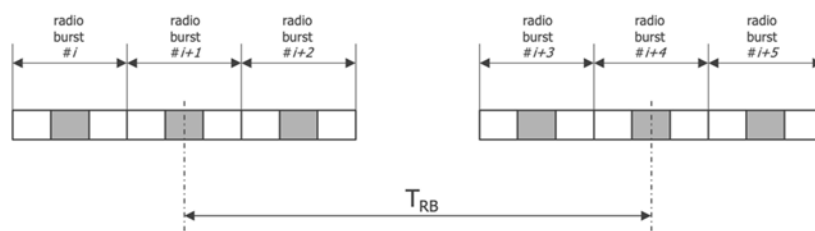


Figure 4-38: T_{RB} definition with concatenated radio-bursts

For the various ULP8 cases in uplink, the sets of radio-burst carrier $C_{RB}(s)$ and radio-burst time $T_{RB}(s)$ of TSMA patterns shall be according to Table 4-117, Table 4-118, Table 4-119, Table 4-120, Table 4-121, and Table 4-122, where s is the sub-packet index, as defined in clause 4.7.4.5, and p is the pattern number in the TSMA pattern group.

Table 4-117: Radio-burst carrier set of Uplink TSMA Pattern Group 4 (UPG4) for extended TSMA mode

p \ s	$C_{RB}(s)$							
	0	1	2	3	4	5	6	7
1	2	3	5	7	1	0	4	6
2	4	5	0	3	6	2	7	1
3	6	3	0	5	4	2	7	1
4	0	3	6	1	4	7	2	5
5	1	3	7	5	2	6	4	0
6	7	4	5	2	6	3	1	0
7	7	6	2	0	1	5	4	3
8	7	3	0	5	6	1	2	4
9	2	6	7	5	0	4	1	3
10	0	2	4	6	1	7	5	3
11	6	1	0	7	2	3	5	4
12	1	7	2	6	0	3	4	5

Table 4-118: Radio-burst carrier set of Uplink TSMA Pattern Group 4 (UPG4) for wide TSMA mode

p \ s	$C_{RB}(s)$							
	0	1	2	3	4	5	6	7
1	23	7	20	14	1	21	15	18
2	12	16	5	11	19	6	22	4
3	3	17	0	10	13	9	2	8
4	0	9	18	3	12	21	6	15
5	4	10	22	16	7	19	13	1
6	23	14	17	8	20	11	5	2
7	21	18	6	2	4	15	12	10
8	23	9	1	16	20	3	7	14
9	8	19	22	17	0	13	5	11
10	0	6	14	18	3	22	16	9
11	19	5	2	21	8	11	17	12
12	4	23	7	20	1	10	13	15

Table 4-119: Radio-burst time set of Uplink TSMA Pattern Group 4 (UPG4)

p \ s	$T_{RB}(s)$ (expressed as number of actual symbols)						
	1	2	3	4	5	6	7
1	1 904	2 171	3 504	3 237	2 704	2 459	2 971
2	2 971	3 504	2 459	1 904	2 704	2 171	3 237
3	2 971	2 171	2 704	3 504	3 237	2 459	1 904
4	1 904	2 171	2 459	2 704	2 971	3 237	3 504
5	3 504	2 459	2 704	1 904	2 171	3 237	2 971
6	3 504	2 171	2 704	1 904	3 237	2 971	2 459
7	2 171	3 504	1 904	2 459	3 237	2 971	2 704
8	2 459	2 971	3 237	3 504	1 904	2 704	2 171
9	2 971	3 237	2 459	2 704	3 504	2 171	1 904
10	2 704	2 459	1 904	3 237	2 971	3 504	2 171
11	2 171	1 904	2 971	3 504	2 704	3 237	2 459
12	2 459	2 971	1 904	2 171	2 704	3 237	3 504

Table 4-120: Radio-burst carrier set of Uplink TSMA Pattern Group 5 (UPG5) for extended TSMA mode

p \ s	$C_{RB}(s)$							
	0	1	2	3	4	5	6	7
1	0	2	4	7	5	1	6	3
2	6	3	1	7	5	2	4	0
3	4	6	5	2	0	3	7	1

Table 4-121: Radio-burst carrier set of Uplink TSMA Pattern Group 5 (UPG5) for wide TSMA mode

p \ s	$C_{RB}(s)$							
	0	1	2	3	4	5	6	7
1	1	8	14	22	17	5	12	3
2	18	4	9	13	15	11	20	0
3	23	19	16	6	2	10	21	7

Table 4-122: Radio-burst time set of Uplink TSMA Pattern Group 5 (UPG5)

p \ s	$T_{RB}(s)$ (expressed as number of actual symbols)						
	1	2	3	4	5	6	7
1	756	688	823	892	621	552	406
2	553	484	756	892	823	688	542
3	877	744	809	477	543	677	611

For the calculation of the extension time and frequency hopping pattern for uplink with ULP8 symbol rate only one T_{RB} and C_{RB} value shall be calculated in the LFSR according to clause 4.7.6.1.7 for one set of three concatenated radio-burst. The T_{RB} time then shall refer to the centre of the second radio-burst of the set of three concatenated radio-bursts. If the last radio-burst does not carry 3 radio-bursts, it shall be assumed that the last radio-burst carry 3 radio-bursts for the timing calculation.

In case of wide TSMA mode, a Sync-Burst shall be transmitted. As there is only one Sync-Burst, it is not possible to concatenate it with other radio-bursts. For timing calculation the centre of the single Sync-Burst burst shall be used. The Sync-Burst reference time shall be T_{UPGx} symbol durations before the centre of the second radio-burst of first set of three concatenated radio-bursts in the core frame.

For the calculation of the extension frame frequency hopping C_{RB} for the extended TSMA mode in 200 kHz channel width, the following formula shall be used:

$$C_{RB}[s_e] = \lfloor (R[s_e]/256) \rfloor \text{ modulo } 8$$

For the wide channel, the formula changes to:

$$C_{RB}[s_e] = \lfloor (R[s_e]/256) \rfloor \text{ modulo } 25$$

4.7.6.1.10 Downlink TSMA patterns for normal radio-bursts

When ULP symbol rate is used for DLA transmission, a radio frame consists of 18 radio-bursts. Therefore, TSMA pattern sets with 18 parameters according to Table 4-123 and Table 4-124 shall be used.

Table 4-123: Radio-burst carrier set of TSMA Pattern Group in downlink (DPG)

s \ p	$C_{RB}(s)$																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	19	18	12	21	15	14	22	2	5	10	17	6	8	4	7	20	13	0
2	10	4	1	7	23	6	3	8	17	2	18	9	22	14	11	16	5	21
3	0	16	11	20	9	13	23	21	2	19	1	15	3	7	12	4	22	6
4	14	9	0	15	7	5	8	18	1	12	19	23	17	16	10	2	13	11
5	6	12	19	10	4	22	13	17	11	5	23	3	1	8	14	0	9	20
6	16	20	3	5	21	10	17	1	12	18	15	11	0	9	2	14	6	8
7	15	0	8	18	9	23	11	20	14	3	16	22	19	13	7	21	12	4
8	4	7	16	22	13	19	2	3	6	15	10	20	23	5	21	17	18	1

Table 4-124: Radio-burst time set of TSMA Pattern Group in downlink (DPG)

s \ p	$T_{RB}(s)$																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	471	595	594	496	545	445	440	535	601	522	430	545	519	439	484	438	605	
2	512	424	649	447	550	611	624	418	501	464	606	509	636	443	465	434	431	
3	625	548	540	434	520	559	488	531	501	465	459	428	444	459	505	459	633	
4	457	489	612	450	457	440	567	538	516	514	540	474	592	445	577	444	493	
5	488	643	626	541	560	550	450	475	520	456	618	447	455	440	455	510	477	
6	548	444	459	529	453	525	440	553	583	527	520	461	575	457	464	533	421	
7	461	607	501	534	505	569	561	472	509	450	555	440	423	494	448	525	485	
8	577	611	464	552	451	508	478	438	443	507	420	553	520	576	580	564	404	

The downlink transmission shall start at predefined time (see clause 4.6.8.1) after an uplink transmission.

The start frequency $f_{0,DL}$ of the DL TSMA pattern is determined as:

$$f_{0,DL} = f_{0,ULRX} + f_{DL-UL} + f_{offset}$$

where:

- $f_{0,ULRX}$ is the start frequency of the received radio frame in the base station excluding uplink carrier offset C_{RF}
- f_{DL-UL} is the offset frequency between uplink channel and downlink channel centre frequency
- f_{offset} is the frequency offset of the downlink

The TSMA pattern number for downlink transmission to the end-point shall be derived from the header CRC according to clause 4.7.6.1.5.

The same TSMA pattern shall be used for the core frame and each block of the extension frame. The start time of the extension frame may vary and shall be indicated by the TSI field in the core frame.

4.7.6.1.11 Timing flexibility procedure

The timing flexibility procedure is available for DLA transmission only. It impacts the three downlink transmission delays (see Figure 4-39):

- the delay between the DLA core block and the first DLA extension block
- the delay between two successive extension blocks in a DLA extension frame
- an additional delay within each block of the DLA extension frame, i.e. an additional delay between the ninth radio-burst (numbered 8) and the tenth radio-burst (numbered 9)

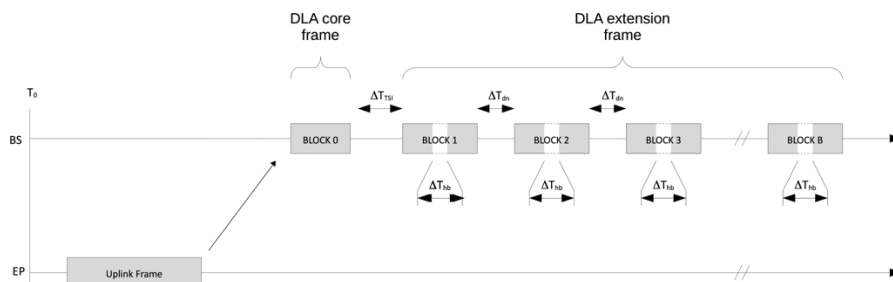


Figure 4-39: Timing flexibility in DLA frame

The base station shall indicate the use of timing flexibility by setting the FTM flag to one (see clause 4.7.2.4), on a DLA frame per DLA frame basis.

Formulae, for delays in case of timing flexibility, include correction factors that shall depend on actual symbol rate, as specified in Table 4-125.

Table 4-125: Correction factors related to timing flexibility

Acronym	Correction factor Name	Symbol rate		
		ULP	ULP2	ULP8
N_{SAF}	Symbol adaptation factor	1	2	8
N_{TAF}	Timing adaptation factor	1	1	2
N_{st}	Stretching factor	1	2	2

NOTE: The delay ranges allowed by timing flexibility are illustrated in Table 4-126.

Table 4-126: Informative delay ranges of timings (in seconds)

		Downlink symbol rate							
		ULP with NO flexibility		ULP with flexibility		ULP2 with flexibility		ULP8 with flexibility	
		min	max	min	max	Min	max	min	max
Flexible delays (approx. values in seconds)	ΔT_{tsi}	0,035	28	0,21	27	0,11	13	0,054	6,7
	ΔT_{dn}	0,21	3,0	0,21	28	0,11	14	0,054	7,0
	ΔT_{hb}	/	/	0	27	0	13	0	3,3

NOTE: The elements in this table are for information only.

4.7.6.1.12 Downlink TSMA patterns for concatenated radio-bursts

When ULP2 or ULP8 symbol rates are used for DLA transmission together with burst concatenation, the sets of three consecutive radio-bursts of the core frame and the extension frame are seamlessly joint together over the air, thanks to specific TSMA pattern tables for the frequency selection and for the radio-burst time selection.

Frequency selection

The concatenated radio-bursts shall use one of the frequency patterns, as specified in Table 4-127.

Table 4-127: Carrier sets for DPG with ULP2 and ULP8 symbol rates

s	$C_{RB}(s)$																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0	0	21	21	21	7	7	7	16	16	16	4	4	4	19	19	19
2	23	23	23	4	4	4	13	13	13	22	22	22	2	2	2	10	10	10
3	3	3	3	11	11	11	20	20	20	5	5	5	14	14	14	9	9	9
4	13	13	13	20	20	20	1	1	1	15	15	15	8	8	8	17	17	17
5	16	16	16	2	2	2	10	10	10	23	23	23	6	6	6	18	18	18
6	5	5	5	19	19	19	3	3	3	11	11	11	21	21	21	12	12	12
7	14	14	14	7	7	7	22	22	22	9	9	9	17	17	17	0	0	0
8	12	12	12	18	18	18	6	6	6	1	1	1	15	15	15	8	8	8

Timing Selection

In case of ULP2 (resp. ULP8) symbol rate, the TSMA radio-burst time distance T_{RB} shall be selected in Table 4-128 (resp. Table 4-129).

Table 4-128: Raw radio-burst time sets for DPG with ULP2 symbol rate

s	$T_{RB}(s)$ (expressed as number of actual symbols)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17																			
1	core frame: $T_{RB} = 28$	250	core frame: $T_{RB} = 28$	175	core frame: $T_{RB} = 28$	200	225	core frame: $T_{RB} = 28$	250	core frame (see note): $T_{RB} = 28$	225	core frame (see note): $T_{RB} = 28$	150	175	core frame (see note): $T_{RB} = 28$	200	225	core frame (see note): $T_{RB} = 28$																		
2																			150	225	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	
3																			225	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	150	225
4																			175	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	150	225
5	extension frame: see below	200	extension frame: see below	175	extension frame: see below	225	250	extension frame: see below	150	extension frame: see below	225	250	extension frame: see below	150	extension frame: see below	225	250	extension frame: see below																		
6																			175	225	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	
7																			225	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	150	225
8																			150	225	250	200	175	150	225	150	225	150	225	150	225	150	225	150	225	150

NOTE: Applicable only in case of frame repetition.

