OpenlinkIQ®
Implementation Guide

Document Content

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1 Introduction

This document is a companion document that supports the OpenlinkIQ® communication protocol implementation. The following topics are included:

- The reasoning for some of the requirements
- Guideline to some of the implementational choices
- Link budget formulas
- Capacity and interference
- Frame application examples

1.1 References

Reference	Description/Link
[1]	FILE100001755-55123270 OpenlinkIQ® Specification, Release D, September 2023 – openlinkiq.org
[2]	EN 13757-4 Communication systems for meters – *Part 4: Wireless M-Bus communication*, CEN/TC294:2019
[3]	Open Metering System Specification – *Volume 2: Primary communication*: Issue 4.5.1 / 2022-12, OMS group

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1.2 Change Log

Rev	Date	Description
A0	2022-05-01	Initial release
C	2023-07-04	Corrected MBAL values in example sections 4.1 - 4.4
D	2023-09-29	Reference updated

1.3 Abbreviations

AES	Advanced Encryption Standard
AFL	M-bus Authentication and Fragmentation Layer
APL	M-Bus Application Layer
CEN	European Committee for Standardization
CHI	Coded Header Information
CI	Control Information
CRC	Cyclic Redundancy Check
ERP	Effective Radiated Power (e.r.p.)
FEC	Forward Error Correction
FSK	Frequency-Shift Keying
GMSK	Gaussian Minimum-Shift Keying
LPWAN	Low Power Wide Area Network
LSB	Least Significant Bit (or byte)
MBAL	M-Bus Adaptation Layer
MCL	Maximum Coupling Loss
MSB	Most Significant Bit (or byte)
MSK	Minimum-Shift Keying
OMS	Open Metering System
TI	Transmission Interval
TPL	M-Bus Transport Layer

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2 Link budget

The link budget is an expression of the ability for a transmitter signal to be well received in a receiver. A higher link budget means a higher margin by which a received signal exceeds the receiver's sensitivity. Therefore, this value is of importance when comparing LPWAN systems. The link budget is calculated using the following formula:

$$LB = MCL + G_{tx} + G_{rx}$$

Where:

- LB is the link budget in dB
- MCL is the maximum coupling loss
- G_{rx} is the receiver antenna gain in dBi
- G_{tx} is the transmitter antenna gain in dBi

Maximum Coupling Loss (MCL) defines the maximum path loss allowed, for which the receiver is still able to receive the signal, independent of the transmitter and receiver antenna gains. The MCL is calculated using the formula:

$$MCL = P_{tx} - R_{sense}$$

Where:

- MCL is the maximum coupling loss
- P_{tx} is the transmitter power in dBm (as specified in [1])
- R_{sense} is the receive sensitivity at a given bit error rate (BER) in dBm

An OpenlinkIQ® end device which fulfils the transmitter parameters defined in section [1], transmitting a frame with 20 bytes payload, with 14 dBm e.r.p. and using Turbo coding with code rate 1/3, can be received at a $BER = 10^{-3}$, using coherent reception and soft bit decision, with a maximum coupling loss of:

$$MCL = P_{tx} - R_{sense}$$

$$\Downarrow$$

$$MCL = 14\ dBm - (-132{,}6\ dBm)$$

$$\Downarrow$$

$$MCL = 146{,}6\ dB$$

In a standard wireless M-Bus mode C solution the MCL under the same conditions can be calculated as:

$$MCL = P_{tx} - R_{sense}$$

$$\Downarrow$$

$$MCL = 14\ dBm - (-102{,}5[1]\ dBm)$$

$$\Downarrow$$

$$MCL = 116{,}5\ dB$$

This shows that OpenlinkIQ® has a potential MCL improvement of more than 30 dB compared to standard wireless M-Bus mode C communication.

[1] Typical value from wireless M-Bus specification [2] converted to a $BER = 10^{-3}$.

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3 Selecting the Turbo code rate

Two different Turbo code rates are supported in OpenlinkIQ®. The coding rate is roughly characterized by the amount of redundant data transmitted. The number of redundant bits scales to the length of the payload in the embedded frame.

The choice of coding rate may depend on a trade-off between the maximum allowed continuous transmission time for the end device, the required payload length, the intervals between transmissions, the allowed channel load and robustness to interference.

The frame validation examples shown in sections 4.2 and 4.3 shows transmission of 99 bytes payload with Turbo code rate 1/2 and 60 bytes payload with a Turbo code rate 1/3 respectively. Both examples end up with similar frame lengths.

Figure 1 illustrates the relations between the total frame transmission time and the payload length.

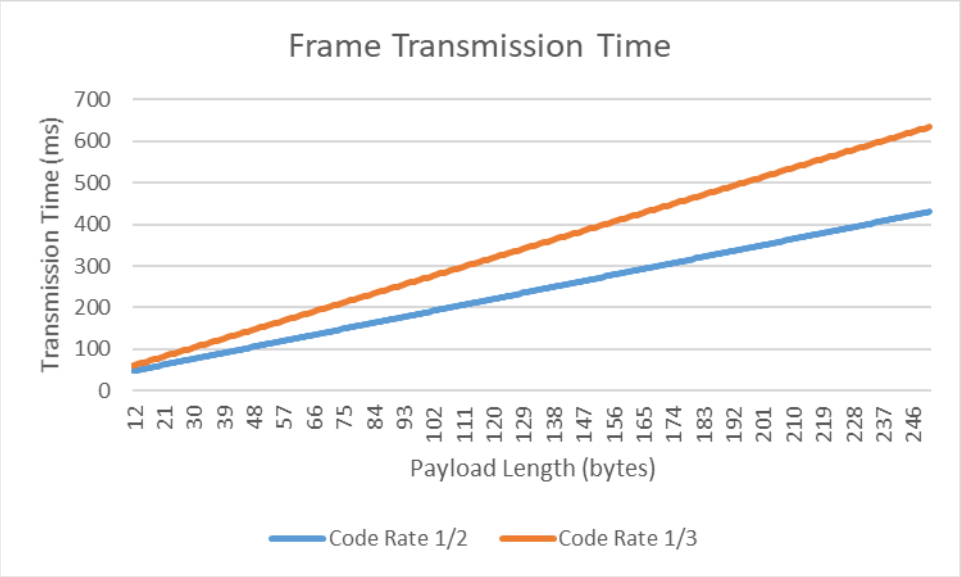

Figure 1 The total frame transmission time as a function of the payload length for different code rates.

If the frame transmission time exceeds the maximum allowed time for a continuous transmit burst in an end device, the redundancy should be reduced ($R = 1/2$) See also chapter 5.

Increasing the redundancy ($R = 1/3$) will provide higher sensitivity and better robustness to interferers.

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4 Frame examples

The examples shown in this chapter are based on different data transmissions from various end device types. The frame examples show the full frame content of the physical frame (before data is precoded[2]), including Turbo FEC, thus providing the possibility to validate the Turbo encoder implementation.

