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OMS LPWAN

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Q.1 Introduction

Q.1.1 Preface

This document describes the specification of the OMS LPWAN.

The specifications in this document enable the development of interoperable LPWAN solutions for OMS end-devices and gateways.

Q.1.2 General

OMS LPWAN specifies a radio protocol especially designed for metering applications, where long range and reliable communication together with long battery lifetime is required. OMS LPWAN may also be used for other Internet of Things (IoT) applications, such as smart city or building applications, where long range and low power operation is also desired.

In detail, the protocol provides the following features:

- extended range and penetration compared to existing radio modes (e.g. wireless M-Bus Mode C)
- energy efficiency for OMS applications
- compatibility with the existing M-Bus protocol stack and current OMS architecture
- interoperability with the existing Open Metering System
- high robustness towards interferers in the crowded and shared license free bands
- economic benefit by reducing number of fixed network equipment

OMS LPWAN is intended for stationary systems using a moderate transmission rate. It is not suitable for very frequent transmissions (such as walk-by and drive-by applications) as this can overload the channel capacity.

OMS LPWAN defines two physical radio technologies and a new wireless M-Bus MAC layer. The new wireless M-Bus MAC layer provides several services, such as link and clock management functions as well as optimization possibilities for communication sequences. The MAC layer introduces a security level independent of the upper M-Bus layers, thus enabling MAC services to be controlled independently of the HES. The upper M-Bus layers provide their own security and apply the OMS security profiles defined in [OMS-S2], 9.1.

OMS LPWAN introduces a new link layer format for wireless M-Bus called “Frame Format C” that is optimized for the usage together with the new MAC layer. Redundant fields of former wireless M-Bus link layer are omitted to reduce the overall number of payload bytes.

Table Q.1 shows an overview of the OMS LPWAN protocol stack. The grey shaded cells indicate the new technical content of this specification document.

Table Q.1 – OMS LPWAN layer structure

OSI Model		OMS LPWAN **Layer Model**	
Application Presentation		APL [OMS-S2], clause 8 [a]	
Session Transport		TPL [OMS-S2], clause 7 [a]	
		AFL [OMS-S2], clause 6 [a]	
Data Link	Logical Link Control (LLC) [b]	Wireless M-Bus Frame Format C	
	Medium Access Control (MAC)	Wireless M-Bus MAC	
Physical		Burst Mode	Splitting Mode

[a] optional upper protocol layer
[b] The LLC may optionally contain the ELL. When using Frame Format C the ELL can be avoided.

The two different PHY technologies are introduced to always provide a best fitting solution based on the individual use cases. With this approach, any system topology (i.e. NNAP and LNAP) can be fulfilled with the minimum total cost of ownership (TCO).

The Burst Mode is more energy efficient and therefore (at least with high data rate) also applicable for battery powered gateways. While the Single-burst variant is suitable for a faster response time, the Multi-burst variant facilitates shorter radio bursts and has better robustness.

Splitting Mode is based on TS-UNB technology described in [ETSI 103 357], section 6. Compared to the definition in [ETSI 103 357], it enlarges the possibilities to gain more flexibility especially for low-power embedded devices. On the other hand, it reduces options that are not needed for the intended metering market with the goal to reach a high interoperability and less variants. It is intended for maximum range and best robustness against interferers. To obtain this performance, an SDR receiver is required in the gateway and in the OMS end-device in case of a bidirectional device.

NOTE: The Splitting Mode uses patents. Therefore, a licence agreement must be obtained (see also Table Q.2, footnote d).

Table Q.2 provides an overview about the properties for the sub-modes of OMS LPWAN used by the OMS end-devices in the uplink.

Table Q.2 – Sub-mode overview of OMS LPWAN uplink

Technology	**Burst Mode**				**Splitting Mode**
Burst type	Single-burst		Multi-burst		
Data rate	125 kcps	10 kcps	125 kcps	10 kcps	2,38 kcps
Range (using SDR [a])	+	++	+	++	+++
Robustness against disturbers	+	+	++	++	+++
Energy efficiency per frame	+++	++	+++	++	+
Short burst length [b]	++	+	+++	++	+++
Response time	++	++	+	+	+
Battery powered gateway feasibility	++	-	+	--	---
SDR [a] in gateway	optional	optional	optional	optional	mandatory
SDR [a] in OMS end-device	optional	optional	optional	optional	mandatory for downlink
Royalty Free IPR available for OMS members	yes [c]	yes [c]	yes [c]	yes [c]	no [d]

NOTE: There is a ranking from “+” (moderate) to +++ (very good). A “-“ signals the level of difficulty.

[a] Software Defined Radio (SDR) enables a significantly better receiver sensitivity but results in a higher implementation complexity.

[b] Longer radio bursts increase the hardware requirements, especially those for power supply.

[c] Royalty free IPR is available for burst mode only. See OMS Articles of Association and relating IPR policy.

[d] A license for standard essential patents covering Splitting Mode may be purchased via Sisvel. See www.sisvel.com for further details.

Q.1.3 Glossary of Terms

Additional terms and clarifications for [OMS-S1], Annex A.3 Glossary of Terms.

Table Q.3 – Glossary of Terms

Term	Description
A	**A**
AO	Access Opportunity
B	**B**
BER	Bit Error Rate
BT	Bandwidth-time product
burst	A single radio transmission or part of a radio transmission that has a continuous centre frequency and a constant transmission power.
C	**C**
CCM	Counter with cipher block chaining message authentication code
Chip	Precoded data bit
CL	Coded length
Coded header	FEC coded header
Coded Payload	FEC encoded variant of PHY Payload
CRC	Cyclic Redundancy Check
CTR	Counter (block cipher mode of operation)
D	**D**
DATA	Data field
DL0	Downlink Single-burst
DL1	Downlink Multi-burst, individual burst 1
DL2	Downlink Multi-burst, individual burst 2
DL3	Downlink Multi-burst, individual burst 3
downlink	Radio link direction from gateway to OMS end-device
DPG	Downlink Pattern Group
DR	Data rate
E	**E**
EFI	Extension Frame Indicator
F	**F**
FEC	Forward Error Correction
FEC Parity	FEC coded variant of PHY Payload
FEC Tail	FEC termination bits
Frame	A related set of one or more radio bursts spread over time and/or frequency that contains data belonging to one datagram.
FTM	Flexible Timing Mode
G	**G**

Term	Description
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
H	**H**
I	**I**
IPR	Intellectual Property Rights
J	**J**
K	**K**
L	**L**
LFSR	Linear-feedback shift register
LNAP	Local Network Access Point
LSBit	Least significant bit
LSB	Least significant byte
M	**M**
MAC Block	MAC layer block containing service functions
MAC Body	Optional part of the MAC layer which can carry MAC security parameters and MAC Blocks
MAC Element	Part of the MAC Header carrying information for accessing the OMS end-device and gateway timing.
MAC Header	Header of the complete MAC layer
MAC Payload	The MAC layer above the MAC services, including LLC-layer and optional upper protocol layers.
MCL	Maximum Coupling Loss
MDerCounter	MAC Derivation Counter
MDerKey	MAC Derived Key (ephemeral key)
MFT	MAC Frame Type
MMAC	MAC Message Authentication Code
MMode	MAC mode
MMsgCounter	MAC Message Counter
Midamble	Synchronisation sequence in the middle of a burst
MPDU	MAC protocol data unit
MPL	Maximum Path Loss
MSBit	Most significant bit
MSB	Most significant byte
MSK	Minimum Shift Keying
MSP	MAC Security Profile

Term	Description
Multi-burst	Burst type for sub-mode Burst Mode with three individual bursts
N	**N**
NNAP	Neighbourhood Network Access Point
NW-Manager	Network Manager. Entity responsible for managing communication links and clock management using MAC services.
O	**O**
P	**P**
PER	Packet error rate
PHR	PHY header
Preamble	Train-up sequence in the beginning of a burst
PSDU	PHY service data unit
PS	Pilot sequence
PSI	Packet size indicator
Q	**Q**
R	**R**
RES	Reserved field
RF	Radio frame
RSC	Recursive systematic convolutional
RX0	Receive window option 0
RX1	Receive window option 1
RX2	Receive window option 2
RX3	Receive window option 3
RX4	Receive window option 4
RX5	Receive window option 5
S	**S**
SDR	Software Defined Radio
Single-burst	Burst type for sub-mode Burst Mode with one individual burst
Symbol	A chip is mapped to a symbol by modulation
Sync	Synchronisation sequence in the beginning of a burst
T	**T**
TCO	Total Cost of Ownership
TDN	Time Delay Extension Frame
THB	Time Delay Half Block
TIV	Timing Input Value
TSI	Transmission Start-time Indicator

Term	Description
TSMA	Telegram Splitting Multiple Access
TS-UNB	Telegram Splitting Ultra Narrow Band
TX0	First individual burst of Multi-burst or Single-burst transmission
TX1	Second individual burst of Multi-burst transmission
TX2	Third individual burst of Multi-burst transmission
U	**U**
UL0	Uplink Single-burst
UL1	Uplink Multi-burst, individual burst 1
UL2	Uplink Multi-burst, individual burst 2
UL3	Uplink Multi-burst, individual burst 3
UPG	Uplink pattern group
uplink	Radio link direction from OMS end-device to gateway
X	**X**
Y	**Y**
Z	**Z**

Q.2 Physical Layer (PHY)

Q.2.1 Overview

OMS LPWAN physical layer includes two technologies named “Burst Mode” and “Splitting Mode”. The two technologies are abbreviated with UL-B and UL-S for uplink and DL-B and DL-S for downlink. The letter “B” is for Burst Mode and letter “S” is for Splitting Mode.

Both technologies apply several sub-modes in each direction. These sub-modes provide different properties, such as communication speed, energy consumption, link budget etc. The individual sub-modes are identified using an abbreviation describing the direction, technology and PHY-index.

As an example, the sub-mode name UL-B2 denotes the second sub-mode (2) for the Burst Mode technology (B) in uplink (UL). Accordingly, sub-mode DL-S1 denotes the first sub-mode (1) for the Splitting Mode technology (S) in downlink (DL).

Even though the sub-modes apply two different technologies, Burst Mode and Splitting Mode, it is possible to combine these two technologies in one product by e.g. applying Burst Mode technology for uplink and Splitting Mode technology for downlink or vice versa. See subclause Q.2.6 where specific rules for this combination are defined.

Q.2.2 Channel Properties

The radio part of an OMS end-device shall, for all parameters, as a minimum conform to the requirements of [EN300220-1] and [EN300220-2], even if some applications require extended temperature or voltage range.

The specific requirements for frequency bands are given in Table Q.4 and Table Q.5.

Table Q.4 – OMS LPWAN, Channel properties, Uplink

Characteristic	min.	nom.	max.	Unit
Frequency band	868,0		868,6	MHz
Transmitted power			25	mW
OMS recommended transmitter duty cycle			0,2	%
Regulatory transmitter duty cycle			1	%

Table Q.5 – OMS LPWAN, Channel properties, Downlink

Characteristic	min.	nom.	max.	Unit
Frequency band	869,4		869,65	MHz
Transmitted power			500	mW
Transmitter duty cycle			10	%

Q.2.3 Physical Link Parameters

The sub-modes are allocated as given in Table Q.6. Technology “B” indicates Burst Mode and technology “S” indicates Splitting Mode. A visualization of the frequency plan is shown in Appendix Q.A.

Table Q.6 – OMS LPWAN, technology and frequencies

Direction	Technology	PHY-index	Chip rate [kcps]	Centre frequency [MHz]	Sub-carrier range
Uplink (UL)	B	1 [a]	10	$868{,}530 + (n-2) \cdot 0{,}015$	$0 \leq n \leq 4$
		2 [a]	10	$868{,}070 + (n-2) \cdot 0{,}015$	$0 \leq n \leq 4$
		3 [c]	10	$868{,}180 + (n-2) \cdot 0{,}015$	$0 \leq n \leq 4$
		4	125	868,350	n.a.
	S	1 [b]	2,380371	868,180	n.a.
		2 [b]	2,380371	868,080	n.a.
		3 [c]	2,380371	868,520	n.a.
Downlink (DL)	B	1	2	$869{,}525 + (n-2) \cdot 0{,}040$	$0 \leq n \leq 4$
		2	4	$869{,}525 + (n-2) \cdot 0{,}040$	$0 \leq n \leq 4$
		3	8	869,525	n.a.
		4	24	869,525	n.a.
	S	1	2,380371	869,575	n.a.
		2	2,380371	869,475	n.a.
		3	4,760742	869,525	n.a.
		4	19,042969	869,525	n.a.

[a] Dual channel usage of both sub-modes

[b] Dual channel usage according to [ETSI 103 357], “EU1 Profile”

[c] Optional extension sub-mode to be used by OMS end-devices only if requested by the NW-Manager.

To increase channel capacity, some sub-modes apply a sub-carrier range. The OMS end-device chooses a sub-carrier index, n, for each individual uplink burst. The OMS end-device informs in the MAC-layer of an uplink transmission about the applied uplink n-values and the expected n-values for the following downlink (see clause Q.3.5).

Q.2.4 Technology – Burst Mode (UL-B / DL-B)

Q.2.4.1 Introduction

The Burst Mode technology provides two different burst methods: Single-burst and Multi-burst. The method applied in a specific burst is indicated in the coded header included in all bursts.

Single-burst provides all information in one Single-burst. For Single-burst, three different FEC rates are supported; rate 7/8, rate 1/2 and rate 1/3. The FEC rate applied is indicated in the coded header. A lower code rate results in a longer burst, but also a higher reception probability.

Multi-burst repeats the information in three individual bursts. Each burst contains one representation of the transmitted payload and can therefore be decoded individually. Each individual burst is FEC encoded using rate 7/8. By combining two or three bursts code rate 7/16 and 7/24 can be achieved, respectively. The more bursts that are received and combined in the receiver, the higher the coding gain and correspondingly a higher reception probability. The receive sequence is determined using the specific timing between the individual bursts. All information regarding timing is included in the coded header.

Independent of Single-burst or Multi-burst, all bursts are generated from the common rate 1/4 convolutional FEC encoding. All contents are furthermore interleaved to improve interference rejection.

The coding of the content of uplink burst and downlink bursts are identical. However, the transmitted burst structure differs slightly as uplink bursts contain both preamble and synchronization word in the beginning of the burst for start of burst detection and midamble for mid of burst detection. Downlink bursts only contains preamble and synchronization word for start of burst detection.

NOTE: The midamble is included to enable optimal reception by an SDR receiver, while the preamble is included to ensure compatibility with conventional receivers.

Figure Q.1 provides an overview of the Burst Mode technology for uplink and downlink. Details are provided in the following subclauses.

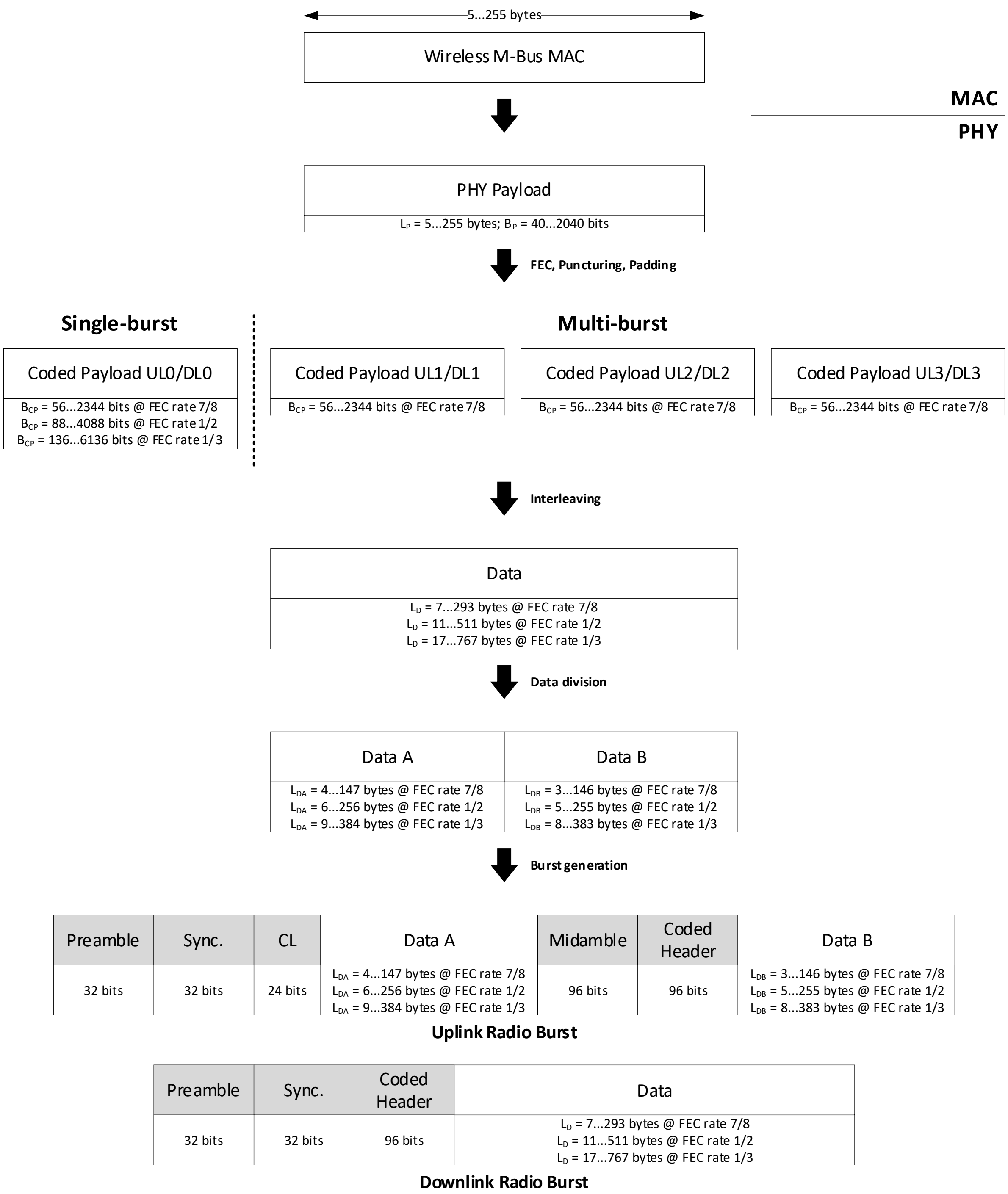

Figure Q.1 – Burst mode overview – uplink and downlink

Q.2.4.2 Transmitter Parameters

The transmitter parameters for Burst Mode shall be as given in Table Q.7 for uplink (UL-B) and Table Q.8 for downlink (DL-B). For details on modulation, see subclause Q.2.4.5.1.

Table Q.7 – Uplink transmitter parameters for Burst Mode, UL-B

Characteristic	Symbol	Sub-mode	min.	nom.	max.	Unit	Note
Centre frequency tolerance	f_{tol}	UL-B (all)	-20	0	20	kHz	±23 ppm tolerance
Centre freq. drift	f_{drift}	UL-B (all)	-200	0	200	Hz/s	See Appendix Q.F
GMSK bandwidth-time product	BT	UL-B (all)		0,5			
GMSK chip rate	f_{chip}	UL-B1 UL-B2 UL-B3	9.999,7	10.000	10.000,3	cps	±30 ppm tolerance
		UL-B4	124.996,25	125.000	125.003,75		
Data rate	DR	UL-B (all)		f_{chip}			
GFSK deviation [a]	f_{dev}	UL-B1 UL-B2 UL-B3	2.490	2.500	2.510	Hz	
		UL-B4	31.200	31.250	31.300		

[a] The GFSK deviation frequencies only applies when using a GFSK modulator to transmit GMSK (see Appendix Q.D).

Table Q.8 – Downlink transmitter parameters for Burst Mode, DL-B

Characteristic	Symbol	Sub-mode	min.	nom.	max.	Unit	Note
Centre frequency precision [a]	f_{prec}	DL-B1	-200	0	200	Hz	
		DL-B2	-400	0	400		
		DL-B3	-800	0	800		
		DL-B4	-2.400	0	2.400		
GFSK bandwidth-time product	BT	DL-B (all)		0,5			
GFSK chip rate	f_{chip}	DL-B1	1.999,94	2.000	2.000,06	cps	±30 ppm tolerance
		DL-B2	3.999,88	4.000	4.000,12		
		DL-B3	7.999,76	8.000	8.000,24		
		DL-B4	23.999,28	24.000	24.000,72		
Data rate	DR	DL-B (all)		f_{chip}			
GFSK deviation	f_{dev}	DL-B1	990	1.000	1.010	Hz	
		DL-B2	1.990	2.000	2.010		
		DL-B3	3.950	4.000	4.050		
		DL-B4	11.950	12.000	12.050		

[a] For downlink sessions, the gateway must estimate the inaccuracy of the OMS end-device centre frequency based on the UL transmission. Subsequent DL transmission(s) associated with an UL transmission shall compensate for the UL inaccuracy, such that the centre frequency offset as perceived by the OMS end-device is within the centre frequency precision, f_{prec}.

Q.2.4.3 Structure and Synchronization

Q.2.4.3.1 Uplink Structure and Synchronization

Q.2.4.3.1.1 Overview

All uplink transmissions of Burst Mode shall apply the burst structure shown in Table Q.9.

Table Q.9 – Uplink structure of Burst Mode

Preamble	Sync	CL	Data A	Midamble	Coded Header	Data B
B_{PRE} bits	B_{SYNC} bits	B_{CL} bits	L_{DA} bytes	B_{MID} bits	B_{CH} bits	L_{DB} bytes

All fields are transmitted with MSBit first. The byte order of Data A and Data B is MSB first.

Q.2.4.3.1.2 Preamble

The preamble field has a fixed length, B_{PRE}, of 32 bits and the value 66666666_h

NOTE: After precoding, the resulting chip sequence is 55555555_h

Q.2.4.3.1.3 Sync

The sync field has a fixed length, B_{SYNC}, of 32 bits and the value $8153884C_h$

NOTE: After precoding, the resulting chip sequence is $C1FA4C6A_h$

Q.2.4.3.1.4 CL

The CL field has a fixed length, B_{CL}, of 24 bits and contains an encoded version of the length, L_{DA}, of the field, Data A.

NOTE: In case of a synchronization by preamble the CL-field is needed to calculate the position of the coded header.

The CL field is divided into two subfields as shown in Table Q.10.

Table Q.10 – Structure of CL

L_{DA}	**CRC15(L_{DA})**
9 bits	15 bits

The L_{DA}-field is here a 9-bit field representing the length, L_{DA}, of Data A.

The CRC15 is a 15-bit CRC calculated over the 9 bit L_{DA}field with the following parameters:

The CRC polynomial is: $x^{15} + x^{14} + x^{10} + x^9 + x^4 + x^2 + x + 1\ (C617_h)$ (Eq.Q.1)

The initial value is 0.

The final CRC is not complemented.

NOTE: The CRC15 may be used to identify multiple bit errors or to correct single bit errors in L_{DA} field.

Example: L_{DA} = 45_d = 000101101_b
CRC15 = 29173_d = 111000111110101_b
CL = 1503733_d = $000101101111000111110101_b$

Q.2.4.3.1.5 Data

The Data of length L_D bytes is the interleaved Coded Payload. See Q.2.4.4 for details on Coded Payload. The interleaver is specified in subclause Q.2.4.5.3. The Data is further divided in the Data A and Data B.

The L_D bytes do not include the CL-field, midamble and coded header.

NOTE: The length L_D can be calculated from the length L_P in the coded header (see Appendix Q.E).

Q.2.4.3.1.6 Data A

The Data A field with length L_{DA} bytes contain the first half of the transmitted Data of L_D bytes. The length of the Data A field is calculated as $L_{DA} = \left\lceil \frac{L_D}{2} \right\rceil$. The result is rounded up to an integer number of bytes.

Q.2.4.3.1.7 Data B

The Data B field with length L_{DB} bytes contain the second half of the transmitted Data with length L_D bytes. The length of the Data B field is calculated as $L_{DB} = L_D - L_{DA}$.

Q.2.4.3.1.8 Midamble

The midamble field has a fixed length, B_{MID}, of 96 bits and the value DF46428F20B9BD70DF46428F$_h$

NOTE: After precoding and assuming that the last bit of Data A is 0, the resulting chip sequence is 3 x B0E563C8$_h$ (B0E563C8B0E563C8B0E563C8$_h$). If the last bit of Data A is 1, the resulting chip sequence after precoding is 30E563C8B0E563C8B0E563C8$_h$.

Q.2.4.3.1.9 Coded Header

Q.2.4.3.1.9.1 Overview

The coded header has a fixed length, B_{CH}, of 96 bits with the content shown in Table Q.11. The coded header is encoded with a fixed FEC code rate of 1/3.

Table Q.11 – Coded header of Burst Mode

Name	Size (bits)	Description / range
Version	2	00$_b$ for initial version
PHY Payload length	8	Length, L_P, in bytes from 5 to 255
Timing Input Value	7	Input value for timing from 0 to 127.
Burst mode	1	0 Single-burst 1 Multi-burst
Burst type	2	Type of burst – see subclause Q.2.4.3.1.9.6 and Q.2.4.3.2.4.
Coded header CRC	8	Checksum of the above fields
FEC parity CH1	28	FEC parity 1 for coded header
FEC parity CH2	28	FEC parity 2 for coded header
FEC tail CH1	6	FEC tail 1 for coded header
FEC tail CH2	6	FEC tail 2 for coded header
Total length of uplink coded header	**96**	

All fields are transmitted with MSBit first. The Version bit is the most significant bit of the most significant byte.

Q.2.4.3.1.9.2 Version (2 bit)

The version field is reserved for future iterations of this specification and is initially set to version 0.

Q.2.4.3.1.9.3 PHY Payload Length (8 bit)

The PHY Payload length field indicate the length of the PHY Payload, L_P.

For information how to calculate the Coded Payload length, B_{CP}, based on PHY Payload length, L_P, see subclause Q.2.4.4.2.1 and subclause Q.2.4.4.3.1 or Appendix Q.E.

Q.2.4.3.1.9.4 Timing Input Value (7 bit)

The timing input value (TIV) is used as input for the calculation of timing as specified in subclause Q.2.4.6. The value shall be uniformly chosen between 0 and 127. It can either be assigned during production, or it can be set after a power-up of the OMS end-device. A downlink frame shall contain the same timing input value as the preceding uplink transmission.

Q.2.4.3.1.9.5 Burst Mode (1 bit)

The Burst Mode field specify whether the burst is a Single-burst or a Multi-burst.

Q.2.4.3.1.9.6 Burst Type – uplink (2 bit)

The value of the burst type field in uplink shall be as specified in Table Q.12.

Table Q.12 – Burst type field for uplink coded header

Name	Size (bits)	Description / range
Burst type	2	In case of Single-burst (Burst mode = 0) 0 Uplink Single-burst, FEC rate 7/8 1 Uplink Single-burst, FEC rate 1/2 2 Uplink Single-burst, FEC rate 1/3 3 Reserved for Future Use In case of Multi-burst (Burst mode = 1) 0 Uplink Multi-burst, Timing 1 (short spacing) 1 Uplink Multi-burst, Timing 2 (medium spacing) 2 Uplink Multi-burst, Timing 3 (long spacing) 3 Reserved for Future Use

The burst type field specify in the case of uplink Multi-burst also the timing selected for the Multi-burst transmission. For uplink Single-burst the type field specify the FEC code rate. For timing, see subclause Q.2.4.6.

Q.2.4.3.1.9.7 Coded Header CRC (8 bit)

The coded header CRC is covering the 20-bit content of the coded header.

The CRC polynomial is: $x^8 + x^2 + x + 1\ (107h)$ (Eq.Q.2)

The initial value is 0.

The final CRC is not complemented.

NOTE: A CRC-8 implementation operating on an integer number of bytes can be used by applying 4 leading bits (set to 0) before the 20-bit content.

Q.2.4.3.1.9.8 FEC Parity CH1 (28 bit) and FEC parity CH2 (28 bit)

The fields FEC parity CH1 and FEC parity CH2 are part of the forward error correction coding of the coded header. The FEC parities for the coded header each have a fixed length of 28 bits. See subclause Q.2.4.5.2.

Q.2.4.3.1.9.9 FEC Tail CH1 (6 bit) and FEC Tail CH2 (6 bit)

The fields FEC tail CH1 and FEC tail CH2 are part of the forward error correction coding of the coded header. The FEC tail for the coded header each has a fixed length of 6 bits. See subclause Q.2.4.5.2.

Q.2.4.3.2 Downlink Structure and Synchronization

Q.2.4.3.2.1 Overview

All downlink transmissions of Burst Mode shall apply the burst structure shown in Table Q.13.

Table Q.13 – Downlink structure of Burst Mode

Preamble	Sync	Coded Header	Data
B_{PRE} bits	B_{SYNC} bits	B_{CH} bits	L_D bytes

All fields are transmitted with MSBit first. The byte order of Data is MSB first.

Q.2.4.3.2.2 Preamble

The preamble field has a fixed length, B_{PRE}, of 32 bits and the following fixed value: 55555555_h

Q.2.4.3.2.3 Sync

The sync field has a fixed length, B_{SYNC}, of 32 bits and the following fixed value: $C1FA4C6A_h$

Q.2.4.3.2.4 Burst type – downlink (2 bit)

The Coded Header in downlink is identical to the Coded Header in uplink as defined in section Q.2.4.3.1.9 except for the burst type field.

The value of the burst type field in downlink shall be as specified in Table Q.14.

Table Q.14 – Burst type field for downlink coded header

Name	Size (bits)	Description / range
Burst type	2	In case of Single-burst (Burst mode = 0) 0 Downlink Single-burst, FEC rate 7/8 1 Downlink Single-burst, FEC rate 1/2 2 Downlink Single-burst, FEC rate 1/3 3 Reserved for Future Use In case of Multi-burst (Burst mode = 1) 0 Downlink Multi-burst 1 Reserved for Future Use 2 Reserved for Future Use 3 Reserved for Future Use

The burst type field specify in the case of downlink Single-burst also the FEC code rate. For timing, see section Q.2.4.6.

Q.2.4.3.2.5 Data

The Data of length L_D bytes is the interleaved Coded Payload. See subclause Q.2.4.4 for details on Coded Payload. The interleaver is specified in subclause Q.2.4.5.3.

Q.2.4.4 Coded Payload

Q.2.4.4.1 General

The structure of the Coded Payload for Burst Mode depends on whether Single-burst or Multi-burst is applied. For Single-burst the Coded Payload is transmitted in a Single-burst. For Multi-burst three different Coded Payload are generated and transmitted in each of the three individual bursts.

The structure of the Coded Payload in uplink (UL-B) and downlink (DL-B) is identical.

Q.2.4.4.2 Single-burst

For Single-burst, the frame consists of one Single-burst with the Coded Payload shown in Table Q.15, Table Q.16 and Table Q.17. The three situations show the Coded Payload in case of the three different available FEC coding rates 7/8, 1/2 and 1/3.

Table Q.15 – Coded Payload of uplink/downlink Single-burst, UL0/DL0, FEC rate 7/8

PHY Payload	7/8-padding	FEC parity 3A	FEC tail 0	Padding
B_P bits	B_{pad78} bits	$\frac{B_{FEC}}{7}$ bits	6 bits	2 bits

Table Q.16 – Coded Payload of uplink/downlink Single-burst, UL0/DL0, FEC rate 1/2

PHY Payload	FEC parity 1	FEC tail 1	Padding
B_P bits	B_{FEC} bits	6 bits	2 bits

Table Q.17 – Coded Payload of uplink/downlink Single-burst, UL0/DL0, FEC rate 1/3

PHY Payload	FEC parity 1	FEC tail 1	Padding	FEC parity 2	FEC tail 2	Padding
B_P bits	B_{FEC} bits	6 bits	2 bits	B_{FEC} bits	6 bits	2 bits

Q.2.4.4.2.1 PHY Payload

The PHY Payload field of length B_P bits is the protocol payload to be transmitted. The length B_P divided by 8 is always an integer as the payload contains an integer number of bytes, $L_P = \frac{B_P}{8}$. The PHY Payload length in bytes, L_P, is transmitted in the coded header.

Q.2.4.4.2.2 7/8-padding

The 7/8-padding is a padding field that is added to the Coded Payload only in case of FEC rate 7/8. The value of the bits of the 7/8-padding is 0. The length of 7/8-padding, B_{pad78}, range from 0 to 6 bits and is calculated as:

$$B_{pad78} = (-B_P)\text{modulo } 7 \qquad \text{(Eq.Q.3)}$$

NOTE 1: In case of FEC rate 1/2 or 1/3 the 7/8-padding is not present, and the length of the 7/8-padding, B_{pad78}, is therefore considered as 0 in these cases.

NOTE 2: This formula uses a modulo operation with a non-negative remainder. For example, if B_P = 3, then B_{pad78} = (-3) modulo 7 = 4. Be aware that some programming languages may return a negative remainder for such cases.

Q.2.4.4.2.3 FEC Parity

The fields FEC parity 1, FEC parity 2 and FEC parity 3A contain variants of the FEC parity output. See section Q.2.4.5.2 for details on FEC encoding. FEC Parity 1 and FEC Parity 2 each has a length of B_{FEC} bits. FEC Parity 3A has a length of $\frac{B_{FEC}}{7}$ bits.

Q.2.4.4.2.4 FEC Tail

The fields FEC tail 0, FEC tail 1 and FEC tail 2 each of fixed length of 6 bit, contain the tail-bits of the FEC encoding. See section Q.2.4.5.2 for details on FEC encoding.

Q.2.4.4.2.5 Padding

The padding field is added to ensure the full Coded Payload to always be an integer number of bytes. The padding field has a fixed length of 2 bits and the value of all bits of the padding field shall be 0_b.

Q.2.4.4.2.6 Calculating length of the Coded Payload

This subclause describes how the length of the Coded Payload is calculated. A summary of calculation of all length fields of Burst Mode is provided in Appendix Q.E.

The length of the data to be FEC-encoded, B_{FEC}, is calculated as follows for the three different coding rates:

FEC rate 7/8: $B_{FEC} = B_P + B_{pad78}$ (Eq.Q.4)

FEC rate 1/2: $B_{FEC} = B_P$ (Eq.Q.5)

FEC rate 1/3: $B_{FEC} = B_P$ (Eq.Q.6)

The length of the Coded Payload, B_{CP}, is calculated as follows for the three different coding rates:

FEC rate 7/8: $B_{CP} = B_P + B_{pad78} + \frac{B_{FEC}}{7} + 8 = B_{FEC} \cdot \frac{8}{7} + 8$ (Eq.Q.7)

FEC rate 1/2: $B_{CP} = B_P + B_{FEC} + 8 = B_{FEC} \cdot 2 + 8$ (Eq.Q.8)

FEC rate 1/3: $B_{CP} = B_P + 2 \cdot B_{FEC} + 16 = B_{FEC} \cdot 3 + 16$ (Eq.Q.9)

Q.2.4.4.3 Multi-burst

For Multi-burst three different Coded Payload for the three individual bursts are generated as shown in Table Q.18, Table Q.19 and Table Q.20. Each individual burst of Multi-burst provides a FEC coding rate of 7/8, however by combining two or three bursts, FEC coding rates of 7/16 and 7/24 can be achieved.

Table Q.18 – Coded Payload of uplink/downlink Multi-burst, UL1/DL1

PHY Payload	7/8-padding	FEC parity 3A	FEC tail 0	Padding
B_P bits	B_{pad78} bits	$\frac{B_{FEC}}{7}$ bits	6 bits	2 bits

Table Q.19 – Coded Payload of uplink/downlink Multi-burst, UL2/DL2

FEC parity 1	FEC parity 3B	FEC tail 1	Padding
B_{FEC} bits	$\frac{B_{FEC}}{7}$ bits	6 bits	2 bits

Table Q.20 – Coded Payload of uplink/downlink Multi-burst, UL3/DL3

FEC parity 2	FEC parity 3C	FEC tail 2	Padding
B_{FEC} bits	$\frac{B_{FEC}}{7}$ bits	6 bits	2 bits

NOTE: FEC parity 1 and FEC parity 2 cover both PHY Payload and 7/8-padding.

Q.2.4.4.3.1 PHY Payload

The field PHY Payload of length B_P bits is the protocol payload to be transmitted. The length B_P divided by 8 is always an integer as the payload contains an integer number of bytes, $L_P = \frac{B_P}{8}$. The PHY Payload length in bytes, L_P, is transmitted in the coded header.

Q.2.4.4.3.2 7/8-padding

The 7/8-padding is a padding field that is added to the Coded Payload. The value of the bits of the 7/8-padding is 0. The length of 7/8-padding, B_{pad78}, range from 0 to 6 bits and is calculated as:

$$B_{pad78} = (-B_P)\text{modulo } 7 \qquad \text{(Eq.Q.10)}$$

NOTE: This formula uses a modulo operation with a non-negative remainder. For example, if B_P = 3, then B_{pad78} = (-3) modulo 7 = 4. Be aware that some programming languages may return a negative remainder for such cases.

Q.2.4.4.3.3 FEC Parity

The fields FEC parity 1, FEC parity 2, FEC parity 3A, FEC parity 3B and FEC parity 3C contain variants of the FEC parity output. See subclause Q.2.4.5.2 for details on FEC encoding. FEC Parity 1 and FEC Parity 2 each has a length of B_{FEC} bits. FEC Parity 3A, FEC Parity 3B and FEC Parity 3C each has a length of $\frac{B_{FEC}}{7}$ bits.

Q.2.4.4.3.4 FEC Tail

The fields FEC tail 0, FEC tail 1 and FEC tail 2 each of fixed length of 6 bit, contain the tail-bits of the FEC encoding. See subclause Q.2.4.5.2 for details on FEC encoding.

Q.2.4.4.3.5 Padding

The padding field is added to ensure the full Coded Payload to always be an integer number of bytes. The padding field has a fixed length of 2 bits and the value of all bits of the padding field shall be 0_b.

Q.2.4.4.3.6 Calculating length of the Coded Payload

This subclause describes how the length of the Coded Payload is calculated. A summary of calculation of all length fields of Burst Mode is provided in Appendix Q.E.

The length of the data to be FEC-encoded, B_{FEC}, is calculated as follows:

$$B_{FEC} = B_P + B_{pad78} \qquad \text{(Eq.Q.11)}$$

The length of the Coded Payload, B_{CP}, is calculated as follows:

$$B_{CP} = B_P + B_{pad78} + \frac{B_{FEC}}{7} + 8 = B_{FEC} \cdot \frac{8}{7} + 8 \qquad \text{(Eq.Q.12)}$$

Q.2.4.5 Functions

Q.2.4.5.1 Modulation

Q.2.4.5.1.1 GMSK Modulation

All UL-B sub-modes defined in Table Q.6, shall be GMSK modulated with the modulation parameters defined in Table Q.7. In the case of GMSK transmission using a GFSK transceiver, where a modulation index of 0,5 cannot be achieved, the GFSK deviation frequency limits in Table Q.7 apply.
NOTE: For details on how to receive and transmit GMSK using a GFSK transceiver, see Appendix Q.D.

Q.2.4.5.1.2 Precoding

Prior to modulation, all UL-B transmissions defined in Table Q.6 must be precoded. The precoding operation is defined by

$$c_k = d_{k-1} \oplus d_k \qquad \text{(Eq.Q.13)}$$

where d_k is the kth bit in the UL-B transmission, c_k is the kth precoded bit (chip), and $\oplus$ denotes the exclusive-OR operation. For all cases, the seed bit is $d_{-1} = 0\text{b}$.

Figure Q.2 illustrates the precoding operation applied to a UL-B transmission.

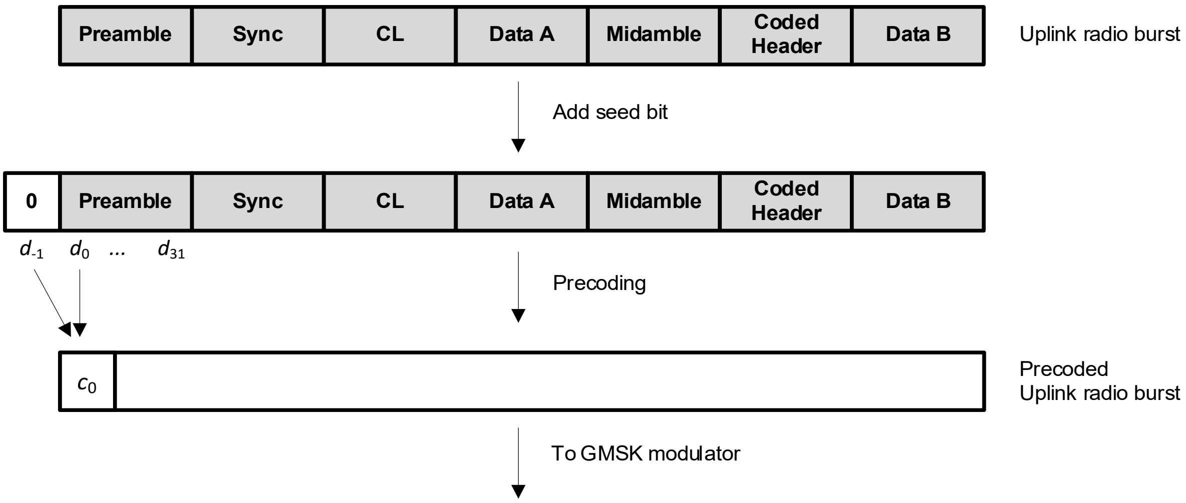

Figure Q.2 – Precoding applied to a UL-B transmission

Test vectors are provided in Appendix Q.Z.

Q.2.4.5.1.3 Signal Mapping of Precoded GMSK

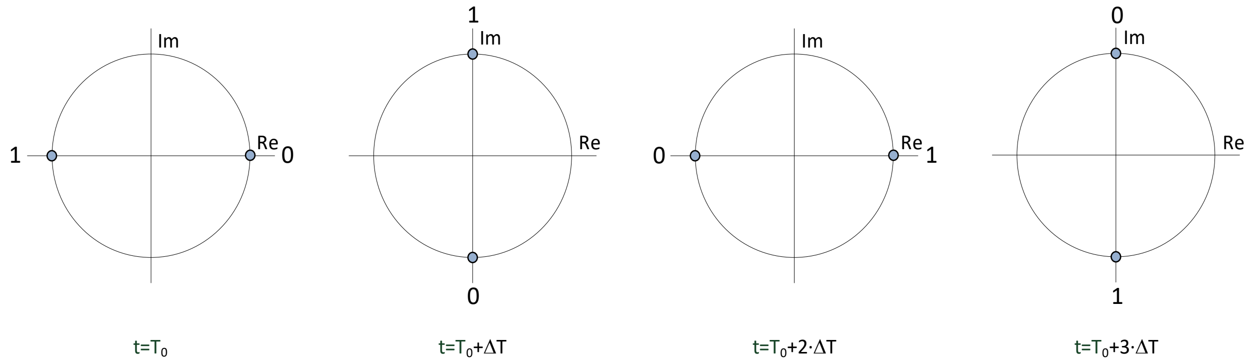

Figure Q.3 – Signal mapping of precoded GMSK

Figure Q.3 shows an idealized signal mapping between phase and data bits for precoded GMSK. The binary values in the figure denote the data bits in the UL-B transmission, T_0 is the start time, and $\Delta T = 1/f_{chip}$ is the chip period. The representation repeats every 4 bits.

Q.2.4.5.1.4 GFSK Modulation

All DL-B sub-modes defined in Table Q.6, shall be GFSK modulated with the modulation parameters defined in Table Q.8.

Q.2.4.5.1.5 Signal Mapping of GFSK

A transmitted 0_b shall use the lower frequency deviation $-f_{dev}$ and a transmitted 1_b shall use the upper frequency deviation $+f_{dev}$ (see Figure Q.4).

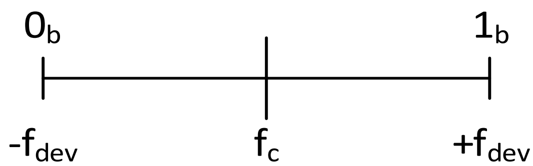

Figure Q.4 – Signal mapping of GFSK

Q.2.4.5.2 Forward Error Correction Coding (FEC)

Q.2.4.5.2.1 Common FEC Encoding Scheme

All forward error correction (FEC) of Burst Mode is enabled using convolutional coding. Independent of whether the bursts to transmit is Single-burst or Multi-burst and independent of whether to encode the coded header or the Coded Payload, the calculations are based on the same common encoding scheme.

The basis for the coding is a recursive systematic convolutional encoder (RSC) with a code rate of 1/4 and a constraint length of 7. The computation is illustrated in Figure Q.5.

Test vectors are provided in Appendix Q.Z.

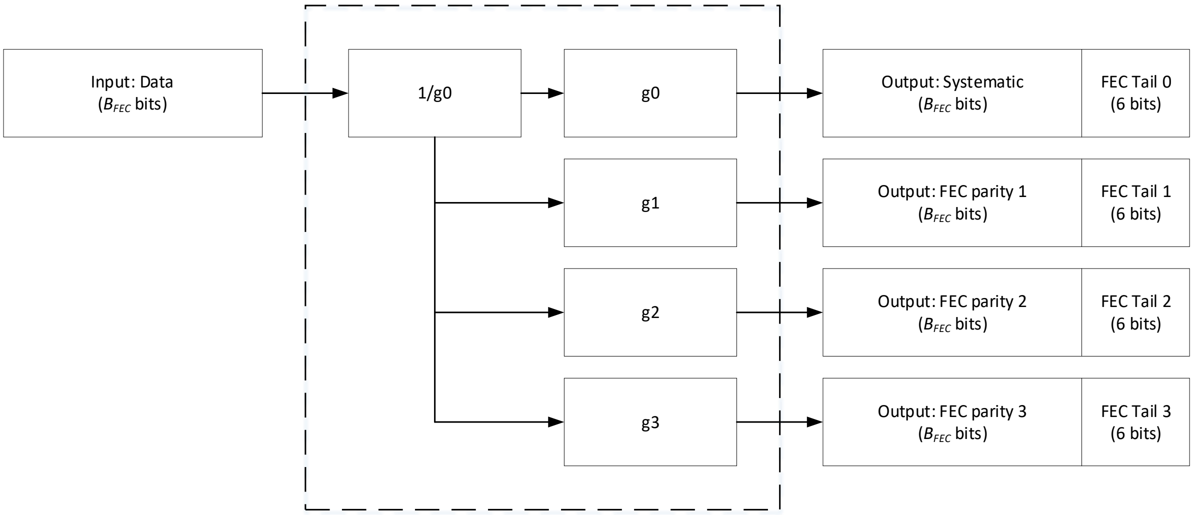

Figure Q.5 – Block diagram of systematic convolutional encoder, rate 1/4

The length of the four outputs, B_{FEC}, is always identical to the length of the input. In addition, each encoding also outputs 6 tail-bits.

Q.2.4.5.2.2 FEC Polynomial

A total number of four polynomial are used for the generation of the four outputs:

$$g_0 = 4D_h\ (115\ octal)$$

$$g_1 = 73_h\ (163\ octal)$$

$$g_2 = 67_h\ (147\ octal)$$

$$g_3 = 5D_h\ (135\ octal)$$

These generator polynomials define the feedback and feedforward connections of the encoder. The resulting RSC encoder is illustrated in Figure Q.6. The figure includes a switch-based strategy to terminate the encoder in an all-zero state. During normal encoding, the switch is set to position A. To terminate the encoder and generate the FEC tail bits, the switch is toggled to position B, enabling a controlled transition to the all-zero state regardless of the encoder's previous state.

