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Part 1: PHY layer**

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Foreword

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

The present document is part 1 of a multi-part deliverable covering Short Range Devices: Smart Metering Wireless Access Protocol.

Part 1: "PHY layer";

Part 2: "Data Link Layer (MAC sub-layer)".

Introduction

The requirement to wirelessly interconnect Smart Meters is one of the responses to the EC's mandate 441 [i.1] for an open architecture for utility meters. Short Range Device (SRD) technology has been identified as a candidate technology to interconnect meters to the Wide Area Network (WAN) Access Point (AP).

The present document is derived from IEEE Std 802.15.4g-2012 [2] (Amendment to IEEE Std 802.15.4-2011 [1]).

The modifications include a restriction of the base document for use in the frequency band 870 to 876 MHz and 915 to 921 MHz.

1 Scope

The present document provides adaptations to IEEE Std 802.15.4g-2012 [2] in order to comply with the European regulations for Short Range Devices (SRDs).

2 References

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

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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2.1 Normative references

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

[1] IEEE Std 802.15.4-2011: "IEEE Standard for Local and metropolitan area networks - Part 15.4: Low Rate Wireless Personal Area Networks (LR-WPANs)".

[2] IEEE Std 802.15.4g-2012: "IEEE Standard for Local and metropolitan area networks - Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 3: Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks".

2.2 Informative references

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

[i.1] M/441: "Standardisation Mandate to CEN, CENELEC and ETSI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability".

3 Definitions and abbreviations

3.1 Definitions

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

Smart metering Utility Network (SUN) device: entity implementing the specification defined in the present document

3.2 Abbreviations

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

AP	Access Point
BDE	Binary Differential Encoding
CCA	Clear Channel Assessment
CP	Cyclic Prefix
DSSS	Direct Sequence Spread Spectrum

ED	Energy Detect
EU	European Union
EVM	Error Vector Magnitude
FCS	Frame Check Sequence
FEC	Forward Error Correction
FSK	Frequency Shift Keying
GFSK	Gaussian-filtered Frequency Shift Keying
HCS	Header Checksum
LTF	Long Training Field
MAC	Medium Access Control
MCS	Modulation and Encoding Scheme
MSB	Most Significant Bit
OFDM	Orthogonal Frequency Division Multiplexing
OFDM	Orthogonal Frequency Division Multiplexing
PER	Packet Error Rate
PHR	PHY Header
PHY	Physical Layer
PIB	Personal Area Network Information Base
PPDU	PHY Protocol Data Unit
PSD	Power Spectral Density
PSDU	PHY Service Data Unit
QPSK	Quadrature Phase Shift Keying
RC	Raised Cosine
RF	Radio Frequency
SFD	Start Frame Delimiter
SHR	Synchronisation Header
SRD	Short Range Device
STF	Short Training Field
SUN	Smart Utility Network
WAN	Wide Area Network

4 Overview

4.1 Introduction to smart metering utility network (SUN)

SUNs are as defined in [2], clause 4.1a with the following text replacing the 2nd paragraph of that clause.

The Gaussian Frequency Shift Keying (GFSK) PHY provides good transmit power efficiency due to the constant envelope of the transmit signal.

The low data rate Offset Quadrature Phase Shift Keying (O-QPSK) PHY shares the characteristics of the GFSK PHY, but provides better receiver sensitivity.

The Orthogonal Frequency Division Multiplexing (OFDM) PHY has good properties in frequency selective channels and can provide higher data rates.

A device shall implement at least one option of the GFSK, O-QPSK or OFDM PHYs to satisfy the requirements of the present document.

4.2 General PHY requirements

GFSK PHY: Gaussian Frequency Shift Keying (GFSK) PHY operating at multiple data rates.

O-QPSK PHY: Offset Quadrature Phase Shift Keying (O-QPSK) PHY operating in a low data rate mode.

OFDM PHY: Orthogonal Frequency Division Multiplexing (OFDM) PHY operating at multiple data rates.

The frequency bands for all PHYs are shown in Table 3. The modulation schemes and corresponding achievable data rates for the GFSK and O-QPSK PHYs are shown in Table 1. The OFDM PHY parameters and data rates are shown in Table 2.