Table 4-129: Raw radio-burst time set for DPG with ULP8 symbol rate

s	$T_{RB}(s)$ (expressed as number of actual symbols)																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17																			
1	core frame: $T_{RB} = 28$	500	core frame: $T_{RB} = 28$	350	core frame: $T_{RB} = 28$	400	450	core frame: $T_{RB} = 28$	500	core frame (see note): $T_{RB} = 28$	450	core frame (see note): $T_{RB} = 28$	300	350	core frame (see note): $T_{RB} = 28$	400	450	core frame (see note): $T_{RB} = 28$																		
2																			300	450	500	400	350	300	450	300	450	300	450	300	450	300	450	300	450	
3																			450	500	400	350	300	450	300	450	300	450	300	450	300	450	300	450	300	450
4																			350	500	400	350	300	450	300	450	300	450	300	450	300	450	300	450	300	450
5	extension frame: see below	400	extension frame: see below	350	extension frame: see below	500	550	extension frame: see below	400	extension frame: see below	550	600	extension frame: see below	450	extension frame: see below	600	650	extension frame: see below																		
6																			400	550	600	500	450	400	550	400	550	400	550	400	550	400	550	400	550	
7																			550	600	500	450	400	550	400	550	400	550	400	550	400	550	400	550	400	550
8																			450	600	500	450	400	550	400	550	400	550	400	550	400	550	400	550	400	550

NOTE: Applicable only in case of frame repetition.

NOTE 1: In the core frame, $T_{RB}(1)$ and $T_{RB}(2)$ are constant and equal to 28 symbols, because radio-bursts are the same size.

The equivalent applies to the other $T_{RB}(s)$ pairs (i.e. $s = \{4,5\}, \{7,8\}, \{10,11\}, \{13,14\}, \{16,17\}$).

NOTE 2: T_{RB} with $s \in \{3,6,9,12,15\}$ are fixed values; they represent the "inter-group" time distances.

In the extension frame, the $T_{RB}(s)$ pairs with $s = \{1,2\}, \{4,5\}, \{7,8\}, \{10,11\}, \{13,14\}, \{16,17\}$ depend on the actual size of the concatenated radio-bursts, which themselves depend on the length of the DATA_B and DATA_C fields derived from the payload size. The $T_{RB}(s)$ pairs shall be evaluated in three steps, as follows:

First step

An index vector $I(i)$ shall be derived from the interleaving scheme, as follows:

$$I(i) = 3(i \text{ modulo } 6) + \left\lfloor \frac{i}{6} \right\rfloor + 15 \cdot \left\lfloor \frac{i}{18} \right\rfloor \quad \text{for } i \in \{0,1, \dots, 647\}$$

Second step

Let $d_B(m, s)$ denote symbol index $m \in \{0,1, \dots, 11\}$ of DATA_B of radio-burst s , which shall be filled with the interleaved data corresponding to:

$$d_B(m, s) = I(s + (2 \cdot m + 12) \cdot 18) \quad \text{for } s \in \{0,1, \dots, 17\}, \quad m \in \{0,1, \dots, 11\}$$

Accordingly, $d_C(m, s)$ denotes the interleaved symbols of DATA_C and shall be filled according to:

$$d_C(m, s) = I(s + 18 + (2 \cdot m + 12) \cdot 18) \quad \text{for } s \in \{0,1, \dots, 17\}, \quad m \in \{0,1, \dots, 11\}$$

Third step

$T_{RB}(s)$, $s \in \{1,2,4,5,7,8,10,11,13,14,16,17\}$ in Table 4-128 and in Table 4-129 shall be calculated for the individual blocks according to:

$$T_{RB}(b, s) = 28 + \sum_{m=0}^{11} \text{int} \left(d_C(m, s-1) < n_{bit}^{coded}(b) \right) + \text{int} \left(d_B(m, s) < n_{bit}^{coded}(b) \right)$$

$$\text{for } b \in \{1, \dots, B\}, \quad s \in \{1,2,4,5,7,8,10,11,13,14,16,17\},$$

where:

- $d < n$ is a boolean expression, that returns true or false as result
- the operator $\text{int}()$ yields a numeric "1" if the result of the operation " $<$ " is boolean true and a numeric "0" if it is false
- B is the number of extension frame blocks that are used for the transmission. It is given by the formula:

$$B = \left\lfloor \frac{P}{24} \right\rfloor \quad P \in \{1,2 \dots 255\} \text{ is PSDU size in byte.}$$

- n_{bit}^{coded} is the number of encoded bits after the forward error correction assigned to block b . It is given by the formula:

$$n_{bit}^{coded}(b) = (8 \cdot n_{byte}(b) + 10 + 6) \cdot 3 \quad \text{for } b \in \{1, \dots, B\}$$

where:

- $n_{byte}(b)$ is the number of PSDU data bytes assigned to one block. In case the PSDU sizes P is not a multiple of the number of blocks B , the remaining bytes $n_r = P - \left\lfloor \frac{P}{B} \right\rfloor \cdot B$ shall be assigned to the blocks in ascending order, as follows:

$$n_{byte}(b) = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor + 1, & \text{for } b \leq n_r \\ \left\lfloor \frac{P}{B} \right\rfloor, & \text{for } b > n_r \end{cases} \quad \text{for } b \in \{1, \dots, B\}$$

NOTE 3: These three steps determine the length of each burst data field (DATA_B or DATA_C) and therefore the T_{RB} . Depending on the length of the PSDU, transmission times T_{RB} ranges from 28 to 51 actual symbols.

NOTE 4: An example of how the initial transmission time T_{RB} is calculated based on the PSDU size P is given annex D.

4.7.6.1.13 Downlink TSMA patterns for HDR burst structure

The downlink TSMA patterns for HDR radio-bursts may be used in class A mode with ULP8 symbol rate. The TSMA pattern are calculated dynamically based on some parameters of the corresponding uplink message of an end-point, which is only known to the base station and the end-point.

A 32-bit BSSH number according to Table 4-130 is composed of the 16 LSB of the unique EP-EUI, which is constant for each end-point, and a 16-bit pseudo-random number consisting of the content of a 16-bit Linear Feedback Shift Register (LFSR).

Table 4-130: BSSH number format (32-bit)

Serialization order	#0 to #15	#16 to #31
Content	R_b [0-15]	EP-EUI [48-63]

$R_b(n)$ denotes the content of the linear feedback shift register for the n -th run of the linear feedback shift register. The most significant bit (MSB) of the 32-bit number corresponds to bit index 0. At the beginning of each Class A ULP8 downlink message the seed $s = R(0)$ of the linear feedback shift register shall be initialized according to Table 4-131, whereby the CRC Header and the CRC Payload are derived from the corresponding uplink message. From the Header CRC only 7 LSB shall be used.

Table 4-131: Initial linear feedback shift register value $s=R(0)$

Serialization order	#0	#1 to #7	#8 to #15
Content	1	CRC Header of UL	CRC Payload of UL

The basic operation of the 16-bit linear feedback shift register is defined in clause 4.7.6.1.7. The polynomial for the Galois-LFSR in hexadecimal notation shall be 0xD09B. For each run n the content of the shift register, which is directly mapped to the upper 16 bits of the BSSH number, is computed based on one shift operation of the linear feedback shift register, i.e.:

$$R(n) = \text{LFSR}(R(n-1)), \quad n \in \{1, 2, \dots\}$$

following the same notation as used in clause 4.7.6.1.7.

The content of the 32-bit BSSH number shall be pseudo-randomized by applying a 32-bit CRC operation to it, which is denoted as CRC32(...). The definition of the CRC calculation follows the notation in clause 4.7.5.2. A CRC of length 32 bits shall be computed based on the polynomial 0x4C11DB7, the initial value for calculation is 0xFFFFFFFF, no XOR is applied:

$$\text{BSSH_CRC} = \text{CRC32}(\text{BSSH_counter}).$$

The result is denoted as BSSH_CRC according to Table 4-132. The bits shall be processed in ascending order and the unsigned integer CRC field shall be applied with the highest term (MSB) first.

Table 4-132: BSSH_CRC and format

Serialization order	#0 to #31
Content	BSSH_CRC [0-31]

Frequency selection

The number of available carriers C_{max} depends on the carrier spacing defined by the TSMA mode in uplink. If the extended TSMA mode is used the channel bandwidth B_{CH} shall be 200 kHz. If wide TSMA mode is used, the channel bandwidth B_{CH} is 750 kHz.

Table 4-133: Number of available carriers C_{max}

B_{CH}	C_{max}	Description
200 kHz	8	carrier spacing for Extended TSMA mode (e.g. EU1)
750 kHz	25	carrier spacing for Wide TSMA mode (e.g. EU2, US0)

The carrier frequency of a radio-burst is defined by the carrier number. The carrier number shall be derived from the 32-bit unsigned number BSSH_CRC. The carrier number of the corresponding radio-burst shall be calculated by:

$$C_{RB}(m) = \lfloor C_{max} * \text{BSSH_CRC}(n) / 2^{32} \rfloor$$

where C_{max} is the number of available carriers according to Table 4-133.

The calculation of the C_{RB} value shall be done block by block for the 5 sub-packets in each block. In order to avoid multiple usage of the same carrier inside of one block, the generation shall be redone with the next value of the LFSR if the same carrier is provided by the formula. This means that the LFSR may be used more often than the number of sub-packets ($n \geq m$).

At the positions, where the C_{RB} value is not discarded the BSSHF_CRC value shall be stored for the following radio-burst time T_{RB} calculation. For the following block(s) the same carrier number(s) may occur again. In these cases, the LFSR shall continue for the following blocks without any reset.

The transmission frequency $f_{RB}(m)$ of the radio-burst m in DLA with HDR burst structure and ULP8 symbol rate is defined as:

$$f_{RB}(m) = f_0 + C_{RB}(m) * B_C + f_{Middle}(s)$$

where:

- B_C is the actual carrier spacing step size in Hz
- f_0 is the start frequency of carrier zero used by the TSMA pattern in Hz
- B_C shall be 14 282,226 Hz for extended TSMA mode and $B_C=28\,565,453$ Hz for wide TSMA mode

The frequency offset $f_{Middle}(s)$ is a variable radio-frame offset, which is calculated according to the formulae given in clause 4.7.6.1.1:

Time Selection

The radio-burst time T_{RB} shall be calculated based on the BSSHF_CRC(m) provided by the sub-packet carrier frequency calculation.

The radio-burst time of radio-bursts shall be calculated by:

$$T_{RB}(m) = (T_{UPGx} + (BSSHF_CRC(m) \text{ modulo } 512)) \cdot \Delta T$$

where:

- T_{UPGx} shall be dependent on the uplink pattern group of the corresponding uplink message.

4.7.6.2 TSMA schemes for DLB transmission mode

4.7.6.2.1 Overview

In DLB transmission mode, a message is split into multiple radio-bursts, that are transmitted onto the resource elements of the DLB frame. The DLB frame contains $N_{RE,bea}$ resource elements (see clause 4.7.2.15.1), which are distributed over time and frequency patterns. These time and frequency patterns are typically different for each base station, because they are derived from the base station unique identifier (BS_EUI) and a pseudo-random number. They are called Base Station Specific Hopping (BSSH) pattern. In each base station, BSSH is used to generate BCCHF (i.e. the frequency domain pattern) and BCCHT (i.e. the time domain pattern).

A BSSH pattern is limited to C_{max} different discrete carriers C in frequency dimension. The number C_{max} depends on the TSMA mode (see Table 4-136) and the used channel bandwidth of DLB transmission mode.

BSSH shall be a 32-bit unsigned integer. It shall be composed according to Table 4-134.

Table 4-134: BSSH number format (32-bit)

Serialization order	0 to 15	16 to 31
Content	Pseudo-random number R_b [0-15]	BS EUI [48-63]
NOTE:	In BSSH, bit with index 0 is the most significant bit.	

Where:

- $R_b[0-15]$ shall be the content of a 16-bit Linear Feedback Shift Register (LFSR). $R_b(n)$ denotes the content of the linear feedback shift register for the b -th DLB frame and for the n -th resource element
- BS_EUI [48-63] shall be composed of the 16 LSB of the unique BS EUI

NOTE 1: BS_EUI[48-63] is a constant value for a given base station, and $R_b[0-15]$ is variable over time.

At the beginning of the DLB frame, numbered BCCNT, the seed $s_b = R_b(0)$ of the linear feedback shift register shall be initialized according to:

$$s_b = R_b(0) = \max\left(\left(\text{BCCNT} * N_{RE,bea}\right) \text{ modulo } 65536, 1\right)$$

The basic operation of the 16-bit linear feedback shift register shall be as described in clause 4.7.6.1.7. The polynomial for the LFSR shall be 0xD09B.

For each new resource element n in the DLB frame, the content of the LFSR shall be computed with a shift operation of the LFSR, as follows:

$$R_b(n) = \text{LFSR}(R_b(n-1)), \quad n \in \{1, 2, \dots, N_{RE,bea} - 1\}$$

where:

- notations are the ones in clause 4.7.6.1.7.

NOTE 2: The applicable values for $N_{RBL,bea}$ (with $N_{RE,bea} = 36 * N_{RBL,bea}$), BS EUI, and the DLB frame counter BCCNT are signalled by the base station to the end-point during the synchronization procedure.

BSSH shall be randomized with a CRC32. The bits shall be processed in ascending order and the unsigned integer CRC field shall be applied with the most significant bit first. Randomization shall be as in clause 4.7.5.2, with the polynomial 0x04C11DB7, the initial value for calculation 0xFFFFFFFF, and no XOR.

The result, named BSSH_F_CRC, is used for the frequency pattern of REs. The 16 lower bits of BSSH_F_CRC are named BSSH_T_CRC and used for the time patterns of REs (see Table 4-135).

Table 4-135: BSSH_F_CRC and BSSH_T_CRC formats

Serialization order	0 to 15	16 to 31
Content	BSSH_F_CRC [0-31]	
		BSSH_T_CRC [0-15]
NOTE: In BSSH_F_CRC and BSSH_T_CRC, bit with index 0 is the most significant bit.		

4.7.6.2.2 Resource element frequency

The frequency of a resource element in a DLB frame is defined by a carrier number, which is then mapped to a transmission frequency. The carrier number of the resource element n shall be derived from BSSH_F_CRC, as follows:

$$C_{RE}(n) = \lfloor C_{max} * \text{BSSH_F_CRC}(n) / 2^{32} \rfloor, \quad n \in \{0, 1, 2, \dots, N_{RE,bea} - 1\}$$

where:

- C_{max} is the number of available carriers, as defined in Table 4-136.