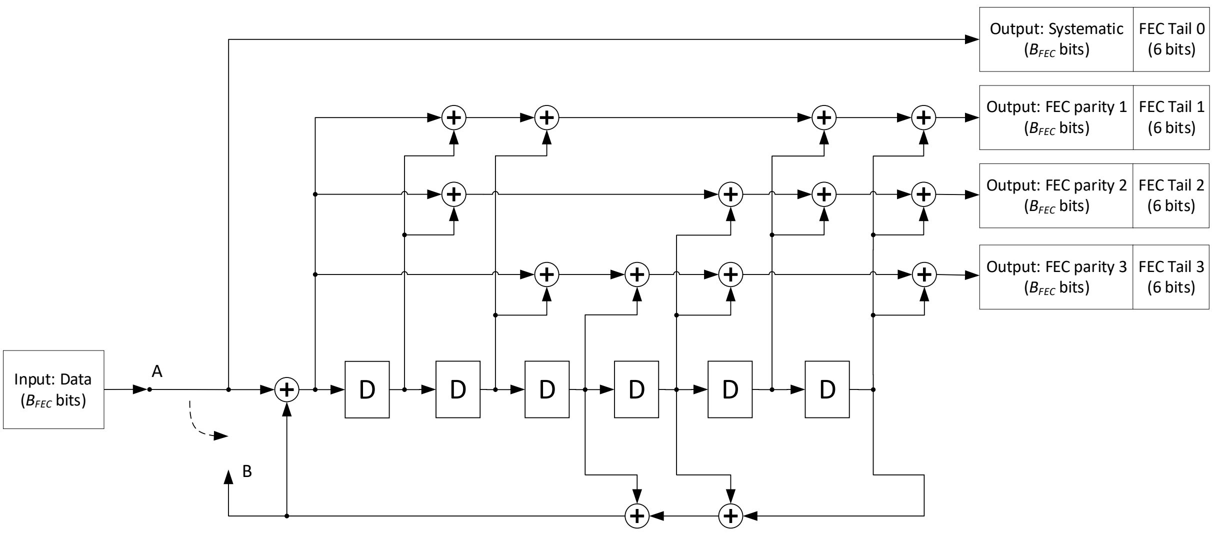

Figure Q.6 – Recursive Systematic Convolutional (RSC) Encoder with switch-based termination strategy

Q.2.4.5.2.3 Input Data

The Input Data is the data to be FEC encoded. The length of the Input Data is denoted as B_{FEC}. For Coded Payload, the Input Data of length B_{FEC} is the PHY Payload field of B_P bits and the 7/8-padding of B_{pad78} bits, field if present, $B_{FEC} = B_P + B_{pad78}$. See subclause Q.2.4.4 for details on Coded Payload.

For Coded Header, the Input Data has a fixed length of B_{FEC} = 28 bits. See subclause Q.2.4.3.1.9 and Q.2.4.3.2.5 for details.

Q.2.4.5.2.4 Systematic Output

The systematic output is identical to the input data and with the same length, B_{FEC}.

Q.2.4.5.2.5 FEC Parity

The output FEC parities are all of the same length, B_{FEC}, as the input data. In this protocol different subsets of the three output FEC parities are used. These subsets are generated using puncturing as described in the following subclauses.

Q.2.4.5.2.5.1 FEC Parity 1 / FEC Parity CH1

The full output FEC parity 1 / FEC Parity CH1 of length B_{FEC} without puncturing.

Q.2.4.5.2.5.2 FEC Parity 2 / FEC Parity CH2

The full output FEC parity 2 / FEC Parity CH2 of length B_{FEC} without puncturing.

Q.2.4.5.2.5.3 FEC Parity 3A

A punctured subset of output FEC parity 3 with length $\frac{B_{FEC}}{7}$ using the following puncturing pattern:

$$P_{3A} = 1000000b$$

NOTE: Then length of the puncturing pattern is 7 bits.

Q.2.4.5.2.5.4 FEC Parity 3B

A punctured subset of output FEC parity 3 with length $\frac{B_{FEC}}{7}$ using the following puncturing pattern:

$$P_{3B} = 0100000b$$

NOTE: Then length of the puncturing pattern is 7 bits.

Q.2.4.5.2.5.5 FEC Parity 3C

A punctured subset of output FEC parity 3 with length $\frac{B_{FEC}}{7}$ using the following puncturing pattern:

$$P_{3C} = 0010000b$$

NOTE: Then length of the puncturing pattern is 7 bits.

Q.2.4.5.2.6 FEC Tail

All FEC tail-bits have a fixed length of 6 bits. To generate the FEC tail-bits the convolutional encoder shall be terminated in an all zero state. A termination strategy is illustrated in Figure Q.6.

Q.2.4.5.3 Interleaving

Q.2.4.5.3.1 Common Interleaving Scheme

The Coded Payload for all individual bursts (both Single-bursts and Multi-bursts) are interleaved using a common interleaving scheme. The interleaver rearranges the elements of its input vector (Coded Payload) without omitting or repeating any elements to its output vector (Data) using a pseudo-random permutation.

Test vectors are provided in Appendix Q.Z.

The computation is illustrated in Figure Q.7.

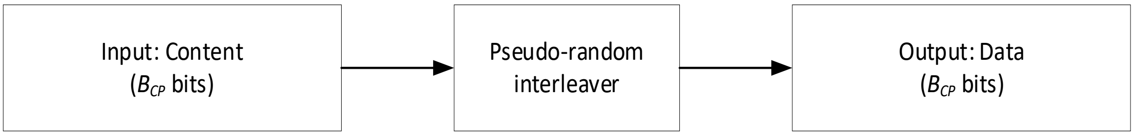

Figure Q.7 – Block diagram of pseudo-random block interleaver

The length of the output vector is always identical to the length of the input vector.

Q.2.4.5.3.2 Pseudo-random Interleaver

The pseudo-random permutation is calculated using the following equation:

$$s(i) = (188527 \cdot i) \text{ modulo } B_{CP} \text{ for } i \in \{0,1,2, \dots B_{CP} - 1\} \qquad \text{(Eq.Q.14)}$$

where *i* is the bit index of Coded Payload and B_{CP} is the total number of bits. The output, $s(i)$, denotes the corresponding bit index of the Data.

Q.2.4.6 Timing

Q.2.4.6.1 Uplink Timing

The timing of uplink transmissions between the individual bursts is depending on whether uplink Single-burst or uplink Multi-burst is applied. Information on whether an uplink frame is applying uplink Single-burst or uplink Multi-burst is contained in the uplink coded header, see Q.2.4.3.1.9.

An uplink transmission can be a part of an uplink communication session used for the transmissions of multiple datagrams (see Q.3.3.6).

Q.2.4.6.1.1 Uplink Single-burst

For uplink Single-burst, the synchronous timing, t_{ACC}, of [EN 13757-4] shall be applied as shown in **Figure Q.**8.

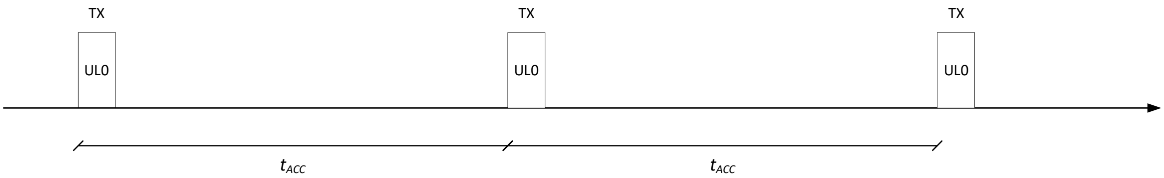

Figure Q.8 – Synchronous timing of uplink Single-burst

For uplink Single-burst an uplink frame consists of only one individual burst, UL0. The synchronous timing of [EN 13757-4] is in this case applied between UL0 of one frame and UL0 of the following frame. No further definition of uplink timing is required in case of uplink Single-burst.

Q.2.4.6.1.2 Uplink Multi-burst

For uplink Multi-burst, the synchronous timing, t_{ACC}, of [EN 13757-4] shall be applied as shown in Figure Q.9. The synchronous timing is applied between frames.

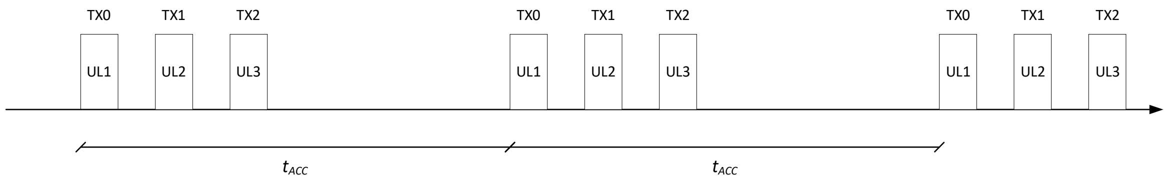

Figure Q.9 – Synchronous timing of uplink Multi-burst

For uplink Multi-burst an uplink frame consists of three individual bursts, UL1, UL2 and UL3. The synchronous timing of [EN 13757-4] is in this case applied between UL1 of one frame and UL1 of the following frame.

The timing between the individual bursts of uplink Multi-burst is shown in

Figure Q.10.

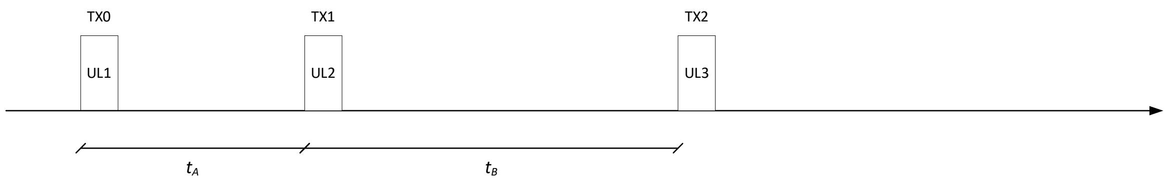

Figure Q.10 – Burst timing of uplink Multi-burst

The timing between UL1 and UL2, t_A, is calculated as:

$$t_A = 0{,}75 \cdot t_{burst} + t_{jitter} \cdot \frac{TIV-64}{64} \qquad \text{(Eq.Q.15)}$$

The timing between UL2 and UL3, t_B, is calculated as:

$$t_B = 1{,}25 \cdot t_{burst} + t_{jitter} \cdot \frac{TIV-64}{64} \qquad \text{(Eq.Q.16)}$$

The timing input value (TIV) is included in the coded header. This value ranges from 0 to 127. See also subclause Q.2.4.3.1.9.4.

The other timing parameters are as specified in Table Q.21.

Table Q.21 – Timing parameters – uplink Multi-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{burst} – short spacing	9 s	3 s
t_{burst} – medium spacing	27 s	9 s
t_{burst} – long spacing	48 s	16 s
t_{jitter}	3 s	1 s

The selected Multi-burst spacing is indicated in the uplink coded header, see section Q.2.4.3.1.9.

A bidirectional OMS end-device operating on UL-B1/UL-B2/UL-B3 should support short or medium spacing. If only long spacing is supported, the response to a command should remain in the application layer for at least 500 seconds.

NOTE: Long spacing on UL-B1/UL-B2/UL-B3 may cause a delay between TX0 of a SND-UD and the TX0 of the REQ-UD of more than 255 seconds (see command timeout defined in [OMS-S2], 8.2.5). To ensure that the application's response to the command in the SND-UD does not timeout before the REQ-UD2 is received, the command timeout needs to be extended.

Q.2.4.6.2 Downlink Timing

The timing of downlink transmissions of Burst Mode is depending on whether uplink Single-burst or uplink Multi-burst is applied and whether downlink Multi-burst is supported or not. Information on whether an uplink frame is applying uplink Single-burst or uplink Multi-burst is contained in the uplink coded header, see subclause Q.2.4.3.1.9. Information on whether downlink Multi-burst is supported or not is contained in the MAC layer of the frame, see subclause Q.3.5.

Q.2.4.6.2.1 Downlink Single-burst after Uplink Single-burst

If uplink Single-burst is applied and downlink Multi-burst is not supported, only one downlink option at RX0 is applied as shown in

Figure Q.11.

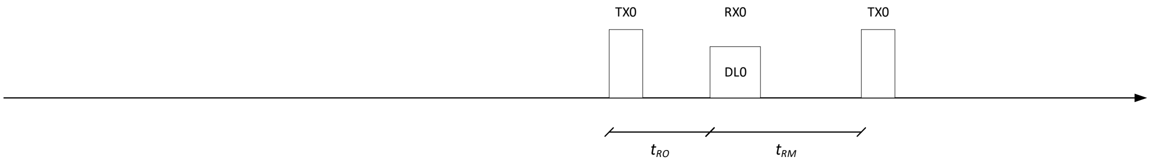

Figure Q.11 – Downlink options – downlink Single-burst after uplink Single-burst

In this situation the gateway can transmit a downlink Single-burst, DL0, at downlink option RX0.

The response delay, t_{RO}, can be chosen between fast, medium or slow response delay as shown in Table Q.22. The response delay is indicated in the MAC layer of the uplink frame, see subclause Q.3.5.

Table Q.22 – t_{RO}, downlink Single-burst after uplink Single-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RO} – fast response delay	4,5 s	1,5 s
t_{RO} – medium response delay	13,5 s	4,5 s
t_{RO} – slow response delay	27 s	9 s

An uplink burst following the downlink burst can be transmitted after a precise response-to-uplink delay, t_{RM}. A total number of 3 different t_{RM} timing values can be requested by the NW-Manager, see Table Q.23. If precise timing is not requested by the NW-Manager, the OMS end-device is free to choose any t_{RM} value up to the maximum response-to-uplink delay. See subclause Q.3.5 on details how to manage precise t_{RM} timing.

Table Q.23 – t_{RM}, uplink Single-burst after downlink Single-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RM} – fast response-to-uplink delay	13,5 s	4,5 s
t_{RM} – medium response-to-uplink delay	27 s	9 s
t_{RM} – slow response-to-uplink delay	54 s	18 s
t_{RM} – maximum response-to-uplink delay	< 50 s	< 50 s

Q.2.4.6.2.2 Downlink Multi-burst after Uplink Single-burst

If uplink Single-burst is applied and downlink Multi-burst is supported, three downlink option at RX0, RX1 and RX2 is applied as shown in Figure Q.12.

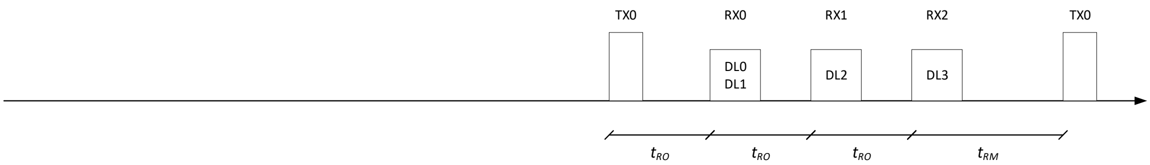

Figure Q.12 – Downlink options – downlink Multi-burst after uplink Single-burst

In this situation the gateway can transmit downlink Multi-bursts, DL1, DL2 and DL3, at downlink option RX0, RX1 and RX2. Alternatively, the gateway may choose to transmit a Single-burst, DL0, at downlink option RX0. For this reason, OMS end-devices supporting downlink Multi-burst shall also support downlink Single-burst.

The response delay, t_{RO}, can be chosen between fast, medium or slow response delay as shown in Table Q.24. The response delay is indicated in the MAC layer of the uplink frame, see subclause Q.3.5.

Table Q.24 – t_{RO}, downlink Multi-burst after uplink Single-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RO} – fast response delay	4,5 s	1,5 s
t_{RO} – medium response delay	13,5 s	4,5 s
t_{RO} – slow response delay	27 s	9 s

An uplink burst following the downlink burst can be transmitted after a precise response-to-uplink delay, t_{RM}. A total number of 3 different t_{RM} timing values can be requested by the NW-Manager, see Table Q.25. If precise timing is not requested by the NW-Manager, the OMS end-device is free to choose any t_{RM} value up to the maximum response-to-uplink delay. See subclause Q.3.5 on details how to manage precise t_{RM} timing.

Table Q.25 – t_{RM}, uplink Single-burst after downlink Multi-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RM} – fast response-to-uplink delay	13,5 s	4,5 s
t_{RM} – medium response-to-uplink delay	27 s	9 s
t_{RM} – slow response-to-uplink delay	54 s	18 s
t_{RM} – maximum response-to-uplink delay	< 50 s	< 50 s

Q.2.4.6.2.3 Downlink Single-burst after Uplink Multi-burst

If uplink Multi-burst is applied and downlink Multi-burst is not supported, one or two downlink options at RX0 and RX3 are possible as shown in Figure Q.13.

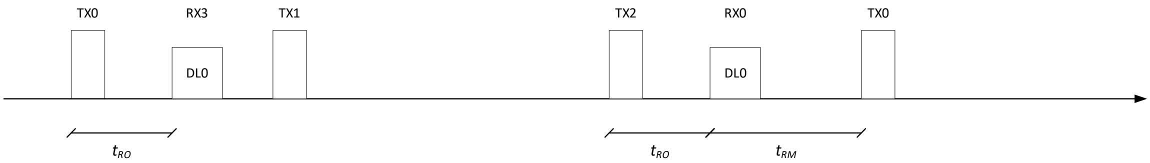

Figure Q.13 – Downlink options – downlink Single-burst after uplink Multi-burst

In this situation the gateway can transmit a downlink Single-burst, DL0, at downlink option RX0 and RX3.

The response delay, t_{RO}, can be chosen between fast, medium or slow response delay as shown in Table Q.26. The response delay is indicated in the MAC layer of the uplink frame, see subclause Q.3.5.

Table Q.26 – t_{RO}, downlink Single-burst after uplink Multi-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RO} – fast response delay	$t_{RO} = \frac{t_A}{2}$	$t_{RO} = \frac{t_A}{2}$
t_{RO} – medium response delay	$t_{RO} = t_A$	$t_{RO} = t_A$
t_{RO} – slow response delay	$t_{RO} = 2 \cdot t_A$	$t_{RO} = 2 \cdot t_A$

An uplink burst following the downlink burst can be transmitted after a precise response-to-uplink delay, t_{RM}. A total number of 3 different t_{RM} timing values can be requested by the NW-Manager, see Table Q.27. If precise timing is not requested by the NW-Manger, the OMS end-device is free to choose any t_{RM} value up to the maximum response-to-uplink delay. See subclause Q.3.5 on details how to manage precise t_{RM} timing.

Table Q.27 – t_{RM}, uplink Multi-burst after downlink Single-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RM} – fast response-to-uplink delay	$t_{RM} = \frac{t_A}{2}$	$t_{RM} = \frac{t_A}{2}$
t_{RM} – medium response-to-uplink delay	$t_{RM} = t_A$	$t_{RM} = t_A$
t_{RM} – slow response-to-uplink delay	$t_{RM} = 2 \cdot t_A$	$t_{RM} = 2 \cdot t_A$
t_{RM} – maximum response-to-uplink delay	< 50 s	< 50 s

The time interval, t_A, is as defined in Q.2.4.6.1.2. Whether additional reception options is enabled or not is indicated in the MAC layer of the uplink frame, see subclause Q.3.5. The downlink options of these two situations are shown in Table Q.28.

Table Q.28 – Downlink options – downlink Single-burst after uplink Multi-burst

Additional reception options enabled	Downlink options
No	RX0
Yes [a]	RX0 + RX3
[a] Only fast response delay, t_{RO}, shall be applied (see Table Q.26)	

Q.2.4.6.2.4 Downlink Multi-burst after Uplink Multi-burst

If uplink Multi-burst is applied and downlink Multi-burst is supported, three or six downlink options at RX0, RX1, RX2, RX3, RX4 and RX5 are possible as shown in Figure Q.14. The downlink options are grouped; RX0 + RX1 + RX2 form the first group and RX3 + RX4 + RX5 form the second group.

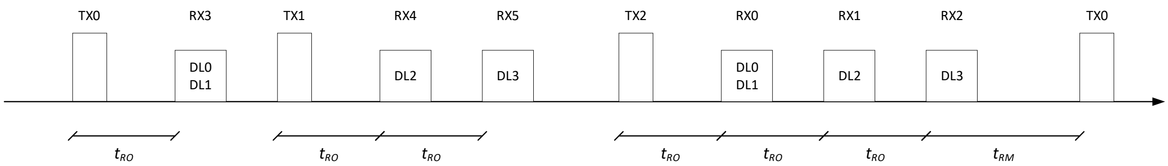

Figure Q.14 – Downlink options – downlink Multi-burst after uplink Multi-burst

In this situation the gateway can transmit downlink Multi-bursts, DL1, DL2 and DL3, at downlink option RX0, RX1, RX2, RX3, RX4 and RX5. Alternatively, the gateway may choose to transmit a downlink Single-burst, DL0, at downlink option RX0 and RX3. For this reason, OMS end-devices supporting downlink Multi-burst shall also support downlink Single-burst. The OMS end-device can, if needed, indicate a maximum receive duration as described in Q.3.5.2.4 to allow an appropriate hardware design.

The response delay, t_{RO}, can be chosen between fast, medium or slow response delay as shown in Table Q.29. The response delay is indicated in the MAC layer of the uplink frame, see subclause Q.3.5.

Table Q.29 – t_{RO}, downlink Multi-burst after uplink Multi-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RO} – fast response delay	$t_{RO} = \frac{t_A}{2}$	$t_{RO} = \frac{t_A}{2}$
t_{RO} – medium response delay	$t_{RO} = t_A$	$t_{RO} = t_A$
t_{RO} – slow response delay	$t_{RO} = 2 \cdot t_A$	$t_{RO} = 2 \cdot t_A$

An uplink burst following the downlink burst can be transmitted after a precise response-to-uplink delay, t_{RM}. A total number of 3 different t_{RM} timing values can be requested by the NW-Manager, see Table Q.30. If precise timing is not requested by the NW-Manager, the OMS end-device is free to choose any t_{RM} value up to the maximum response-to-uplink delay. See subclause Q.3.5 on details how to manage precise t_{RM} timing.

Table Q.30 – t_{RM}, uplink Multi-burst after downlink Multi-burst

Parameter	Uplink sub-mode UL-B1, UL-B2, UL-B3	Uplink sub-mode UL-B4
t_{RM} – fast response-to-uplink delay	$t_{RM} = \frac{t_A}{2}$	$t_{RM} = \frac{t_A}{2}$
t_{RM} – medium response-to-uplink delay	$t_{RM} = t_A$	$t_{RM} = t_A$
t_{RM} – slow response-to-uplink delay	$t_{RM} = 2 \cdot t_A$	$t_{RM} = 2 \cdot t_A$
t_{RM} – maximum response-to-uplink delay	< 50 s	< 50 s

The time interval, t_A, is as defined in Q.2.4.6.1.2.

Whether additional reception options are enabled or not is indicated in the MAC layer of the uplink frame, see subclause Q.3.5. The downlink options of these two situations are shown in Table Q.31.

Table Q.31 – Downlink options – downlink Multi-burst after uplink Multi-burst

Additional reception options enabled	Downlink options
No	RX0 + RX1 + RX2
Yes [a]	RX0 + RX1 + RX2 + RX3 + RX4 + RX5
[a] Only fast response delay, t_{RO}, shall be applied (see Table Q.29)	

Q.2.4.6.3 Timing Tolerances

For the OMS end-device, the timing tolerances of all timing parameters of Burst Mode, t_{ACC}, t_A, t_B and t_{RM}, shall follow the definition of both the static and the dynamic tolerances according to

[EN 13757-4], subclause 12.6.2. The mentioned non-accumulative jitter shall only be used for t_{ACC}. For t_A and t_B, a non-accumulative jitter of up to ±0,5 ms shall be applied and for t_{RM}, a non-accumulative jitter of up to ±2 ms shall be applied.

For the gateway, the tolerances of the timing parameter, t_{RO}, shall be limited to -20/+30 ppm. A non-accumulative jitter of up to ±2 ms shall be applied.

If the gateway only received the first individual uplink burst at TX0 of a Multi-burst transmission, it can still respond in RX0 as long as it complies with the required tolerances. The time from gateway reception to gateway transmission will in this case be $t_{TX0 \rightarrow RX0} = t_A + t_B + t_{RO}$.

The OMS end-device shall consider the scenario where only the first individual burst is received in the gateway together with its own timing tolerance when opening the listening windows.

Example 1:

An OMS end-device transmits Multi-burst using sub-mode UL-B4 with long spacing, a TIV-value of 64, and applying fast response delay. It has a negative timing tolerance of max. -30 ppm and a positive tolerance of max. +80 ppm. If only the first individual uplink burst at TX0 was received, the downlink in RX0 will be transmitted with following tolerance:

$$t_{TX0 \rightarrow RX0} = (t_A + t_B + t_{RO}) \cdot (1 \pm total\ tolerance) \pm t_{Non-acc.jitter} \qquad \text{(Eq.Q.17)}$$

$$t_{TX0 \rightarrow RX0(\min)} = (12 + 20 + 6) \cdot \left(1 - \frac{20 + 30}{10^6}\right) - 0{,}002 = 37{,}9961\ s$$

$$t_{TX0 \rightarrow RX0(\max)} = (12 + 20 + 6) \cdot \left(1 + \frac{30 + 80}{10^6}\right) + 0{,}002 = 38{,}0062\ s$$

Example 2:

Given the same situation as in Example 1, but where the reception happens in last reception slot RX2, the downlink tolerances are:

$$t_{TX0 \rightarrow RX2} = (t_A + t_B + 3 \cdot t_{RO}) \cdot (1 \pm total\ tolerance) \pm t_{Non-acc.jitter} \qquad \text{(Eq.Q.18)}$$

$$t_{TX0 \rightarrow RX2(\min)} = (12 + 20 + 3 \cdot 6) \cdot \left(1 - \frac{20 + 30}{10^6}\right) - 0{,}002 = 49{,}9955\ s$$

$$t_{TX0 \rightarrow RX2(\max)} = (12 + 20 + 3 \cdot 6) \cdot \left(1 + \frac{30 + 80}{10^6}\right) + 0{,}002 = 50{,}0075\ s$$

Q.2.4.6.4 Synchronous Transmission

The OMS end-device shall support a synchronous uplink transmission timing according to [OMS-S2], 4.3.2.1. The individual transmissions interval t_{ACC} of the synchronous transmission shall be calculated from the nominal transmission interval t_{NOM}, according to [EN 13757-4], 12.6.2. The nominal transmission interval shall be less or equal to the limits in Table Q.32.

Table Q.32 – Nominal transmission interval

Mode	t_{NOM} (max)
UL-B1 UL-B2 UL-B3	120 min
UL-B4	15 min

Q.2.4.6.5 Reference time point

Q.2.4.6.5.1 General

Reference time point is used to enable precise timing of PHY-layer and for application means.

Q.2.4.6.5.2 PHY layer reference time point

To enable precise timing of the physical layer, a reference time point within a transmission is defined. For Burst Mode only one reference time point within a burst is needed. All PHY timing like t_A, t_B, t_{RO} and t_{RM} refer to this reference time point within a burst.

The reference time point within a burst in both directions is defined as the time point after the complete transmission of the Sync-field. Which burst to be considered is shown in the respective figures of clause Q.2.4.6.1 and Q.2.4.6.2.

The reference time point within the first burst of a Multi-burst transmission is called T_0. The reference time point within the last burst of a Multi-burst transmission is called T_2. In case of Single-burst transmission there is only one transmitted burst. In this case $T_0 = T_2$.

These definitions of T_0 and T_2 are mainly used for the definition of timings and delays on the MAC-layer, see subsection Q.3.

Q.2.4.6.5.3 Application reference time point

To enable precise timing of the application in the case of a Multi-burst transmissions scheme, a reference time point is defined. Reference time point of application is e.g. needed for the timing of data elements in the uplink direction or the timing of a clock setting command in the downlink direction. The time point within the burst is as defined in subclause Q.2.4.6.5.2 and the burst of interest is defined as:

Uplink Single-burst:	The single burst, UL0 (T_0).
Uplink Multi-burst:	The first individual burst, UL1 (T_0).
Downlink Single-burst:	The single burst, DL0, transmitted in the primary time slot, RX0.
Downlink Multi-burst:	The first individual burst, DL1, transmitted in the primary time slot, RX0.

In some situations, the downlink transmission is received in another receive time slot than RX0. In such cases, the time difference, Δt, to the reference time point in RX0 shall be calculated as follows:

DL2 reception at RX1:	$\Delta t = -t_{RO}$	(Eq.Q.19)
DL3 reception at RX2:	$\Delta t = -2 \cdot t_{RO}$	(Eq.Q.20)
DL0/DL1 reception at RX3:	$\Delta t = t_A + t_B$	(Eq.Q.21)
DL2 reception at RX4:	$\Delta t = t_B$	(Eq.Q.22)
DL3 reception at RX5:	$\Delta t = t_B - t_{RO}$	(Eq.Q.23)

The gateway shall use the start time T_0 for assigning a timestamp to a received radio frame of an OMS end-device. Only with this concept the correct time assignment e.g. to metering values contained in the radio frame is guaranteed.

Q.2.5 Technology – Splitting Mode (UL-S / DL-S)

Q.2.5.1 Introduction

Splitting Mode is an OMS variant of the TS-UNB protocol family defined in clause 6 of [ETSI 103 357]. The Splitting Mode specification uses references to [ETSI 103 357] wherever applicable. It uses the so-called TSMA (telegram splitting multiple access) technology. Deviations from [ETSI 103 357] are clearly defined in the following subclauses.

The term “symbol” is introduced for the Splitting Mode to enable a consistent description with [ETSI 103 357]. Here a chip is mapped on one symbol, hence the chip rates are of the same value as the symbol rates. Accordingly, chip time periods are of the same value as symbol time periods.

In Splitting Mode, the transmission of a radio-frame is split into several short radio-bursts, which are distributed over time and frequency within the radio-frame. The functional set of radio-bursts belonging to one datagram are 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 time and frequency by defined hopping patterns.

Figure Q.15 and Figure Q.16 provide an overview of the Splitting Mode technology for uplink and downlink.

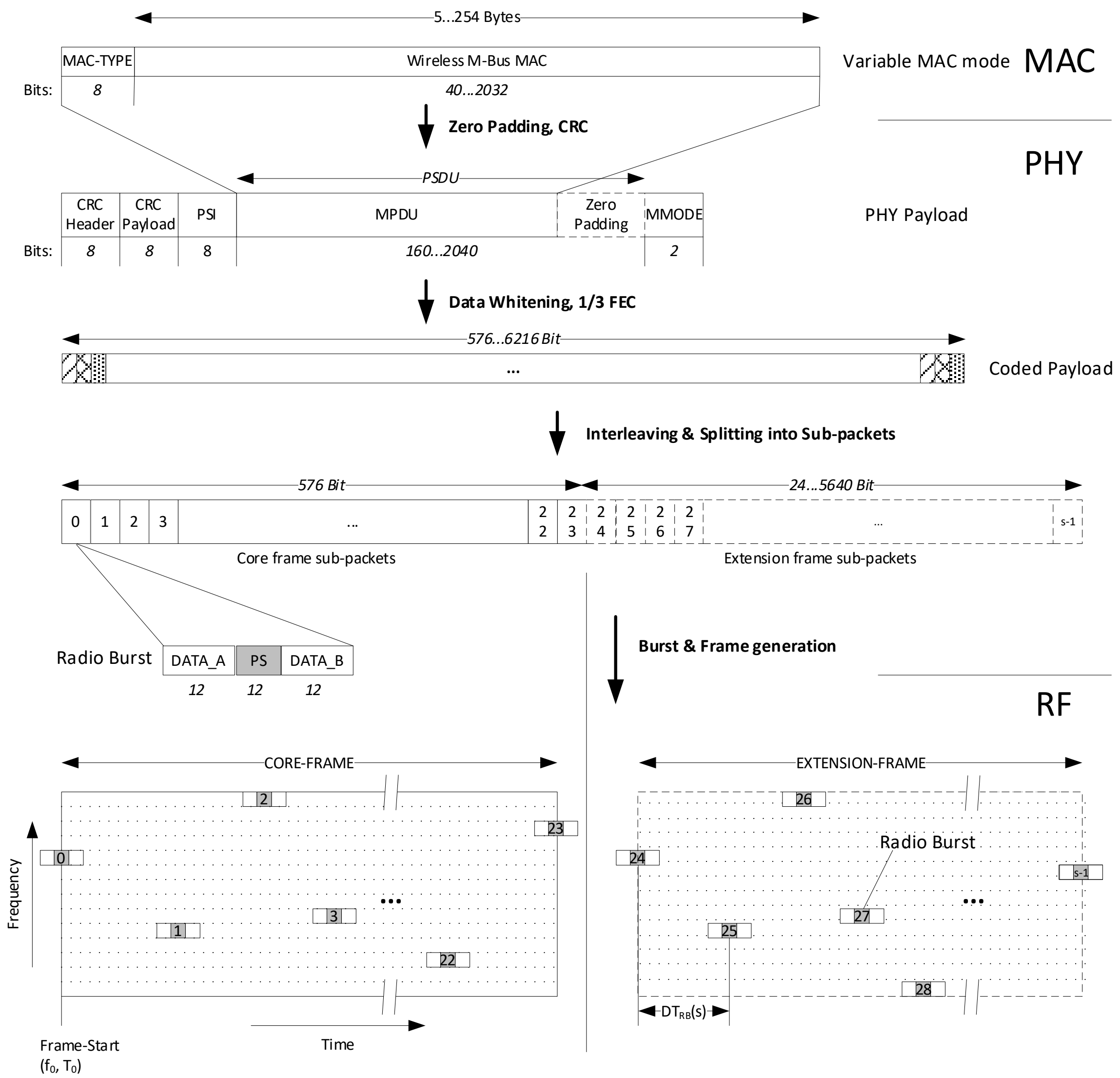

Figure Q.15 – Overview Uplink Format

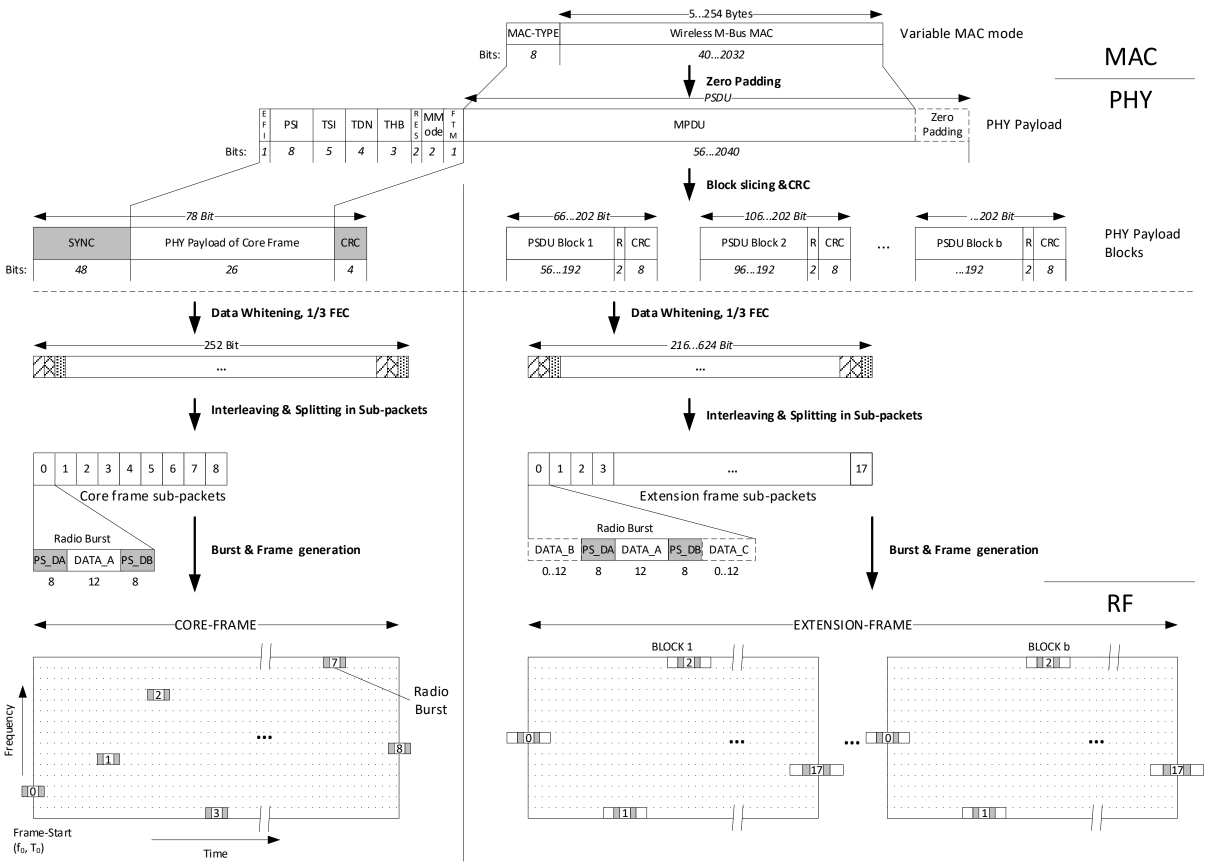

Figure Q.16 – Overview Downlink Format

Q.2.5.2 Transmitter Parameters

The transmitter parameters for Splitting Mode shall be as given in Table Q.33 for uplink (UL-S) and Table Q.34 for downlink (DL-S).

Table Q.33 – Uplink transmitter parameters for Splitting Mode, UL-S

Characteristic	Symbol	Sub-mode	min.	nom.	Max.	Unit	Note
Frequency tolerance	f_{tol}	UL-S (all)	-17,4	0	17,4	kHz	±20 ppm tolerance
Carrier spacing	f_{car}	UL-S (all)	[e]	2380,371	[e]	Hz	
Carrier spacing accuracy	f_{car_drift}	UL-S (all)	-20	0	20	Hz	Across 24 consecutive radio burst [b]
GMSK bandwidth-time product	BT	UL-S (all)		1,0			
GMSK chip rate	f_{chip}	UL-S (all)	2380,132	2380,371	2380,609	cps	+/- 100 ppm tolerance [c]
Data rate	DR	UL-S (all)		f_{chip}			
GFSK [a] deviation	f_{dev}	UL-S (all)	590,0	595,093	600,0	Hz	
Burst drift [d]	t_{burst_drift}	UL-S (all)	- 105	$t_{RB}(s)$	105	µs	

[a] If radio equipment is not directly supporting a GMSK, it can be achieved by using a GFSK and selecting an appropriate frequency deviation. Only in this situation this value is applicable.

[b] Includes spreading of carrier spacing caused by the crystal tolerance up to +/-15 Hz for 20 ppm crystal offset

[c] Also Includes the crystal offsets of up to 20 ppm

[d] Tolerance of the pairwise transmission time of radio burst to nominal time over 24 successive radio bursts. Includes spreading of time positions caused by the crystal tolerance, which is 70 µs at 20 ppm crystal offset.

[e] Absolute tolerance is depending on the number of bursts respecting the carrier spacing accuracy.

5

Table Q.34 – Downlink transmitter parameters for Splitting Mode, DL-S

Characteristic	Symbol	Sub-mode	min.	nom.	Max.	Unit	Note
Frequency tolerance	f_{tol}	DL-S (all)	-6,1	0	6,1	kHz	±7 ppm reference frequency tolerance of the gateway
Centre frequency precision [a]	f_{prec}	DL-S1	-250	0	250	Hz	
		DL-S2	-250	0	250		
		DL-S3	-500	0	500		
		DL-S4	-2000	0	2000		
Carrier spacing	f_{car}	DL-S (all)	[d]	2380,371	[d]	Hz	
Carrier spacing accuracy	f_{car_drift}	DL-S1 DL-S2	-2	0	2	Hz	Across 18 radio bursts
		DL-S3	-4	0	+4	Hz	
		DL-S4	-16	0	+16	Hz	
GMSK chip rate	f_{chip}	DL-S1	2380,359	2380,371	2380,383	cps	±5 ppm tolerance [c]
		DL-S2	2380,359	2380,371	2380,383		
		DL-S3	4760,718	4760,742	4760,766		
		DL-S4	19042,873	19042,968	19043,063		
Data rate	DR	DL-S (all)		f_{chip}			
GFSK [b] deviation	f_{dev}	DL-S1	590,0	595,093	600,0	Hz	
		DL-S2	590,0	595,093	600,0		
		DL-S3	1180,0	1190,186	1200,0		
		DL-S4	4720,0	4760,74	4800,0		

[a] Centre frequency precision denotes the precision of the centre frequency of downlink transmissions relative to the tolerance of the end device measured on the preceding uplink transmission.

[b] If radio equipment is not directly supporting a GMSK, it can be achieved by using a GFSK and selecting an appropriate frequency deviation. Only in this situation this value is applicable.

[c] The +- 5 ppm are relative to the expected data rate of the end node. The base station is adjusting the data rate after an uplink Reception.

[d] Absolute tolerance is depending on the number of bursts respecting the carrier spacing accuracy.

Q.2.5.3 Structure and Synchronization

Q.2.5.3.1 Uplink Structure and Synchronization

Q.2.5.3.1.1 Radio Burst

The Splitting Mode uplink transmission consists of several radio bursts in each radio frame. Each radio burst shall consist of one 12-bit long pilot sequence (PS field) and two accompanying 12-bit long data fields (DATA_A, DATA_B) according to Table Q.35.

Table Q.35 – Uplink Radio Burst format

DATA_A	PS	DATA_B
12 bits	12 bits	12 bits

The DATA fields are filled according to the rules described in Q.2.5.5.5.

A 36-byte long synchronization sequence is split into pilot sequences (PS) of 12 bit, distributed over the core frame and recombined in the gateway 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 Q.2.5.3.1.2.3) shall be filled with the sequence (0, 1, 0, 0, 1, 1, 1, 1, 1, 0, 1, 0).

NOTE: The “sync-burst Data Unit” of [ETSI 103 357], clause 6.4.2.1.2 is not supported by the Splitting Mode as the approach of low complexity receivers are solved by the respective sub-modes of the Burst Mode.

Q.2.5.3.1.2 Radio-Frame

Q.2.5.3.1.2.1 Overview

The radio frame of the Splitting Mode uplink transmission shall consist of a core frame, followed by an additional extension frame, if the PHY payload length exceeds the minimum of 186 bits (see Figure Q.15). The maximum PHY payload length that can be transmitted is 2066 bits

Q.2.5.3.1.2.2 Core Frame

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

Q.2.5.3.1.2.3 Extension Frame

The uplink extension frame structure shall be derived from the information of the core frame according to clause Q.2.5.7.4.2. For each additional byte in the PSDU, the frame shall be extended by one radio-burst.

Q.2.5.3.2 Downlink Structure and Synchronization

Q.2.5.3.2.1 Radio Burst

The radio burst of the downlink transmission in Splitting Mode shall be formatted according to Table Q.36. The optional DATA_B and DATA_C fields shall not be used for transmission of the core frame, only for the extension frame.

Table Q.36 – Downlink Radio Burst format

DATA_B	PS_DA	DATA_A	PS_DB	DATA_C
Optional	Mandatory	Mandatory	Mandatory	Optional
12 bits	8 bits	12 bits	8 bits	12 bits

The radio burst in the downlink shall consist of at least one 12-bit data field DATA_A, accompanied by two 8-bit long pilot sequence fields PS_DA and PS_DB. The data fields DATA_B and DATA_C shall be added dependent on the PSDU length (see clause Q.2.5.3.2.2.3.1). The optional DATA_B and DATA_C fields shall not be used for transmission of the core frame.

The DATA fields are filled according to the rules described in Q.2.5.5.5.

NOTE: The "sync-burst Data Unit" of [ETSI 103 357], clause 6.4.3.1.2.2 is not supported by the Splitting Mode as the approach of low complexity receivers are solved by the respective sub-modes of the Burst Mode. Also, the downlink Single-burst (DL-SB) mode of [ETSI 103 357], clause 6.4.3.1.1 is not supported by the Splitting Mode as the approach of low complexity in the downlink are solved by respective sub-modes of the Burst Mode.

Q.2.5.3.2.2 Radio Frame

Q.2.5.3.2.2.1 Overview

The radio frame of the Splitting Mode downlink transmission shall consist of a core frame, followed by an extension frame (see Figure Q.16). The core frame is used as wakeup and provides the timing information for the following extension frame. The succeeding extension frame shall be indicated in the core frame.

The maximum PHY payload length that can be transmitted is 2066 bits, the minimum is 82 bits.

Q.2.5.3.2.2.2 Core Frame

Q.2.5.3.2.2.2.1 Introduction

The downlink core frame shall consist of 9 radio bursts according to the structure described in clause Q.2.5.3.2.1, where only the first 9 carrier numbers of the downlink pattern according to Table Q.59 and the first 8 time differences according to Table Q.58, or Table Q.60 shall be used. Pilot sequence field PS_DA and pilot sequence field PS_DB of each radio-burst in the core frame shall be filled with the encoded bits of the Sync field (see Q.2.5.3.2.2.2.3) according to the interleaving described in Q.2.5.5.5.

Q.2.5.3.2.2.2.2 Format

The downlink core frame shall have the format according to Table Q.37.

Table Q.37 – Downlink Core frame

Sync	PHY Payload of Core frame	CRC
48 bits	26 bits	4 bits

The PHY Payload of the Core frame is explained in detail in Q.2.5.4.2. Other fields not contained in the PHY payload are explained in the following subclauses.

Q.2.5.3.2.2.2.3 Sync

The Sync field shall be filled with the pilot sequences PS_A and PS_B of the extension frame radio-burst (Table Q.39) according to Table Q.38.

Table Q.38 – Sync field in variable MAC mode

Bits: 0-7	8-15	16-23	24-31	32-39	40-47
PS_A	PS_B	PS_A	PS_B	PS_A	PS_B

Q.2.5.3.2.2.2.4 Downlink Core Frame CRC

The downlink core frame CRC shall be 4 bit and calculated (see Q.2.5.5.3) over the 26 bits “PHY Payload of Core frame” shown in Table Q.37.

Q.2.5.3.2.2.3 Extension Frame

Q.2.5.3.2.2.3.1 Introduction

The extension frame is used to transmit the PSDU data with a minimum of 56 bits (7 bytes) and a maximum 2040 bits (255 bytes). The extension frame shall be divided 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 Q.2.5.3.2.1.

The radio burst of the extension frame shall use the pilot sequence PS_A to fill the pilot sequence field PS_DA and the pilot sequence PS_B to fill the pilot sequence field PS_DB for all radio-bursts. PS_A and PS_B are defined in Table Q.39.

Table Q.39 – Downlink Extension Frame pilot sequences

Pilot Sequence A (PS_A)	(0, 1, 0, 0, 0, 0, 1, 0)
Pilot Sequence B (PS_B)	(1, 1, 1, 0, 1, 0, 0, 0)]

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.

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

$$B = \left\lceil \frac{P}{24} \right\rceil, \qquad \text{(Eq.Q.24)}$$

where $P \in \{7,8 \dots 255\}$, 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 assigned to one block n_b 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 $n_r = P - \left\lfloor \frac{P}{B} \right\rfloor \cdot B$ shall be assigned to the blocks in ascending order.

$$n_b = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor + 1, & for\ b \le n_r \\ \left\lfloor \frac{P}{B} \right\rfloor, & for\ b > n_r \end{cases} \quad \text{(Eq.Q.25)}$$

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 Q.2.5.5.5.

Q.2.5.3.2.2.3.2 Format

The extension frame is sliced in maximal 11 blocks that shall have the format according to Table Q.40.

Table Q.40 – Downlink Extension Frame Blocks

PSDU Block	Reserved	CRC
56 … 192 bits	2 bits	8 bits
Block 1		

PSDU Block	Reserved	CRC
96 … 192 bits	2 bits	8 bits
Block 2		

…

PSDU Block	Reserved	CRC
… 192 bits	2 bits	8 bits
Block b		

The overall PSDU (as shown as PSDU (Payload) in Table Q.42) is sliced into PSDU blocks of at most 24 bytes according to clause Q.2.5.3.2.2.3.1. A PSDU block is the variable size part of the overall PSDU that is assigned to one block. The two bits after the PSDU block are reserved and shall be set to 0. The 8-bit CRC checksum shall be calculated over the used bits of the block PSDU (not the padding bits, see Q.2.5.4.2.9) and the reserved bits according to clause Q.2.5.5.3.

The first byte of the overall PSDU will be located as first byte in the first PSDU Block (Block 1) and accordingly for all following bytes.

Q.2.5.4 Content

Q.2.5.4.1 Uplink Content

Q.2.5.4.1.1 Introduction

The PHY Payload in uplink shall consist of the following fields in Table Q.41.

Table Q.41 – Uplink PHY Payload

PHR			PSDU (Payload)	MMode
Header CRC	Payload CRC	PSI		
8 bits	8 bits	8 bits	160 … 2040 bits	2 bits

Header CRC, Payload CRC and PSI form the PHY Header (PHR) influences the radio-burst transmission time and frequency of the extension frame (Q.2.5.7.4.2).

Q.2.5.4.1.2 Header CRC

The Header CRC shall be 8 bit and calculated over Payload CRC and PSI as shown in Figure Q.17.

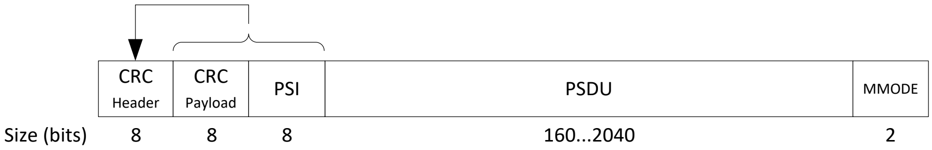

Figure Q.17 – Calculation of Header CRC

Q.2.5.4.1.3 Payload CRC

The payload CRC shall be 8 bit and calculated over MPDU and MMODE field as shown in Figure Q.18. In case of zero padding (of PSDU) the padded zeros shall be omitted for the CRC calculation.