Table 1: GFSK and O-QPSK PHY parameters and data rates

PHY	Data Parameters					
	Option	**Modulation Index**	**Symbol Rate (ksymbol/s) †**	**Data Rate (kb/s)**	**Symbols**	**Notes**
GFSK	1	0,5	100	{100, 50}*	Binary	See note 1
	2	0,5	200	{200, 100}*	Binary	See note 1
	3	1	50	{50, 25}*	Binary	See note 2
	4	0,5	150	{150, 75}*	Binary	See note 2
	5	0,33	100	{200, 100}*	4-ary	See note 2
O-QPSK	1	N/A	100	6,25	Binary	See note 1
	2	N/A	200	12,5	Binary	See note 1

* For the GFSK PHY, pairs of rates {x, y} are shown. The first rate, x corresponds to the PSDU bit rate when FEC is not enabled, and the second rate, y corresponds to the PSDU bit rate when FEC is enabled.
† For the O-QPSK PHY, the symbol rate is equal to the chip rate with unit "kchip/s".
NOTE 1: GFSK and O-QPSK Options 1 & 2, these PHYs are defined in a manner intended to facilitate detection and interpretation of modulation and data rate from the received synchronization header (SHR).
NOTE 2: GFSK Options 3-5 may also be implemented with mutual detection and interpretation of modulation and data rate but with additional complexity.

Table 2: OFDM PHY parameters and data rates

OFDM PHY Parameters and data rates	As defined in [2], table 148, Options 3 and 4 only.

NOTE 1: OFDM options are defined using similar occupied bandwidth as the GFSK & O-QPSK PHYs to permit, as far as possible, implementations which support multiple different PHYs.
NOTE 2: Option 3 may be subject to specific regulatory limits owing to its occupied bandwidth.

4.3 Channel numbering

Channel numbering shall be as defined in [2], clause 8.1.2.9 with the following constraints:

- The channel centre frequency ChanCentreFreq is as follows:

  $ChanCentreFreq = ChanCentreFreq_0 + N\ x\ (NumChan \times ChanSpacing)$

  Where:

  - N is the number of bonded channels and can take values 1 or 2

- The parameters *ChanSpacing*, *TotalNumChan*, and $ChanCentreFreq_0$ for different frequency bands and modulation schemes are specified in Table 3.

Table 3: Total number of channels and first channel centre frequencies

Frequency band (MHz)	***ChanSpacing* (MHz)**	***TotalNumChan***	**$ChanCentreFreq_0$ (MHz)**
870-876	0,2	29	870,2
915-921	0,2	29	915,2

4.4 Receiver sensitivity definition

The receiver sensitivity shall be as defined in [2], clause 8.1.7 with the additional constraints given in Table 4.

Table 4: Receiver sensitivity definition

Term	Definition of term	Conditions
Receiver sensitivity	-	– PSDU length = 7 or 18 octets for the O-QPSK PHY PPDU Type 2 according to the SFD used – PER < 10 %

4.5 PHY constants

The PHY constants are given in Table 5.

Table 5: PHY Constants

Constant	Description & Max Value
aMaxPHYPacketSize	As defined in [2], clause 9.2
aTurnaroundTime	As defined in [2], clause 9.2

4.6 PHY PIB attributes

The PHY PIB is as described in [2], clause 9.3. The relevant attributes are presented in Table 6.

Table 6: PHY PIB attributes

Attribute	Type	Valid range	Description
phyGFSKSFD	-	-	As defined in [2], clause 9.3 for *phyMRFSKSFD* This attribute is only valid for the GFSK PHY.
phyGFSKPreambleRepetitions	Integer	4-64	The number of times the 1-octet preamble pattern (see clause 5.2) is repeated.

5 GFSK PHY specification

5.1 PPDU format for GFSK

The GFSK PPDU shall be as defined in [2], clause 18.1.1 excluding the format of the Mode Switch PPDU. The PHR is as defined in clause 5.2.2.

5.2 Preamble field

The preamble shall be as defined in [2], clause 18.1.1.1 for 2FSK substituting GFSK for FSK and replacing *phyFSKPreambleRepetitions* with *phyGFSKPreambleRepetitions*.