4.1 Installation message example for a water meter using security mode 5 with Turbo encoded data (rate 1/2)

Medium	Water (cold)
Manufacturer	KAW
Serial number	12341234
Version	27
Model/Version	IQ3100
Hardware version	1.5
Metrology FW version	1.1
Nominal Tx periods[3]	1200 s

AES key according to ISO/IEC 18033-3:

= Manufacturer specified (at least 8 bytes unique for each end device)

= 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

AES CBC initial vector according to ISO/IEC 18033-3:

= M field + A field + 8 bytes of access No

= 37 2C 34 12 34 12 1B 16 01 01 01 01 01 01 01 01

Configuration field (CF) parameter

Bit	Configuration field	Value	Comment
0	Hop counter 'H'	0_b	Not repeated
1	Repeater access 'R'	0_b	No repeater access
2..3	Content of message 'CC'	00_b	Standard data message
4..7	Number of blocks 'NNNN'	0010_b	Two encrypted blocks
8..12	Security mode 'MMMMM'	00101_b	Mode 5
13	Synchronised 'S'	0_b	Not a synchronised transmission
14	Accessibility 'A'	0_b	No access window
15	Bidirectional communication 'B'	0_b	Unidirectional end device

[2] Data precoded and FSK modulated is recognized using MSK demodulation.

[3] Recommended in [3].

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Installation data – SND-IR (security mode 5)					
Byte No	**Field name**	**Content**	**Plain data**	**Transmitted data**	**Layer**
1	Preamble	MSB		55_h	Physical
2	Preamble			55_h	
3	Preamble			55_h	
4	Preamble			55_h	
5	Preamble			55_h	
6	Preamble			55_h	
7	Preamble			55_h	
8	Preamble			55_h	
9	Preamble			55_h	
10	Preamble			55_h	
11	Preamble			55_h	
12	Preamble	LSB		55_h	
13	Synch.	MSB		06_h	
14	Synch.			$E5_h$	
15	Synch.			$E7_h$	
16	Synch.	LSB		$D1_h$	
17	Delimiter /Length	2 bit delimiter (11b) Length[7:2] (=49 bytes)		CC_h	Physical
18	Length/ CHI	Length[1:0] Coded Header Information[73:68]		48_h	Physical
19	CHI	CHI[67:60]		DE_h	
20	CHI	CHI[59:52]		49_h	
21	CHI	CHI[51:44]		$5C_h$	
22	CHI	CHI[43:36]		$D1_h$	
23	CHI	CHI[35:28]		75_h	
24	CHI	CHI[27:20]		12_h	
25	CHI	CHI[19:12]		40_h	

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Installation data – SND-IR (security mode 5)						
Byte No	**Field name**	**Content**	**Plain data**	**Transmitted data**	**Layer**	
26	CHI	CHI[11:4]		$2F_h$		
27	CHI/ Term. DF	CHI[3:0] Termination Data Frame[11:8]		00_h		
28	Term. DF	Termination Data Frame[7:0]		$2F_h$		
29	Control field	Priority transmissions		01_h	MBAL frame	
30	M field	Manufacturer code (KAW)		37_h		
31	M field			$2C_h$		
32	A field	Serial No LSB (BCD)		34_h		
33	A field	Serial No (BCD) (=12341234)		12_h		
34	A field	Serial No (BCD)		34_h		
35	A field	Serial No MSB (BCD)		12_h		
36	A field	Version (27)		$1B_h$		
37	A field	Device type (Heat meter)		16_h		
38	MBAL field	SND-IR, no access		06_h	MBAL	
39	CRC16			BA_h	MBAL frame	
40	CRC16			92_h		
41	CI field	$7A_h$ means 4 bytes header		$7A_h$	TPL	
42	Access number	Transmission counter		01_h		
43	Status	No errors reported		00_h		
44	CF	NNNNCCRH$_b$ (2 encr. blocks)		20_h		
45	CF	BAS0MMMM$_b$ (unidir., AES)		05_h		
46	AES-Verify	Encryption verification	$2F_h$	19_h	AES-Encryption Block 1	
47	AES-verify	Encryption verification	$2F_h$	32_h		
48	DR1	DIF (variable length)	$0D_h$	29_h		Application layer (APL)
49	DR1	VIF (extension)	FD_h	BC_h		
50	DR1	VIFE (Version)	$0C_h$	$E6_h$		
51	DR1	LVAR (= 6 bytes text string)	06_h	$4D_h$		
52	DR1	Value (LSB)	30_h	65_h		
53	DR1	Value (= IQ3100)	30_h	$1F_h$		
54	DR1	Value	31_h	$1D_h$		

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Installation data – SND-IR (security mode 5)						
Byte No	**Field name**	**Content**	**Plain data**	**Transmitted data**	**Layer**	
55	DR1	Value	33_h	ED_h		
56	DR1	Value	51_h	42_h		
57	DR1	Value (MSB)	49_h	68_h		
58	DR2	DIF (2 digit BCD)	09_h	73_h		
59	DR2	VIF (extension)	FD_h	03_h		
60	DR2	VIFE (Hardware Version)	$0D_h$	$B2_h$		
61	DR2	Value (=1.5)	15_h	$9A_h$		
62	DR3	DIF (2 digit BCD)	09_h	$F6_h$	AES-Encryption Block 2	
63	DR3	VIF (extension)	FD_h	$A6_h$		
64	DR3	VIFE (Metrology FW Version)	$0E_h$	80_h		
65	DR3	Value (=1.1)	11_h	53_h		
66	DR4	DIF (16-bit integer/Binary)	02_h	36_h		
67	DR4	VIF (extension)	FD_h	08_h		
68	DR4	VIFE (Period of nominal Tx in seconds)	$3C_h$	$4A_h$		
69	DR4	Value LSB (= 1200)	$B0_h$	$0C_h$		
70	DR5	Value MSB	04_h	$C4_h$		
71	Dummy	Fill byte due to AES	$2F_h$	$B4_h$		
72	Dummy	Fill byte due to AES	$2F_h$	$B9_h$		
73	Dummy	Fill byte due to AES	$2F_h$	23_h		
74	Dummy	Fill byte due to AES	$2F_h$	71_h		
75	Dummy	Fill byte due to AES	$2F_h$	$A3_h$		
76	Dummy	Fill byte due to AES	$2F_h$	CA_h		
77	Dummy	Fill byte due to AES	$2F_h$	$B9_h$		
78	CRC32	MSB		05_h	Physical	
79	CRC32			$A3_h$		
80	CRC32			$B6_h$		
81	CRC32	LSB		BB_h		
82	Parity DF	Parity Data Frame[423:416]		09_h		
83	Parity DF			$D3_h$		
84	Parity DF			$5F_h$		
85	Parity DF			$E3_h$		
86	Parity DF			FB_h		

Installation data – SND-IR (security mode 5)					
Byte No	**Field name**	**Content**	**Plain data**	**Transmitted data**	**Layer**
87	Parity DF			$1A_h$	
88	Parity DF			82_h	
89	Parity DF			28_h	
90	Parity DF			AC_h	
91	Parity DF			$6C_h$	
92	Parity DF			$8D_h$	
93	Parity DF			$1A_h$	
94	Parity DF			78_h	
95	Parity DF			80_h	
96	Parity DF			$F5_h$	
97	Parity DF			$D5_h$	
98	Parity DF			CC_h	
99	Parity DF			$2A_h$	
100	Parity DF			$A0_h$	
101	Parity DF			$1D_h$	
102	Parity DF			$C1_h$	
103	Parity DF			05_h	
104	Parity DF			$9F_h$	
105	Parity DF			49_h	
106	Parity DF			$E6_h$	
107	Parity DF			DF_h	
108	Parity DF			AB_h	
109	Parity DF			EF_h	
110	Parity DF			60_h	
111	Parity DF			$D3_h$	
112	Parity DF			CA_h	
113	Parity DF			$8E_h$	
114	Parity DF			82_h	
115	Parity DF			ED_h	
116	Parity DF			27_h	
117	Parity DF			$D7_h$	
118	Parity DF			$8F_h$	
119	Parity DF			$3F_h$	