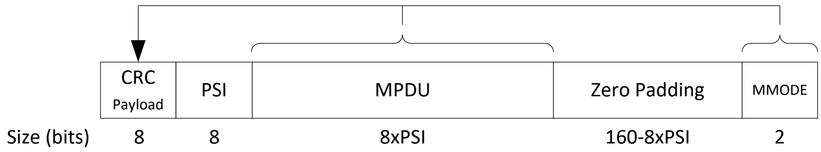

Figure Q.18 – Calculation of Payload CRC

Q.2.5.4.1.4 Packet Size Indicator (PSI)

The Packet Size Indicator (PSI) field shall be 8 bit long and shall indicate the length of the MPDU (= PSDU without zero padding) in bytes. According to the MAC layer definition (see subclause Q.3) the valid value range for MPDU is from 6 to 255 bytes.

Q.2.5.4.1.5 PHY Service Data Unit (PSDU)

The 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, see Q.2.5.4.3). If the MPDU size is below 20 bytes, the PSDU shall be filled to 20 bytes by zero padding behind 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.

Q.2.5.4.1.6 MAC Mode (MMode)

The 2-bit long field MMode shall indicate which MAC mode is used. The MMode bits shall be set to (0,1) to indicate the variable MAC mode as described in [ETSI 103 357], clause 6.4.2.3.6.

Q.2.5.4.2 Downlink Content

Q.2.5.4.2.1 Introduction

The PHY Payload in downlink shall consist of the following fields in Table Q.42.

Table Q.42 – Downlink PHY Payload

EFI	PSI	TSI	TDN	THB	Reserved	MMode	FTM	PSDU (Payload)
1 bit	8 bits	5 bits	4 bits	3 bits	2 bits	2 bits	1 bit	56…2040 bits

It is based on the PHY Payload of [ETSI 103 357] Table 6-39 but provides additional options for optimized energy buffer design and computing performance of the endpoints. The indication of these different formats can be recognized by the FTM field (see Q.2.5.4.2.8).

NOTE: By applying the timings defined for [ETSI 103 357] compatibility (see Table Q.45) any (already existing TS-UNB) endpoint can understand the downlink frame.

The two reserved bits between THB and MMode shall be set to 0.

Q.2.5.4.2.2 Extension Frame Indicator (EFI)

The Extension Frame Indicator (EFI) field shall be one bit and indicates, that the core frame is followed by an extension frame. The EFI bit shall always be set to 1 as Splitting Mode needs an Extension Frame in any case.

Q.2.5.4.2.3 Packet Size Indicator (PSI)

The packet size indicator (PSI) shall be 8 bit long and shall indicate the length of the downlink MPDU (= PSDU without zero padding) in bytes. According to the MAC layer definition (see subclause Q.3) the valid value range for MPDU is from 6 to 255 byte.

Q.2.5.4.2.4 Transmission Start Time Indicator (TSI)

The transmission start time indicator (TSI) indicates the time interval between core frame and extension frame. It shall consist of 5 bits, which are interpreted as an unsigned integer number ranging from 0 to 31. 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 Q.45) in number of chip time periods shall be calculated from the TSI value according to the following formula:

$$\Delta T_{TSI} = N_{TAF} \cdot 512 \cdot r_{TSI}, \qquad \text{(Eq.Q.26)}$$

with

$$r_{TSI} = \begin{cases} 1 & for\ TSI = 0 \\ (4 \cdot TSI) & for\ TSI > 0 \end{cases} \qquad \text{(Eq.Q.27)}$$

and N_{TAF} as the timing adaptation factor according to Table Q.46.

NOTE: The last radio-burst of the core frame is burst 8 as repetition according to of [ETSI 103 357], clause 4.7.6.1.3 is not applied in flexible timing mode (see Q.2.5.4.2.8).

Q.2.5.4.2.5 Time Delay Extension Frame (TDN)

The time delay extension frame (TDN) field indicates the time interval between blocks of an extension frame. The time offset ΔT_{dn} (see Table Q.45) in number of chip time periods shall be calculated according to the following formula:

$$\Delta T_{dn} = N_{TAF} \cdot 512 \cdot r_{TDN}, \qquad \text{(Eq.Q.28)}$$

with N_{TAF} as the timing adaptation factor according to Table Q.46 and

r_{TDN} defined by the 4-bit TDN field according to the following mapping Table Q.43.

Table Q.43 – Mapping of TDN field to r_{TDN}

TDN	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

Q.2.5.4.2.6 Time Delay Half Block (THB)

The time delay half Block (THB) field indicates an additional time delay between the two radio-bursts with index s=8 and index s=9 (the first radio burst starts at index s = 0 in number of chip time periods) in each block of the downlink extension frame. The additional time delay ΔT_{hb} (see Table Q.45) in number of chip time periods shall be calculated according to the following formula:

$$\Delta T_{hb} = 2\,048 \cdot r_{THB}, \qquad \text{(Eq.Q.29)}$$

where r_{THB} is defined by the 3-bit THB field according to the following mapping Table Q.44:

Table Q.44 – Mapping of THB field to r_{THB}

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

Q.2.5.4.2.7 MAC Mode (MMode)

This field is as defined in Q.2.5.4.1.6.

Q.2.5.4.2.8 Flexible Timing Mode (FTM)

The FTM field shows the applied downlink timing mode. For the Splitting Mode it shall be set to 1 to indicate the flexible timing mode structure as shown in Table Q.42.

Q.2.5.4.2.9 PHY Service Data Unit (PSDU)

The PSDU may hold a variable length of up to 255 bytes of data. The minimum PSDU length shall be 7 bytes. It is filled with the MAC Protocol Data Unit (MPDU, see Q.2.5.4.3). If the MPDU size is below 7 bytes, the PSDU shall be filled to 7 bytes by zero padding behind the MPDU. Therefore, a minimum number of 7 bytes is always transmitted, regardless of the actual MPDU size.

Q.2.5.4.3 MPDU

The PSDU of uplink and downlink contains the MPDU (see Q.2.5.4.1.5 and Q.2.5.4.2.9). The first byte of the MPDU is the MAC-TYPE field as defined in [ETSI 103 357] for the so-called variable MAC (see Q.2.5.4.1.6). The pre-defined value of the MAC-TYPE for the introduction of the new wireless M-Bus MAC according to Q.3 is 02h.

The length of the MPDU is minimum 6 bytes (MAC-TYPE, MHCTL[0], MAC CRC) to a maximum of 255 bytes.

NOTE: The following byte after MAC-TYPE will be the MHCTL[0] of the MAC layer.

Q.2.5.5 Functions

Q.2.5.5.1 Modulation

Q.2.5.5.1.1 Precoding

Prior to modulation, all Splitting Mode transmissions defined in Table Q.6 must be precoded. The precoding operation is defined by:

$$c_k = d_{k-1} \oplus d_k \qquad \text{(Eq.Q.30)}$$

where d_k is the kth bit in the Splitting Mode transmission, c_k is the k^{th} precoded bit (chip), and $\oplus$ denotes the exclusive-OR operation. For all cases, the seed bit is d_{-1} = 0b. Figure Q.19 illustrates the precoding operation applied to a Splitting Mode transmission.

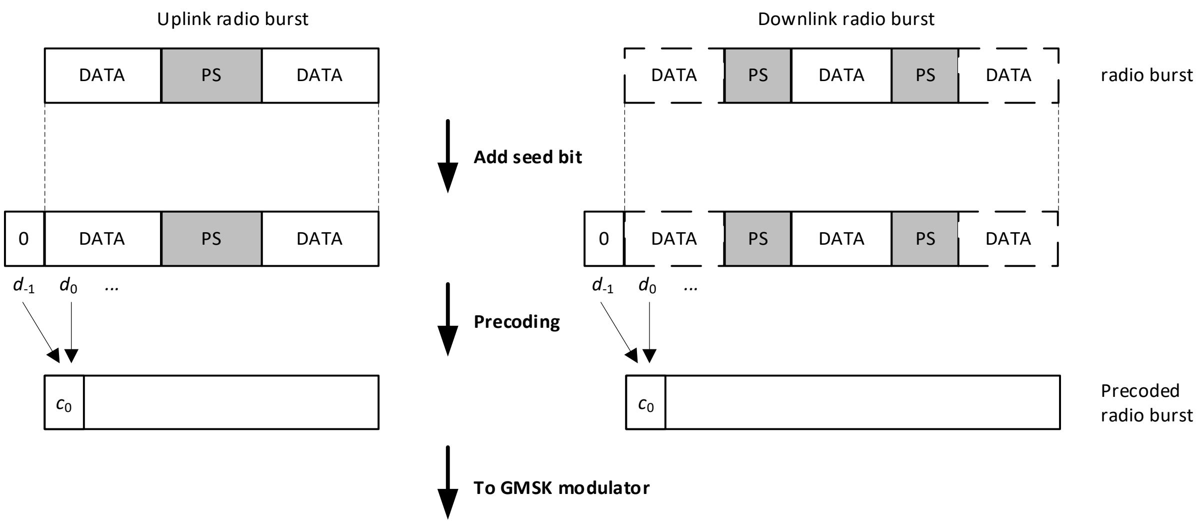

Figure Q.19 – Precoding applied to a Splitting Mode transmission

Test vectors (of Burst Mode that applies an equal precoding) are provided in Q.Z.3.

Q.2.5.5.1.2 GMSK Modulation

All Splitting Modes shall be GMSK modulated with the modulation parameters defined in Table Q.33 and Table Q.34. In the case where a modulation index of 0,5 cannot be achieved, the GFSK deviation frequency limits in Table Q.33 and Table Q.34 apply. A transmitted 0_b shall use the lower frequency deviation $-\frac{f_{chip}}{4}$ and a transmitted 1_b shall use the upper frequency deviation $+\frac{f_{chip}}{4}$ as shown in Figure Q.20.

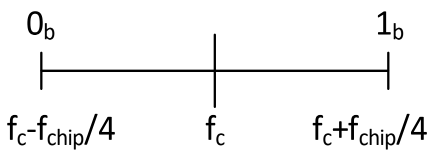

Figure Q.20 – Signal mapping of GMSK

NOTE: For details on how to receive and transmit GMSK using a GFSK transceiver, see Appendix Q.D.

Q.2.5.5.1.3 Signal Mapping of Precoded GMSK

Figure Q.21 shows an idealized signal mapping between phase and data bits for precoded GMSK. The binary values in the figure denote the data bits in the Splitting Mode transmission, T_0 is the start time, and $\Delta T = 1/f_{chip}$ is the chip period. The representation repeats every 4 bits.

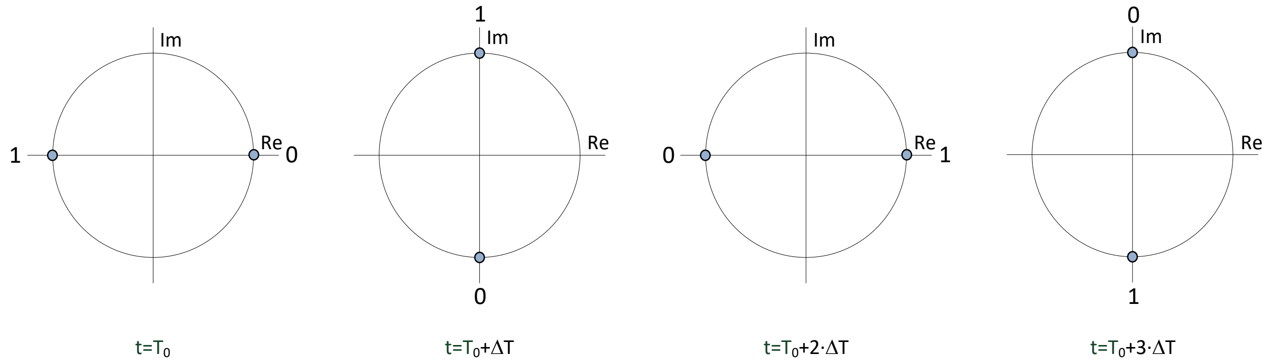

Figure Q.21 – Signal mapping of precoded GMSK

Q.2.5.5.1.4 Chip Rate

The chip rate f_{chip} of the (G)MSK Modulation shall be:

Uplink

- $f_{chip}^{UL-S} = 3 \cdot 26 \cdot 10^6 \cdot 2^{-15} = 2\,380{,}371$ cps for all UL-S modes

Downlink:

- $f_{chip}^{DL-S1} = 3 \cdot 26 \cdot 10^6 \cdot 2^{-15} = 2\,380{,}371$ cps for mode DL-S1/DL-S2
- $f_{chip}^{DL-S3} = 3 \cdot 26 \cdot 10^6 \cdot 2^{-14} = 4\,760{,}742$ cps for mode DL-S3
- $f_{chip}^{DL-S4} = 3 \cdot 26 \cdot 10^6 \cdot 2^{-12} = 19\,042{,}969$ cps for mode DL-S4

All chip rates can easily be derived from a 26 MHz reference frequency. The chip time period T_{chip} corresponds to the inverse chip rate of the respective mode, i.e. $T_{chip} = 1/f_{chip}$.

Q.2.5.5.2 Data Whitening

Data Whitening shall be done using the PN9 sequence defined in [IEEE 802.15.4].

In the uplink the complete PHY payload as shown in Table Q.41 shall be whitened.

In the downlink the core frame as shown in Table Q.37 as well as each extension frame block as shown in Table Q.40 shall be whitened.

Q.2.5.5.3 CRC

The CRC code is defined by a polynomial of degree n:

$$G_n(x) = x^n + g_{n-1} \cdot x^{n-1} + \cdots + g_2 \cdot x^2 + g_1 \cdot x^1 + 1 \qquad \text{(Eq.Q.31)}$$

with $g_i \in \{0,1\}, \quad i \in \{1,2,\ldots,n-1\}$.

The CRC calculation may be performed by means of a shift register containing n register stages, equivalent to the degree of the polynomial. At the beginning of the CRC calculation, all register stage contents are initialized with 1. After completion of the CRC calculation the CRC bits shall not be inverted (no XOR).

All 2-bit CRCs shall be calculated with the following parameters:

- 2-bit length (CRC-2)
- Polynomial: $x^2 + x^1 + 1$ (Eq.Q.32)
- Initial value: 3_h

All 4-bit CRCs shall be calculated with the following parameters:

- 4-bit length (CRC-4)
- Polynomial: $x^4 + x^1 + 1$ (Eq.Q.33)
- Initial value: F_h

All 8-bit CRCs shall be calculated with the following parameters:

- 8-bit length (CRC-8)
- Polynomial: $x^8 + x^7 + x^4 + x^3 + x^1 + 1$ (Eq.Q.34)
- Initial value: FF_h

Q.2.5.5.4 Forward Error Correction Coding (FEC)

Forward error correction in uplink shall be done according [ETSI 103 357], clause 6.4.4.5.

Forward error correction in downlink shall be done according [ETSI 103 357], clause 6.4.5.4.2.

Q.2.5.5.5 Interleaving

Interleaving in uplink shall be done according [ETSI 103 357], clause 6.4.4.6. Interleaving in downlink shall be done according [ETSI 103 357], clause 6.4.5.5.

Q.2.5.6 Timing

Q.2.5.6.1 General

Downlink data can only be transmitted after the reception of an uplink transmission. After sending an uplink packet to the gateway, an OMS end-device may enable a 2-way session by opening a downlink window for the reception of a gateway transmission. The downlink transmission shall start after the response delay t_{RO} (equals to ΔT_{ud} in [ETSI 103 357]) after the reception of the uplink transmission. All necessary timing information are provided by the OMS end-device within the MAC layer (see Q.3.5.2.1.2).

The NW-Manager can advise the OMS end-device with the downlink about an expected response-to-uplink delay t_{RM} (equals to ΔT_{du} in [ETSI 103 357]). This can be beneficial for the timing management in the gateway, especially for battery driven gateways. If the NW-Manager does not request this precise timing the OMS end-device is free to select any t_{RM} value up to the maximum response-to-uplink delay of 50 seconds. See Figure Q.22 for an overview of the uplink/downlink scheduling.

The response delay t_{RO} is defined as the time between T_2 of the uplink transmission to T_0 of the downlink transmission. The response-to-uplink delay t_{RM} is defined as the time between T_2 of the downlink transmission to T_0 of the next uplink transmission (see Q.2.5.6.4).

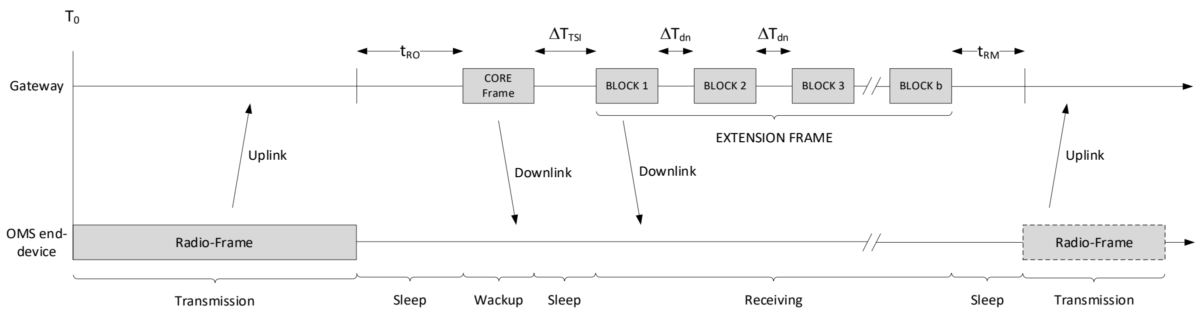

Figure Q.22 – Uplink/Downlink Scheduling

Table Q.45 gives the time intervals for the uplink/downlink scheduling and provides the values for a full [ETSI 103 357] compatible setup (see Q.2.5.4.2.8).

NOTE: Table Q.G.1 in Appendix Q.G shows the resulting absolute times for information.

Table Q.45 – Uplink/downlink time intervals

Para-meter	Range of values	Values for compatibility to [ETSI 103 357]	Associated Parameter Field	Description
t_{RO}	$N_{SAF} \cdot 2\,048$, for RTO = 1 $N_{SAF} \cdot 2\,048 \cdot 2^{RTO}$, for RTO > 1 with RTO according to Table Q.84	16384 ➔ RTO $= 3$	DL-AC (MAC Layer MElement_UA)	Time interval between UL and DL transmission in number of chip time periods
ΔT_{TSI}	$N_{TAF} \cdot 512 \cdot r_{TSI}$, with $r_{TSI} \in \{1,4,8,12,16,\ldots 124\}$	2048 ➔ $r_{TSI} = 4$	TSI (DL-PHY Core Frame)	Time interval between DL core frame and DL extension frame in number of chip time periods (see clause Q.2.5.4.2.4)
ΔT_{dn}	$N_{TAF} \cdot 512 \cdot r_{TDN}$, with r_{TDN} according Table Q.43	512 ➔ $r_{TDN} = 1$	TDN (DL-PHY Core Frame)	Time interval between blocks of DL extension frame in number of chip time periods (see clause Q.2.5.4.2.5)
ΔT_{hb}	$2\,048 \cdot r_{THB}$, with $r_{THB} \in \{0,4,8,12,16,20,24,48\}$	0 ➔ $r_{THB} = 0$	THB (DL-PHY Core Frame)	Additional time delay between the two DL radio-bursts with burst index s=8 and burst index s=9. The first radio burst starts at index s = 0 in number of chip time periods (see clause Q.2.5.4.2.6)
t_{RM}	$N_{SAF} \cdot 2\,048$, for RTO = 1 $N_{SAF} \cdot 2\,048 \cdot 2^{RTO}$, for RTO > 1 with RTO according to Table Q.84	No requirement	RTRM (MAC Layer MElement_DA)	Time interval between DL and UL transmission in number of chip time periods
NOTE:	The chip time period $T_{chip} = 1/f_{chip}$ is based on the mode specific DL chip rates f_{chip} (see Q.2.5.5.1.4) N_{SAF} and N_{TAF} are the adaptation factors as specified in Table Q.46. *RTO* is the response timing option as specified in Table Q.84			

Two mode dependent adaption factors are defined. These are the symbol adaption factor N_{SAF} and the timing adaption factor N_{TAF}. They are defined as follows in Table Q.46:

Table Q.46 – Adaptation Factors

Sub-Mode	N_{SAF}	N_{TAF}
DL-S1, DL-S2	1	1
DL-S3	2	1
DL-S4	8	2

Q.2.5.6.2 Tolerances

The following Table Q.47 and Table Q.48 show the timing tolerances for uplink and downlink.

Table Q.47 – Timing tolerances uplink

Parameter	Tolerance	Description
$\Delta T_{RB\ 1st\_last}$	+/- 105 us	Overall summed up tolerance from timing of 1st radio burst to last radio burst within the core frame and within each consecutive 24 bursts of the extension frame
t_{RM}	+/- 2 ms	Timing tolerance between downlink and following uplink, see Table Q.45

Table Q.48 – Timing tolerances downlink

Parameter	Tolerance [chip time periods] [a]	Description
t_{RO}	+/- 2	Timing tolerance between uplink and following downlink, see Table Q.45
ΔT_{TSI}	+/- 2	Timing tolerance between downlink core frame and extension fame, see Table Q.45
ΔT_{dn}	+/- 0,5	Timing tolerance between blocks of downlink extension frame, see Table Q.45
$\Delta T_{RB1,18}$	+/- 0,125	Overall summed up time tolerance of each block for $\Delta T_{hb} = 0$
$\Delta T_{RB1,9}$ $\Delta T_{RB10,18}$	+/- 0,06125	Time tolerance of each half block for $\Delta T_{hb} \neq 0$
ΔT_{hb}	+/- 0,125	Time tolerance of half block distance, see Table Q.45

[a] The chip time period $T_{chip} = 1/f_{chip}$ is based on the mode specific DL chip rates f_{chip} (see Q.2.5.5.1.4)

Q.2.5.6.3 Synchronous transmission

The OMS end-device shall support a synchronous uplink transmission timing according to [OMS-S2], 4.3.2.1. The individual transmissions interval t_{ACC} of the synchronous transmission shall be calculated from the nominal transmission interval t_{NOM}, according to [EN 13757-4], 12.6.2. The nominal transmission interval shall be less or equal to the limits in Table Q.49.

Table Q.49 – Nominal transmission interval

Mode	t_{NOM} (max)
UL-S1 UL-S2 UL-S3	180 min

Q.2.5.6.4 Reference time point

Q.2.5.6.4.1 General

Reference time points are used to enable precise timing of PHY-layer and for application means.

Splitting Mode has two reference time points in each uplink or downlink radio frame called T_0 and T_2. The start time T_0 is defined as the middle of the first radio-burst of the core frame (see Figure Q.23 for the explanation of “middle”). The end time T_2 is defined as the middle of the last transmitted radio-burst of the radio frame.

Q.2.5.6.4.2 PHY layer reference time point

Several PHY timings refers to the two reference time points as explained in the respective chapters, e.g. Q.2.5.6.1 for the definition of t_{RO} and t_{RM}.

Q.2.5.6.4.3 Application reference time point

The precise timing of the application requires the management of the reference time points in the OMS end-device and in the gateway. As Splitting Mode radio frames can have a longer on-airtime (up to minutes) it is essential to use the correct reference time point for the application.

The gateway shall use the start time T_0 for assigning a timestamp to a received radio frame of an OMS end-device. Only with this concept the correct time assignment e.g. to metering values contained in the radio frame is guaranteed.

The OMS end-device shall use T_0 of the downlink frame for its internal processing of the application data. This is especially important in case of a time adjustment command (providing absolute time) contained in the application data.

Q.2.5.7 Splitting Mode Details

Q.2.5.7.1 Scheme

The radio-bursts within a radio-frame are spread over 25 carriers in the uplink extension frame and 24 carriers in all other cases with a carrier spacing step size of B_{C0}.

In the uplink core frame, the downlink core and downlink extension frame the way the radio-bursts are distributed over time and frequency is called pattern. A pattern consists of a set of carrier numbers and time spacing 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…23) with a carrier spacing of B_{C0}. In uplink the core frame of a radio-frame shall consist of 24 radio-bursts and in downlink the pattern shall consist of 18 radio-bursts. In downlink the same pattern shall be used for the core frame and each block of the extension frame.

In the uplink extension frame all 25 carriers are used for the transmission of radio-bursts. The carrier numbers and time spacing are derived from the Header and the Payload CRC.

In uplink one pattern group called UPG with 8 different patterns is available.
In downlink one pattern group called DPG is available.

For the transmission of a radio-frame one pattern out of the pattern group shall be selected as described in clause Q.2.5.7.4.1. The pattern shall vary from radio-frame to radio-frame. The start time $T0$ and the start frequency f_0 of the pattern are varying between the different OMS end-devices.

[ETSI 103 357], Figure 6-17 shows a scheme of a radio frame.

The radio-frame shall be transmitted on a channel with the channel centre frequency f_c taking crystal tolerances (see Table Q.33) and pseudorandom carrier frequency offset f_{offset} (see clause Q.2.5.7.3 into account.

NOTE: If no frequency offset applies the nominal carrier frequency of carrier 12 is denoted as centre frequency f_c of the channel.

The transmission frequency $f_{RB}(s)$ of radio-burst s (Radio-burst Frequency) is defined for the Splitting Modes as:

$$f_{RB}(s) = f_c + f_{offset} + N_{st} \cdot (C_{RB}(s) - 12) \cdot B_{C0} \qquad \text{(Eq.Q.35)}$$

where:

C_{RB} is the radio-burst carrier number according to the UL- or DL-pattern chosen for the transmission of the radio-frame according to Table Q.51 for the uplink pattern group (UPG) and Table Q.56 or Table Q.59 for the downlink pattern group (DPG);

B_{C0} is the fixed carrier spacing step size of 2 380,371 Hz

N_{st} is a stretching factor depending on the mode, where:

- N_{st} = 1 for all UL-S modes and DL-S1/S2
- N_{st} = 2 for modes DL-S3 and DL-S4

When 24 carriers are used per UL or DL-pattern, the occupied bandwidth per radio frame is

- 57.13 kHz for sub-modes UL-S and DL-S1/S2 ($BW_{carrier} = 2\,380{,}371$ Hz).
- 114.26 kHz for sub-mode DL-S3 ($BW_{carrier} = 4\,760{,}742$ Hz)
- 128.54 kHz for sub-mode DL-S4 ($BW_{carrier} = 19\,042{,}969$ Hz)

The used bandwidth $BW_{carrier}$ of one carrier in up- or downlink is considered to correspond to the respective chip rate f_{chip} (see Q.2.5.5.1.4) and is shown in brackets.

The frequency offset f_{offset} is a variable radio-frame offset, which is calculated according to the following formula:

$$f_{offset} = C_{RF} \cdot B_{C0} \qquad \text{(Eq.Q.36)}$$

where:

C_{RF} determines the additional frequency offset in integer mulitples of B_C selected by the OMS end-device and set for every radio-frame depending on 7 bits of the payload CRC in case of uplink (see clause Q.2.5.7.3).

If two radio channels (secondary channel; UL-S2, DL-S2) are used, the frame transmissions shall be alternated between the two channels. The channel to be used for transmission in UL shall be derived from bit 0 of the payload CRC according to Table Q.50. The channel for DL shall be selected according to DL-SM subfield of Table Q.80.

Q.2.5.7.2 Radio-burst Time

The start time T_0 of the first radio-burst s=0 of a radio-frame is chosen by the OMS end-device and defined at the middle of the radio-burst. The distance time between two radio-bursts $DT_{RB}(s)$ is defined as the time difference between two radio-bursts measured from the middle of radio-burst s to the middle of the previous radio-burst s-1 in number of chip durations as illustrated in Figure Q.23.

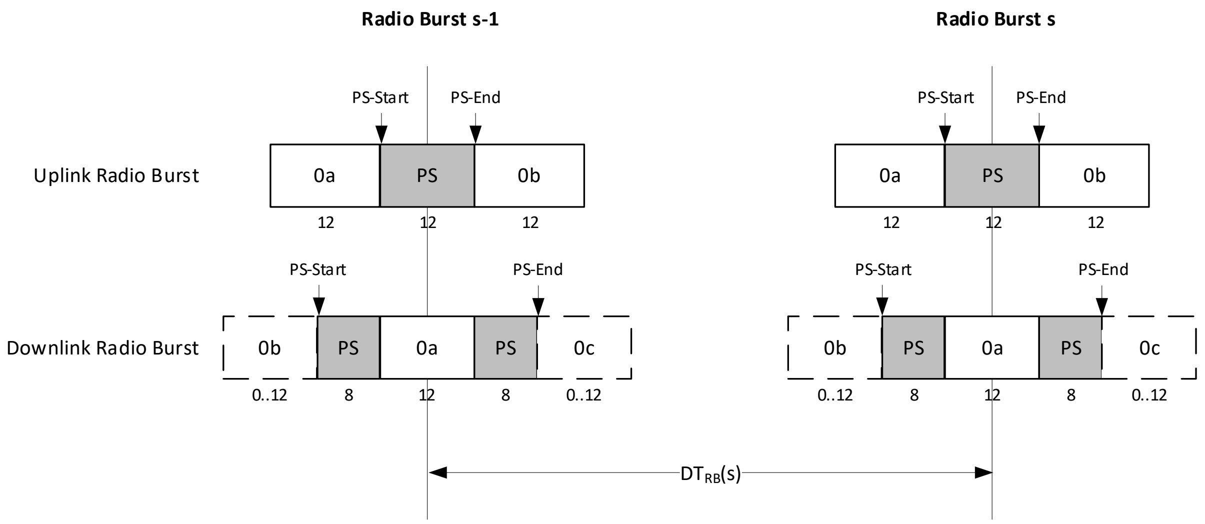

Figure Q.23 – Definition of Radio-burst Time $DT_{RB}(s)$

The distance time between two radio-bursts Time $DT_{RB}(s)$ is calculated according to the following formula:

$$DT_{RB}(s) = T_{RB}(s) + T_{offset}(s) \qquad \text{(Eq.Q.37)}$$

where:

T_{RB} is the initial radio-burst time in number of chip time periods according to the UL- or DL-pattern chosen for the transmission of the radio-frame according to Table Q.52 for UPG and Table Q.57, Table Q.58 and Table Q.60 for DPG

T_{offset} is an additional delay of the time difference between two neighbouring radio-bursts in number of chip durations. It shall be assigned according to:

- $T_{offset}(s) = 0 \ for \ s \in \{1,2,\ldots 23\}$ for all UL-S modes

For all downlink modes (DL-S1, DL-S2, DL-S3 and DL-S4), T_{Offset} shall be set as follows:

- $T_{offset}(s) = 0$ for $s \neq 9$ AND
- $T_{offset}(9) = \Delta T_{hb}$ for $s = 9$

ΔT_{hb} are specified according to Table Q.45 in clause Q.2.5.6.

Q.2.5.7.3 Carrier offset

For OMS LPWAN Splitting Mode a pseudo-random carrier offset C_{RF} will shift the selected pattern start frequency $f_{RB}(0)$ for every radio-burst of a frame as exemplarily shown in Figure Q.24. The resulting transmission frequency $f_{RB}(s)$ is calculated as shown in formula (Eq.Q.35).

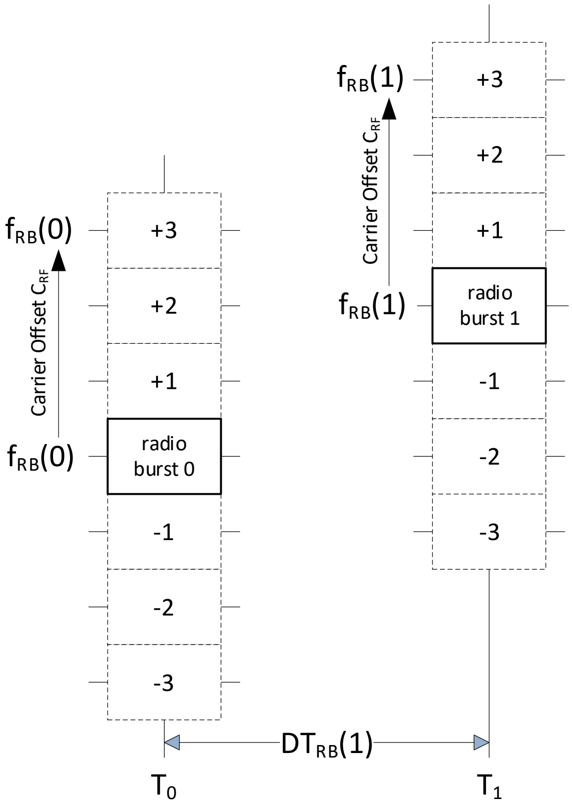

Figure Q.24 – Carrier offset

C_{RF} shall be derived from payload CRCs (see Q.2.5.4.1.3). According to Table Q.50, bit 1 to bit 7 shall be used as carrier offset random value v_{co} to calculate the carrier offset C_{RF}. Bit 0 of the associated payload CRC shall be used for the selection of the channel if dual channel operation is activated (see Table Q.6 and Table Q.80).

Table Q.50 – Bit representation of Payload CRC

Payload CRC	Value	Used as
Bit 0 (LSBit)	0/1	Channel selection for frame transmission in dual channel for mode [a] 0: UL-S1 1: UL-S2
Bit 1 to Bit 7 (MSBit)	0…127	Carrier offset random value v_{co}
[a] The gateway shall select the downlink sub-mode DL-S2 if uplink sub-mode UL-S2 was received and DL-S1 if UL-S1 was received (see also Table Q.80).		

The variable carrier offset C_{RF} shall be limited to a range in order to keep the signal within the channel bandwidth B_{ch}. Depending on the transmission mode, the range of the carrier offset is configured by n_{co} as follows:

- $n_{co} = 3$ for all modes UL-S and DL-S1/S2 (carrier offset $C_{RF} \in \{-1, 0, \ldots 1\}$)
- $n_{co} = 19$ for mode DL-S3 (carrier offset $C_{RF} \in \{-9, -8, \ldots 9\}$)
- $n_{co} = 5$ for mode DL-S4 (carrier offset $C_{RF} \in \{-2, -1, \ldots 2\}$)

The carrier offset shall be calculated for up- and downlink according to the following formula:

$$C_{RF} = (v_{co} \text{ modulo } n_{co}) - \lfloor {n_{co}}/{2} \rfloor \qquad \text{(Eq.Q.38)}$$

Q.2.5.7.4 Uplink Pattern

Q.2.5.7.4.1 Core Frame

The following Table Q.51 and Table Q.52 give the sets of radio-burst carrier $C_{RB}(s)$ and initial radio-burst time $T_{RB}(s)$ of the uplink pattern for all uplink modes UL-S. The used abbreviations are:

- s = radio burst index
- p = uplink pattern index

Table Q.51 – Radio-burst carrier set of Uplink Pattern Group (UPG)

s / p	$C_{RB}(s)$											
	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

s / p	$C_{RB}(s)$											
	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 Q.52 – Initial Radio-burst time set of Uplink Pattern Group (UPG)

s / p	$T_{RB}(s)$											
	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
s / p	$T_{RB}(s)$											
	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	

For uplink, the Pattern 1-6 shall be used for uplink communication with the pattern sequence order (1,2,3,4,1,2,3,4,5,1,2,3,4,5,6). The sequence is cyclically repeated. Pattern 7 shall be used for high priority messages (e.g. alarms). Pattern 6 may be used for dedicated OMS end-devices which have high coupling loss due to the radio channel and are typically located far from the base station. Other OMS end-devices located near to the base station don't use this pattern and does not introduce interference for the dedicated OMS end-devices. The pattern 8 is reserved for future use.

Q.2.5.7.4.2 Extension Frame

The pattern for the extension frame in all UL-S modes is derived from information of the core frame. The 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 the concatenated Header CRC and the Payload CRC as shown in Table Q.53. The highest bit of this seed shall be always set to 1.

Table Q.53 – LFSR Seed R[0]

Bit 15 (MSBit)	Bit 14 – 8	Bit 7 – 0 (LSBit)
1	Header CRC [7 LSBits]	Payload CRC

The polynomial for the Galois-LFSR in hexadecimal notation shall be B4F3$_h$. 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:

$$R[s_e] = LFSR(R[s_e - 1]) \quad \text{(Eq.Q.39)}$$

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:

$$T_{RB}[s_e] = (337 + (R[s_e]\ modulo\ 128)) \qquad \text{(Eq.Q.40)}$$

For the first radio-burst in the extension frame, this time denotes the delay between the centre of the pilot chips of the last radio-burst of the core frame and the centre of the pilot chips 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:

$$C_{RB}[s_e] = \lfloor (R[s_e]/256) \rfloor \text{ modulo } 25 \qquad \text{(Eq.Q.41)}$$

It shall be emphasized that the carrier indices here range from C=0 to C=24, i.e. covering 25 carrier indices, while for the core frame they range only from 0 to 23.

Q.2.5.7.5 Downlink Pattern

Q.2.5.7.5.1 Downlink Transmission Pattern Overview

Every downlink transmission starts with a core frame, which may be followed by an optional extension frame. The extension frame shall be indicated by the core frame. The core frame consists of 9 radio-bursts, each carrying 28 coded bits, as described in clause Q.2.5.5.5. The DATA_B and DATA_C fields of Table Q.36 are not used. The extension frame is subdivided into 1 to 11 blocks, each block comprising 18 radio bursts. The number of blocks B that shall be used for transmission is defined by the amount of user data as described in clause Q.2.5.3.2.2.3.

For the core frame 8 fixed time-frequency patterns for the transmission of the corresponding radio-bursts are specified in terms of tables. One of these must be selected for a downlink transmission.

The gateway shall select the downlink pattern based on the bit representation of the Header CRC (see Q.2.5.4.1.2) in the preceding uplink transmission of the OMS end-device. The OMS end-device and the gateway shall apply this downlink pattern index p_{DL} according to the following formula:

$$p_{DL} = (v_{DL} modulo\ 8) + 1 \qquad \text{(Eq.Q.42)}$$

v_{DL} is specified according to Table Q.54.

Table Q.54 – Downlink pattern selection based on Header CRC

Header CRC	Value	Used as
Bit 0 (LSBit) to Bit 3	n.a.	Not used for pattern selection
Bit 4 to Bit 7 (MSBit)	0…15	Downlink pattern selection value v_{DL}

The same pattern index p_{DL} 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 5-bit TSI field in the downlink core frame (see clause Q.2.5.4.2.4).

The pattern index is calculated independent of the uplink mode (all UL-Sx). However, based on the selected downlink modes the resulting pattern index leads to different downlink patterns (as explained in Q.2.5.7.5.2 and Q.2.5.7.5.3).

The downlink transmission shall start at predefined time (see Q.2.5.6) after an uplink transmission.

The centre frequency $f_{C,DL}$ of the downlink pattern is determined as:

$$f_{C,DL} = f_{C,ULRX} + f_{DL-UL} \qquad \text{(Eq.Q.43)}$$

where: $f_{C,ULRX}$ is the centre frequency of the received radio-frame in the gateway, whereby oscillator frequency deviations are considered here

f_{DL-UL} is the offset frequency between uplink channel and downlink channel centre frequency as denoted in Table Q.55.

Table Q.55 – Uplink downlink frequency offsets

Uplink Mode	Uplink Frequency [MHz]	Downlink Mode	Downlink Frequency [MHz]	f_{DL-UL} [MHz]
ULS1	868.180	DLS1	869.575	1.395
ULS2	868.080	DLS2	869.475	1.395
ULS3	868.520	DLS1	869.575	1.055
ULS3	868.520	DLS2	869.475	0.955
ULS1	868.180	DLS3/DLS4	869.525	1.345
ULS2	868.080	DLS3/DLS4	869.525	1.445
ULS3	868.520	DLS3/DLS4	869.525	1.005

Q.2.5.7.5.2 Downlink pattern for DL-S3 and DL-S4-mode

In downlink modes DL-S3 and DL-S4 each block shall consist of 18 radio-bursts, where 3 consecutive radio-bursts are seamlessly joint together. Therefore 8 different pattern sets with 6 different carrier frequencies for each group of 3 contiguous radio-bursts according to the following Table Q.56 shall be used.

The used abbreviations in the following tables are:

- *s* = radio burst index
- p_{DL} = downlink pattern index

Table Q.56 – Radio-burst carrier set of Pattern Group for downlink modes DL-S3 and DL-S4

s / p_{DL}	$C_{RB}(s)$																	
	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

Table Q.57 and Table Q.58 show the initial transmission times T_{RB} for the two downlink modes DL-S3 and DL-S4. The first 2 time durations $T_{RB}(1)$ and $T_{RB}(2)$ in each table specify the 2 time differences between the middle of the first radio-burst to the middle of the second radio-burst and from there to the middle of the third radio-burst. In case of a core frame those durations are constant

$$T_{RB}(1) = T_{RB}(2) = 28.$$

For extension frame blocks the times are variable because the radio-burst size depends on the PSDU size $P \in \{1,2 \ldots 255\}$. The equivalent applies to the other transmission time pairs $T_{RB}(s)$ with $(s = \{4,5\},\{7,8\},\{10,11\},\{13,14\},\{16,17\})$ of the remaining 5 groups of three consecutive radio-bursts for the extension frame blocks. Table Q.57 and Table Q.58 show fixed time durations T_{RB} for all core frame radio-bursts and for extension frame radio-bursts with index $s \in \{3,6,9,12,15\}$. The 5 associated T_{RB} numbers represent the “inter-group” time distances.

Table Q.57 – Initial Radio-burst time set of Pattern Group for downlink modes DL-S4

<table>
<tr><td rowspan="2">s / pDL</td><td colspan="17">$T_{RB}(s)$</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td></tr>
<tr><td>1</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>500</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>350</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>400</td><td colspan="2" rowspan="8">extension frame block: variable distance</td><td>450</td><td colspan="2" rowspan="8">extension frame block: variable distance</td><td>300</td><td colspan="2" rowspan="8">extension frame block: variable distance</td></tr>
<tr><td>2</td><td>300</td><td>450</td><td>500</td><td>400</td><td>350</td></tr>
<tr><td>3</td><td>450</td><td>500</td><td>300</td><td>350</td><td>400</td></tr>
<tr><td>4</td><td>350</td><td>300</td><td>400</td><td>450</td><td>500</td></tr>
<tr><td>5</td><td>500</td><td>450</td><td>350</td><td>400</td><td>300</td></tr>
<tr><td>6</td><td>400</td><td>350</td><td>300</td><td>500</td><td>450</td></tr>
<tr><td>7</td><td>350</td><td>450</td><td>450</td><td>300</td><td>450</td></tr>
<tr><td>8</td><td>300</td><td>400</td><td>350</td><td>450</td><td>500</td></tr>
<tr><td colspan="18">**NOTE**: The chip time period T_{chip} is based on the DL-S4</td></tr>
</table>

Table Q.58 – Initial Radio-burst time set of Pattern Group for downlink modes DL-S3

<table>
<tr><td rowspan="2">s / pDL</td><td colspan="17">$T_{RB}(s)$</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td></tr>
<tr><td>1</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>250</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>175</td><td colspan="2" rowspan="8">core frame: $T_{RB} = 28$
extension frame block: variable distance</td><td>200</td><td colspan="2" rowspan="8">extension frame block: variable distance</td><td>225</td><td colspan="2" rowspan="8">extension frame block: variable distance</td><td>150</td><td colspan="2" rowspan="8">extension frame block: variable distance</td></tr>
<tr><td>2</td><td>150</td><td>225</td><td>250</td><td>200</td><td>175</td></tr>
<tr><td>3</td><td>225</td><td>250</td><td>150</td><td>175</td><td>200</td></tr>
<tr><td>4</td><td>175</td><td>150</td><td>200</td><td>225</td><td>250</td></tr>
<tr><td>5</td><td>250</td><td>225</td><td>175</td><td>200</td><td>150</td></tr>
<tr><td>6</td><td>200</td><td>175</td><td>150</td><td>250</td><td>225</td></tr>
<tr><td>7</td><td>175</td><td>225</td><td>225</td><td>150</td><td>225</td></tr>
<tr><td>8</td><td>150</td><td>200</td><td>175</td><td>225</td><td>250</td></tr>
<tr><td colspan="18">**NOTE**: The chip time period T_{chip} is based on the DL-S3</td></tr>
</table>

For extension frame radio-bursts with $(s = \{1,2\},\{4,5\},\{7,8\},\{10,11\},\{13,14\},\{16,17\})$ the T_{RB} represents the variable time distances. As the radio-burst durations depend on the DL payload size, these T_{RB} are variable and computed as follows. First, the length of the data fields DATA_B and DATA_C is derived based on the payload size, then the resulting middle-to-middle distance T_{RB} within each group of three bursts is computed.

The interleaving of the extension frame is done block-wise, as shown in [ETSI 103 357] Table 6-45. The maximal input length of the interleaver shall be 648 bits. In a first step an index vector $I(i)$ is derived from the interleaving scheme according to:

$$I(i) = 3(i \text{ modulo } 6) + \left\lfloor \frac{i}{6} \right\rfloor + 15 \cdot \left\lfloor \frac{i}{18} \right\rfloor \qquad for\ i \in \{0,1,\dots,647\} \qquad \text{(Eq.Q.44)}$$

In a second step the interleaved bits are mapped to the symbols in the required DATA_B and DATA_C field of [ETSI 103 357] Table 6-45. 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 reordered data corresponding to

$$d_B(m,s) = I(s + (2 \cdot m + 12) \cdot 18) \qquad for\ s \in \{0,1,\dots,17\}, \quad m \in \{0,1,\dots,11\} \qquad \text{(Eq.Q.45)}$$

Accordingly, $d_C(m,s)$ denote the interleaved symbols of DATA_C and shall be filled according to

$$d_C(m,s) = I(s + 18 + (2 \cdot m + 12) \cdot 18) \qquad for\ s \in \{0,1,\dots,17\}, \quad m \in \{0,1,\dots,11\}. \qquad \text{(Eq.Q.46)}$$

The mapping of interleaved bits to data field DATA_A, as well as to the two pilot sequence fields PS_DA and PS_DB is not relevant here, because their symbol length is always constant. As can be seen from Figure Q.23, the total length of these 3 fields (PS_DA, DATA_A and PS_DB) together is 28 symbols.

The 12 payload-size dependent initial transmission times $T_{RB}(s),\ s \in \{1,2,4,5,7,8,10,11,13,14,16,17\}$ from Table Q.57 or Table Q.58 are calculated for the individual blocks according to:

$$T_{RB}(b,s) = 28 + \sum_{m=0}^{11} int\left(d_c(m,s-1) < n_{bit}^{coded}(b)\right) + int\left(d_B(m,s) < n_{bit}^{coded}(b)\right) \qquad \text{(Eq.Q.47)}$$

$$for\ \ b \in \{1, \dots B\}, \quad s \in \{1,2,4,5,7,8,10,11,13,14,16,17\},$$

where $d < n$ is a boolean expression, that returns true or false as result. In this formula the operator int() yield a numeric "1" if the result of the operation " $<$" is boolean true and a numeric "0" if it is false. This determines the length of each burst data field (DATA_B or DATA_C). Depending on the length of the PSDU, transmission times T_{RB} will range from 28 to 51 symbols.

B denotes the number of extension frame blocks that shall be used for the transmission according to the following formula from clause Q.2.5.3.2.2.3:

$$B = \left\lceil \frac{P}{24} \right\rceil \qquad \text{(Eq.Q.48)}$$

where $P \in \{1,2 \dots 255\}$, shall be the PSDU size in byte. The 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 encoded bits n_{bit}^{coded} after the forward error correction assigned to block b are ranging from 216 to 624 bits and can be obtained from the relation

$$n_{bit}^{coded}(b) = \left(8 \cdot n_{byte}(b) + 10 + 6\right) \cdot 3 \qquad for\ \ b \in \{1, \dots B\}, \qquad \text{(Eq.Q.49)}$$

where the number of PSDU data bytes $n_{byte}(b)$ assigned to one block is a result of spreading the data evenly over all blocks as shown in clause Q.2.5.3.2.2.3. In case the number of bytes P is not a multiple of the number of blocks B, the remaining bytes $n_r = P - \left\lfloor \frac{P}{B} \right\rfloor * B$ shall be assigned to the blocks in ascending order.

$$n_{byte}(b) = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor + 1, & for\ b \le n_r \\ \left\lfloor \frac{P}{B} \right\rfloor, & for\ b > n_r \end{cases} \qquad for\ \ b \in \{1, \dots B\}\,. \qquad \text{(Eq.Q.50)}$$

So, the sizes of the sub-packets can differ inside of one block.

An example of how the initial transmission time T_{RB} is calculated based on the PSDU size P is given in Appendix Q.H.

