IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)		
Title	TG4g Proposals - Common parts and differences		
Date Submitted	9 November 2009		
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Re:	Task Group 15.4g		
Abstract	This document is a compilation of the TG4g proposals, containing both the common parts and differences.		
Purpose	Discussion within task group		
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Release	The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.		

4. Acronyms and abbreviations

Insert the following acronyms in alphabetical order:

AFA	adaptive frequency agility
CP	cyclic prefix
FCF	format change frame
FFT	Fast Fourier Transform
FSK	frequency shift keying
IFFT	inverse Fast Fourier Transform
LTF	long training field
MRFSK	multi-regional frequency shift keying
MR2-FSK	multi-rate and multi-region frequency shift keying
MSK	minimum shift keying
NF	normal frame
OFDM	orthogonal frequency division multiplexing
QAM	quadrature amplitude modulation
QPSK	quadrature phase-shift keying
SOI	sphere of influence
STF	short training field
SUN	smart utility network
TPC	transmit power control

5. General description

5.1 Introduction

Insert the following new paragraphs after the third paragraph of 5.1:

Battery powered devices are energy constrained and typically less functional than devices that are powered by a limited source of energy. Battery powered devices also typically have smaller amounts of data to be transported either to or from the device. For these reasons, battery powered devices operate and tend to operate in the future at a lower data rate than full function devices.

Full function devices are powered devices that typically have higher data transfer requirements than battery powered devices. An emerging and future proof standard shall provide support for fast data rates to support known and future data transfer requirements between full function devices. At the same time, low data rates are crucial for increasing the link budget, communication range and performance of communication in certain environments.

Change the last paragraph of 5.1 as indicated:

In addition, two optional PHYs are specified. A UWB PHY with optional ranging is one option while a CSS PHY operating in the 2450 MHz band is the second. As a further addition, an optional OFDM PHY is specified.

5.2 Components of the IEEE 802.15.4 WPAN

5.3 Network topologies

5.4 Architecture

5.4.1 Physical layer (PHY)

Insert the following text to the end of the first dashed list in 5.4.1:

- 400–430 MHz (Japan)
- 433–435 MHz (Europe)
- 470–510 MHz (People’s Republic of China)
- 863–868 MHz (Europe)
- 868–870 MHz (Europe)

Insert the following paragraph after the dashed list:

In addition to the unlicensed bands specified, the OFDM radio may also operate using TV white spaces.

5.4.1.1 Advantages of the UWB PHY for LR-WPAN

5.4.1.2 Advantages of the CSS (2450 MHz) PHY for LR-WPAN

5.4.1.3 UWB band coexistence

Insert the following three new subclauses after 5.4.1.3:

5.4.1.3a General characteristics of the multi-regional, frequency-shift keying (MRFSK) PHY

The primary PHY layer considerations for smart utility network (SUN) devices are ubiquity, robustness, and scalability.

The combined requirements of low required data rate, high reliability/availability, and flexible adaptability are well addressed by a channel plan defined across multiple bands, which includes a large number of narrow channels.

The general characteristics of the MRFSK PHY include support for the following:

- Various data rate options, dependent on the bandwidth capacity of the frequency band(s) of interest
  - Low data rate of 50 kbps, medium data rate of 100 kbps, and high data rates of 200/400 kbps
  - Additional data rates available for frequency bands with bandwidth restrictions: 5/10 kbps low rate, 20 kbps medium rate, 40 kbps high rate
  - Frequency bands without bandwidth restrictions have mandatory data rate of 100 kbps in all applicable bands
- Optional operation in multiple frequency bands, including narrow band (bandwidth-restricted) channels, thus allowing the use of small “slices” of underutilized spectrum
- Channel spacing optimized to meet regulatory constraints
- Optional frequency hopping
- Large packet size
  - 2047 octet payload capable of efficient IP support
  - 32-bit CRC FCS
- Robust, simple FSK modulation/demodulation
  - GFSK and MSK modulation
  - Rates of 1 and 2 bits per symbol (via 2- and 4-FSK, respectively)
  - Ability to demodulate under conditions of simultaneous channel occupancy
  - Constant envelope modulation, independent of data patterns and pattern lengths
- Optional forward error correction (FEC)
- Data whitening (scrambling) of payload data
- Transmit power control (TPC) for adapting to both the regulatory domain and observed link conditions
- Monotonic received signal strength indication (RSSI)

5.4.1.3b General Characteristics of the multi-rate and multi-region frequency-shift keying (MR2-FSK) PHY

The general characteristics of the MR2-FSK PHY include support for the following features:

a) Low data rates to support basic devices (i.e., 40 kbps) but also “high” data rates to support data intensive devices and applications (i.e., 320 kbps).

b) Low data rates to increase the range of communication.

c) Ubiquitous network support for battery powered (e.g., gas and water) and full function (i.e., electric) devices. All devices are interoperable.

d) Minimal infrastructure requirements (in many cases, nothing required except the utility devices).

e) Worldwide operation.

f) Efficient support for communication with legacy devices.

g) Efficient data rate changes at PHY Layer.

h) Efficient switching between PHYs (e.g., FSK, OFDM, DSSS).

5.4.1.3c Advantages of the OFDM PHY for LR-WPAN

The OFDM PHY uses a scalable FFT so that the OFDM Symbol Time and OFDM Frequency Subcarrier spacing can be maintained “constant” irrespective of the Bandwidth Option that is chosen. Bandwidth scaling from 1MHz down to less than 100KHz is achieved in this fashion by scaling the FFT options from 128 point FFT down to 8 point. Because of this, the OFDM Physical layer definition is “RF Band Agnostic”. OFDM is a spectrally efficient modulation with RF robustness and performance and is adaptable to multiple regulatory considerations.

5.4.2 MAC sublayer

Insert the following text after the second paragraph:

SUN systems are designed primarily for low-duty cycle applications. The MAC sublayer must be optimized for high data delivery reliability, low data throughput, effective support of IP traffic, and efficient support to upper layers for ad-hoc, multi-hop networking.

The general characteristics of the MAC sublayer required to support the MRFSK PHY include the following:

- Link control and timing, including exchanging and maintaining timing information between peer nodes
- Optional support for frequency hopping
- Support for transmit power control (TPC) (i.e., the ability to adjust the transmit power to fit local regulations and/or operating conditions)
- Data whitening
- Support for both 16-bit and 32-bit FCS

5.5 Functional overview

5.5.1 Superframe structure

5.5.2 Data transfer model

5.5.2.1 Data transfer to a coordinator

5.5.2.2 Data transfer from a coordinator

5.5.2.3 Peer-to-peer data transfers

Insert the following paragraph at the end of 5.5.2.3:

The peer-to-peer topology is important to SUN systems. Peer devices within each other's radio sphere of influence (SOI) are referred to as “directly connected” or “adjacent.” In order to exchange data, the peer devices wishing to communicate may use frequency hopping sequence information. Note that the protocol can operate with or without frequency hopping. Hopping is used, when appropriate, to meet regional regulations, bands and applications. If frequency hopping is used, peer devices may use frequency hopping sequence information at appropriate times, involving local synchronization of the relevant nodes.

5.5.3 Frame structure

5.5.3.1 Beacon frame

Replace Figure 10 with the new figure shown:

The lengths have been changed for both the PHR and MFR fields in the replacement Figure 10. The changes to the PHR length originates from one submission. All three FSK submissions provide for an expansion of the MFR (i.e., FCS).

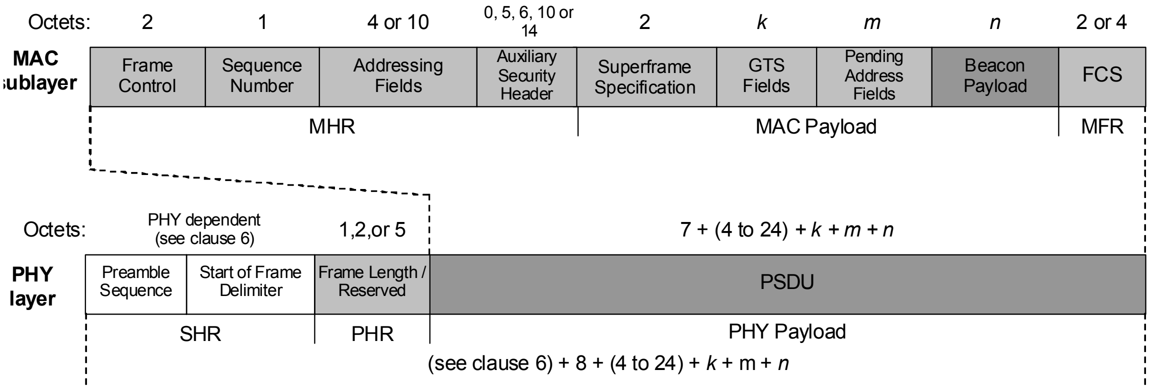


Figure 10—Schematic view of the beacon frame and the PHY packet

Insert the following figure (Figure 10a) after Figure 10:

Figure 10a shows the structure of the beacon frame and the OFDM PHY packet.

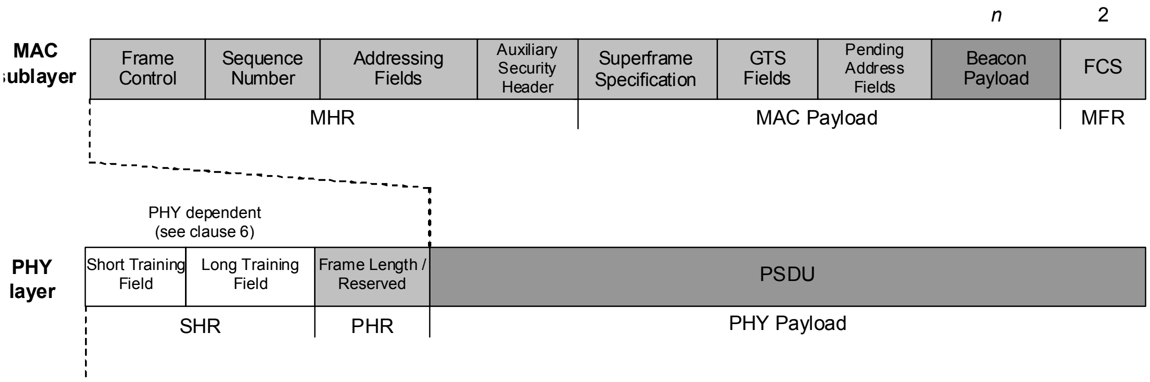


Figure 10a—Schematic view of the beacon frame and the OFDM PHY packet

5.5.3.2 Data frame

Replace Figure 11 with the new figure shown:

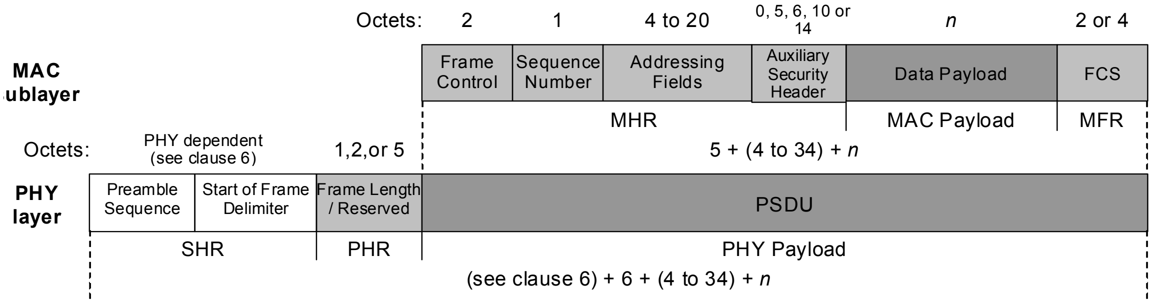


Figure 11—Schematic view of the data frame and the PHY packet

The lengths have been changed for both the PHR and MFR fields in the replacement Figure 11. The changes to the PHR length originates from one submission. All three FSK submissions provide for an expansion of the MFR (i.e., FCS).

Insert the following figure (Figure 11a) after Figure 11:

Figure 11a shows the structure of the data frame and the OFDM PHY packet.

5.5.3.3 Acknowledgment frame

Replace Figure 12 with the new figure shown:

The lengths have been changed for both the PHR and MFR fields in the replacement Figure 12. The changes to the PHR length originates from one submission. All three FSK submissions provide for an expansion of the MFR (i.e., FCS).

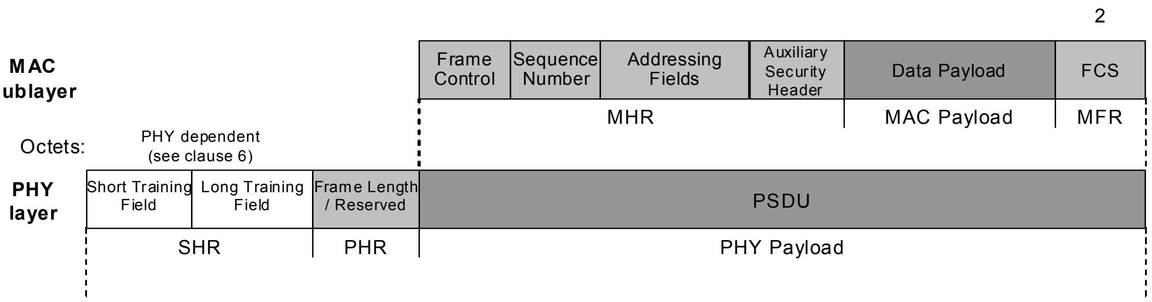


Figure 11a—Schematic view of the data frame and the OFDM PHY packet

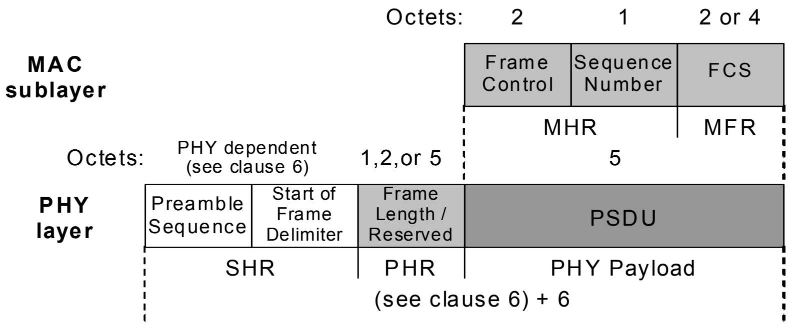


Figure 12—Schematic view of the acknowledgment frame and the PHY packet

Insert the following figure (Figure 12a) after Figure 12:

Figure 12a shows the structure of the acknowledgment frame and the OFDM PHY packet.

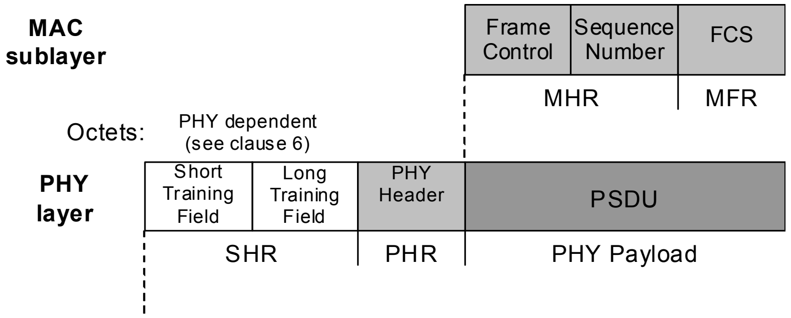


Figure 12a—Schematic view of the acknowledgment frame and the OFDM PHY packet

5.5.3.4 MAC command frame

Replace Figure 13 with the new figure shown:

The lengths have been changed for both the PHR and MFR fields in the replacement Figure 13. The changes to the PHR length originates from one submission. All three FSK submissions provide for an expansion of the MFR (i.e., FCS).

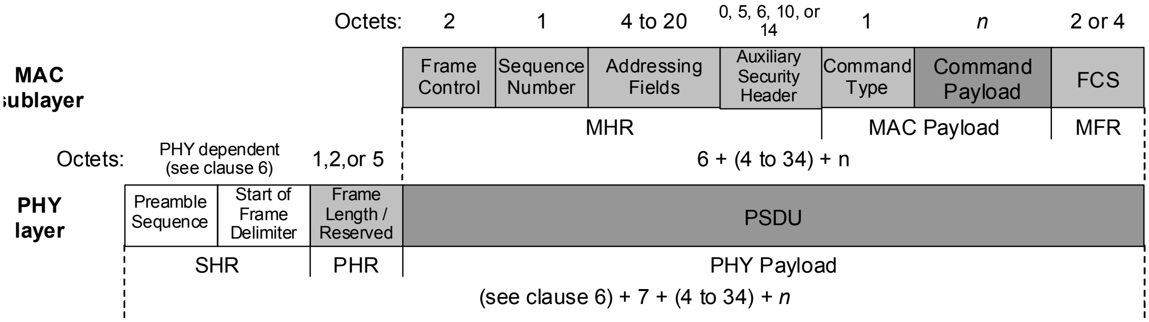


Figure 13—Schematic view of the MAC command frame and the PHY packet

Insert the following figure (Figure 13a) after Figure 13:

Figure 13a shows the structure of the MAC command frame and the OFDM PHY packet.