NOTE 1: The number of available carriers C_{max} depends on the channel bandwidth B_{CH} . The channel bandwidth B_{CH} for the DLB transmission mode can be either 25 kHz, 100 kHz (standard mode) or 800 kHz (wide mode) according to clause 4.8.1. If two radio channels A and B are used, the occupied bandwidth B_{OBW} will increase to 200 kHz (EU1 profile) or 1 600 kHz (EU2 or US0 profile). Because the valid TS-UNB profile is known by the end-point, C_{max} does not have to be signalled by the base station., Depending on the TS-UNB profile or TSMA mode, were single or dual channel DLB transmission mode is used directly results in the right C_{max} as specified in Table 4-136.

Table 4-136: Number of available carriers C_{max} depending on profile and bandwidth B_{CH}

B_{CH}	C_{max}	Description
25 kHz	33	single channel DLB transmission mode
100 kHz	37	single channel DLB transmission mode with standard TSMA mode (e.g. EU0, EU1)
800 kHz	26	single channel DLB transmission mode with wide TSMA mode (e.g. EU2, US0)

The actual frequency $f_{RE,DLB}(n)$ of resource element n in a DLB frame shall be, as follows:

$$f_{RE,DLB}(n) = f_{0,DLB} + C_{RE}(n) * B_C; n \in \{0,1,2, \dots, N_{RE,bea} - 1\}$$

where:

- B_C is the actual carrier spacing step size in Hz
- $f_{0,DLB}$ is the lowest frequency (in Hz) available in the channel for the BSSH pattern (i.e. centre frequency of carrier 0)

Frequency $f_{0,DLB}$ shall be calculated, as follows:

$$f_{0,DLB} = f_{C,DLB} - \lfloor C_{max}/2 \rfloor * B_C$$

where:

- $f_{C,DLB}$ is the downlink channel centre frequency according to Table 4-137.

NOTE 2: Relationship between channel bandwidth B_{CH} and carrier spacing B_C are detailed in clause 4.8.1

Table 4-137: Downlink channel centre frequency derivation from TS-UNB profiles

Profile	Function
Single channel (A)	$f_{C,DLB} = f_{C,DL,A}$
Dual Channel (A&B)	$f_{C,DLB} = a * f_{C,DL,A} + (1 - a) * f_{C,DL,B}$ where $a=BCCNT$ modulo 2
NOTE:	$f_{C,DL,A}$ and $f_{C,DL,B}$ are the centre frequencies of the respective downlink channels of the currently used TS-UNB profile (see Annex A) and $BCCNT$ is the beacon counter.

NOTE 3: In a single channel system (e.g. EU0 profile with channel A), transmission always happens in channel A. In a dual channel system, transmissions alternate between channel A and channel B depending on the beacon counter.

4.7.6.2.3 Resource element time

The transmission time of REs in a DLB frame is derived from the 16-bit unsigned integer number BSSHT_CRC. For resource element n , which denotes element $m = n$ modulo 36 within its physical resource block, the time offset R_{RE} shall be generated in three steps.

First step:

It shall evaluate $r(n)$, as follows:

$$r(n) = \lfloor BSSHT_CRC(n) * (2 * c_s(m) + 1)/2^{16} \rfloor - c_s(m), n \in \{0,1,2, \dots, N_{RE,bea} - 1\}$$

where:

- the values $c_s(m)$ shall be derived from Table 4-139.

Second step

The sequence of $r(n)$ shall be accumulated, as follows:

$$R_{RE}'(n) = \begin{cases} 2^{15} + r(n), & \text{for } m = 0 \\ (R_{RE}'(n-1) + r(n)) \text{ modulo } 2^{17}, & \text{else} \end{cases}$$

for each PRB, where the modulo operation is expected to always return non-negative values.

Third step

The actual time offset shall be generated, as follows:

$$R_{RE}(n) = \begin{cases} \lfloor (R_{RE}'(n) * c_w(m) + R_{DC}(n) * (260 - c_w(m)) + 2^{15}) / 2^{16} \rfloor - 130, & \text{for } R_{RE}'(n) < 2^{16} \\ \lfloor ((2^{17} - 1 - R_{RE}'(n)) * c_w(m) + R_{DC}(n) * (260 - c_w(m)) + 2^{15}) / 2^{16} \rfloor - 130, & \text{for } R_{RE}'(n) \geq 2^{16} \end{cases}$$

$$R_{RE} \in \{-130, -129, \dots, +130\}$$

where:

- the windowing function $c_w(m)$, which governs the transition to the pseudo random offset $R_{DC}(n)$, shall be derived from Table 4-139,

The offset $R_{DC}(n)$ shall be calculated in three steps, as follows:

First step

$$R_E(n) = \left\lfloor \frac{BCCNT * N_{RE,bea} + n + 18}{36} \right\rfloor \text{ modulo } 2^{16}$$

Second step

Concatenation, as defined in Table 4-138.

Table 4-138: BSSHE number format (32-bit)

Bits: 0-15	Bits: 16-31
R_E [0-15]	BS EUI [48-63]

Third step:

A uniformly distributed offset $R_{DC}(n)$ shall be obtained: as follows:

$$R_{DC}(n) = CRC32(BSSHE(R_E(n))) \text{ modulo } 2^{16}$$

Table 4-139: Time pattern step size $c_s(m)$ and windowing function $c_w(m)$

m	0	1	2	3	4	5	6	7	8
$c_s(m)$	32 768	0	0	0	0	0	0	0	0
$c_w(m)$	28	56	84	112	140	168	196	224	252

m	9	10	11	12	13	14	15	16	17
$c_s(m)$	5 201	7 057	7 057	7 057	7 057	7 057	7 057	7 057	7 057
$c_w(m)$	260	260	260	260	260	260	260	260	260

m	18	19	20	21	22	23	24	25	26
$c_s(m)$	7 057	7 057	7 057	7 057	7 057	7 057	7 057	7 057	7 057
$c_w(m)$	260	260	260	260	260	260	260	260	260

m	27	28	29	30	31	32	33	34	35
$c_s(m)$	5 201	0	0	0	0	0	0	0	0
$c_w(m)$	252	224	196	168	140	112	84	56	28

The centre position $T_{RB}(n)$ of a radio-burst n in a DLB frame shall be defined, as follows:

$$T_{RB}(n) = T_{n,DLB} + R_{RE}(n) * \Delta T_{ULP}, \quad n \in \{0, 1, 2, \dots, N_{RE}\},$$

where:

- $R_{RE}(n)$ is the time offset relative to the periodic time grid $T_{n,DLB}$
- ΔT_{ULP} is the standard symbol duration

The time grid (see Figure 4-40) for resource element n shall be defined, as follows:

$$T_{n,DLB} = T_{0,DLB} + n * 260 * \Delta T_{ULP}, \quad n \in \{1,2,3, \dots, N_{RE}\},$$

where:

- $T_{0,DLB}$ is the initial time instance of resource element 0.

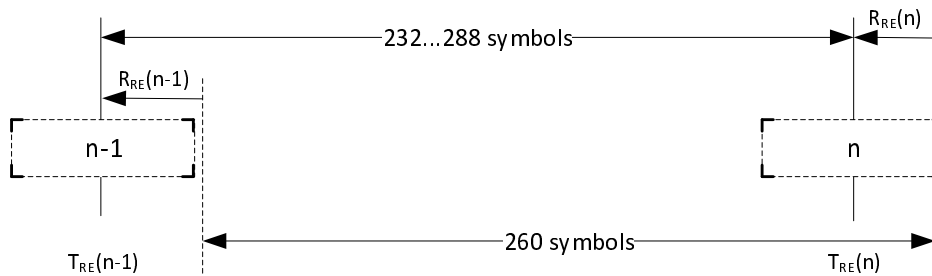


Figure 4-40: Definition of radio-burst centres $T_{RB}(n)$ relative to the periodic time grid

NOTE: All the above calculations guarantee that the time difference between the centres of two adjacent resource elements is in the range of $232 * \Delta T_{ULP} \leq T_{RB}(n + 1) - T_{RB}(n) \leq 288 * \Delta T_{ULP}$.

4.7.6.2.4 Introduction to mapping of radio-bursts onto DLB frame resource elements

As stated in clause 4.7.2.15.1, a DLB frame is divided into a sequence of $N_{RE,bea}$ resource elements named $RE(n)$, where $n \in \{0, 1, \dots (N_{RE,bea} - 1)\}$; each 36 consecutive resource elements form a physical resource block.

In the following the mapping of radio-bursts to resource elements is described in detail.

The notation " $RB(k, [v], [z]) \rightarrow RE(n)$ " means that the radio-burst with burst index k associated to an end-point is mapped onto the resource element with index n . Indexes v and z are optional, depending on frame type and addressing mode. Individual radio-bursts of a DLB frame may be omitted, if they are in conflict with other downlink radio-burst transmissions.

4.7.6.2.5 Sync_Frame mapping for 25kHz and 100kHz channels

In 25 kHz and 100 kHz channels, the Sync_Frame is transmitted at the beginning of DLB frames with a specific time and frequency pattern (see Figure 4-41).

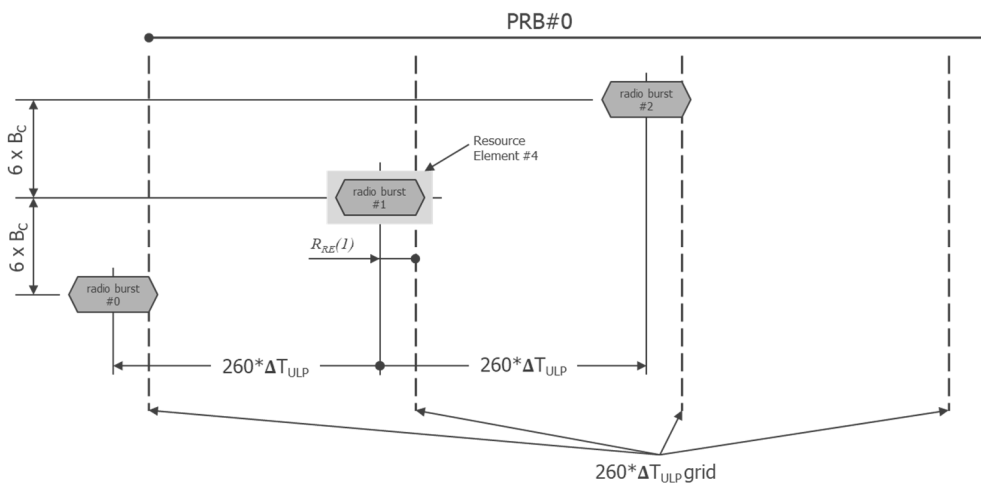


Figure 4-41: Specific time&frequency pattern of Sync_Frame radio-bursts with $B_{CH} = 25$ kHz

The three radio-bursts of a Sync-frame shall be numbered 0, 1, and 2.

The radio-burst #1 of the Sync_Frame shall be transmitted at the time position of resource elements #1 (i.e. at $T_{RB}(1)$) in the DLB frame.

The radio-burst #0 of the Sync_Frame shall be transmitted with a fixed offset of $-260 \cdot \Delta T_{ULP}$ relative to $T_{RB}(1)$, regardless of actual $T_{RB}(0)$ values.

The radio-burst #2 of the Sync_Frame shall be transmitted with a fixed offset of $+260 \cdot \Delta T_{ULP}$ relative to $T_{RB}(1)$, regardless of actual $T_{RB}(2)$ values.

The three radio-burst frequencies of a Sync_Frame shall be calculated in two steps, as follows:

Step 1:

The channel number of each radio-burst shall be set, according to Table 4-140.

Table 4-140: Carrier numbers of radio-bursts in a Sync_Frame

Radio-burst number	Carrier number C_{SC}	
	$B_{CH} = 25$ kHz	$B_{CH} = 100$ kHz
0	0	0
1	6	1
2	12	2

Step 2:

The transmission frequency of the radio-bursts shall be calculated, as follows:

$$f_{SC_DLB}(l) = f_{0,DLB} + C_{SC}(l) * B_C$$

where:

- $l \in \{0,1,2\}$
- B_C is the actual carrier spacing step size in Hz
- $f_{0,DLB}$ is the start frequency of the DLB TSMA pattern in Hz

NOTE 1: Both values B_C and $f_{0,DLB}$ are detailed in clause 4.7.6.2.2.

NOTE 2: In dual channel mode, the $f_{0,DLB}$ value alternates between channels A and B, which gives an alternating transmission of the Sync_Frame in channel A and B.

NOTE 3: The fixed time&frequency pattern of the Sync_Frame radio-bursts is an interesting feature for improving receiver detection algorithms.

4.7.6.2.6 Sync_Frame mapping for 750 kHz channels

Reserved for further description.

4.7.6.2.7 Sync Data frame mapping for 25 kHz and 100 kHz channels

In 25 kHz and 100 kHz channels, the sync data frame is transmitted directly after the Sync_Frame (clauses 4.7.6.2.5 and 4.7.6.2.6) with a specific time and frequency pattern (see Figure 4-42).

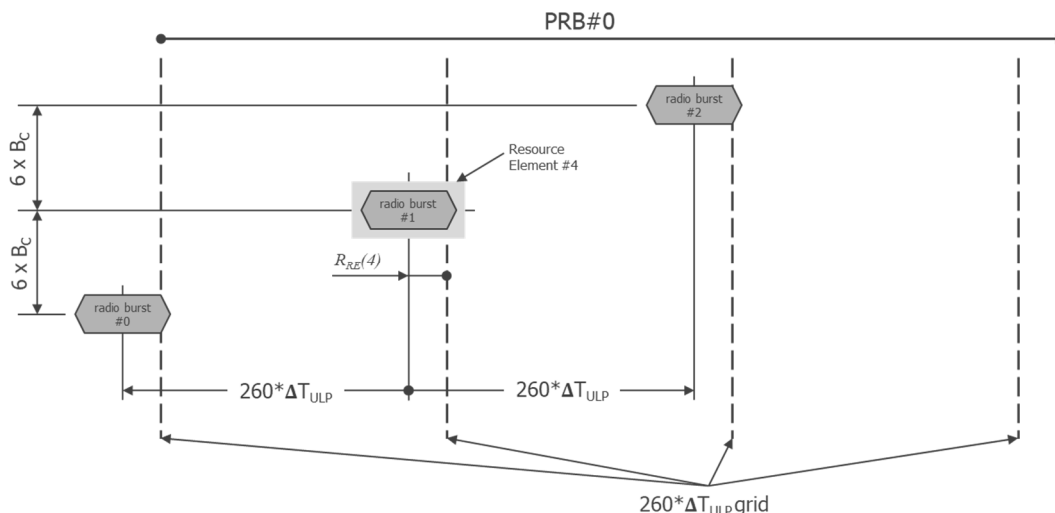


Figure 4-42: Specific time&frequency pattern of sync data frame radio-bursts with B_{CH} = 25 kHz

The three radio-bursts of a sync data frame shall be numbered 0, 1, and 2.