Once the pattern p_{DL} is selected, the first 9 values from Table Q.56 and the first 8 values from Table Q.57 or Table Q.58 are used for transmission of the core frame.

Q.2.5.7.5.3 Downlink pattern for DL-S1 and DL-S2 mode

In the downlink mode DL-S1 and DL-S2 each block shall consist of 18 radio-bursts. Therefore 8 different pattern sets with each 18 carrier frequencies according to the following Table Q.59 shall be used.

Table Q.59 – Radio-burst carrier set of Pattern Group for modes DL-S1 and DL-S2

s / p_{DL}	$C_{RB}(s)$																	
	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

The initial transmission time of a radio-burst is defined as the time difference between two radio-bursts from the middle of radio-burst s to the middle of the previous radio-burst s-1 in number of chip durations T_{chip} as illustrated in Figure Q.23.

Once the pattern p_{DL} is selected, the first 9 values from Table Q.59 and the first 8 values from Table Q.60 are used for transmission of the core frame.

Table Q.60 – Initial Radio-burst time set of Pattern Group for modes DL-S1 and DL-S2

s	$T_{RB}(s)$																
pDL	**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
NOTE: The chip time period T_{chip} is based on the DL-S1 and DL-S2.																	

Q.2.5.7.6 Frequency and Burst Time Compensation

The downlink in the splitting mode shall be very accurate in time and in frequency. Therefore, the base station estimates time and frequency deviations of the end-device during one of the last uplink transmissions. Typically, the last uplink transmission is used. Normally the receive windows of the downlink radio bursts is assumed to be generated by a time crystal running for example at 32768 Hz. The carrier frequency for reception of the radio bursts is assumed to be generated by a high frequency crystal running for example at 39 MHz. The deviation Δf_{HF_LF} between the low frequency signal (32768 HZ) and the high frequency signal (39 MHz) shall be measured within a hardware timer inside a microcontroller of the OMS end-device.

The uplink bursts transmitted from the OMS end-device shall be transmitted with a time correction factor based on the deviation Δf_{HF_LF}. The distances between the burst DT_{RB} shall be corrected according to the following formula:

$$DT_{RB}(s) = DT_{RB}(s) \cdot \Delta f_{HF_{LF}} \qquad \text{(Eq.Q.51)}$$

s is the burst number.

For example, if the $DT_{RB}(s)$ is 1 second and $\Delta f_{HF_{LF}}$ is +50 ppm the time correction factor will be +50 μs.

The gateway shall estimate the chip rate offset of the OMS end-device based on the received carrier frequency offset:

$$\Delta f_{chip} \sim \frac{f_{c,RX} - f_{c,expected}}{f_{c,expected}} \qquad \text{(Eq.Q.52)}$$

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

The downlink is transmitted with the adapted chip rate and the adapted carrier frequency. In this way the OMS end-device receiver sees almost no frequency and chip time deviations.

Q.2.6 Combination of Technologies

Q.2.6.1 Introduction

The uplink and downlink technologies of Burst Mode and Splitting Mode can be combined in one OMS end-devices. This means the uplink and downlink technology can be different. This can be beneficial in special situations where e.g. a very high robustness is needed in downlink (uplink Burst Mode, downlink Splitting Mode) or when the end-device can only send but not receive Splitting Mode (uplink Splitting Mode, downlink Burst Mode).

The following subclauses describe the applicable rules for the combination of technologies. The OMS end-device will inform in the MAC layer of the uplink about the applicable and expected downlink technology.

Q.2.6.2 Timing

The definition of the timing for downlink accessibility (see Q.3.5.2.1) is taken from the intended downlink technology. This means a Burst Mode uplink applying a Splitting Mode downlink uses the accessibility defined in Table Q.83. A Splitting Mode uplink with a Burst Mode downlink applies Table Q.81.
The reference time points are defined according to the definitions for each technology respecting the direction uplink or downlink. For Burst Mode this is defined in Q.2.4.6.5, for Splitting Mode it is Q.2.5.6.4.

Q.2.6.3 Burst Mode Uplink with Splitting Mode Downlink

The uplink can be Single-burst or Multi-burst. The additional reception window RX3 (see e.g. Q.2.4.6.2.3) shall not be applied. The Splitting Mode downlink shall always be after the last uplink burst at T_2 (see Q.2.4.6.5) applying the response delay t_{RO} defined by the intended Splitting Mode.

The Burst Mode uplink shall follow the rules for synchronous transmission as defined in Q.2.4.6.4 applying the tolerances of Q.2.4.6.3.

The Splitting Mode needs a selection of the pattern p_{DL} (see Q.2.5.7.5.1) and the carrier offset C_{RF} (see Q.2.5.7.3) to be used for downlink. As the Header CRC and the Payload CRC of the Splitting Mode are not available in Burst Mode uplink the 4 byte MAC CRC (see Q.3.2.5) shall be used instead to generate the necessary random values. Table Q.61 shows the input values for the calculation of p_{DL} and C_{RF} as explained in the linked clauses.

Table Q.61 – Input values based on MAC CRC

MAC CRC	Value	Used as
Bit 0 (LSBit)	**n.a.**	Not used
Bit 7 to Bit 1	**0…127**	Carrier offset random value v_{co}
Bit 11 to Bit 8	**0…15**	Downlink pattern selection value v_{DL}
Bit 31 to Bit 12	**n.a.**	Not used

The dual channel option for a Splitting Mode downlink in the case of combined technologies can be applied. The OMS end-device can select the intended uplink sub-mode (e.g. UL-B1, UL-B2) and shall inform about the intended downlink sub-mode in MElement_UA (see Q.3.5.2.1).

NOTE: The reception timing of Splitting Mode downlink only allows small tolerances as it is based on SDR technology. As the OMS end-device has limited resources this leads to a challenge in terms of power and memory calculation.

If Multi-burst is used in the uplink, it can happen that just one out of three radio bursts is correctly received by a gateway. In this case the downlink timing calculation is limited to this dedicated received radio burst without having any additional timing information of the other two missing radio bursts. A too high jitter created by crystal tolerances of this OMS end-device uplink will result in a too high tolerance for the downlink timing of the gateway. This finally would end up in a too large reception window in the OMS end-device that has to do an SDR-based reception. Therefore, the standard tolerances for Burst Mode (see Q.2.4.6.3) are too wide when combining the technologies and must in this situation be limited by the following additional definitions in Table Q.62.

Table Q.62 – Tolerance limitations

Parameter	Tolerance	Notes
Remaining frequency error of OMS end-device after LF and HF crystal calibration	+/- 2 ppm	See Appendix Q.I
Maximum frequency estimation error at SDR gateway	+/- 1 ppm	Referred to absolute gateway HF crystal frequency
Duration of the minimum reception time window of the OMS end-device	+/- 4 symbols	Referred to the ideal reception time point expected by OMS end-device. According to Table Q.48 the t_{RO} tolerance of +/- 2 symbols are already used by the gateway.

By keeping this additional tolerance limitations any combination of UL-B4 with Splitting Mode downlink is possible. Also, any combination of UL-B1, UL-B2 or UL-B3 with DL-S1, DL-S2 or DL-S3 is possible.

There is one special scenario for the combination of UL-B1, UL-B2 or UL-B3 with DL-S4. Considering the remaining error of 3 ppm (sum of both errors after calibration, see Appendix Q.I) either the limitation of the total time between up- and downlink needs to be limited or the minimum reception time window has to be increased. The total time is calculated as the sum of t_A, t_B, t_{RO} and the length of the downlink core frame. If the reception time window shall not exceed the +/- 4 symbols the total time shall not exceed 70 seconds. In case, the OMS end-device can handle a bigger reception time window for its SDR-based reception also the total time can be higher than the 70 seconds.

As described in Q.2.5.7.6 the gateway shall estimate the chip rate offset of the OMS end-device based on the received carrier frequency offset or based on the timing offset of the received radio-bursts. The downlink chip rate and carrier frequency shall be adapted in the downlink transmission of the radio frame.

Q.2.6.4 Splitting Mode Uplink with Burst Mode Downlink

The Burst Mode downlink can be Single-burst or Multi-burst. The additional reception window RX3 (see e.g. Q.2.4.6.2.3) and therefore the access options #2 and #4 (see Table Q.81) cannot be applied. The downlink shall start after the response delay t_{RO} as defined for the uplink sub-modes UL-B1, UL-B2 and UL-B3 in Table Q.22 and Table Q.24. The downlink sub carrier shall be provided with MElement_UC (see Table Q.86) if sub-modes DL-B1 or DL-B2 are announced.

The TIV of the downlink coded header is in this combination of technologies set to a fixed value of 0.

The Splitting Mode uplink shall follow the rules for synchronous transmission as defined in Q.2.5.6.3.

The OMS end-point shall inform about the intended downlink sub-mode as usual within the MElement_UA (see Q.3.5.2.1).

Q.3 Medium Access Control layer (MAC)

Q.3.1 Introduction

The MAC layer offers different kinds of functionalities in a flexible and efficient way. The first functionality that it provides is data integrity protection by use of a mandatory 32-bit CRC. The CRC covers the entire PHY-payload.

The remaining functionalities are divided into two main groups:

- Communication sequence control and
- MAC services.

Communication sequence control contains all information necessary to run a two-way session via OMS LPWAN PHY. The communication sequence control contains information about the applied downlink channel including information like downlink technology, downlink sub-mode, and downlink timing. This information is intended to be used by the gateway to localise where and when an OMS end-device provides an access opportunity.

The MAC services are used to manage the OMS end-device. Using MAC services, the MAC layer offers a limited set of functionalities like Link Management and Clock Management. Link Management is used to adjust the bidirectional link between the OMS end-device and the gateway. The Clock Management is used to manage the real time clock of the OMS end-device. MAC services require security and for this reason a dedicated MAC key is used. MAC services are optional in an OMS end-device. The MAC services are intended to be used by a NW-Manager. Such entity can either be located in the gateway or it can be located behind the gateway in the cloud (or as part of the HES, see Figure Q.25).

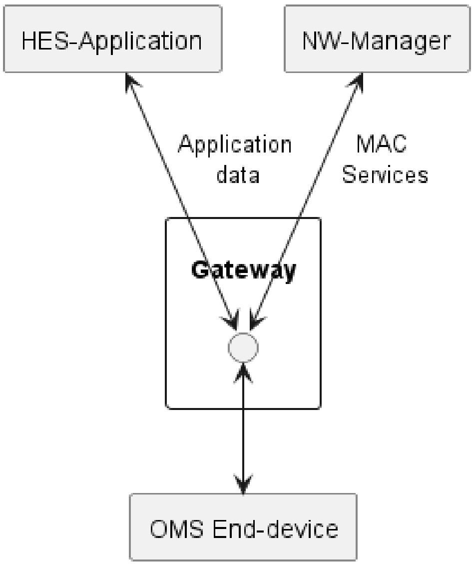

Figure Q.25 – Communication Endpoints

The MAC Payload contains the LLC-layer and the optional upper protocol layers starting with the LLC-layer in Frame Format C. An upper layer communication session can run independently from the MAC layer services as the communication endpoints for upper layer session and MAC layer services are independent from each other. A downlink frame from an gateway to an OMS end-device can contain both a MAC service request and an upper layer request, or it can contain only one of them.

The structure of the MAC layer is described in detail in the following clauses.

NOTE: Frame Format C is an extension to the existing wM-Bus frame formats; Frame Format A and Frame Format B (see [EN 13757-4], 12.3 and 12.4) are not applicable for OMS LPWAN.

Q.3.2 MAC Structure

Q.3.2.1 Overview

The MAC consists of 4 clusters. The MAC Header and the MAC CRC shall always be present. The MAC Body will be present if some additional MAC information is transported. MAC Payload is present if at least the Logical Link Control and maybe other upper protocol layer exists (see Table Q.63).

Table Q.63 – Overview about MAC layer

MAC Cluster	MAC Header	MAC Body	MAC Payload	MAC CRC
Presence	Mandatory	Optional	Optional	Mandatory
Bytes	1..8	0..65	Variable	4

Q.3.2.2 MAC Header

Q.3.2.2.1 MAC Header Structure

The MAC Header starts with the MAC Control fields MHCTL (see Table Q.64). The MHCTL[0]-field shall always be present. The following MHCTL fields may be present if needed. The presence is indicated by the Extension bit of the previous MHCTL-field.

Table Q.64 – MAC Header fields

Field	MHCTL [0]	MHCTL [1]	MHCTL [2]	MEle-ment[0]	MEle-ment[1]	MEle-ment[2]	MEle-ment[3]	MEle-ment[4]
Presence	Manda-tory	Optional	Optional	Optional	Optional	Optional	Optional	Optional
Bytes	1	1	1	1	1	1	1	1

Thereafter, the MAC Element fields MElement as described in subsection Q.3.2.2.3 may follow.

Q.3.2.2.2 MAC Header Control

Q.3.2.2.2.1 MHCTL

The MHCTL[0]-field (see Table Q.65) provides the control bits to define the structure of the MAC Header and MAC Body.

Table Q.65 – MHCTL[0]-field

Bit	Symbol	Name	Description
7	XP	Extension present	If the bit is set, the MHCTL[1] field is present
6	EP	Elements present	If the bit is set, the MElement[0] is present
5	BP	Body present	If the bit is set, the MAC Body is present
4	VN [a]	Version	Declares the version of MHCTL-field 0 - correspond to this version 1 - reserved for future use
3	MFT	MAC Frame Type	Bit 3 to bit 0 of MAC Frame Type according to, (see Q.3.2.2.2.3)
2			
1			
0			

[a] If VN is set to 1, the definition of bits 0 to 3 of MHCTL[0] and all bits of MHCTL[1] to MHCTL[2] may be different.

NOTE: In case the version or the MAC frame type is unknown to the OMS end-device (e.g. Version = 1) a reaction cannot be expected as the frame analysis will fail and the message including the upper layer will be discarded.

MHCTL[1] (see Table Q.66) is present only if the XP bit in MHCTL[0] is set. If MHCTL[1] and MHCTL[2] are not present, then all bits of the missing fields shall be considered as 0_b.

Table Q.66 – MHCTL[1]-field

Bit	Symbol	Name	Description
7	XP [a]	Extension present	If the bit is set, the MHCTL[2] field is present
6	MSP	MAC Security profile	Bit 6 and bit 5 according to Q.3.2.2.2.2
5			
4	(RFU)	Reserved	Reserved for future use (always 0)
3	(RFU)	Reserved	Reserved for future use (always 0)
2	(RFU)	Reserved	Reserved for future use (always 0)
1	(RFU)	Reserved	Reserved for future use (always 0)
0	(RFU)	Reserved	Reserved for future use (always 0)

[a] As long as MHCTL[2] is not defined the bit XP shall be 0.

The field MHCTL[2] is reserved for future use.

Q.3.2.2.2.2 MHCTL-subfield – MSP

Table Q.67 shows the configuration of the MAC security profile MSP via the MAC Header field MHCTL[1] (see Q.3.4.5.2 for details).

Table Q.67 – Configuration of MAC Security Profile

MAC Header.MHCTL[1] Bit 6	MAC Header.MHCTL[1] Bit 5	MAC Security Profile (MSP)
0	0	MSP1 [a]
0	1	Reserved for future use
1	0	Reserved for future use
1	1	Reserved for future use

[a] Default MAC security profile

Q.3.2.2.2.3 MHCTL-subfield – MFT

The MAC Frame type MFT is coded with 4 bits of MHCTL[0].

The MAC Frame types are described in Q.3.3.

Q.3.2.2.3 MAC Elements

MAC Elements contain information for accessing the OMS end-device and gateway timing. The MAC Elements are present only if the bit EP in the MHCTL[0] is set. The number of MElements bytes are determined by bit 7 of each byte which serves as an extension bit. An additional MElement byte follow if the bit 7 is set to 1. Details are described in Q.3.5.

Q.3.2.3 MAC Body

Q.3.2.3.1 Overview

The MAC Body is present only if the bit BP in the MHCTL[0] is set (see Q.3.2.2.2.1). Table Q.68 shows the general structure of the MAC Body.

Table Q.68 – MAC Body Structure

Field	MBCTL [0]	MBCTL [1]	MDer Counter	MMsg Counter	MMAC	MBlock 1	...	MBlock N
Presence	Manda-tory	Optional	Optional	Optional	Optional	Optional		Optional
Bytes	1	1	1	2	Variable	Variable		Variable

Q.3.2.3.2 MAC Body Control

If the MAC Body is present, then the first byte shall be the MBCTL[0] field. The MBCTL[0] is structured according to Table Q.69.

Table Q.69 – MBCTL[0]-field

Bit	Symbol	Name	Description
7	XP	Extension present	If the bit is set, the MBCTL[1] field is present
6	MDCP	MDerCounter present	If the bit is set, the MDerCounter field is present.
5	SP	Security present	If this bit is set security is enabled for this Message Frame Type.
4	ML0	MBodyLength	Bit 4 to bit 0 of MBodyLength MBodyLength counts all bytes after the MBCTL[0] field (if XP is not set) or after the MBCTL[1] field (if XP is set) to the end of the last MBlock.
3			
2			
1			
0			

MBCTL[1] (see Table Q.70) is present only if the XP bit in MBCTL[0] is set. If MBCTL[1] is not present, then all bits of the missing MBCTL[1] field shall be considered as 0_b.

Table Q.70 – MBCTL[1]-field

Bit	Symbol	Name	Description
7	(RFU)	Reserved	Reserved for future use (always 0)
6	(RFU)	Reserved	Reserved for future use (always 0)
5	(RFU)	Reserved	Reserved for future use (always 0)
4	(RFU)	Reserved	Reserved for future use (always 0)
3	(RFU)	Reserved	Reserved for future use (always 0)
2	(RFU)	Reserved	Reserved for future use (always 0)
1	(RFU)	Reserved	Reserved for future use (always 0)
0	ML1	MBodyLength	Bit 5 of MBodyLength. MBodyLength counts all bytes after the MBCTL[1] field to the end of the last MBlock.

Q.3.2.3.2.1 MBCTL-subfield – ML

The MAC Body length field, MBodyLength, is coded with 6 bits taken from the concatenation of ML1 of MBCTL[1] and ML0 of MBCTL[0].

$$ML = ML1 \,||\, ML0 \qquad \text{(Eq.Q.53)}$$

If the MBCTL[1] is not present the ML1-bit shall be set to 0.

Q.3.2.3.3 MDerCounter

The MDerCounter is the MAC derivation counter used to generate the applicable ephemeral MDerKey (see Q.3.4.2.2).

The MDerCounter is present only if the MDCP bit in the MBCTL[0] is set.

Q.3.2.3.4 MMsgCounter

The MMsgCounter is the MAC Message counter used to ensure that each secured MAC Message becomes unique (see Q.3.4.3.2.1).

The MMsgCounter is present only if the SP bit in the MBCTL[0] signals security present (see Table Q.69).

The transmission order of MMsgCounter shall be LSB first.

Q.3.2.3.5 MMAC

The MMAC contains the Message Authentication Code of the MAC Layer. The size of the MMAC is defined by the MAC Security profile (see Q.3.4.5.2).

The MMAC is present only if the SP bit in the MBCTL[0] signals security present (see Q.3.2.2.2.3).

In deviation to the usual transmission order of multi byte fields the MMAC shall be transmitted with MSB first.

Q.3.2.3.6 MBlocks

Q.3.2.3.6.1 MBlock Structure

If the MBodyLength indicates that more bytes in the MAC Body follows, then the next fields can contain the MDerCounter, the MMsgCounter, the MMAC and one or several MBlocks until the start of the MAC Payload.

An MBlock consist of a header and a value field (see Table Q.71).

Table Q.71 – MBlock Structure

Name	MBlock Header			MBlock Value
Symbol	MBH[0]	MBH[1]	MBH[2]	MBV
Presence	Mandatory	Optional	Optional	Optional
Bytes	1	1	1	MBlockLength

Q.3.2.3.6.2 MBlock Header

The MBlock header consists of up to three fields (see Table Q.72 and Table Q.73), the mandatory MBH[0] and the optional MBlock header extensions MBH[1] and MBH[2].

Table Q.72 – MBH[0] field

Bit	Symbol	Name	Description
7	XP	Extension present	If the bit is set, MBH[1] field is present.
6	(RFU)	Reserved	Reserved for future use (always 0)
5	MBL0	MBlockLength	Bit 1 and bit 0 of MBlockLength
4			
3	MID0	MBlockID	Bit 3 to bit 0 of MBlockID (see Q.3.6.2)
2			
1			
0			

Table Q.73 – MBH[1] field

Bit	Symbol	Name	Description
7	XP [a]	Extension present	If the bit is set, MBH[2] field is present.
6	MBL1	MBlockLength	Bit 4 to bit 2 of MBlockLength
5			
4			
3	(RFU)	Reserved	Reserved for future use (always 0)
2	(RFU)	Reserved	Reserved for future use (always 0)
1	MID1	MBlockID	Bit 5 to bit 4 of MBlockID
0			
[a] As long as MBH[2] is not defined the bit XP shall be 0.			

MBH[2] is reserved for future use.

Q.3.2.3.6.3 MBlock Header subfields

Q.3.2.3.6.3.1 MBlockID

The MBlockID is used to identify the MAC Block function (see Q.3.6).

The MBlockID is calculated with

$$\text{MBlockID} = \text{MID1} \,||\, \text{MID0} \qquad \text{(Eq.Q.54)}$$

If the MBH[1] is not present the MID1 shall be set to 0.

Q.3.2.3.6.3.2 MBlockLength

The MBlockLength defines the number of bytes for the MBlock Value field. It is calculated with

MBlockLength = MBL1 || MBL0 (Eq.Q.55)

If the MBH[1] is not present the MBL1 shall be set to 0.

If the structure of the MBlocks and the sum of all MBlockLength fields indicates a different number of bytes than the field MBodyLength defines, then all MBlocks have to be considered as corrupt and shall be discarded (see Q.3.3.4.3).

Q.3.2.3.6.4 MBlock Value

The MBlock Value contains the data. The byte order for the data is least significant byte first. The interpretation of the data depends on the applied MBlockID (see Q.3.6.2).

The MBlock Value is not present if the MBlockLength is 0.

Q.3.2.4 MAC Payload

The MAC Payload of variable length contains the LLC-layer and upper protocol layers. It starts with Logical Link Control (see Q.4).

Q.3.2.5 MAC CRC

The MAC CRC is a 32-bit CRC covering the MAC Header, MAC Body and MAC Payload.

The CRC polynomial is:

$$x^{32}+x^{31}+x^{30}+x^{29}+x^{28}+x^{26}+x^{23}+x^{21}+x^{19}+x^{18}+x^{15}+x^{14}+x^{13}+x^{12}+x^{11}+x^{9}+x^{8}+x^{4}+x+1$$

($1F4ACFB13_h$) (Eq.Q.56)

The initial value is 0. The final CRC is not complemented.

In deviation to the usual transmission order of multi byte fields the MAC CRC shall be transmitted with MSB first.

Q.3.3 MAC Frame Types

Q.3.3.1 Overview

The message exchange between the NW-Manager and the OMS end-device is controlled by the MAC Frame type. The MAC Frame type defines:

- the applied direction (up- or downlink),
- the meaning of the frame and the MAC Body,
- and whether a response is expected.

The coding of MAC Frame types is defined in Table Q.74.

Table Q.74 – MAC Frame types

Bits of MFT-field	Sym-bol	Frame Name	Direction	LLC present	Usage
0000_b	MSNR	MAC Send-No-Reply	Uplink	Yes	Send unsolicited MAC data, no reply (see Q.3.3.2.3)
0001_b	MRSP	MAC Response	Uplink	Yes	Send response to command (MCMD), (see Q.3.3.2.4)
0010_b	MERR	MAC Error	Uplink	Yes	Send Error response to invalid command (MCMD) (see Q.3.3.2.4)
0011_b to 0111_b					Reserved for future use
1000_b	MACC	MAC Access	Uplink	Yes	Access frame (see Q.3.3.2.1)
1001_b	MACK	MAC Acknowledge	Uplink	No	Acknowledge frame (see Q.3.3.2.2)
1010_b to 1011_b					Reserved for future use
1100_b	MCNR	MAC Command-No-Reply	Downlink	Yes	Command, no reply (see Q.3.3.3.1)
1101_b	MCMD	MAC Command	Downlink	Yes	Command, response expected (MRSP) (see Q.3.3.3.1)
1110_b to 1111_b					Reserved for future use

Q.3.3.2 UL-MAC-Frame types

Q.3.3.2.1 MACC

The MAC frame type MACC is used by the OMS end-device to provide an additional access slot to the gateway (See Appendix Q.J.4).

The delay of the MACC after session interrupt can be configured with the MBlockID 12h (see Table Q.103). If configured, the OMS end-device shall provide a MACC when a bidirectional session is interrupted (see Q.3.3.5).
The OMS end-device may also send MACC unsolicited outside of a communication session. Alternatively, the NW-Manager can request an extraordinary transmission of a MACC with the MBlockID 03h (see Table Q.95) to start a new session after a certain time.

To save energy the MACC should be transmitted without upper protocol layers.

The MACC shall provide the Link Layer Control (see Q.4) with address information of the transmitter.

Q.3.3.2.2 MACK

MACK is only used for Burst Mode in the case of Multi-burst.

This MAC Frame type is used only during a bidirectional communication session. If a gateway receives the last uplink message successfully, it will respond within the next downlink slot.

If the downlink transmission is successfully finished in the early reception slots RX3, RX4 or RX5 then the OMS end-device skips the transmission of the remaining UL-bursts and transmits in the remaining slots, TX1 / TX2, a MACK frame. This MACK frame acknowledges, to the gateway, the successful reception of the last downlink message, so that transmission of the remaining bursts in RX4, RX5 respectively in RX0, RX1, RX2 can be skipped.

If the downlink transmission was not completed in the reception slots RX3, RX4 or RX5 but the last uplink transmission was successful then the OMS end-device should skip the transmission of the remaining bursts. A successful uplink prior to a downlink can be recognized by the OED with at least the correct reception of the coded header within one downlink burst. The gateway shall in this situation continue to transmit the remaining downlink bursts.

The MACK shall be transmitted as Single-burst preferably with FEC coding rate 1/3 for improved reception probability. The only purpose of the MACK is to inform the gateway about the successful reception of the downlink. The MACK shall not provide an Access Opportunity.

NOTE: Sending MACK instead of the individual burst containing application data will save energy in the OMS end-device twice. The transmission in the uplink direction becomes significantly shorter. In addition, after the MACK transmission the remaining reception windows for the downlink bursts need no longer to be served. The next transmission will in this case be the subsequent uplink burst.

The MACK shall not be used together with upper protocol layer in the MAC Payload.

The MACK should neither provide Link Layer Control nor address information. It is identified by the correct transmission timing (see Q.2.4.6.2).

Q.3.3.2.3 MSNR

If the transmission is initiated from OMS end-device, then it uses the MAC Frame type MSNR. The OMS end-device may provide an MSNR either piggybacked with upper protocol layer data or with MAC layer data only.

This transmission may contain only MElements or additionally a MAC Body with MDerCounter and/or MBlocks. If there is an MDerCounter or any MBlock requiring a secured transmission, then the MAC Body is secured. This is indicated with setting the flag Security Present (SP) in MBCTL[0]. Otherwise, the MSNR frame is not secured.

MSNR should also be used for upper protocol layer UL-messages without any MAC information.

The MSNR shall provide the Link Layer Control (see Q.4) with address information of the transmitter.

Q.3.3.2.4 MRSP and MERR

If the MAC Layer of the OMS end-device receives a MAC Frame type MCMD (command) then it shall provide a response. If the security verification of an MCMD fails (see Q.3.4.6) or an unsupported MSP (see Q.3.4.5.2) is received, the OMS end-device will respond with MERR to signal a security problem. Such MERR-Frame shall not contain a MAC-Body and therefore no secured information. When receiving such invalid command for the first time in a communication sequence the OMS end-device may ignore further such commands until the next valid secured MCMD has been received.

NOTE 1: Secured data in an MERR frame are not allowed to avoid the manipulation of the MMsgCounter.

NOTE 2: An OMS end-device that does not provide MAC layer services will interpret a secured MCMD as a security problem and will therefore respond with MERR.

If the security verification of the MCMD pass then the OMS end-device shall response with a MAC Frame type MRSP, even if the execution of the command fails (see Q.3.3.4.3).

The MAC Frame type MRSP always applies a secured transmission of data.

The MRSP and MERR shall provide the Link Layer Control (see Q.4) with address information of the transmitter. Optionally the receiver address can additionally be requested in the preceding downlink (see RRX-bit in Q.4.2.2).

Q.3.3.3 DL-MAC-Frame types

Q.3.3.3.1 MCMD and MCNR

The NW-Manager can send commands with an MDerCounter and/or MBlocks to the OMS end-device. If the NW-Manager expects a response, then it shall use MAC Frame type MCMD. Otherwise, it uses the MAC Frame type MCNR.

Commands containing an MDerCounter and/or MBlock always apply a secured transmission.

MCNR should also be used for upper protocol layer DL-messages without MAC information.

The MCMD and MCNR shall provide the LLC with address information of the receiver in the M2-Field and A2-Field (see Q.4.2.6 and Q.4.2.7).

If the RRX-bit in LC[0] is set to 1, the M-field and A-field is also required (see Q.4.2.2).

Q.3.3.4 MBlocks in different MAC Frame types

Q.3.3.4.1 Overview

The meaning of the MBlock (see Q.3.6) depends on the applied MAC Frame type (see Q.3.3.1). It can be a:

- Command (in case of MAC Frame Type MCMD and MCNR) or
- Response (in case of MAC Frame Type MRSP) or
- Unsolicited uplink data (in case of MAC Frame Type MSNR).

Q.3.3.4.2 Command

A command (MCMD and MCNR) sending an MBlock without any MBlock Value field (MBlockLength=0) is to be considered as request (GET) to provide data with the same MBlockID (Get-command).

If the MBlock Value is present (MBlockLength>0) then the attached value shall be written (SET) as parameter in the OMS end-device (Set-command).

NOTE: Multiple MBlocks can be applied in parallel within a command.

Q.3.3.4.3 Response

If an OMS end-device receives a command with a response request (MAC Frame type MCMD) containing an MDerCounter and/or one or several MBlocks and it could execute the command successfully, then it will, in the next transmission, respond (using MAC Frame type MRSP), containing all MBlocks with the same MBlockID as in the command. Additionally, it provides the MBlock Value field containing the requested data (in case of a Get-command) or the written data (in case of a Set-command).

If the command execution of an MBlock fails or the MBlock is not supported, the OMS end-device will still provide the MBlock with the MBlockID but no MBlock Value field (MBlockLength=0).

If an MBlock of a command is corrupt (e.g. MBodyLength check failure) all MBlocks of the MBody shall be discarded and the response provided shall be a secured MBody without any MBlocks. Upper layers shall not be affected.

NOTE 1: Commands (with MAC Frame type MCMD) rejected by invalid security settings will not provide a MAC Frame type MRSP (see Q.3.3.2.4).

NOTE 2: If the command uses MAC Frame type MCNR, then the command is executed silently. There will be no notification about the success. The result might be included in the next unsolicited OMS end-device transmission (e.g. when uplink parameters have been changed).

Q.3.3.4.4 Unsolicited Uplink Data

The OMS end-device may provide one or several MBlocks unsolicited with MAC Frame type MSNR. The coding of such MBlocks is identical to MBlocks in an MRSP frame.

Q.3.3.5 Downlink Communication Session

In exception to the definition of [OMS-S2], 4.3.3.3 OMS end-devices according to this annex shall not apply the Frequent access cycle. Instead, a downlink communication session is used.

If the OMS end-device receives a valid downlink message, it enters the downlink communication session. The session ends either if it is closed or by timeout.

The last frame sent down to the OMS end-device within a downlink communication session shall be indicated with a set Session Control bit (SC) in MElement_DA (see Table Q.89). All other DL-frames shall use a cleared SC-bit. If the OMS end-device receives a set SC-bit it closes the downlink communication session after transmitting the respective response, if any. If this transmission of the respective response fails, the response cannot be requested anymore. The status of the command processing is unclear in that case.
NOTE 1: To avoid an unclear processing state, the SC-bit should be set in a final empty command without response, e.g. a MAC frame type MCNR with potentially an LLC-frame SND-NKE.

NOTE 2: Closing a session means the OMS end-device performs the same actions as if it had received an SND-NKE message.

If the downlink communication session is interrupted before a downlink message with a set SC-bit is received, then the OMS end-device shall provide a MACC (see Q.3.3.2.1) if configured accordingly (see Table Q.103). If even no further downlink messages of the communication partner are received in the reception windows after this MACC transmission, then the downlink communication session has ended by timeout.

Q.3.3.6 Uplink Communication Session

An OMS end-device can provide more than one uplink frame in its nominal transmission interval if needed. This can be beneficial if the uplink message needs a fragmentation or if messages with different content shall be transmitted in a row of uplink transmissions. The OMS end-device will signal the uplink communication session to the gateway with the bits UL-SC in the MElement_UA (see Table Q.80). The last transmission of the uplink session will indicate that the session is over.

An example of an uplink communication session for a Burst Mode applying Multi-burst is shown in Figure Q.26.

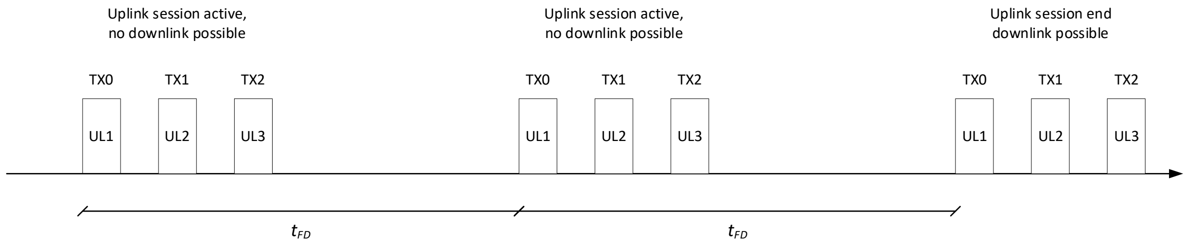

Figure Q.26 – Example for uplink communication session

As this is a pure uplink function of the OMS end-device it can be applied by unidirectional and bidirectional devices. Bidirectional devices can not provide a downlink access during an active uplink session. The last of such uplink transmissions will indicate that the session is over and can then (if wanted) provide downlink access. This means in general the uplink communication session will always be in front of a bidirectional communication session.

Table Q.75 – Uplink Session Control (UL-SC)

UL-SC (Bit 4 to Bit 3 of MElement_UA)	Frame distance time t_{FD} [seconds]		
	Burst Mode		Splitting Mode
	Single-burst	Multi-burst	
00	No uplink session		
01	$1 \cdot t_{RO}$ [a]	$3 \cdot t_{burst}$ [b]	$3 \cdot t_{RO(RTO\#5)}$ [c]
10	$3 \cdot t_{RO}$ [a]	$6 \cdot t_{burst}$ [b]	$6 \cdot t_{RO(RTO\#5)}$ [c]
11	$6 \cdot t_{RO}$ [a]	$9 \cdot t_{burst}$ [b]	$9 \cdot t_{RO(RTO\#5)}$ [c]

[a] According to Table Q.22 using the t_{RO} for fast response delay
[b] According to Table Q.21 respecting the spacing values that are provided in the coded header (see Table Q.12)
[c] According to Table Q.84

The uplink communication session applies a predictable timing between the uplink frames. This enables e.g. a battery driven gateway to close the reception window after the first transmission and to reopen it in time for the next uplink of this session. This so-called frame distance time t_{FD} is always measured between the reference time point T_0 (see Q.2.4.6.5.2 and Q.2.5.6.4.2) of the first uplink frame to T_0 of the following frame (see Table Q.75). The frame distance time shall not be changed during an uplink communication session.

An uplink communication session shall be finished before the next synchronous transmission starts (see Q.2.4.6.4 and Q.2.5.6.3).

The tolerance of t_{FD} shall be according to Q.2.4.6.3 for Burst Mode and equal to the tolerance of t_{RM} as shown in Table Q.47 for Splitting Mode.

Q.3.4 MAC Security

Q.3.4.1 Principles

The MAC layer security includes the usage of a dedicated MAC key. The MAC key-based security protects only the parameters of the MAC Body. It does not secure the LLC-layer and upper protocol layers provided in the MAC Payload or the MAC CRC. Due to this the upper protocol layers must apply their own security measures such as transport layer security or application layer security.

The parameters which are essential for the communication are contained in the mandatory MAC Header. Due to this the MAC Header is neither encrypted nor authenticated. All other parameters are contained in the optional MAC Body.

The parameters of the optional MAC Body are classified according to their relevance into privileged and non-privileged. This classification is marked with the Security-flag checkbox in the definition of each MBlock (see Q.3.6). The privileged parameter, e.g. MBlocks with Security-flag marked, are secured by a message authentication code (named as MMAC) to ensure integrity and authenticity. In addition, they are encrypted to ensure confidentiality. The non-privileged parameters, e.g. MBlocks with Security-flag not marked, require no security i.e. neither encryption nor authentication.

If the MAC Body contains at least one privileged parameter, then the encryption and authentication is applied to all MAC Body parameter. In a MAC command (MCMD) or MAC response (MRSP) frame all MAC Body parameters are encrypted and authenticated independent of their classification.

The bit Security Present (SP) in the sub-field MBCTL[0] of the MAC Body indicates if a MAC frame is secured.

The MAC CRC covers all MAC layer fields i.e. MAC Header, MAC Body and MAC Payload to provide consistency (see Q.3.2.5). The MAC layer security provides a method to protect against replay attacks. To achieve a limited lifetime of the encryption and authentication key an ephemeral key is derived from the MAC key.

The Table Q.76 shows security methods applied to MAC layer fields to explain the principle of the MAC layer security.

Table Q.76 – MAC layer security principle

Field	MAC Header	MAC Body	MAC Payload	MAC CRC
Encryption	No	Conditional [a]	No	No
Authentication	No	Conditional [a]	No	No
[a] Yes in case at least one MBlock with Security-flag required present or MAC Body present in MAC command or MAC response; No in all other cases				

Q.3.4.2 Key Definitions

Q.3.4.2.1 MAC Key

In accordance with the predefined OMS-KeyIDs defined in [OMS-S2], 9.2 these persistent symmetric AES keys are used for the MAC layer:

- MAC key with KeyID 0Fh to provide the MAC layer security
- Communication security wrapper key for the key update of the MAC key acc. to definition in [OMS-S2], 9.2

Q.3.4.2.2 MDerKey

The persistent MAC key defined in chapter Q.3.4.2.1 is intended to be used by an operator for a long validity time. To give the operator means to limit the lifetime of the applied key and to perform an easy key update the ephemeral key MDerKey is used for encryption and authentication. The symmetric AES-128 MDerKey is derived with the key derivation function defined in chapter Q.3.4.5.1 from the persistent MAC key. The key update of the MDerKey is done by providing a new valid key derivation counter to the device (see Q.3.4.3.1).

Q.3.4.3 Counter Definitions

Q.3.4.3.1 Key Derivation Counter

The key derivation function KDF described in chapter Q.3.4.5.1 applies the persistent key derivation counter MDerCounter which has a size of one byte to generate a new ephemeral key, MDerKey. The initial value of MDerCounter in the OMS end-device shall be 0. After an update of the persistent MAC key the OMS end-device shall re-set the MDerCounter to 0.

As the MDerCounter is an input for the MAC layer security it is only allowed in secured MAC messages where it can be optionally contained.

For an update of the MDerKey the communication partner provides a new MDerCounter to the OMS end-device within the secured MAC command MCMD. This secured MAC command shall apply the new MDerKey based on this new MDerCounter and shall contain the new CMD-MMsgCounter to be stored in the OED (see Q.3.4.3.2.3). The OMS end-device accepts the provided MDerCounter only if the received value is higher than its current value. If the received value is accepted, then the OMS end-device shall use it for the derivation of a temporary valid MDerKey. If the security verification with this temporary MDerKey according to chapter Q.3.4.6 is successful, then the received MDerCounter and CMD-MMsgCounter are accepted and updated into the OMS end-device. In addition, the OMS end-device re-sets the SNR-MMsgCounter (see Q.3.4.3.2.2) to 0. As the confirmation of a successful update the OMS end-device responds with a secured MRSP which shall contain the new updated MDerCounter. In case of an invalid MDerCounter or a failed security verification the OMS end-device shall respond with an MERR according to chapter Q.3.4.7. The new updated MDerCounter value shall be applied to derive a new MDerKey used for all further secured MAC commands and their responses. Due to this handling the OMS end-device shall not autonomously increment the MDerCounter.

The MDerCounter shall not roll over. If the MDerCounter has reached its maximum i.e. 255 a key update of the MAC key should be done which causes the re-set of the MDerCounter to 0.

The MDerCounter is intended to be updated on a regular basis. It shall provide a limited lifetime and an easy key replacement of the MDerKey. Due to its limited size of one byte, it is recommended not to be incremented too often e.g. not after every usage in a secured frame.

For a valid update of the MDerCounter value the communication partner shall know the current value of the OMS end-device. As there is no dedicated unsecured MAC command to request this value from the OMS end-device it should be sent on a regular basis in a secured unsolicited uplink frame MSNR . It is recommended to provide it twice a day.

Q.3.4.3.2 Message Counter

Q.3.4.3.2.1 MMsgCounter

The MAC security uses the counter provided by the field MMsgCounter in the MAC Body to make the message unique and to avoid replay attacks. The MMsgCounter contains the two different counters depending on the frame type. These two counters are the SNR-MMsgCounter and the CMD-MMsgCounter with the length of two bytes each.

As the MMsgCounter is an input for the MAC layer security it is only allowed to be contained in a secured MAC message. It is mandatory for secured MAC messages.

Q.3.4.3.2.2 SNR-MMsgCounter

The persistent SNR-MMsgCounter is included in an unsolicited uplink frame. It is mandatory in the unsolicited secured uplink frame MSNR. It is not allowed to send it in an unsecured MAC frame in any other MAC frame type.

The initial value of the SNR-MMsgCounter in the OMS end-device shall be 0. After an update of the persistent MAC key or after the derivation of a new MDerKey the OMS end-device shall re-set the SNR-MMsgCounter to 0 (see Q.3.4.3.1).

The OMS end-device shall increment the SNR-MMsgCounter by 1 prior to generating a new authenticated and/or encrypted MAC message, MSNR. The receiving instance can identify with the SNR-MMsgCounter if an unsolicited uplink frame is re-sent.

When the SNR-MMsgCounter reaches the maximum value, it shall not roll over with next increment. The OMS end-device is not allowed to generate a new MSNR message because thus may cause security issues. For this reason, either the MAC key or the MDerKey should be updated before the counter reaches its maximum value.

If the SNR-MMsgCounter reaches its maximum value, then a bidirectional OMS end-device should add the MDerCounter to the MSNR message to provide the other device the current MDerCounter value which is of interest for a new MDerKey derivation.

In a unidirectional device no MAC key or MDerKey update is possible. Therefore, the transmission interval of the MSNR must be selected in such a way that during the lifetime of the OMS end-device the maximum value of the SNR-MMsgCounter is not reached.

The SNR-MMsgCounter must not be incremented with every unsolicited uplink frames. A secured MSNR frame with a repeated MAC Body content should not increment the SNR-MMsgCounter. If no MAC Body is present in a MSNR frame, then the OMS end-device shall not increment the SNR-MMsgCounter.

Q.3.4.3.2.3 CMD-MMsgCounter

The persistent CMD-MMsgCounter is included into MAC commands and their response. It is mandatory within secured commands (MCMD and MCNR) and secured responses (MRSP). It shall not be used in other MAC Frame types.

The initial value of the CMD-MMsgCounter in the OMS end-device shall be 0. After an update of the persistent MAC key the OMS end-device shall set the CMD-MMsgCounter to 0. After the derivation of a new MDerKey the OMS end-device shall set the CMD-MMsgCounter to the value received in the secured MAC message (see Q.3.4.3.1).

The NW-Manager is responsible for the CMD-MMsgCounter and shall increment it by 1 prior to generating an encrypted and authenticated MAC message. When the OMS end-device receives a secured MAC command from the communication partner, then the received value of the CMD-MMsgCounter shall be verified (see Q.3.4.6).

The OMS end-device shall only accept the messages if the received CMD-MMsgCounter value is higher than the current stored value. In case of an invalid CMD-MMsgCounter or a security verification error the OMS end-device shall respond with an MERR according to chapter Q.3.4.7. In case the verification is passed the current value shall be updated in the OMS end-device to the received value CMD-MMsgCounter. This updated CMD-MMsgCounter is used for encryption and/or authentication of the MRSP response.

The OMS end-device can verify with the CMD-MMsgCounter that the MAC command is not replayed. If the OMS end-device receives MAC command with the same CMD-MMsgCounter before the session timeout (see Q.3.3.5) then this MAC command is identified as a repetition. In this case, the command shall not be executed again. In case of an MCMD frame, the stored response frame MRSP or MERR shall be retransmitted.

Before the CMD-MMsgCounter reaches the maximum value either the MAC key or MDerKey should be replaced. The communication partner should initiate this key replacement before the CMD-MMsgCounter rolls over as a roll over is not accepted by the OMS end-device. If the other device did not trigger the key replacement in time and the CMD-MMsgCounter has reached its maximum, then no further derivation of an MDerKey is possible because no new MDerCounter can be sent to the OMS end-device. In this case only a key update of the MAC key can be done.

Before CMD-MMsgCounter reaches its maximum the OMS end-device should add the MDerCounter to the MSNR message to provide the other device the current MDerCounter value which is of interest for a new MDerKey derivation.

The CMD-MMsgCounter in the OMS end-device needs to be in synchronization with the one managed by the NW-Manager. As there is no dedicated unsecured MAC command to request the CMD-MMsgCounter from the OMS end-device it should be sent in the secured unsolicited uplink frame MSNR twice a day. Synchronization can be achieved by an update of the MAC key or the MDerKey.

Q.3.4.4 Secured Data

From the MAC fields only the MAC Body but not the MAC Header, MAC Payload or MAC CRC are secured.

If the Security-flag of an MBlock is set (see Q.3.6), the MBlock shall be transmitted secured. If there is at least one secured MBlock present in a frame, then all other MBlocks shall be also secured even if the sub-field Security-flag is not marked. In a MAC command and MAC response all MBlocks shall be secured i.e. independent of the corresponding Security-flag.

All MBlocks in the MAC Body of a secured frame shall be encrypted and authenticated (see red fields in Table Q.77). The MBCTL, MDerCounter and MMsgCounter of the MAC Body shall be unencrypted but authenticated (see green fields in Table Q.77). The MMAC (see yellow field in Table Q.77) is encrypted depending on the selected security profile (see Q.3.4.5.2).

Table Q.77 – Encrypted and Unencrypted Data

Field	MAC Body						
Sub-Field	MBCTL [a]	MDerCounter	MMsgCounter	MMAC	MBlock 1	...	MBlock N
Encrypt	No	No	No	conditional	Yes	Yes	Yes
[a] MBCTL is MBCTL[0] and optionally additionally MBCTL[1]							

Q.3.4.5 Security Mechanisms

Q.3.4.5.1 Key Derivation Function

The key derivation function shall apply the CMAC function according to [RFC4493]. It is used to derive the MDerKey from the persistent MAC Key. There are these input values for the KDF:

- MAC Key
  according to chapter Q.3.4.2.1
- MDerCounter
  according to chapter Q.3.4.3.1
  The key derivation counter MDerCounter is a dynamic input value to generate a new key.
- M-field of the OMS end-device or radio adapter taken from LLC-layer (see Q.4)
  This is the 2 byte Manufacturer ID with LSB first.
- ID of the OMS end-device or radio adapter taken from LLC-layer (see Q.4)
  This is the 4 byte identification number with LSB first.
- Padding
  The remaining bytes of the 16 byte block are filled with a padding sequence. The padding is fixed and consists of nine octets each containing the value of 0x09.

The calculation of the ephemeral key MDerKey shall be done as follows:

MDerKey =
CMAC (MAC Key, MDerCounter || M-field || ID || 09_h || 09_h || 09_h || 09_h || 09_h || 09_h || 09_h || 09_h || 09_h)

Q.3.4.5.2 Security Profile

The security algorithm which shall be applied for encryption and authentication is defined by a MAC security profile, MSP. The applied security profile is declared in the subfield MSP of MHCTL[1] (see

Q.3.2.2.2). If MHCTL[1] is not present in the MAC Header then the default security profile MSP1 shall be used.

The Table Q.78 shows the definition of the MAC security profiles.