5.2.1 SFD

The SFD shall be as defined in [2], clause 18.1.1.2 with the following constraints:

- Devices which do not support FEC shall support at least one of the SFDs associated with uncoded (PHR+PSDU). Devices which support FEC shall support at least one pair of SFDs corresponding to one value of the PIB attribute *phyGFSKSFD*. (See clause 4.6.)

- Which of the two groups of SFD is used shall be controlled by the PIB attribute *phyGFSKSFD*.

5.2.2 PHR

The PHR shall be as defined in [2], clause 18.1.1.3 with the following constraints:

- The Mode Switch bit shall be set to 0.
- The FCS bit shall be set to 0.
- The Frame Length is a value between 0 and *aMaxPHYPacketSize*, as defined in clause 4.5.

5.2.3 PSDU field

The PSDU field shall be as defined in [2], clause 18.1.1.5.

5.3 Modulation and coding for GFSK

The modulation and coding for GFSK are shown in Table 1 and the channel spacing is shown in Table 3.

5.3.1 Bit-to-symbol mapping

The bit-to-symbol mapping shall be as defined in [2], clause 18.1.2.2 replacing GFSK for each occurrence of 'filtered FSK'.

5.3.2 Forward error correction (FEC)

Forward error correction (FEC) shall be as defined in [2], clause 18.1.2.4.

5.3.3 Code-symbol interleaving

Code-symbol interleaving shall be as defined in [2], clause 18.1.2.5.

5.4 Data whitening for GFSK

Data Whitening shall be as defined in [2], clause 18.1.3.

5.5 GFSK PHY RF requirements

5.5.1 Operating frequency range

The GFSK PHY operates in the bands given in Table 3.

5.5.2 Radio frequency tolerance

The single-sided clock frequency at the transmitter shall be 30 ppm. Oscillators determining transmit centre frequency and symbol time frequency shall be derived from the same reference oscillator.

5.5.3 Transmitter symbol rate tolerance

The transmitter symbol rate tolerance shall be as defined in [2], clause 18.1.5.5.

5.5.4 Channel switch time

Channel switch time shall be as defined in [2], clause 18.1.5.4.

5.5.5 Receiver sensitivity

The GFSK receiver sensitivity shall be as defined in [2], clause 18.1.5.7 with the following constraint:

S_0 is –91.

5.5.6 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as defined in [2], clause 18.1.5.9.

5.5.7 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as defined in [2], clause 18.1.5.10.

5.5.8 Receiver interference rejection

The interference rejection shall be measured as follows: The desired signal shall be a compliant GFSK PHY signal, as defined in this clause 5, of pseudo-random data at the centre frequency of the desired channel.

The desired signal is input to the receiver at a level 3 dB above the receiver sensitivity given in clause 5.5.5.

The interferer is an unmodulated carrier which is separated in frequency $\pm\Delta f$ from the centre frequency of the desired signal. The interferer is input at the level relative to the level of the desired signal as shown in Table 7.

Table 7: Minimum receiver interference rejection requirements for GFSK

Option	Δ*f* = 200 kHz	Δ*f* = 400 kHz	Δ*f* = 600 kHz	Δ*f* = N*200 kHz (See note)
1	10 dB	25 dB	30 dB	30 dB
2	10 dB	20 dB	25 dB	30 dB
3	10 dB	30 dB	30 dB	30 dB
4	10 dB	20 dB	25 dB	30 dB
5	10 dB	20 dB	25 dB	30 dB
NOTE: N = {4, 5, …, 28} for channels within the band of operation.				

The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in clause 4.4 under these conditions.

5.5.9 Transmitter accuracy

Modulation quality shall be measured by observing the frequency deviation tolerance and the zero crossing tolerance of the eye diagram caused by a PN9 sequence of length 511 bits.

5.5.9.1 Frequency deviation tolerance

Modulation frequency tolerance shall be as defined in [2], clause 18.1.2.3.1 substituting GFSK for filtered FSK.

5.5.9.2 Zero crossing tolerance

Zero crossing tolerance shall be as defined in [2], clause 18.1.2.3.2 substituting GFSK for filtered FSK.

5.5.10 Transmit power

Transmit power shall be as defined in [2], clause 18.1.5.11.

The maximum transmit power is limited by local regulatory bodies.

5.5.11 Receiver maximum input level of desired signal

The receiver maximum input level shall be as defined in [2], clause 18.1.5.12 substituting GFSK for MR-FSK.