Installation data – SND-IR (security mode 5)					
Byte No	**Field name**	**Content**	**Plain data**	**Transmitted data**	**Layer**
120	Parity DF			$5D_h$	
121	Parity DF			49_h	
122	Parity DF			96_h	
123	Parity DF			16_h	
124	Parity DF			51_h	
125	Parity DF			$7E_h$	
126	Parity DF			CF_h	
127	Parity DF			77_h	
128	Parity DF			$7A_h$	
129	Parity DF			$D7_h$	
130	Parity DF			$F0_h$	
131	Parity DF			$6C_h$	
132	Parity DF			$F7_h$	
133	Parity DF			$8F_h$	
134	Parity DF	Parity Data Frame[7:0]		19_h	

4.2 OMS security profile B (security mode 7) with Turbo encoded data (rate 1/2) for a Heat Meter

Medium	Heat (volume measured at return temperature: outlet)
Manufacturer	KAM
Serial number	71006389
Version	52
Main Energy	550 kWh
Main Volume	4,631 m^3
Volume flow	0,184 m^3/h
Flow temperature	0,10 °C
Return temperature	1,00 °C
Power	10,800 kW
Storage Date	01.09.2020
Storage energy	361 kWh
Storage volume	13,86 m^3
Max flow	1,222 m^3/h

AES master key (persistent key):

= 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F

Encryption Session Key (Kenc by KDF A):

= EC CF 39 D4 75 D7 30 B8 28 4F DF DC 19 95 D5 2F

MAC Session Key (Kmac by KDF A):

= C9 CD 19 FF 5A 9A AD 5A 6B BD A1 3B D2 C4 C7 AD

Message counter:

= 82501

= 45 42 01 00 (LSB first)

AES CBC initial vector according to ISO/IEC 18033-3:

= empty IV

= 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00

Configuration field (CF) parameter

Bit	Configuration field	Value	Comment
0..2	Content index 'III'	000_b	No specific content
3	TPL padding 'P'	0_b	TPL padding not present
4..7	Number of blocks 'NNNN'	0100_b	Four encrypted blocks
8..12	Security mode 'MMMMM'	00111_b	Mode 7
13	Counter size 'Z'	0_b	Counter not present in TPL
14..15	Content of message 'CC'	00_b	Standard data message

Configuration field extension (CFE) parameter

Bit	Configuration field extension	Value	Comment
0..3	Key ID 'KKKK'	0000_b	Key ID = 0
4..5	KDF Selection 'DD'	01_b	Key derivation function A
6	Version 'V'	0_b	Key version field not present
7	Reserved	0_b	Reserved

Unsolicited meter data – SND-NR (security mode 7)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**
1	Preamble	MSB		55_h		Physical
2	Preamble			55_h		
3	Preamble			55_h		
4	Preamble			55_h		
5	Preamble			55_h		
6	Preamble			55_h		
7	Preamble			55_h		
8	Preamble			55_h		
9	Preamble			55_h		
10	Preamble			55_h		
11	Preamble			55_h		
12	Preamble	LSB		55_h		
13	Synch.	MSB		06_h		
14	Synch.			$E5_h$		
15	Synch.			$E7_h$		
16	Synch.	LSB		$D1_h$		
17	Delimiter /Length	2 bit delimiter (11b) Length[7:2] (=99 bytes)		$D8_h$		Physical
18	Length/ CHI	Length[1:0] Coded Header Information[73:68]		$D1_h$		Physical
19	CHI	CHI[67:60]		$E7_h$		
20	CHI	CHI[59:52]		09_h		
21	CHI	CHI[51:44]		AF_h		
22	CHI	CHI[43:36]		91_h		
23	CHI	CHI[35:28]		$9E_h$		
24	CHI	CHI[27:20]		11_h		

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Unsolicited meter data – SND-NR (security mode 7)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**
25	CHI	CHI[19:12]		67_h		
26	CHI	CHI[11:4]		79_h		
27	CHI/ Term. DF	CHI[3:0] Termination Data Frame[11:8]		$0E_h$		
28	Term. DF	Termination Data Frame[7:0]		$4B_h$		
29	Control field	Scheduled transmissions		00_h		MBAL frame
30	M field	Manufacturer code (KAM)		$2D_h$		
31	M field			$2C_h$		
32	A field	Serial No LSB (BCD)		89_h		
33	A field	Serial No (BCD) (=71006389)		63_h		
34	A field	Serial No (BCD)		00_h		
35	A field	Serial No MSB (BCD)		71_h		
36	A field	Version		34_h		
37	A field	Device type (Heat meter - outlet)		04_h		
38	MBAL field	SND-NR, no access		04_h		MBAL
39	CRC16			58_h		MBAL frame
40	CRC16			$A3_h$		
41	CI field	Authentication and Fragmentation layer		90_h		AFL
42	AFLL	AFL Length (all AFL bytes after AFLL)		$0F_h$		
43	FCL	Fragmentation Control Field (LSB)		00_h		
44	FCL	Fragmentation Control Field (LSB)		$2C_h$		
45	MCL	Message Control Field		25_h	X	
46	MCR	Message Counter (LSB)		45_h	X	
47	MCR	Message Counter		42_h	X	
48	MCR	Message Counter (= 82.501)		01_h	X	
49	MCR	Message Counter (MSB)		00_h	X	
50	MAC	AES-CMAC (MSB)		$C9_h$		

Unsolicited meter data – SND-NR (security mode 7)							
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**	
51	MAC	AES-CMAC		FE_h			
52	MAC	AES-CMAC		78_h			
53	MAC	AES-CMAC		01_h			
54	MAC	AES-CMAC		18_h			
55	MAC	AES-CMAC		$B7_h$			
56	MAC	AES-CMAC		$E8_h$			
57	MAC	AES-CMAC (LSB)		31_h			
58	CI field	$7A_h$ means 4 bytes header		$7A_h$	X	TPL	
59	Access number	Transmission counter		12_h	X		
60	Status	Temporary Error, Permanent error		18_h	X		
61	CF	$NNNNPIII_b$ (4 encr. blocks)		40_h	X		
62	CF	$CCZMMMMM_b$ (security mode 7)		07_h	X		
63	CFE	$0VDDKKKK_b$ (KDF function A)		10_h	X		
64	AES-Verify	Encryption verification	$2F_h$	35_h	X	AES-Encryption Block 1	
65	AES-verify	Encryption verification	$2F_h$	CD_h	X		
66	DR1	DIF (4 byte integer)	04_h	99_h	X		Application layer (APL)
67	DR1	VIF (Energy x 10^3 Wh)	06_h	$1D_h$	X		
68	DR1	Value LSB	26_h	$E9_h$	X		
69	DR1	Value (= 550)	02_h	$C5_h$	X		
70	DR1	Value	00_h	$3C_h$	X		
71	DR1	Value MSB	00_h	$5D_h$	X		
72	DR2	DIF (4 byte integer)	04_h	CC_h	X		
73	DR2	VIF (Volume x 10^{-2} m^3)	14_h	31_h	X		
74	DR2	Value LSB	17_h	05_h	X		
75	DR2	Value (= 4631)	12_h	01_h	X		
76	DR2	Value	00_h	87_h	X		
77	DR2	Value MSB	00_h	82_h	X		
78	DR3	DIF (4 byte integer)	04_h	$D7_h$	X		
79	DR3	VIF (manufacturer specific)	FF_h	$2D_h$	X		
80	DR3	VIFE	22_h	$1C_h$	X	AES	