Table Q.78 – MAC Security Profiles

Profile	Encryption	Authentication	Key
MSP1	AES-128-CCM (Q.3.4.5.3)	CCM (CBC-MAC with 4 Byte length)	128 bit ephemeral key (derived from key derived from persistent key with KeyID acc. to Q.3.4.2.1)

Q.3.4.5.3 Security Mechanism AES-128-CCM

Q.3.4.5.3.1 General

The MAC security is based on a symmetric AES-128 key for authentication and encryption. The CCM is used to provide assurance of the confidentiality and the authenticity of data by combining the techniques of the Counter mode encryption and the Cipher Block Chaining-Message Authentication Code (CBC-MAC) algorithm. The CCM calculates the CBC-MAC for authentication over the CCM payload and CCM associated data and encrypts the authenticated CCM payload and the CBC-MAC with a CTR cipher algorithm.

The CCM mode shall be implemented as defined in the NIST recommendations for block cipher modes of operation, according to [NIST 800-38C].

Q.3.4.5.3.2 CCM-Counter

The CCM Counter uses the counter provided by the field MMsgCounter in the MAC Body. It is the variable input for the nonce of the CCM.

Q.3.4.5.3.3 Authentication Tag

This security mechanism applies an encrypted Authentication Tag in the MMAC field. The length of the MMAC is defined by the MAC security profile according to chapter Q.3.4.5.2.

Q.3.4.5.3.4 CCM Key

For the CCM specification refer to [NIST 800-38C], Clause 6.

The CCM-key, K, is defined by the MDerKey according to chapter Q.3.4.2.2.

Q.3.4.5.3.5 CCM Payload

For the CCM specification refer to [NIST 800-38C], Clause 6.

The payload, P, is set to the encrypted data. According to chapter Q.3.4.4 the encrypted data is the concatenation of the following fields:

MAC-Body.MBlock 1 || …|| MAC-Body.MBlock N

Q.3.4.5.3.6 CCM Associated data

For the CCM specification refer to [NIST 800-38C], Clause 6.

The associated data, A, is set to the unencrypted fields. According to chapter Q.3.4.4 the data to be unencrypted is the concatenation of the following fields:

MBCTL || MDerCounter

Where MBCTL is MBCTL[0] || [MBCTL[1]. If the optional MBCTL[1] is not present then it is not used.

NOTE: The MMsgCounter is authenticated by party of the CCM Nonce. Therefore, it is not part of the CCM associated data.

Q.3.4.5.3.7 CCM Nonce

For the CCM specification, refer to [NIST 800-38C], Clause 6.

The length, n, of the nonce, N, is fixed to 13 bytes. The nonce is specified in the next Table Q.79.

Table Q.79 – Structure of the nonce

12	11	10	9	8	7	6	5	4	3	2	1	0
Manufacturer (LSB first)		Identification Number (LSB first)				Version	Device Type	Usage	00_h	00	MMsgCounter (MSB first)	

With:

- Manufacturer: Manufacturer ID of OMS end-device or radio adapter taken from LLC-layer (see Q.4).
- Identification Number: Identification Number of OMS end-device or radio adapter taken from LLC-layer (see Q.4).
- Version: Version of OMS end-device or radio adapter taken from in LLC-layer (see Q.4).
- Device Type: Device Type of OMS end-device or radio adapter taken from in LLC-layer (see Q.4).
- Usage: This field shall ensure a different nonce.
  - BIT7- BIT2: 000000_b
  - BIT1: Type of the MMsgCounter
    0_b: SNR-MMsgCounter
    1_b: CMD-MMsgCounter
  - BIT0: Direction
    0_b: Uplink
    1_b: Downlink
- MMsgCounter: either CMD-MMsgCounter or SNR-MMsgCounter

Q.3.4.6 Security Verification

For each received frame the security must be verified. For the security verification of a secured frame the MMAC and the received MBlocks are validated. In an unsecured frame it is checked that no data are contained which require security (see Q.3.4.4). The OMS end-device verifies that the mandatory CMD-MMsgCounter and optional MDerCounter received within the MBody are valid (see Q.3.4.3.2.3 and Q.3.4.3.1).

In case one of these verification fails the OMS end-device shall behave as described in chapter Q.3.4.7.

The receiving instance shall detect with the SNR-MMsgCounter that the unsolicited uplink frame is re-send. Duplicate or old frames shall be not accepted. In the response message to a secured command the receiving instance shall verify a valid value of the CMD-MMsgCounter.

Q.3.4.7 Security Error Handling

In case the OMS end-device receives a MAC command for which the security verification (see Q.3.4.6) fails then this frame is identified as invalid. An invalid MAC command is not processed and the received CMD-MMsgCounter and MDerCounter will not be updated in the OMS end-device. In case the invalid MAC command requires a response then the short error message MERR is sent according to Q.3.3.2.4.

Q.3.5 MAC Element

Q.3.5.1 General

The MAC Elements (MElements) provide the possibility for flexible timing options mainly for bidirectional communications. With this an optimized communication can be achieved for any kind of use case or situation. The MElements especially respect the different hardware situation of OMS end-devices and allows optimized usage of the respective power supply or the capacity. They are composed in a way to limit the needed number of bytes and their definition is independent per direction of communication, uplink or downlink.

Q.3.5.2 Uplink MElements

A number of uplink MElement bytes are defined and named MElement_UA, MElement_UB, MElement_UC etc. Each MElement can include a condition to be applied as the next MElements byte as shown in Figure Q.27.

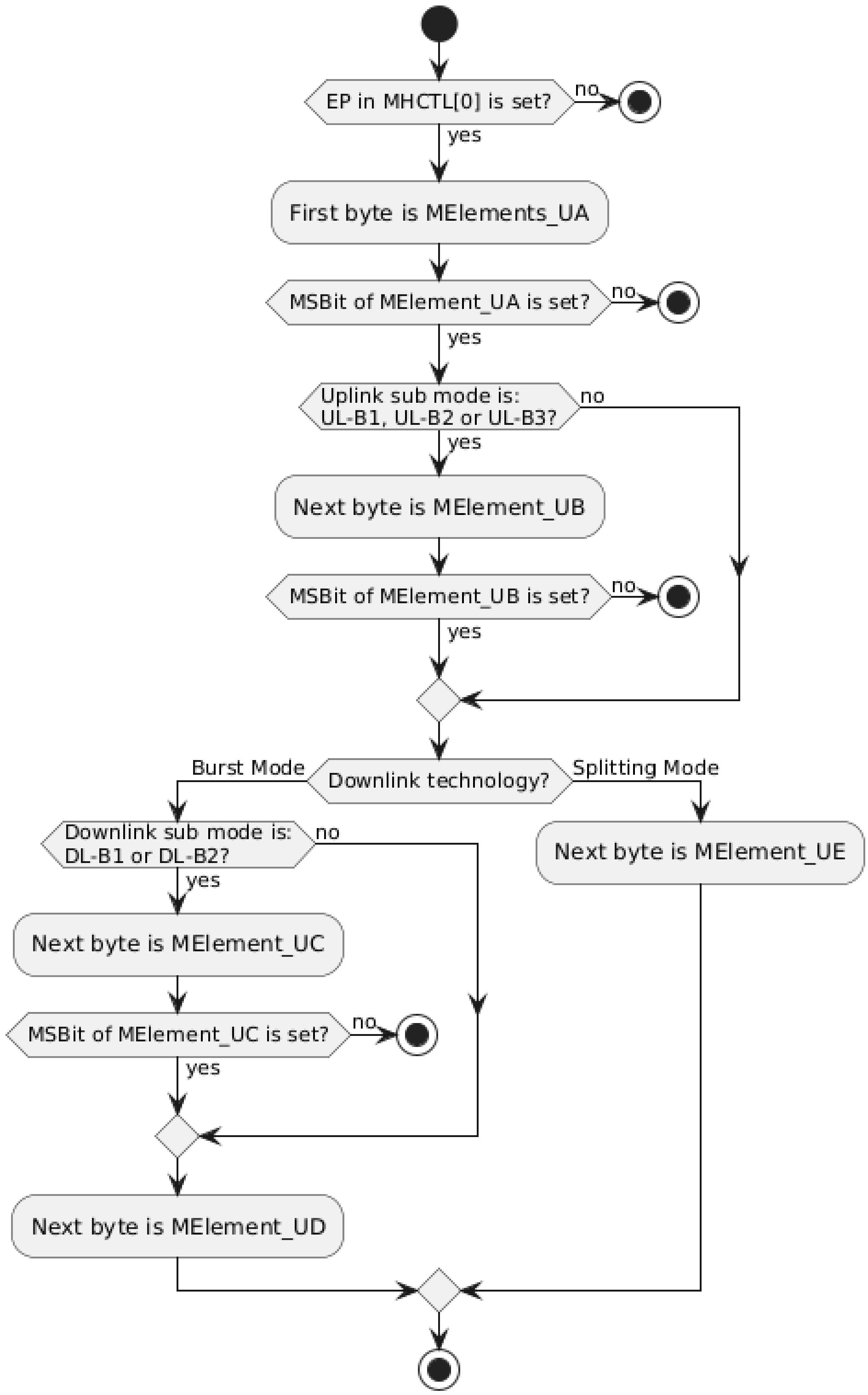

Figure Q.27 – Order of uplink MElement bytes

The individual uplink MElement bytes are defined in the following subclauses.

Q.3.5.2.1 Uplink MElement, MElement_UA

If MElements are enabled in the MHCTL[0]-byte, this byte is the mandatory first byte (see Table Q.80). Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.80 – Definition of MElement_UA-field

Bit	Symbol	Name	Description
7	XP	Extension Present	If the bit is set, an additional MElement byte follows.
6	LMS	Link management state	0: Frame represents current link management state. 1: Frame does not represent current link management state.
5	DL-T [a]	Downlink technology	0: Downlink Burst Mode 1: Downlink Splitting Mode
4	DL-SM / UL-SC	Downlink sub-mode	If DL-AC >= 2: 0: DL-B1 / DL-S1 (dual channel [b]) 1: DL-B2 / DL-S2 2: DL-B3 / DL-S3 3: DL-B4 / DL-S4
3		Uplink session control	If DL-AC < 2: See Table Q.75
2	DL-AC	Downlink accessibility	0: No access 1: Temporary no access 2: Access option #1 [c] 3: Access option #2 [c] 4: Access option #3 [c] 5: Access option #4 [c] 6: Access option #5 [c] 7: Access option #6 [c]
1			
0			

[a] If no bidirectionality (DL-AC < 2), this sub field is set to 0 and ignored in the gateway.
[b] A Splitting Mode OMS end-device in dual channel mode (see Table Q.6) shall always choose DL-SM = 0 (see also Table Q.50).
[c] See Table Q.81 for Burst Mode and Table Q.83 for Splitting Mode.

An OMS end-device that is link managed by a gateway respectively a NW-Manager will maintain the UL state decided by the uplink algorithm in the NW-Manager (see Q.3.7.1). If the OMS end-device transmits UL frames with transmission parameters diverting from those defined by its uplink state, the LMS bit shall be set to 1 indicating to the NW-Manager that those frames, when received, shall not be taken into consideration for UL link management. An OMS end-device that does not support any link management functions shall nevertheless set this bit per default to 0.

Q.3.5.2.1.1 Access option – Burst Mode

The Table Q.81 shows the access options for Burst Mode.

Table Q.81 – Access option – Burst Mode

Access option	Access	Additional listening window	Downlink Multi-burst enabled	Default Response timings (Table Q.82)	Default downlink maximum receive duration, DL-RXM	
					UL-B1, UL-B2, UL-B3	UL-B4
#1	Limited	No	No [a]	#2	400 ms	75 ms
#2	Limited	Yes	No [a]	#2	400 ms	75 ms
#3	Limited	No	Yes	#2	300 ms	50 ms
#4	Limited	Yes	Yes	#2	300 ms	50 ms
#5	Unlimited [b]	N/A	No [a]	N/A	Unlimited	Unlimited
#6	Unlimited [b]	N/A	Yes	N/A	Unlimited	Unlimited

[a] In case of Downlink Single-burst, the OED shall support all three FEC coding rates (see also Q.2.4.3.2).
[b] An OED with unlimited access shall support all three t_{RM} options.

The Table Q.82 shows the response timing options for Burst Mode.

Table Q.82 – Response timings t_{RO} and t_{RM} – Burst Mode

Response timing option	Response delay t_{RO}	Minimum response-to-uplink delay t_{RM}
#1	Fast	Fast
#2	Fast	Medium
#3	Fast	Slow
#4	Medium	Fast
#5	Medium	Slow
#6	Slow	Fast
#7	Slow	Medium
#8	Slow	Slow

If an OMS end-device wants to apply slow or medium response delay or wants to apply another value for either the minimum t_{RM} or the DL-RXM than the default values of Table Q.81, such specific information shall be added in MElement_UD. These settings are only valid for the following downlink (t_{RO}) respectively the following uplink (t_{RM}).
The minimum response-to-uplink delay signals the minimum response-to-uplink time that the OMS end-device can guarantee for predictable response-to-uplink delay. The NW-Manager can instruct the OMS end-device in MElement_DA to apply a specific response-to-uplink delay that fulfils this minimum response-to-uplink delay.

If the NW-Manager does not request a specific value with the help of the MElement_DA (see Table Q.89) the OMS end-device is free to select any t_{RM} value up to the maximum response-to-uplink delay.

Q.3.5.2.1.2 Access option – Splitting Mode

The Table Q.83 shows the access options for Splitting Mode.

Table Q.83 – Access option – Splitting Mode

Access option	Access	Downlink Sub-Mode	Default response timings (Table Q.84)	TSI (5 Bit)	TDN (4 Bit)	THB (3 Bit)
#1[a]	Limited	DL-S1, DL-S2	n. a.	n. a.	n. a.	n. a.
		DL-S3	#4	11111	1111	111
		DL-S4	#3	00000	0000	000
#2[b]	Limited	DL-S1, DL-S2	#4	10001	1010	110
		DL-S3	#3	00010	0110	010
		DL-S4	#2	00000	0000	000
#3[c]	Limited	DL-S1, DL-S2	#3	00001	0000	000
		DL-S3	#2	00001	0000	000
		DL-S4	#1	00000	0000	000
#4[d]	Limited	DL-S1, DL-S2	#2	00000	0000	000
		DL-S3	#1	00000	0000	000
		DL-S4	#1	00000	0000	000
#5	RFU	RFU	RFU	RFU	RFU	RFU
#6	Unlimited	RFU	RFU	RFU	RFU	RFU

[a] Optimized for devices with limited hardware possibilities (e.g. 860 uF Elko). Only DL-S3 and DL-S4 possible in combination with any Burst Mode uplink
[b] Optimized for devices with medium hardware possibilities (e.g. 2160 uF Elko)
[c] Providing compatibility to [ETSI 103 357]
[d] Optimized for devices with sophisticated hardware (e.g. with HLC – Hybrid Layer Capacitor)

With the help of the access options, the OMS end-device informs about its default timings for a 2-way session depending on the intended downlink sub-mode (DL-SM, see Table Q.80). The response timing options are defined in Table Q.84. The default response timings shall be applied unless the OMS end-device offers other timings with help of MElement_UE (see Table Q.88).

The minimum downlink timings of the core frame (TSI, TDN, THB, see Table Q.45) are also provided with help of the access option. The OMS end-device shall select the access option where it complies to. The NW-Manager is free to choose higher values (resulting in more relaxed timings) in its downlink core frame.

Table Q.84 – Response timings t_{RO} and t_{RM} – Splitting Mode

Response timing option (RTO)	Response delay t_{RO} in seconds (rounded) [a]	Minimum response-to-uplink delay t_{RM} in seconds [a]
#1	0,860	0,860
#2	3,441	3,441
#3	6,883	6,883
#4	13,766	13,766
#5	27,532	27,532

[a] The exact values in seconds are calculated based on the formulas $N_{SAF} \cdot 2\,048 \cdot 2^{RTO}$, for RTO > 1
$N_{SAF} \cdot 2\,048$, for RTO = 1
providing chip time periods (see Table Q.46).

The response timing options defines the response delay t_{RO} (time between end of uplink and start of downlink) and a minimum value for the response-to-uplink delay t_{RM} (time between end of downlink and start of next uplink during a 2-way session). This t_{RM} value informs the gateway about which minimum delay the OMS end-device can guarantee. If the gateway does not request a specific value with help of the MElement_DA (see Table Q.89) the OMS end-device is free to select any t_{RM} value up to the maximum response-to-uplink delay (see Q.2.5.6.1).

Q.3.5.2.2 Uplink MElement, MElement_UB

This MElements_UB field is only applied if uplink sub-mode is UL-B1, UL-B2 or UL-B3 (see Table Q.85). In case downlink accessibility is provided (see Table Q.80), the MElement_UB is mandatory. Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.85 – Definition of MElement_UB-field

Bit	Symbol	Name	Description
7	XP	Extension Present	If the bit is set, an additional MElement byte follows.
6	UL-SCI	Uplink – SubCarrierIndex	Bit 0 to 6 represents a value for UL-SCI that is calculated as: $\text{UL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0$ n_0: Uplink sub carrier index for UL0/UL1 n_1: Uplink sub carrier index for UL2 n_2: Uplink sub carrier index for UL3 All *n*-values range from 0...4. n_1 and n_2 are set to 0 in case of uplink single burst.
5			
4			
3			
2			
1			
0			

The uplink sub carrier index, *n*, for UL-B1, UL-B2 and UL-B3, is defined in Table Q.6.

If for example a Multi-burst transmission is carried out with the first burst, UL1, transmitted with $n_0 = 2$, the second burst, UL2, transmitted with $n_1 = 4$ and the third burst, UL3, transmitted with $n_2 = 0$, the UL-SCI is calculated as:

$$\text{UL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0 = 0 \cdot 25 + 4 \cdot 5 + 2 = 22 \qquad \text{(Eq.Q.57)}$$

If for example a Single-burst transmission is carried out with the single burst, UL0, transmitted with $n_0 = 3$, the UL-SCI is calculated as:

$$\text{UL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0 = 0 \cdot 25 + 0 \cdot 5 + 3 = 3 \qquad \text{(Eq.Q.58)}$$

Q.3.5.2.3 Uplink MElement, MElement_UC

This MElements_UC field is only applied if downlink sub-mode is DL-B1 or DL-B2 (see Table Q.86). Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.86 – Definition of MElement_UC-field

Bit	Symbol	Name	Description
7	XP	Extension Present	If the bit is set, an additional MElement byte follows.
6	DL-SCI	Downlink – SubCarrierIndex	Bit 0 to 6 represents a value for DL-SCI that is calculated as: $\text{DL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0$ n_0: Downlink sub carrier index of RX0 + RX3 n_1: Downlink sub carrier index of RX1 + RX4 n_2: Downlink sub carrier index of RX2 + RX5 All *n*-values range from 0...4. n_1 and n_2 are set to 0 in case of downlink single burst.
5			
4			
3			
2			
1			
0			

The downlink sub carrier index, *n*, for DL-B1 and DL-B2, is defined in Table Q.6.

If for example a Multi-burst reception is provided at RX0 + RX3 with $n_0 = 4$, at RX1 + RX4 with $n_1 = 1$ and at RX2 + RX5 with $n_2 = 3$, the DL-SCI is calculated as:

$$\text{DL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0 = 3 \cdot 25 + 1 \cdot 5 + 4 = 84 \qquad \text{(Eq.Q.59)}$$

If for example a Single-burst reception is provided at RX0 + RX3 with $n_0 = 2$, the DL-SCI is calculated as:

$$\text{DL-SCI} = n_2 \cdot 25 + n_1 \cdot 5 + n_0 = 0 \cdot 25 + 0 \cdot 5 + 2 = 2 \qquad \text{(Eq.Q.60)}$$

Q.3.5.2.4 Uplink MElement, MElement_UD

This MElements_UD field is only applied if downlink technology is Burst Mode (see Table Q.87). Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.87 – Definition of MElement_UD-field

Bit	Symbol	Name	Description
7	XP	Extension Present	If the bit is set, an additional MElement byte follows.
6 5 4	DL-RT [a]	Downlink – Response Timing	0: Response timing option #1 [b] 1: Response timing option #2 [b] 2: Response timing option #3 [b] 3: Response timing option #4 [b] 4: Response timing option #5 [b] 5: Response timing option #6 [b] 6: Response timing option #7 [b] 7: Response timing option #8 [b]
3 2 1 0	DL-RXM	Downlink – Maximum receive duration	0: Unlimited 1: 25 ms 2: 35 ms 3: 50 ms 4: 75 ms 5: 110 ms 6: 150 ms 7: 200 ms 8: 300 ms 9: 400 ms 10: 500 ms 11: 650 ms 12: 800 ms 13: 1150 ms 14: 1600 ms 15: 2200 ms

[a] If “additional listening window” is selected in MElement_UA, only Response timing options #1 to #3 are applicable.
[b] See Table Q.82.

The DL-RXM signals the maximum downlink receive duration for one burst supported by the OMS end-device. The NW-Manager can use this information to determine the maximum frame length that can be transmitted in downlink to the OMS end-device taking the actual chip rate and FEC rate into account.

Q.3.5.2.5 Uplink MElement, MElement_UE

This MElements_UE field is only applied if intended downlink is Splitting Mode (see Table Q.88). Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.88 – Definition of MElement_UE-field

<table>
<tr><th>Bit</th><th>Symbol</th><th>Name</th><th>Description</th></tr>
<tr><td>7</td><td>XP</td><td>Extension Present</td><td>If the bit is set, an additional MElement byte follows.</td></tr>
<tr><td>6</td><td rowspan="3">DL-RT</td><td rowspan="3">Downlink – Response Timing</td><td rowspan="3">0: Response timing option #1 [a]
1: Response timing option #2 [a]
2: Response timing option #3 [a]
3: Response timing option #4 [a]
4: Response timing option #5 [a]
5: (RFU)
6: (RFU)
7: Applying default timings</td></tr>
<tr><td>5</td></tr>
<tr><td>4</td></tr>
<tr><td>3</td><td>(RFU)</td><td>(RFU)</td><td>Reserved for future use, set to 0</td></tr>
<tr><td>2</td><td>(RFU)</td><td>(RFU)</td><td>Reserved for future use, set to 0</td></tr>
<tr><td>1</td><td>(RFU)</td><td>(RFU)</td><td>Reserved for future use, set to 0</td></tr>
<tr><td>0</td><td>(RFU)</td><td>(RFU)</td><td>Reserved for future use, set to 0</td></tr>
<tr><td colspan="4">[a] See Table Q.84.</td></tr>
</table>

The DL-RT shall be provided by the OMS end-device if other response timings than the default timings of Table Q.83 are in use.

Q.3.5.3 Downlink MElements

MElements are included in the frame if indicated in the MHCTL[0]-byte.

The number of bytes of MElements are determined by the bit 7 of each byte which serves as an extension bit. An additional MElement byte follow if the bit 7 is set to 1.

The individual MElement bytes are defined in the following subclauses.

Q.3.5.3.1 Downlink MElement, MElement_DA

If MElements are enabled in the MHCTL-field, this byte is the mandatory first byte. If it is not provided the value 00_h shall be assumed (see Table Q.89). Another MElement byte follows if XP is set to 1 (bit 7 is set).

Table Q.89 – Definition of MElement_DA-field

Bit	Symbol	Name	Description
7	XP	Extension Present	If the bit is set, an additional MElement field follows.
6 5 4	RTRM	Requested t_{RM}	0: No specific timing required 1: t_{RM} of timing option #1 [a] 2: t_{RM} of timing option #2 [a] 3: t_{RM} of timing option #3 [a] 4: t_{RM} of timing option #4 [b] 5: t_{RM} of timing option #5 [b] 6: RFU 7: RFU
3	(RFU)	(RFU)	Reserved for future use, set to 0
2	(RFU)	(RFU)	Reserved for future use, set to 0
1	ACP	Alternative Communication Partner	0: Transmission from assigned communication infrastructure partner 1: Transmission from non-assigned (alternative) communication partner [c]
0	SC	Session control	0: More downlink frames will follow [d] 1: This is the last downlink frame

[a] For Burst Mode according Table Q.82, for Splitting Mode according Table Q.84.
[b] For Burst Mode RFU, for Splitting Mode according Table Q.84.
[c] Allows for alternative functionality when received from e.g. a service tool. (see Table Q.93)
[d] See Q.3.3.5

Q.3.5.3.1.1 Requested t_{RM}

The NW-Manager can use the RTRM in MElement_DA to instruct the OMS end-device to apply the requested timing for the rest of a 2-way session. The NW-Manager shall respect the minimum t_{RM} supported by the OMS end-device, see Table Q.82.

Such specific response-to-uplink timing is especially beneficial for battery driven gateways. If no specific t_{RM} is requested (RTRM = 0, or no MElement_DA-field) by the NW-Manager, the OMS end-device is free to select the time of transmission, typically as soon as possible.

Q.3.6 MAC Block Functions

Q.3.6.1 Terms

Table Q.90 describes terms used in the tables of subclause Q.3.6.3.

Table Q.90 – Terms used for the MBlock description

Term	Description
MBlockID	Hexadecimal Identifier of the MBlock function (coding is according to Q.3.6.2).
MBlock-Name	Short decription of the MBlock function.
Mandatory	Condition when this MBlock function shall be supported by the OMS end-device.
Release	This MBlock function has been available since the mentioned revision year of publication of the current specification.
Security flag	If enabled, the content shall be secured. If disabled, this MBlock is allowed to be transmitted in an unsecured MSNR frame type (see Q.3.3.2.3)
MBlockLength	Length of a (command or response) MBlock Value coded according to 0.
Data type of MBlock Value	Data type of the MBlock Value field is either defined as bit fields or acc. to [EN 13757-3], Annex A. If not all bits are declared then unused bits shall be 0.
GET	If enabled, the MBlock function can be used with a Get-command (see Q.3.3.4.2).
SET	If enabled, the MBlock function can be used with a Set-command (see Q.3.3.4.2).

Q.3.6.2 List of supported MBlockID's

Table Q.91 list all supported MBlockID's.

Table Q.91 – List of supported MBlockID's

MBlockID	MTag-Name	Release	Reference
00_h	Link status	2023	Table Q.92
01_h	Fallback status	2023	Table Q.93
02_h	Fallback counter	2023	Table Q.94
03_h	Session request	2023	Table Q.95
04_h	Clock Time management	2023	Table Q.96
05_h	UL link management	2023	Table Q.97
06_h	DL link management	2023	Table Q.98
07_h	CMD-MMsgCounter	2023	Table Q.99
08_h – $0E_h$	*Reserved*		
$0F_h$	Manufacturer specific	2023	Table Q.100
10_h	Supported MBlock functions	2023	Table Q.101
11_h	Supported release	2023	Table Q.102
12_h	Session resume delay	2023	Table Q.103
13_h	OMS end-device capability	2023	Table Q.104
14_h	Access Opportunity Interval	2023	Table Q.105
15_h – 37_h	*Reserved*		
38_h – $3E_h$	Manufacturer specific	2023	Table Q.100
$3F_h$	*Reserved*		

NOTE: The format of MBlocks is defined in Q.3.2.3.6

Q.3.6.3 MBlock-Functions

MBlocks are coded according to subsection Q.3.2.3.6. The following tables show the coding for the MBlock's that are listed in Table Q.91.

Table Q.92 – Link status

MBlockID:	**00_h**	***MBlock name:***	**Link status**	***Security flag:***	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1..2	*Data type of MBlock Value:*	Bit array	*GET:* *SET:*	☒ ☐
Description	This MBlock indicates the status of the uplink transmit parameters and downlink link quality as perceived by the OMS end-device. The first byte is always present. The second byte is optionally transmitted in unsolicited uplink. It is always transmitted in the response to a get command.				
Coding	BYTE0 BIT7 – BIT3: *Reserved* BIT2 – BIT0: UL Transmit power reduction in steps of 3 dB: 000_b: 0 dB 001_b: 3 dB 010_b: 6 dB 011_b: 9 dB 100_b: 12 dB 101_b: 15 dB 110_b: 18 dB 111_b: 21 dB				
	BYTE1 (optional) BIT15 – BIT13: Downlink reception link margin in steps of 4 dB 000_b: link margin <= 0 dB or no DL received 001_b: link margin]0;4] dB 010_b: link margin]4;8] dB 011_b: link margin]8;12] dB 100_b: link margin]12;16] dB 101_b: link margin]16;20] dB 110_b: link margin > 20 dB 111_b: N.A BIT12 – BIT8: The number of successfully corrected bit errors after applying FEC on downlink frame in % of the entire frame length.				

	00000$_b$-11101$_b$: Corrected bit errors rate in % (0-29 %) 11110$_b$: 30 % or more 11111$_b$: N.A. The OMS end-device decides on which basis the reported values are calculated. If the value is currently not available or not supported in the OMS end-device N.A. is reported. Any DL link parameters shall be re-evaluated when DL link parameters are changed.	
Example:	Uplink frame: OMS end-device reports a transmission power reduction of 3 dB in the current frame:	10$_h$ 01$_h$
	Get-command to request the link status information:	00$_h$
	Response: OMS end-device reports transmission power of reduction of 3 dB in the current frame, A DL receive margin more than 16 dB and a successfully corrected bit error rate of 5 % after FEC.	20$_h$ 01$_h$ A5$_h$

Table Q.93 – Fallback status

MBlockID:	**01$_h$**	*MBlock name:*	**Fallback status**	*Security flag:*	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1	*Data type of MBlock Value:*	Bit array	*GET:* *SET:*	☒ ☐
Description	This MBlock contains a representation of the fallback counter value (an urgency indicator) that can be used by the other device to prioritize responses to the OMS end-device. A counter value is updated within the OMS end-device by adjusting the counter value for each non-used or unsuccessfully used access opportunities offered after nominal data transmissions. The urgency indicator is transmitted in at least some of those uplink data frames that provide an access opportunity, wherein the urgency indicator depends on the counter value. The fallback counter will reset to a pre-set value each time a response is received in a downlink access opportunity unless the ACP bit in MElement_DA (Table Q.89) is set. If not serviced before the value reaches 0, the OMS end-device will enter a fallback. The value in this MBlock represents a sub-interval of the full fallback counter. **NOTE:** When a fallback occurs in the OMS end-device, the fallback counter is set to the default permanent counter value (see Table Q.94).				
Coding:	BIT7-BIT6: Next uplink fallback state (see Q.3.7.1.4.2). 00$_b$: "Soft" – Power and coding rate providing highest link budget on same bandwidth 01$_b$: "Hard" – Power and coding rate providing highest link budget on next bandwidth (< current bandwidth) 10$_b$: *Reserved* 11$_b$: No fallback (already at maximum link budget)				

	BIT5-BIT0: Fallback counter representation 000000b – 001111b: Fallback counter = 0 – 15 01nnnnb: Fallback counter ≥ $16 + 8 \cdot nnnn$ (16, 24, …, 136) 1nnnnnb: Fallback counter ≥ $256 + 256 \cdot nnnnn$ (256, 512, …, 8192)	
Example:	Get-command to request the fallback status:	01_h
	Response: OMS end-device reports "hard" as the next fallback state and a fallback counter value greater or equal to 1.280:	11_h 64_h

Table Q.94 – Fallback counter

MBlockID:	**02_h**	***MBlock name:***	**Fallback counter**	***Security flag:***	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	2	*Data type of MBlock Value:*	Bit array	*GET:* *SET:*	☒ ☒
Description	This MBlock is used to manipulate the fallback counter value (Q.3.7.1.4.1). When used in a downlink command frame the fallback counter value is programmed. When requesting the value with a Get-command, the programmed value is returned in the response for this MBlock [a].				
Coding:	BYTE0 BIT7 – BIT0 (LSB): The value of the fallback counter represents the number of access opportunities the OMS end-device will accept to be unexploited or unsuccessful before a fallback occurs. The average access opportunity interval can be requested as described in Table Q.105. Fallback counter [7:0]				
	BYTE1 BIT15: Temporary 0_b: Counter value shall be stored and used to (re-)load the fallback counter (permanent). This value will be used to set the fallback counter after fall-back or after a response is received in the OMS end-device. 1_b: Counter value shall be used to load the fall-back counter once (temporary). **NOTE:** The permanent fallback value is unaffected by this action. **NOTE:** When a new response is received in the OMS end-device, or a new permanent value is programmed, the fallback counter is loaded with the permanent value and the temporary value is discarded. A Get-command will always return the permanent fallback counter value. BIT14 – BIT8 (MSB):				

	Fallback counter [14:8]	
Example:	Get-command to request the fallback counter: Response: OMS end-device reports a (permanent) fallback value of 1.507: Command: Program a temporary fallback value (20.000):	02_h 22_h $E3_h$ 05_h 22_h 20_h CE_h
[a] The consequence of a successful command (get or set), is that the fallback counter is preset with a configured value.		

Table Q.95 – Session request

MBlockID:	**03_h**	*MBlock name:*	**Session request**	*Security flag:*	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1	*Data type of MBlock Value:*	Type C	*GET:* *SET:*	☐ ☒
Description	This MBlock is used to request a new session after a period of time (e.g. 10 Minutes). An example of use is, if a NW-Manager needs another session after fetching data from the HES. The meter shall provide the new session with the transmission of an MACC frame. The Session request is a one-time request and the value of this MBlock is updated to 00h after the transmission of the MACC frame. **NOTE:** The delay is measured between T_0 of the downlink transmission containing this MBlock and T_0 of the MACC frame. The value selected shall consider the rest of the session and all timings to avoid conflicts with the current session. See subsections Q.2.4.6.5 for details on timing.				
Coding:	BIT7-BIT0: Delay (minutes) after the downlink transmission of this MBlock till the transmission of the MACC: 00_h: Disabled 01_h-FF_h: 1 min – 255 min				
Example:	Request the OMS end-device to transmit an MACC frame after 10 minutes		13_h $0A_h$		

Table Q.96 – Clock Time management

MBlockID:	**04_h**	*MBlock name:*	**Clock Time management**	*Security flag:*	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1 or 3	*Data type of MBlock Value:*	Type B Type J [a]	*GET:* *SET:*	☒ ☒
Description	This MBlock provides the possibility of clock adjustment from the gateway/NW-Manager (entirely within the MAC layer). For security reasons the adjustment is limited. Only a defined number of seconds can be corrected during a defined period. See [OMS-S2] Annex M, UC-04 for details. A command to set a new date and time is not supported by the MAC layer and must be authorized and fulfilled by the application layer.				

	The SET command can be sent as “time adjustment” indicated by an MBlockLength=1 or as “Time correction” indicated by an MBlockLength=3. The response to a SET command follows the rules specified in Q.3.3.4.3: - Error: MBlockLength = 0 bytes in return - Successful time correction: 3 bytes in return (same value as in request) - Successful time adjustment: 1 byte in return (same value as in request) **NOTE:** The returned value is not providing the current clock of the OMS end-device. It only indicates the command is acknowledged and the clock adjustment will be performed within the next 12 hours (see UC-04 in OMS-S2 Annex M). The GET command shall apply an MBlockLength=0. The response of a GET command or the push message are both using MBlockLength=3 providing the (current) clock time of the OMS end-device. To validate a clock adjustment a readout after 12 hours is recommended.	
Coding	MBlockLength = 3: Type J according to [EN 13757-3:2018], Annex A MBlockLength = 1: Type B according to [EN 13757-3:2018], Annex A	
Example:	Time correction to 22:17:03 Time adjustment -40 seconds GET Clock Time	34_h 03_h 11_h 16_h 14_h $D8_h$ 04_h
[a] The OED can set Bit 6 (so far not used) to indicate that standard time instead of local time is applied. Data type J will be enhanced in [EN 13757-3:2024] to provide standard time as well.		

Table Q.97 – UL link management

MBlockID:	**05_h**	***MBlock name:***	**UL link management**	***Security flag:***	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1..2	*Data type of MBlock Value:*	Bit array	*GET:* *SET:*	☒ ☒
Description	This MBlock contains the command to instruct the OMS end-device which uplink parameters to use in the next uplink transmission (starting with the reply to this command). The selection must comply with the OMS end-device supported uplink capabilities (see Table Q.104). If not, all values shall remain unchanged. The second byte applies if one of the burst modes is selected. This byte instructs on specific sub-mode details to be exploited in the OMS end-device uplink frames. Parameters shall be considered persistent in the OMS end-device device until re-programmed or a fallback occurs.				
Coding:	BYTE0 BIT7: Temporary (see Q.3.7.1.5) 0_b: The parameters set are persistent and shall be used in all further transmitted uplink frames. 1_b: The parameters set are temporary and shall be active until the session is terminated or interrupted (see Q.3.3.5).				

	NOTE 1: If the “Temporary” bit is set during programming of UL parameters the persistent parameters shall still be available and set in the OMS end-device after the session is terminated. BIT6-BIT4: UL Power reduction relative to the device specific maximum transmit power (in steps of 3 dB) 000_b: 0 dB 001_b: 3 dB 010_b: 6 dB 011_b: 9 dB 100_b: 12dB 101_b: 15 dB 110_b: 18 dB 111_b: 21 dB **NOTE 2:** If a command is received with a higher power reduction than supported by the OED, the maximum supported power reduction shall be applied. BIT3-BIT0: UL sub-mode(s) 0000_b: UL-B1 0001_b: UL-B2 0010_b: UL-B3 0011_b: UL-B4 0100_b: UL-B1 + UL-B2 0101_b: UL-S1 0110_b: UL-S2 0111_b: UL-S3 1000_b: UL-S1 + UL-S2 1001_b-1111_b: *Reserved*
	BYTE1 (burst-mode) In UL burst mode, the following denotes the coding of sub-carriers that the meter can operate on in parallel: BIT15: *Reserved* BIT14: $n = 4$ BIT13: $n = 3$ BIT12: $n = 2$ BIT11: $n = 1$ BIT10: $n = 0$ BIT9-BIT8:

	UL FEC coding rate 00_b: Single burst, FEC rate 7/8 01_b: Single burst, FEC rate 1/2 10_b: Single burst, FEC rate 1/3 11_b: Multi-burst **NOTE:** For dual channel modes the same range of *n* values applies for all sub-modes. **NOTE:** For UL-B4, that only applies *n* = 0, BIT11 to BIT14 shall be ignored.	
Example:	Get-command to request the UL link parameters. Response: Splitting mode on 868,180 MHz with 3 dB power reduction. Program for multi burst mode on 868,070 MHz only using a power reduction of 6 dB.	05_h 15_h 15_h 25_h 21_h 13_h

Table Q.98 – DL link management

MBlockID:	**06_h**	***MBlock name:***	**DL link management**	***Security flag:***	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1	*Data type of MBlock Value:*	Bit array	*GET:* *SET:*	☒ ☒
Description	This MBlock contains the command to instruct the OMS end-device which downlink parameters to use in the downlink access elements. The selection must comply with the OMS end-device supported downlink capabilities. If not, all values shall remain unchained. The parameters shall be applied when the OMS end-device offers the next access opportunity. All parameters shall be considered persistent in the OMS end-device device until re-programmed or a fallback occurs.				
Coding:	Downlink link parameters: BIT7: Temporary (see Q.3.7.1.5) 0_b: The parameters set are persistent and shall be requested in all further transmitted uplink frames providing access opportunities. 1_b: The parameters set are temporary and shall be active until the session is terminated or interrupted (see Q.3.3.5). BIT6-BIT4: *Reserved* BIT3: DL Burst Mode [a] 0_b: DL Single Burst 1_b: DL Multi-burst BIT2-BIT1:				

	DL PHY-index 00_b: DL-B1 or DL-S1 01_b: DL-B2 or DL-S2 10_b: DL-B3 or DL-S3 11_b: DL-B4 or DL-S4 BIT0: DL Technology 0_b: Burst mode (B) 1_b: Splitting mode (S) **NOTE:** If the “Temporary” bit is set during programming of DL parameters the persistent parameters shall still be available and set in the OMS end-device after the session is terminated.	
Example:	Get-command to request the DL link parameters Set DL-B3, multi-burst, temporary	06_h 16_h $8C_h$
[a] For splitting mode this bit is ignored.		

Table Q.99 – CMD-MMsgCounter

MBlockID:	07_h	*MBlock name:*	CMD-MMsgCounter	*Security flag:*	☒
Release:	A	*Mandatory:*	If any MBlock function is supported in a two-way enabled OMS end-device, this MBlock is mandatory to implement for the OMS end-device.		
MBlock-Length:	2	*Data type of MBlock Value:*	Type C	*GET:* *SET:*	☐ ☐
Description	This MBlock is used to provide the current CMD-MMsgCounter in an MSNR-Message.				
Coding:	BIT15-BIT0: CMD-MMsgCounter[15:0]				
Example:	CMD-MMsgCounter value 100 in a MAC Frame type MSNR			27_h 64_h 00_h	

Table Q.100 – Manufacturer specific

MBlockID:	$0F_h$, 38_h – $3E_h$	*MBlock name:*	***Manufacturer specific***	*Security flag:*	☐ N.A.
Release:	2023	*Mandatory:*	No		
MBlock-Length:	N.A.	*Data type of MBlock Value:*	N.A.	*GET:* *SET:*	☐ N.A. ☐ N.A.
Description	When using this MBlockID, a manufacturer specific MBlock is expected. The manufacturer is identified by the full address specified in the Logical Link Layer (see Q.4.2.4).				

	All fields defined in the MAC Body Control (Q.3.2.3.2) shall be set and used as intended. The MBlockID and the MBlockLength in the MBlock Header shall be set and used as intended (see Q.3.2.3.6.2).	
Coding:	N.A.	
Example:	N.A.	N.A

Table Q.101 – Supported MBlock functions

MBlockID:	**10_h**	***MBlock name:***	**Supported MBlock functions**	***Security flag:***	☐
Release:	2023	*Mandatory:*	If any other MBlock function is supported, then this MBlock is mandatory for the bidirectional OMS end-device.		
MBlock-Length:	3..8	*Data type of MBlock Value:*	Type D	*GET:* *SET:*	☒ ☐
Description	This MBlock is used to read the supported MBlock functions. If the OMS end-device supports the GET- or SET-command of an MBlock function listed in Table Q.91, then the concerning bit is set. Otherwise, the bit is clear. The bit position represents the MBlockID. BIT0 refers MBlockID 00_h, BIT1 refers to MBlockID 01_h and so on. Manufacturer-specific MBlockID's can optionally be declared by this MBlock. The response may have a size of between 3 and 8 bytes. Bytes which are not transmitted has to be considered as 00_h.				
Coding:	BYTE0 BIT7-BIT0 (LSB): MBlockID 07_h to MBlockID 00_h				
	BYTE1 BIT15-BIT8: MBlockID $0F_h$ to MBlockID 08_h				
	BYTE2 BIT23-BIT16: MBlockID 17_h to MBlockID 10_h				
	BYTE3 (optional) BIT31-BIT24: MBlockID $1F_h$ to MBlockID 18_h				
	BYTE4 (optional) BIT39-BIT32: MBlockID 27_h to MBlockID 20_h				
	BYTE5 (optional) BIT47-BIT40: MBlockID $2F_h$ to MBlockID 28_h				
	BYTE6 (optional) BIT55-BIT48: MBlockID 37_h to MBlockID 30_h				
	BYTE7 (optional) BIT63-BIT56 (MSB): MBlockID $3F_h$ to MBlockID 38_h				
Example:	Get-command to request the supported MBlock functions:			80_h 01_h	
	Response: MBlock functions with MBlockID 00_h to 07_h and 10_h to 11_h are supported.			$B0_h$ 01_h FF_h 00_h 03_h	

Table Q.102 – Supported release

MBlockID:	11_h	*MBlock name:*	**Supported release**	*Security flag:*	☐
Release:	2023	*Mandatory:*	If any other MBlock function is supported then this MBlock is mandatory for the bidirectional OMS end-device.		
MBlock-Length:	2	*Data type of MBlock Value:*	Type C	*GET:* *SET:*	☒ ☐
Description	The supported commands and its values may change in future versions of the OMS-specification. This MBlock is used to identify the applied specification date. This command parameter provides: The release year of this OMS annex supported by the OMS end-device. (Byte 1)				
Coding:	BYTE0 BIT7-BIT0: *Reserved (0 by default)*				
	BYTE1 BIT15-BIT8: Supported release year (up to year 2255) A value of e.g. 23 corresponds to a release of OMS-Spec. Vol.2 Annex Q in year 2023. A value of 0 means undefined. **NOTE:** The release year is noted on the front page of this annex.				
Example:	Get-command to request the supported release: Response: OMS end-device supports OMS-release in year 2023:			81_h 01_h $A1_h$ 01_h 00_h 17_h	

Table Q.103 – Session resume delay

MBlockID:	12_h	*MBlock name:*	**Session resume delay**	*Security flag:*	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1	*Data type of MBlock Value:*	Type C	*GET:* *SET:*	☒ ☒
Description:	This MBlock contains the command to configure an access frame (MACC) to be transmitted before a downlink communication session fails. The parameter is a specified delay after the last uplink transmission before the session fails. The delay is measured between T_0 of this last uplink transmission and T_0 of the MACC frame. It can be used by the other device to resume an interrupted downlink communication session. The OMS end-device shall be able to provide the applicative answer until the end of the session (see Appendix Q.J.4).				
Coding:	BIT7-BIT0: MACC frame insertion delay (in 2 seconds steps) after incomplete two-way session termination:				

	00h: No MACC frame insertion 01h-FFh: 2 s – 510 s The effective minimum delay shall consider the duration of the complete uplink the response delay and the complete downlink (T_0 to T_0).	
Example:	Configure an MACC frame to be inserted after 4 minutes	92h 01h 78h

Table Q.104 – OMS end-device capability

MBlockID:	**13h**	***MBlock name:***	**OMS end-device capability**	***Security flag:***	☒
Release:	2023	*Mandatory:*	If any link management is supported, this MBlock function is mandatory for the OMS end-device.		
MBlock-Length:	2..3	*Data type of MBlock Value:*	Type D	*GET:* *SET:*	☒ ☐
Description	This MBlock carries the information about the capability of the OMS end-device. For example, the uplink and downlink modes supported, the coding rates and multi-burst spacing supported. This can be used for the selection of link parameters to be used for link management and to predict physical parameters of the next fallback state. Each bit indicates if a capability is available (1b) or not (0b).				
Coding:	BYTE0 Uplink Sub-mode BIT7: Dual mode supported [b] BIT6: UL-S3 BIT5: UL-S2 BIT4: UL-S1 BIT3: UL-B4 BIT2: UL-B3 [a] BIT1: UL-B2 [a] BIT0: UL-B1 [a]				
	BYTE1 Downlink Sub-mode BIT15: DL-S4 BIT14: DL-S3 BIT13: DL-S2 BIT12: DL-S1 BIT11: DL-B4 BIT10: DL-B3 BIT9: DL-B2 [a] BIT8: DL-B1 [a]				
	BYTE2 [c]				

	Reserved for future use BIT23-BIT21: *Reserved* Downlink multi-burst support BIT20: DL multi-burst supported. Uplink FEC coding rate support BIT19: Multi-burst BIT18: Single burst, FEC 1/3 BIT17: Single burst, FEC 1/2 BIT16: Single burst, FEC 7/8	
Example:	Get-command to request the OMS end-device capabilities. Response: All burst modes and support of all FEC coding options.	83_h 01_h $B3_h$ 01_h $0F_h$ $0F_h$ $1F_h$
[a] If enabled, all values of *n* shall be supported in OMS end-device. [b] If set the simultaneous use of UL-B1 + UL-B2 and/or UL-S1 + UL-S2 is supported. [c] Only applicable if burst-mode capability (UL/DL) is supported.		

Table Q.105 – Access opportunity interval

MBlockID:	**14_h**	***MBlock name:***	Access opportunity interval	***Security flag:***	☒
Release:	2023	*Mandatory:*	No		
MBlock-Length:	1..3	*Data type of MBlock Value:*	Type C	*GET:* *SET:*	☒ ☐
Description	This MBlock is used to get the access opportunity interval of the OMS end-device. When requesting the value with a Get-command, the programmed value is returned in the response for this MBlock. The value expresses the average interval (in seconds) between nominal scheduled access opportunities offered by the OMS end-device. This can be used by a NW-Manager to predict the time where an OMS end-device will enter a fallback. See sections Q.3.7.1.3 and Q.3.7.1.4.3.				
Coding:	BYTE0 (mandatory) BIT7-BIT0 (LSB): Average access opportunity time interval indicates the average time interval (in seconds) between two consecutive receive windows provided after an uplink transmission. AOTimeInterval[7:0]				
	BYTE1 (optional) BIT15-BIT8 (MSB): Average access opportunity interval. Time value in seconds. AOTimeInterval[15:8]				
	BYTE2 (optional) BIT23-BIT16 (MSB):				

	Average access opportunity interval. Time value in seconds. AOTimeInterval[23:16]	
Example:	Get-command to request the access opportunities: Response: OMS end-device reports an access opportunity time interval of 4 minutes:	84_h 01_h 94_h 01_h $F0_h$

Q.3.7 MAC Services

Q.3.7.1 Link Management

Q.3.7.1.1 Overview

This subclause is only relevant for OMS end-devices which support link management.