5.5.12 Receiver ED

The receiver ED measurement is an estimate of the received signal power within the bandwidth of the channel. No attempt is made to identify or decode signals on the channel. The time over which the ED measurement is averaged shall be equal to 160 μs.

The ED value zero shall indicate received power less than 10 dB above the maximum allowed receiver sensitivity as defined in clause 5.5.5. The mapping from the received power in decibels to ED value shall be linear with an accuracy of ±6 dB.

5.5.13 Clear channel assessment (CCA)

The PHY shall provide the capability to perform CCA. CCA shall report a busy medium on detecting any energy ≥ ED value of zero as defined in clause 5.5.12.

6 O-QPSK PHY specification

6.1 PPDU format for O-QPSK

The O-QPSK PPDU shall support two PPDU types. For PPDU Type 1, a variable PSDU length shall be supported, as shown in Figure 1.

	Octets		
	3	variable	
Preamble	SFD-1	as defined in clause 6.1.3	PSDU
SHR		PHR	PHY payload

Figure 1: Format of the O-QPSK PHY for PPDU Type 1

For PPDU Type 2, the number of octets contained in the PSDU (payload) shall be either 7 octets (SFD-2 is used) or 18 octets (SFD-3 is used). The format of PPDU Type 2 is shown in Figure 2.

	Octets	
	7 or 18	
Preamble	SFD-2 or SFD-3	PSDU
SHR		PHY payload

Figure 2: Format of the O-QPSK PHY for PPDU Type 2

6.1.1 Preamble field

The Preamble field for O-QPSK shall contain a sequence of 30 zero bits.

6.1.2 SFD

The SFD for O-QPSK shall be a 16-bit sequence as shown in Table 8. The leftmost bit, b_0, shall be processed first in time, and the last bit, b_{15}, shall be processed last in time.

Table 8: Format of the SFD for O-QPSK PHY

SFD	SFD value (b_0–b_{15})	Indication
SFD-1	1110 1011 0110 0010	PPDU Type 1: variable PSDU length
SFD-2	1110 1001 1111 1101	PPDU Type 2: 7 octets PSDU
SFD-3	1101 1111 0000 1001	PPDU Type 3: 18 octets PSDU

6.1.3 PHR

The PHR shall be as defined in [2], clause 18.3.1.3 with the following additional constraints:

- The PHY Header (PHR) shall be used for PPDU Type 1. The format of the 24-bit PHR sequence is shown in Figure 3. The leftmost bit, b_0, shall be processed first in time, and the last bit, b_{23}, shall be processed last in time. All multi-bit sub-fields of the PHR are unsigned integers and shall be processed MSB first.

Bit String	b0-b4	b5-b15	b16-b23
Bit Mapping	R_4 - R_0	L_{10} - L_0	H_7 – H_0
Field Name	Reserved	Frame Length	HCS

Figure 3: Format of the PHR for O-QPSK

- The Reserved subfield R_4 to R_0 shall always be set to 00000.

6.1.4 PSDU field

The PSDU field shall be as defined in [2], clause 18.3.1.4.

6.2 Modulation and coding for O-QPSK

6.2.1 Overview

There are two PHY options for the O-QPSK PHY, denoted as PHY Option 1 and Option 2 respectively. The main parameters of the O-QPSK PHY are shown in Table 9.

Table 9: Parameters of the O-QPSK PHY

Parameter	Unit	Value	
		PHY Option 1	**PHY Option 2**
Frequency band	MHz	870-876 and 915-921	
Chip rate f_{chip}	kchip/s	100	200
SHR coding	-	BDE	
SHR spreading	-	(32,1)-DSSS	
PHR + PSDU coding	-	Rate ½ -FEC + Interleaving + BDE	
PHR + PSDU spreading	-	$(8,1)_{0/1}$-DSSS	
PSDU data rate	kb/s	6,25	12,5
Modulation	-	RC shaped O-QPSK	

6.2.2 SHR coding and spreading

For the 46 SHR bits, bit differential encoding (BDE), see clause 6.2.7, and subsequently spreading by (32,1)-DSSS shall be applied (see clause 6.2.8). This shall result in an SHR chip sequence c_{SHR}.