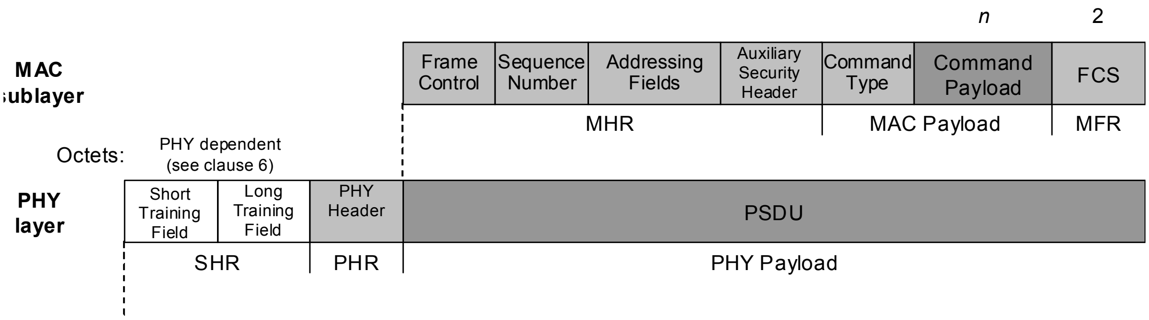


Figure 13a—Schematic view of the MAC command frame and the OFDM PHY packet

5.5.4 Improving probability of successful delivery

Insert the following text at the end of the paragraph in 5.5.4:

The MRFSK PHY is further improved by including a mandatory forward error correction to the PHR and a CRC-32 Koopman algorithm.

Insert the following paragraph at the end of 5.5.4:

Successful data delivery is further improved by optionally including data whitening, forward error correction, including a stronger frame check sequence (FCS), enabling frequency hopping, and introducing robust data modulation techniques.

5.5.4.1 CSMA-CA mechanism

5.5.4.2 ALOHA mechanism for the UWB device

5.5.4.3 Frame acknowledgment

5.5.4.4 Data verification

5.5.4.5 Enhanced robustness features for the UWB PHY

Insert the following two new subclauses after 5.5.4.5:

5.5.4.5a Enhanced features of the MR2-FSK PHY

The MR2-FSK PHY was specifically designed to provide standard devices with flexible and efficient functionalities to interoperate, while at the same time supporting multiple data rate and communication with legacy devices, switch from one data rate to another as well as to switch from one PHY to another. To accomplish these features, device have the following functionalities:

a) The MR2-FSK PHY supports at least three data rate, which will be referred as the low, middle and high data rates.
b) The devices start communication at the lowest data rate, allowing a device to reach the largest number of devices. This allow all devices to only listen for a single data rate prior to switching to a faster data rate.
c) The MR2-FSK PHY uses two types of frames: format change frame (FCF) and normal frame (NF) (see clause 6).
d) The transmitter informs the receiver about its intention to switch data rates by transmitting an FCF before the NF. When no data rate change takes places the transmitter only sends the NF.
e) An FCF and the NF are separated by a “settling delay” (see clause 6).
f) The MR2-FSK PHY uses the special short frame in front of the normal frame to provide information about the switching or not of data rates; it contains a minimum of information that allows the receiver to determine if the remainder of the message is transmitted at the lowest data rate, or if there is a data rate change before the remainder of the message is transmitted. It also indicates the PHY parameters for the new data rate to the receiver.
g) The MR2-FSK PHY allows devices and system to choose one of the following modes:
    1) operate only at the lowest data rate, or
    2) start operating at the lowest data rate and use an FCF to switch from the lowest bit rate to a higher data rate mode.

For interoperability between devices that support multiple data rates, the MR2-FSK PHY supports the following behavior:

a) use the lowest data rate as the default rate
b) listen for an FCF or a NF at this default data rate.
c) for data rate changes, the MR2-FSK PHY decodes information from the FCF. The FCF is composed of a preamble, start-of-frame delimiter, and fields to specify the new data rate.
d) the MR2 FSK PHY switches from the default (lowest) data rate to one of two data rates using the information from the FCF.

e) The NF is transmitted by itself (without being preceded by an FCF) when communications are at the default data rate.

f) The NF follows the FCF when the data rate is changed to a higher data rate. In this case, the NF is transmitted at the higher data rate, as specified in the FCF.

5.5.4.5b Enhanced robustness features for the OFDM PHY

The OFDM PHY was specifically designed to provide enhanced robustness for LR-WPAN applications. This enhanced robustness is a result of several PHY features:

- The use of a cyclic prefix and frequency domain equalization provides very robust performance under harsh multipath conditions.
- A forward error correction (FEC) system provides flexible and robust performance under harsh multipath conditions.
- The use of frequency domain spreading provides robust performance even in low signal-to-noise ratio conditions.

5.5.5 Power consumption considerations

Insert the following paragraph at the end of 5.5.5:

The primary mechanisms for reducing power consumption in SUN applications are to reduce duty cycle, keep overhead bits to a minimum, and enable implementation of collision avoidance via frequency hopping thus reducing retry and receive time.

6. PHY specification

6.1 General requirements and definitions

Insert the following items to the end of the first dashed list:

- Forward error correction (FEC) for the multi-regional frequency shift keying (MRFSK) PHY (optional)
- Frequency hopping for the MRFSK PHY (optional)

Insert the following items to the second dashed list:

- A 400 MHz PHY employing Gaussian frequency-shift keying (GFSK) modulation
- A 950 MHz PHY employing GFSK modulation
- An RF Band agnostic OFDM PHY which supports signal bandwidths from 1MHz down to <100kHz with 9765.625 Hz tone spacing and 128 µs symbol duration.

Change the last paragraph of 6.1 as indicated:

In further additions to the PHYs supported in IEEE Std 802.15.4-2006, and IEEE Std 802.15.4a-2007, and IEEE Std 802.15.4c-2009, ~~two~~ additional PHYs have been added. They are BPSK and GFSK PHYs operating in the Japanese 950 MHz band, two GFSK PHYs operating in the Japanese 400 MHz and 950 MHz bands targeting SUN applications, and a SUN-DSSS-PHY operating in the 780, 868, 915 MHz and 2.4 GHz band.

6.1.1 Operating frequency range

Change Table 1 (the entire table is not shown) as indicated:

Insert the following table and accompanying text after the second paragraph:

A compliant SUN-DSSS-PHY device shall operate in one or several frequency bands using the modulation and spreading forms summarized in Table 1a. The modulation and spreading formats are categorized into two modes: the Simple Spread Spectrum (SSS) scheme and the Constant Amplitude-Code Division Multiplexing (CA-CDM) scheme

Insert the following three tables and accompanying text after the second paragraph:

The MRFSK PHY is intended to operate over a variety of license-exempt and dedicated use frequency bands. The inclusion of flexible, narrow channel bandwidths enables the use of many regionally available frequency bands, in small increments, making it possible to fit channels within small spaces in the spectrum. This allows for efficient utilization of available spectrum, which varies greatly regionally.

A summary of the modulation and channel parameters for the ISM, general use, and Smart Grid (SG) bands suitable for the MRFSK PHY is captured in Table 1b.

Table 1c gives a summary of modulation and channel parameters for the bands with very narrow channel requirements.

Regulatory changes are underway in several regions specifically to address spectrum needs of the SUN deployment. Table 1d lists other dedicated use bands, some of which are bandwidth-limited, which may be/ become available. It is the intent of the proposed PHY to accommodate a flexible channel plan and leave

Table 1—Frequency bands and data rates

PHY (MHz)	Frequency (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbols/s)	Symbols
950[*]	950–956	—	GFSK	100	100	Binary
400	TBD (1 MHz within 400–430 MHz)	—	GFSK	50[†]	100	Binary
			GFSK	100		
			GFSK	200	200	
			4GFSK	400		4-ary
950[‡]	950–956	—	GFSK	50[†]	100	Binary
			GFSK	100		
			GFSK	200	200	
			4GFSK	400		4-ary
SUN DSSS 780	778-787	500	O-QPSK or GMSK	31.25 62.5 125 250		
SUN DSSS 868	863-870	125	O-QPSK or GMSK	15.625 62.5		
SUN DSSS 915	902-928	1000	O-QPSK or GMSK	31.25 125 250 500		
SUN DSSS 2450	2400-2483.5	1000	O-QPSK or GMSK	31.25 125 250 500		

[*] ~~For the 950 MHz PHYs, at~~ At least one of the two 950 MHz PHYs specified in IEEE 802.15.4d-2009 shall be implemented.

[†] FEC scheme applied, as described in 6.12a.3.5.

[‡] As specified in P802.15.4g.

specific frequency specification up to the implementer. Determination of which bands may be used at a given time or in a given location is an upper layer function and is tied to local regulations.

Insert the following table and accompanying text after the second paragraph:

General overview of frequency band plans and a summary of the modulation and channel parameters for the ISM and Smart Grid bands for the MR2-FSK (multi-rate, multi-region FSK) PHY is shown in Table 1e.

Table 1a—Frequency bands and data rates for SUN-DSSS-PHY

PHY (MHz)	Frequency Band (MHz)	Chip rate (kchip/s)	Bit rate (kb/s)	Spreading code
915	902–928	1000	500	CA-CDM (16,8)
			250	SSS (16,4)
			125	CA-CDM (64,8)
			62.5	CA-CDM (128,8)
2450	2400–2483.5	2000	500	SSS (16,4)
			250	SSS (32,4)
			125	CA-CDM (128,8)
			62.5	CA-CDM (128,4)

Table 1b—Modulation and channel parameters for ISM, general use, and SG use bands

Frequency band (MHz)	Parameter	Low rate 50kbps	Medium rate 100kbps[*]	High rate 200/400 kbps
400–430 (Japan, 4/5 ch.) 950.9–955.7 (Japan, 24/23 ch.) 470–510 (China, 200 ch.)	Channel spacing (kHz)	200	200	400
	Modulation[†]	GFSK	GFSK	GFSK/4GFSK
	Modulation index	1.0	1.0	1.0/0.33
863–870 (Europe)	Channel spacing (kHz)	250	250	250/500
	Modulation[†]	GFSK	GFSK	GFSK/4GFSK
	Modulation index	0.5	0.5	0.5/0.33
902–928 (US, 85 Ch.) 2400–2483.5 (Worldwide, 261 ch.)	Channel spacing (kHz)	300	300	300/500
	Modulation[†]	FSK (GFSK)	FSK (GFSK)	FSK/4FSK (GFSK/ 4GFSK)
	Modulation index	0.5	0.5	0.5

[*] Mandatory data rate.
[†] For GFSK, BT=0.5.

Table 1c—Modulation and channel parameters for bands with very narrow channels

Frequency band (MHz)	**Parameter**	**Low rate 5/10kbps**	**Medium rate 20kbps**	**High rate 40 kbps**
433.05–434.79 (Europe) 863–870 (Europe)	Channel spacing (kHz)	12.5/25	50	100
	Modulation	GFSK	GFSK	GFSK
	Modulation index	1.0	1.0	1.0
Other bands with narrow channels, as shown in Table 1d	Channel spacing	12.5/25	50	100
	Modulation	GFSK	GFSK	GFSK
	Modulation index	0.5	0.5	0.5

Table 1d—Other dedicated use bands which are now or may become available

Frequency band (MHz)		**Notes**
220	222	US and Canada
450	470	FCC Part 90
700	TBD	
896	901	FCC Part 90
901	902	PCS Part 24
928	960	Non-contiguous
1427	1452	US and Canada, non-contiguous
1492	1518	
1605	1625	Non-contiguous
1800	1830	US and Canada

Insert the following paragraph after the second paragraph in 6.1.1:

The OFDM PHY covers each of the following frequency bands:

- International ISM 2.4 GHz
- United States 915 MHz
- Europe 863-870 MHz
- Japan 950 MHz
- China 783 MHz
- Korea 922 MHz
- TV white spaces

Table 1e—Modulation and channel parameters for MR2-FSK (ISM and Smart Grid bands)

Frequency band (MHz)	Parameter	Low data rate	Medium data rate	High data rate
400–430 (1 MHz), 950.0–955.7 (Japan)	Data rate	50 kbps	100 kbps[*]	200/400 kbps
	Modulation scheme	2-GFSK	2-GFSK	4-GFSK
	Modulation index	1.0	1.0	0.5
	BT	0.5	0.5	0.5
	Channel spacing	200 kHz	200 kHz	400 kHz
470–510 (China)	Data rate	40 kbps[*]	80 kbps	160 kbps
	Modulation scheme	2-GFSK	2-GFSK	4-GFSK
	Modulation index	1.0	1.0	1.0
	BT	0.5	0.5	0.5
	Channel spacing	200 kHz	200 kHz	200 kHz
863–870 (Europe)	Data rate	40 kbps[*]	80 kbps	160/320 kbps
	Modulation scheme	2-GFSK	2-GFSK	4-GFSK
	Modulation index	1.0	1/3	1.0
	BT	0.5	0.5	0.5
	Channel spacing	200 kHz	200/400 kHz	400 kHz
902–928 (US)	Data rate	40 kbps[*]	160 kbps	320 kbps
	Modulation scheme	2-GFSK	2-GFSK	4-GFSK
	Modulation index	1.0	1.0	0.5
	BT	0.5	0.5	0.5
	Channel spacing	200/400 kHz	400 kHz	400 kHz
2.400–2.4385 (Worldwide)	Data rate	40 kbps[*]	160 kbps	320 kbps
	Modulation scheme	2-GFSK	2-GFSK	4-GFSK
	Modulation index	1.0	1.0	0.5
	BT	0.5	0.5	0.5
	Channel spacing	400 kHz	400 kHz	400 kHz

[*] Mandatory data rate

***Insert the following new subclauses (6.1.1.1–6.1.1.6.1) following 6.1.1*:**

6.1.1.1 MR2-FSK PHY 400 MHz band

The current allocation for low power radio operation in Japan allows operation in the 426, 429, 449, and 469 MHz bands.

6.1.1.1.1 Data rate and modulation

The MR2-FSK PHY shall support the mandatory and optional modes shown in Table 1f (details to be added):

Table 1f—Modulation and channel parameters for MR2-FSK (450 MHz Japan band)[*]

	Low (optional)	**Mid (default)**	**High (optional)**	**High (optional)**
Data rate	50 kbps	100 kbps	200 kbps	400 kbps
Channel spacing	200 kHz	200 kHz	200 kHz Signal Bandwidth: 400 kHz with bundling	200 kHz Signal Bandwidth: 400 kHz with bundling
Number of channels	4~5	4~5	3~4	3~4
Modulation technique	GFSK	GFSK	GFSK	4-GFSK
Modulation index	2.0 (±50 kHz)	1.0 (±50 kHz)	TBD e.g., 50 kHz freq. sep. (-75, -25, +25, +75 kHz)	0.5 (±50 kHz)
BT	0.5	0.5	0.5	0.5

[*] Note that channel spacing for data rate higher than 100kbps is under negotiation about spectrum mask.

6.1.1.2 MR2-FSK PHY 470–510 MHz band (China)

- Max output power = 50 mW (+17 dBm)
- Channel spacing = 200 kHz
- Frequency hopping spread spectrum (FHSS) across the whole 40 MHz
- Dynamic power control

Table 1g—Modulation and channel parameters for MR2-FSK (400 MHz China band)

Number of channels	**Channel spacing (kHz)**	**Modulation**	**Data rate (kbps)**	**Max output power (dBm)**
200	200	2-GFSK	40	+17
200	200	2-GFSK	80	+17
200	200	4-GFSK	160	+17

Multiple set of (offset) channels could be defined to support several co-existing networks in the same area.

6.1.1.3 MR2-FSK PHY 863-870 MHz band (Europe)

6.1.1.3.1 Data rate and modulation

- Unit channel spacing = 200 kHz
- Channel spacing: Nx200 kHz, N = 1,2,3,6.
- Number of channels:
    - 31 x 200 kHz
    - 14 x 400 kHz
    - 9 x 600 kHz
    - 4 x 1200 kHz
- Adaptive Frequency Agility (AFA) with Listen-before-Talk (LBT)

The 863–870 MHz PHY supports the data rates shown in Table 1h:

Table 1h—Modulation and channel parameters for MR2-FSK (863-870 MHz European band)

	Low (mandatory)	**Medium (optional)**	**High (optional)**
Data rate	40 kbps	80 kbps	160/320 kbps
Channel spacing	200 kHz	200 kHz	400 kHz
Modulation technique	GFSK (FHSS)	GFSK (AFA with LBT)	4-GFSK (AFA with LBT)
Modulation index	1.0	1.0	1/3
BT	0.5	0.5	0.5

6.1.1.4 MR2-FSK PHY 902–928 MHz band

6.1.1.4.1 Data rate and modulation

The PHY shall support the data rates shown inTable 1i.

6.1.1.5 MR2-FSK PHY 950 MHz band

6.1.1.5.1 Data rate and modulation

The PHY shall implement a mandatory data rate and optional higher and lower data rates.

For devices that support multiple data rates, communications will start at the default rate (100 kbps) and can be switched to the high/lower data rate.

Two options are shown in Table 1j for the high data rate, and one of these two will be removed.

:

Table 1i—Modulation and channel parameters for MR2-FSK (902-928 MHz US band)

	Low (mandatory)	Mid	High
Data rate	40 kbps	160 kbps	320 kbps
Channel spacing	200/400 kHz	400 kHz	400 kHz
Number of channels	128/64	64	64
Modulation technique	GFSK	GFSK	4-GFSK
Modulation index	1.0 (±40 kHz)	1.0 (±160 kHz)	0.5 (80 kHz freq separation -120, -40, +40, +120 kHz)
BT	0.5	0.5	0.5

Table 1j—Modulation and channel parameters for MR2-FSK (950 MHz Japan band)[*] [†]

	Low (optional)	Mid (mandatory)	High (optional)	High (optional)
Data rate	50 kbps	100 kbps	200 kbps	400 kbps
Channel spacing	200 kHz	200 kHz	200 kHz Signal Bandwidth: 400 kHz with bundling	200 kHz Signal Bandwidth: 400 kHz with bundling
Number of channels	24	24	23	23
Modulation technique	GFSK	GFSK	GFSK	4-GFSK
Modulation index	2.0 (±50 kHz)	1.0 (±50 kHz)	TBD e.g., 50 kHz freq. sep. (-75, -25, +25, +75 kHz)	0.5 (±50 kHz)
BT	0.5	0.5	0.5	0.5

[*] Note that the mid (default) data rate matches the IEEE Std 802.15.4d-2009 definition for 950 MHz GFSK systems.
[†] Channel spacing for data rate higher than 100kbps is under negotiation about spectrum mask.