Link management is used to optimize the link between OMS end-devices and gateways. The optimization is targeting the minimization of impact to the radio spectrum and thus also enabling energy savings in the OMS end-device. The following parameters can be dynamically changed to optimize the communication link during normal operation:

- Manage transmission bandwidth (sub-mode)
- Manage transmission power
- Manage coding rate

An OMS end-device that supports link management should default to the highest link budget supported according to the parameters supported (see Table Q.104) after installation for the intended operational use.

Q.3.7.1.2 Link management responsibility

Figure Q.28 shows the responsibility for different elements of link management.

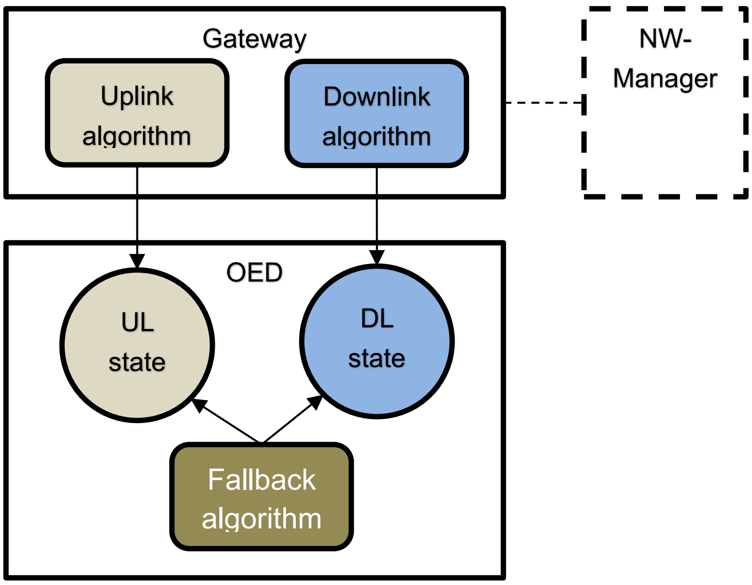

Figure Q.28 – Link management responsibility overview

The NW-Manager is responsible for the link management algorithms. The NW-Manager can either be implemented in the gateway or it can be implemented as a service behind the gateway in the cloud (or as part of the HES). The link management algorithms can control the radio transmission link parameters in both uplink and downlink directions. The link management algorithm itself is not in scope for the current specification.

The OMS end-device is responsible of maintaining the state of link parameters used in uplink transmissions as well as the state of link parameters that it will request in an access opportunity.

The OMS end-device shall provide status information of uplink link parameters for the current transmitted uplink frame that cannot be resolved in the gateway itself, and that is needed to complete the inputs for the uplink link management algorithm in the NW-Manager.

NOTE: On the PHY-layer the gateway can determine technology, sub-mode and code rate which can then be provided in parallel to the NW-Manager.

The OMS end-device shall also provide information of the downlink quality as perceived by the OMS end-device to complete the inputs for the downlink link management algorithm in the NW-Manager. The MBlockID in Table Q.92 carries the necessary OMS end-device status information and should be included in uplink frames where access opportunity is provided.

Furthermore, the OMS end-device shall be able to update its state of link parameters when receiving instructions for this from the NW-Manager, for uplink (Table Q.97) or downlink (Table Q.98).
If the NW-Manager is implemented in the gateway, only one gateway should be responsible for controlling a meter's link management states but can be influenced by a coordinating network manager entity (optional).

Q.3.7.1.3 The concept of access opportunity

An access opportunity is applied after providing downlink information in the MElement_UA of an uplink frame. For OMS end-devices with limited downlink options, access opportunities are related to the nominal transmission interval configured in the OMS end-device. Depending on the necessary responsiveness for an OMS end-device, access opportunities may be provided after each nominal transmitted frame or more seldomly and may also be applied using a certain randomness. The average time interval between access opportunities can be reported according to Table Q.105. The following example is depicted in Figure Q.29.

Example: An OMS end-device has a nominal transmission interval $\mathrm{t_{NOM}}$ of 20 minutes and is configured to provide an access opportunity after 2 out of 3 nominal uplink transmissions. The time value read out with the Access opportunity interval MBlock function is $\frac{3}{2} \cdot t_{NOM} = 30$ minutes.

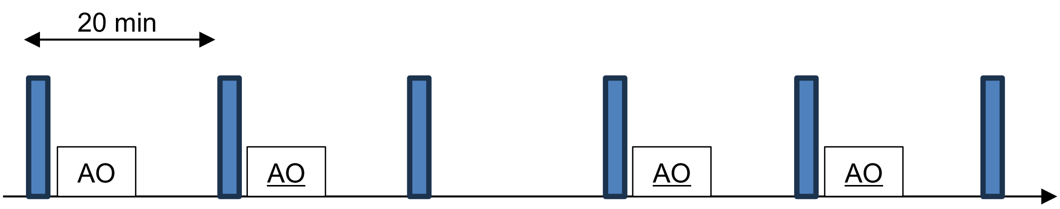

Figure Q.29 – Access opportunity (AO) vs. transmission intervals.

When the OMS end-device is in an active communication session, an access opportunity shall be provided after all uplink frames.

Q.3.7.1.4 Fallback mechanism

When link management is applied, the target might be to optimize the link between the OMS end-device and a single gateway.

In case the spectrum changes for a link that is managed optimally the communication might be lost. The fallback mechanism is used to ensure that the OMS end-device will fall back to a link state with a better link budget (using relevant link parameters), which enables the re-establishment of the link to the responsible gateway or a secondary gateway.

The OMS end-device is responsible for implementing the fallback mechanism.

Q.3.7.1.4.1 Fallback counter

The gateway is not obliged to respond to the OMS end-device each time an access opportunity (AO) is provided. If the gateway decides to respond at an AO, it must respect the channel and channel mode specified in the downlink information sent within the uplink frame (see Q.3.5.2.1). If a response is not received by the OMS end-device after a scheduled AO (either because the gateway did not transmit a response, or due to a packet error on the channel), the fallback counter shall be decremented by one in the OMS end-device.

Every time a response is successfully received, the counter shall be set to the pre-set value configured in the OMS end-device or programmed according to Table Q.94. A temporary fallback counter value can also be programmed. This value can be used to extend the time once before a fallback occurs. An example is shown in Appendix Q.J.5.2.

If the fallback counter reaches zero, a fallback shall occur (see Q.3.7.1.4.2) and the fallback counter shall be set to the pre-set permanent value.

In case fallback occurs at highest link budget (see Q.3.7.1.4.2), the fallback counter shall remain zero until a downlink response has been received.

Q.3.7.1.4.2 Fallback states

Fallback states are defined in the OMS end-device. There are two categories of fallbacks. “Hard” fallback and “soft” fallback.

“Soft” fallback is where the OMS end-device adjusts the uplink parameters (transmission power and FEC code rate) to the highest available link budget supported in the OMS end-device while keeping the current sub-mode fixed. The soft fallback state is the fallback mode to be applied if transmission power and FEC code rate is currently not set to the highest available link budget.

“Hard” fallback is applied if the OMS end-device is already in the soft fallback state. At hard fallback the OMS end-device adjusts the uplink link parameters (transmission power, FEC code rate and PHY-index) to the highest available link budget on the next available sub-mode. Hard fallback results in adjusting the current uplink PHY-index one row up according to Table Q.106.

Table Q.106 – Hard fallback ladder

Uplink – PHY-index (lowest chip rate)
UL-S1, UL-S2, UL-S3
UL-B1, UL-B2, UL-B3
UL-B4
Uplink – PHY-index (highest chip rate)

The next uplink fallback state is signalled in the fallback status MBlock (Table Q.93). With this information a NW-Manager will be able to predict the transmission parameters after a fallback in case it has also the knowledge about the capabilities of the OMS end-device (Table Q.104). No further fallback possible can also be reported.

Example: An OMS end-device has the capabilities to operate on UL-B1, UL-B2 and UL-B4, single burst FEC 7/8, FEC 1/2 and FEC 1/3, and all power reductions.

An OMS end-device is currently operating on UL-B4, single burst FEC 1/2 and with a power reduction of 6dB,

A “soft” fallback will result in the OMS end-device operating in UL-B4, single burst FEC 1/3 and power reduction 0dB.

A “hard” fallback will result in the OMS end-device operating in UL-B1/B2, single burst FEC 1/3 and power reduction 0dB.

NOTE: As part of the uplink fallback, an adjustment of the downlink parameters that will be requested by the OMS end-device may be applied in the OMS end-device accordingly (e.g. in dB).

Q.3.7.1.4.3 Fallback time prediction

The current value of the fallback counter indicates the remaining number of access opportunities until fallback.

To predict when a fallback will occur in the future, the counter value can be used in combination with the average time interval between scheduled access opportunities. This is a value that can be fetched as described in Table Q.105.
Example: If the fallback counter is 10 and the average scheduled nominal access opportunity interval is 40 minutes, a fallback is expected to happen after approximately 400 minutes.

Q.3.7.1.5 Temporary link parameters

Link management is controlled by the NW-Manager. The optimal link parameters are determined from an overall knowledge, achieved by the NW-Manager entity, about the link condition between OMS end-devices and an gateway.

Nevertheless, the NW-Manager can decide to program temporary link parameters (see Table Q.97 and Table Q.98) into the OMS end-device while in an active communication session to ensure or optimize the successful execution of a predictive large communication queue to the OMS end-device.
NOTE: This might only be possible to exploit if the gateway has instant access to the NW-Manager.

Temporary UL and DL link parameters are used in the OMS end-device until the communication session is terminated. Preceding the next upcoming unsolicited frame or access frame, the OMS end-device shall revert to the last permanent programmed UL and DL link parameters (see Table Q.97 and Table Q.98).

Q.3.7.1.6 Link management information flow

Appendix Q.J.5.1 shows an example of the link management information flow that leads to a fallback situation.

Q.3.7.2 Clock Management

Q.3.7.2.1 Overview

Figure Q.30 gives an overview over the clock services supporting the use cases in [OMS-S2] Annex M, UC-04. Clock services from the HES is out of scope for the MAC services.

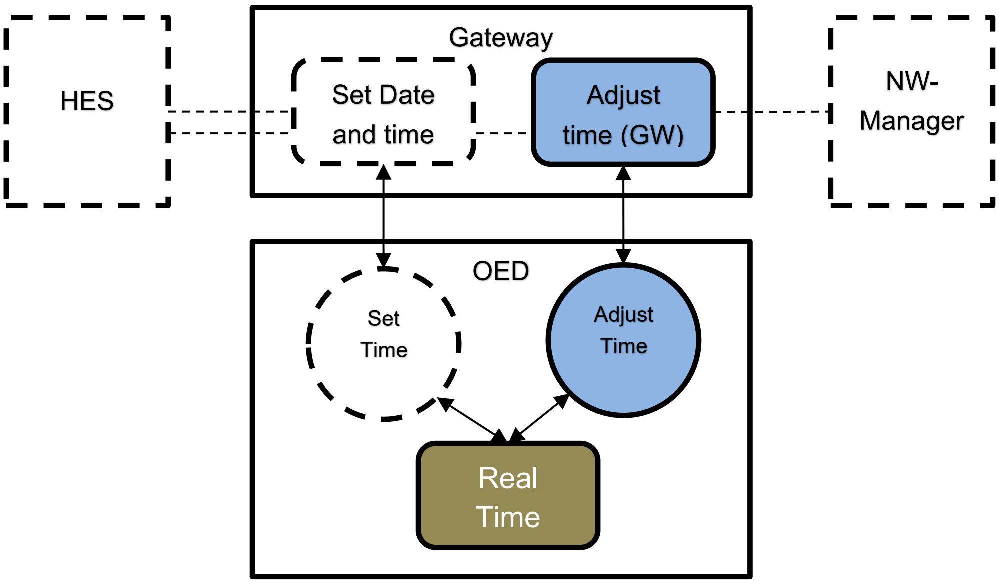

Figure Q.30 – Time services overview

This subclause is only relevant for OMS end-device's which supports the MAC service "Clock Management".

Clock management is used to adjust the real time clock of the OMS end-device. As this is a MAC service it can be fulfilled by the NW-Manager (in case located in the gateway) independent of the HES-Application. Due to this it is restricted in its possibilities what means only a few number of seconds can be adjusted during a defined period. A completely new definition of the real time clock with help of a "SetDateTime" (see [OMS-S2] Annex M, UC-04) command is not supported.

The NW-Manager itself needs a synchronized time to be able to fulfil this MAC service meaningful. There are two ways to do the clock management, either by providing the absolute time on a regular basis (called "Time correction") or by adjusting the OMS end-device's real time clock relatively by adding or subtracting a number of seconds (called "Time adjustment").

This MAC service offers a SET and a GET command applying the MBlock "Clock Time management" (see Table Q.96). Both needs to be secured as described in clause Q.3.4.
The clock management is a time sensitive service. Therefore, it is essential that the correct time reference according to the physical layer definitions is applied (see Q.2.4.6.5 and Q.2.5.6.4).

NOTE: A full flavoured clock management can alternatively be provided by the HES-Application. For this see [OMS-S2] Annex M, UC-04.

Q.3.7.2.2 Time Correction

For a time correction the NW-Manager provides the correct absolute time to the OMS end-device with help of the SET command. This can be done on a regular basis depending on the intended clock tolerance and accuracy of the OMS end-device. The OMS end-device shall respect the limits defined in [OMS-S2] Annex M, UC-04.

There is no need to know the current time of the OMS end-device in advance. However this can be used to limit the amount of time correction commands.

Q.3.7.2.3 Time Adjustment

For a time adjustment the NW-Manager needs to know the current time of the OMS end-device. This can be achieved either by a regular push (e.g. one time a week) of the time by the OMS end-device or by using the GET command by the NW-Manager. The received OMS end-device time can then be compared with the internal NW-Manager time to calculate the deviation to the correct time. With help of the SET command the deviation of the OMS end-device real time clock can then be adjusted.

The intended clock tolerance of the whole system as well as the limits defined in [OMS-S2] Annex M, UC-04 shall be considered by the NW-Manager to avoid unnecessary communication.

Q.3.8 MAC size limitations

The size of the MAC layer is defined by the PHY Payload Length of the physical layer (see Q.2). The structure of the MAC layer is specified in Q.3.2. There are different limitations on the size of the MAC layer depending on the PHY technology and the actual link state. The limitations are specified in the following subsections.

Q.3.8.1 Uplink

In uplink, the individual OED may have limitations on the size of the MAC layer depending on the implementation.

NOTE: In case that a response to a command exceeds this limitation, the Advanced OED need to apply fragmentation in the upper layers (AFL) to accommodate this limitation.

Q.3.8.2 Downlink

Q.3.8.2.1 Burst Mode

For Burst Mode, the individual Advanced OED may have further restrictions in downlink based on the link management state. In Burst Mode the OED declares, in the preceding uplink transmission, the downlink maximum receive duration, DL-RXM. This information is located in MElement_UD, if present, and otherwise in MElement_UA. The OED further declares, in MElement_UA of the preceding uplink transmission, the sub mode to be applied for downlink. The COP determines the FEC-rate to be applied for the downlink transmission.

NOTE 1: In case that the size of the downlink MAC layer exceeds this limitation, the COP need to apply fragmentation in the upper layers (AFL) to accommodate this limitation.

NOTE 2: The downlink sub mode may be managed by the COP using the link management commands of the MAC-layer.

The parameters: downlink maximum receive duration; downlink sub-mode and FEC-rate are used to determine the maximum size of the downlink MAC layer according to Table Q.107.

Table Q.107 – Maximum size of downlink MAC layer in bytes (Burst Mode)

Downlink maximum receive duration, DL-RXM.	DL-B1			DL-B2			DL-B3			DL-B4		
	Single-Burst, FEC=1/3	Single-Burst, FEC=1/2	Multi-Burst and Single-Burst, FEC=7/8	Single-Burst, FEC=1/3	Single-Burst, FEC=1/2	Multi-Burst and Single-Burst, FEC=7/8	Single-Burst, FEC=1/3	Single-Burst, FEC=1/2	Multi-Burst and Single-Burst, FEC=7/8	Single-Burst, FEC=1/3	Single-Burst, FEC=1/2	Multi-Burst and Single-Burst, FEC=7/8
25 ms	-	-	-	-	-	-	-	-	-	-	27	47
35 ms	-	-	-	-	-	-	-	-	-	27	42	73
50 ms	-	-	-	-	-	-	-	-	25	42	64	112
75 ms	-	-	-	-	-	-	-	27	47	67	102	178
110 ms	-	-	-	-	-	29	29	44	77	102	154	255
150 ms	-	-	-	-	27	47	42	64	112	142	214	255
200 ms	-	-	25	26	39	69	59	89	156	192	255	255
300 ms	-	27	47	42	64	112	92	139	244	255	255	255
400 ms	26	39	69	59	89	156	126	189	255	255	255	255
500 ms	34	52	91	76	114	200	159	239	255	255	255	255
650 ms	46	70	123	101	152	255	209	255	255	255	255	255
800 ms	59	89	156	126	189	255	255	255	255	255	255	255
1150 ms	88	133	232	184	255	255	255	255	255	255	255	255
1600 ms	126	189	255	255	255	255	255	255	255	255	255	255
2200 ms	176	255	255	255	255	255	255	255	255	255	255	255
Unlimited	255	255	255	255	255	255	255	255	255	255	255	255

Q.3.8.2.2 B.2.7.2.2 Splitting Mode

For Splitting Mode, an Advanced OED shall support MAC layer sizes up to 254 bytes.

Q.4 Logical Link Control (LLC)

Q.4.1 Introduction of Frame Format C

The OMS LPWAN protocol applies a logical link control layer Frame Format C (FFC). It is intended for lower layers like OMS LPWAN PHY and OMS LPWAN MAC that provide services like length indication and integrity validation. For this reason the FFC does not include length indication and integrity validation.

The FFC is flexible and only the link layer control field, LC-field, is mandatory. Such flexibility may be used for link layers where only transmitter address or receiver address is required. Such minimum link layer may be used by lower layers like OMS LPWAN MAC that rely on the address of the link layer but do not require other fields of the link layer.

The presence of the fields of FFC is indicated in the mandatory control-field. The fields that can be optionally enabled are selected in a way that all information from the wM-Bus frame format A and frame format B can be enabled (except length indication and integrity validation).

In addition, fields from the wM-Bus extended link layer are selected as well in order to have the most commonly used fields, like ACC-number and receiver address, available directly in the FFC.

As an alternative to enabling fields that is originally located in the existing wM-Bus extended link layer, the existing wM-Bus extended link layers may also be applied as a whole using the CI-field approach, if the selected fields for enablement are not sufficient. If an element is provided both directly in the FFC structure enabled by the LC-field and in the extended link layer, the element of the extended link layer shall be ignored.

The FFC also provides a new function for adapters.

NOTE: The fields of the LLC-layer are in general not secured. Their integrity however can be checked by the MAC CRC field of the MAC layer (see Q.3.2.5).

Q.4.2 Structure of Frame format C

Q.4.2.1 Overview

Table Q.108 – Overview of Frame Format C

Field	Presence	Bytes
LC[0]-field	Mandatory	1
LC[1]-field	Optional	1
LC[2]-field	Optional	1
C-field	Optional	1
M-field	Optional	2
A-field	Optional	6
M2-field	Optional	2
A2-field	Optional	6
ACC-field	Optional	1
RTD-field	Optional	2
RAS-field	Optional	1
CI-field	Optional	1
Data-field	Optional	Variable

The Frame Format C starts with the Link Control fields, LC. The LC[0]-field shall always be present. The following LC-fields may be present if needed. The presence is indicated by the Extension bit of the previous LC-field.

The remaining fields are optional and in case provided in the order shown in Table Q.108. Their presence in the frame is depending on the value of the LC-field.

NOTE: The CRC is provided by the MAC-Layer (see Q.3.2).

Q.4.2.2 LC-Field

LC-field enables fields of the Frame Format C. The first byte LC[0] (see Table Q.109) of the LC-field is mandatory and can be optionally extended with LC[1] (see Table Q.110) by enabling the XP-bit of LC[0]. If LC[1] is not present, then all bits of LC[1] are to be considered as 0.The field LC[2] is reserved for future use.

Table Q.109 – LC[0]-field

Bit	Symbol	Name	Direction	Description
7	XP	Extension present	Uplink and downlink	If the bit is set, LC[1] byte follows.
6	S	Synchronized transmission	Uplink	Synchronized Subfield as defined in [EN 13757-4], 13.2.7.4.
	RRX	Request uplink receiver address	Downlink	Uplink response shall contain M2-field and A2-field.
5	(RFU)	Reserved	Uplink and downlink	Reserved for future use (always 0).
4	ULP	Upper protocol layer present	Uplink and downlink	CI-field and Data-field present.
3	ANP	Access Number present	Uplink and downlink	ACC-field present.
2	RAP	Receiver Address present	Uplink and downlink	M2-field and A2-field present.
1	TAP	Transmitter Address present	Uplink and downlink	M-field and A-field present.
0	CFP	C-field present	Uplink and downlink	C-field present.

Table Q.110 – LC[1]-field

Bit	Symbol	Name	Direction	Description
7	XP [a]	Extension present	Uplink and downlink	If the bit is set, LC[2] byte follows.
6	(RFU)	Reserved	Uplink and downlink	Reserved for future use (always 0).
5	(RFU)	Reserved	Uplink and downlink	Reserved for future use (always 0).
4	(RFU)	Reserved	Uplink and downlink	Reserved for future use (always 0).
3	RASP	Radio Adapter Status present	Uplink	RAS-field present.
2	H	Hop Count	Uplink and downlink	Hop Count Subfield according to [EN 13757-4], 13.2.7.5.
1	RTDP	Run Time Delay present	Uplink and downlink	00_b – Frame Run Time Delay not present. 01_b – Frame Run Time Delay present, resolution 1/256 s.

Bit	Symbol	Name	Direction	Description
0				10_b – Frame Run Time Delay present, resolution 2 s. 11_b – Reserved for future usage.
a	As long as LC[2] is not defined the bit XP shall be 0.			

If the RRX-bit is set (and a transmitter address is provided) in a downlink to the OMS end-device, it shall include the receiver address (indicated by a set RAP-bit) in the following uplink transmission. The receiver address will in this case always be the address of the gateway.

Q.4.2.3 C-Field (Control)

Control field according to [EN 13757-4], 12.5.4.

Q.4.2.4 M-Field (Manufacturer ID)

Manufacturer ID of transmitter according to [EN 13757-4], 12.5.5.

Q.4.2.5 A-Field (Address)

Address of transmitter according to [EN 13757-4], 12.5.6.

Q.4.2.6 M2-Field (Manufacturer ID 2)

Manufacturer ID of receiver according to [EN 13757-4], 13.2.9.

Q.4.2.7 A2-Field (Address 2)

Address of receiver according to [EN 13757-4], 13.2.10.

Q.4.2.8 ACC-Field (Access Number)

Access number according to [OMS-S2], 7.2.2.1.

Q.4.2.9 RTD-Field (Run Time Delay)

Run Time Delay according to [EN 13757-4], 13.2.13.

Q.4.2.10 RAS-Field (Radio Adapter Status)

Radio adapter status field enables the possibility to provide the status of a radio adapter in the LLC-layer of uplink frame. This is independent to the status byte of the TPL that is owned by the transported application, e.g. a metering device. In case of an integrated device (using a short TPL header) the status shall be provided in the TPL and not in the LLC.

The coding of the one-byte RAS-field is as defined in [EN 13757-7], 7.5.6.

Q.4.2.11 CI-Field (Control Information)

Control Information field according to [EN 13757-4], 12.5.8.

Q.4.2.12 Data-Field (Data)

The Data field contains the upper protocol layer data relevant to the CI-field.

Appendix Q.A (informative): Frequency Plan Visualization

This appendix serves as a visualization overview of the OMS LPWAN frequency plan (see Figure Q.A.1, Figure Q.A.2 and Figure Q.A.3). It displays the location of sub-modes for both the Burst Mode and Splitting Mode technologies. The frequency plans are divided into separate uplink and downlink illustrations. To increase the readability of the overlapping downlink sub-modes the illustration is further divided by technology i.e. Burst Mode and Splitting Mode.

NOTE: The figures serve as an illustrative overview hence there is no y-axis. The only reason for the difference in height of the modes is to enable labelling and readability of the different modes.

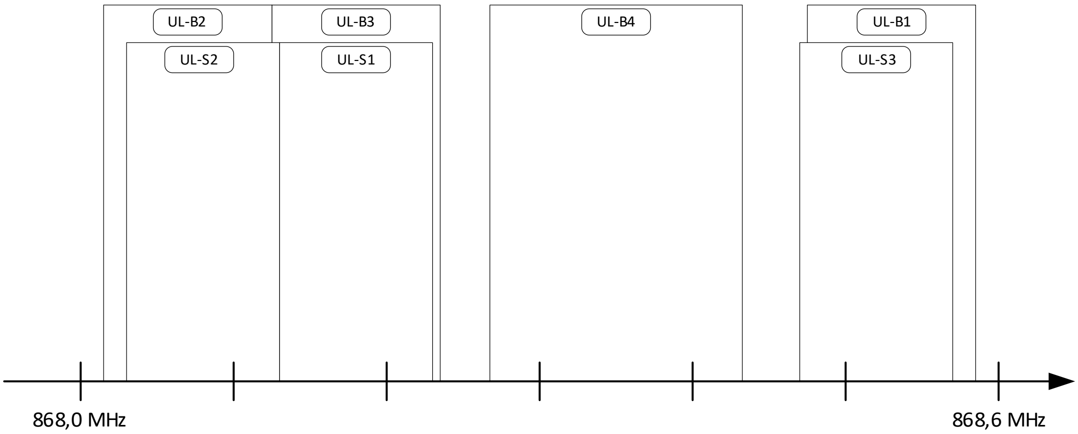

Figure Q.A.1 - OMS LPWAN uplink frequency plan

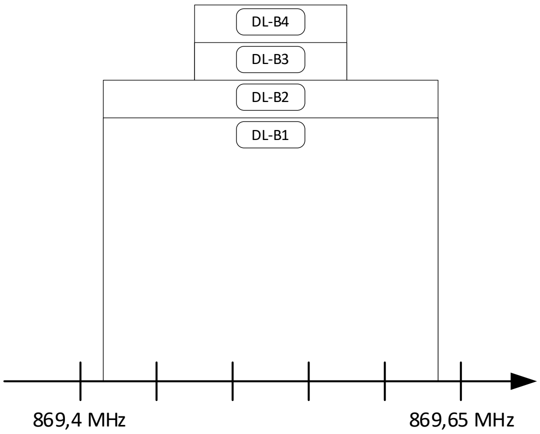

Figure Q.A.2 - OMS LPWAN Burst Mode downlink frequency plan

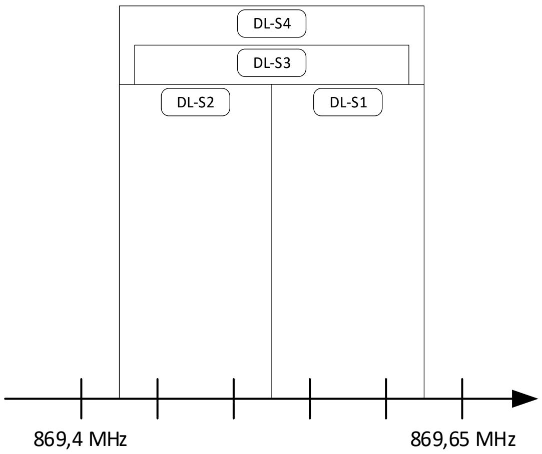

Figure Q.A.3 - OMS LPWAN Splitting Mode downlink frequency plan

Appendix Q.B (informative): MCL and MPL Calculations

The Maximum Coupling Loss (MCL) serves as a metric for assessing the coverage capability of a radio access technology. It represents the maximum permissible reduction in the conductive power level for the system to remain operational, which is defined by the minimum acceptable received power level. The MCL is calculated as the difference between the conductive power levels measured at the transmitting and receiving antenna ports, with the directional gain of the antenna being excluded in the calculation.

Table Q.B.1 serves as an MCL overview of the different sub-modes of OMS LPWAN.

Table Q.B.1 – OMS LPWAN sub-mode MCL overview

Sub-mode	Receiver Type	NF [dB]	Receiver BW [kHz]	MCL [dB]	Note
UL-B1 UL-B2 UL-B3	SDR [a]	4	10	147	14 dBm ERP, ~9 dB coding gain (incl. linear gain), SNR = -3 dB
UL-B4	SDR [a]	4	125	136	
DL-B1	Conventional Receiver [b]	6	4	157	27 dBm ERP, ~6 dB coding gain (incl. linear gain), coding gain capped by sync sensitivity, SNR = 2 dB
DL-B2	Conventional Receiver [b]	6	8	154	
DL-B3	Conventional Receiver [b]	6	16	151	
DL-B4	Conventional Receiver [b]	6	48	146	
UL-S1 UL-S2 UL-S3	SDR [a]	4	~2.4	153	14 dBm ERP, ~9 dB coding gain (incl. linear gain), SNR = -3 dB
DL-S1 DL-S2	SoC w/ SDR mode [c]	6	~2.4	163	27 dBm ERP, ~9 dB coding gain (incl. linear gain), SNR = -3 dB
DL-S3	SoC w/ SDR mode [c]	6	~4.8	160	
DL-S4	SoC w/ SDR mode [c]	6	~19	154	

[a] Phase-coherent receiver with midamble detection and soft-decision FEC decoding

[b] Non-coherent receiver with sync detection and hard-decision FEC decoding

[c] System-on-chip receiver with midamble detection and soft-decision FEC decoding

The coverage of a radio technology can also be expressed through the Maximum Path Loss (MPL). Path loss refers to the reduction in signal strength along its propagation path, resulting from factors such as distance, building penetration, etc. MPL is calculated as the difference between the radiated power levels at the transmitting and receiving antennas, taking into account the antenna gain at both the transmitter and receiver.

Table Q.B.2 expresses the symmetrical MPL for different combinations of sub-mode UL/DL in relation to gateway antenna gains.

Table Q.B.2 – OMS LPWAN sub-mode MPL overview

Uplink sub-mode	Downlink sub-mode	G_{GW} [a] [dBd]	G_{ED} [b] [dBd]	Symmetric MPL [dB]
UL-B1 UL-B2 UL-B3	DL-B1	10	0	157
	DL-B2	7	0	154
	DL-B3	4	0	151
	DL-B4	-1	0	146
UL-B4	DL-B1	21	0	157
	DL-B2	18	0	154
	DL-B3	15	0	151
	DL-B4	10	0	146
UL-S1 UL-S2 UL-S3	DL-S1 DL-S2	10	0	163
	DL-S3	7	0	160
	DL-S4	1	0	154
UL-B1 UL-B2 UL-B3	DL-S1 DL-S2	16	0	163
	DL-S3	13	0	160
	DL-S4	7	0	154
UL-B4	DL-S1 DL-S2	27	0	163
	DL-S3	24	0	160
	DL-S4	18	0	154
UL-S1 UL-S2 UL-S3	DL-B1	4	0	157
	DL-B2	1	0	154
	DL-B3	-2	0	151
	DL-B4	-7	0	146

[a] Gateway antenna gain required for symmetric MPL

[b] End device antenna gain required for symmetric MPL

Appendix Q.C (informative): On-Air Times

This appendix provides on-air time calculations at three PHY Payload lengths for the different sub-modes.

Q.C.1 Burst Mode

Table Q.C.1 gives the transmission times for different Burst Modes with different payload sizes.

Table Q.C.1 – Burst Mode On-Air Time

	Burst mode	FEC rate	PHY payload size on-air time [ms]		
			10 bytes	**50 bytes**	**100 bytes**
UL-B1 UL-B2 UL-B3	Single-burst	7/8	38,0	74,8	120
		1/2	44,8	109	189
		1/3	53,6	150	270
	Multi-burst [a]	7/8 (7/24)	38,0 (114)	74,8 (224)	120 (361)
UL-B4	Single-burst	7/8	3,04	5,98	9,63
		1/2	3,58	8,70	15,1
		1/3	4,29	12,0	21,6
	Multi-burst [a]	7/8 (7/24)	3,04 (9,12)	5,98 (18,0)	9,63 (28,9)
DL-B1	Single-burst	7/8	130	314	542
		1/2	164	484	884
		1/3	208	688	1288
	Multi-burst [a]	7/8 (7/24)	130 (390)	314 (942)	542 (1626)
DL-B2	Single-burst	7/8	65,0	157	271
		1/2	82,0	242	442
		1/3	104	344	644
	Multi-burst [a]	7/8 (7/24)	65,0 (195)	157 (471)	271 (813)
DL-B3	Single-burst	7/8	32,5	78,5	136
		1/2	41,0	121	221
		1/3	52,0	172	322
	Multi-burst [a]	7/8 (7/24)	32,5 (97,5)	78,5 (236)	136 (407)
DL-B4	Single-burst	7/8	9,29	22,4	38,7
		1/2	11,7	34,6	63,1
		1/3	14,9	49,1	92,0
	Multi-burst [a]	7/8 (7/24)	9,29 (27,9)	22,4 (67,3)	38,7 (116)

[a] Values in brackets denotes the FEC rate and on-air-time for the combination of all three bursts.

Q.C.2 Splitting Mode

Table Q.C.2 gives the transmission times for different Splitting Modes with different payload sizes.

Table Q.C.2 – Splitting Mode On-Air Time

	Radio-Burst duration [ms]	Core Frame on-air time [ms]	Extension Frame on-air time	MPDU size (Byte) on-air time [ms]		
				10 byte	50 byte	100 byte
UL-S (all)	15,12	362,97	15,12 ms per add. Byte in MPDU	363,0	816,7	1 572,9
DL-S4	1,47…2,68	13,23	26,47…48,21ms per add. Extension frame block (18 Byte)	43,5	129,2	227,5
DL-S3	5,88…10,71	52,93	105,87…192,83 ms per add. extension frame block (18 Byte)	173,9	516,7	909,9
DL-S1 DL-S2	11,76…21,43	105,87	211,73…385,65 ms per add. extension frame block (18 Byte)	347,8	1 033,5	1 819,9

In all sub-modes, a radio-burst is always followed by a radio transmission pause, thus implementing a certain duty cycle according to the used pattern. The on-air time of the uplink extension frame is extended by one radio-burst per additional byte of user data. The on-air time of the downlink extension frame with a fixed number of radio-bursts varies depending on the length of the payload to be transmitted.

Appendix Q.D (informative): Precoded GMSK using GFSK Transceiver

Q.D.1 GMSK Modulation using GFSK Modulator

GMSK can be generated using a GFSK modulator where the deviation frequency is adjusted to match a modulation index of 0.5. The modulation index for binary FSK is calculated using the formula

$$h = \frac{2 \cdot f_{dev}}{f_{chip}} \qquad \text{(Eq.Q.D.1)}$$

where f_{dev} is the deviation frequency and f_{chip} is the chip rate. When $h = 0.5$, we have that $f_{dev} = \frac{f_{chip}}{4}$. Hence, as an example, a GMSK signal with $f_{chip} = 125$ kcps can be generated using a GFSK modulator with a deviation frequency of $f_{dev} = \frac{f_s}{4} = 31.25$ kHz.

NOTE: To generate precoded GMSK using a GFSK transmitter, the data must also be precoded prior to GFSK modulation.

Q.D.2 Inverse Precoding

For certain types of GMSK/GFSK demodulators, the bits may remain precoded after demodulation. To recover the data bits the precoding must be reverted. The inverse precode operation is given by

$$d_k = d_{k-1} \oplus c_k \qquad \text{(Eq.Q.D.2)}$$

where d_k is the kth bit in the demodulated uplink radio burst bit stream $d_0, d_1, d_2, \ldots$, and c_k is the kth precoded bit (chip). The seed bit, d_{-1}, is applied in front of the first preamble bit.

The d_{-1} seed value is 0_b.

NOTE: Demodulation errors will propagate when applying inverse precoding. Hence, it is generally recommended to avoid demodulators that require inverse precoding.

Appendix Q.E (informative): Summary of Length Calculations of Burst Mode

This appendix provides a summary of the length calculations of Burst Mode in Table Q.E.1.

Table Q.E.1 – Length calculations for Burst Mode

Length name	Burst Type [b]	Equation	Range
PHY Payload [a]	All	L_P	5 … 255 bytes
		$B_P = 8 \cdot L_P$	40 … 2040 bits
7/8-padding	Multi-burst	$B_{pad78} = (-B_P)\text{modulo } 7$	0 … 6 bits
	Single burst, FEC rate 7/8		
FEC input	Multi-burst	$B_{FEC} = B_P + B_{pad78}$	42 … 2044 bits
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2	$B_{FEC} = B_P$	40 … 2040 bits
	Single burst, FEC rate 1/3		
Coded Payload	Multi-burst	$B_{CP} = B_{FEC} \cdot \frac{8}{7} + 8$	56 … 2344 bits
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2	$B_{CP} = B_{FEC} \cdot 2 + 8$	88 … 4088 bits
	Single burst, FEC rate 1/3	$B_{CP} = B_{FEC} \cdot 3 + 16$	136 … 6136 bits
Data	Multi-burst	$L_D = \frac{B_{CP}}{8}$	7 … 293 bytes
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2		11 … 511 bytes
	Single burst, FEC rate 1/3		17 … 767 bytes
Data A	Multi-burst	$L_{DA} = \left\lceil \frac{L_D}{2} \right\rceil$	4 … 147 bytes
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2		6 … 256 bytes
	Single burst, FEC rate 1/3		9 … 384 bytes
Data B	Multi-burst	$L_{DB} = L_D - L_{DA}$	3 … 146 bytes
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2		5 … 255 bytes
	Single burst, FEC rate 1/3		8 … 383 bytes
Preamble	All	$B_{PRE} = 32$	32 bits
Sync	All	$B_{SYNC} = 32$	32 bits
CL	All	$B_{CL} = 24$	24 bits

Length name	Burst Type [b]	Equation	Range
Midamble	All	$B_{MID} = 96$	96 bits
Coded Header	All	$B_{CH} = 96$	96 bits
Uplink Radio Burst	Multi-burst	$B_{UL} = B_{PRE} + B_{SYNC} + B_{CL} + 8 \cdot (L_{DA} + L_{DB}) + B_{MID} + B_{CH}$	336 … 2624 bits
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2		368 … 4368 bits
	Single burst, FEC rate 1/3		416 … 6416 bits
Downlink Radio Burst	Multi-burst	$B_{DL} = B_{PRE} + B_{SYNC} + B_{CH} + 8 \cdot L_D$	216 … 2504 bits
	Single burst, FEC rate 7/8		
	Single burst, FEC rate 1/2		248 … 4248 bits
	Single burst, FEC rate 1/3		296 … 6296 bits

[a] The *PHY Payload Length*, L_P, is indicated in the Coded Header.

[b] The *Burst Type*, is indicated in the Coded Header.

Appendix Q.F (informative): Centre Frequency Drift of Burst Mode

The centre frequency drift requirement reflects the necessity of having a stable carrier frequency under all conditions when transmitting precoded GMSK. Seen from a coherent receiver a centre frequency drift causes an unwanted phase change. A higher drift causes a faster phase change. If this phase change becomes too high, an erroneous reception will likely occur.

Q.F.1 Common Causes and Techniques to Reduce Centre Frequency Drift

A common cause of centre frequency drift in the endpoint transmitter stems from impairments on the RF reference clock. Instability on the RF reference clock voltage supply, start-up characteristics of the RF reference clock and heat transfer from transceiver to RF reference clock are some of the most common impairments.

The frequency/voltage coefficient is normally specified in the clock devices datasheets. Even small fluctuations of the voltage will cause noticeably frequency shifts which will translate into centre frequency drift on the transmitted signals. It is therefore important to use a hardware design which insures a stable voltage supply at all times.

As for start-up characteristics, there is a number of device options for reference clock, e.g. XOs, SPXOs, TCXO, etc. These devices each have different start-up characteristics which normally is not specified in the datasheets. There is sometimes specified a start-up time but it is not sufficient as it usually only specifies a time where the clock is within +/- 1 PPM of the final frequency.

In general, the passive component XOs have a faster settling time than TCXOs for instance. TCXOs are a crystal oscillators with a temperature-sensitive control loop which compensate the frequency-temperature characteristics of the crystal unit. The slower settling time is cause by the control loop which often uses several milliseconds to converge.

A simple technique to mitigate the drift caused by the XO devices is to add a “warm-up” period before transmitting a burst. The technique is very effective and can be used on all the different reference clock options.

If heat transfer from transceiver chip to the RF reference clock causes a centre frequency drift it can be mitigated by small changes of the PCB design. Often a very small change of position of the reference clock is enough to minimize the unwanted effect.

Appendix Q.G (informative): Splitting Mode Timing Overview

In contrast to Table Q.45, Table Q.G.1 this subclause shows information regarding the lower (ΔT_{min}) and upper (ΔT_{max}) range values in seconds. Due to the fact, that the conversion of time intervals from a number of symbols into seconds may cause numerical inaccuracies, the fourth column should only be taken as informative supplement. The numbers representing the physical time in seconds are rounded accordingly.

Table Q.G.1 – Uplink/downlink time intervals

Parameter	Associated Parameter Field	ΔT_{min} ... ΔT_{max} in *seconds*
t_{RO}	DL-AC (MAC Layer MElement_UA)	0,860 … 27,532
ΔT_{TSI}	TSI (DL PHY Payload)	0,053 … 6,67 (DL-S4) 0,108 … 13,3 (DL-S3) 0,215 … 26,7 (DL-S1/DL-S2)
ΔT_{dn}	TDN (DL PHY Payload)	0,053 … 7,0 (DL-S4) 0,108 … 14,0 (DL-S3) 0,215 … 28,0 (DL-S1/DL-S2)
ΔT_{hb}	THB (DL PHY Payload)	0 … 3,33 (DL-S4) 0 … 13,3 (DL-S3) 0 … 26,7 (DL-S1/DL-S2)
t_{RM}	RTRM (MAC Layer MElement_DA)	0,860 … 120

Working example: The transmission start time indicator (TSI) is communicated via the core frame PHY payload (see Q.2.5.4.2.1). The TSI field consists of 5 bits, which are interpreted as an unsigned integer number ranging from 0 to 31. The value r_{TSI} is calculated from the TSI value according to clause Q.2.5.4.2.4.

If e.g. the TSI field reports 01010$_b$ ($TSI = 10$), the mapped value becomes $r_{TSI} = 40$. Assuming DL-S3 mode, i.e. $N_{TAF} = 1$, the time offset ΔT_{TSI} is $20\,480$. For DL-S3 mode, the DL chip rate is $f_{chip} = 4\,760{,}742\text{cps}$, so that the physical time offset related is calculated according to

$$(20\,480\text{chips})/(4\,760{,}742\text{cps}) \approx 4{,}302\ sec.$$

Appendix Q.H (informative): Calculating the Initial Radio-Burst Times for DL-S4 and DL-S3

Q.H.1 Application Example for Table Q.57

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 Q.57 is illustrated in this subclause in terms of an example. The physical layer service data unit (PSDU) may hold a variable data length of up to 255 bytes. For this example, a PSDU size of $\mathrm{P} = 90$ bytes will be assumed. Using the formula from clause Q.2.5.7.5.2 for the calculation of the number of blocks

$$B = \left\lceil \frac{P}{24} \right\rceil \qquad \text{(Eq.Q.H.1)}$$

in an extension frame, this results in a value of $B = 4$ and for the remaining bytes $n_r = P - \left\lfloor \frac{P}{B} \right\rfloor \cdot B$ one yields $n_r = 2$. With

$$n_{byte}(b) = \begin{cases} \left\lfloor \frac{P}{B} \right\rfloor + 1, & for\ b \le n_r \\ \left\lfloor \frac{P}{B} \right\rfloor, & for\ b > n_r \end{cases} \qquad for\ \ b \in \{1, \dots 4\} \qquad \text{(Eq.Q.H.2)}$$

the number of PSDU data bytes assigned to one block results in $n_{byte} = \{23,23,22,22\}$. 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, see Q.2.5.3.2.2.3.2) 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 and the whole block is encoded by a 1/3-rate convolutional code with constraint length 7 as described in [ETSI 103 357], clause 6.4.5.4.2. This leads to

$$n_{bit}^{coded}(b) = \left(8 \cdot n_{byte}(b) + 10 + 6\right) \cdot 3 \qquad for\ \ b \in \{1, \dots 4\} \qquad \text{(Eq.Q.H.3)}$$

encoded bits after the forward error correction assigned to block b. n_{bit}^{coded} ranges from 216 to 624 bits. For above 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 [ETSI 103 357], clause 6.4.4.6) is done according to Q.2.5.7.5.2 by calculating $d_B(m,s)$ and $d_C(m,s)$. The initial transmission times are calculated for the individual blocks according to the relationship:

$$T_{RB}(b,s) = 28 + \sum_{m=0}^{11} int\left(d_c(m,s-1) < n_{bit}^{coded}(b)\right) + int\left(d_B(m,s) < n_{bit}^{coded}(b)\right) \qquad \text{(Eq.Q.H.4)}$$

$$for\ \ b \in \{1, \dots 4\}, \quad s \in \{1,2,4,5,7,8,10,11,13,14,16,17\}$$

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 Q.36), 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 Q.H.1. 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 $T_{RB}(b,s), b \in \{1, \dots 4\},\ s \in \{3,6,9,12,15\}$ can be taken from Table Q.57 or Table Q.58.

Table Q.H.1 – Initial Radio-burst time set of Pattern Group for downlink modes DL-S4 and DL-S3

s / b	$T_{RB}(\mathbf{b}, s)$ (in multiples of chip time periods)																
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	50	50		49	49		50	50		49	49		50	50		49	49
2	50	50		49	49		50	50		49	49		50	50		49	49
3	48	48		48	48		48	48		48	48		48	48		48	48
4	48	48		48	48		48	48		48	48		48	48		48	48

Appendix Q.I (informative): Calibration of Low-Frequency and High-Frequency crystal

The calibration of low frequency (LF) crystal and high frequency (HF) crystal is a method to minimize the overall tolerances of an OMS end-device to enable a precise downlink reception timing for an SDR-based reception with Splitting Mode. The method is essential for any Splitting Mode downlink and therefore also beneficial for the combination of a Burst Mode uplink with a Splitting Mode downlink and is described as follow:

1. While doing the transmission of the first radio burst for Burst Mode uplink, a calibration measurement of the LF and HF crystal is done. The information of the different offsets in ppm is used to adjust the LF crystal and achieve an adjusted tolerance of +/- 2 ppm to the tolerance in ppm of the HF crystal (see Figure Q.I.1).

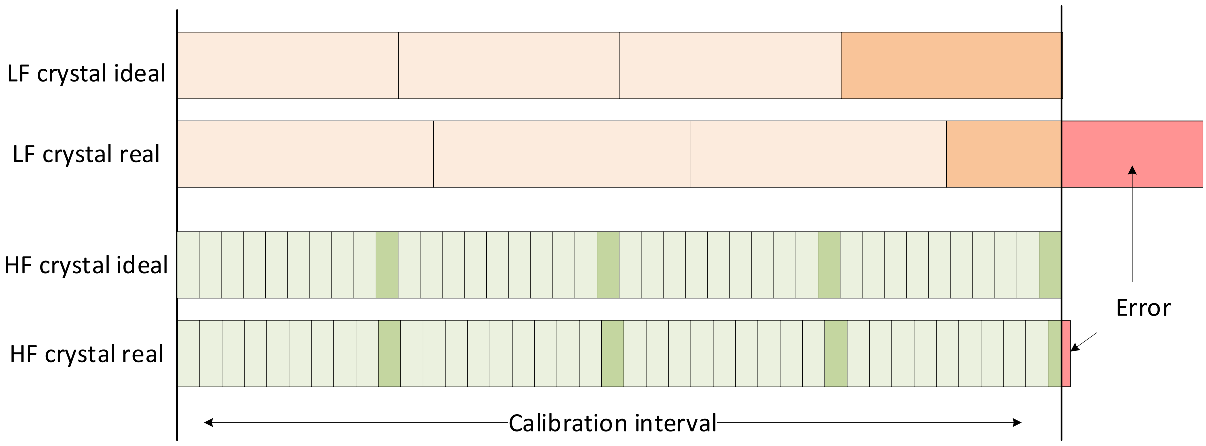

Figure Q.I.1 - Calibration principle

2. The transmission of the following two radio bursts of Burst Mode as well as the reception of the core frame is now based on reference timing from the calibrated LF crystal. Depending on the necessary calibration time (to reach the achieved tolerance) and the duration time of the first burst it might be necessary for the OMS end-device to start the calibration before the first burst is transmitted (see Figure Q.I.2). The active crystal times are equivalent to the power consumption. This means that if both crystals are active a high-power consumption is necessary whereas if only LF crystal is active the power consumption is low.