6.2.3 PHR coding and spreading

The PHR field, consisting of 24 information bits, shall be processed by rate ½ FEC (see clause 6.2.5) and interleaving (see clause 6.2.6), resulting in 60 interleaved code-bits. For the interleaved PHR code-bits, BDE (see clause 6.2.7) and subsequently spreading by $(8,1)_{0/1}$-DSSS shall be applied (see clause 6.2.8). This shall result in a PHR chip sequence c_{PHR}.

6.2.4 PSDU coding and spreading

For each octet of the PSDU with frame length in octets (LENGTH), the least significant bit shall be processed first in time, beginning with the left most octet and ending with the right most octet. The resulting bit stream, b_0, b_1, …, $b_{8\times\mathrm{LENGTH}-1}$, shall be first processed by rate ½ FEC as described in clause 6.2.5, delivering a sequence of code-bits. The code-bits shall be interleaved as described in clause 6.2.6. For the interleaved PSDU code-bits, BDE (see clause 6.2.7) and subsequently spreading by $(8,1)_{0/1}$-DSSS shall be applied (see clause 6.2.8). The obtained chip sequence shall be extended by pilot sequences (see clause 6.2.9), resulting in a chip sequence c_{PSDU}.

6.2.5 Forward error correction (FEC)

Forward error correction (FEC) as defined in [2], clause 18.3.2.6 shall be applied to the bits of the PHR and PSDU field as indicated in Table 9.

For PPDU-Type 2, the PHR bits and the six, zero bits following the PHR bits shall be omitted.

6.2.6 Code-bit interleaving

Code-bit interleaving shall be as defined in [2], clause 18.3.2.7 with the following constraints:

- Interleaving of PHR code-bits only applies to PPDU Type 1.
- Interleaver parameters for PPDU Type 2 are given in Table 10.

Table 10: Interleaver Parameters

PPDU Type		degree λ	depth N_{INTRLV}
Type 2	PSDU: 7 octets	7	18 × 7 = 126
	PSDU: 18 octets	6	25 × 6 = 150

6.2.7 Bit differential encoding (BDE)

BDE shall be as defined in [2], clause 18.3.2.8 with the following constraints:

- BDE is always applied as indicated in Table 9.
- The number of SHR bits (N_{SHR}) is 46.
- M_p = 512 is the pilot spacing (see clause 6.2.9), and N = 8 is the spreading factor of $(8,1)_{0/1}$-DSSS (see clause 6.2.8).
- For PPDU Type 2, let the sequence of differentially encoded PSDU code bits, E_n, be defined as:

$$E_n = \begin{cases} R_n \oplus E_{45}^{SHR}, & n = 0 \\ R_n \oplus 0, & (n \bmod M) = 0 \text{ and } n \neq 0 \\ R_n \oplus E_{n-1}, & (n \bmod M) \neq 0 \end{cases}$$

For PPDU Type 2, referencing to E_{45}^{SHR} assures, that during non-coherent differential detection, the very first interleaved PSDU code-bit can be referenced to the last SHR bit.

6.2.8 Spreading

For spreading, direct sequence spread spectrum (DSSS) shall be used. This is achieved by mapping a single bit to a sequences of N binary valued chips, $c_0, c_1, ..., c_{N-1}$, called (N,1)-DSSS.

The differentially encoded SHR bits shall be spread by (32,1)-DSSS as shown in Table 11.

Table 11: (32,1)-DSSS bit-to-chip mapping

Input bit	Chip values $c_0, c_1, \ldots, c_{31}$
0	1101 1110 1010 0010 0111 0000 0110 0101
1	0010 0001 0101 1101 1000 1111 1001 1010

For the interleaved code-bits of the PHR and PSDU, two spreading codes are defined, denoted as $(8,1)_0$-DSSS and $(8,1)_1$-DSSS. The mapping is shown in Table 12.