6.1.1.6 MR2-FSK PHY 2.4 GHz band

6.1.1.6.1 Data rate and modulation

The PHY shall support one mandatory low data rate.

Two optional higher data rates are defined. SeeTable 1k.

Table 1k—Modulation and channel parameters for MR2-FSK (2.4 GHz Worldwide band)

	Low (mandatory)	**Mid (optional)**	**High (optional)**
Data rate	40 kbps	160 kbps	320 kbps
Channel spacing	400 kHz	400 kHz	400 kHz
Number of channels	200	200	200
Modulation technique	GFSK	GFSK	4-GFSK
Modulation index	1.0 (±40 kHz)	1.0 (±160 kHz)	0.5 80 kHz freq. sep. (-120, -40, +40, +120 kHz)
BT	0.5	0.5	0.5

6.1.2 Channel assignments

6.1.2.1 Channel numbering

6.1.2.2 Channel numbering for CSS PHY

6.1.2.3 Channel numbering for 779–787 MHz band

6.1.2.4 Channel numbering for 950 MHz PHYs

6.1.2.5 Channel numbering for UWB PHY

Insert the following new subclauses (6.1.2.5a–6.1.2.5h) after 6.1.2.5:

Subclauses 6.1.2.5a, 6.1.2.5b, and 6.1.2.5c–6.1.2.5h provide different approaches to the channel numbering text.

6.1.2.5a Channel numbering for MRFSK PHY

Regulatory requirements affect the channel plan for a given frequency band. Regulatory requirements, such as maximum transmit power, power spectrum density levels, out-of-band requirements, the available bandwidth, and the channel hopping requirements (if any), should be considered when defining the channel plan.

Out-of-band emission regulatory requirements may lead to guard band allocation on either side of the frequency band. The amount of guard band G, shown in Equation (1), relates to the carrier transmit power and carrier attenuation from nearby channels. $P_{emission}$ is the emission power limit, $M(N_{nearest})$ is the maximum transmit power of nearest carrier, and A is the attenuation per unit of frequency.

$$G = \frac{M(N_{nearest}) - P_{emission}}{A} \tag{1}$$

The carrier frequency as a function of the channel index N is shown in Equation (2). S is the start of the frequency band, C is the channel bandwidth (or spacing), GL is the allocated guard band on the low side of the band, GH is the allocated guard band on the high side of the band, and W is the width of the available band.

$$F(N) = S + max(GL + C/2, C) + C \times N \tag{2}$$

where

$$N \in \left[0, floor\frac{(W - max[GL, C/2] - max[GH, C/2] - C)}{C}\right]$$

Equation (2) is valid for contiguous bands. For non-contiguous frequency bands, each piece of spectrum i is planned individually and then concatenated over i as shown in Equation (3).

$$F(N) = concat[F(N_i)] \tag{3}$$

Refer to Annex M for specific information on channel numbering for individual frequency bands.

6.1.2.5b Channel numbering for MRFSK PHY

The following specifies the channel allocation for the GFSK PHY operating in the 950–956 MHz band. In channel page 6, 12 channels are allocated for GFSK at 100 kb/s. In channel page 7, 11 channels are allocated for GFSK at 100 kb/s. In channel page 8, 23 channels are allocated for GFSK at 50 kb/s. In channel page 9, 22 channels are allocated for GFSK at 200 kb/s. In channel page 10, 22 channels are allocated for 4GFSK at 400 kb/s.

Next, the following specifies the channel allocation for the GFSK PHY operating in the 400–430 MHz band. In channel page 11, five channels are allocated for GFSK at 100 kb/s, five channels are allocated for GFSK at 50 kb/s, four channels are allocated for GFSK at 200 kb/s, and four channels are allocated for 4GFSK at 400 kb/s.

The center frequency F_c of these channels is defined in the following equations. Note that k represents the channel number in each equation.

In channel page 7,

$$F_c = 951.3 + 0.4k \text{ MHz, for } k = 0,\ldots 10 \tag{4}$$

In channel page 8,

$$F_c = 951.1 + 0.2k \text{ MHz, for } k = 0,\ldots,22 \tag{5}$$

In channel page 9,

$$F_c = 951.2 + 0.2k \text{ MHz, for } k = 0,\ldots,21 \quad (6)$$

In channel page 10,

$$F_c = 951.2 + 0.2k \text{ MHz, for } k = 0, \ldots, 21$$

In channel page 11,

$$Fc = a\ (\text{TBD MHz}) + 0.2\ k \text{ in megahertz, for } k = 0, \ldots, 3 \quad (7)$$

$$F_c = a + 0.2k \text{ MHz, for } k = 4, \ldots, 7 \quad (8)$$

$$F_c = (a + 0.1) + 0.2k \text{ MHz, for } k = 8, \ldots, 10 \quad (9)$$

$$F_c = (a + 0.1) + 0.2k \text{ MHz, for } k = 11, \ldots, 13 \quad (10)$$

For each PHY supported, a compliant device shall support all channels allowed by regulations for the region in which the device operates, except for the following: channels 3 and 6 in channel page 7; channels 7, 8, 13 and 14 in channels page 8; channels 6, 7, 8, 12, 13 and 14 in channel page 9; and channels 6, 7, 8, 12, 13 and 14 in channel page 10, which are optional.

6.1.2.5c Channel numbering for MR2-FSK PHY 400 MHz

For systems that only use the low data rate, 200 kHz channels can be used. For systems using the mid or high rates, 400 kHz channels will be used.

6.1.2.5c.1 Channel assignments for 200 kHz channel spacing

As for system channel band, 1 MHz or less bandwidth in 400MHz~430 MHz are under consideration.

The channel assignments are calculated using a 200 kHz channel spacing. The frequencies shown in Table 3a are the center frequencies of channel 1 through 4~5 and are calculated as follows:

$$Freq = SystemBandEdge + 0.1 + (Channel - 1) \times 0.2 \quad (11)$$

Table 3a—Channel assignments for 200 kHz channel spacing

Channel	Frequency
1	SystemBandEdge + 0.1
2	SystemBandEdge + 0.3
3	SystemBandEdge + 0.5
4	SystemBandEdge + 0.7
5 (could be ignored)	SystemBandEdge + 0.9

6.1.2.5c.2 Channel assignments for 400 kHz channel spacing

As for system channel band, 1 MHz or less bandwidth in 400MHz~430 MHz are under consideration.

The channel assignments are calculated using a 400 kHz channel spacing. The frequencies shown in Table 3b are the center frequencies of channel 1 and 2 and are calculated as follows:

$$Freq = SystemBandEdge + 0.2 + (Channel - 1) \times 0.4 \tag{12}$$

Table 3b—Assignments for channels 1 and 2 – 400 kHz channel spacing

Channel	Frequency
1	SystemBandEdge + 0.2
2	SystemBandEdge + 0.6

Furthermore, additional channels numbered 3 and 4 are calculated as follows (see Table 3c for the center frequencies):

$$Freq = SystemBandEdge + 0.4 + (Channel - 3) \times 0.4 \tag{13}$$

Table 3c—Assignments for channels 3 and 4 – 400 kHz channel spacing

Channel	Frequency
3	SystemBandEdge + 0.4
4	SystemBandEdge + 0.8

6.1.2.5d Channel numbering for MR2-FSK PHY 863–870 MHz FHSS

Max output power = 25mW e.r.p.

200 kHz channel spacing (Table 3d)

400 kHz channel spacing (Table 3e)

600 kHz channel spacing (Table 3f)

1200 kHz channel spacing (Table 3g)

6.1.2.5e Channel numbering for MR2-FSK PHY 863–870 MHz AFA

Table 3h

Table 3d—Channel assignments for 200 kHz channel spacing

Channel	Frequency (MHz)	Channel	Frequency (MHz)
1		17	
2		18	
3		19	
4		20	
5		21	
6		22	
7		23	
8		24	
9		25	
10		26	
11		27	
12		28	
13		29	
14		30	
15		31	
16			

Table 3e—Channel assignments for 400 kHz channel spacing

Channel	Frequency (MHz)
1	
2	
3	
4	

Table 3e—Channel assignments for 400 kHz channel spacing

Channel	Frequency (MHz)
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	

Table 3f—Channel assignments for 600 kHz channel spacing

Channel	Frequency (MHz)
1	
2	
3	
4	
5	
6	
7	
8	
9	

6.1.2.5f Channel numbering for MR2-FSK PHY 902–928 MHz band

The systems that shift data rates from low to mid or high shall use 64 channels. The 64 channels are identified by 400 kHz channel spacing.

Optionally, the systems may use only the mandatory data rate (i.e., the lowest data rate). In this case, the system may use a total number of 128 channels. The 128 channels are identified by 200 kHz channel spacing.

Table 3g—Channel assignments for 1200 kHz channel spacing

Channel	Frequency (MHz)
1	
2	
3	
4	
5	
6	
7	
8	
9	

Table 3h—AFA Channel Plan

Channel	Frequency (MHz)	Max output power (dBm)
1	TBD	TBD
2	TBD	TBD
3	TBD	TBD
4	TBD	TBD
5	TBD	TBD

6.1.2.5f.1 Channel assignments for 200 kHz channel spacing

The channel assignment is calculated using 200 kHz channel spacing. The frequencies shown in Table 3i are the center frequencies and are calculated as follows:

$$Freq = 902.2 + (Channel - 1) \times 0.2 \text{ MHz} \quad (14)$$

Table 3i lists the channel assignments; it only presents the start and the end of the channel plan.

6.1.2.5f.2 Channel assignments for 400 kHz channel spacing

The channel assignment is calculated using 400 kHz channel spacing. The frequencies shown in Table 3j are the center frequencies and are calculated as follows:

$$Freq = 902.4 + (Channel - 1) \times 0.4 \text{ MHz} \quad (15)$$

Table 3i—Channel assignments for 200 kHz channel spacing

Channel	Frequency (MHz)	Channel	Frequency (MHz)		Channel	Frequency (MHz)
1	902.2	17	905.4	…	115	924.8
2	902.4	18	905.6		116	925.0
3	902.6	19	905.8		117	925.2
4	902.8	20	906.0		118	925.4
5	903.0	21	906.2		119	925.6
6	903.2	22	906.4		120	925.8
7	903.4	23	906.6		121	926.0
8	903.6	24	906.8		122	926.2
9	903.8	25	907.0		123	926.4
10	904.0	26	907.2		124	926.6
11	904.2	27	907.4		125	926.8
12	904.4	28	907.6		126	927.0
13	904.6	29	907.8		127	927.2
14	904.8	30	908.0		128	927.4
15	905.0	31	908.2		129	927.6
16	905.2	32	908.4		130	927.8

Table 3j—Channel assignments for 400 kHz channel spacing

Channel	Frequency (MHz)	Channel	Frequency (MHz)	Channel	Frequency (MHz)	Channel	Frequency (MHz)
1	902.4	17	908.8	33	915.2	49	921.6
2	902.8	18	909.2	34	915.6	50	922.0
3	903.2	19	909.6	35	916.0	51	922.4
4	903.6	20	910.0	36	916.4	52	922.8
5	904.0	21	910.4	37	916.8	53	923.2
6	904.4	22	910.8	38	917.2	54	923.6

Table 3j—Channel assignments for 400 kHz channel spacing

Channel	Frequency (MHz)	Channel	Frequency (MHz)	Channel	Frequency (MHz)	Channel	Frequency (MHz)
7	904.8	23	911.2	39	917.6	55	924.0
8	905.2	24	911.6	40	918.0	56	924.4
9	905.6	25	912.0	41	918.4	57	924.8
10	906.0	26	912.4	42	918.8	58	925.2
11	906.4	27	912.8	43	919.2	59	925.6
12	906.8	28	913.2	44	919.6	60	926.0
13	907.2	29	913.6	45	920.0	61	926.4
14	907.6	30	914.0	46	920.4	62	926.8
15	908.0	31	914.4	47	920.8	63	927.2
16	908.4	32	914.8	48	921.2	64	927.6

6.1.2.5g Channel numbering for MR2-FSK PHY 950 MHz band

For systems that only use the low data rate, 200 kHz channels can be used. For systems using the mid or high rates, 400 kHz channels will be used.

6.1.2.5g.1 Channel assignments for 200 kHz channel spacing

The channel assignments are calculated using 200 kHz channel spacing. The frequencies shown in Table 3k are the center frequencies and are calculated as follows:

$$Freq = 951.0 + (Channel - 1) \times 0.2 \text{ MHz} \quad (16)$$

Table 3k lists the channel plan.

6.1.2.5g.2 Channel assignments for 400 kHz channel spacing

The channel assignments are as per IEEE Std 802.15.4d-2009, where the 950 MHz GFSK channels are numbered 1 through 12. The frequencies shown in Table 3l are the center frequencies and are calculated as follows:

$$Freq = 951.1 + (Channel - 1) \times 0.4 \text{ MHz} \quad (17)$$

Table 3l lists the channel plan and channel numbers as per IEEE Std 802.15.4d-2009.

Furthermore, additional channels numbered 13 through 23 are calculated as follows (see Table 3m for the center frequencies):

$$Freq = 951.3 + (Channel - 13) \times 0.4 \text{ MHz} \quad (18)$$

.

Table 3k—Channel assignments for 200 kHz channel spacing

Channel	Frequency (MHz)	Channel	Frequency (MHz)
1	951.0	13	953.4
2	951.2	14	953.6
3	951.4	15	953.8
4	951.6	16	954.0
5	951.8	17	954.2
6	952.0	18	954.4
7	952.2	19	954.6
8	952.4	20	954.8
9	952.6	21	955.0
10	952.8	22	955.2
11	953.0	23	955.4
12	953.2	24	955.6

Table 3l—Assignments for channels 1 through 12 – 400 kHz channel spacing

Channel	Frequency (MHz)
1	951.1
2	951.5
3	951.9
4	952.3
5	952.7
6	953.1
7	953.5
8	953.9
9	954.3
10	954.7
11	955.1
12	955.5

6.1.2.5h Channel numbering for MR2-FSK PHY 2.4 GHz band

The mandatory channel spacing is 400 kHz.

Table 3m—Assignments for channels 13 through 23 – 400 kHz channel spacing

Channel	Frequency (MHz)
13	951.3
14	951.4
15	952.1
16	952.5
17	952.9
18	953.3
19	953.7
20	954.1
21	954.5
22	954.9
23	955.3

6.1.2.5h.1 Channel assignments

The channel assignment is calculated using 400 kHz channel spacing. The frequencies shown in Table 3n are the center frequencies and are calculated as follows:

$$Freq = 2400.4 + (Channel - 1) \times 0.4 \text{ MHz} \qquad (19)$$

To allow devices to comply with emission regulations in the 2483.5 to 2500 MHz restricted band, there is a guard band of approximately 3 MHz at the high end of the band.

Table 3n lists the channel assignments; the table presents only the start and the end of the channel plan.

6.1.2.5i Channel numbering for SUN DSSS PHY

6.1.2.5i.1 Channel numbering for 779–787 MHz frequency band

For channel page X, 7 channels numbered 0 to 6 are available across 780 MHz band. The center frequency of these channels is defined as follows:

$$F_c = 780 + 1k \text{ in megahertz, for } k = 0, \ldots, 6$$

where k is the channel number.

6.1.2.5i.2 Channel numbering for 863–870 MHz frequency band

For channel page X+1, 13 channels numbered 0 to 12 are available across 863-870 MHz band. The center frequency of these channels is shown in Table 3o.

Table 3n—Channel assignments for 2.4 GHz band

Channel	Frequency (MHz)	Channel	Frequency (MHz)		Channel	Frequency (MHz)
1	2400.4	17	2406.8	...	193	2477.2
2	2400.8	18	2407.2		194	2477.6
3	2401.2	19	2407.6		195	2478.0
4	2401.6	20	2408.0		196	2478.4
5	2402.0	21	2408.4		197	2478.8
6	2402.4	22	2408.8		198	2479.2
7	2402.8	23	2409.2		199	2479.6
8	2403.2	24	2409.6		200	2480.0
9	2403.6	25	2410.0			
10	2404.0	26	2410.4			
11	2404.4	27	2410.8			
12	2404.8	28	2411.2			
13	2405.2	29	2411.6			
14	2405.6	30	2412.0			
15	2406.0	31	2412.4			
16	2406.4	32	2412.8			

Table 3o—Center frequencies for the SUN DSSS PHY of the 863-870 MHz band

Channel number	Center Frequency (MHz)
0	863.400
1	863.800
2	864.200
3	864.600
4	865.000
5	865.400
6	866.000
7	866.600
8	867.200
9	867.800
10	868.300
11	868.950
12	869.525

6.1.2.5i.3 Channel numbering for 902–928 MHz frequency band

For channel page X+2, 57 channels numbered 0 to 56 are available across 915 MHz band (overlapping channels). The center frequency of these channels is defined as follows:

$$F_c = 906 + 0.4k \text{ in megahertz, for } k = 0, \ldots, 56$$

where k is the channel number.

6.1.2.5i.4 Channel numbering for 2400–2483.5 MHz frequency band

For channel page X+3, 196 channels numbered 0 to 195 are available across 2.4 GHz band (overlapping channels). The center frequency of these channels is defined as follows:

$$F_c = 2404 + 0.4k \text{ in megahertz, for } k = 0, \ldots, 195$$

where k is the channel number.