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Unsolicited meter data – SND-NR (security mode 7)							
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**	
81	DR3	Value (LSB)	18_h	DB_h	X		
82	DR3	Value	01_h	39_h	X		
83	DR3	Value	00_h	$C5_h$	X		
84	DR3	Value (MSB)	00_h	DB_h	X		
85	DR4	DIF (4 byte integer)	04_h	$1B_h$	X		
86	DR4	VIF (Volume flow x 10^{-3} m^3/h)	$3B_h$	$7C_h$	X		
87	DR4	Value LSB	$B8_h$	21_h	X		
88	DR4	Value (= 184)	00_h	82_h	X		
89	DR4	Value	00_h	05_h	X		
90	DR4	Value MSB	00_h	$7E_h$	X		
91	DR5	DIF (2 byte integer)	02_h	19_h	X		
92	DR5	VIF (Flow temp. x 10^{-2} °C)	59_h	35_h	X		
93	DR5	Value LSB	$0A_h$	$D7_h$	X		
94	DR5	Value MSB (= 10)	00_h	73_h	X		
95	DR6	DIF (2 byte integer)	02_h	AF_h	X		
96	DR6	VIF (Return temp. x 10^{-2} °C)	$5D_h$	DA_h	X	AES-Encryption Block 3	
97	DR6	Value LSB	64_h	AA_h	X		
98	DR6	Value MSB (= 100)	00_h	24_h	X		
99	DR7	DIF (4 byte integer)	04_h	$F4_h$	X		
100	DR7	VIF (power x 10^2 W)	$2D_h$	FA_h	X		
101	DR7	Value LSB	$6C_h$	17_h	X		
102	DR7	Value (= 108)	00_h	38_h	X		
103	DR7	Value	00_h	$E2_h$	X		
104	DR7	Value MSB	00_h	BD_h	X		
105	DR8	DIF (Data type G, storage no 1)	42_h	$8B_h$	X		
106	DR8	VIF (Month Log: Date)	$6C_h$	13_h	X		
107	DR8	Value LSB	81_h	$F3_h$	X		
108	DR8	Value MSB (= 2020-09-01)	29_h	FC_h	X		
109	DR9	DIF (4 byte integer, storage no 1)	44_h	77_h	X		
110	DR9	VIF (Month Log: Energy x 10^3 Wh)	06_h	$A3_h$	X		

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Unsolicited meter data – SND-NR (security mode 7)							
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**	
111	DR9	Value LSB	69_h	$2B_h$	X		
112	DR9	Value (= 361)	01_h	68_h	X	AES-Encryption Block 4	
113	DR9	Value	00_h	$F1_h$	X		
114	DR9	Value MSB	00_h	$D1_h$	X		
115	DR10	DIF (4 byte integer, storage no 1)	44_h	$2E_h$	X		
116	DR10	VIF (Month Log: Volume x 10^{-2} m^3)	14_h	73_h	X		
117	DR10	Value LSB	$6A_h$	66_h	X		
118	DR10	Value (= 1386)	05_h	FE_h	X		
119	DR10	Value	00_h	$C6_h$	X		
120	DR10	Value MSB	00_h	$1D_h$	X		
121	DR11	DIF (4 byte integer, storage no 1)	54_h	69_h	X		
122	DR11	VIF (Month Log: Max flow x 10^{-3} m^3/h)	$3B_h$	$D7_h$	X		
123	DR11	Value LSB	$C6_h$	$E7_h$	X		
124	DR11	Value (= 1222)	04_h	81_h	X		
125	DR11	Value	00_h	$C2_h$	X		
126	DR11	Value MSB	00_h	88_h	X		
127	Dummy	Fill byte due to AES	$2F_h$	65_h	X		
128	CRC32	MSB		$4A_h$		Physical	
129	CRC32			$C9_h$			
130	CRC32			DC_h			
131	CRC32	LSB		38_h			
132	Parity DF	Parity Data Frame[823:816]		04_h			
133	Parity DF			85_h			
134	Parity DF			$F9_h$			
135	Parity DF			43_h			
136	Parity DF			$6A_h$			
137	Parity DF			$6A_h$			
138	Parity DF			$B1_h$			
139	Parity DF			76_h			
140	Parity DF			99_h			

Unsolicited meter data – SND-NR (security mode 7)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**
141	Parity DF			22_h		
142	Parity DF			26_h		
143	Parity DF			$A2_h$		
144	Parity DF			$0C_h$		
145	Parity DF			65_h		
146	Parity DF			$C6_h$		
147	Parity DF			$5B_h$		
148	Parity DF			AE_h		
149	Parity DF			$8F_h$		
150	Parity DF			96_h		
151	Parity DF			$D5_h$		
152	Parity DF			$F7_h$		
153	Parity DF			52_h		
154	Parity DF			$B4_h$		
155	Parity DF			96_h		
156	Parity DF			76_h		
157	Parity DF			$4D_h$		
158	Parity DF			DF_h		
159	Parity DF			$A6_h$		
160	Parity DF			13_h		
161	Parity DF			$F9_h$		
162	Parity DF			AC_h		
163	Parity DF			$7F_h$		
164	Parity DF			87_h		
165	Parity DF			AF_h		
166	Parity DF			20_h		
167	Parity DF			AC_h		
168	Parity DF			AD_h		
169	Parity DF			$E8_h$		
170	Parity DF			35_h		
171	Parity DF			$8C_h$		
172	Parity DF			84_h		

Unsolicited meter data – SND-NR (security mode 7)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**
173	Parity DF			$4D_h$		
174	Parity DF			76_h		
175	Parity DF			77_h		
176	Parity DF			$2A_h$		
177	Parity DF			94_h		
178	Parity DF			$F3_h$		
179	Parity DF			$1F_h$		
180	Parity DF			49_h		
181	Parity DF			$8D_h$		
182	Parity DF			$6D_h$		
183	Parity DF			15_h		
184	Parity DF			53_h		
185	Parity DF			$C7_h$		
186	Parity DF			DD_h		
187	Parity DF			FB_h		
188	Parity DF			BD_h		
189	Parity DF			$8D_h$		
190	Parity DF			84_h		
191	Parity DF			74_h		
192	Parity DF			$7D_h$		
193	Parity DF			24_h		
194	Parity DF			87_h		
195	Parity DF			$5A_h$		
196	Parity DF			12_h		
197	Parity DF			43_h		
198	Parity DF			50_h		
199	Parity DF			61_h		
200	Parity DF			$7E_h$		
201	Parity DF			08_h		
202	Parity DF			77_h		
203	Parity DF			$5D_h$		
204	Parity DF			23_h		

Unsolicited meter data – SND-NR (security mode 7)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authenti-cated data [x]**	**Layer**
205	Parity DF			93_h		
206	Parity DF			00_h		
207	Parity DF			25_h		
208	Parity DF			$0A_h$		
209	Parity DF			$1B_h$		
210	Parity DF			DA_h		
211	Parity DF			$1A_h$		
212	Parity DF			BD_h		
213	Parity DF			AA_h		
214	Parity DF			$E6_h$		
215	Parity DF			87_h		
216	Parity DF			59_h		
217	Parity DF			12_h		
218	Parity DF			$D9_h$		
219	Parity DF			11_h		
220	Parity DF			66_h		
221	Parity DF			$2D_h$		
222	Parity DF			$F6_h$		
223	Parity DF			87_h		
224	Parity DF			CC_h		
225	Parity DF			12_h		
226	Parity DF			$F9_h$		
227	Parity DF			$F2_h$		
228	Parity DF			67_h		
229	Parity DF			63_h		
230	Parity DF			$5D_h$		
231	Parity DF			31_h		
232	Parity DF			$F8_h$		
233	Parity DF			13_h		
234	Parity DF	Parity Data Frame[7:0]		$6C_h$		