Table 12: $(8,1)_k$ - DSSS bit-to-chip mapping

k	Input bit	Chip values $c_0, c_1, \ldots, c_7$
0	0	1011 0001
	1	0100 1110
1	0	0110 0011
	1	1001 1100

The two spreading codes shall be applied in an alternating manner, denoted as $(8,1)_{0/1}$-DSSS. In particular, let $\{E_0^{PHR}, \ldots, E_{59}^{PHR}\}$ be the sequence of differentially encoded PHR code-bits (for PPDU type 1) and $\{E_0^{PSDU}, \ldots, E_{2N_D-1}^{PSDU}\}$ be the sequence of differentially encoded PSDU code-bits. The even indexed bits, E_{2k}^{X}, shall be spread with $(8,1)_0$-DSSS and the odd indexed bits, E_{2k+1}^{X}, shall be spread with $(8,1)_1$-DSSS, where $X \in \{PHR, PSDU\}$. The time variance of the spreading code improves spectral properties while preserving a robust and simple mechanism for carrier sense.

For each chip sequence, $c_0, c_1, ..., c_{N-1}$, the first component, c_0, shall be transmitted first in time, and the last component, c_{N-1}, shall be transmitted last in time.

6.2.9 Pilot insertion

Pilot insertion shall be as defined in [2], clause 18.3.2.12 with the following constraints:

Table 13 shows the value M_P of the pilot spacing and the pilot sequence.

Table 13: Pilot spacing and sequence

Spacing M_p	Pilot Length N_p	Pilot sequence $p = (p_0, p_1, ..., p_{N_P-1})$
512	32	1101 1110 1010 0010 0111 0000 0110 0101

For PPDU Type 1, the pilot extended PSDU chip sequence is given by:

$$c_{PSDU} = \{p, u^0, p, u^1, \cdots, p, u^{L-1}\}$$

For PPDU Type 2, the very first pilot sequence is omitted. The pilot extended PSDU chip sequence is given by:

$$c_{PSDU} = \{u^0, p, u^1, \cdots, p, u^{L-1}\}$$

6.2.10 PPDU Chip sequence

The PPDU chip sequence is given by $P_1 = \{c_{SHR}, c_{PHR}, c_{PSDU}\}$ (PPDU Type 1) or $P_2 = \{c_{SHR}, c_{PSDU}\}$

(PPDU Type 2) or any sequence obtained by concatenating multiples of P_1 and P_2.

6.2.11 Modulation

Let $c_{PPDU} = \{c_0, c_1, \cdots, c_{N_{PPDU}-1}\}$ be the chip sequence belonging to a complete PPDU. The modulating value $\alpha_k \in \{-1, +1\}$ input to the modulator is:

$$\alpha_k = 2c_k \text{ -1, for } k = 0,1,\cdots, N_{PPDU} \text{ -1}$$

The function *p*, defining the impulse response of a raised cosine shaping filter is given by:

$$p(t) = \begin{cases} \dfrac{\sin(\pi t / T_c)}{\pi t / T_c} \times \dfrac{\cos(r\pi t / T_c)}{1 - 4r^2 t^2 / T_c^2}, & t \neq 0 \\ 1, & t = 0 \end{cases}$$

with roll-off factor *r* = 0.8 and chip duration $T_c = 1/f_{chip}$. The continuous-time pulse shaped complex baseband signal is given by:

$$y(t) = \sum_{k=0}^{N_{PPDU}/2-1} \alpha_{2k}\, p(t - 2kT_c) + j\alpha_{2k+1}\, p(t - (2k+1)T_c) \qquad (1)$$

with $j = \sqrt{-1}$.

6.3 O-QPSK PHY RF requirements

6.3.1 Operating frequency range

The O-QPSK PHY shall operate in the 870-876 MHz and 915-921 MHz band.

6.3.2 Radio frequency and symbol rate tolerance

The single-sided clock frequency and symbol rate tolerance at the transmitter shall be 20 ppm. Oscillators determining transmit centre frequency and symbol time frequency shall be derived from the same reference oscillator.

6.3.3 Channel switch time

Channel switch time shall be less than or equal to 500 µs. The channel switch time is defined as the time elapsed when changing to a new channel, including any required settling time.

6.3.4 Receiver sensitivity

Under the conditions specified in clause 4.4, a compliant device shall be capable of achieving a sensitivity of -110 dBm or better for PHY Option 1, and a sensitivity of -107 dBm or better for PHY Option 2.

6.3.5 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as defined in [2], clause 18.3.4.5.

6.3.6 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as defined in [2], clause 18.3.4.6.