6.1.2.6 Channel pages

Change Table 4 (the entire table is not shown) as indicated:

6.1.3 Minimum long interframe spacing (LIFS) and short interframe spacing (SIFS) periods

Change Table 5 (the entire table is not shown) as indicated:

6.1.4 RF power measurement

6.1.5 Transmit power

Insert the following paragraph at the end of 6.1.5:

For the MRFSK PHY, the transmit power array is expanded to allow for a greater range of transmit power levels. The number of power levels supported shall be indicated by the PHY PIB attribute *phyMRFSKNumTxPowerLevels*, and the array of transmit power levels corresponding to each of these level numbers is stored in *phyMRFSKTxPower*. The desired transmit power level shall be chosen by setting *phyMRFSKPowerIndex* accordingly. An indexed transmit power array does not require the individual power levels to be separated by linear steps.

6.1.6 Out-of-band spurious emission

6.1.7 Receiver sensitivity definitions

Change the first paragraph of 6.1.7 as indicated:

The receiver sensitivity definitions used throughout this standard are defined in Table 6, with the exception that the receiver sensitivity definition for the OFDM PHY is defined in 6.12b.4.2.

Insert text into Table 6 (the entire table is not shown) as indicated:

Table 4—Channel page and channel number

Channel page (decimal)	Channel page[*] (binary) $(b_{31}, b_{30}, b_{29}, b_{28}, b_{27})$	Channel number(s) (decimal)	Channel number description
6[†]	0 0 1 1 0	0–9	Channels 0 to 9 are in 950 MHz band using BPSK
		10–21	Channels 10 to 21 are in 950 MHz band using GFSK
7[‡]	0 0 1 1 1	0–10	Channels 0 to 10 are in 950 MHz band using GFSK at 100 kb/s
		11–26	Reserved
8	0 1 0 0 0	0–22	Channels 0 to 22 are in 950 MHz band using GFSK at 50 kb/s
		23–26	Reserved
9	0 1 0 0 1	0–21	Channels 0 to 21 are in 950 MHz band using GFSK at 200 kbps
		22–26	Reserved
10	0 1 0 1 0	0–21	Channels 0 to 21 are in 950 MHz band using GFSK at 400 kbps
		22–26	Reserved

Table 4—Channel page and channel number

Channel page (decimal)	Channel page[*] (binary) $(b_{31}, b_{30}, b_{29}, b_{28}, b_{27})$	Channel number(s) (decimal)	Channel number description
11	0 1 0 1 1	0–3	Channels 0 to 3 are in 400 MHz band using GFSK at 100 kbps
		4–7	Channels 4 to 7 are in 400 MHz band using GFSK at 50 kbps
		8–10	Channels 8 to 10 are in 400 MHz band using GFSK at 200 kbps
		11–13	Channels 11 to 13 are in 400 MHz band using 4GFSK at 400 kbps
		14–26	Reserved
12	—	0–84	Channels 0 to 84 are in 902 MHz band using MRFSK
13	—	0–260	Channels 0 to 260 are in 2.4 GHz band using MRFSK
TBD			
TBD			
TBD–31	TBD–1111	Reserved	Reserved

[*] The number of channels per page shall be increased beyond what is defined in IEEE Std 802.15.4-2006 in order to support the larger number of channels available with the MRFSK PHY solution.
[†] As specified by IEEE Std 802.15.4d-2009.
[‡] As specified by P802.15.4g

Table 5—Minimum LIFS and SIFS period

PHY	*macMinLIFSPeriod*	*macMinSIFSPeriod*	Units
950–956 MHz GFSK[*]	40	12	Symbols
400 MHz GFSK	40	12	Symbols
950 MHz GFSK[†]	40	12	Symbols

[*] As specified by IEEE Std 802.15.4d-2009
[†] As specified by P802.15.4g

Table 6—Receiver sensitivity definitions

Term	Definition of term	Conditions
Receiver sensitivity	Threshold input signal power that yields a specified PER.	– PSDU length = 20 octets. – PSDU length for MRFSK = 1500 octets. – PER < 1%. – Power measured at antenna terminals. – Interference not present.

6.2 PHY service specifications

All changes/additions to 6.2 originate from one submission.

6.2.1 PHY data service

6.2.1.1 PD-DATA.request

Two ways for controlling the length of FCS are included. The length of the FCS is determined by a parameter in the PD-DATA.request primitive and by a PIB attribute.

Two ways for controlling FEC coding are included. The control for turning FEC coding on and off is determined by a parameter in the PD-DATA.request primitive and by a PIB attribute

6.2.1.1.1 Semantics of the service primitive

Insert the following new parameters at the end of the list in 6.2.1.1.1 (before the closing parenthesis):

TxChannelId,
TxPage,
ModulationOrder,
Coding,
FCSOption,
RequestedTxTime

Insert the following new rows at the end of Table 8:

6.2.1.1.2 Appropriate usage

6.2.1.1.3 Effect on receipt

Change the first paragraph of 6.2.1.1.3 as indicated:

Table 8—PD-DATA.request parameters

Name	Type	Valid range	Description
TxChannelId	Unsigned integer	≤ *phyMRFSKMaxChanSeqSize*	The channel ID (index) on which the PSDU is to be transmitted. This parameter is band and implementation dependent.
TxPage	Integer	0–31	The current channel page.
ModulationOrder	Boolean	TRUE or FALSE	A value of FALSE indicates 2-level modulation, and a value of TRUE indicates 4-level modulation
Coding	Boolean	TRUE or FALSE	A value of FALSE indicates that coding is off, and a value of TRUE indicates that coding is on.
FCSOption	Boolean	TRUE or FALSE	A value of FALSE indicates that the FCS contains a 32-bit CRC. A value of TRUE indicates a 16-bit CRC.
RequestedTxTime	Integer	0x000000–0xffffff	Optional. The time to attempt packet transmission. This is a 24-bit value, and the precision of this value shall be a minimum of 20 bits, with the lowest 4 bits being the least significant.

The receipt of the PD-DATA.request primitive by the PHY entity will cause the transmission of the supplied PSDU to be attempted on the channel and channel page specified by the TxChannelId and TxPage parameters, respectively. Optionally, the PSDU transmission may be attempted once an internal timer reaches the value specified by the RequestedTxTime parameter. Provided the transmitter is enabled (TX_ON state), the PHY will first construct a PPDU, containing the supplied PSDU, and then transmit the PPDU. When the PHY entity has completed the transmission, it will issue the PD-DATA.confirm primitive with a status of SUCCESS.

Insert the following paragraph after the third paragraph of 6.2.1.1.3:

If the RequestedTxTime parameter was included and PHY entity was unable to transmit the PSDU at the specified time, the PHY entity will discard the PSDU and issue the PD-DATA.confirm primitive with a status of TX_TIME_PAST.

6.2.1.2 PD-DATA.confirm

6.2.1.2.1 Semantics of the service primitive

Insert the following new parameter at the end of the list in 6.2.1.2.1 (before the closing parenthesis):

TxTimestamp

Change the first row of Table 9 as indicated, and insert the following new row at the end of Table 9:

Table 9—PD-DATA.confirm parameters

Name	Type	Valid range	Description
status	Enumeration	SUCCESS, RX_ON, TRX_OFF, BUSY_TX, ~~or~~ UNSUPPORTED_PRF, UNSUPPORTED_RANGING, or TX_TIME_PAST	The result of the request to transmit a packet. A value of UNSUPPORTED_PRF indicates that the PHY is not capable of transmitting at the requested PRF. A value of UNSUPPORTED_RANGING is returned if the PHY does not implement a ranging counter.
TxTime-stamp	Integer	0x000000–0xffffff	Optional. The time at which the data were transmitted (see 6.12a.6). The value of this parameter will be considered valid only if the value of the status parameter is SUCCESS. This is a 24-bit value, and the precision of this value shall be a minimum of 20 bits, with the lowest 4 bits being the least significant.

6.2.1.2.2 When generated

6.2.1.2.3 Appropriate usage

6.2.1.3 PD-DATA.indication

6.2.1.3.1 Semantics of the service primitive

Insert the following new parameter at the end of the list in 6.2.1.3.1 (before the closing parenthesis):

RxChannelId,
RxPage,
RxTimestamp

Insert the following new rows at the end of Table 10:

6.2.1.3.2 When generated

Table 10—PD-DATA.indication parameters

Name	Type	Valid range	Description
RxChannelId	Unsigned integer	≤ *phyMRFSKMaxChanSeqSize*	The channel ID (index) on which the PSDU was received. This parameter is band and implementation dependent
RxPage	Integer	0–31	The current channel page.
RxTimestamp	Integer	0x000000–0xffffff	Optional. The time at which the data were received (see 6.12a.6). This is a 24-bit value, and the precision of this value shall be a minimum of 20 bits, with the lowest 4 bits being the least significant.

6.2.1.3.3 Appropriate usage

6.2.2 PHY management service

6.2.3 PHY enumerations description

Insert the following new row at the end of Table 25:

Table 25—PHY enumerations description

Enumeration	Value	Description
TX_TIME_PAST		The packet was not transmitted at the specified time.

6.3 PPDU format

Change the third paragraph of subclause 6.3 as indicated:

Each PPDU packet consists of the following basic components.

- A synchronization header (SHR), which allows a receiving device to synchronize and lock onto the bit stream, containing the preamble and the SFD
- A PHY header (PHR), which contains frame control, frame length information and, for UWB PHYs, rate, ranging, and preamble information
- A variable length payload, which carries the MAC sublayer frame (including the FCS)

Insert the following new paragraphs after the third paragraph of 6.3:

The MR2-FSK PHY has two mandatory frame formats:

- normal frame (NF)
- format change frame (FCF)

The FCF is multi-fold:

- It used to switch from the mandatory data rate to the optional (higher) data rates.
- It is used to switch from one PHY to another (e.g., from FSK to OFDM).
- It is used to switch from a standard PHY to a legacy PHY.

Each mandatory NF has the following components:

- A synchronization header (SHR) containing the preamble field and the SFD.
- A physical header (PHR) containing information about frame control and the frame length information.
- A PSDU containing the PHY Payload and the FCS/CRC.

Each mandatory FCF has the following components:

- A SHR containing the preamble field and the SFD.
- A PHR containing control information for the normal frame (NF), when the latter one is following the FCF.

Insert the following new paragraph after the third paragraph of 6.3:

Each OFDM PPDU packet consists of the following basic components:

- A Short Training Field (STF), which allows a receiving device to perform automatic gain control (AGC), packet detection, de-assertion of CCA (Clear Channel Assessment) based on CCA-Modes (Mode 1,2 or 3 as defined in 6.13.9) and coarse synchronization
- A Long Training Field (LTF), which allows a receiving device to do fine synchronization and perform channel estimation
- A PHY header (PHR), which contains frame data-rate and frame-length information. The PHY Header shall be encoded at the lowest data-rate supported for each bandwidth option.
- A variable length PSDU, which carries
    - The MAC sub-layer frame (MAC Header, MAC Payload and MAC-CRC-32 as defined in 7.2
    - Convolutional encoder tail-bits (6-zeros) and
    - Zero pad-bits to extend the data fill an integer number of OFDM symbols.

Change the fourth paragraph of 6.3 as indicated:

The PPDU packet structure shall be formatted as illustrated in Figure 24, Figure 25, ~~or~~ Figure 26, ***Figure 26a***, ***Figure 26b***, ***Figure 26c***, Figure 26d/Figure 26e, Figure 26f, Figure 26g, or Figure 26h.

Insert the following new figures after Figure 26:

.

		Octets			
		2		**3**	**variable**
Preamble	SFD	Frame control (5 bits)	Frame length (11 bits)	PHR parity (optional)	PSDU
SHR		PHR			PHY payload

Figure 26a—Format of the MRFSK PPDU

Octets				
4/8/16	2	2		variable
Preamble	SFD	Frame control (5 bits)	Frame length (11 bits)	PSDU
SHR		PHR		PHY payload

Figure 26b—Format of the enhanced MRFSK PPDU

Octets						
variable	2	2				
Preamble	SFD	Header FEC1 (5 bits)	Legacy (1 bit)	Format change (1 bit)	Settling delay (1 bit)	Modulation/channel/ data rate (8 bits)
SHR		PHR				

Figure 26c—Format of the MR2-FSK FCF

Octets								
variable	2	2						
Preamble	SFD	Header FEC1 (5 bits)	Legacy (1 bit)	Format change (1 bit)	PSDU FEC (optional) (2 bits)	Data whitening (1 bit)	RFU (2 bits)	Network ID (4 bits)
SHR		PHR (continued in Figure 26e)						

Figure 26d—Format of the MR2-FSK NF (continued in Figure 26e)

Octets		
2		variable
Header FEC2 (5 bits)	Frame length (11 bits)	PSDU
PHR (continuation)		PHY payload

Figure 26e— Format of the MR2-FSK NF (continuation)

Number of OFDM Symbols			
4	2	M	N
STF	LTF	PHR (see 6.3.4c.2.1)	PSDU
SHR		PHR	PHY payload

Figure 26f—Format of the OFDM PPDU

		Octets	
		2	**Variable**
Preamble	SFD	Frame length	PSDU
SHR		PHR	PHY payload

Figure 26g—Format of the PPDU for SUN DSSS

Octets				
4 / 8	1	2		4-2047
Preamble	SFD	Frame Control (5 bit)	Frame Length (11 bit)	PSDU
SHR		PHR		PHY payload

Figure 26h—PPDU Format of the SUN DSSS PHY

The accompanying text for Figure 26a, Figure 26b, Figure 26g, and Figure 26h follows immediately. The text for Figure 26c and Figure 26d/Figure 26e is contained in 6.3.4a–6.3.4b.11. The text for Figure 26f is contained in 6.3.4c–6.3.4c.2.1.

6.3.1 Preamble field

Insert the following paragraphs after the third paragraph of 6.3.1:

For the MRFSK PHY, the preamble bit sequence and the number of times the preamble bit sequence is repeated are variables controlled by the MLME via the PHY PIB attributes *phyMRFSKPreambleValue* and *phyMRFSKNumPreambleRepetitions*, respectively (see 6.4). The preamble is formed by repeating the bit sequence *phyMRFSKPreambleValue* by *phyMRFSKNumPreambleRepetitions* times. Together, these two attributes determine the preamble length.

The Preamble field is replaced by the STF and LTF for OFDM, and the STF is defined in 6.3.4c.1.1 and the LTF is defined in 6.3.4c.1.2.

Preamble lengths for CA-CDM are expressed in the unit of octet since the preamble for CA-CDM is defined using a special symbol. For all PHYs except the CA-CDM PHY, the bits in the Preamble field shall be binary zeros.

The CA-CDM preamble format is described in 6.12c.3.6.

The preamble field of the SUN DSSS PHY consists of 8 octets (frequency band 779-787 MHz, 902-928 MHz and 2400 - 2483.5 MHz) or 4 octets (frequency band 863-870 MHz), each having the value 0x00.

Insert the following text into the last paragraph of 6.3.1:

The bits in the preamble field for the 400 MHz GFSK PHY and 950 MHz GFSK PHY shall be multiple strings of “01010101.”

Change Table 26 (the entire table is not shown) as indicated:

6.3.2 SFD field

Change the first paragraph of 6.3.2 as indicated:

The SFD is a field indicating the end of the SHR~~ and the start of the packet data~~. The SFD is also used to distinguish between different frame types following the SHR. The length of the SFD for the different PHYs is shown in Table 27. The SFD field shall not be transmitted for the OFDM PHY.

Change Table 27 (the entire table is not shown) as indicated:

Change the second paragraph of 6.3.2 as indicated:

For all PHYs, except for the ASK, CSS, ~~and~~ UWB, MRFSK, and the CA-CDM PHYs, the SFD is an 8-bit field. The SFD field shall not be transmitted for the OFDM PHY. For the ASK and CA-CDM PHYs ~~PHY~~, the SFD is defined using a special symbol. The lengths of the SFD for both the ASK ~~PHY~~ and CA-CDM PHYs are expressed in equivalent octet times. The SFD for all PHYs except the ASK, CSS, UWB, MRFSK, and CA-CDM ~~PHY~~ PHYs shall be formatted as illustrated in Figure 27. The SFD for the ASK PHY is defined in 6.9.4.2. The SFD for the CA-CDM PHY is defined in 6.12c.3.6.

Table 26—Preamble field length

PHY	Bit rate (kb/s)	Length		Duration (µs)
950–956 MHz GFSK[*]		4 octets	32 symbols	320
400-430 MHz, 50 kb/s		variable (8,16 octets)	variable (64, 128 symbols)	640, 1280
400-430 MHz, 100 kb/s		variable (4, 8 octets)	variable (32, 64 symbols)	320, 640
400-430 MHz, 200 kb/s				160, 320
400-430 MHz, 400 kb/s				160, 320
950-956 MHz, 50 kb/s[†]		variable (8, 16 octets)	variable (64, 128 symbols)	640, 1280
950-956 MHz, 100 kb/s[†]		variable (4, 8 octets)	variable (32, 64 symbols)	320, 640
950-956 MHz, 200 kb/s[†]				160, 320
950-956 MHz, 400 kb/s[†]				160, 320
902–928 MHz O-QPSK	500	4 octets	4 symbols	256
	250	4 octets	8 symbols	128
	125	4 octets	4 symbols	1024
	62.5	4 octets	4 symbols	2048
2400–2483.5 MHz O-QPSK	500	4 octets	8 symbols	128
	250	4 octets	8 symbols	128
	125	4 octets	4 symbols	1024
	62.5	2 octets	4 symbols	1024

[*] As specified by IEEE 802.15.4d-2009
[†] As specified by P802.15.4g

Replace Figure 27 with the following new figure:

Insert the following new paragraphs and new tables (Table 28a, Table 28b) at the end of 6.3.2:

The SFD used by the MRFSK PHY shall be a 16-bit sequence selected from the list of values in Table 28a. At the implementer's discretion, the 8-bit SFD sequence specified by IEEE Std 802.15.4d-2009 may also be supported to indicate the packet format from that standard. Additional SFD values may be added to support additional PHR configurations as needed, providing a simple mechanism for extensibility to future versions of the standard with compatibility for prior versions.