The radio-burst #1 of the sync data frame shall be transmitted at the time position of resource elements #4 (i.e. at $T_{RB}(4)$) in the DLB frame.

The radio-burst #0 of the sync data frame shall be transmitted with a fixed offset of $-260 \cdot \Delta T_{ULP}$ relative to $T_{RB}(4)$, regardless of actual $T_{RB}(3)$ values.

The radio-burst #2 of the sync data frame shall be transmitted with a fixed offset of $+260 \cdot \Delta T_{ULP}$ relative to $T_{RB}(4)$, regardless of actual $T_{RB}(5)$ values.

The three radio-burst frequencies of a sync data frame shall be calculated in two steps, as follows:

Step 1:

The channel number of each radio-burst shall be set, according to Table 4-141.

Table 4-141: Carrier numbers of radio-bursts in a Sync Data Frame

Radio-burst number	Carrier number C_{SC}	
	B _{CH} = 25 kHz	B _{CH} = 100 kHz
0	18	3
1	24	4
2	30	5

Step 2:

The transmission frequency of the radio-bursts shall be calculated, as follows:

$$f_{SC_DLB}(l) = f_{0,DLB} + C_{SC}(l) * B_C$$

where:

- $l \in \{0,1,2\}$
- B_C is the actual carrier spacing step size in Hz
- $f_{0,DLB}$ is the start frequency of the DLB TSMA pattern in Hz

NOTE 1: Both values B_C and $f_{0,DLB}$ are detailed in clause 4.7.6.2.2.

NOTE 2: In dual channel mode, the $f_{0,DLB}$ value alternates between channels A and B, which gives an alternating transmission of the sync data frame in channel A and B.

NOTE 3: The fixed time&frequency pattern of the sync data frame radio-bursts is an interesting feature for improving receiver detection algorithms.

4.7.6.2.8 Sync Data frame mapping for 750 kHz channels

Reserved for further description.

4.7.6.2.9 Beacon core frame mapping

The 9 radio-bursts of the beacon core frame, denoted as $RB_{bcore}(k)$, shall be mapped to the second 9 even-indexed resource elements of a beacon period, as follows:

$$RB_{bcore}(k) \rightarrow RE(2 * k), \text{ for } 9 \leq k < 18$$

4.7.6.2.10 Beacon extension frame mapping

Each beacon extension frame consists of 18 radio-bursts, which are denoted as $RB_{bext}(k, v)$, where $k \in \{0, 1, \dots, 17\}$ denotes the k -th radio-burst index of the v -th extension frame, $v \in \{0, 1, \dots, (N_{ext,bea} - 1)\}$, and where $N_{ext,bea}$ is the number of beacon extension frames.

The radio-bursts of beacon extension frames shall be mapped to even-indexed resource elements, as follows:

$$RB_{bext}(k, v) \rightarrow RE(2 * k + W(v)), \text{ for } 0 \leq k < 18$$

where:

$$W(v) = 36 + v * 36 * (N_{RBL,data} + 1), \text{ for } 0 \leq v < N_{ext,bea}$$

4.7.6.2.11 DLB Data frame mapping

In two-stage scheduling mode, DLB Data frames, which are addressed by a beacon extension frame, shall be transmitted in the data region which immediately follows the considered beacon extension frame.

In single-stage addressing mode, there is only one data region in the DLB frame, where one DLB Data frame is transmitted to one address (one end-point in unicast, group of end-points in multicast). The corresponding resource blocks used for transmission of DLB Data frames are denoted as data resource blocks.

Unlike in beacon core or extension frames, data resource blocks may be used in high density configuration, also allocating odd-indexed resource elements to radio-burst transmission. The selection between low and high density configuration shall be based on the total amount of data to be transmitted within one data region. When this amount exceeds the capacity of the data region with all data resource blocks in low density configuration, the first data resource block of the data region shall be switched to the high density configuration. This shall be repeated with the next data resource block in the data region, until the capacity requirement of the data region is fulfilled.

For the sake of simplicity in the following the simplified notation "end-point group" is used instead of "end-point or group of end-points".

The number of end-point groups scheduled in a considered data region v is denoted as $N_{ep}(v)$, where v is the index of the associated extension frame, $v \in \{0, 1, \dots, (N_{ext,bea} - 1)\}$. While the number of data resource blocks in each data region of a considered beacon period is identical, the number of scheduled end-point groups may vary from data region to data region within the same beacon period. The number of radio-bursts to be transmitted to an end-point group depends on the payload data size and is denoted as $N_{RB}(z, v)$, where $z \in \{0, 1, \dots, (N_{ep}(v) - 1)\}$ is the index of the end-point group which is addressed by extension frame v . $N_{RB}(z, v)$ has to be an integer multiple of 18 and can take on a maximum value of $11 * 18 = 198$, as each DLB Data frame may consist of a maximum of 198 radio-bursts.

A physical resource block in low density configuration shall contain one data block, and shall use only even indexed resource elements.

A physical resource block in high density configuration shall contain two data blocks, the first data block using the first 18 resource elements and the second data block using the second 18 resource elements.

The number of data blocks required for the transmission to end-point group z accordingly results as:

$$N_{DBL}(z, v) = \frac{N_{RB}(z, v)}{18}$$

The mapping of each data region associated to extension frame v shall be done data region per data region, as follows:

First step

the total number of required data blocks in the data region shall be determined, as follows:

$$N_{DBL}(v) = \sum_{z=0}^{N_{ep}(v)-1} N_{DBL}(z, v)$$

Second step:

The number $h(v)$ of resource blocks in high density configuration shall be determined, as follows:

$$h(v) = \begin{cases} 0 & \text{for } N_{RBL,data} \geq N_{DBL}(v) \\ N_{DBL}(v) - N_{RBL,data} & \text{for } N_{RBL,data} < N_{DBL}(v) \end{cases}$$

Third step:

The relative starting data block indexes $i_{DBL,start}(z, v)$ of each DLB Data frame of end-point group z shall be calculated, as follows:

$$i_{DBL,start}(z, v) = \sum_{l=0}^{z-1} N_{DBL}(l, v), \text{ for } 1 \leq z < N_{ep}(v)$$

where:

- $i_{DBL,start}(0, v) = 0$
- The value $i_{DBL,start}(z, v)$ denotes the relative index of the data block within data region v , onto which the first radio-burst of end-point group z is mapped

Fourth step:

The relative starting index of the first resource element of the first data block of each DLB Data frame of end-point group z shall be calculated, as follows:

$$i_{start}(z, v) = \begin{cases} 18 \cdot i_{DBL,start}(z, v) & \text{for } i_{DBL,start}(z, v) \leq 2h \\ 36 \cdot (i_{DBL,start}(z, v) - h) & \text{for } i_{DBL,start}(z, v) > 2h \end{cases}, \text{ for } 0 \leq z < N_{ep}(v)$$

Fifth step:

The radio-bursts $RB_{bdata}(k, v, z)$ of end-point group z in data region v shall be mapped to resource elements, as follows:

$$RB_{bdata}(k, v, z) \rightarrow RE(k + i_{start}(z, v) + W(v)), \quad \begin{array}{l} \text{for } 0 \leq k < N_{RB}(z, v) \\ \text{for } 0 \leq z < N_{ep}(v) \end{array}$$

when:

- $i_{start}(z, v) + k \leq 36h$

and

$$RB_{bdata}(k, v, z) \rightarrow RE(2k + i_{start}(z, v) + W(v)), \quad \begin{array}{l} \text{for } 0 \leq k < N_{RB}(z, v) \\ \text{for } 0 \leq z < N_{ep}(v) \end{array}$$

when:

$$i_{start}(z, v) + k > 36h$$

For two-stage addressing, $W(v)$ shall be evaluated as follows:

$$W(v) = 72 + v \cdot 36 \cdot (N_{RBL,data} + 1), \text{ for } 0 \leq v < N_{ext,bea}$$

For single-stage addressing, $W(v)$ shall be, as follows:

$$W = 36$$

4.7.6.3 TSMA schemes for DLC transmission mode

4.7.6.3.1 Overview

In DLC transmission mode, a message is split into multiple radio-bursts, that are transmitted onto the resource elements of the DLC frame. Resource Elements of DLC frame (DLC RE) are always related to the preceding resource element of the DLB structure.

4.7.6.3.2 Resource element frequency for ULP symbol rate

The frequency of a resource element in a DLC frame is defined by a carrier number, which is then mapped to a transmission frequency. The carrier number of the resource element in DLC frame is the same as for the preceding resource element of DLB frame.

4.7.6.3.3 Resource element frequency for ULP8 symbol rate

As the bandwidth of ULP8 radio-bursts is increased, different frequencies are used and the number of channels is decreased.

The number of available carriers C_{max} depends on the channel bandwidth B_{CH} . The channel bandwidth B_{CH} for DLC with ULP8 symbol rate may be either 2 times 100 kHz (extended TSMA mode) or 2 times 750 kHz (wide TSMA mode). C_{max} shall be chosen from Table 4-142.

Table 4-142: Number of available carriers C_{max} depending on profile and bandwidth B_{CH}

B_{CH}	C_{max}	Description
100 kHz	5	single channel DLB transmission mode with extended TSMA mode (e.g. EU0, EU1)
750 kHz	25	single channel DLB transmission mode with wide TSMA mode (e.g. EU2, US0)

When operating in a extended TSMA mode with spectrum bandwidth B_{CH} of two times 100 kHz, B_C shall be 14 282,226 Hz and for a wider bandwidth of two times $B_{CH} = 750$ kHz a carrier spacing $B_C = 28 565,453$ Hz shall be used instead.

The downlink start frequency $f_{0,DLB}$ is the carrier frequency of carrier zero of the C_{max} carriers used by DLC TSMA pattern. It is derived from DLB communication, which means that both DLB and DLC communication operate in the same frequency band. If in DLB the two channels are used in the alternating mode, the $f_{0,DLB}$ shall already include this frequency alternating.

For the extended carrier spacing TSMA mode C_{RE} shall be calculated according to the following formula:

$$C_{RE} = (R_{RE}(n_{RE}) + BCCNT \text{ xor } BS_EUI) \text{ mod } C_{max}$$

where:

- C_{max} is the number of available carriers according to Table 4-142
- $BCCNT$ is the actual beacon period counter and shall be provided by the DLB communication as well
- $R_{RE}(n_{RE})$ shall be chosen from Table 4-143, according to the current RE counter n_{RE}

Table 4-143: Relative carrier number

RE counter n_{RE}	Relative carrier number R_{RE}
0	0
1	3
2	2
3	4
4	1

n_{RE} is the actual RE counter and shall be calculated by the following formula based on parameters of the DLB communication:

$$n_{RE} = (BCCNT \cdot N_{RE,bea} + n) \bmod 5$$

where:

- $N_{RE,bea}$ is the number of resource element within one DLB frame
- n is the actual DLB RE index within the current DLB frame

For the wide carrier spacing TSMA mode, the following formula for C_{RE} shall be used for calculation:

$$C_{RE} = \lfloor C_{max} \cdot BSSHF_CRC(n) / 2^{32} \rfloor$$

where:

- C_{max} is the number of available carriers according to Table 4-142.

$BSSHF_CRC(n)$ shall be provided by the DLB communication and shall be different for each RE and is also dependent on the DLB RE index n .

The C_{RE} value gives the corresponding carrier number for the resource element at this time reference.

The downlink start frequency $f_{0,DLB}$ is the carrier frequency of carrier zero of the C_{max} carriers used by the TSMA pattern. It is derived from the variable downlink channel centre frequency $f_{C,DLB}$ by:

$$f_{0,DLB} = f_{C,DLB} - \lfloor C_{max} / 2 \rfloor * B_C$$

where:

- $f_{C,DLB}$ is the downlink channel centre frequency according to Table 4-144
- C_{max} is the number of carriers used

Table 4-144: Downlink centre frequency derivation from TS-UNB profiles

Profile	Function
Single channel (A)	$f_{C,DLB} = f_{C,DL,A}$
Dual Channel (A&B)	$f_{C,DLB} = a * f_{C,DL,A} + (1 - a) * f_{C,DL,B}$ with $a = BCCNT \bmod 2$

NOTE: $f_{C,DL,A}$ and $f_{C,DL,B}$ are the center frequencies of the respective downlink channels of the currently used TS-UNB profile (see annex A) and $BCCNT$ is the beacon period counter.

In a single channel transmission mode (e.g. EU0 profile with channel A) transmission always happens in channel A. In a dual channel mode transmissions are alternating between channel A and B depending on the beacon period counter $BCCNT$.

The frequency location $f_{RE}(n)$ of resource element with the RE counter n in the Class C communication is defined as:

$$f_{RE}(n) = f_{0,DLB} + C_{RE}(n) * B_C$$

where:

- B_C is the actual carrier spacing size in Hz.

4.7.6.3.4 Resource element time

The transmission time of REs in a DLC frame shall have a fixed time offset to the preceding resource element of DLB frame (see Figure 4-43), as follows:

- 136 symbols with standard symbol duration in case of ULP symbol rate;
- 78,75 symbols with standard symbol duration in case of ULP8 symbol rate and HDR burst structure.

NOTE: The distance between two consecutive radio-burst with HDR burst structure is 17,5 symbols with standard symbol duration.