6.3.7 Receiver Interference Rejection

The interference rejection shall be measured as follows: the desired signal shall be a compliant O-QPSK PHY signal, as defined in this clause 6, of pseudo-random data at the centre frequency of the desired channel.

The desired signal shall be input to the receiver at a level 3 dB above the receiver sensitivity given in clause 6.3.4.

The interferer shall be an unmodulated carrier which is separated in frequency $\pm\Delta f$ from the centre frequency of the desired signal. The interferer is input at the level relative to the level of the desired signal, as shown in Table 14.

Table 14: Minimum receiver interference rejection requirements for O-QPSK

Option	Δ*f* = 200 kHz	Δ*f* = 400 kHz	Δ*f* = 600 kHz	Δ*f* = N*200 kHz (See note)
1	10 dB	30 dB	30 dB	30 dB
2	10 dB	25 dB	30 dB	30 dB
NOTE: N = {4, 5, …, 28} for channels within the band of operation.				

The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in clause 4.4 under these conditions.

6.3.8 Error-vector magnitude (EVM) definition

EVM shall be as defined in [2], clause 18.3.4.7.

6.3.9 Transmit power

Transmit power shall be as defined in [2], clause 18.3.4.9.

6.3.10 Receiver maximum input level of desired signal

The receiver maximum input level is as defined in [2], clause 18.3.4.10.

6.3.11 Receiver ED

The receiver ED measurement is an estimate of the received signal power within the bandwidth of the channel. No attempt is made to identify or decode signals on the channel. The time over which the ED measurement is averaged shall be equal to 1 280 µs for Option 1 and 640 µs for Option 2.

The ED value zero shall indicate received power of at most -90 dBm. The mapping from the received power in decibels to ED value shall be linear with an accuracy of ±6 dB.

6.3.12 Clear channel assessment (CCA)

The PHY shall provide the capability to perform CCA. CCA shall report a busy medium on detecting any energy ≥ ED value of zero as defined in clause 6.3.11.

7 OFDM PHY specification

The OFDM PHY shall be as defined in [2], clause 18.2 restricted to Option 3 and Option 4 and operation in the frequency bands defined in Table 3. Data rates range from 50 kb/s to 600 kb/s with occupied bandwidths less than 300 kHz for Option 3 and less than 200 kHz for Option 4.

7.1 PPDU format for OFDM

The PPDU format shall be as defined in [2], clause 18.2.1 substituting OFDM for MR-OFDM.

7.1.1 Short Training field (STF)

The following clauses describe the STF.

7.1.1.1 Frequency domain STF

The frequency domain STF shall be as defined in [2], clause 18.2.1.1.1 excluding the STF defined for Options 1 and 2.

7.1.1.2 Time domain STF generation

The time domain STF generation shall be as defined in [2], clause 18.2.1.1.2.

7.1.1.3 Time domain STF repetition

Time domain STF repetition shall be as defined in [2], clause 18.2.1.1.4 restricted to Option 3 and Option 4 only.

7.1.1.4 STF normalization

STF normalization shall be as defined in [2], clause 18.2.1.1.4.

7.1.2 Long Training field (LTF)

The LTF structure in both the frequency and time domain shall be as described in the following clauses.

7.1.2.1 Frequency domain LTF

The frequency domain LTF shall be as defined in [2], clause 18.2.1.2.1 excluding the LTF defined for Options 1 and 2.

7.1.2.2 Time domain LTF generation

The time domain STF generation shall be as defined in [2], clause 18.2.1.2.2.

7.1.2.3 LTF normalization

LTF normalization shall be as defined in [2], clause 18.2.1.2.3.

7.1.3 PHR

The PHR shall be as defined in [2], clause 18.2.1.3 excluding consideration of Options 1 and 2.

7.1.4 PSDU field

The PSDU field shall be as defined in [2], clause 18.2.1.4.

7.2 Data rates for OFDM

Data rates for OFDM shall be as defined in [2], clause 18.2.2 excluding Options 1 and 2.

The OFDM PHY parameters and data rates are found in Table 2.

7.3 Modulation and coding for OFDM

7.3.1 Reference modulator diagram

The reference modulator diagram shall be as defined in [2], clause 18.2.3.1.

7.3.2 Bit-to-symbol mapping

Bit-to-symbol mapping shall be as defined in [2], clause 18.2.3.2.