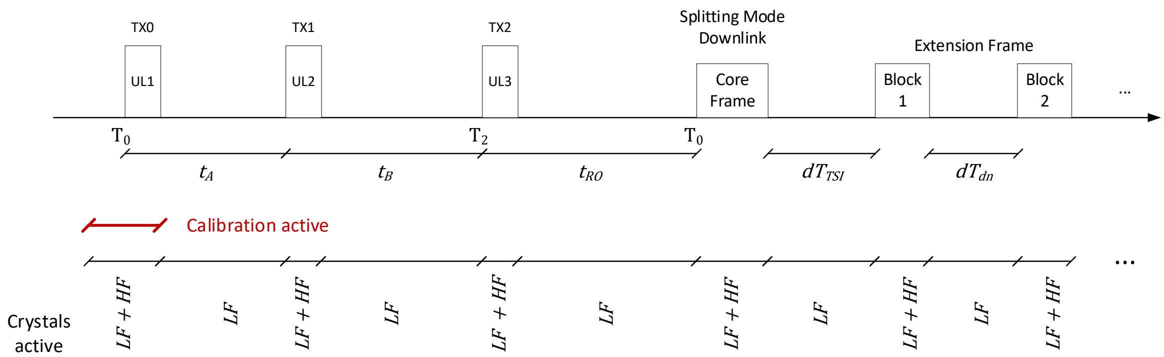

Figure Q.I.2 - Calibration timing overview

NOTE: During the core frame and the extension frame blocks of Splitting Mode downlink LF and HF is only partly active as between the single radio bursts HF can be deactivated to lower down the power consumption. An activated ΔT_{hb} would even allow to deactivate HF in the middle of each burst.

3. The SDR gateway must estimate the frequency of the received radio burst of Burst Mode uplink. This can be done even only one of the three radio bursts is correctly received. The accuracy of this frequency estimation shall have maximum +/- 1 ppm offset referred to the absolute gateway HF crystal frequency.
4. Now the gateway knows the frequency offset of the OMS end-device in ppm and as the LF crystal of the OMS end-device haven been calibrated on the HF crystal, the gateway also knows the timing offset (within the limits of calibration accuracy).
5. With both information the gateway can now adapt the downlink so that the downlink transmission radio frequency fits to the reception radio frequency of the OMS end-device and also adjust all applicable timings (t_{RO}, $T_{RB}(s)$, ΔT_{TSI}, ΔT_{dn}, ΔT_{hb}) so that it fits to the expected timings the OMS end-device.

Example: The HF crystal has a maximum allowed tolerance of 20 ppm. By calibration of the LF and HF crystal a tolerance of 18 ppm for the LF crystal can be achieved worst-case for the time intervals of t_A, t_B and t_{RO} after transmission of first radio burst of Burst Mode.

By estimating the received frequency of the radio burst, the gateway knows that the HF crystal of the OMS end-device has a relative offset of maximum 26 ppm (20 ppm from end-device, -5 ppm from gateway and 1 ppm from estimation). Now the gateway will adjust the ideal downlink frequency by 26 ppm to match the offset from OMS end-device.

Also, the time is adjusted by 26 ppm and therefore having a total relative error referred to the calibrated OMS end-device of 3 ppm (-5 ppm plus 26 ppm minus 18 ppm). This is far below the maximum error of 13 ppm which is allowed for a DL-S4 reception timing tolerance.

Appendix Q.J (informative): MAC Sequence Diagrams

Q.J.1 Piggyback Examples

Q.J.1.1 Examples of Unidirectional Piggybacked MAC Transmissions

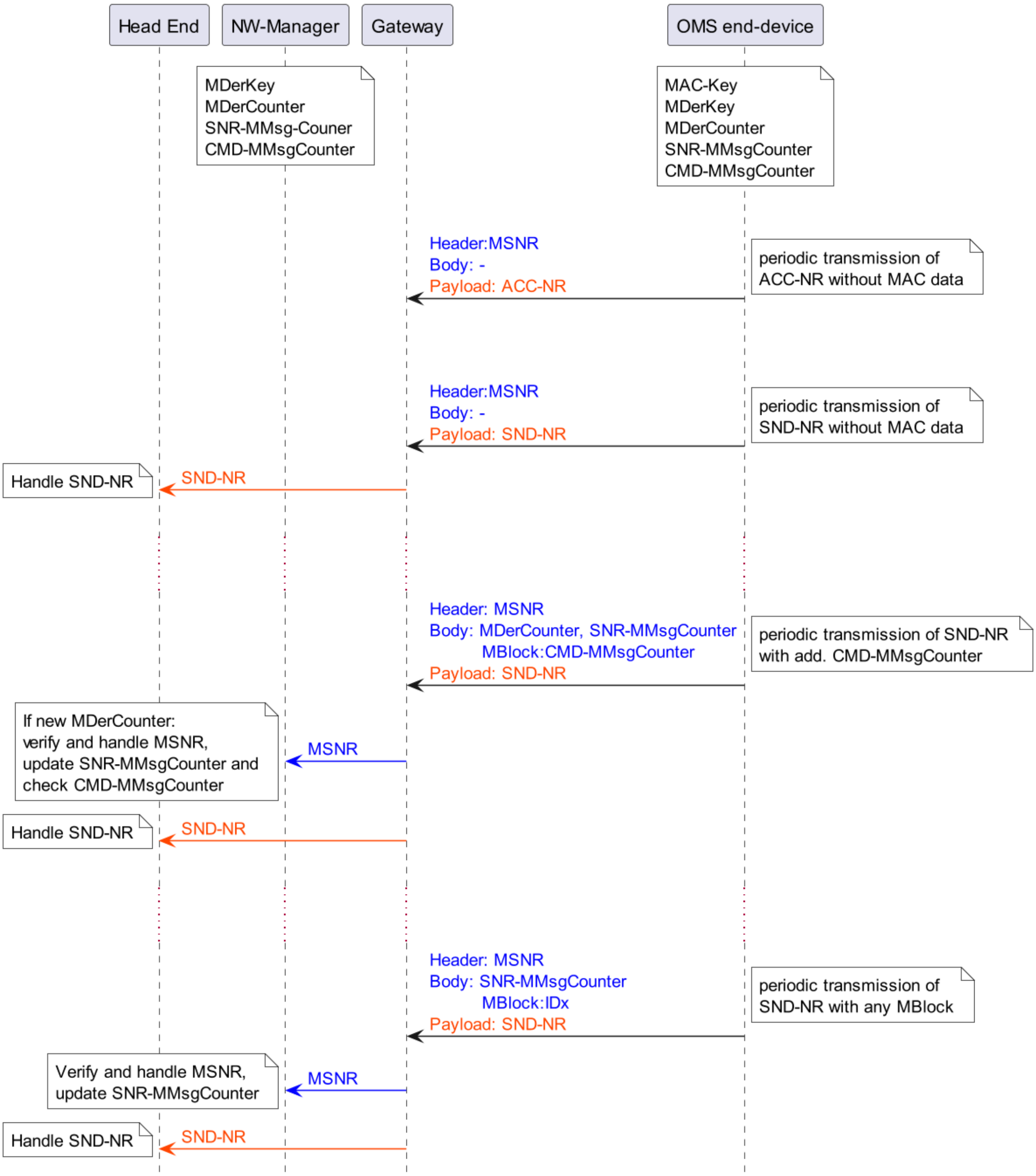

Figure Q.J.1: Piggybacked MAC Data in unidirectional

Q.J.1.2 Examples of Bidirectional Piggybacked MAC Transmissions

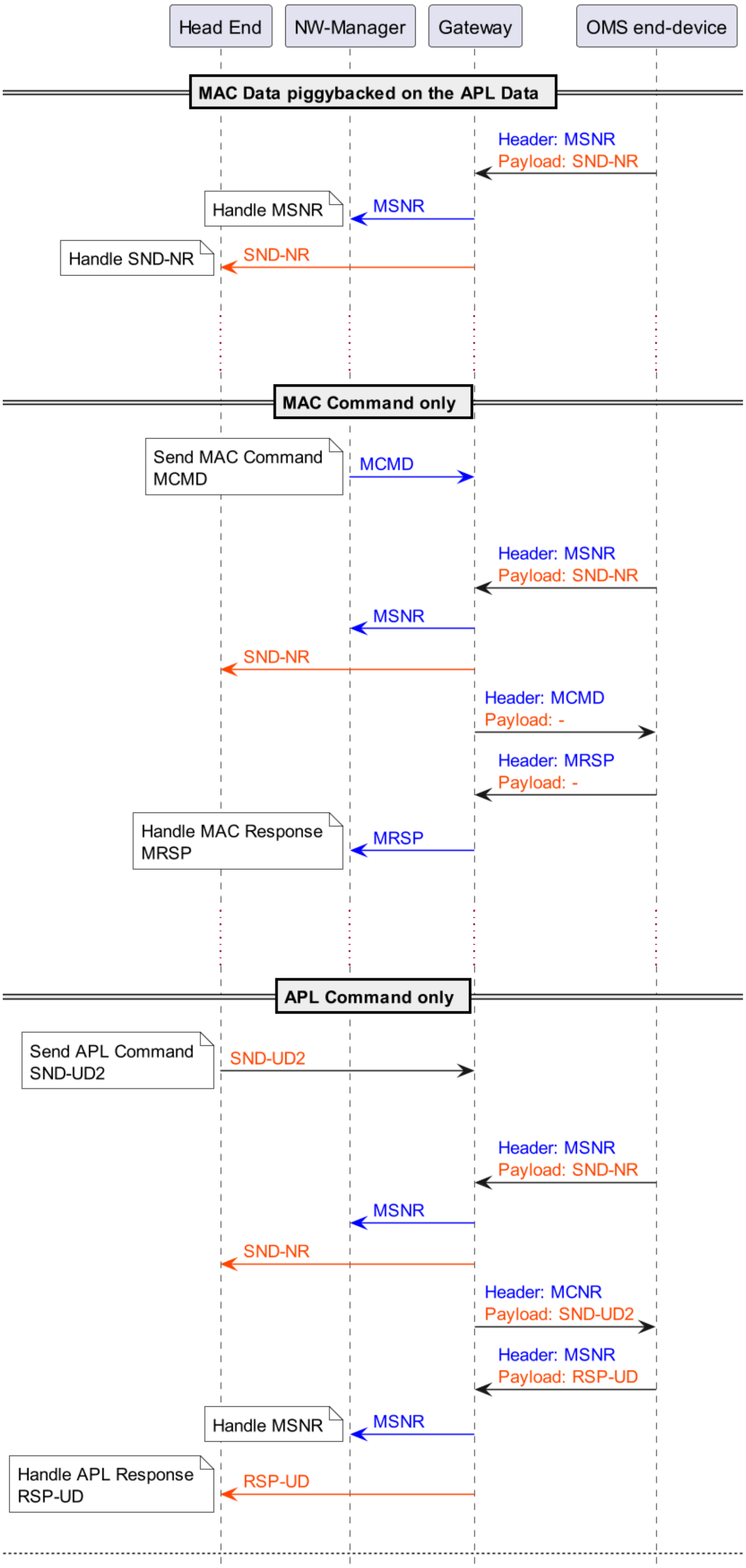

Figure Q.J.2: Piggybacked MAC Data in bidirectional messages.

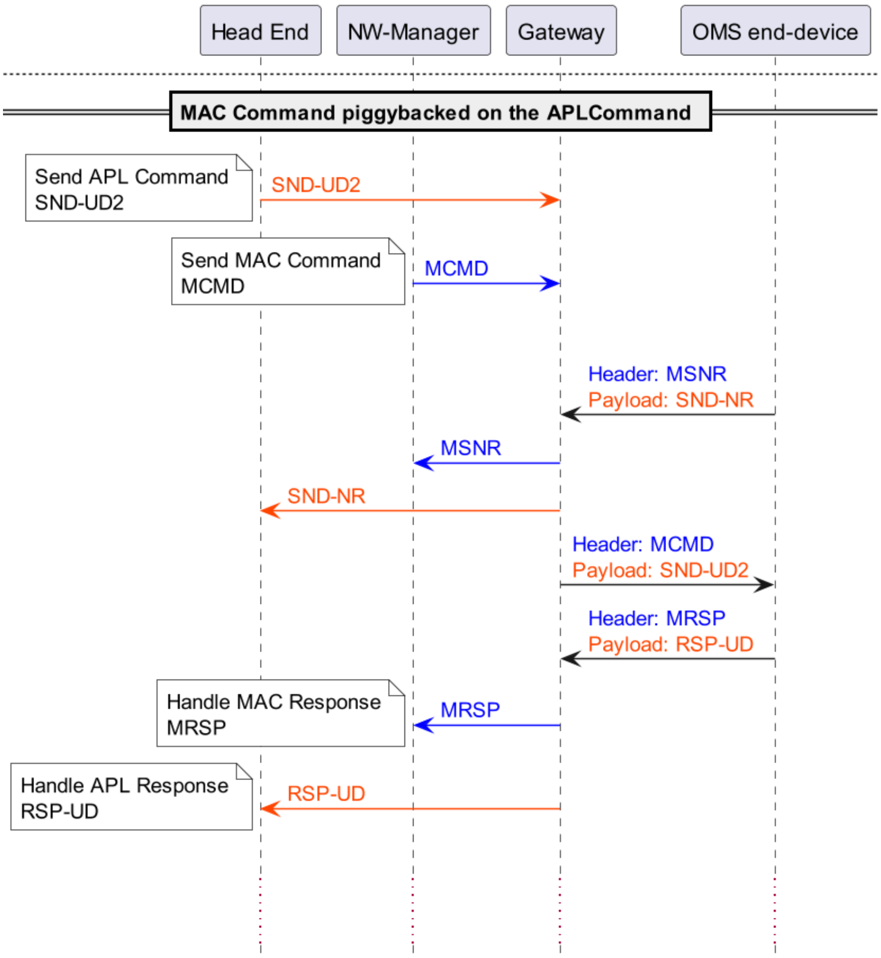

Figure Q.J.2 (continued): Piggybacked MAC Data in bidirectional messages.

Q.J.2 OMS-LPWAN Multi-burst Examples

Q.J.2.1 Scenarios with Transmission Errors

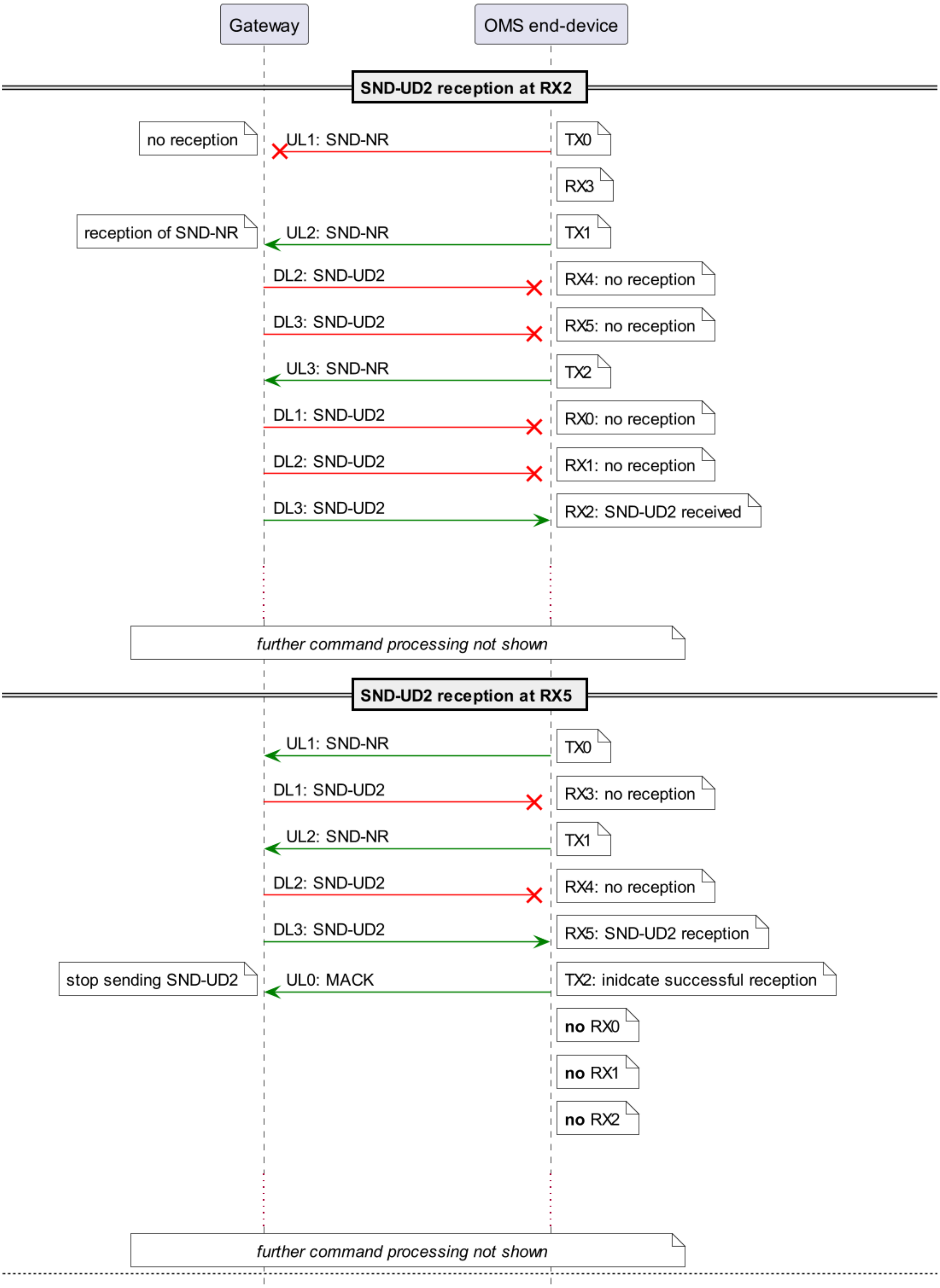

Figure Q.J.3: Multi-burst commands with transmission errors

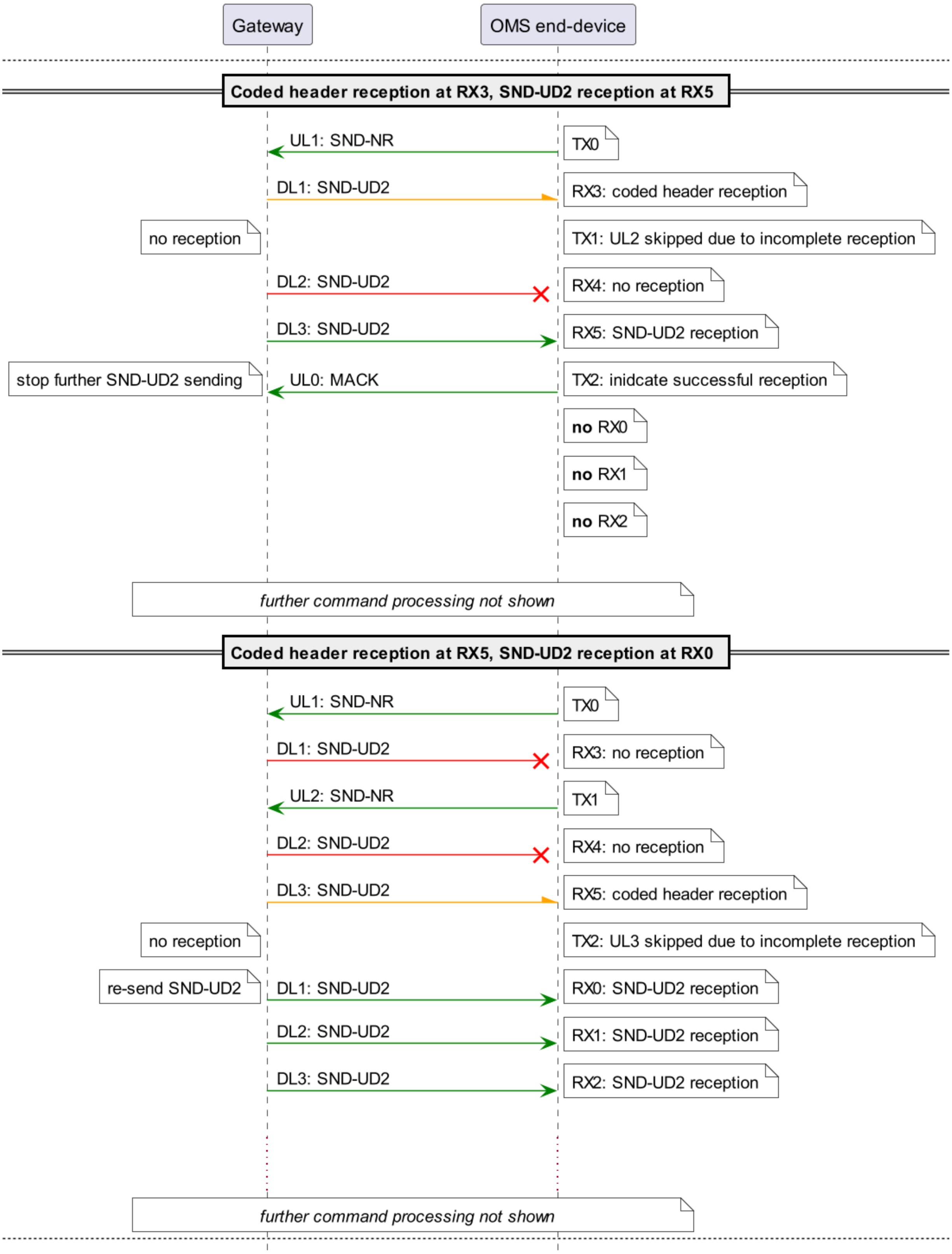

Figure Q.J.3 (continued): Multi-burst commands with transmission errors

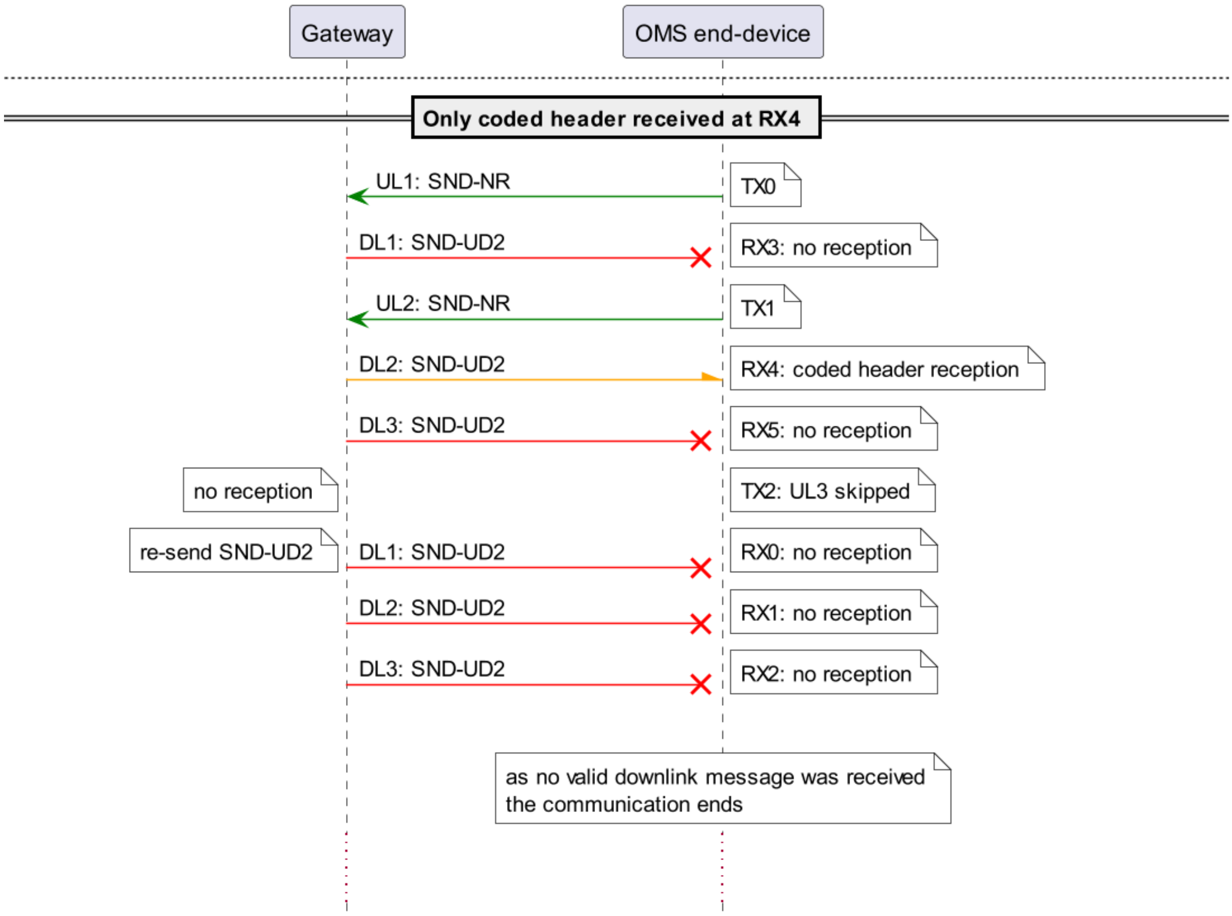

Figure Q.J.3 (continued): Multi-burst commands with transmission errors

Q.J.2.2 Optimised Transmission Sequence for Commands

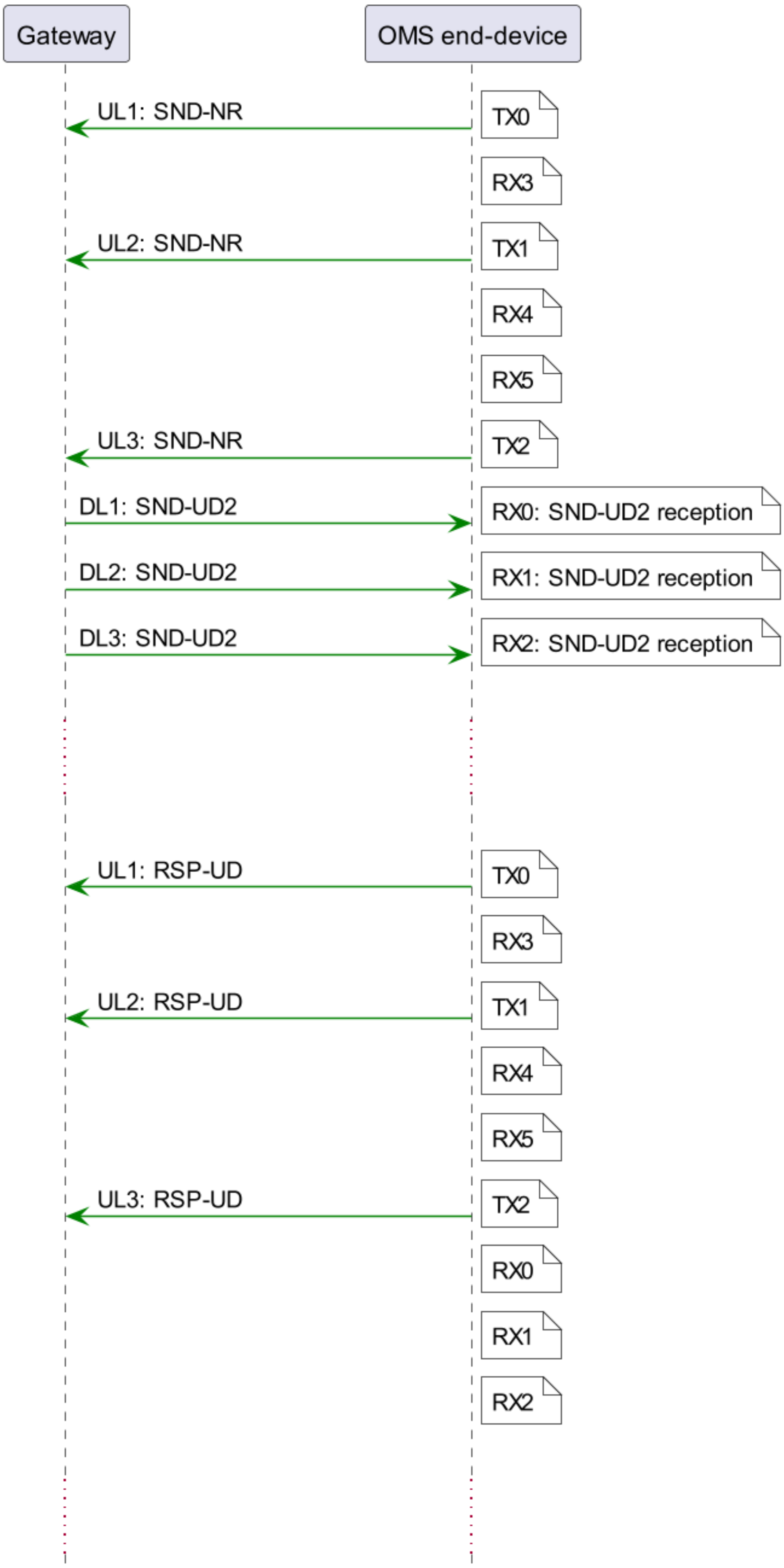

Figure Q.J.4: Transmission Sequence without MAC optimization

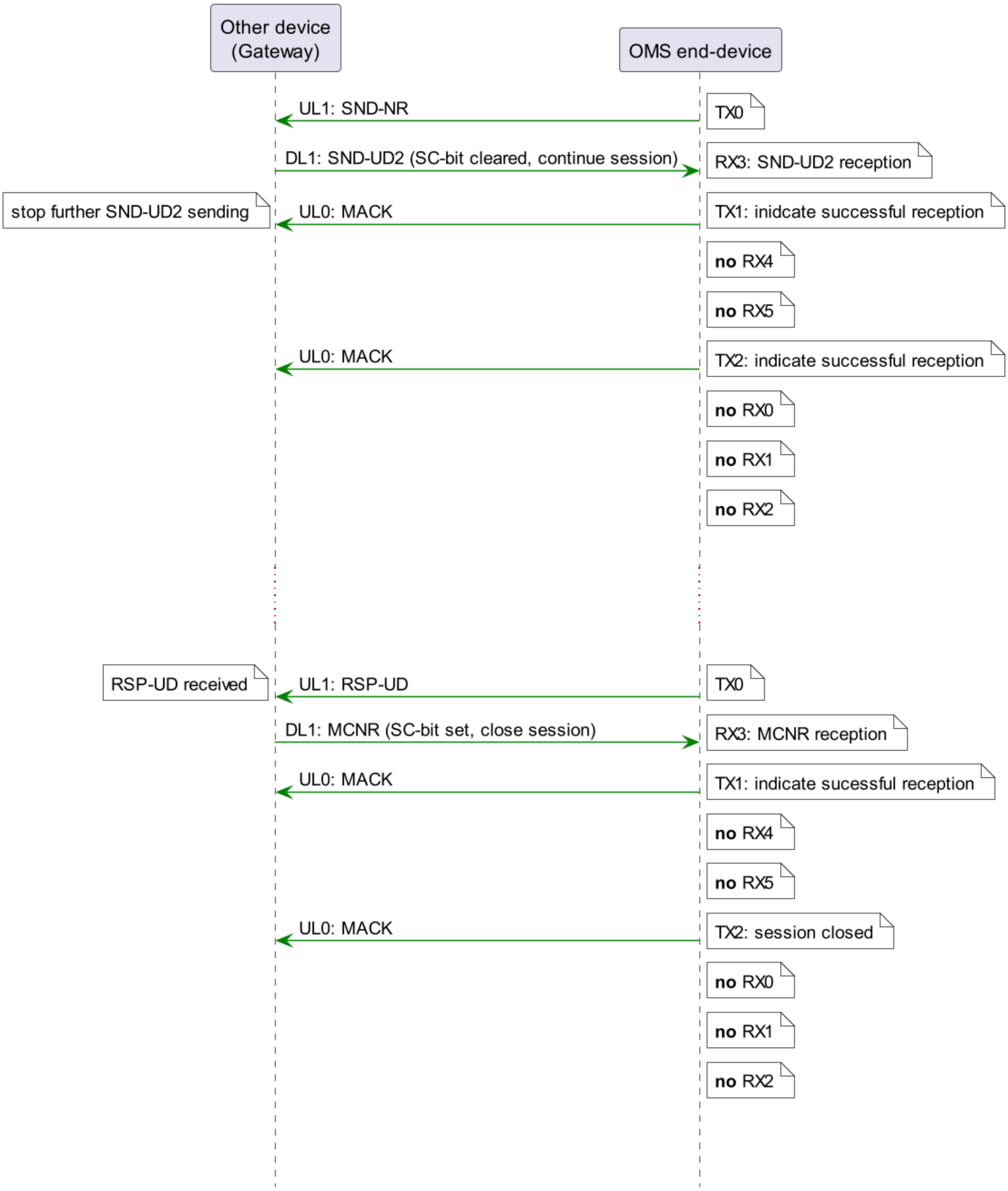

Figure Q.J.5: Transmission Sequence with MAC optimization

Q.J.3 MMsgCounter Synchronisation

Q.J.3.1 Example for Start Up

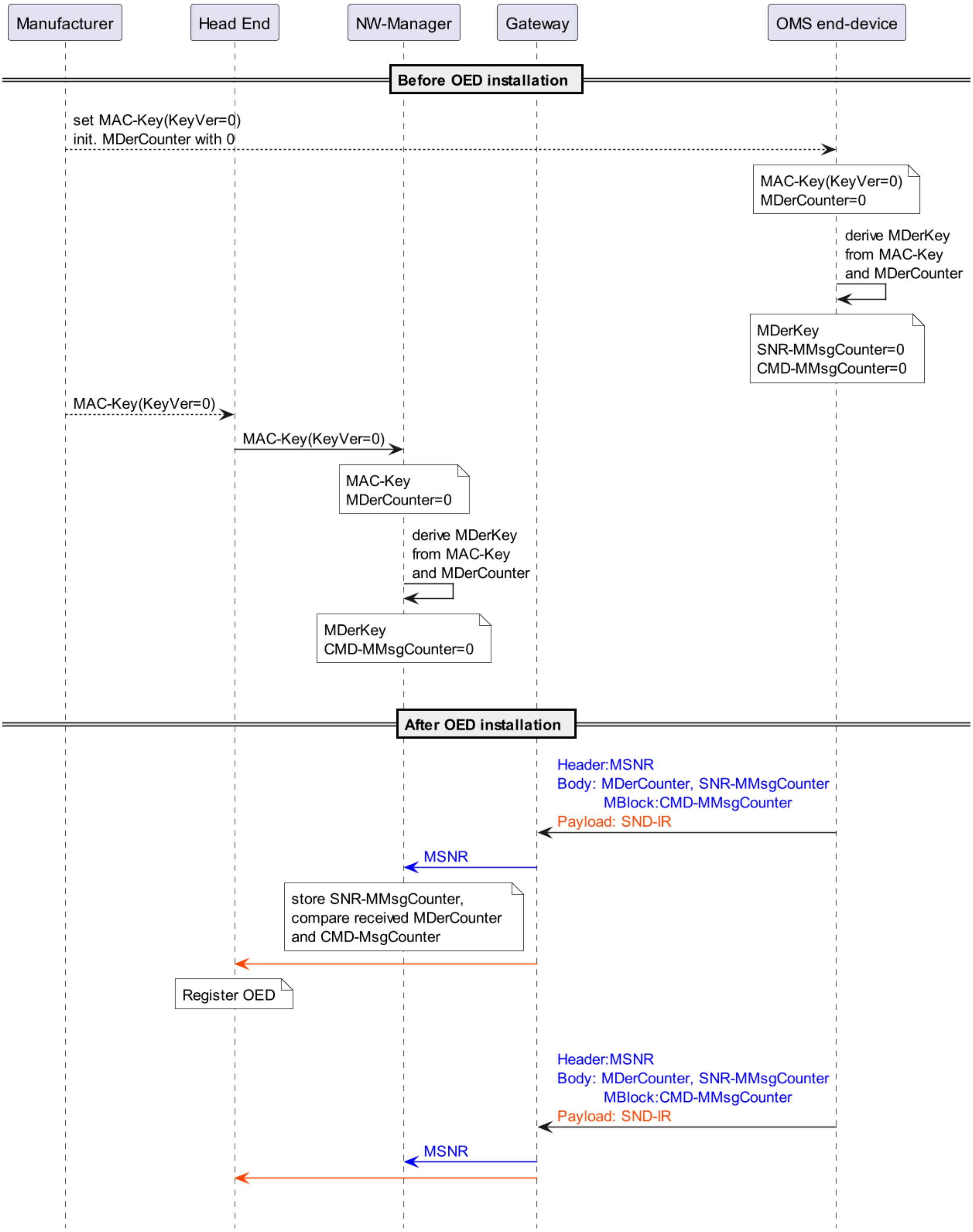

Figure Q.J.6: Installation process with SND-IR

Q.J.3.2 Examples for MAC Counters

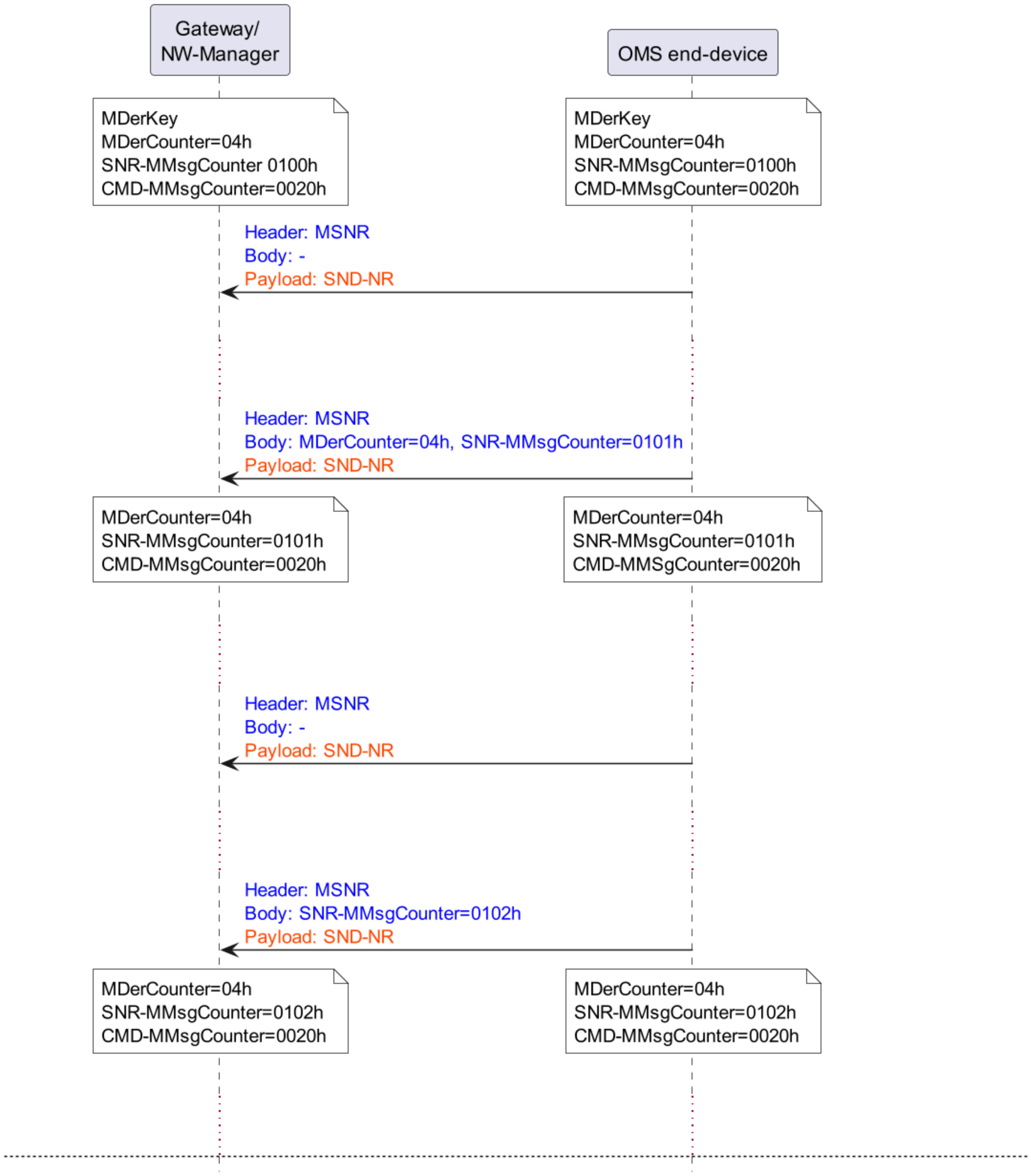

Figure Q.J.7: MAC Counter Handling for SND-MMsgCounter

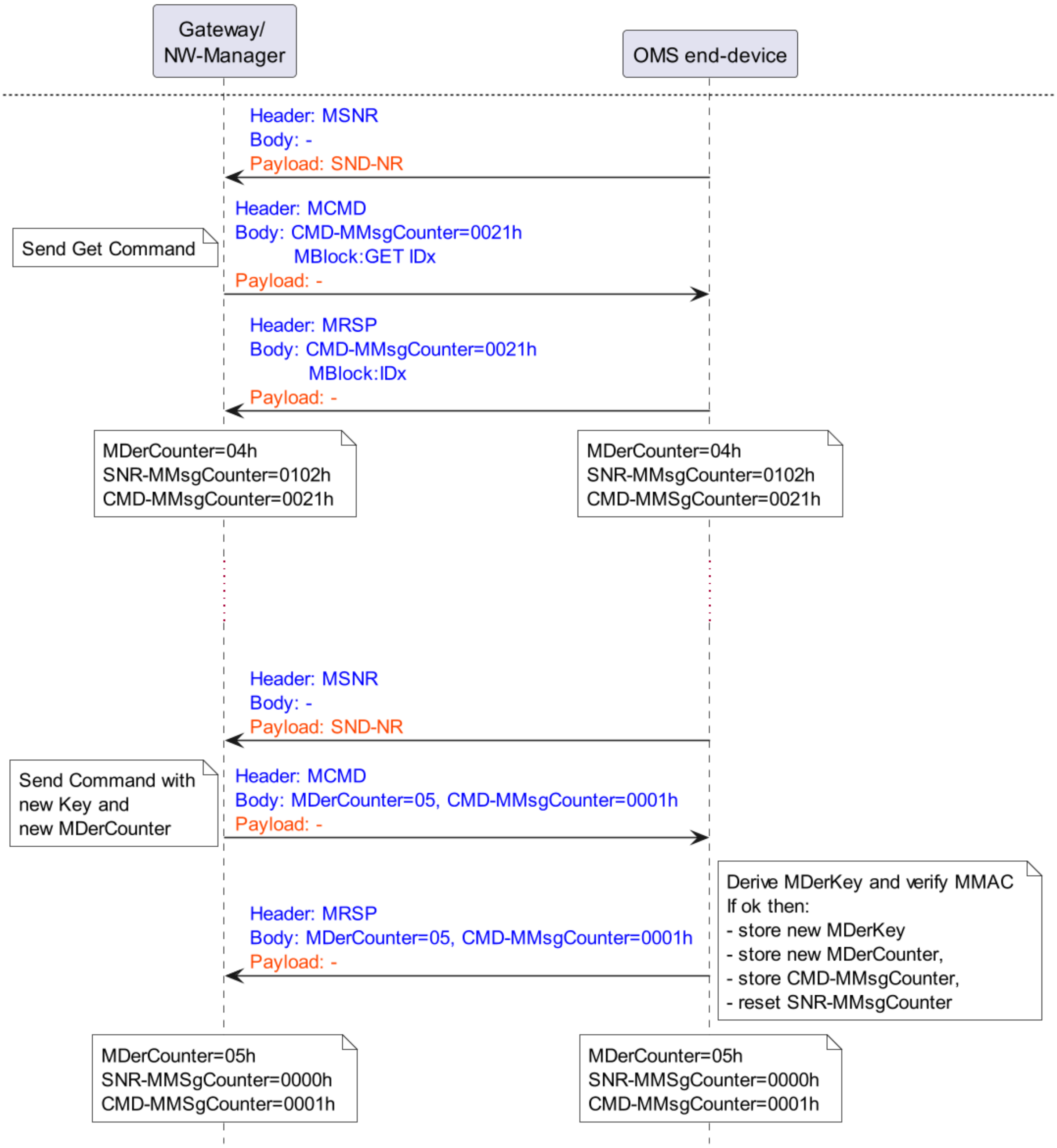

Figure Q.J.8: MAC Counter Handling for CMD-MMsgCounter

Q.J.4 Response Timeout Example

The following Figure Q.J.9 shows the different timeouts of the command response between the application and the response buffer of the Link Layer.

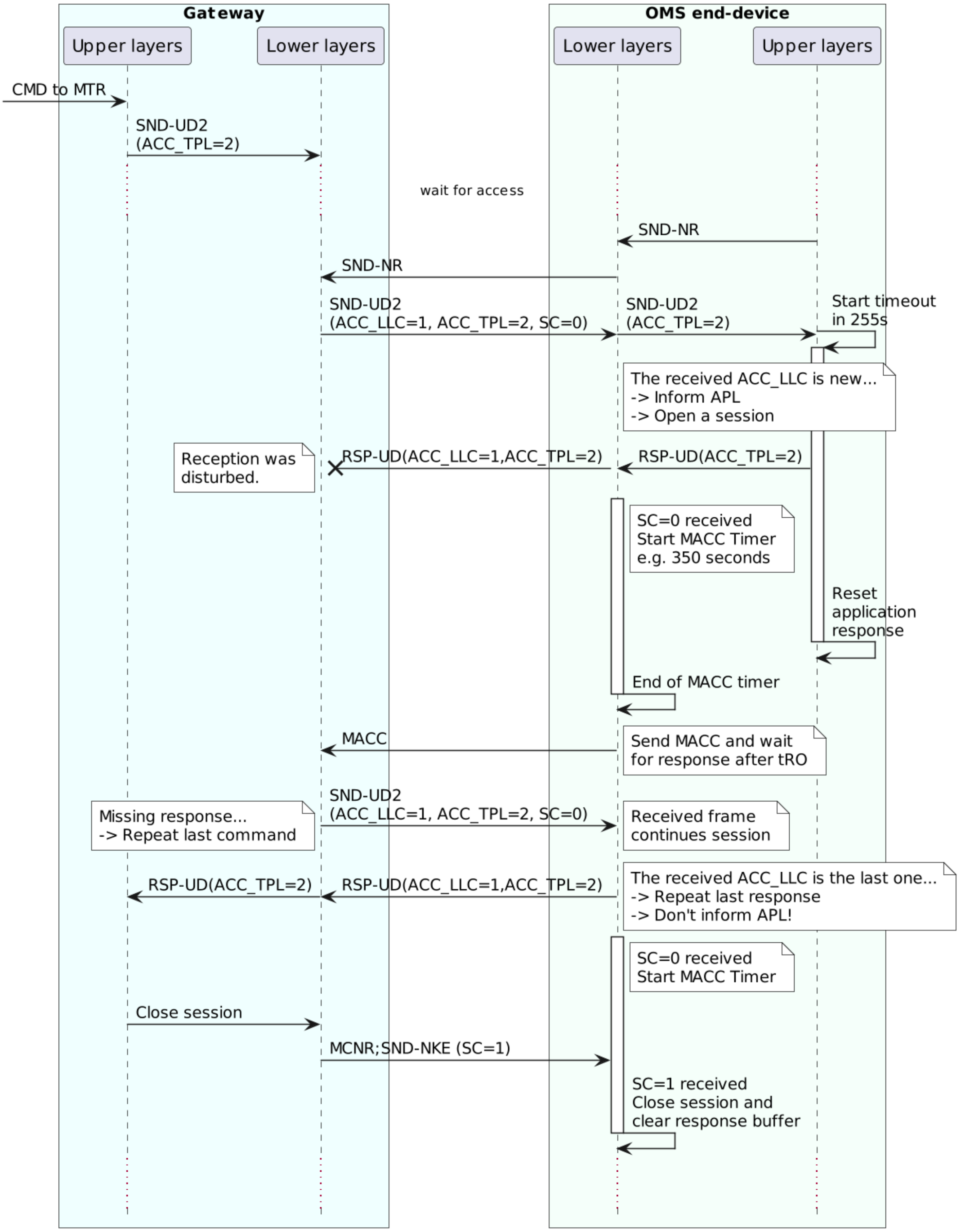

Figure Q.J.9: OED Response Timeout

Q.J.5 Link Management Sequences

Q.J.5.1 Link Management Information Flow

Example: During link management uplink parameters are optimized. Uplink power is reduced, while downlink parameters are unchanged.