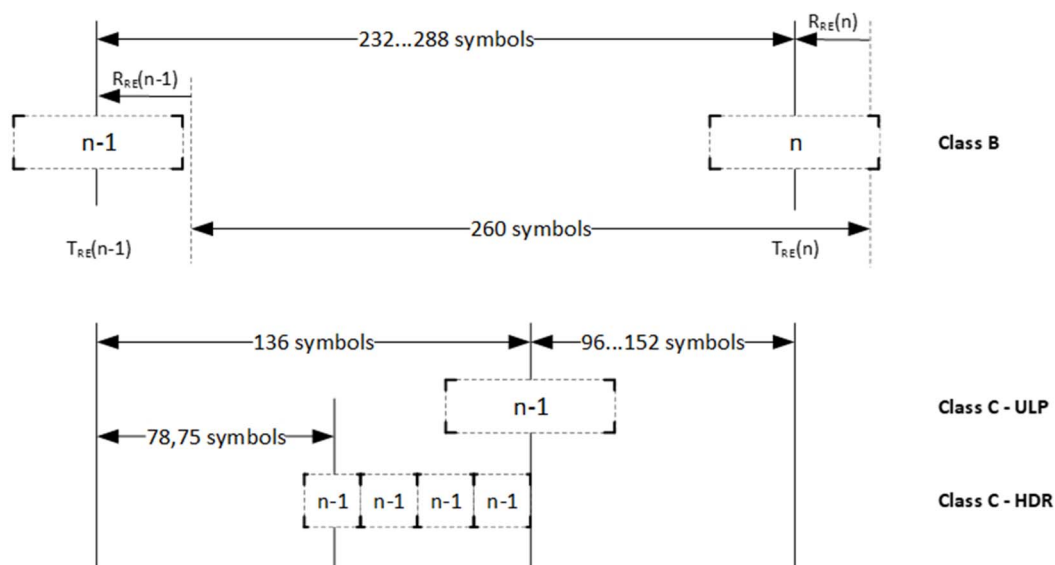


Figure 4-43: Time relation of DLC resource elements to DLB resource elements

4.7.6.3.5 DLC_core and extension frame mapping

Resource elements of a DLC frame may be mapped in low or high density mode like for DLB. In low density mode only the even RE indices n shall be used, which means one block of 18 radio-bursts consumes 36 RE's for the transmission, but only the even ones contain the radio-bursts of the DLC frame. In high density mode all RE indices n shall be used, therefore one block consumes 18 consecutive RE's where all are used for the transmission. n shall be same RE index as for DLB and shall be 0 at the start of each new beacon period.

High or low dense mode are not used dynamically based on the amount of transmitted data, but shall be selected as a fixed network setting or signalled during a sync attach procedure.

All radio-bursts shall be transmitted in consecutive order without any gaps. Individual radio-burst of a DLC frame may be omitted. A DLC frame transmission may start at any DLC RE or it may start only at known DLC RE indices n . Which mode is used shall be signalled during the sync attach procedure and shall be the RE start index number $n_{(RE_start)}$ according to Table 4-145.

Table 4-145: DLC frame start index

Start index number $n_{(RE_start)}$	0	1	2	3
Possible start indices n in low dense mode	$n \bmod 2 = 0$	$n \bmod 6 = 0$	$n \bmod 18 = 0$	$(n - 8) \bmod 36 = 0$
Possible start indices n in high dense mode	$n \bmod 1 = 0$	$n \bmod 3 = 0$	$n \bmod 9 = 0$	$(n - 9) \bmod 18 = 0$

In order to map the radio-bursts of the blocks with the sub-packet index s provided by the interleaver to the DLC RE's with the index n the following formula applies for the low density mode:

$$s = \left\lfloor \frac{(n-8)}{2} \right\rfloor \bmod 18$$

and for the high density mode:

$$s = (n - 9) \bmod 18$$

This results in a way that not in all cases the sub-packet with the number zero 0 shall be transmitted first.

4.7.6.3.6 DLC core and extension frame mapping for HDR burst structure

A DLC frame with HDR burst structure consists of blocks with up to 5 radio-bursts each carrying sub-packets with sub-packet index $s = 0 \dots 4$. The first transmission of a block is called primary transmission. A block of 5 radio-bursts can be repeated, the repetition is called auxiliary transmission. The auxiliary transmission can comprise up to 5 radio-bursts and might comprise less or more radio-burst than the primary transmission.

The DLC resource element consists of 4 slots where a radio-burst may be transmitted.

A DLC frame may start at any DLC resource element with the primary transmission and shall occupy one slot within the resource element. A DLC frame block transmission may occupy up to 5 consecutive resource elements. An optional auxiliary transmission of the block may be transmitted within the remaining slots of a DLC structure area within 10 resource elements starting from the start resource element of the primary transmission at $n_{RE,start}$.

The radio-bursts of the primary transmission are mapped to resource elements according to the following formula:

$$RB(k) \rightarrow RE(n_{RE,start} + k), slot(l_p);$$

$$\text{with } l_p = 0 \dots 3; k = 0 \dots 4$$

$n_{RE,start}$: absolute RE start index, where primary transmission starts

The auxiliary transmission can start at any resource element beginning with $n_{RE,start}$ or up to 5 RE later and within any unoccupied slots:

$$RB(k) \rightarrow RE(n_{RE,start} + i + k), slot(l_A);$$

$$\text{with } l_A = 0 \dots 3; l_B \neq l_A; k = 0 \dots 4$$

$$i \in \{0, 1, 2, 3, 4, 5\}$$

The subpacket carried by the transmitted radio-bursts depends on the selected RE counter n_{RE} and slot according to Table 4-146.

Table 4-146: Subpacket index assignment to RE and slots

Slot l=	RE with RE counter n_{RE}				
	RE(0)	RE(1)	RE(2)	RE(3)	RE(4)
0	0	1	2	3	4
1	3	4	0	1	2
2	2	3	4	0	1
3	1	2	3	4	0

The RE counter value n_{RE} is derived from the absolute resource element number, where the radio-burst is mapped to:

$$n_{RE} = (BCCNT \cdot N_{RE,bea} + n) \bmod 5$$

The k radio-bursts of one block shall be transmitted on consecutive resource elements. Individual radio-bursts of a DLC frame may be omitted. A minimum of 2 radio-bursts per block of a DLC frame shall be transmitted.

The second block and any following blocks of a DLC frame shall always start between 3 and 5 resource elements after the first resource element of the previous block.

4.8 Radio characteristics

4.8.1 Carrier spacing and spectrum use

The TS-UNB protocol may be configured to different spectrum requirements. It may be operated in different SRD sub bands in Europe by adjusting the carrier spacing of the TSMA patterns.

The radio band with a center frequency $f_{center,band}$ may be divided into two collocated channels with channel bandwidth B_{ch} . The channel center frequencies $f_{c,A}$ and $f_{c,B}$ are separated by number N_{re} times carriers spacings. A radio frame shall occupy one channel per transmission. Transmissions may alternate between two channels. For higher symbol rates with a broader bandwidth the two channels may be combined to a larger channel with two times the channel bandwidth (see Figure 4-44).

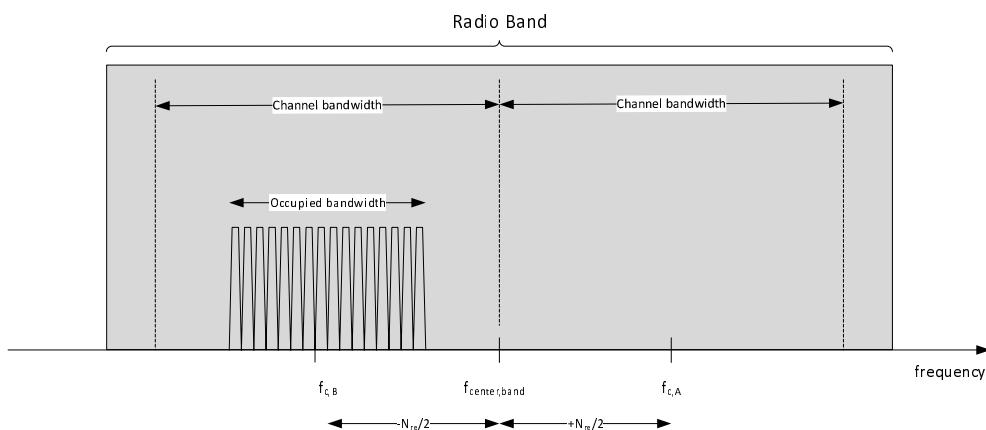


Figure 4-44: Radio band and radio channel definitions

The occupied bandwidth depends on the carrier spacing. TSMA modes shall implement carrier spacing as defined in Table 4-147.

Table 4-147: TSMA mode and carrier spacing definition

TSMA Mode	Stretching factor N_{ST}	Carrier Spacing B_c (in Hz)	
		formal	approx.
Narrow	1/6	$\frac{26 \cdot 10^6}{2^{16}}$	396,729
Standard	1	$\frac{26 \cdot 10^6 \times 3}{2^{15}}$	2 380,371
Medium	2	$\frac{26 \cdot 10^6 \times 3}{2^{14}}$	4 760,742
Extended	6	$\frac{26 \cdot 10^6 \times 3^2}{2^{14}}$	14 282,227
Wide	12	$\frac{26 \cdot 10^6 \times 3^2}{2^{13}}$	28 564,453

The TSMA modes may be used for different symbol rates in uplink (see Table 4-148) and downlink (see Table 4-149).

Table 4-148: TSMA mode usage in uplink

		TSMA mode (carrier spacing)				
		Narrow	Standard	Medium	Extended	Wide
Symbol rate	ER	x	x	-	-	x
	ULP	x	x	-	-	x
	ULP8	-	-	-	x	x

Table 4-149: TSMA mode usage in downlink

		TSMA mode (carrier spacing)				
		Narrow	Standard	Medium	Extended	Wide
Symbol rate	ULP	x	x	-	-	x
	ULP2	-	-	x	-	x
	ULP8	-	-	x	-	x
	ULP8 / HDR burst	-	-	-	x	x

Table 4-150 illustrates the spectrum use of one radio frame (i.e. the occupied bandwidth) for various transmission configuration and with crystal tolerance sets to zero.

Table 4-151 illustrates the spectrum use a channel (i.e. minimum single channel bandwidth) for various transmission configuration, when all crystal tolerances are taken into consideration.

Table 4-150: Examples of occupied bandwidth (in Hz) for one radio frame

		TSMA mode				
		Narrow	Standard	Medium	Extended	Wide
Symbol rate	ER	12 616				
	ULP		60 223			688 641
	ULP2			63 318		691 736
	ULP8			81 885		710 303

NOTE: The elements in this table are for information only.

Table 4-151: Minimum single channel bandwidth (in kHz) for various transmission configuration

		TSMA mode				
		Narrow	Standard	Medium	Extended	Wide
Symbol rate	ER	25	100	-	-	800
	ULP	-	100	-	-	800
	ULP2	-	200	200	-	800
	ULP8	-	-	-	200	800

NOTE: The elements in this table are for information only.

4.8.2 On-air times

The TS-UNB protocol may use random channel access without listen before talk. The relevant radio regulations on duty cycle limit the number of messages and data that can be transmitted. Table 4-152 gives the transmission times for different TS-UNB protocol modes.

Table 4-152: Examples of radio transmission times

Transmission mode	Symbol rate	Radio-burst structure	Radio-burst duration	Core Frame on-air time	Extension Frame on-air time
ULZ	ULP	Standard	15,14 ms	362,97 ms	15,14 ms per add. Byte in MPDU
ULZ	ER	Standard	90,74 ms	2 177,81 ms	90,74 ms per add. Byte in MPDU
ULZ	ULP8	Concatenated	1,89 ms	45,37 ms	1,89 ms per add. Byte in MPDU
DLA	ULP	Standard	11,76...21,43 ms	105,87 ms	211,73...383,13 ms per add. Extension frame block
DLA	ULP2	Standard	5,88...10,71 ms	52,93 ms	105,87...191,57 ms per add. Extension frame block
DLA	ULP8	Concatenated	1,47...2,68 ms	13,23 ms	26,47...47,89 ms per add. Extension frame block
DLA	ULP8	HDR	3,57...7,35 ms	32,14 ms	64,28...133,33 ms per add. Extension frame block
DLB	ULP	Standard	11,76...21,43 ms	105,87 ms	383,13 ms per add. Beacon Extension frame 211,73...383,13 ms per add. data frame block
DLC	ULP	Standard	11,76...21,43 ms	211,73...383,13 ms	211,73...383,13 ms per add. data frame block
DLC	ULP8	HDR	3,57...7,35 ms	64,28...133,33 ms	64,28...133,33 ms per add. Extension frame block

NOTE: The elements in this table are for information only.

In the TSMA scheme, a radio-burst is always followed by a radio transmission pause, thus implementing a certain duty cycle according to the TSMA pattern used. The transmission time of the uplink extension frame is extended by one radio-burst per additional byte user data. The transmission time of the downlink extension frame with a fixed number of radio-bursts varies depending on the payload to be transmitted.

For implementation reasons an end-point or base station may require to transmit a portion of a radio signal some time before the wanted transmission of the radio-burst, e.g. settling of TX signal. This additional radio signal shall be transmitted as guard symbols with the same modulation and symbol rate as subsequent radio-burst. The value of the guards symbol may be chosen randomly, but the mapping of the guard symbols shall follow clauses 4.7.3.2 for uplink and 4.7.4.7 for downlink. Table 4-153 gives the maximum number of additional guard symbols per symbol rate.

Table 4-153: Number of possible guard symbols before radio-burst transmission

Symbol rate	No. of guard symbols
ER	0..2
ULP	0..2
ULP2	0..4
ULP8	0..16

The additional guard symbols shall be considered in the duty cycle calculation of the transmitter.

4.8.3 Implementation tolerances

4.8.3.1 Definitions

The values given in the present document are nominal values. In practical implementations, these parameters will be affected by inaccuracies of the hardware components. In this clause additional tolerances are given in order to achieve proper communication between end-point and base station.