7.3.3 PIB attribute values for *phySymbolsPerOctet*

The number of symbols per octet shall be as defined in [2], clause 18.2.3.3 excluding Options 1 and 2.

7.3.4 Forward error correction (FEC)

FEC shall be as defined in [2], clause 18.2.3.4.

7.3.5 Interleaver

The interleaving process shall be as defined in [2], clause 18.2.3.5 excluding Options 1 and 2.

7.3.6 Frequency spreading

Frequency spreading shall be as defined in [2], clause 18.2.3.6 excluding sub-clause 18.2.3.6.2.

7.3.7 Pilot tones/null tones

Pilot tones/null tones shall be as defined in [2], clause 18.2.3.7 excluding Options 1 and 2.

7.3.8 Cyclic prefix (CP)

The CP shall be as defined in [2], clause 18.2.3.8.

7.3.9 PPDU Tail Bit field (TAIL)

The Tail field shall be as defined in [2], clause 18.2.3.9.

7.3.10 Pad bits (PAD)

The PAD field shall be as defined in [2], clause 18.2.3.10.

7.3.11 Scrambler and scrambler seeds

The scrambler and scrambler seeds shall be as defined in [2], clause 18.2.3.11.

7.4 OFDM PHY RF requirements

7.4.1 Operating frequency range

The OFDM PHY shall operate in the 870-876 MHz and 915-921 MHz band.

7.4.2 Transmit power spectral density (PSD) mask

The OFDM transmit PSD mask shall be as defined in [2], clause 18.2.4.2.

7.4.3 Receiver sensitivity

Receiver sensitivity shall be as defined in [2], clause 18.2.4.3 excluding Options 1 and 2.

7.4.4 Receiver interference rejection

The interference rejection shall be measured as follows: the desired signal shall be a compliant OFDM PHY signal, as defined in this clause 7, of pseudo-random data at the centre frequency of the desired channel.

The desired signal shall be input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity given in clause 7.4.3.

The interferer shall be an unmodulated carrier which is separated in frequency $\pm\Delta f$ from the centre frequency of the desired signal. The interferer is input at the level indicated in Table 15 relative to the level of the desired signal.

Table 15: OFDM receiver interference rejection

MCS level	Δf = 200 kHz	Δf = 400 kHz	Δf = 600 kHz	Δf = N*200 kHz (see note)
1	10 dB	26 dB	30 dB	30 dB
2	7 dB	23 dB	30 dB	30 dB
3	7 dB	23 dB	30 dB	30 dB
4	5 dB	21 dB	28 dB	30 dB
5	2 dB	18 dB	25 dB	30 dB
6	−2 dB	14 dB	21 dB	30 dB
NOTE: N = {4, 5, …, 28} for channels within the band of operation.				

The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in clause 4.4 under these conditions.

7.4.5 Tx-to-Rx turnaround time

The Tx-to-Rx turnaround time shall be as defined in [2], clause 18.2.4.6.

7.4.6 Rx-to-Tx turnaround time

The Rx-to-Tx turnaround time shall be as defined in [2], clause 18.2.4.7.

7.4.7 Error-vector magnitude (EVM) definition

EVM shall be as defined in [2], clause 18.2.4.8 excluding MCS 0.

7.4.8 Transmit centre frequency and symbol tolerance

The transmit centre frequency tolerance shall be as defined in [2], clause 18.2.4.9.

7.4.9 Transmit power

Transmit power shall be as defined in [2], clause 18.2.4.10.

7.4.10 Receiver maximum input level of desired signal

The receiver maximum input level shall be as defined in [2], clause 18.2.4.11.

7.4.11 Receiver ED

The receiver ED measurement is an estimate of the received signal power within the bandwidth of the channel. No attempt is made to identify or decode signals on the channel. The time over which the ED measurement is averaged shall be equal to 960 µs.

The ED value zero shall indicate received power less than 10 dB above the maximum allowed receiver sensitivity as defined in clause 7.4.3. The mapping from the received power in decibels to ED value shall be linear with an accuracy of ±6 dB.

7.4.12 Clear channel assessment (CCA)

The PHY shall provide the capability to perform CCA. CCA shall report a busy medium on detecting any energy ≥ ED value of zero as defined in clause 7.4.11.

History

Document history		
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