4.3 Security mode 10 with Turbo encoded data (rate 1/3) for an OMS sensor device

Medium	Combined Humidity, temperature and door/window contact sensor[4]
Manufacturer	KAM
Serial number	05040302
Version	06
Temperature	28,3 °C
Humidity	57,8 %
Door/window status	Open
Storage date	2021.03.11
Storage time	9:30 AM

Configuration field (CF) parameter

Bit	Configuration field	Value	Comment
0..7	Number of encrypted bytes 'NNNNNNNN'	11111111_b	All bytes encrypted
8..12	Security mode 'MMMMM'	01010_b	Security mode 10
13	Counter size 'Z'	1_b	4 bytes counter in TPL
14..15	Content of message 'CC'	00_b	Standard data message

Configuration field extension (CFE) parameter

Bit	Configuration field extension	Value	Comment
0..3	Key ID 'KKKK'	0000_b	Key ID = 0
4..5	KDF Selection 'DD'	01_b	Key derivation function A
6	Version 'V'	0_b	Version field not present
7	Reserved	0_b	Reserved
8..9	Authenticated tag size 'OO'	01_b	8 bytes tag
10..13	Content index 'IIII'	0000_b	Content index 0 (unused)
14..15	Reserved	00_b	

Persistent key:

= 00 11 22 33 44 55 66 77 88 99 AA BB CC DD EE FF

Ephemeral / derived key:

= 09 DA 87 83 92 07 01 FC 5F 66 F8 B9 41 D3 C6 0C

Nonce, N:

[4] Specified according to [3], Annex B and C.

= KAM | Meter ID | Version | Device type | 00_b | Message counter

= 2D 2C 02 03 04 05 06 00 00 CC DD EE FF

Associated data:

= CI | Access no | Status | CF | CFE

= 7A 22 AB FF 2A 10 01

Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
1	Preamble	MSB		55_h		Physical
2	Preamble			55_h		
3	Preamble			55_h		
4	Preamble			55_h		
5	Preamble			55_h		
6	Preamble			55_h		
7	Preamble			55_h		
8	Preamble			55_h		
9	Preamble			55_h		
10	Preamble			55_h		
11	Preamble			55_h		
12	Preamble	LSB		55_h		
13	Synch.	MSB		06_h		
14	Synch.			$E5_h$		
15	Synch.			$E7_h$		
16	Synch.	LSB		$D1_h$		
17	Delimiter /Length	2 bit delimiter (11b) Length[7:2] (=60 bytes)		CF_h		Physical
18	Length/ CHI	Length[1:0] Coded Header Information[73:68]		$0A_h$		Physical
19	CHI	CHI[67:60]		89_h		

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Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
20	CHI	CHI[59:52]		13_h		
21	CHI	CHI[51:44]		$5B_h$		
22	CHI	CHI[43:36]		52_h		
23	CHI	CHI[35:28]		$C6_h$		
24	CHI	CHI[27:20]		52_h		
25	CHI	CHI[19:12]		$F2_h$		
26	CHI	CHI[11:4]		$F2_h$		
27	CHI/ Term. DF	CHI[3:0] Termination Data Frame[11:8]		17_h		
28	Term. DF	Termination Data Frame[7:0]		56_h		
29	Control field	Scheduled transmissions		00_h		MBAL frame
30	M field	Manufacturer code (KAM)		$2D_h$		
31	M field			$2C_h$		
32	A field	Serial No LSB (BCD)		02_h		
33	A field	Serial No (BCD) (=05040302)		03_h		
34	A field			04_h		
35	A field	Serial No MSB (BCD)		05_h		
36	A field	Version (6)		06_h		
37	A field	Device type (Other/sensor)		00_h		
38	MBAL field	SND-NR, no access		04_h		MBAL
39	CRC16			08_h		MBAL frame
40	CRC16			$1C_h$		
41	CI field	$7A_h$ means 4 bytes header		$7A_h$	X	TPL
42	Access no	Access number		22_h	X	
43	Status	State contents, errors and alerts (manufacturer specific permanent error)		AB_h	X	
44	Conf. (CF)	$NNNNNNNN_b$ (all bytes encrypted)		FF_h	X	
45	Conf. (CF)	$CCZMMMMM_b$ (Content=0, 4 bytes counter, Security mode 10)		$2A_h$	X	

Unsolicited data frame – SND-NR (security mode 10)							
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**	
46	Conf. ext. (CFE)	0VDDKKKK$_b$ (no key version field, KDF A, user key 0)		10$_h$	X		
47	Conf. ext. (CFE)	00IIIIOO$_b$ (Content index unused, authentication tag size = 8 bytes)		01$_h$	X		
48	Message number	Transmission counter (LSB)		FF$_h$			
49	Message number	Transmission counter (=CCDDEEFF$_h$)		EE$_h$			
50	Message number	Transmission counter		DD$_h$			
51	Message number	Transmission counter (MSB)		CC$_h$			
52	DR1	DIF (variable length)	0D$_h$	E6$_h$	X	Ciphertext (C)	Application layer (APL)
53	DR1	VIF (extension – ID09)	FD$_h$	0D$_h$	X		
54	DR1	VIFE (Device type list)	09$_h$	1F$_h$	X		
55	DR1	LVAR (= 3 bytes)	E3$_h$	01$_h$	X		
56	DR1	Value (Door/window Contact Sensor)	0A$_h$	DA$_h$	X		
57	DR1	Value (Temperature sensor)	03$_h$	B0$_h$	X		
58	DR1	Value (Humidity sensor)	01$_h$	E2$_h$	X		
59	DR2	DIF (1 byte, storage no 1)	41$_h$	83$_h$	X		
60	DR2	VIF (string)	7C$_h$	2A$_h$	X		
61	DR2	Length of string (“DS4")	03$_h$	65$_h$	X		
62	DR2	VIB type (“4")	34$_h$	18$_h$	X		
63	DR2	VIB type (“S")	53$_h$	00$_h$	X		
64	DR2	VIB type (“D")	44$_h$	3E$_h$	X		
65	DR2	Device status (= open)	0D$_h$	E7$_h$	X		
66	DR3	DIF (2 byte integer, storage no 1)	42$_h$	42$_h$	X		
67	DR3	VIF (temperature x 10^{-1} °C)	66$_h$	4E$_h$	X		
68	DR3	Value LSB	1B$_h$	E8$_h$	X		
69	DR3	Value MSB (= 283)	01$_h$	65$_h$	X		
70	DR4	DIF (2 byte integer, storage no 1)	42$_h$	DF$_h$	X		
71	DR4	VIF (extension)	FB$_h$	EE$_h$	X		