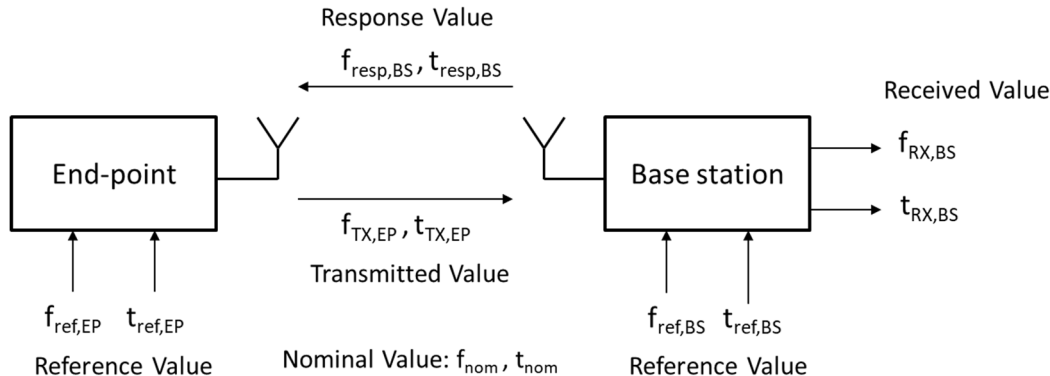


Figure 4-45: Overview of time and frequency parameters of the communication

Figure 4-45 shows the relation between the different signals in the communication protocol defined by frequency and time values. Basically each communication partner uses a crystal as frequency and time reference (f_{ref} , t_{ref}) to generate a transmitted signal (f_{TX} , t_{TX}). In some cases the received signal can be used to derive a reference signal based on which the transmit signal is generated. In this case the transmitted signal is defined as response signal (f_{resp} , t_{resp}).

Table 4-154 gives the definition of the different tolerance values.

Table 4-154: Offset value definitions

Name	Definition	Variable names
Offset	Difference between values (e.g. transmitted value and nominal value)	
Tolerance	Range of allowed offsets (\pm max. offset)	
Nominal value	Value as defined in the present document	f_{nom}, t_{nom}
Reference value	Value of reference signal derived from reference oscillator (e.g. crystal) or synchronized to a received signal	f_{ref}, t_{ref}
Transmitted value	Value of the signal generated by the radio hardware relative to the reference value	f_{TX}, t_{TX}
Received value	Value estimated by the radio receiver	f_{RX}, t_{RX}
Response value	Value of the signal generated by the radio hardware relative to a received value	f_{resp}, t_{resp}

4.8.3.2 End-point tolerances

4.8.3.2.1 EP frequency tolerances

In the end-point, symbol time and carrier frequency generation maybe derived from a common reference oscillator (preferable with a frequency of 26 MHz) with a tolerance below ± 20 ppm. Table 4-155 gives an overview of the frequency tolerances for the generation of the transmit signal in the end-point (uplink).

Table 4-155: Uplink frequency tolerances

Name	Definition	Variable	Value
Center frequency tolerance	Tolerance of centre frequency of a radio frame transmitted over the air (Offset of transmitted value to nominal value)	Δf_c	± 20 ppm (see note 1)
Carrier spacing tolerance	Tolerance of the pairwise carrier spacing over 24 successive radio-bursts (Offset of transmitted value to nominal value)	ΔB_c	ER/ULP/ULP8: ± 50 Hz (see note 2)
GMSK symbol rate tolerance	Tolerance of the on-air uplink symbol rate during one radio-bursts (Offset of transmitted value to nominal value)		± 100 ppm (see note 3)
GMSK deviation tolerance	Tolerance of frequency deviation of the on-air uplink GMSK modulation during one radio-burst (Offset of transmitted value to nominal value)		ER: $\pm 0,8$ Hz ULP: ± 5 Hz ULP8: ± 40 Hz (see note 4)

NOTE 1: Crystal tolerance according to center frequency tolerance.
NOTE 2: Includes spreading of carrier spacing caused by the crystal tolerance of up to ± 15 Hz for ± 20 ppm crystal offset.
NOTE 3: Includes also the crystal offsets of up to 20 ppm.
NOTE 4: Includes also the additional deviation tolerance of up to $\pm 0,02$ Hz for 20 ppm crystal offset.

4.8.3.2.2 EP time tolerances

Table 4-156 summarizes the time tolerance for the generation of the transmit signal in the end-point (uplink).

Table 4-156: Uplink time tolerances

Name	Definition	Variable	Value
Time reference tolerance class Z/A	Tolerance of the time reference of the end-point (Offset of reference value to nominal value)		± 20 ppm
Time tolerance of radio-burst	Tolerance of the pairwise time distance over 24 successive transmitted radio-bursts (between any two radio-bursts within 24 consecutive radio-bursts)	$\Delta T_{RB1,n}$	$\pm T_{symbol}/4$ ULP: $\pm 105 \mu s$ ($T_{symbol}/4$) (see note)

NOTE: Includes spreading of time positions caused by the crystal tolerance, which is $70 \mu s$ at 20 ppm crystal offset.

4.8.3.3 Base station tolerances

4.8.3.3.1 BS frequency tolerances

Table 4-157 summarizes the frequency tolerances for the generation of the transmit signal in the base station (downlink).

Table 4-157: Downlink frequency tolerance

Name	Definition	Variable	Value
Crystal frequency tolerance	crystal center frequency tolerance (Offset of reference value to nominal value)		± 7 ppm
Center frequency tolerance	Tolerance of the on-air downlink centre frequency relative to the on-air uplink centre frequency (Offset of response value to transmitted value)	Δf_c	ULP: ± 250 Hz relative to uplink centre frequency ULP2: ± 500 Hz relative to uplink centre frequency ULP8: $\pm 2\,000$ Hz relative to uplink centre frequency
Carrier spacing tolerance	Tolerance of the pairwise carrier spacing over 18 successive radio-bursts (Offset of response value to nominal value)	ΔB_c	ULP/ULP2/ULP8: ± 16 Hz (see note)
GMSK symbol rate tolerance	Tolerance of the on-air downlink symbol rate during one radio-burst (Offset of response value to nominal value)		± 100 ppm
GMSK deviation tolerance	Tolerance of frequency deviation of the on-air downlink GMSK modulation relative to the on-air uplink transmission		ULP: ± 5 Hz ULP2: ± 10 Hz ULP8: ± 40 Hz

NOTE: Includes spreading of carrier spacing caused by the crystal tolerance of up to $\pm 5,25$ Hz for ± 7 ppm crystal.

4.8.3.3.2 BS time tolerances

Table 4-158 summarizes the time tolerances for the generation of the transmit signal in the base station (downlink).

Table 4-158: Downlink time tolerances

Name	Definition	Variable	Value
Uplink-Downlink delay tolerance	Time tolerance between uplink and following downlink relative to the uplink on-air	ΔT_{ud}	± 2 Symbol duration (relative to symbol rate)
Core frame time interval tolerance	Tolerance of time interval between downlink core frame and extension frame	ΔT_{TSI}	± 2 Symbol duration (relative to symbol rate)
Extension frame time interval tolerance	Tolerance of time interval between two downlink extension frame blocks	ΔT_{dn}	$\pm 0,5$ Symbol duration (relative to symbol rate)
Time tolerance of radio-burst for $T_{hb} = 0$	Tolerance of the pairwise time distance over 18 successive radio-bursts of a block (between any two radio-bursts within 18 consecutive radio-bursts)	$\Delta T_{RB1,18}$	$\pm 0,125$ Symbol duration (relative to symbol rate)
Time tolerance of half radio block for $T_{hb} = 0$	Tolerance of the pairwise time distance over 9 successive radio-bursts of a halfblock (between any two radio-bursts within 9 consecutive radio-bursts)	$\Delta T_{RB1,9}$ $\Delta T_{RB10,18}$	$\pm 0,06125$ Symbol duration (relative to symbol rate)
Half block time distance tolerance	Tolerance of radio-burst time interval between radio-burst 8 and 9 (half block distance)	ΔT_{hb}	$\pm 0,125$ Symbol duration (relative to symbol rate)

4.8.4 Receiver bandwidth

The receiver bandwidth depends on the system mode of operation and shall be set accordingly.

Annex A (informative): TS-UNB Profiles

A.1 Overview

The TS-UNB profiles, stated in the present annex, define several TS-UNB protocol settings that help interoperability of end-points and base stations operating in a TS-UNB based LTN network. These profiles are purely indicative and may be completed with other interoperability profiles, when needed by specific deployment cases.

A.2 EU0 Profile

A.2.1 Spectrum Use

Table A-1: UL channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	868,180 MHz	100 kHz

Table A-2: DL channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	869,575 MHz	100 kHz

The frequency offset between uplink and downlink is $f_{DL-UL} = 1,395 \text{ MHz}$.

A.2.2 Mode of operation

Table A-3: Mode of operation of EU0 profile

	Uplink	Downlink (optional)
PHY Mode	Telegram Splitting (TS)	
Modulation	(G)MSK	(G)MSK
Symbol rate	ULP	ULP
TSMa Mode	standard (Carrier spacing: 2 380,371 Hz)	
Sync Burst	off	
Repetition	off	
Channels	Single Channel	

A.3 EU1 Profile

A.3.1 Spectrum Use

Table A-4: UL channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	868,180 MHz	100 kHz
B (secondary)	868,080 MHz	100 kHz

Table A-5: DL channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	869,575 MHz	100 kHz
B (secondary)	869,475 MHz	100 kHz

The frequency offset between uplink and downlink is $f_{DL-UL} = 1,395 \text{ MHz}$. For frame repetition in dual channel mode a carrier frequency offset step $N_{re} = 42$ is used.

A.3.2 Mode of operation

Table A-6: Mode of operation of EU1 profile

	Uplink	Downlink (optional)
PHY Mode	Telegram Splitting (TS)	
Modulation	(G)MSK	(G)MSK
Symbol rate	ULP	ULP
TSMa Mode	standard (Carrier spacing: 2 380,371 Hz)	
Sync Burst	off	
Repetition	off/on	
Channels	Dual Channel	

A.4 EU2 Profile

A.4.1 Spectrum Use

Table A-7: Channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	867,625 MHz	800 kHz
B (secondary)	866,825 MHz	800 kHz

Both channels are overlapping resulting in an overall channel bandwidth of 1,46 MHz. For frame repetition in dual channel mode a carrier frequency offset step $N_{re} = 28$ is used.

The same channel is used in uplink and downlink. The frequency offset between uplink and downlink is $f_{DL-UL} = 0 \text{ Hz}$.

A.4.2 Mode of operation

Table A-8: Mode of operation of EU2 profile

	Uplink	Downlink (optional)
PHY Mode	Telegram Splitting (TS)	
Modulation	(G)MSK	(G)MSK
Symbol rate	ULP	ULP
TSMa Mode	Wide (Carrier spacing: 28 564,453 Hz)	
Sync Burst	on	
Repetition	on/off	
Channels	Dual Channel	

A.5 US0 Profile

A.5.1 Spectrum Use

Table A-9: UL channel characteristics

Channel name	Channel centre frequency f_c	Channel bandwidth
A (primary)	916,400 MHz	800 kHz
B (secondary)	915,600 MHz	800 kHz

Both channels are overlapping resulting in an overall channel bandwidth of 1,46 MHz. For frame repetition in dual channel mode a carrier frequency offset step $N_{re} = 28$ is used.

The same channel is used for uplink and downlink. The frequency offset between uplink and downlink is $f_{DL-UL} = 0$ Hz.

A.5.2 Mode of operation

Table A-10: Mode of operation of US0 profile

	Uplink	Downlink (optional)
PHY Mode	Telegram Splitting (TS)	
Modulation	(G)MSK	(G)MSK
Symbol rate	ULP	ULP
TSMa Mode	Wide (Carrier spacing: 28 564,453 Hz)	
Sync Burst	on	
Repetition	on/off	
Channels	Dual Channel	

Annex B (informative): TS-UNB MAC payload formats for M-Bus

B.1 Overview

This informative annex gives hints on MPF values that may be used to encapsulate M-Bus packets in TS-UNB packets.

B.2 MPF = 0x80

This MPF value is used if the MAC Payload contains M-Bus upper layer data according to the so-called CI-field principle defined in EN 13757-7:2018 [i.7], clause 5.2. This means the first payload byte is the CI-field that indicates the following structure of further M-Bus defined data. With this approach, the full flexibility of the M-Bus protocol stack is applicable. It can be decided which features of the M-Bus protocol like security, fragmentation or different M-Bus application protocols are needed, e.g. by starting with CI-field 0x90 that indicates AFL (Authentication and Fragmentation layer).

B.3 MPF = 0x81

This MPF value is used if the MAC Payload contains M-Bus application layer data according EN 13757-3:2018 [i.10], clause 6. It means that the first payload byte is a DIF (data information field) as defined in the M-Bus data record structure (EN 13757-3:2018 [i.10], table 2). This approach fits well if only M-Bus application data (i.e. metering data like volume) are transported and other possibilities of the M-Bus protocol stack like security features, status information, application select or clock synchronization are not needed.

B.4 MPF = 0x83

This MPF value is used if the MAC Payload contains M-Bus upper layer data that are introduced by the M-Bus adaptation layer control field (MBAL-CL) according to EN 13757-8:2023 [i.13], clause 7.2.1. This means the first payload byte is the MBAL-CL followed by the CI-field of the next higher layer. With this approach, the advantages of the MPF value 0x80 can be combined with the features of the M-Bus adaptation layer that provides "M-Bus over LPWAN" services (e.g. it provides M-Bus Message Types and Access information).

Annex C (informative): Possible durations and layouts of DLB structure

Table C-1 illustrates the possible durations and internal layouts of DLB frames, with regards to NPRB_IDX values.