The OMS end-device starts to lose downlink frames, and the fallback counter decreases accordingly. The link is eventually lost, and the OMS end-device performs a “soft” fallback.

After the fallback the OMS end device reports the next fallback state to be “hard”.

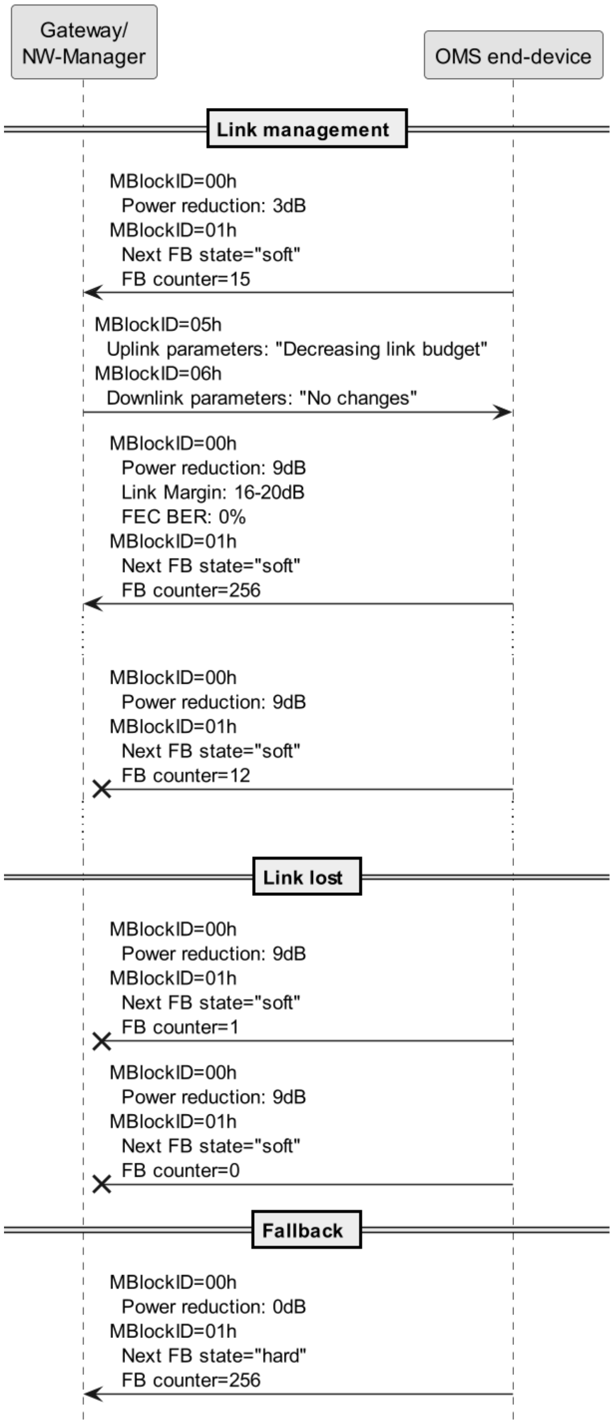

Figure Q.J.10: Link Management flow

Q.J.5.2 Temporary Fallback Sequence

Example: An upcoming system maintenance predicts that OMS end-devices cannot be served within the permanent fallback counter cycle (i.e. 400 unexploited access opportunities). A higher temporary fallback value (20.000) is programmed to avoid fallback. The permanent fallback counter value is loaded on first exploited access opportunity.

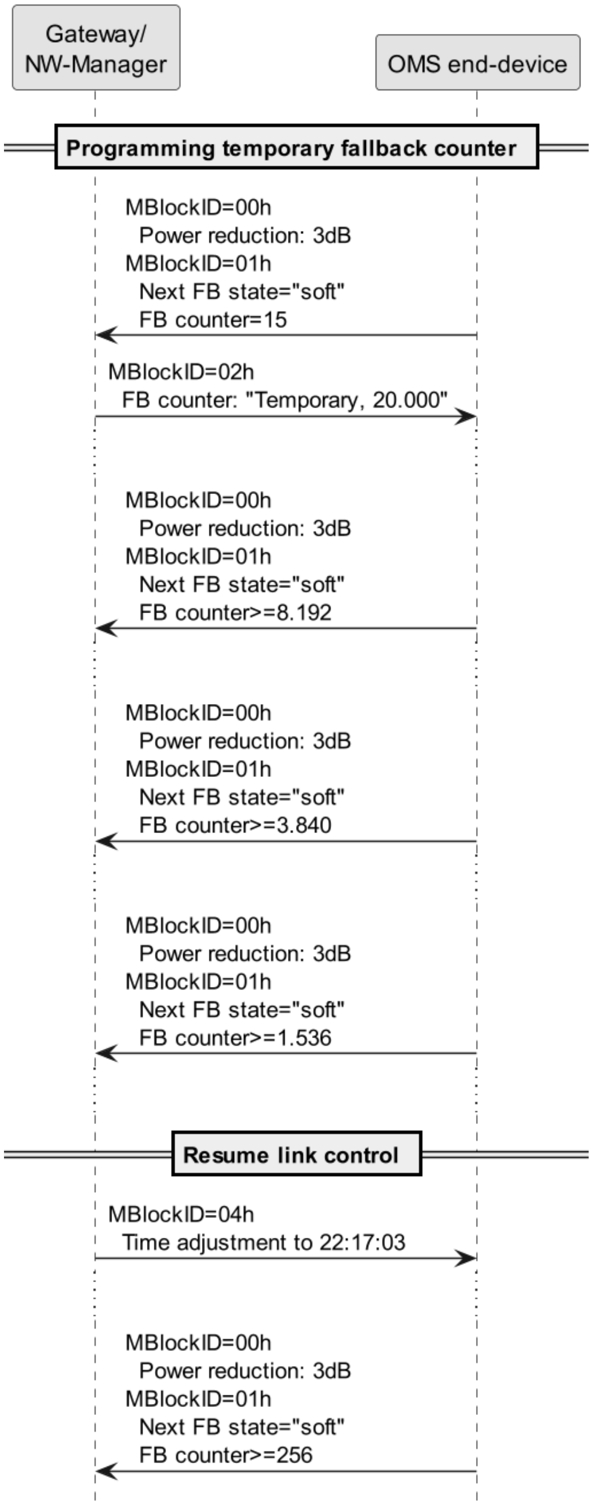

Figure Q.J.11: Temporary fallback programming sequence

Appendix Q.K (informative): Frame Examples

Q.K.1 General

The examples in this appendix apply the persistent MAC Key shown in Table Q.K.1.

Table Q.K.1 – Persistent MAC Key

Persistent MAC Key
= 10 11 12 13 14 15 16 17 18 19 1A 1B 1C 1D 1E 1F

With an MDerCounter value of 1, this results in the MAC Derivation Key shown in Table Q.K.2.

Table Q.K.2 – MAC Derivation Key

MAC Derivation Key MDerKey
= CMAC(MAC Key, MDerCounter || M-field || Ident No || padding) = CMAC(MAC Key, 01||A7||3D||78||56||34||12||09||09||09||09||09||09||09||09||09) = C1 6A 16 81 7B 37 B0 8F 61 6A A7 ED 9E 74 68 50

Q.K.2 Send No Reply Example

This example (see following Table Q.K.3) shows a regular uplink for a unidirectional OMS end-device. It applies the minimum size of the MAC layer.

Table Q.K.3 – Uplink MSNR, SND-NR

Byte No	Field Name	OMS LPWAN frame Content	OMS end-device -> GW Bytes [hex] plain	OMS end-device -> GW Bytes [hex] secured	Layer
1	MHCTL[0]	MSNR		00h	MAC
2	LC[0]-Field	S, ULP, ANP,TAP, CFP		5Bh	LLC(Format C)
3	C-Field	Send - No Reply		44h	
4	M-Field	Manufacturer code		A7h	
5	M-Field	Manufacturer code		3Dh	
6	A-Field	Ident No LSB (BCD)		78h	
7	A-Field	Ident No (BCD)		56h	
8	A-Field	Ident No (BCD) (= 12345678)		34h	
9	A-Field	Ident No MSB (BCD)		12h	
10	A-Field	Version (or Generation number)		15h	
11	A-Field	Device type (Medium = Gas)		03h	
12	Access No.	LLC-Access Counter of Meter		75h	
13	CI Field	Authentication and Fragmentation layer		90h	AFL
14	AFLL	AFL Length (all AFL bytes after AFLL)		0Fh	
15	FCL	Fragmentation Control Field (LSB)		00h	
16	FCL	Fragmentation Control Field (MSB)		2Ch	
17	MCL	Message Control Field		25h	
18	MCR	Message Counter C (LSB)		B3h	
19	MCR	Message Counter C		0Ah	

20	MCR	Message Counter C (e.g.=2739)		00h	
21	MCR	Message Counter C (MSB)		00h	
22	MAC	AES-CMAC (MSB)		21h	
23	MAC	AES-CMAC		92h	
24	MAC	AES-CMAC		4Dh	
25	MAC	AES-CMAC		4Fh	
26	MAC	AES-CMAC		2Fh	
27	MAC	AES-CMAC		B6h	
28	MAC	AES-CMAC		6Eh	
29	MAC	AES-CMAC (LSB)		01h	
30	CI	CI-Field		7Ah	TPL
31	ACC	Access number (TPL)		75h	
32	STS	Status		00h	
33	CF	Configuration field (LSB)		20h	
34	CF	Configuration field (MSB)		07h	
35	CFE	Configuration field extension		10h	
36	AES-Verify	Decryption verification	2Fh	90h	
37	AES-Verify	Decryption verification	2Fh	58h	
38	DR1 DIF	Curr. meter reading	0Ch	47h	APL
39	DR1 VIF	Curr. meter reading	14h	5Fh	
40	DR1 Value	Curr. meter reading	27h	4Bh	
41	DR1 Value	Curr. meter reading	04h	C9h	
42	DR1 Value	Curr. meter reading	85h	1Dh	
43	DR1 Value	Curr. meter reading	02h	F8h	
44	DR2 DIF	Curr. date/time	04h	78h	
45	DR2 VIF	Curr. date/time	6Dh	B8h	
46	DR2 Value	Curr. date/time	32h	0Ah	
47	DR2 Value	Curr. date/time	37h	1Bh	
48	DR2 Value	Curr. date/time	1Fh	0Fh	
49	DR2 Value	Curr. date/time	15h	98h	
50	DR3 DIF	Curr. status	02h	B6h	
51	DR3 VIF	Curr. status	FDh	29h	
52	DR3 VIFE	Curr. status	17h	02h	
53	DR3 Value	Curr. status	00h	4Ah	
54	DR3 Value	Curr. status	00h	ACh	
55	Dummy	Fill Byte due to AES	2Fh	72h	
56	Dummy	Fill Byte due to AES	2Fh	79h	
57	Dummy	Fill Byte due to AES	2Fh	42h	
58	Dummy	Fill Byte due to AES	2Fh	BFh	
59	Dummy	Fill Byte due to AES	2Fh	C5h	
60	Dummy	Fill Byte due to AES	2Fh	49h	
61	Dummy	Fill Byte due to AES	2Fh	23h	
62	Dummy	Fill Byte due to AES	2Fh	3Ch	
63	Dummy	Fill Byte due to AES	2Fh	01h	
64	Dummy	Fill Byte due to AES	2Fh	40h	
65	Dummy	Fill Byte due to AES	2Fh	82h	
66	Dummy	Fill Byte due to AES	2Fh	9Bh	
67	Dummy	Fill Byte due to AES	2Fh	93h	

68	MAC-CRC	CRC (32 bit)		2Bh	MAC
69	MAC-CRC			E5h	
70	MAC-CRC			B9h	
71	MAC-CRC			B7h	

Q.K.3 Pure MAC Examples

Table Q.K.4 – Uplink MACK

Byte No		OMS LPWAN frame	OMS end-device -> GW	Layer
	Field Name	Content	Bytes [hex]	
			plain	
1	MHCTL[0]	MACK	09h	MAC
2	MAC-CRC	CRC (32 bit)	83h	
3	MAC-CRC		78h	
4	MAC-CRC		CFh	
5	MAC-CRC		C7h	

Table Q.K.5 – Uplink MERR

Byte No		OMS LPWAN frame	OMS end-device -> GW	Layer
	Field Name	Content	Bytes [hex]	
			plain	
1	MHCTL[0]	MERR, EP	42h	MAC
2	MElement_UA	DL-Splitting, DL-AC#1	22h	
3	LC[0]-Field	TAP	02h	LLC(Format C)
4	M-Field	Manufacturer code	A7h	
5	M-Field	Manufacturer code	3Dh	
6	A-Field	Ident No LSB (BCD)	78h	
7	A-Field	Ident No (BCD)	56h	
8	A-Field	Ident No (BCD) (= 12345678)	34h	
9	A-Field	Ident No MSB (BCD)	12h	
10	A-Field	Version (or Generation number)	15h	
11	A-Field	Device type (Medium = Gas)	03h	
12	MAC-CRC	CRC (32 bit)	9Fh	MAC
13	MAC-CRC		07h	
14	MAC-CRC		FCh	
15	MAC-CRC		0Fh	

Table Q.K.6 – Downlink MCMD

Byte No	Field Name	Content	GW->OMS end-device Bytes [hex] plain	GW->OMS end-device Bytes [hex] secured	Layer
		OMS LPWAN frame			
1	MHCTL[0]	MCMD, BP		2Dh	MAC
2	MBodyCTL	MDCP,SP,ML=8bytes		68h	
3	MDerCounter	MAC derivation counter		01h	
4	MMsgCounter	CMD-MMsgCounter		37h	
5	MMsgCounter	CMD-MMsgCounter		01h	
6	MMAC	AES-CMAC		40h	
7	MMAC	AES-CMAC		A8h	
8	MMAC	AES-CMAC		53h	
9	MMAC	AES-CMAC		A8h	
10	MBlock0	Get Link Status	00h	93h	
11	LC[0]-Field	RAP		04h	LLC(Format C)
12	M2-Field	Manufacturer code		A7h	
13	M2-Field	Manufacturer code		3Dh	
14	A2-Field	Ident No LSB (BCD)		78h	
15	A2-Field	Ident No (BCD)		56h	
16	A2-Field	Ident No (BCD) (= 12345678)		34h	
17	A2-Field	Ident No MSB (BCD)		12h	
18	A2-Field	Version (or Generation number)		15h	
19	A2-Field	Device type (Medium = Gas)		03h	
20	MAC-CRC	CRC (32 bit)		51h	MAC
21	MAC-CRC			E4h	
22	MAC-CRC			A0h	
23	MAC-CRC			D6h	

Q.K.4 Piggyback Examples

MAC Layer: MCMD
Upper Layer: REQ-UD2

Table Q.K.7 – Downlink MCMD, REQ-UD2

Byte No	Field Name	Content	GW->OMS end-device Bytes [hex] plain	GW->OMS end-device Bytes [hex] secured	Layer
		OMS LPWAN frame			
1	MHCTL[0]	MCMD, BP		2Dh	MAC
2	MBodyCTL	MDCP,SP,ML=8bytes		68h	
3	MDerCounter	MAC derivation counter		01h	
4	MMsgCounter	CMD-MMsgCounter		38h	
5	MMsgCounter	CMD-MMsgCounter		01h	
6	MMAC	AES-CMAC		D4h	
7	MMAC	AES-CMAC		EFh	
8	MMAC	AES-CMAC		39h	
9	MMAC	AES-CMAC		BCh	
10	MBlock0	Get Link Status	00h	31h	
11	LC[0]-Field	ULP, ANP, RAP, CFP		1Dh	LLC

12	C-Field	Request user data class 2		7Bh	
13	M2-Field	Manufacturer code		A7h	
14	M2-Field	Manufacturer code		3Dh	
15	A2-Field	Ident No LSB (BCD)		78h	
16	A2-Field	Ident No (BCD)		56h	
17	A2-Field	Ident No (BCD) (= 12345678)		34h	
18	A2-Field	Ident No MSB (BCD)		12h	
19	A2-Field	Version (or Generation number)		15h	
20	A2-Field	Device type (Medium = Gas)		03h	
21	Access No.	LLC-Access		08h	
22	CI Field	Pure TPL (short header)		93h	TPL
23	Access No.	TPL-Access number of GW		75h	
24	Status	GW State RSSI level (-84dBm)		17h	
25	Config Field	0000CCRHb		00h	
26	Config Field	BASMMMMMb		00h	
27	MAC-CRC	CRC (32 bit)		DAh	MAC
28	MAC-CRC			CEh	
29	MAC-CRC			F8h	
30	MAC-CRC			3Ch	

MAC Layer: MRSP
Upper Layer: RSP-UD

Table Q.K.8 – Uplink MRSP, RSP-UD

Byte No	Field Name	OMS LPWAN frame Content	OMS end-device -> GW Bytes [hex] plain	 Bytes [hex] secured	Layer
1	MHCTL[0]	MRSP, EP, BP		61h	MAC
2	MElement_UA	DL-Splitting, DL-AC#1		22h	
3	MBodyCTL	MDCP,SP,ML=10bytes		6Ah	
4	MDerCounter	MAC derivation counter		01h	
5	MMsgCounter	CMD-MMsgCounter		38h	
6	MMsgCounter	CMD-MMsgCounter		01h	
7	MMAC	AES-CMAC		22h	
8	MMAC	AES-CMAC		D3h	
9	MMAC	AES-CMAC		2Dh	
10	MMAC	AES-CMAC		B3h	
11	MBlock0	Link Status	20h	04h	
12	MBlock0	Link Status Byte 0	01h	81h	
13	MBlock0	Link Status Byte 1	C5h	ACh	
14	LC[0]-Field	ULP, ANP, TAP, CFP		1Bh	LLC(Format C)
15	C-Field	Respond user data		08h	
16	M-Field	Manufacturer code		A7h	
17	M-Field	Manufacturer code		3Dh	
18	A-Field	Ident No LSB (BCD)		78h	
19	A-Field	Ident No (BCD)		56h	
20	A-Field	Ident No (BCD) (= 12345678)		34h	
21	A-Field	Ident No MSB (BCD)		12h	
22	A-Field	Version (or Generation number)		15h	

23	A-Field	Device type (Medium = Gas)		03h	
24	Access No.	LLC-Access		08h	
25	CI Field	Authentication and Fragmentation layer		90h	Authentication and Fragmentation Layer (AFL)
26	AFLL	AFL Length		0Fh	
27	FCL	Fragmentation Control Field (LSB)		00h	
28	FCL	Fragmentation Control Field (MSB)		2Ch	
29	MCL	Message Control Field		25h	
30	MCR	Message Counter C (LSB)		B3h	
31	MCR	Message Counter C		0Ah	
32	MCR	Message Counter C (e.g. = 2739)		00h	
33	MCR	Message Counter C (MSB)		00h	
34	MAC	AES-CMAC (MSB)		21h	
35	MAC	AES-CMAC		92h	
36	MAC	AES-CMAC		4Dh	
37	MAC	AES-CMAC		4Fh	
38	MAC	AES-CMAC		2Fh	
39	MAC	AES-CMAC		B6h	
40	MAC	AES-CMAC		6Eh	
41	MAC	AES-CMAC (LSB)		01h	
42	CI Field	7Ah (short header)		7Ah	TPL
43	Access No.	TPL Access Number of GW		75h	
44	Status	Meter status		00h	
45	Config Field	NNNNPIIIb		20h	
46	Config Field	CCZMMMMMb		07h	
47	CFE	0VDDKKKKb		10h	
48	AES-Verify	Decryption verification	2Fh	90h	
49	AES-Verify	Decryption verification	2Fh	58h	
50	DR1	DIF (8 digit BCD)	0Ch	47h	Application Layer (APL)
51	DR1	VIF (Volume 0,01 m³)	14h	5Fh	
52	DR1	Value LSB	27h	4Bh	
53	DR1	Value	04h	C9h	
54	DR1	Value (= 28504,27 m³)	85h	1Dh	
55	DR1	Value MSB	02h	F8h	
56	DR2	DIF (Time at readout; Type F)	04h	78h	
57	DR2	VIF (Date, Time)	6Dh	B8h	
58	DR2	Value LSB	32h	0Ah	
59	DR2	Value	37h	1Bh	
60	DR2	Value (31.05.2008 23:50)	1Fh	0Fh	
61	DR2	Value MSB	15h	98h	
62	DR3	DIF (2 byte integer)	02h	B6h	
63	DR3	VIF (VIF-Extension Table FD)	FDh	29h	
64	DR3	VIFE (error flag)	17h	02h	
65	DR3	Value LSB	00h	4Ah	
66	DR3	Value MSB (= 0)	00h	ACh	
67	Dummy	Fill Byte due to AES	2Fh	72h	
68	Dummy	Fill Byte due to AES	2Fh	79h	
69	Dummy	Fill Byte due to AES	2Fh	42h	
70	Dummy	Fill Byte due to AES	2Fh	BFh	
71	Dummy	Fill Byte due to AES	2Fh	C5h	
72	Dummy	Fill Byte due to AES	2Fh	49h	
73	Dummy	Fill Byte due to AES	2Fh	23h	

74	Dummy	Fill Byte due to AES	2Fh	3Ch	
75	Dummy	Fill Byte due to AES	2Fh	01h	
76	Dummy	Fill Byte due to AES	2Fh	40h	
77	Dummy	Fill Byte due to AES	2Fh	82h	
78	Dummy	Fill Byte due to AES	2Fh	9Bh	
79	Dummy	Fill Byte due to AES	2Fh	93h	
80	MAC-CRC	CRC (32 bit)		6Dh	MAC
81	MAC-CRC			BEh	
82	MAC-CRC			2Fh	
83	MAC-CRC			D6h	

Appendix Q.Z (informative): Test Vectors

This appendix provides test vectors for the different aspects of the specification.

Q.Z.1 Burst Mode – FEC Test Vector

This subclause shows one example of how input data is encoded.

Input data	= 11000000110111101111111011101101000$_b$
Systematic output = Input data	= 11000000110111101111111011101101000$_b$
FEC parity 1	= 10001110100000001100111100111110110 0$_b$
FEC parity 2	= 10110110110101010100101010101100011$_b$
FEC parity 3	= 11110101110011100001000111111001110$_b$
FEC parity 3A	= 11101$_b$
FEC parity 3B	= 11000$_b$
FEC parity 3C	= 11010$_b$
FEC tail 0	= 111000$_b$
FEC tail 1	= 101000$_b$
FEC tail 2	= 001000$_b$
FEC tail 3	= 111000$_b$

The FEC parity 3A, FEC parity 3B and FEC parity 3C are punctured variants of FEC parity 3. Puncturing is applied using the puncturing pattern, P_{3A}, P_{3B} and P_{3C}. As the puncturing pattern P_{3A} is $P_{3A} = 1000000b$ this means that FEC parity 3A is generated by taking the first bit out of every seven bits of FEC parity 3. And as the puncturing pattern P_{3B} is $P_{3B} = 0100000b$ this means that FEC parity 3B is generated by taking the second bit out of every seven bits of FEC parity 3, etc.

Q.Z.2 Burst Mode – Interleaver Test Vector

The following test vectors can be used to verify a given interleaver implementation.

40-bit Test vector:

Coded Payload =

0101011000110000110100000001111001001011 0$_b$

Data =

001101010000001000000101101010011010011101$_b$

80-bit Test vector:

Coded Payload =

10110011110000001000100100111000100110100000110100100110100001100111001110101001 0$_b$

Data =

1010010001110111010011110100000000000000000111100100000011101011101111101001000 10$_b$

Q.Z.3 Burst Mode – Precoding Test Vector

The following test vectors can be used to verify a given precoding implementation.

Test vector 1:

Uplink Radio Burst:

Preamble:	66666666$_h$
Sync:	8153884C$_h$
CL:	03DE4B$_h$
Data A (fictive data):	56361021413150$_h$
Midamble:	DF46428F20B9BD70DF46428F$_h$
Coded header (fictive data):	0354178025B5AD02A9A5A179$_h$
Data B (fictive data):	88E038484CA8$_h$

Precoded Uplink Radio Burst:

55555555C1FA4C6A02316EFD2D1831E1A9F8B0E563C8B0E563C8B0E563C882FE1C4037 6F7B83FD7771C54C90246C6AFC$_h$

Test vector 2:

Uplink Radio Burst:

Preamble:	66666666$_h$
Sync:	8153884C$_h$
CL:	03DE4B$_h$
Data A (fictive data):	75803310367459$_h$
Midamble:	DF46428F20B9BD70DF46428F$_h$
Coded header (fictive data):	0354178025B5AD02A9A5A179$_h$
Data B (fictive data):	E4CDE59E56AB$_h$

Precoded Uplink Radio Burst:

55555555C1FA4C6A02316ECF402A982D4E7530E563C8B0E563C8B0E563C882FE1C40376F7B83 FD7771C516AB17517DFE$_h$

Q.Z.4 Burst Mode – Full Test Vectors

Q.Z.4.1 Uplink

Q.Z.4.1.1 Uplink PHY Payload

Table Q.Z.1 – Uplink PHY Payload

Field Name	Content	Bytes
MHCTL[0]	MSNR	40_h
MElement_UA	DL-B4, Access option #2	$1A_h$
LC[0]	TAP	02_h
M-Field	Manufacturer code	$A7_h$
M-Field	Manufacturer code	$3D_h$
A-Field	Ident No LSB (BCD)	78_h
A-Field	Ident No (BCD)	56_h
A-Field	Ident No (BCD) (= 12345678)	34_h
A-Field	Ident No MSB (BCD)	12_h
A-Field	Version (or Generation number)	15_h
A-Field	Device type (Medium = Gas)	03_h
MAC-CRC	CRC32 MSB	AC_h
MAC-CRC	CRC32	$B4_h$
MAC-CRC	CRC32	62_h
MAC-CRC	CRC32 LSB	71_h

Q.Z.4.1.2 Uplink Single-burst, FEC rate 7/8

Table Q.Z.2 – Coded header info, Uplink Single-burst, FEC rate 7/8

Name	Description / range	Value
Version	Version 0	00_b
PHY Payload length	15 bytes	00001111_b
Timing Input Value	TIV = 89d	1011001_b
Burst mode	Single-burst	0_b
Burst type	Uplink Single-burst, FEC rate 7/8	00_b

Table Q.Z.3 – Burst generation, Uplink Single-burst, FEC rate 7/8

	Length symbol	Length	Value
PHY Payload	L_P [bytes]	15	401A02A73D785634121503ACB46271h
Coded Payload ULO	B_{CP} [bits]	152	401A02A73D785634121503ACB4627101 826E0Ch
Data ULO	L_D [bytes]	19	22500904966F2114F90204FC23AC1E76 106312h
Data A ULO	L_{DA} [bytes]	10	22500904966F2114F902h
Data B ULO	L_{DB} [bytes]	9	04FC23AC1E76106312h
Preamble ULO	B_{PRE} [bits]	32	66666666h
Sync ULO	B_{SYNC} [bits]	32	8153884Ch
CL ULO	B_{CL} [bits]	24	0528E4h
Midamble ULO	B_{MID} [bits]	96	DF46428F20B9BD70DF46428Fh
Coded Header ULO	B_{CH} [bits]	96	03EC85902836700252E0A914h
Radio Burst ULO	B_{UL} [bits]	432	666666668153884C0528E42250090496 6F2114F902DF46428F20B9BD70DF4642 8F03EC85902836700252E0A91404FC23 AC1E76106312h
Radio Burst (after precoding) ULO	B_{UL} [bits]	432	55555555C1FA4C6A07BC9633780D86DD 58B19E8583B0E563C8B0E563C8B0E563 C8821AC7583C2D48037B90FD9E068232 7A114D18529Bh

Q.Z.4.1.3 Uplink Single-burst, FEC rate 1/2

Table Q.Z.4 – Coded header info, Uplink Single-burst, FEC rate 1/2

Name	Description / range	Value
Version	Version 0	00b
PHY Payload length	15 bytes	00001111b
Timing Input Value	TIV = 43d	0101011b
Burst mode	Single-burst	0b
Burst type	Uplink Single-burst, FEC rate 1/2	01b

Table Q.Z.5 – Burst generation, Uplink Single-burst, FEC rate 1/2

	Length symbol	Length	Value
PHY Payload	L_P [bytes]	15	401A02A73D785634121503ACB46271$_h$
Coded Payload UL0	B_{CP} [bits]	248	401A02A73D785634121503ACB462717A 1B9F29CB709268422DEADF70E955DC$_h$
Data UL0	L_D [bytes]	31	383F074B5D2D8C282B661C10659A80DD 0DFA53552FA65247C48EA065B32267$_h$
Data A UL0	L_{DA} [bytes]	16	383F074B5D2D8C282B661C10659A80DD$_h$
Data B UL0	L_{DB} [bytes]	15	0DFA53552FA65247C48EA065B32267$_h$
Preamble UL0	B_{PRE} [bits]	32	66666666$_h$
Sync UL0	B_{SYNC} [bits]	32	8153884C$_h$
CL UL0	B_{CL} [bits]	24	0803AD$_h$
Midamble UL0	B_{MID} [bits]	96	DF46428F20B9BD70DF46428F$_h$
Coded Header UL0	B_{CH} [bits]	96	03D599802AE5EC027361D741$_h$
Radio Burst UL0	B_{UL} [bits]	528	666666668153884C0803AD383F074B5D 2D8C282B661C10659A80DDDF46428F20 B9BD70DF46428F03D599802AE5EC0273 61D7410DFA53552FA65247C48EA065B3 2267$_h$
Radio Burst UL0 (after precoding)	B_{UL} [bits]	528	55555555C1FA4C6A0C027BA42084EEF3 BB4A3C3ED512185757C0B330E563C8B0 E563C8B0E563C8823F55403F971A034A D13CE18B077AFFB8757B6426C9F0576A B354$_h$

Q.Z.4.1.4 Uplink Single-burst, FEC rate 1/3

Table Q.Z.6 – Coded header info, Uplink Single-burst, FEC rate 1/3

Name	Description / range	Value
Version	Version 0	00$_b$
PHY Payload length	15 bytes	00001111$_b$
Timing Input Value	TIV = 26d	0011010$_b$
Burst mode	Single-burst	0$_b$
Burst type	Uplink Single-burst, FEC rate 1/3	10$_b$

Table Q.Z.7 – Burst generation, Uplink Single-burst, FEC rate 1/3

	Length symbol	Length	Value
PHY6 Payload	L_P [bytes]	15	401A02A73D785634121503ACB46271$_h$
Coded Payload ULO	B_{CP} [bits]	376	401A02A73D785634121503ACB462717A1B9F29CB709268422DEADF70E955DC6DC5EF66400CB4A93AFDB57E2DBD794C$_h$
Data ULO	L_D [bytes]	47	08B2A605823E0F137D0948100C1B22C1F397DF456B6D861492FA9F0534FBFB5F2C2DF60E4758BE6152B24F5D7EC94B$_h$
Data A ULO	L_{DA} [bytes]	24	08B2A605823E0F137D0948100C1B22C1F397DF456B6D8614$_h$
Data B ULO	L_{DB} [bytes]	23	92FA9F0534FBFB5F2C2DF60E4758BE6152B24F5D7EC94B$_h$
Preamble ULO	B_{PRE} [bits]	32	66666666$_h$
Sync ULO	B_{SYNC} [bits]	32	8153884C$_h$
CL ULO	B_{CL} [bits]	24	0C6170$_h$
Midamble ULO	B_{MID} [bits]	96	DF46428F20B9BD70DF46428F$_h$
Coded Header ULO	B_{CH} [bits]	96	03CD23502BF4600265578569$_h$
Radio Burst ULO	B_{UL} [bits]	656	666666668153884C0C617008B2A605823E0F137D0948100C1B22C1F397DF456B6D8614DF46428F20B9BD70DF46428F03CD23502BF460026557856992FA9F0534FBFB5F2C2DF60E4758BE6152B24F5D7EC94B$_h$
Radio Burst ULO (after precoding)	B_{UL} [bits]	656	55555555C1FA4C6A0A51C80CEBF5074321089AC38DEC180A16B3A10A5C30E7DEDB451EB0E563C8B0E563C8B0E563C8822BB2F83E0E500357FC47DD5B87D087AE8606F0BA3B0D0964F4E151FBEB68F3C1ADEE$_h$

Q.Z.4.1.5 Uplink Multi-burst

Table Q.Z.8 – Coded header info, Uplink Multi-burst

Name	Description / range	Value
Version	Version 0	00_b
PHY Payload length	15 bytes	00001111_b
Timing Input Value	TIV = 37d	0100101_b
Burst mode	Multi-burst	1_b
Burst type	Uplink Multi-burst Timing 2 (medium spacing)	01_b

Table Q.Z.9 – Burst generation, Uplink Multi-burst

		Length symbol	Length	Value
PHY Payload		L_P [bytes]	15	$401A02A73D785634121503ACB46271_h$
Coded Payload	**UL1**	B_{CP} [bits]	152	$401A02A73D785634121503ACB4627101826E0C_h$
Coded Payload	**UL2**	B_{CP} [bits]	152	$7A1B9F29CB709268422DEADF70E9552E2F32E4_h$
Coded Payload	**UL3**	B_{CP} [bits]	152	$6DC5EF66400CB4A93AFDB57E2DBD7990097F54_h$
Data	**UL1**	L_D [bytes]	19	$22500904966F2114F90204FC23AC1E76106312_h$
Data	**UL2**	L_D [bytes]	19	$03715E9B88076A4C69198C677B2AF679A6A7AF_h$
Data	**UL3**	L_D [bytes]	19	$1E34C4CD5BBBC31A4ED91F1A6615D77BCA7B94_h$
Data A	**UL1**	L_{DA} [bytes]	10	$22500904966F2114F902_h$
Data A	**UL2**	L_{DA} [bytes]	10	$03715E9B88076A4C6919_h$
Data A	**UL3**	L_{DA} [bytes]	10	$1E34C4CD5BBBC31A4ED9_h$
Data B	**UL1**	L_{DB} [bytes]	9	$04FC23AC1E76106312_h$
Data B	**UL2**	L_{DB} [bytes]	9	$8C677B2AF679A6A7AF_h$
Data B	**UL3**	L_{DB} [bytes]	9	$1F1A6615D77BCA7B94_h$
Preamble	**All**	B_{PRE} [bits]	32	66666666_h
Sync	**All**	B_{SYNC} [bits]	32	$8153884C_h$
CL	**All**	B_{CL} [bits]	24	$0528E4_h$
Midamble	**All**	B_{MID} [bits]	96	$DF46428F20B9BD70DF46428F_h$
Coded Header	**All**	B_{CH} [bits]	96	$03D2DD302ABBB402770EE4C7_h$

	Length symbol	Length	Value
Radio Burst UL1	B_{UL} [bits]	432	666666668153884C0528E42250090496 6F2114F902DF46428F20B9BD70DF4642 8F03D2DD302ABBB402770EE4C704FC23 AC1E76106312$_h$
Radio Burst UL2	B_{UL} [bits]	432	666666668153884C0528E403715E9B88 076A4C6919DF46428F20B9BD70DF4642 8F03D2DD302ABBB402770EE4C78C677B 2AF679A6A7AF$_h$
Radio Burst UL3	B_{UL} [bits]	432	666666668153884C0528E41E34C4CD5B BBC31A4ED9DF46428F20B9BD70DF4642 8F03D2DD302ABBB402770EE4C71F1A66 15D77BCA7B94$_h$
Radio Burst UL1 (after precoding)	B_{UL} [bits]	432	55555555C1FA4C6A07BC9633780D86DD 58B19E8583B0E563C8B0E563C8B0E563 C8823BB3A83FE66E034C8996A4868232 7A114D18529B$_h$
Radio Burst UL2 (after precoding)	B_{UL} [bits]	432	55555555C1FA4C6A07BC9602C9F1D64C 04DF6A5D9530E563C8B0E563C8B0E563 C8823BB3A83FE66E034C8996A44A54C6 BF8D4575F478$_h$
Radio Burst UL3 (after precoding)	B_{UL} [bits]	432	55555555C1FA4C6A07BC96112EA6ABF6 66229769B530E563C8B0E563C8B0E563 C8823BB3A83FE66E034C8996A4909755 1F3CC62F465E$_h$

Q.Z.4.2 Downlink

Q.Z.4.2.1 Downlink PHY Payload

Table Q.Z.10 – Downlink PHY Payload

Field Name	Content	Bytes
MHCTL[0]	MCNR	$4C_h$
MElement_DA	SC=1; Last Frame	01_h
LC[0]	RAP	04_h
M-Field	Manufacturer code	$A7_h$
M-Field	Manufacturer code	$3D_h$
A-Field	Ident No LSB (BCD)	78_h
A-Field	Ident No (BCD)	56_h
A-Field	Ident No (BCD) (= 12345678)	34_h
A-Field	Ident No MSB (BCD)	12_h
A-Field	Version (or Generation number)	15_h
A-Field	Device type (Medium = Gas)	03_h
MAC-CRC	CRC32 MSB	65_h
MAC-CRC	CRC32	$0C_h$
MAC-CRC	CRC32	99_h
MAC-CRC	CRC32 LSB	BA_h

Q.Z.4.2.2 Downlink Single-burst, FEC rate 7/8

Table Q.Z.11 – Coded header info, Downlink Single-burst, FEC rate 7/8

Name	Description / range	Value
Version	Version 0	00_b
PHY Payload length	15 bytes	00001111_b
Timing Input Value	TIV = 127d	1111111_b
Burst mode	Single-burst	0_b
Burst type	Downlink Single-burst, FEC rate 7/8	00_b

Table Q.Z.12 – Burst generation, Downlink Single-burst, FEC rate 7/8

	Length symbol	Length	Value
PHY Payload	L_P [bytes]	15	4C0104A73D785634121503650C99BA$_h$
Coded Payload DL0	B_{CP} [bits]	152	4C0104A73D785634121503650C99BA00 3440FC$_h$
Data DL0	L_D [bytes]	19	02541B861E254158D4379468E1241C17 184A12$_h$
Preamble DL0	B_{PRE} [bits]	32	55555555$_h$
Sync DL0	B_{SYNC} [bits]	32	C1FA4C6A$_h$
Coded Header DL0	B_{CH} [bits]	96	03FF8DC029FD22024B40BA92$_h$
Radio Burst DL0	B_{DL} [bits]	312	55555555C1FA4C6A03FF8DC029FD2202 4B40BA9202541B861E254158D4379468 E1241C17184A12$_h$

Q.Z.4.2.3 Downlink Single-burst, FEC rate 1/2

Table Q.Z.13 – Coded header info, Downlink Single-burst, FEC rate 1/2

Name	Description / range	Value
Version	Version 0	00$_b$
PHY Payload length	15 bytes	00001111$_b$
Timing Input Value	TIV = 62d	0111110$_b$
Burst mode	Single-burst	0$_b$
Burst type	Downlink Single-burst, FEC rate 1/2	01$_b$

Table Q.Z.14 – Burst generation, Downlink Single-burst, FEC rate 1/2

		Length symbol	Length	Value
PHY Payload		L_P [bytes]	15	4C0104A73D785634121503650C99BA$_h$
Coded Payload	**DL0**	B_{CP} [bits]	248	4C0104A73D785634121503650C99BA72 E9C976AC7DDAD68C377B22872E3E58$_h$
Data	**DL0**	L_D [bytes]	31	5976296214070CF8F7341AA054230D71 2DB87A1E4F26C81B869AC5F4179F7A$_h$
Preamble	**DL0**	B_{PRE} [bits]	32	55555555$_h$
Sync	**DL0**	B_{SYNC} [bits]	32	C1FA4C6A$_h$
Coded Header	**DL0**	B_{CH} [bits]	96	03DF1C902A23DF027D698B3C$_h$
Radio Burst	**DL0**	B_{DL} [bits]	408	55555555C1FA4C6A03DF1C902A23DF02 7D698B3C5976296214070CF8F7341AA0 54230D712DB87A1E4F26C81B869AC5F4 179F7A$_h$

Q.Z.4.2.4 Downlink Single-burst, FEC rate 1/3

Table Q.Z.15 – Coded header info, Downlink Single-burst, FEC rate 1/3

Name	Description / range	Value
Version	Version 0	00$_b$
PHY Payload length	15 bytes	00001111$_b$
Timing Input Value	TIV = 9d	0001001$_b$
Burst mode	Single-burst	0$_b$
Burst type	Downlink Single-burst, FEC rate 1/3	10$_b$

Table Q.Z.16 – Burst generation, Downlink Single-burst, FEC rate 1/3

		Length symbol	Length	Value
PHY Payload		L_P [bytes]	15	4C0104A73D785634121503650C99BA$_h$
Coded Payload	**DL0**	B_{CP} [bits]	376	4C0104A73D785634121503650C99BA72 E9C976AC7DDAD68C377B22872E3E5866 B6F044BB34DEECCC8D614F47D277F8$_h$
Data	**DL0**	L_D [bytes]	47	3DC4BE4DB03F427815026D3255329443 30AE6F8152CF8D18B6697C7F3A839F5D BD0161D3AF8192123FB69E587057AF$_h$
Preamble	**DL0**	B_{PRE} [bits]	32	55555555$_h$
Sync	**DL0**	B_{SYNC} [bits]	32	C1FA4C6A$_h$
Coded Header	**DL0**	B_{CH} [bits]	96	03C4AF402B113F02698A1BEB$_h$
Radio Burst	**DL0**	B_{DL} [bits]	536	55555555C1FA4C6A03C4AF402B113F02 698A1BEB3DC4BE4DB03F427815026D32 5532944330AE6F8152CF8D18B6697C7F 3A839F5DBD0161D3AF8192123FB69E58 7057AF$_h$

Q.Z.4.2.5 Downlink Multi-burst

Table Q.Z.17 – Coded header info, Downlink Multi-burst

Name	Description / range	Value
Version	Version 0	00$_b$
PHY Payload length	15 bytes	00001111$_b$
Timing Input Value	TIV = 109d	1101101$_b$
Burst mode	Multi-burst	1$_b$
Burst type	Downlink Multi-burst	00$_b$

Table Q.Z.18 – Burst generation, Downlink Multi-burst

		Length symbol	Length	Value
PHY Payload		L_P [bytes]	15	4C0104A73D785634121503650C99BA$_h$
Coded Payload	**DL1**	B_{CP} [bits]	152	4C0104A73D785634121503650C99BA00 3440FC$_h$
Coded Payload	**DL2**	B_{CP} [bits]	152	72E9C976AC7DDAD68C377B22872E3E6A 93FB34$_h$
Coded Payload	**DL3**	B_{CP} [bits]	152	66B6F044BB34DEECCC8D614F47D277C1 2D4844$_h$

		Length symbol	Length	Value
Data	**DL1**	L_D [bytes]	19	02541B861E254158D4379468E1241C17184A12$_h$
Data	**DL2**	L_D [bytes]	19	2BBA6B3C572D9F0974A664AB47BB4792FAF4BE$_h$
Data	**DL3**	L_D [bytes]	19	397F999213CDB35549AB3E03002174DDF4D393$_h$
Preamble	**All**	B_{PRE} [bits]	32	55555555$_h$
Sync	**All**	B_{SYNC} [bits]	32	C1FA4C6A$_h$
Coded Header	**All**	B_{CH} [bits]	96	03F6C3902910A60247285386$_h$
Radio Burst	**DL1**	B_{UL} [bits]	312	55555555C1FA4C6A03F6C3902910A6024728538602541B861E254158D4379468E1241C17184A12$_h$
Radio Burst	**DL2**	B_{UL} [bits]	312	55555555C1FA4C6A03F6C3902910A602472853862BBA6B3C572D9F0974A664AB47BB4792FAF4BE$_h$
Radio Burst	**DL3**	B_{UL} [bits]	312	55555555C1FA4C6A03F6C3902910A60247285386397F999213CDB35549AB3E03002174DDF4D393$_h$

Q.Z.5 Splitting Mode – Test Vector

The following example illustrates the different steps which will be performed inside the PHY layer when using the Splitting Mode. It uses the example for an MERR frame as shown in Table Q.K.5:

- Generation of the PHY frame structure (CRCs + Padding)
- Whitening
- FEC
- Interleaving
- Radio-burst assignment of the core frame

Test Vector (uplink):

wM-Bus MAC: 422202A73D7856341215039F07FC0F$_h$

MAC-TYPE: 02$_h$

MPDU: 02422202A73D7856341215039F07FC0F$_h$

PSDU: 02422202A73D7856341215039F07FC0F00000000$_h$

MMode: 01$_b$ (variable MAC)

PSI (8 bit): 10$_h$

CRC Payload (8 bit): A0$_h$

CRC Header (8 bit): C1$_h$

PHY Payload (186 bit):

11000001101000000000100000000000100100001000100010000000101010011100111101011110000 10101100011010000010010000101010000000111001111100000111111111000000111100000000000 00000000000000000000001$_b$

PHY Payload after whitening (186 bit):

11001110110100001010001101101101000000011011101001001010000010011000000111101111011011100010100111000001110000011010001111001010011110101001010000111000001101101011000001011101111110001110$_b$

Coded Payload (576 bit):

1110111111101111011001011000001101010111010010101000111000011101101010000000010110011011000011010111010010100111110001110111110010111101100111110101101100001010011111101101100100110001000110101101000010001101001111110110001011111111110010010001111111101011001101101000111100000110011100010010111010110110011000000110000100110110011000000111110011001010011010001111011110000111010001101100010010110101111110001011010010011101111110110110010100100000010011011001011100111001011001101011010010101101111111010000010010011010100101100000100111110011110011011111101001101100110011100$_b$

EFEF6583574A8E1DA8059B0D74A7C77CBD9F5B0A7ED9311AD08D3F62FFC91FEB368F06712E B6606136607CCA68F78746C4B5F8B49DF6CA409B2E72CD695BF4126A5827CF37E9B338$_h$

Coded Payload after interleaving (576 bit):

0110001001101100101011001010001110010101111010011111000010111001010110000011110110000000111010100100110010110100110011110110111001100111100111001000101010111010001001101001100010111111001010010111011110101110110110001001100010001011000000011100111100101010011110111011111111111100100001110101001111011100110110101100101110101011110111110110000101101111100111100010100111111111101100111001111001100000101001100110000100010010110001110110101110111100000000011011100011001100011100001001011110100111111010011001100001100110111100010101010111001010110010110010001101100110101000010$_b$

626CACA395E9F0B9583D81D499699EDCCF3915744D317CA5DEBB62622C073CA9EEFFF21D4F 736B2EAF7D85BE78A7FF673CC14CC2258ED778037198E12F4FD330CDE2AB959646CD42$_h$

Resulting 24 Radio-bursts of core frame:

Table Q.Z.19 contains the bits for each radio-burst including the pilot sequence in the middle after 12 data bits. Radio-burst carrier and timestamp are assigned exemplarily for pattern 2 of the UPG according to Table Q.51 and Table Q.52.

Table Q.Z.19 – Example of Radio-bursts of a core frame

Radio-burst number s	Data	Radio-burst carrier $C_{RB}(s)$	Radio-burst time $T_{RB}(s)$ [a]
0	$01100010011001110100001011001010110 0_b$	4	0
1	$101000111001011101000010010111101001_b$	20	330
2	$111100000101101110100001010010101100 0_b$	12	717
3	$001111011000011101000010000111010100_b$	1	1152
4	$100110010110011101000010100110011110_b$	17	1482
5	$110111001100011101000010111100111001_b$	9	1869
6	$000101010111011101000010010001001101_b$	0	2278
7	$001100010111011101000010110010100101_b$	16	2608
8	$110111101011011101000010101101100010_b$	8	2995
9	$011000100010011101000010110000000111_b$	6	3393
10	$001111001010011101000010100111101110_b$	22	3723
11	$111111111111011101000010001000011101_b$	14	4110
12	$010011110111011101000010001101101011_b$	7	4480
13	$001011101010011101000010111101111101_b$	23	4810
14	$100001011011011101000010111001111000_b$	15	5197
15	$101001111111011101000010111101100111_b$	2	5558
16	$001111001100011101000010000101001100_b$	18	5888
17	$110000100010011101000010010110001110_b$	10	6275
18	$110101110111011101000010100000000011_b$	5	6747
19	$011100011001011101000010100011100001_b$	21	7077
20	$001011110100011101000010111111010011_b$	13	7464
21	$001100001100011101000010110111100010_b$	3	7986
22	$101010111001011101000010010110010110_b$	19	8316
23	$010001101100011101000010110101000010_b$	11	8703

[a] in number of chip time periods