Unsolicited data frame – SND-NR (security mode 10)							
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**	
72	DR4	VIFE (relative humidity x 10^{-1} %)	$1A_h$	22_h	X		
73	DR4	Value LSB	42_h	53_h	X		
74	DR4	Value MSB (= 578)	02_h	$C0_h$	X		
75	DR5	DIF (Data type F, storage no 1)	44_h	$D6_h$	X		
76	DR5	VIF (Log: Date and Time)	$6D_h$	35_h	X		
77	DR5	Value LSB	$1E_h$	EE_h	X		
78	DR5	Value (= 2021.03.11, 09:30 std. time)	29_h	$E6_h$	X		
79	DR5	Value	AB_h	69_h	X		
80	DR5	Value MSB	23_h	77_h	X		
81	Auth. tag	Authentication tag		$F4_h$			TPL
82	Auth. tag	Authentication tag		20_h			
83	Auth. tag	Authentication tag		$4B_h$			
84	Auth. tag	Authentication tag		$A9_h$			
85	Auth. tag	Authentication tag		$3F_h$			
86	Auth. tag	Authentication tag		$D3_h$			
87	Auth. tag	Authentication tag		44_h			
88	Auth. tag	Authentication tag		$1C_h$			
89	CRC32	MSB		$3F_h$		Physical	
90	CRC32			DD_h			
91	CRC32			BB_h			
92	CRC32	LSB		AD_h			
93	Parity DF	Parity Data Frame[1023:1016]		00_h			
94	Parity DF			35_h			
95	Parity DF			$D1_h$			
96	Parity DF			$C8_h$			
97	Parity DF			$5E_h$			
98	Parity DF			90_h			
99	Parity DF			BF_h			
100	Parity DF			04_h			
101	Parity DF			$5C_h$			
102	Parity DF			BE_h			
103	Parity DF			EA_h			

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Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
104	Parity DF			$F3_h$		
105	Parity DF			79_h		
106	Parity DF			11_h		
107	Parity DF			ED_h		
108	Parity DF			$A3_h$		
109	Parity DF			$D5_h$		
110	Parity DF			89_h		
111	Parity DF			73_h		
112	Parity DF			$A3_h$		
113	Parity DF			59_h		
114	Parity DF			$0B_h$		
115	Parity DF			$3A_h$		
116	Parity DF			EF_h		
117	Parity DF			$C2_h$		
118	Parity DF			DF_h		
119	Parity DF			$5D_h$		
120	Parity DF			$C5_h$		
121	Parity DF			47_h		
122	Parity DF			$9A_h$		
123	Parity DF			49_h		
124	Parity DF			89_h		
125	Parity DF			$6D_h$		
126	Parity DF			$F4_h$		
127	Parity DF			$B9_h$		
128	Parity DF			$5B_h$		
129	Parity DF			$C0_h$		
130	Parity DF			08_h		
131	Parity DF			$2E_h$		
132	Parity DF			01_h		
133	Parity DF			31_h		
134	Parity DF			$C3_h$		
135	Parity DF			59_h		

Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
136	Parity DF			$A8_h$		
137	Parity DF			39_h		
138	Parity DF			32_h		
139	Parity DF			74_h		
140	Parity DF			78_h		
141	Parity DF			92_h		
142	Parity DF			$B3_h$		
143	Parity DF			39_h		
144	Parity DF			BB_h		
145	Parity DF			$4B_h$		
146	Parity DF			12_h		
147	Parity DF			91_h		
148	Parity DF			79_h		
149	Parity DF			CD_h		
150	Parity DF			$2E_h$		
151	Parity DF			$E9_h$		
152	Parity DF			DD_h		
153	Parity DF			$5A_h$		
154	Parity DF			$0B_h$		
155	Parity DF			64_h		
156	Parity DF			$B5_h$		
157	Parity DF			22_h		
158	Parity DF			03_h		
159	Parity DF			32_h		
160	Parity DF			$C9_h$		
161	Parity DF			33_h		
162	Parity DF			57_h		
163	Parity DF			$9B_h$		
164	Parity DF			$0B_h$		
165	Parity DF			75_h		
166	Parity DF			81_h		
167	Parity DF			19_h		

Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
168	Parity DF			84_h		
169	Parity DF			92_h		
170	Parity DF			$0E_h$		
171	Parity DF			$E6_h$		
172	Parity DF			$5E_h$		
173	Parity DF			48_h		
174	Parity DF			92_h		
175	Parity DF			DF_h		
176	Parity DF			45_h		
177	Parity DF			18_h		
178	Parity DF			02_h		
179	Parity DF			28_h		
180	Parity DF			CE_h		
181	Parity DF			91_h		
182	Parity DF			$C6_h$		
183	Parity DF			78_h		
184	Parity DF			$A7_h$		
185	Parity DF			$6A_h$		
186	Parity DF			$7A_h$		
187	Parity DF			BC_h		
188	Parity DF			$E1_h$		
189	Parity DF			$E7_h$		
190	Parity DF			AF_h		
191	Parity DF			64_h		
192	Parity DF			$5B_h$		
193	Parity DF			$2A_h$		
194	Parity DF			03_h		
195	Parity DF			$C3_h$		
196	Parity DF			$E2_h$		
197	Parity DF			96_h		
198	Parity DF			$1F_h$		
199	Parity DF			$7A_h$		

Unsolicited data frame – SND-NR (security mode 10)						
Byte No	**Field name**	**Content**	**Plain data**	**Tx data**	**Authen-ticated data [x]**	**Layer**
200	Parity DF			$4F_h$		
201	Parity DF			$7D_h$		
202	Parity DF			48_h		
203	Parity DF			$B1_h$		
204	Parity DF			71_h		
205	Parity DF			$D6_h$		
206	Parity DF			$C9_h$		
207	Parity DF			CE_h		
208	Parity DF			35_h		
209	Parity DF			FD_h		
210	Parity DF			$0F_h$		
211	Parity DF			$2C_h$		
212	Parity DF			$0D_h$		
213	Parity DF			$B9_h$		
214	Parity DF			$E2_h$		
215	Parity DF			08_h		
216	Parity DF			$E9_h$		
217	Parity DF			$1F_h$		
218	Parity DF			$4D_h$		
219	Parity DF			$4B_h$		
220	Parity DF	Parity Data Frame[7:0]		02_h		

4.4 Unencrypted Turbo encoded data (rate 1/3) for a sensor device

Medium	Combined Humidity, temperature and door/window contact sensor[5]
Manufacturer	KAM
Serial number	05040302
Version	06
Temperature	28,3 °C
Humidity	57,8 %
Door/window status	Open

[5] Specified according to [3], Annex B and C, although transmission of data with no security/header is not allowed in OMS.

Storage date 2021.03.11

Storage time 9:30 AM

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
1	Preamble	MSB	55_h	Physical
2	Preamble		55_h	
3	Preamble		55_h	
4	Preamble		55_h	
5	Preamble		55_h	
6	Preamble		55_h	
7	Preamble		55_h	
8	Preamble		55_h	
9	Preamble		55_h	
10	Preamble		55_h	
11	Preamble		55_h	
12	Preamble	LSB	55_h	
13	Synch.	MSB	06_h	
14	Synch.		$E5_h$	
15	Synch.		$E7_h$	
16	Synch.	LSB	$D1_h$	
17	Delimiter /Length	2 bit delimiter (11b) Length[7:2] (=46 bytes)	CB_h	Physical
18	Length/ CHI	Length[1:0] Coded Header Information[73:68]	$8D_h$	Physical
19	CHI	CHI[67:60]	EC_h	
20	CHI	CHI[59:52]	$D3_h$	
21	CHI	CHI[51:44]	$A9_h$	
22	CHI	CHI[43:36]	$D2_h$	
23	CHI	CHI[35:28]	33_h	