Table C-1: Possible durations and layouts of DLB frames

NPRB_IDX	Number of PRBs	DLB frame duration [s] (rounded to 0,1 s)	Max. supported MPDU size in two-stage addressing mode [bytes]	Max. supported MPDU size in single-stage addressing mode [bytes]	Supported number of data regions in two-stage addressing mode
0	3	11,8	48	96	{1}
1	4	15,7	96	144	{1}
2	5	19,7	144	192	{1, 2}
3	7	27,5	240	255	{1, 2, 3}
4	9	35,4	255	255	{1, 2, 4}
5	11	43,3	255	255	{1, 2}
6	13	51,1	255	255	{1, 2, 3, 4}
7	17	66,8	255	255	{1, 2, 4}
8	25	98,3	255	255	{1, 2, 3, 4}
9	31	121,9	255	255	{1, 2, 3}
10	37	145,5	255	255	{1, 2, 3, 4}
11	49	192,7	255	255	{1, 2, 3, 4}
12	73	287,0	255	255	{1, 2, 3, 4}
13	121	475,8	255	255	{1, 2, 3, 4}
14	169	664,5	255	255	{1, 2, 3, 4}
15	217	853,3	255	255	{1, 2, 3, 4}

Annex D (informative): Numerical examples

D.1 Time & frequency pattern calculation of a base station (BSSH)

With reference to clause 4.7.6.2.1, an example of time and frequency pattern calculation of a base station is, as follows:

Communication Parameters for Class B/C

- Beacon-Counter: 0x 0b 8d e1
- Beacon Core BCSYNC: 0x aa 62 8d 22 34 1b
- Frame-Counter = 0
- RE-Index = 0
- NRBIDX = 3 -> $N_{RE,bea} = 252$
- Next,Bea = 1
- $C_{max} = 37$
- Carrier Spacing: $B_c = 2\,380,371$ Hz
- Center frequency $f_c = 868,180$ MHz
- BwMode = dual band

Payload:

- User Data: 0x 4d 49 4f 54 59 (ASCII "MIOTY")
- BS_EUI = 0x 70 b3 d5 67 70 02 00 07

Frequency & Time pattern:

Table D-1: Calculated values for BS frequency & time patterns

<i>Radio Burst n</i>	0	1	2	3	...
$R_p(n)$	0x A9 7C	0x 54 BE	0x 2A 5F	0x C5 B4	
$BSSH(n)$	0x A9 7C 00 07	0x 54 BE 00 07	0x 2A 5F 00 07	0x C5 B4 00 07	
$BSSH_CRC(n)$	0x E9 D8 5B 5B	0x 43 6E E8 B7	0x 16 35 B1 41	0x C3 85 5F 88	
$C_{RE}(n)$	33	9	3	28	
$R_{RE}(n)$	-81	-76	-70	-65	

D.2 Time intervals for concatenated radio-bursts in DLA

This numerical example illustrates the determination of the 12 data-dependent transmission times $T_{RB}(s)$, $s \in \{1,2,4,5,7,8,10,11,13,14,16,17\}$ from Table 4-128 and Table 4-129 in clause 4.7.6.1.12.

Let assume a PSDU size of $P = 90$. The number of blocks in the extension frame is:

$$B = \left\lceil \frac{P}{24} \right\rceil = 4$$

and the number of remaining bytes is:

$$n_r = P - \left\lfloor \frac{P}{B} \right\rfloor \cdot B = 2$$

The number of bytes per block is:

$$n_{byte}(b) = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor + 1, & \text{for } b \leq n_r \\ \left\lfloor \frac{P}{B} \right\rfloor, & \text{for } b > n_r \end{cases} \quad \text{for } b \in \{1, \dots, 4\}$$

$$n_{byte} = \{23, 23, 22, 22\}$$

This means, that the PSDU size of 90 bytes are spread over 4 blocks in portions of 23 bytes each for the first two blocks and 22 bytes each for the last two blocks.

By adding 10 bits (8 bits CRC-field and 2 reserved bits), and, if necessary, padding zeros (if the PSDU size is less than 7 bytes), the overall PHY payload contains at least 66 and at most 202 bits. To this payload, 6 zero (tail) bits are appended.

The whole block is encoded by a 1/3-rate convolutional code with constraint length 7 (see clause 4.7.5.3). This leads to:

$$n_{bit}^{coded}(b) = (8 \cdot n_{byte}(b) + 10 + 6) \cdot 3 \quad \text{for } b \in \{1, \dots, 4\}$$

encoded bits after the forward error correction assigned to block b . In this example, this yields to $n_{bit}^{coded} = \{600, 600, 576, 576\}$ bits for the 4 blocks.

The calculation of the two interleaved data fields DATA_B and DATA_C (see clause 4.7.4.5.2) is done by calculating $d_B(m, s)$ and $d_C(m, s)$. The raw transmission times are calculated for the individual blocks according to the relationship:

$$T_{RB}(b, s) = 28 + \sum_{m=0}^{11} \text{int} \left(d_C(m, s-1) < n_{bit}^{coded}(b) \right) + \text{int} \left(d_B(m, s) < n_{bit}^{coded}(b) \right)$$

$$\text{for } b \in \{1, \dots, 4\}, \quad s \in \{1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 16, 17\}$$

For the calculation of $T_{RB}(1, 1)$ one has to compare all twelve elements of the first column of $d_C(m, 0)$ as well as the twelve elements of the second column of $d_B(m, 1)$ each with the threshold value $n_{bit}^{coded}(1) = 600$. For both columns, there are eleven elements that satisfy the inequality. Together with the value of 28 for the 3 constant fields (PS_DA, DATA_A and PS_DB, see Table 4-89), this gives an initial transmission time of $T_{RB}(1, 1) = 50$ symbols.

The 12 time differences for all 6 groups of three consecutive radio-bursts and for all 4 blocks are listed in Table D-2 and D3. Thereby up to 3 different values of the initial transmission times T_{RB} can occur.

The time values between the groups of three consecutive radio-bursts $T_{RB}(b, s)$, $b \in \{1, \dots, 4\}$, $s \in \{3, 6, 9, 12, 15\}$ are taken from Table 4-128 for downlink mode ULP2 and from Table 4-129 for ULP8 mode.

Table D-2: Example of raw radio-burst time set of DPG for downlink modes ULP2

b \ s	$T_{RB}(b, s)$ (expressed as number of actual symbols)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	50	50	250	49	49	175	50	50	200	49	49	225	50	50	150	49	49
2	50	50	150	49	49	225	50	50	250	49	49	200	50	50	175	49	49
3	48	48	225	48	48	250	48	48	150	48	48	175	48	48	200	48	48
4	48	48	175	48	48	150	48	48	200	48	48	225	48	48	250	48	48

Table D-3: Example of raw radio-burst time set of DPG for downlink modes ULP8

b \ s	$T_{RB}(b, s)$ (expressed as number of actual symbols)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	50	50	500	49	49	350	50	50	400	49	49	450	50	50	300	49	49
2	50	50	300	49	49	450	50	50	500	49	49	400	50	50	350	49	49
3	48	48	450	48	48	500	48	48	300	48	48	350	48	48	400	48	48
4	48	48	350	48	48	300	48	48	400	48	48	450	48	48	500	48	48

D.3 Test vector examples

D.3.1 General

This Test Vector Example covers only the MAC and the physical layer. The message is generated with a valid user payload and the fixed MAC.

End-point parameters:

- EUI: 0x 70 b3 d5 c1 f0 01 50 3a
- NwkKey: 0x e6ad e660 5a92 ddd2 a2b2 cf39 5eb1 2662
- Short Address: 0x f0 01

Communication Parameter for Class Z/A:

- Fixed MAC Mode: MMode = 0b00
- MPDUCNT: 0x 0b 8d e1
- MAC Header: 0x 00 (Initial MAC Version, no MPF-Field, data only, no response expected, no receive window for DL, short addressing, regular data packet, no DL message received since last uplink)
- TSI value: 128

Base station parameters:

- BSEUI: 0x 70 b3 d5 67 70 02 00 07
- DLB-Key/ Sync System Key: 0x 5c96 ea65 f7e3 21e0 df6c d4ea 8259 4997
- Short Address: 0x 00 07

D.3.2 Class Z

Data Payload: 0x 4d 49 4f 54 59 (ASCII "MIOTY")

MAC Payload: 0x 4c bf 63 8d dc (encrypted)

MPDU: 0x 00 f0 01 0b 8d e1 4c bf 63 8d dc d3 d2 30 ae

Data input

The PSDU data field contains a vector of 15 Byte, therefore the message uses the core frame only. The PSDU data are generated out of the user data and the endpoint parameters such as the network key. The 15 Byte sequence is zero padded in the physical layer to 20 byte.

PSDU: 0x 00 f0 01 0b 8d e1 4c bf 63 8d dc d3 d2 30 ae

In addition, the MAC-Mode is set to the fixed MAC. The vector shows the bits.

MMode: 0b00

CRC calculation

The CRC calculation of the header CRC yields the following result. The value appears as byte.

Header CRC: 0xd0

The CRC calculation of the payload CRC yields the following result. The value appears as byte.

Payload CRC: 0x16

PHY Payload

0x d0 16 0f 00 f0 01 0b 8d e1 4c bf 63 8d dc d3 d2 30 ae 00 00 00 00 00 00

Corresponding binary bit vector:

```
1101 0000 0001 0110 0000 1111 0000 0000
1111 0000 0000 0001 0000 1011 1000 1101
1110 0001 0100 1100 1011 1111 0110 0011
1000 1101 1101 1100 1101 0011 1101 0010
0011 0000 1010 1110 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 00
```

Radio-burst Data Unit as binary vector (red=pilot sequence)

```
rb(0) = [0 1 0 1 1 1 0 0 1 1 1 0 0 1 1 0 0 1 1 0 1 0 0 0 0 1 0 1 1 1 1 1 0 0 0 1 0 1 0]
rb(1) = [1 1 0 0 0 0 0 1 0 0 0 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 0 1 1 1 1 0 0 0 0 1 0 1]
rb(2) = [1 1 1 0 1 1 0 0 1 0 1 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 1 0 0 0 1 0 1 0 0 1 1 0]
rb(3) = [0 0 1 0 0 0 0 1 1 1 0 1 0 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 0 0 1 1 0 0 0 0 1 1 0]
rb(4) = [1 0 0 1 1 0 0 0 0 0 1 0 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 1 0 1 0 0 0 0 1 0 0]
rb(5) = [1 1 1 1 0 1 1 0 1 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 0 0 0 1 1 1 0 0 0 1]
rb(6) = [0 0 1 1 0 1 1 1 0 0 1 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 1 1 1 0 1 1 1 1 1 0 1]
rb(7) = [0 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 1 0 1 0 0 1 0 0 0 1]
rb(8) = [1 0 0 0 1 1 0 0 0 0 1 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 1 1 1 0 0 0 0 1 1 0]
rb(9) = [0 0 1 1 0 1 0 0 1 0 1 0 1 0 0 1 1 1 0 1 0 0 0 0 1 0 1 0 0 1 1 0 1 0 1 0 0 1]
rb(10) = [0 0 0 0 1 0 1 1 1 1 0 0 0 1 1 1 0 1 0 0 0 0 1 0 0 1 0 0 1 1 0 0 1 0 1 0 1]
rb(11) = [1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 1 0 0 1 0 1 0 0 1 1 1 1 1 1]
rb(12) = [0 0 1 1 1 1 0 1 1 0 0 1 0 1 1 0 1 1 0 1 0 0 0 0 1 0 1 0 0 0 1 0 0 0 0 1 0 1]
rb(13) = [0 0 1 1 0 0 0 1 1 0 1 0 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 1 1 1 1 1 1 1 1 0 1]
rb(14) = [1 0 1 0 0 0 0 0 0 0 1 1 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 1 0 1 0 0 0 1 1 0 0]
rb(15) = [1 0 1 0 1 1 1 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 1 0 1 1 1 0 0 0 0 1 0 0 1 1]
rb(16) = [0 1 1 0 1 0 1 1 1 1 1 1 0 0 1 1 0 1 0 0 0 0 1 0 0 0 1 1 1 1 0 1 1 0 0 0]
rb(17) = [1 1 1 0 1 1 0 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0]
rb(18) = [1 1 0 0 0 0 0 1 0 0 0 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 1 0 0 1 0 1 0 1 1 1]
rb(19) = [0 1 0 0 1 0 0 1 0 1 0 0 0 0 1 1 1 0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 1 1 1]
rb(20) = [0 1 1 0 0 1 1 0 0 0 1 0 0 1 1 1 0 1 0 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 1 1]
rb(21) = [0 0 0 0 0 1 1 0 1 0 0 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 0 1 1 0 0 0 1 1 1 0]
rb(22) = [1 1 0 0 0 1 1 0 0 0 1 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 0 1 0 0 1 0 1 0 0 0]
rb(23) = [0 1 0 0 1 1 0 0 1 1 1 1 0 1 1 1 0 1 0 0 0 0 1 0 1 1 0 1 0 1 0 0 0 0 0 0]
```

D.3.3 Class A

Data Payload: 0x 4d 49 4f 54 59 (ASCII "MIOTY")

MAC Payload: 0x 4c bf 63 8d dc (encrypted)

MPDU: 0x 00 03 a6 c3 e7 0f 3a 43 1f fa

SYNC: 0x 3c d2 87 98 c9 e5

PHY Payload

0b 1000 0101 0000 0001 0000 0000 00 + MPDU

CRC calculation

The CRC calculation of the core CRC yields the following result. The value appears as bits.

Core Frame CRC: 0b 01 00

Core Frame bit vector

The CMAC, CRC, EFI, PSI, TSI and MMode are concatenated to a corresponding bit vector.

```
0011 1100 1101 0010 1000 0111 1001 1000
1100 1001 1110 0101 1000 0101 0000 0001
0000 0000 0001 00
```

Radio-burst data Unit of Core Frame

The interleaved array is assigned to the 9 subpackets of the core frame. Each line shows the bits for each subpacket.

```
rb(0) = [1 0 0 0 1 1 1 0 1 0 0 0 1 0 0 0 0 1 0 1 0 0 0 0 0 1 0 1]
rb(1) = [0 0 0 0 0 1 0 0 0 1 1 1 1 1 0 0 0 1 1 1 0 0 1 1 1 1 1 1]
rb(2) = [0 1 0 0 0 1 0 1 1 0 0 1 0 0 0 1 0 1 1 1 1 1 1 0 1 1 0 1]
rb(3) = [1 0 1 0 1 1 1 1 1 0 0 1 0 1 0 1 1 1 1 1 0 0 1 0 0 1 0 0]
rb(4) = [0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 1 1 1 0 1 0 1 0 0 1 0 1 0]
rb(5) = [0 1 0 1 1 0 1 0 1 1 0 0 1 1 0 0 1 0 1 1 0 1 0 0 1 1 0 0]
rb(6) = [1 0 0 1 0 1 0 0 1 1 0 0 0 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1]
rb(7) = [1 0 0 1 1 1 0 1 1 1 1 1 0 0 0 1 0 1 1 1 0 1 0 0 1 0 0 0]
rb(8) = [1 1 0 0 1 0 1 1 0 1 1 0 0 0 0 1 1 0 1 1 0 0 1 0 1 1 1 1]
```

Extension Frame

The extension frame consists of one block

CRC calculation for Extension Frame

The CRC calculation of the extension frame CRC yields the following result. The value appears as bits.