The SFD patterns used by the MRFSK PHY shall be composed of complementary Golay sequences **a** and **b**. The Golay sequences shall be specified as **a** = [-1 1 -1 -1 -1 -1 -1 1] and **b** = [1 -1 1 1 -1 -1 -1 1]. The SFD field length is given in Table 27, and the SFD patterns are given in Figure 28b. The transmission sequence starts with LSB in the left to MSB in the right.

Table 27—SFD field length

PHY	Bit rate (kb/s)	Length	
950–956 MHz GFSK[*]		1 octet	8 symbols
400-430 MHz, 50 kb/s		2 octets	16 symbols
400-430 MHz, 100 kb/s			
400-430 MHz, 200 kb/s			
400-430 MHz, 400 kb/s			
950-956 MHz, 50 kb/s[†]		2 octets	16 symbols
950-956 MHz, 100 kb/s[†]			
950-956 MHz, 200 kb/s[†]			
950-956 MHz, 400 kb/s[†]			
MRFSK		2 octets	—
902–928 MHz O-QPSK	500	1 octet	1 symbol
	250	1 octet	2 symbols
	125	1 octet	1 symbol
	62.5	1 octet	1 symbol
2400–2483.5 MHz O-QPSK	500	1 octet	2symbols
	250	1 octet	2 symbols
	125	1 octet	1 symbol
	62.5	0.5 octet	1 symbol

[*] As specified by IEEE Std 802.15.4d-2009
[†] As specified by P802.15.4g

Bits: 0	1	2	3	4	5	6	7
1	1	1	0	0	1	0	1

Figure 27—Format of the SFD field (except for ASK, UWB, ~~and~~ CSS, MRFSK and CA-CDM PHYs)

Table 28a—MRFSK PHY SFD values

Format of the SFD field	Indicates
TBD	Uncoded MRFSK, SFF
TBD	FEC-coded MRFSK (see 6.12a.3.5)
11100101	IEEE Std 802.15.4d-2009

Table 28b—Format of the SFD field for MRFSK PHY

SFD Pattern	Golay Sequence 1	Golay sequence 2
SFD #1	**a**	**-b**
SFD #2	**b**	**a**
SFD #3	**b**	**-a**

Insert the following new subclauses after 6.3.2:

6.3.2a Frame Control field

The black portion of the text originates from two submissions.

The Frame Control field is 5 bits in length and is shown in Figure 27a. This field controls the effective data rate of the PSDU and specifies the length of the FCS.

Bits		
3	**1**	**1**
Reserved	Modulation order	FCS option

Figure 27a—Format of the Frame Control field for MRFSK

The gray portion of the text originates from a third submission.

The Frame Control field of the SUN DSSS PHY is 5 bits in length and is shown in Figure 27b.

Bits(0:4)		
2	**1**	**2**
Rate Mode	Reserved	Parity Check

Figure 27b—Format of the Frame Control field for SUN-DSSS

6.3.2a.1 Modulation Order field (refers to Figure 27a)

Text originates from two submissions.

A Modulation Order field set to zero shall indicate that data are transmitted at a rate of 1 bit per symbol (GFSK is used). A value of one shall indicate that data are transmitted at a rate of 2 bits per symbol (4-GFSK is used).

6.3.2a.2 FCS Option field (refers to Figure 27a)

Text originates from two submissions, with the exception of the last sentence.

If the FCS Option field is set to zero, the FCS field (7.2.1.9) contains a 32-bit CRC. If the field is set to one, the FCS field contains a 16-bit CRC. Zero shall be the default value.

6.3.2a.3 Rate Mode field (refers to Figure 26a)

Text originates from one submission.

The SUN DSSS PHY supports up to four different PSDU rate modes within each frequency band. Table 28c shows the mapping of the bit values to the variable *RateMode*.

Table 28c—Rate mode mapping of the SUN DSSS PHY

Bits(0:1)	RateMode
00	0
10	1
01	2
11	3

6.3.2a.4 Reserved field (refers to Figure 26a)

Text originates from one submission.

The reserved subfield is for future usage and should be set to 0 if not used.

6.3.2a.5 Parity check field (refers to Figure 26a)

Text originates from one submission.

Two additional parity bits as a function of the Frame Length field, the reserved field and the rate mode field should be computed, given by the following equations:

TBD

6.3.3 Frame Length field

The maximum value of the Frame Length field for MRFSK has two possible definitions as indicated by two PIB attributes.

Insert the following three new paragraphs after the first paragraph of 6.3.3:

For the MRFSK PHY, the Frame Length field is 11-bits in length. It is a value between 0 and *aMaxPHYPacketSize*.***<OR>*** It is a value between 0 and *aMaxMRFSKPHYPacketSize* octets (see 6.4).

In the case of the MRFSK PHY, the Frame Length field shall be formatted with the MSB to be transmitted first.

The Frame Length field is replaced by the PHY Header (PHR) for the OFDM PHY. The PHR for the OFDM PHY is described in 6.3.4c.2.1.

Insert the following new row at the end of Table 29:

Table 29—Frame length values

Frame length values	Payload
9 to *aMaxMRFSKPHYPacketSize*	MPDU (MRFSK PHY)

The SUN-DSSS-PHY Frame Length field text submissions follow.

Insert the following new paragraphs after the first paragraph of 6.3.3:

The Frame Length field in the PHR of IEEE Std 802.15.4-2006 has been extended from one byte to two bytes in order to support the packet length of up to 1500 bytes, as illustrated in Figure 27c. Where Bit 15 (bit 7 of the Frame Control Field in IEEE Std 802.15.4-2006 packet) of the PHR is used to determine whether the packet is a long packet (≥127 bytes) or a short packet (≤127 bytes).

The Actual Frame Length field is 11 bits and it specifies the total number of octets contained in the PSDU (i.e., PHY payload). This Frame Length field can support a PHY payload up to 2047 bytes. Bits 0–10 show the format of the Frame Length field. Table 29a summarizes the type of payload versus the frame length value.

Bits: 0-10	11-12	13	14	15
Actual frame length	Data rate	Parity check	Reserved	Frame length 0: Length ≤ 127 bytes 1: 127 bytes < Length ≤ 2047 bytes

Figure 27c—Format of the frame length field

Table 29a—Frame length values

Frame length field values	Payload
0-4	Reserved
5	MPDU (Acknowledgement)
6-8	Reserved
9-2047	MPDU

Bits 11-12 are used to determine data rate as illustrated in Figure 27d.

Bits:11-12	**00**	**01**	**10**	**11**
Bit rate (kb/s)	62.5	125	250	500

Figure 27d—Data rates

Bit 13 is Parity Check bit for frame length to avoid unnecessary receiver power consumption due to errors in frame length. Bit 15 shows whether it is a short or a long frame. When Bit 15 is 0, it is a short frame with frame length to be less than or equal to 127 bytes. Otherwise it is a long frame whose length is greater than 127 bytes and less than or equal to 2047 bytes.

For the SUN DSSS PHY, the Frame Length field is 11 bits in length and specifies the total number of octets contained in the PSDU (i.e., PHY payload). It is a value between 4 and *aMaxSUN_DSSS_PHY_PacketSize* octets (see 6.4).

Insert the following new row at the end of Table 29:

Table 29—Frame length values

Frame length values	**Payload**
4 to *aMaxSUN_DSSS_PHY_PacketSize*	MPDU (SUN DSSS PHY)

Insert the following new subclause after 6.3.3:

6.3.3a PHR Parity field (optional)

The PHR Parity field is 24 bits in length and can optionally be included to increase the robustness of the PHR. The PHR Parity field is only present when transmitting an FEC-coded PPDU. For more information on PHR protection, 6.12a.3.5.2.

6.3.4 PSDU field

Insert the following new subclauses (6.3.4a through 6.3.4c.2.1) at the end of 6.3.1:

6.3.4a Field descriptions of the FCF structure for the MR2-FSK PHY

The values of the PPDU fields described below can be (re-)configured by MAC Sublayer or “hard-coded” at the PHY Layer. At this time, for the sake of simplicity, we consider all these values being set as a function of the Physical Information Base (PIB), even if in some situations the MAC Sublayer can override some of these values or directly ask the PHY Layer to change these values via MAC-to-PHY service primitives.

6.3.4a.1 Preamble field

The Preamble field is used by the transceiver to obtain bit and symbol synchronization with an incoming message. The preamble is an integer number of octets, but variable in size. The length is set by *phyNBFHPreambleLength*.

The preamble is an alternating stream of ‘0’s and ‘1’s. Its value is set by *phyNBFHPreambleValue*.

6.3.4a.2 SFD field

The Start-of-Frame Delimiter (SFD) is a field indicating the end of the preamble and the start of the packet data. The length of the SFD is two octets. The P802.15.4g MRFSK PHY shall use a single and unique SFD value. Multiple SFD values are not allowed.

The PHY shall always use this unique value to indicate the end of the preamble and the start of the frame data (PHR + PSDU). The PHY shall not use the SFD word for other purposes than that of delimiting sections of PHY frame structure.

One exception from the above rule shall be allowed. In order to cope with the co-existence issue between IEEE 802.15.4d-2009 and P802.15.4g in Japan band, two different SFDs can be used to differentiate between IEEE 802.15.4d-2009 frames and P802.15.4g frames.

The value of SFD is set by the PIB attribute *phySFDValue*.

6.3.4a.3 Header FEC field

Header FEC is mandatory.

It is a 5-bit wide extended code (e.g., single error correct, double error detect) covering the following the 11-bit Frame length field.

6.3.4a.4 Legacy field

The Legacy field indicates if the frame is received from or is destined to a legacy device.

The use of this field shall be explained in Annex N: The use of Format Frame Change and Annex O: Supporting communication with legacy devices.

The value of this field is set by the PIB attribute *phyLegacyValue*.

6.3.4a.5 Format change field

The Format Change field indicates if there will be a change in the format of the frame.

The use of this field shall be explained in Annex N: The use of Format Frame Change.

The value of this field is set by the PIB attribute *phyFormatChangeValue*.

6.3.4a.6 Settling delay field

The Settling delay field indicates if the frame (transmitted at the new data rate, modulation scheme, etc.) following the Format Change Frame is transmitted after a default or extended settling delay. Settling delay values are functions of the Modulation/data rate/channel field.

The use of this field shall be explained in Annex N: The use of Format Frame Change.

The value of this field is set by the PIB attribute *phySettlingDelayValue*.

6.3.4a.7 Modulation/channel/data rate field

The Modulation/channel/data rate field indicates the modulation, channel, and data rate to be used for the frame that follows the Format Change Frame (i.e., the normal PHY frame).

The use of this field shall be explained in Annex N: The use of Format Frame Change and Annex O: Supporting communication with legacy devices.

The value of this field is set by the PIB attribute *phyModulation_Channel_DataRate_Value*.

6.3.4b Field descriptions of the NF structure for the MR2-FSK PHY

6.3.4b.1 Preamble field

The Preamble field is used by the transceiver to obtain chip and symbol synchronization with an incoming message. The preamble is an integer number of octets, but variable in size. The length is set by *phyNBFHPreambleLength*.

The preamble is an alternating stream of ‘0’s and ‘1’s. The value of this field is set by *phyNBFHPreambleValue*.

Notice: When the MR2-FSK PHY is switching from the lowest data rate to higher data rate, the preamble of the NF can be shorter because the devices are partially synchronized.

6.3.4b.2 SFD field

The Start-of-Frame Delimiter (SFD) is a field indicating the end of the preamble and the start of the packet data. The length of the SFD is two octets. The P802.15.4g MRFSK PHY shall use a single and unique SFD value. Multiple SFD values are not allowed.

The MRFSK PHY shall always use this unique value to indicate the end of the preamble and the start of the frame data (PHR + PSDU). The PHY shall not use the SFD word for other purposes than that of delimiting sections of PHY frame structure.

A single exception from the above rule shall be allowed. In order to cope with co-existence issue between IEEE 802.15.4d-2009 and P802.15.4g in Japan band, two different SFDs can be used to differentiate between IEEE 802.15.4d-2009 frames and P802.15.4g frames.

The value of SFD is set by the PIB attribute *phySFDValue*.

6.3.4b.3 Header FEC1 field

Header FEC is mandatory.

It is a 5-bit wide extended code (e.g., single error correct, double error detect) covering the following the 11-bit Frame length field.

6.3.4b.4 Legacy field

The Legacy field indicates if the frame is received from or is destined to a legacy device.

The use of this field shall be explained in Annex N: The use of Format Frame Change and Annex O: Supporting communication with legacy devices.

The value of this field is set by the PIB attribute *phyLegacyValue*.

6.3.4b.5 Format change field

The Format Change field indicates if there will be a change in the format of the frame.

The use of this field shall be explained in Annex N: The use of Format Frame Change.

The value of this field is set by the PIB attribute *phyFormatChangeValue*.

6.3.4b.6 PSDU FEC field (optional)

The PSDU FEC field is optional.

The PSDU FEC field indicates if FEC is used for the PHY payload. Options are provided for simple (i.e. block) or more complex (convolutional) algorithms. The use of this field is as follows:

- PSDU FEC field value = 0 => no FEC (PHY frame payload is not coded)
- PSDU FEC value = 1 => PHY Frame payload is coded with a specific algorithm => option #1, using for example a 6-bit, Reed-Solomon (RS) (52,38) code.
- PSDU FEC field value = 2 => PHY frame payload is coded with a different algorithm => option #2, using for example convolutional coding.
- PSDU FEC field value = 3 is reserved for further use.

The value of this field is set using the PIB attribute *phyDataWhitening*.

6.3.4b.7 Data whitening field

This field indicates if scrambling is enabled on the PHY payload.

For a frequency hopping system, if scrambling is enabled (i.e., Data whitening field value = 1) the seed value for scrambling algorithm is based on the channel number, on which the transmitter/receiver hops.

The value of this 1-bit field is set using the PIB attribute *phyDataWhitening*.

6.3.4b.8 RFU field

This field is reserved for future use. These bits shall be set to zero.

6.3.4b.9 Network ID field

This field indicates the utility network ID.

The value of this field is set using the PIB attribute *phyNetworkID*.

6.3.4b.10 Header FEC2 field

Header FEC is mandatory.

It is a 5-bit wide extended code (e.g., single error correct, double error detect) covering the following the 11-bit Frame length field.

6.3.4b.11 Frame length field

This field indicates the length of the PHY payload.

6.3.4c Field descriptions for the OFDM PHY

6.3.4c.1 Preamble field

The Preamble field is replaced by the STF and LTF for OFDM, and the STF is defined in 6.3.4c.1.1 and the LTF is defined in 6.3.4c.1.2.

6.3.4c.1.1 Short Training field for OFDM

Frequency Domain STF:

The STF for the five scalable bandwidth OFDM options are defined by the following Matlab equations in the Frequency Domain:

STF_freq(Option-1) = sqrt(108/24)*[0, zeros(1,7), -1-j, zeros(1,7), -1-j, zeros(1,7), 1+j, zeros(1,7), 1+j, zeros(1,7), 1+j zeros(1,7), 1+j, zeros(1,15), zeros(1,16), 1+j, zeros(1,7), -1-j, zeros(1,7), 1+j, zeros(1,7), -1-j, zeros(1,7), -1-j, zeros(1,7), 1+j, zeros(1,7)];

Note: STF Option-1 will be modified to have non-zero elements every 4 tones so that the repetition period is 1/4 of the useful part of the OFDM symbol.

STF_freq(Option-2) = sqrt(52/24)*[0, zeros(1,3), -1-j, zeros(1,3), -1-j, zeros(1,3), 1+j, zeros(1,3), 1+j, zeros(1,3), 1+j, zeros(1,3), 1+j, zeros(1,7), zeros(1,8),1+j, zeros(1,3) -1-j, zeros(1,3) 1+j, zeros(1,3) -1-j, zeros(1,3) -1-j, zeros(1,3) 1+j, zeros(1,3)];

STF_freq(Option-3) = sqrt(26/12)*[0,zeros(1,3),-1-j, zeros(1,3), 1+j, zeros(1,3), 1+j, zeros(1,3), zeros(1,4), 1+j, zeros(1,3),-1-j,zeros(1,3),-1-j,zeros(1,3)]

STF_freq(Option-4) = sqrt(14/12)*[0,0,-1-j,0,1+j,0,1+j,0,0,0,1+j,0,-1-j,0,-1-j,0]

STF_freq(Option-5) = sqrt(6/4)*[0,0,1+j,0,0,0,-1-j,0]

(Figure 27e)

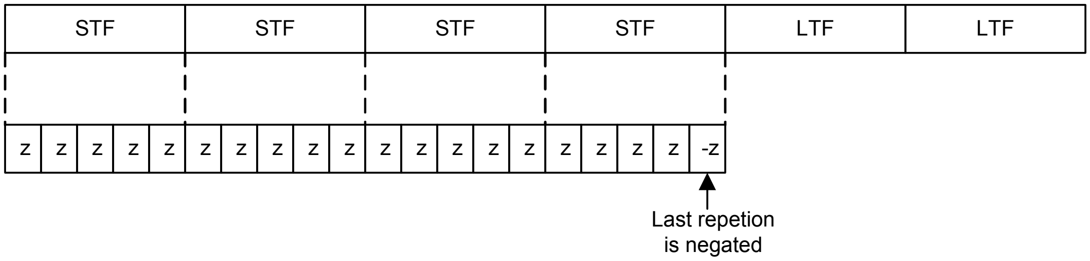


Figure 27e—Structure of STF for OFDM

There are 4 STF OFDM symbols, and the last 1/4 of the useful part of the 4th OFDM symbol is negated in the time domain.