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
24	CHI	CHI[27:20]	10_h	
25	CHI	CHI[19:12]	$0B_h$	
26	CHI	CHI[11:4]	$C0_h$	
27	CHI/ Term. DF	CHI[3:0] Termination Data Frame[11:8]	15_h	
28	Term. DF	Termination Data Frame[7:0]	96_h	
29	Control field	Scheduled transmissions	00_h	MBAL frame
30	M field	Manufacturer code (KAM)	$2D_h$	
31	M field		$2C_h$	
32	A field	Serial No LSB (BCD)	02_h	
33	A field	Serial No (BCD) (=05040302)	03_h	
34	A field		04_h	
35	A field	Serial No MSB (BCD)	05_h	
36	A field	Version (6)	06_h	
37	A field	Device type (Other/sensor)	00_h	
38	MBAL field	SND-NR, no access	04_h	MBAL
39	CRC16		08_h	MBAL frame
40	CRC16		$1C_h$	
41	CI field	$7A_h$ means 4 bytes header	$7A_h$	TPL layer
42	Access number	Transmission counter	$2A_h$	
43	Status	No errors reported	00_h	
44	CF	$0000CCRH_b$	00_h	
45	CF	$BASMMMMM_b$	00_h	
46	DR1	DIF (variable length)	$0D_h$	Application layer (APL)
47	DR1	VIF (extension – ID09)	FD_h	
48	DR1	VIFE (Device type list)	09_h	
49	DR1	LVAR (= 3 bytes)	$E3_h$	
50	DR1	Value (Door/window Contact Sensor)	$0A_h$	
51	DR1	Value (Temperature sensor)	03_h	
52	DR1	Value (Humidity sensor)	01_h	
53	DR2	DIF (1 byte, storage no 1)	41_h	
54	DR2	VIF (string)	$7C_h$	

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
55	DR2	Length of string ("DS4")	03_h	
56	DR2	VIB type ("4")	34_h	
57	DR2	VIB type ("S")	53_h	
58	DR2	VIB type ("D")	44_h	
59	DR2	Device status (= open)	$0D_h$	
60	DR3	DIF (2 byte integer, storage no 1)	42_h	
61	DR3	VIF (temperature x 10^{-1} °C)	66_h	
62	DR3	Value LSB	$1B_h$	
63	DR3	Value MSB (= 283)	01_h	
64	DR4	DIF (2 byte integer, storage no 1)	42_h	
65	DR4	VIF (extension)	FB_h	
66	DR4	VIFE (relative humidity x 10^{-1} %)	$1A_h$	
67	DR4	Value LSB	42_h	
68	DR4	Value MSB (= 578)	02_h	
69	DR5	DIF (Data type F, storage no 1)	44_h	
70	DR5	VIF (Log: Date and Time)	$6D_h$	
71	DR5	Value LSB	$1E_h$	
72	DR5	Value (= 2021.03.11, 09:30 std. time)	29_h	
73	DR5	Value	AB_h	
74	DR5	Value MSB	23_h	
75	CRC32	MSB	67_h	Physical
76	CRC32		97_h	
77	CRC32		$A1_h$	
78	CRC32	LSB	74_h	
79	Parity DF	Parity Data Frame[799:792]	00_h	
80	Parity DF		35_h	
81	Parity DF		$D1_h$	
82	Parity DF		$C8_h$	
83	Parity DF		$5E_h$	
84	Parity DF		90_h	
85	Parity DF		BF_h	
86	Parity DF		04_h	

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
87	Parity DF		$5C_h$	
88	Parity DF		BE_h	
89	Parity DF		EA_h	
90	Parity DF		$F3_h$	
91	Parity DF		79_h	
92	Parity DF		$1E_h$	
93	Parity DF		00_h	
94	Parity DF		00_h	
95	Parity DF		00_h	
96	Parity DF		09_h	
97	Parity DF		FC_h	
98	Parity DF		99_h	
99	Parity DF		50_h	
100	Parity DF		$C7_h$	
101	Parity DF		70_h	
102	Parity DF		CA_h	
103	Parity DF		$0A_h$	
104	Parity DF		21_h	
105	Parity DF		$C9_h$	
106	Parity DF		$9C_h$	
107	Parity DF		65_h	
108	Parity DF		$7E_h$	
109	Parity DF		EC_h	
110	Parity DF		ED_h	
111	Parity DF		$D6_h$	
112	Parity DF		AA_h	
113	Parity DF		$2F_h$	
114	Parity DF		$C3_h$	
115	Parity DF		$6F_h$	
116	Parity DF		$F7_h$	
117	Parity DF		08_h	

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
118	Parity DF		$5F_h$	
119	Parity DF		$0C_h$	
120	Parity DF		$4C_h$	
121	Parity DF		82_h	
122	Parity DF		32_h	
123	Parity DF		$B1_h$	
124	Parity DF		87_h	
125	Parity DF		$A5_h$	
126	Parity DF		50_h	
127	Parity DF		BD_h	
128	Parity DF		00_h	
129	Parity DF		$2D_h$	
130	Parity DF		$C5_h$	
131	Parity DF		$9D_h$	
132	Parity DF		$A2_h$	
133	Parity DF		EF_h	
134	Parity DF		84_h	
135	Parity DF		16_h	
136	Parity DF		54_h	
137	Parity DF		77_h	
138	Parity DF		$0A_h$	
139	Parity DF		20_h	
140	Parity DF		74_h	
141	Parity DF		$F5_h$	
142	Parity DF		63_h	
143	Parity DF		59_h	
144	Parity DF		$E9_h$	
145	Parity DF		30_h	
146	Parity DF		BC_h	
147	Parity DF		$8E_h$	
148	Parity DF		25_h	

Unsolicited data frame – SND-NR (no security)				
Byte No	**Field name**	**Content**	**Tx data**	**Layer**
149	Parity DF		$B0_h$	
150	Parity DF		$C9_h$	
151	Parity DF		$A7_h$	
152	Parity DF		$6B_h$	
153	Parity DF		$9A_h$	
154	Parity DF		$6B_h$	
155	Parity DF		AB_h	
156	Parity DF		FE_h	
157	Parity DF		$C7_h$	
158	Parity DF		$1A_h$	
159	Parity DF		CB_h	
160	Parity DF		$B1_h$	
161	Parity DF		$6E_h$	
162	Parity DF		68_h	
163	Parity DF		$2F_h$	
164	Parity DF		43_h	
165	Parity DF		$2D_h$	
166	Parity DF		BA_h	
167	Parity DF		$1E_h$	
168	Parity DF		$A3_h$	
169	Parity DF		DB_h	
170	Parity DF		35_h	
171	Parity DF		FB_h	
172	Parity DF		$D3_h$	
173	Parity DF		33_h	
174	Parity DF		$D2_h$	
175	Parity DF		FB_h	
176	Parity DF		EE_h	
177	Parity DF		$5F_h$	
178	Parity DF	Parity Data Frame[7:0]	76_h	

5 Capacity and interference

The periodic frame examples in section 4.2 and 4.3 show a total frame size of 234 bytes and 220 bytes respectively.

The total number of bits for the 234 bytes frame (as an example) is:

$$l_{total} = 8 \cdot 234 = 1.872\ bit,$$

The transmission time for this frame can be expressed as:

$$t_{tx} = \frac{l_{total}(bits)}{10\ (\frac{kbits}{s})} = \frac{1.872}{10} ms = 187{,}2ms$$

The uplink capacity and interference can be calculated using two simple models.