Core Frame CRC: 0x d

Extension Frame Bit vector

```
0000 0000 0000 0011 1010 0110 1100 0011
1110 0111 0000 1111 0011 1010 0100 0011
0001 1111 1111 1010 0011 0111 01
```

Radio-burst data Unit of Extension Frame

The encoded bit vector is interleaved and assigned to the 18 subpackets of the core frame. Each line shows the bits for each subpacket.

```
rb(0) = [1 0 0 1 0 0 0 0 1 0 0 1 1 1 0 0 1 1 0 1 0 0 1 1 1 0 1 0 0 0 0]
rb(1) = [1 0 0 1 0 0 0 0 1 0 0 1 1 0 0 0 0 1 1 1 0 1 1 1 1 0 1 0 0 0 1 0]
rb(2) = [0 0 0 1 0 0 0 0 1 0 0 1 0 1 0 1 1 0 0 0 0 1 1 1 1 0 1 0 0 0 0 0]
rb(3) = [1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 1 0 0 1 0 0 1 1 1 1 1 0 1 0 0 0 1 0]
rb(4) = [1 1 0 1 0 0 0 0 1 0 1 0 0 1 1 1 1 1 0 0 0 1 1 1 1 0 1 0 0 0 0 0]
rb(5) = [1 1 0 1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 1 1 0 0 1 1 1 0 1 0 0 0 0 1]
rb(6) = [0 0 0 1 0 0 0 0 1 0 0 1 0 1 0 1 0 0 0 0 0 0 1 1 1 0 1 0 0 0 0 0]
rb(7) = [0 0 0 1 0 0 0 0 1 0 0 0 0 0 1 0 1 0 0 0 0 0 1 1 1 0 1 0 0 0 0 1]
rb(8) = [0 1 0 1 0 0 0 0 1 0 0 0 1 1 0 1 0 0 0 0 0 1 1 1 1 0 1 0 0 0 1 0]
rb(9) = [0 0 0 1 0 0 0 0 1 0 0 1 1 0 0 0 0 0 1 1 1 1 1 1 1 0 1 0 0 0 0 1]
rb(10) = [1 0 0 1 0 0 0 0 1 0 1 1 1 0 1 0 0 0 0 0 0 1 1 1 1 0 1 0 0 0 0 1]
rb(11) = [1 0 0 1 0 0 0 0 1 0 1 0 1 0 0 0 0 0 0 1 0 0 1 1 1 0 1 0 0 0 1 1]
rb(12) = [0 0 0 1 0 0 0 0 1 0 0 0 1 0 1 1 1 0 0 1 0 0 1 1 1 0 1 0 0 0 1 0]
rb(13) = [0 1 0 1 0 0 0 0 1 0 0 0 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 0 0 0 1 0]
rb(14) = [0 1 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 1 0 0 1 1 1 1 0 1 0 0 0 1 1]
rb(15) = [1 1 0 1 0 0 0 0 1 0 0 0 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 0 0 0 1 0]
rb(16) = [1 1 0 1 0 0 0 0 1 0 1 1 0 1 0 0 1 1 1 0 1 1 1 1 1 0 1 0 0 0 1 1]
rb(17) = [1 0 0 1 0 0 0 0 1 0 1 1 0 1 0 1 0 1 1 0 1 1 1 1 1 0 1 0 0 0 0 1]
```

D.3.4 Class B

- DLB-Frame: One data frame, two stage scheduling.

Data frame 1

- Data payload: 0x 00 4d 49 4f 54 59
- MAC payload (encrypted): 0x 00 19 61 c9 1d e5 dd 1e 2c 7a

CRC calculation

The CRC calculation of the data frame CRC yields the following result. The value appears as byte.

Data Frame CRC: 0x C8

Data frame bit vector

The PSDU and the CRC are concatenated to a corresponding bit vector.

```
0000 0000 0001 1001 0110 0001 1100 1001
0001 1101 1110 0101 1101 1101 0001 1110
0010 1100 0111 1010 0011 0010 00
```

Radio-burst Data Unit of Data Frame

The encoded bit vector is interleaved and assigned to the 18 subpackets of the beacon extension. Each line shows the bits for each subpacket.

```
rb(0) = [1 1 0 1 0 0 0 0 1 0 0 1 1 0 1 0 0 1 0 0 1 0 1 1 1 0 1 0 0 0 1 0]
rb(1) = [0 1 0 1 0 0 0 0 1 0 0 0 1 1 1 0 0 0 1 1 1 1 1 1 1 0 1 0 0 0 1 0]
rb(2) = [1 0 0 1 0 0 0 0 1 0 0 1 0 1 0 1 0 1 0 0 1 1 1 1 1 0 1 0 0 0 0 1]
rb(3) = [0 0 0 1 0 0 0 0 1 0 0 1 0 0 0 1 0 1 0 1 0 1 1 1 1 0 1 0 0 0 1 0]
rb(4) = [1 1 0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 0 1 0 1 1 1 1 1 0 1 0 0 0 0 0]
rb(5) = [1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 1 0 0 1 1 1 1 1 0 1 0 0 0 0 0]
rb(6) = [0 0 0 1 0 0 0 0 1 0 0 0 1 0 1 0 1 1 1 0 0 0 1 1 1 0 1 0 0 0 1 1]
rb(7) = [1 0 0 1 0 0 0 0 1 0 0 1 1 0 1 1 1 0 0 0 0 0 1 1 1 0 1 0 0 0 0 1]
rb(8) = [0 0 0 1 0 0 0 0 1 0 0 0 0 1 1 1 0 0 1 0 1 1 1 1 1 0 1 0 0 0 1 1]
rb(9) = [0 1 0 1 0 0 0 0 1 0 0 1 1 0 0 1 0 0 0 1 1 1 1 1 1 0 1 0 0 0 0 0]
rb(10) = [1 0 0 1 0 0 0 0 1 0 1 0 0 0 1 1 1 1 0 1 1 1 1 1 1 0 1 0 0 0 0 0]
rb(11) = [1 0 0 1 0 0 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 1 1 1 1 0 1 0 0 0 1 0]
rb(12) = [0 0 0 1 0 0 0 0 1 0 0 1 1 1 1 1 1 0 0 1 1 0 1 1 1 0 1 0 0 0 0 0]
rb(13) = [1 0 0 1 0 0 0 0 1 0 0 1 0 1 0 0 0 1 0 0 0 1 1 1 1 0 1 0 0 0 1 1]
rb(14) = [0 0 0 1 0 0 0 0 1 0 0 1 1 0 0 1 1 1 0 1 1 1 1 1 1 0 1 0 0 0 1 1]
rb(15) = [1 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 1 0 1 1 1 1 0 1 0 0 0 1 0]
rb(16) = [0 0 0 1 0 0 0 0 1 0 1 1 1 0 0 1 0 0 0 0 0 1 1 1 1 0 1 0 0 0 1 0]
rb(17) = [0 0 0 1 0 0 0 0 1 0 1 1 1 1 0 1 1 0 0 0 0 0 1 1 1 0 1 0 0 0 0 0]
```

Beacon Core

BC_MPDU_01: 0x 00 80 00 40 (only 26 MSBs used)

BC_MPDU (encrypted): 0x a4 35 0f 5f (only 26 MSBs used)

CRC calculation

The CRC calculation of the beacon core CRC yields the following result. The value appears as bits.

Core Frame CRC: 0b 00 10

Beacon Core frame bit vector

The BC_SYNC and BC_MPDU and CRC are concatenated to a corresponding bit vector.

```
1010 1010 0110 0010 1000 1101 0010 0010
0011 0100 0001 1011 1010 0100 0011 0101
0000 1111 0100 10
```

Radio-burst Data Unit of Beacon Core Frame

The interleaved array is assigned to the 9 subpackets of the beacon core frame. Each line shows the bits for each subpacket.

```
rb(0) = [1 1 0 0 1 1 0 1 0 0 0 1 1 1 0 1 1 0 1 0 0 0 1 1 1 1 0 0]
rb(1) = [1 1 0 1 0 1 0 1 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 1 1 0 0]
rb(2) = [1 1 1 0 1 1 0 0 0 1 1 0 1 1 1 0 0 1 1 1 0 0 1 0 1 1 0 0]
rb(3) = [0 1 1 0 1 1 0 1 0 1 1 1 0 1 1 1 1 1 0 0 1 0 0 0 1 1 0 0]
rb(4) = [1 0 0 0 1 1 1 0 0 1 0 1 0 0 0 0 1 1 1 0 1 1 0 0 0 1 0 0]
rb(5) = [0 0 1 0 0 1 0 1 0 0 1 0 1 1 0 1 0 1 1 1 1 0 0 1 1 0 0 1]
rb(6) = [0 1 0 0 1 0 1 1 0 0 1 1 0 0 0 0 0 1 0 1 0 1 1 0 1 0 1 1]
rb(7) = [0 0 0 0 1 1 1 0 1 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0]
rb(8) = [0 0 1 1 1 0 0 0 0 1 0 1 1 0 1 1 0 0 1 1 0 1 0 1 0 1 0 0]
```

Beacon Extension

BE_MPDU: 0x 05 f0 01 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00

BE_MPDU (encrypted): 0x b3 ab f9 38 40 b6 da 96 07 9c c5 50 5b 1a 65 c8 94 47 94 e7 10 9a f7 d8

CRC calculation

The CRC calculation of the beacon extension CRC yields the following result. The value appears as byte.

Beacon Extension Frame CRC: 0x 00

Beacon Extension frame bit vector

The BE_MPDU and the CRC are concatenated to a corresponding bit vector.

```
1011 0011 1010 1011 1111 1001 0011 1000
0100 0000 1011 0110 1101 1010 1001 0110
0000 0111 1001 1100 1100 0101 0101 0000
0101 1011 0001 1010 0110 0101 1100 1000
1001 0100 0100 0111 1001 0100 1110 0111
0001 0000 1001 1010 1111 0111 1101 1000
0000 0000 00
```

Radio-burst Data Unit of Beacon Extension Frame

The encoded bit vector is interleaved and assigned to the 18 subpackets of the beacon extension. Each line shows the bits for each subpacket.

```
rb(0) = [0 0 1 1 1 1 1 1 1 0 1 1 0 1 0 0 0 0 1 0 1 0 1 1 0 1 0 1 1 1 0 0 1 1 1 0 1 0 0 0 1 1 1 1 1 1 1 0 1 0 1]
rb(1) = [0 0 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 0 0 0 1 0 1 0 0 1 1 0 1 0 0 0 1 0 1 1 1 0 1 0 0 0 1 0 1 0 1 0 0 0 1 0 0]
rb(2) = [1 0 0 1 0 0 0 1 1 0 0 1 0 1 0 0 0 0 1 0 1 1 1 1 0 0 1 0 0 0 1 0 1 1 1 0 1 0 0 0 1 0 0 1 0 1 1 1 1 0 1 0]
rb(3) = [1 0 1 1 0 0 1 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 1 0 1 0 0 0 0 1 1 0 1 1 1 0 1 0 0 0 1 0 0 0 0 0 0 0 0 1 0]
rb(4) = [1 1 0 1 0 1 1 1 0 0 0 0 1 0 0 0 0 1 0 1 0 1 1 1 1 0 0 1 0 1 0 1 1 1 0 1 0 0 0 1 1 0 0 0 1 0 0 1 0 0 1 0 0]
rb(5) = [1 0 1 0 0 0 1 0 0 1 0 0 1 0 0 0 0 1 0 1 1 0 1 0 0 0 0 0 0 1 1 1 1 1 0 1 0 0 0 0 1 1 0 0 1 0 0 0 0 1]
rb(6) = [1 1 1 0 1 1 1 1 1 1 0 1 0 1 0 0 0 0 1 0 1 1 1 0 1 1 1 0 1 0 1 0 1 1 1 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0]
rb(7) = [0 0 1 1 0 0 0 1 0 0 0 1 0 1 0 0 0 0 1 0 0 0 0 1 1 1 1 0 1 1 0 0 1 1 1 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1]
rb(8) = [0 0 0 1 1 0 1 0 0 1 1 1 0 1 0 0 0 0 1 0 0 0 1 1 1 1 0 0 0 0 1 1 1 1 1 0 1 0 0 0 0 0 1 1 0 1 1 0 1 0 1]
rb(9) = [1 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 0 0 1 0 1 0 1 1 1 1 0 1 0 0 1 1 1 1 1 0 1 0 0 0 1 0 0 0 0 0 1 1 1 0 1]
rb(10) = [0 1 1 1 1 1 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 0 0 0 1 0 0 0 0 0 1 1 0 0 0]
rb(11) = [1 1 0 0 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 1 0 0 1 0 0 0 0 0 0 1 1 1 1 1 0 1 0 0 0 1 1 1 1 0 1 1 0 1 0 1 0]
rb(12) = [1 0 1 0 0 1 1 0 1 1 0 0 0 1 0 0 0 0 1 0 1 1 0 0 1 1 1 1 1 1 0 1 1 1 0 1 1 0 1 0 0 0 0 1 0 0 1 1 1 1 1 1 0]
rb(13) = [1 1 1 1 0 0 0 0 1 1 0 0 0 1 0 0 0 0 1 0 0 1 1 1 1 0 0 1 0 0 1 0 1 1 1 0 1 0 0 0 0 1 1 0 0 1 0 1 0 0 0]
rb(14) = [0 1 1 1 1 0 0 1 0 0 1 1 0 1 0 0 0 0 1 0 0 1 0 1 0 1 1 0 0 1 0 1 1 1 1 0 1 0 0 0 1 1 0 1 0 1 1 1 1 1 0 0]
rb(15) = [1 1 0 0 1 0 0 0 1 1 0 0 0 1 0 0 0 0 1 0 0 0 1 1 0 1 1 0 1 0 0 0 1 1 1 0 1 0 0 0 0 1 0 1 1 1 0 1 1 0 1 0 0]
rb(16) = [0 0 1 0 0 0 1 0 1 0 1 0 1 0 0 0 0 1 0 1 1 0 1 0 0 1 0 1 1 1 1 1 1 1 1 0 1 0 0 0 1 0 0 0 1 1 1 1 1 1 1]
rb(17) = [0 0 1 1 1 0 0 0 0 1 1 0 1 0 0 0 0 1 0 0 1 1 0 0 0 0 0 1 1 0 0 1 1 1 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 1 0 1 0]
```

History

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