STF Normalization:

The STF uses lesser number of tones than the data-portion. Hence, normalization of the frequency domain STF is required to ensure that the STF power is same as the rest of the data-frame. The normalization value is sqrt(N_{active}/ (2*N_{stf})) where N_{active} is the number of used subcarriers in rest of the OFDM frame for the particular FFT option and N_{stf} is the number of subcarriers used in the STF.

Time Domain STF Generation:

The Time-Domain STF for Option-n (n=1,2,3,4,5) is obtained as follows:

STF_time(Option-n) = IFFT(STF_freq(Option-n))

Time Domain STF Repetition:

The time-domain STF is repeated to fill 4-OFDM symbols (512us) before transmission.

6.3.4c.1.2 Long Training field for OFDM

Frequency Domain LTF:

The LTF for the five scalable bandwidth OFDM options are defined by the following Matlab equations in the Frequency Domain:

LTF_freq(Option-1)= {0,0,-1,1,1,-1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1, zeros(1,17),1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,-1,-1,-1,1,0}

LTF_freq(Option-2)= {0,1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1, -1,1,1,1,1,zeros(1,11),1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1, 1,1,1}

LTF_freq(Option-3)= {0,1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,zeros(1,5),1,1,-1,-1,1,1,-1,1,-1,1,1,1,1}

LTF_freq(Option-4)= {0,1,-1,-1,1,1,-1,1,zeros(1,1),-1,1,-1,1,1,-1,1}

LTF_freq(Option-5)= {0,1,-1,-1, zeros(1,1),1,-1,1}

Time Domain LTF Generation:

The Time-Domain LTF for Option-n (n=1,2,3,4,5) is obtained as follows:

LTF_time(Option-n) = IFFT(LTF_freq(Option-n))

Time Domain LTF Repetition:

The time-domain LTF is repeated to fill 2-OFDM symbols (256us) before transmission.

6.3.4c.2 Frame Length field

The Frame Length field is replaced by the PHY Header (PHR) for the OFDM PHY. The PHR for the OFDM PHY is described in 6.3.4c.2.1.

6.3.4c.2.1 PHY Header for OFDM

The PHY Header (PHR) field is encoded using the lowest data-rate in each OFDM bandwidth option for Robustness. The list of data-rates for each OFDM bandwidth option can be found in 6.12b.1.

The PHR field structure shall be formatted as illustrated in Figure 27f.

Rate (5 bits)	Reserved (1 bit)	Length (11 bits)	Reserved (2 bits)	Scrambler (2 bits)	Reserved (1 bit)	HCS (8 bits)	Tail (6 bits)

Figure 27f—PHY header fields for OFDM

The PHY header fields include:

- Rate field specifies the data rate of the payload frame (5 bits)
- 1 Reserved bit after the Rate field
- Length specifies the length of the payload (11 bits)
- 2 Reserved bits after the Length field
- Scrambling seed (2 bits)
- 1 Reserved bit after the Scrambler field
- Header Check sequence 8 bit CRC taken over the data fields only
- Tail bits for Viterbi decoder flushing

All reserved bits shall be set to “0” value.

<Editor’s Note: The PHY Header would occupy M OFDM symbols. The value of M varies from 2 to 4 depending on the OFDM bandwidth option. The exact value of M would be derived once the PHY header is frozen.>

6.4 PHY constants and PIB attributes

6.4.1 PHY constants

Change Table 30 (the entire table is not shown) as indicated:

6.4.2 PHY PIB attributes

Change Table 31 (the entire table is not shown) as indicated:

Please note some differences related to Table 31. The length of the FCS is determined by a parameter in the PD-DATA.request primitive and by a PIB attribute. The control for turning FEC coding on and off is determined by a parameter in the PD-DATA.request primitive and by a PIB attribute. The maximum value of the Frame Length field has two possible definitions as indicated by two PIB attributes. The size of

Table 30—PHY constants

Constant	Description	Value
aMaxPHYPacketSize	The maximum PSDU size (in octets) in the PHY shall be able to receive	~~127~~ 2047
aMaxMRFSKPHYPacketSize	The maximum PSDU size (in octets) the MRFSK PHY shall be able to receive.	2047
aMaxMRFSKNumPreambleRepetitions	The maximum number of times the MRFSK PHY preamble bit sequence shall be repeated.	16
aMaxSUN_DSSS_PHY_PacketSize	The maximum PSDU size (in octets) the SUN DSSS PHY shall be able to receive.	2047
aSUN_DSSS_PHY_TurnaroundTime	RX-to-TX or TX-to-RX maximum turnaround time (in milliseconds) (see 6.13.1 and 6.13.2).	1

the array containing channels supported for this PHY can be represented by phyChannelsSupported (defined in 15.4-2009) or by phyMRFSKChannelsSupported (defined in this doc).

6.5 2450 MHz PHY specifications

6.6 2450 MHz PHY chirp spread spectrum (CSS) PHY

6.7 868/915/950 MHz band binary phase-shift keying (BPSK) PHY specifications

6.8 780 MHz band (optional) O-QPSK PHY specifications

6.9 868/915 MHz band (optional) amplitude shift keying (ASK) PHY specifications

6.10 868/915 MHz band (optional) O-QPSK PHY specifications

6.11 950 MHz band Gaussian frequency-shift keying (GFSK) PHY specifications

6.12 UWB PHY specification

Insert after 6.12.15.3 the following new subclauses (6.12a through 6.12c.x.x):

6.12a MRFSK PHY specification

The requirements for the MRFSK PHY are specified in 6.12a.1 through 6.12a.7. The MRFSK PHY provides for effective use of license-exempt frequency bands with a simple radio suitable for low cost implementations, high spectral efficiency, and good coexistence properties. Suitable separation mechanisms are included for overlapping piconets in the presence of overlapping SOI and given the need for SOI scaling.

Table 31—PHY PIB attributes

Attribute	Identifier	Type	Range	Description
phyCurrentChannel	0x00	Integer	1–*phyMRFSK-MaxChanSeq-Size*	The RF channel to use for all following transmissions and receptions (see 6.1.2).
phyMaxFrameDuration	0x05	Integer	55, 212, 266, 1064, 16440, 16472, 16536 except UWB and CSS PHYs	The maximum number of symbols in a frame, except for UWB and CSS PHYs: = *phySHRDuration* + ceiling([*aMaxPHYPacketSize* + 1] × *phySymbolsPerOctet*) For UWB PHYs, see 6.4.2.1. For CSS PHYs, one of two values depending on data rate. See 6.4.2.2.
phySHRDuration	0x06	Integer	3, 7, 10, 40, 80, 144 except UWB and CSS PHYs. For UWB PHYs see 6.4.2.1 For CSS PHY, 12, 24.	The duration of the synchronization header (SHR) in symbols for the current PHY. For CSS PHY, a value of 12 corresponds to 1 Mb/s and 24 corresponds to 250 kb/s.
phySymbolsPerOctet	0x07	Float	0.4, 1.3, 1.6, 2, 5.3, 8	The number of symbols per octet for the current PHY. For UWB PHYs, see 6.4.2.1. For CSS PHYs, 4/3 corresponds to 1 Mb/s and 32/6 corresponds to 250 kb/s.
phyMode				Sets the modulation type, band to use, and symbol rate.
phyMRFSKChannelsSupported		Array	An R x 512 bit array, where R ranges from 1 to 32	Bitmap of supported channels.
phyFCSOption		Integer	0,1	See 6.3.2a.
phyFECOption		Boolean	TRUE or FALSE	Indication of whether FEC is used.

Table 31—PHY PIB attributes

Attribute	Identifier	Type	Range	Description
phyFrameFormat		Integer	0, 1	Indication of the PPDU format currently supported: 0: conventional PPDU in IEEE Std 802.15.4-2006 1: enhanced PPDU in P802.15.4g
phyMRFSKMaxChanSeqSize		Integer	Frequency band dependent (see Table 4)	The number of channels supported by the frequency band currently in use for a transmission/reception.
phyMRFSKNumPreambleRepetitions		Integer	4 - *aMaxMRFSKNumPreambleRepetitions*	The number of times the preamble bit pattern *phyMRFSKPreambleValue* is repeated. This field shall not be equal to zero. The default value shall be seven.
phyMRFSKNumTxPowerLevels[*]		Integer	1–255	The number of power levels supported by the MRFSK PHY.
phyMRFSKPowerIndex		Integer	1 - *phyMRFSKNumTxPowerLevels*	An index into the array of transmit power levels, as given by the *phyMRFSKTxPower* attribute.
phyMRFSKPreambleValue		Bit field	0–0xff	The bit pattern chosen for the preamble. The default value shall be 0xaa (i.e., alternating ones and zeros).
phyMRFSKTxPower[†]		Array	A 1 x *phyMRFSKNumTxPowerLevels* array	An array storing the transmit power values, in dBm, for each transmit power level.
phyPreambleLength		Integer	See Table 26	Indication of the number of octets in the preamble field.
phyScramblerSeedValue		Octet	0–0xff	A non-zero value shall specify the value used to seed the data scrambler during PPDU transmit and receive operations; see 6.12a.4 for a description of data whitening. A value of zero shall disable the scrambler.
phySUNDSSSModulationType		Integer	0-1	For SUN DSSS PHY, 0 is for O-QPSK modulation and 1 is for GMSK modulation.

[*] Read-only attribute.
[†] Read-only attribute.

6.12a.1 Data rates

In order to take full advantage of the available spectrum in diverse regions, a selection of data rates are available, as shown in Table 75a.

When FEC coding is used, the effective data rate is reduced according to the code rate.

Table 75a—Data rate parameters

Raw data rate (kbps)	Symbol Rate (kHz)	Modulation
200, 400	200	2 or 4-GFSK, 2 or 4-MSK
100, 200	100	2 or 4-GFSK, 2 or 4-MSK
50	50	2-GFSK or 2-MSK
40	40	2-GFSK
20	20	2-GFSK
5, 10	5, 10	2-GFSK

The data rate of the GFSK PHY operating in the 400–430 MHz and 950–956 MHz bands shall be as specified in Table 1. When implementing the 400 kb/s option, the SHR and PHR shall be transmitted at 200 kb/s.

6.12a.2 Data transfer

We have different figures for PHY signal flow and different descriptions (figure and text) for how the PPDU is constructed.

Figure 65a shows the general processing steps to create and transmit a PHY packet (i.e., PPDU).

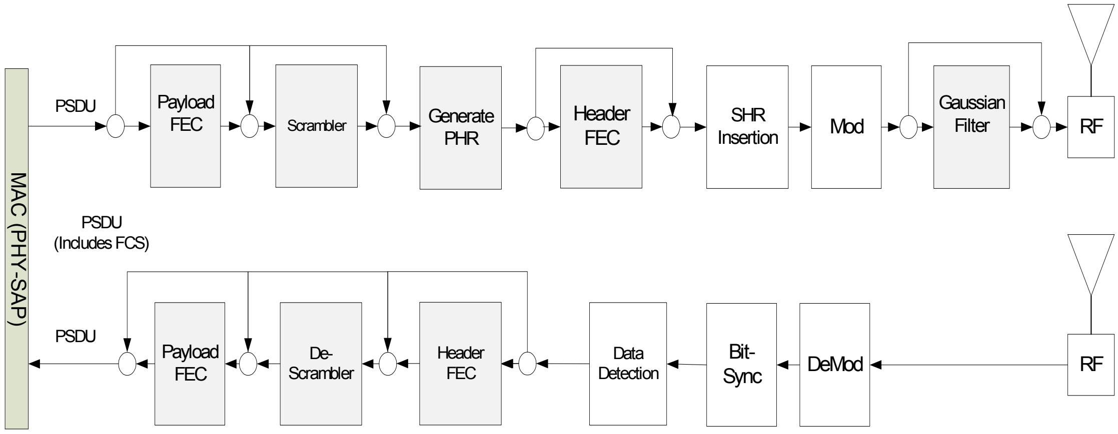


Figure 65a—PHY signal flow

Figure 65b shows the general processing steps to create and transmit a PHY packet (i.e., PPDU).

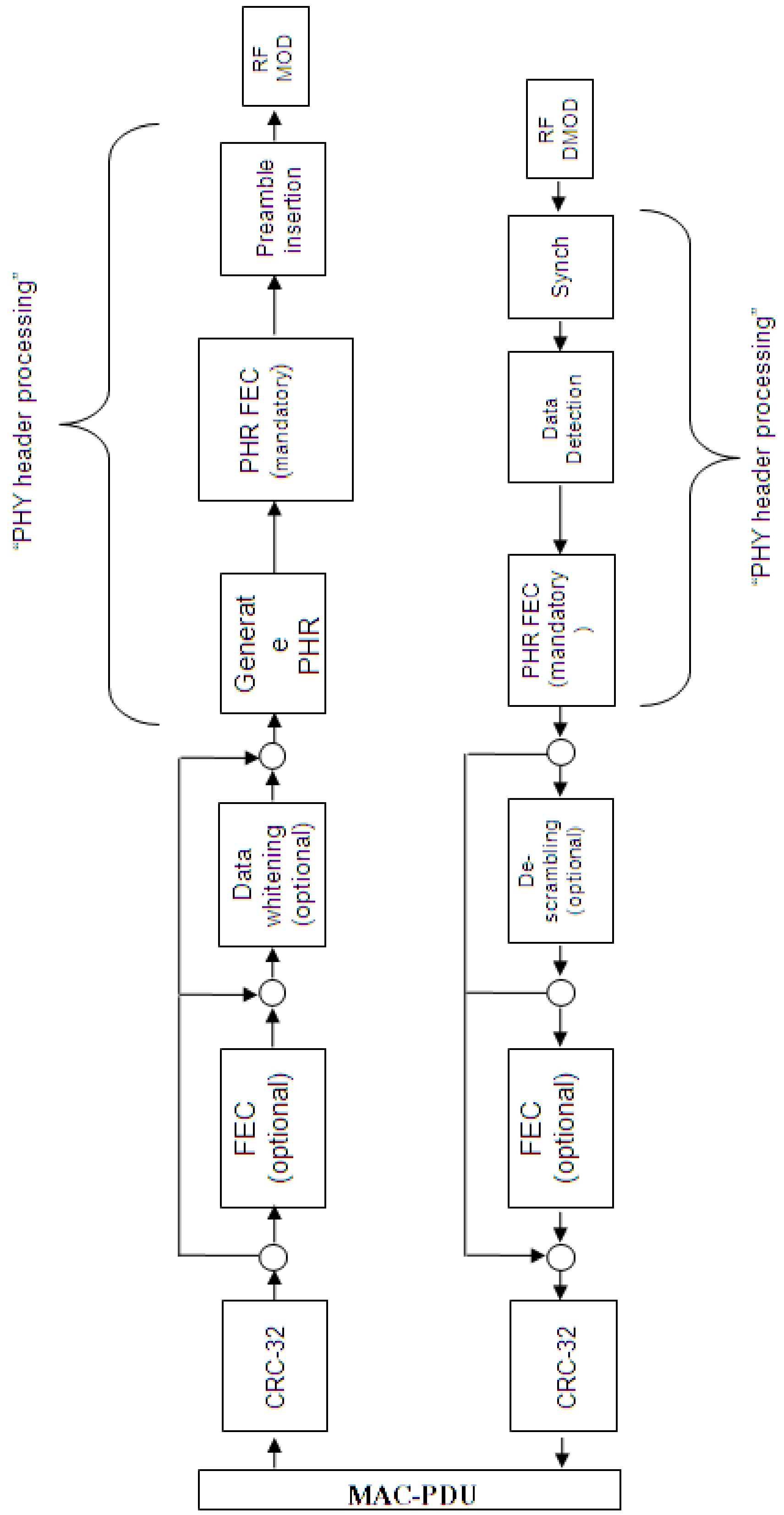


Figure 65b—PHY signal flow

.The functional block diagram of GFSK PHY signal flow shall be as given in Figure 65c.

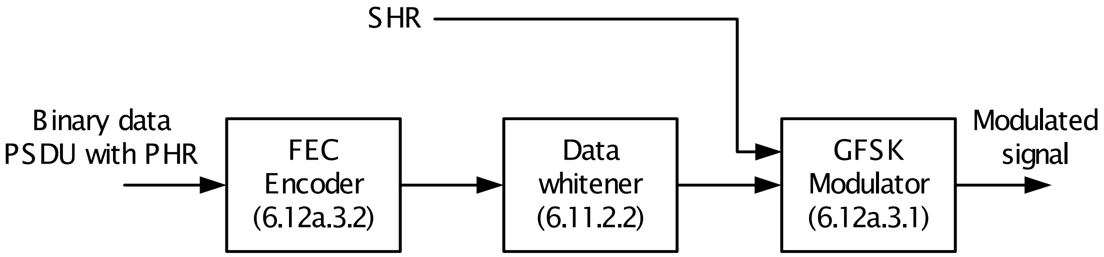


Figure 65c—Functional Diagram for GFSK PHY signal flow

The functional diagram for the GFSK PHY signal flow is shown in Figure 65d.

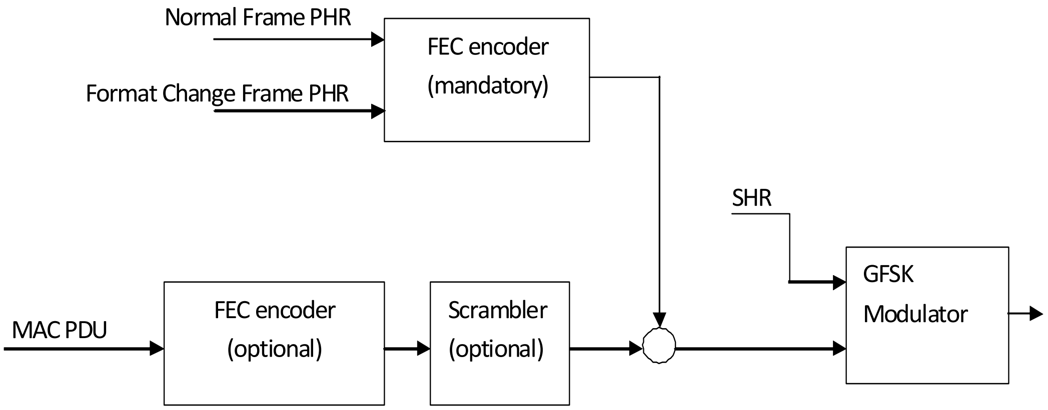


Figure 65d—Functional diagram for GFSK PHY signal flow

The steps for encoding an MPDU (i.e., PSDU) and inserting it into a PPDU for transmission are illustrated in Figure 65e.