5.1 Uplink capacity channel load model

For this model a maximum load $load_{max}$ (%) is assigned to each of the 4 uplink channels. If it is assumed the transmissions from the end devices are uniformly distributed over time, the following formula applies for the total number of frame transmissions allowed per hour:

$$Tframes_{allowed} = \frac{3.600.000\ ms}{t_{tx}} \cdot load_{max} \cdot 4$$

If a 25% channel load is targeted per channel the total number of example frames allowed per hour is

$$Tframes_{allowed} = 19.230\ {}^{frames}/_{hour}$$

The number of end devices ED_{max} that can be deployed is thus determined by the transmission interval TI as defined in [1]:

$$ED_{max} = \frac{TI\ s}{3.600\ s} \cdot Tframes_{allowed}$$

For a population of end devices all transmitting similar frames 3 times per hour the maximum number of end devices are:

$$ED_{max} = \frac{1.200\ s}{3.600\ s} \cdot Tframes_{allowed}$$

$$\Downarrow$$

$$ED_{max} = 6.410$$

5.2 Self-interference level

The number of frames allowed per channel is determined as:

$$C_{frames} = \frac{Tframes_{allowed}}{4} = 4.807\ {}^{frames}/_{hour}$$

The interference level for a single channel is calculated as:

$$Channel\ interference\ level = 1 - \left(1 - \frac{t_{tx}}{3.600}\right)^{C_{frames}} \%$$

$$\Downarrow$$

$$Channel\ Interference\ level = 1 - \left(1 - \frac{187{,}2 \cdot 10^{-3} s}{3.600 s}\right)^{4807} \% = 22{,}1\%$$

The total interference level for the utilized band (OBW ~ 180 kHz) is:

$$Total\ interference\ level = 1 - (1 - Channel\ Interference\ level)^4$$

$$\Downarrow$$

$$Total\ interference\ level = 1 - (1 - 22{,}1\%)^4 = 63{,}2\%$$

This means that there will be one or more end devices transmitting in one of the four channels 63,2% of the time, but only 22,1% of the time when looking at a single channel.

6 Frequency stability parameter details

Coherent receivers are based on the phase information in the transmitted signal (the carrier phase) to recover the transmitted data. A constellation diagram is shown in Figure 2. If the frequency changes during reception will affect the phase information.

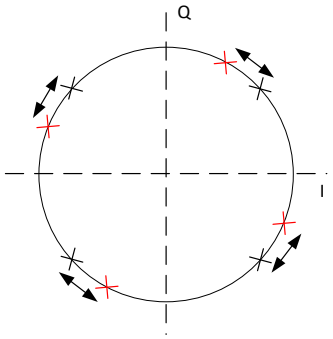

Figure 2 Constellation diagram for precoded GMSK. Coherent reception is sensible about df/dt (phase error) when determining symbols.

The two frequency dynamic drift requirements from the transmitter parameters in [1] are illustrated in Figure 3. Two examples of frequency stability are shown on the upper diagrams. Both examples shows a sequence of the carrier frequency over time:

- During the time interval after a certain start-up time of the oscillator (e.g. from sleep mode), until the preamble and synchronization word is transmitted, the Transitional Frequency Dynamic Drift requirement applies.
- During the transmission of the maximum OpenlinkIQ® data frame after the synchronization word, the Established Frequency Dynamic Drift requirement applies.

The target carrier frequency is indicated by f_c.

The bottom diagrams illustrate the derivate examples with the requirement limits. The expected errors when limits are exceeded are mentioned and finally, an example of possible mitigation activities are shown.

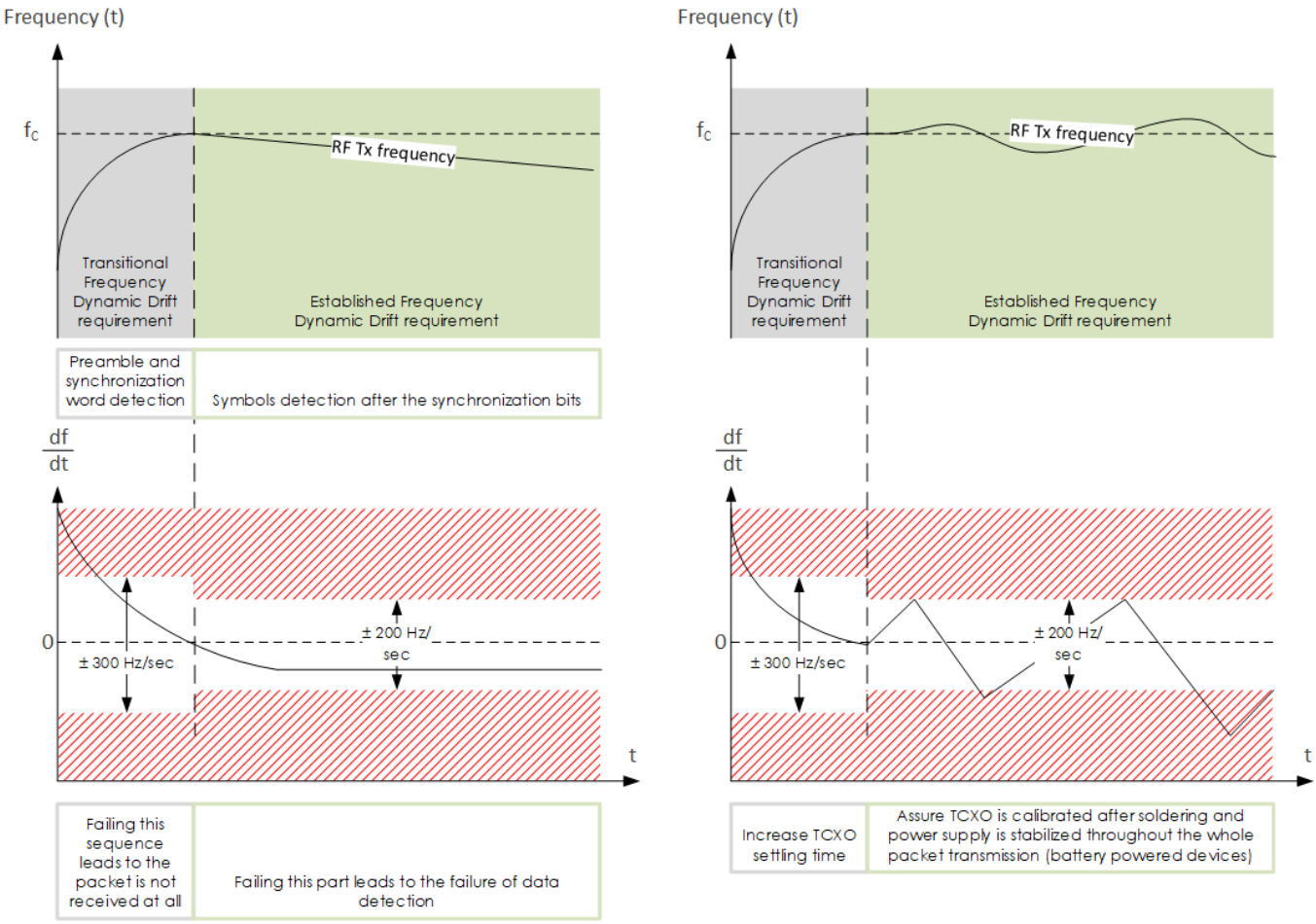

Figure 3 Illustration of Transitional Frequency Dynamic Drift and Established Frequency Dynamic Drift.