The PPDU shall be constructed as follows:

- encode the PSDU and PHR
- scramble the encoded PSDU and PHR
- prepend the SHR to the encoded-and-scrambled PSDU with PHR
- modulate the encoded-and-scrambled PSDU, PHR and SHR

6.12a.3 Modulation and coding

The modulation choices provided by the MRFSK PHY are MSK and GFSK. For 2-MSK and 2-GFSK, each data symbol encodes 1 information bit. In 4-GFSK each data symbol encodes 2 information bits. Modulation parameters are given in 6.12a.3.3.

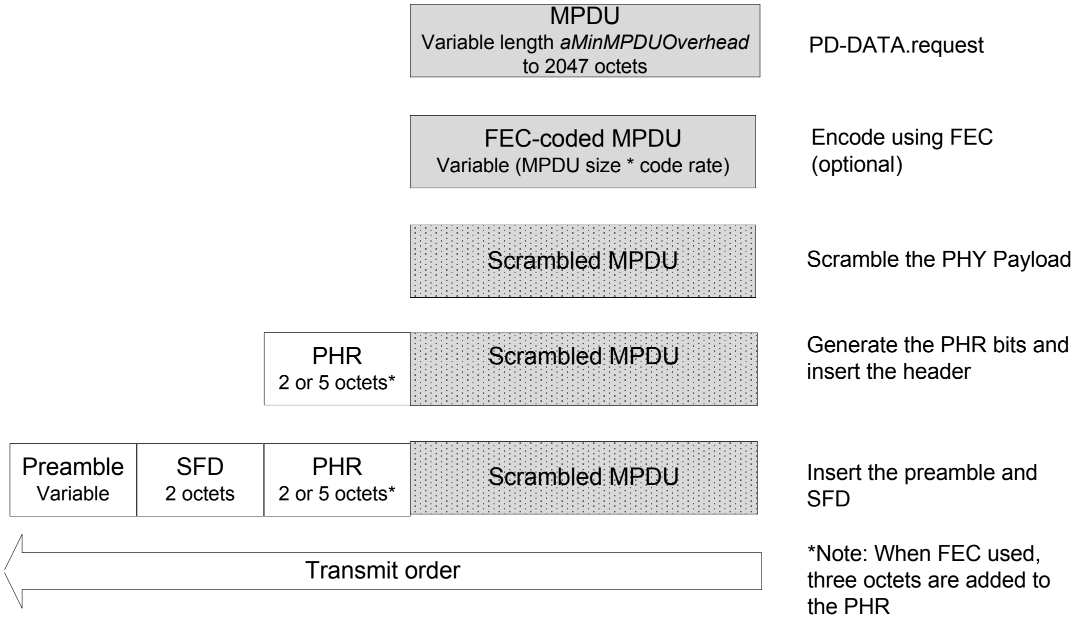


Figure 65e—PPDU encoding process

6.12a.3.1 Reference modulator diagram

The bit sequences are modulated onto the carrier using GFSK with modulation index (i.e. two times the nominal frequency deviation divided by symbol rate) and Gaussian filter BT. The modulation parameters are given in Table 75b.

Table 75b—Modulation parameters for GFSK PHY

Data rate (kb/s)	Symbol rate (ksymbol/s)	Modulation order	Modulation index	Gaussian filter BT
50/100	100	2	1.0	0.5
200	200	2	1.0	
400	200	4	0.33	

The bit rate for GFSK and 4GFSK are specified in Table 1.

The nominal frequency deviation, Δf, shall be 50 kHz for 50/100 kb/s GFSK modulation, 100 kHz for 200 kb/s GFSK modulation, and 33 kHz for 400kb/s 4GFSK modulation. The deviation shall be between 70% and 130% of the nominal deviation. In cases where GFSK modulation is employed, for the sequence 0101, the deviation shall be between 70% and 110% of the nominal deviation, and for the sequence 00001111, the deviation shall be between 80% and 130% of the nominal deviation.

For data rate of 400 kb/s, an incoming bit stream at 400 kb/s will be converted to 2-bit words or symbols, with a rate of 200 ksymbol/s. The first received bit will be encoded as the LSB of the symbol in Table 75b. The bits will be encoded into symbols as shown in Table 75c.

Table 75c—Symbol encoding into carrier deviation for GFSK PHY

50, 100, 200 kb/s for GFSK	
Symbol	**Carrier deviation**
1	Δf
0	$-\Delta f$
400 kb/s for 4GFSK	
Symbol	**Carrier deviation**
10	$3 * \Delta f$
11	Δf
01	$- \Delta f$
00	$-3 * \Delta f$

The functional block diagram for the FSK modulator is shown in Figure 65f.

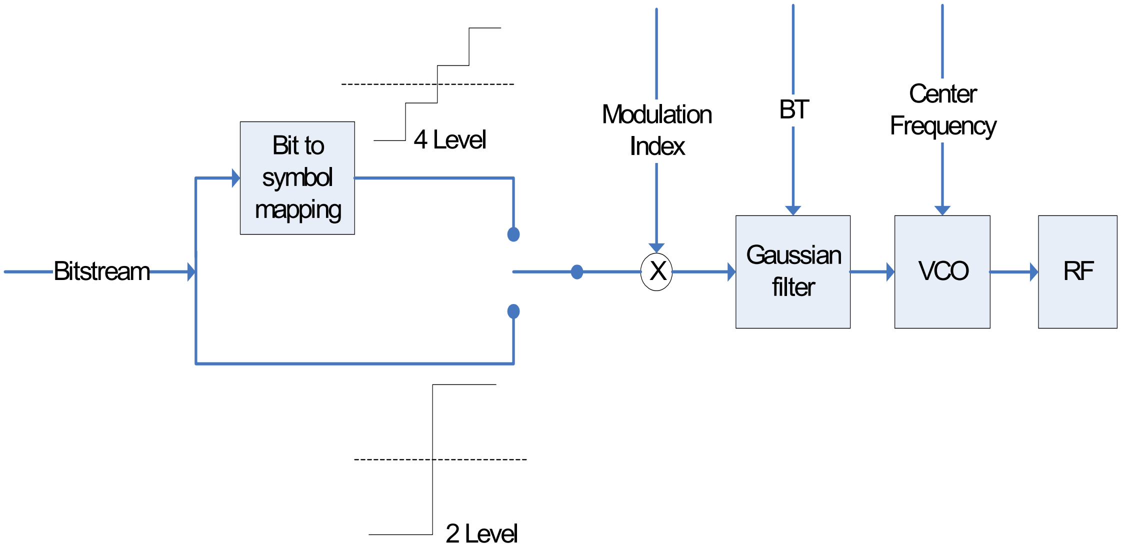


Figure 65f—Reference modulator diagram (FSK)

6.12a.3.2 Bit-to-symbol mapping

Each FSK symbol represents one data bit for 2-MSK and 2-GFSK, and two data bits for 4-FSK and 4-GFSK. For 2-FSK, the offset is toggled by the transmit data bit so that a positive offset is generated for a ‘1’ and a negative offset is generated for a ‘0.’ For 4-FSK, bits are mapped using Gray coding, to frequency offsets, as shown in Table 75d.

Table 75d—Symbol constellation for 4-level modulation

Value	Frequency offset
11	Positive frequency offset largest in value
10	Positive frequency offset smallest in value
00	Negative frequency offset smallest in value
01	Negative frequency offset largest in value

6.12a.3.3 Modulation parameters

The modulation parameters are optimized for each frequency band, as shown in 6.1.1. The bit sequences are modulated onto the carrier using either FSK or GFSK. When GFSK is employed, the Gaussian filter BT is 0.5. The modulation index varies from 0.33 to 1, depending on which combination of frequency band and data rate is being used.

6.12a.3.4 Gaussian filtering

TBD

6.12a.3.5 Forward error correction (FEC)

Different methods of FEC are proposed.

6.12a.3.5.1 Systematic convolutional code

When FEC coding is enabled, the PHR and PSDU shall be protected with a systematic convolutional code.

Several data rate modes specified in Table 1 shall be encoded with a convolutional encoder. The systematic convolutional encoder shall use the industry-standard generator polynomials, $g_0=35_8$ and $g_1=23_8$, of rate R=1/2 and constraint length K=5. Output data A and B are the output of the encoder, with A as the uncoded data similar to the input data. If necessary, uncoded data may be obtained at the receiver. In cases where a decoder is applied, the Viterbi algorithm is recommended.

The encoder is shown in Figure 65g

6.12a.3.5.2 BCH code / convolutional code

When FEC coding is enabled, the PHR shall be protected with a (40,16) BCH code, and the PSDU shall be protected with a ½-rate convolutional code.

A BCH (63,39), t=4 error correcting code is shortened to produce a BCH (40,16) code, which is used to encode the 16 PHR bits and produce 24 parity bits.

The generator polynomial shall be as shown in Equation (20):

$$G_{BCH}(X) = X^{24}+X^{23}+X^{22}+X^{20}+X^{19}+X^{17}+X^{16}+X^{13}+X^{10}+X^{9}+X^{8}+X^{6}+X^{5}+X^{4}+X^{2}+X^{1}+1$$

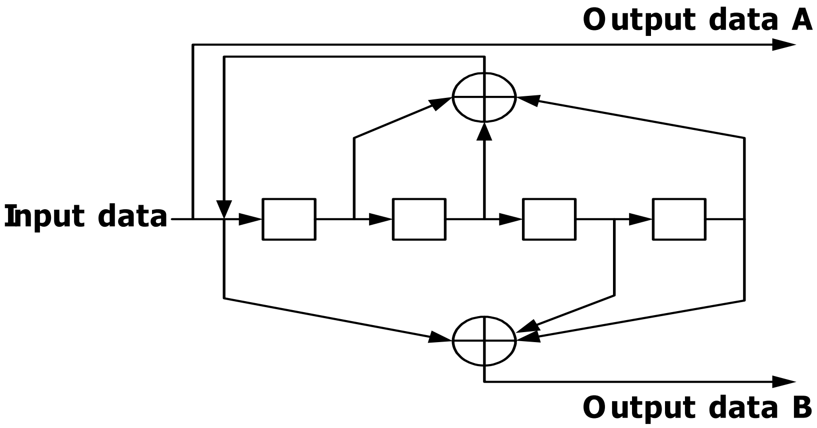


Figure 65g—Convolutional encoder

(20)

The PSDU shall be encoded using a ½ rate K=5 convolutional code using the generator polynomials shown in Equation (21) and Equation (22):

$$G_A(X) = X^4 + X^1 + 1 \tag{21}$$

$$G_B(X) = X^4 + X^3 + X^2 + 1 \tag{22}$$

The encoder is shown in Figure 65h.

The PSDU and four “0” tails bits shall be concatenated prior to encoding, as shown in Figure 65i.

PSDU (Includes FCS)	Four ‘0’ tail bits

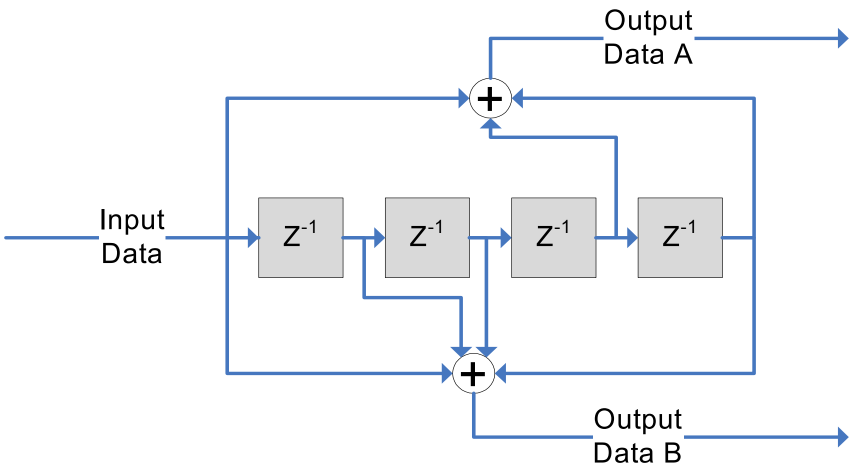
Figure 65i—Data prior to encoding

Encoding shall begin from the left of the data in Figure 65i, and the encoded bits for transmission shall be assembled as shown in Figure 65j .

6.12a.3.5.3 PSDU Forward Error Correction

The PSDU shall be coded using one of the following options:

- No coding
- Reed Solomon
- Convolutional



Convolutional Encoder: Rate ½, constraint length K=5
Generator polynomials [23, 35]

Figure 65h—Convolutional encoder

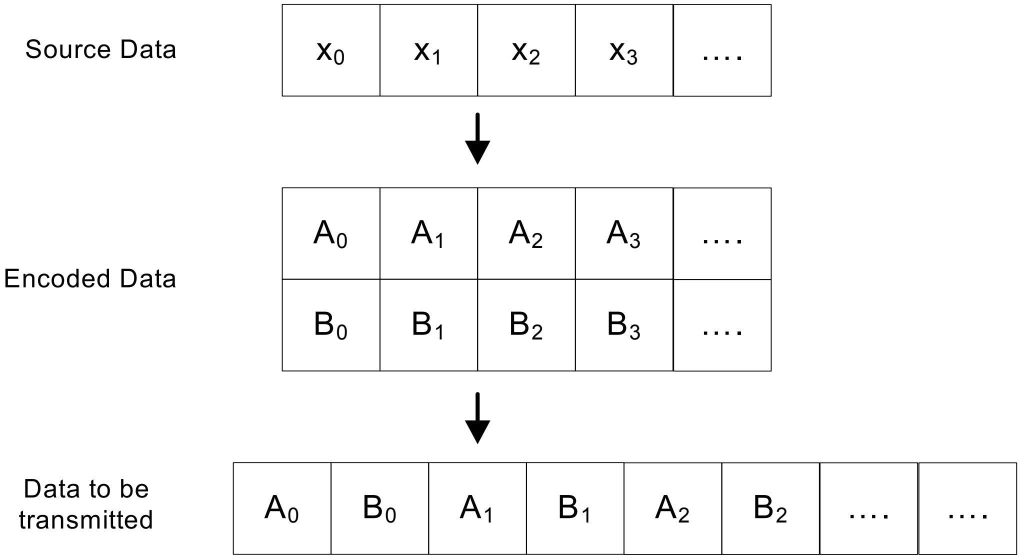


Figure 65j—Encoded bits for transmissions

— Reserved for further use.

The process for a 6-bit, Reed-Solomon (RS) (52,38) coding is described in the following paragraphs.

The PSDU to be FEC-encoded is a sequence of octets. The first step of the encoding process is to convert it to a sequence of 6-bit symbols. This requires appending 0, 2 or 4 pad bits. The conversion is performed in a little-endian fashion, with the LSB of each octet treated as being first in time sequence. Thus, the first six-bit symbol in the sequence consists of bits 0 through 5 of the first octet in the PSDU; the second six-bit symbol in the sequence consists of bits 6 and 7 of the first octet in its two LSBs, and bits 0 through 3 of the second octet in its four MSBs; and so forth.

This symbol sequence is then split into one or more segments. The final segment has a length between 1 and 46 symbols, and all preceding segments (if any) have a length of exactly 46 symbols.

Each segment is then Reed-Solomon encoded according to Table 75e. Here the (n, k) notation is used to indicate a codeword with n total symbols and k information symbols, where $r = n - k$ is the number of check symbols. The above-described segments, before encoding, contain k symbols.

RS parameters are m, n, and k.

- m = symbol size
- n = total symbols per codeword
- k = information symbols per codeword

$t = (n - k)/2$ is the correction ability

Table 75e shows the 6-bit coding format for the PSDU (i.e., MPDU).

Table 75e—6-bit coding format for the PSDU

Range of k	**Value of r**	**Code**	**Base code rate**
41–46	16	(k + 16, k)	(62, 46) rate .74
33–40	14	(k + 14, k)	(54, 40) rate .74
27–32	12	(k + 12, k)	(44, 32) rate .73
21–26	10	(k + 10, k)	(36, 26) rate .72
15–20	8	(k + 8, k)	(28, 20) rate .71
1–14	6	(k + 6, k)	(20, 14) rate .70

In performing the above encoding, the r check symbols for each codeword in the encoded PSDU are transmitted immediately following the message symbols for that codeword, and the entire transmission for the PSDU consists of a sequence of one or more such encoded codewords.

The Galois field arithmetic employed is described by the following: the coefficients of the degree-six field generator polynomial are equal to the hexadecimal value 0x43. Field element alpha generates the field and is represented by hexadecimal value 0x02. Thus, field element alpha 6 is represented by hexadecimal value 0x03.

For the RS(n, k) code with $r = n - k$, the roots of the code generator polynomial are as follows:

$$alpha^0, alpha^1, \ldots, alpha^{r-1} \tag{23}$$

Each encoded codeword can be viewed as a polynomial of degree n - 1. The first message symbol transmitted corresponds to the term of order n - 1, and the final message symbol transmitted corresponds to the term of order r. The next symbol transmitted is the first check symbol and corresponds to a polynomial term of order r - 1, and the final check symbol transmitted corresponds to a polynomial term of order zero.

Encoding is systematic, with the check polynomial equal to the remainder of the message polynomial divided by the code generator polynomial.

Convolutional coding is TBD.

6.12a.3.5.4 PHR Forward Error Correction

Standard PHRs (Frame Change Format PHR and Normal Frame PHR) shall be coded. The algorithm to be used is yet to be defined.

6.12a.4 Data whitening

We have different methods for data whitening.

<editor's note: Subclause 6.11.2.2 refers to the data whitening procedure described in IEEE 802.15.4d-2009. It is also shown in the draft of the roll up doc 802.15.4-2009.>

The data whitening process shall be specified as in 6.11.2.2.

Data whitening is used when the 1-bit Data whitening field is set to one. The default mode of operation when data whitening is enabled is to scramble the PSDU field.

The data whitening algorithm is an additive 8-bit Linear Feedback Shift Register (LFSR) with feedback polynomial $x^8 + x^6 + x^5 + x^4 + 1$ as shown in Figure 65k. The seed value for the LFSR is set based on the channel number (1-200). The feedback polynomial yields a maximum length sequence ($2^8 - 1$).

In frequency hopping systems, when data whitening is enabled, the seed for the scrambling algorithm shall be equal to the channel number within the hopping sequence, as generated by the MAC sublayer.

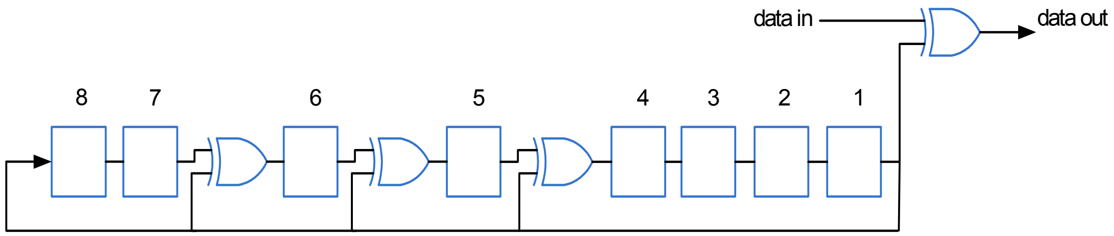


Figure 65k—Representation of data whitening algorithm

If *phyScramblerSeedValue* is set to a non-zero 8-bit value, that value shall be used to seed the scrambler for transmission and reception of PPDUs. The PSDU shall be whitened using an additive, 8-stage (255 bit sequence) shift register generator with taps at bits [8,4,3,2] in a simple shift register generator (SSRG) representation. The SHR and PHR shall not be scrambled.

If *phyScramblerSeedValue* is set to a zero value, the scrambler is effectively disabled.

6.12a.5 Frequency hopping modes (optional)

Frequency hopping is an optional feature of the MRFSK PHY and is used, when appropriate, to meet regional regulations, bands and applications. The decision of whether or not to hop is made by the upper layers.

Two types of frequency hopping may be employed: PHY hopping and MAC hopping. For PHY hopping, the content of a PPDU is spread across multiple channels in the sequence, with two octets transmitted per channel. For MAC hopping, one (or more) PHY packet (i.e., PPDU) is transmitted entirely on one channel before moving to the next channel in the sequence to transmit an additional packet(s). MAC hopping is controlled by the MAC sublayer and is discussed further in Clause 7.

6.12a.6 Packet timestamping

The PHY may capture the time of transmission and/or the time of arrival of each PPDU. If the transmit time of a PPDU is to be recorded, the PHY shall timestamp the data at the time of transmission of the first bit of the PHR. The timestamp shall then be reported to the MAC sublayer via the PD-DATA.confirm primitive.

If the receive time of a PPDU is to be recorded, the PHY shall timestamp the data at the time of reception of the first bit of the PHR. The timestamp shall then be reported to the MAC sublayer along with the received PSDU via the PD-DATA.indication primitive.

6.12a.7 Radio specification

One set of radio parameters is shown in Table 75f, one set is shown in Table 75g, and another set is shown in subclauses 6.12a.8.1–6.12a.8.5.

Table 75f contains parameters specific to the MRFSK PHY.

Table 75f—MRFSK radio parameters for the 902/2400 MHz bands

Parameter	Value	Notes
Minimum receiver sensitivity	–90 dBm	PER = 10^{-2} for 1500 octet payload
Adjacent channel separation	300 kHz	
Alternate channel separation	600 kHz	
Adjacent channel rejection	10 dB	Measured at sensitivity + 3dB against a modulated signal with balanced ones and zeros.
Alternate channel rejection	30 dB	Measured at sensitivity + 3dB against a modulated signal with balanced ones and zeros.
Nominal modulation index	0.5	
Modulation index range	±20%	Supports ±5 kHz
Nominal data rate	100 kb/s	
Data rate tolerance	±1 kb/s	PN 9 encoded (run length ≤ 9)
Frequency tolerance/stability	±10 ppm	
System time stability	±10 ppm	
TX amplifier rise time	≤ 100µs	
Channel switch time	≤ 500µs	

Table 75g

Table 75g—Other MR2-FSK parameters

Parameter	**Notes**	
	Band	
FSK	400–430 MHz 950.9–955.7 MHz	FHSS MAC controlled
	470–510 MHz	FHSS MAC controlled
	863–870 MHz	–/FHSS MAC controlled/AFA
	902–928 MHz	FHSS, MAC controlled
	2.4 GHz	FHSS MAC controlled
Transmit power	Per regulatory requirements	
Transmit power control	Available	

6.12a.8 Coexistence between FSK frequency hopping systems and OFDM

Channelization between MR2-FSK and OFDM is shown in Table 75h.

6.12a.8.1 Operating frequency range

The 400 MHz GFSK PHY and the 950 MHz GFSK PHY operate in the frequency bands specified in Table 1.

6.12a.8.2 Transmit PSD Mask

The PSD transmit mask of the 400 MHz GFSK PHY and the 950 MHz GFSK PHY shall be as specified in Figure 65l and Figure 65n, respectively.

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6.12a.8.3 Symbol rate

The 400 MHz GFSK PHY and 950 MHz GFSK PHY symbol rates shall be specified as in Table 1 with an accuracy of ± 20 ppm.

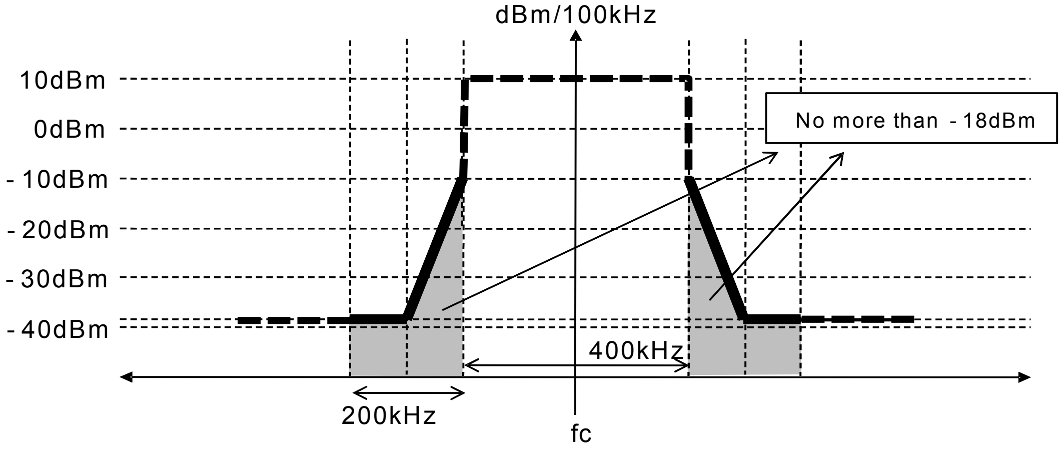


Figure 65l—PSD Transmit mask for 400 MHz GFSK PHY

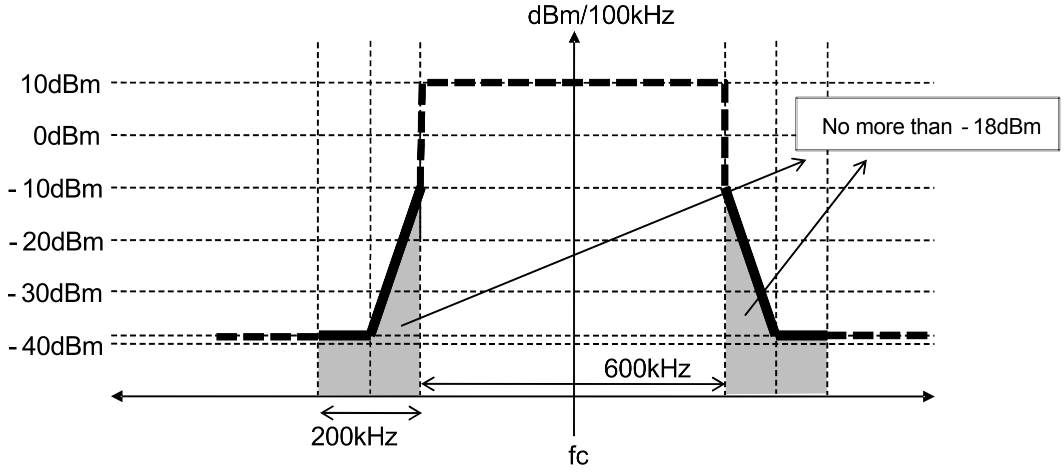


Figure 65n—PSD Transmit mask for 950 MHz GFSK PHY

6.12a.8.4 Receiver sensitivity

Under the conditions specified in 6.1.7, a compliant devices shall be capable of achieving a sensitivity as specified in Table 75i.

Under the conditions specified in 6.1.7, a compliant devices shall be capable of achieving a sensitivity as specified in Table 76.

6.12a.8.5 Receiver adjacent and alternate channel resistance

The minimum resistance levels are given in Table . The adjacent channels are the ones on either side with the closest center frequency to the desired channel, and the alternate channels are the ones with the center frequency nearest to an adjacent channel. For example, if channel 5 is the desired channel, channel 4 and channel 6 are the adjacent channels, whereas channel 3 and channel 7 are the alternate channels.

Table 75h—Channelization between MR2-FSK and OFDM

Frequency band	OFDM bandwidth	OFDM max data rate (kbps)	FSK low data rate	FSK medium data rate	FSK high data rate
426.025–469.4875 MHz (Japan)	200 kHz (16 pt FFT)	281.25 kbps	200 kHz	200 kHz	200 kHz
863–870 MHz (Europe)	200 kHz (16 pt FFT) 400 kHz (32 pt FFT) 600 kHz (64 pt FFT)	281.25 kbps 562.5 kbps 750 kbps	200 kHz	400 kHz	600 kHz
902–928 MHz (US)	200 kHz (16 pt FFT) 400 kHz (32 pt FFT) 800 kHz (64 pt FFT)	281.25 kbps 562.5 kbps 750 kbps	200/ 400 kHz	400 kHz	400 kHz
950.9–955.7 MHz (Japan)	200 kHz (16 pt FFT) 600 kHz (64 pt FFT)	281.25 kbps 750 kbps	200 kHz	200 kHz	200 kHz
2,400–2,483.5 MHz (Worldwide)	200 kHz (16 pt FFT) 400 kHz (32 pt FFT) 800 kHz (64 pt FFT)	281.25 kbps 562.5 kbps 750 kbps	200/ 400 kHz	400 kHz	400 kHz
TV white space	1200 kHz (128 pt FFT)	750 kbps			

Table 75i—Minimum receiver sensitivity for GFSK PHY

Data rate (kb/s)	Sensitivity (dBm)
50	TBD
100	-85
200	TBD
400	TBD

Minimum receiver adjacent and alternate channel resistance

PHY (MHz)	Adjacent channel rejection	Alternate channel rejection
400	0 dB	24 dB
950	0 dB	24 dB

Table 76—Receiver Sensitivity for MR2-FSK

Data rate (kbps)	Receiver sensitivity (dBm)
40	TBD
160	TBD
320	TBD

6.12b OFDM PHY specification

There was only one OFDM submission. Text is shown in black.

6.12b.1 Data rates

There are 5 OFDM options with 5 different recommended FFT sizes of 128, 64, 32, 16, and 8.

The device shall support one or several of the data rates shown in Table 75a:

Table 75a—Data Rates for OFDM PHY

Parameter	OFDM Option 1	OFDM Option 2	OFDM Option 3	OFDM Option 4	OFDM Option 5	Unit
FFT size	128	64	32	16	8	
Active tones	104	52	26	14	6	
# Pilot tones	8	4	2	2	2	
# Data tones	96	48	24	12	4	
MCS0 (BPSK rate 1/2 with 4x repetition)	93.75					kbps
MCS1 (BPSK rate 1/2 with 2x repetition)	187.5	93.75	46.88			kbps
MCS2 (BPSK rate 1/2 OR QPSK rate 1/2 and 2x repetition)	375	187.5	93.75	46.88		kbps
MCS3 (QPSK rate 1/2 OR DCM QPSK rate 1/2)	750	375	187.5	93.75		kbps
MCS4 (QPSK rate 3/4 OR DCM QPSK rate 3/4)		562.5	281.25	140.63	46.88	kbps
MCS5 (16-QAM rate 1/2)		750	375	187.5	62.5	kbps
MCS6 (16-QAM rate 3/4)			562.5	281.25	93.75	

6.12b.2 Data transfer

6.12b.3 Modulation and coding

6.12b.3.1 Reference modulator diagram

(Figure 65o)

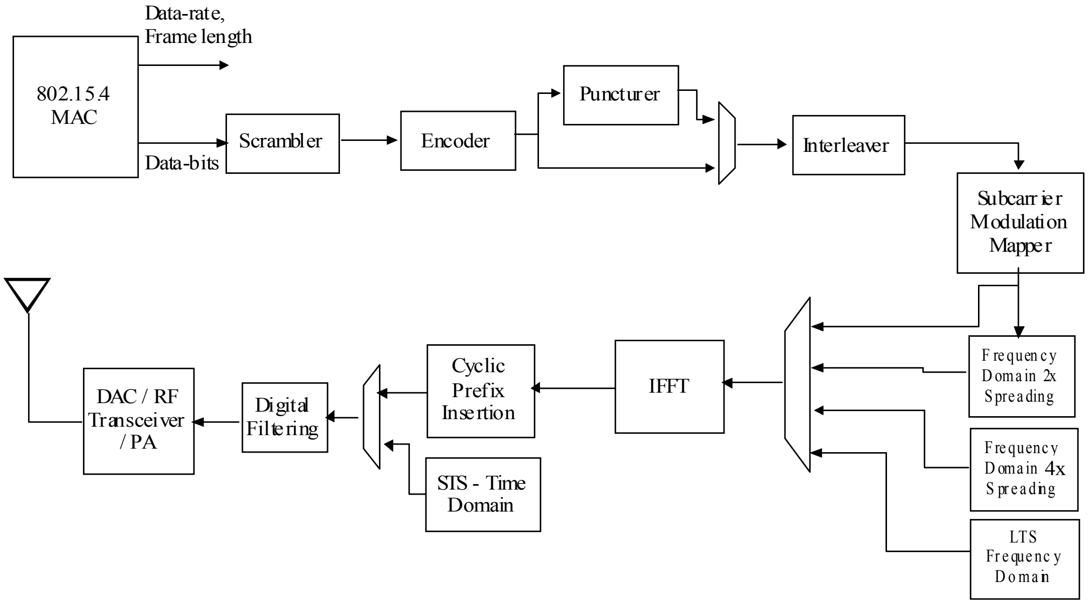


Figure 65o—Reference modulator diagram for OFDM

6.12b.3.2 Bit-to-symbol mapping

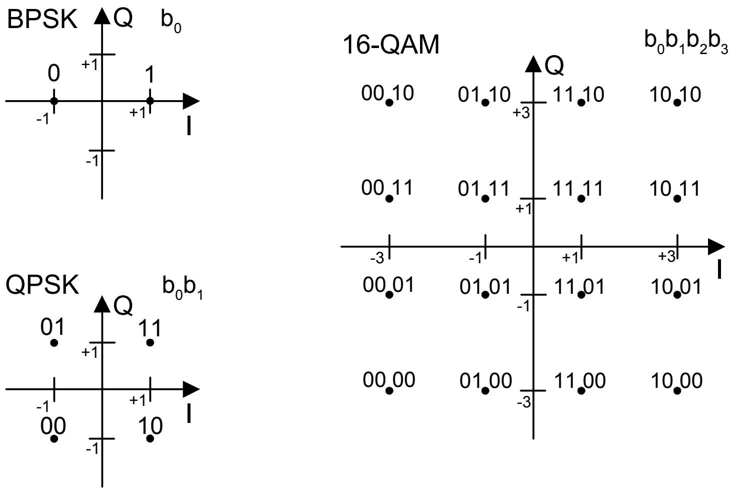


Figure 65p—Bit to symbol mapping for OFDM

For BPSK, b0 determines the I value, as illustrated in Table 75b. For QPSK, b0 determines the I value and b1 determines the Q value, as illustrated in Table 75c. For 16-QAM, b0b1 determines the I value and b2b3 determines the Q value, as illustrated in Table 75d.

The output values, d, are formed by multiplying the resulting (I+jQ) value by a normalization factor K_{MOD}, as described in Equation (24).

$$d = (I + jQ) \times K_{MOD} \tag{24}$$

The normalization factor, K_{MOD}, depends on the base modulation mode, as prescribed in Table 75e. The purpose of the normalization factor is to achieve the same average power for all mappings.

Table 75b—BPSK encoding table

Input bit (b_0)	I-out	Q-out
0	-1	0
1	1	0

Table 75c—QPSK encoding table

Input bit (b_0)	I-out
0	-1
1	1

Input bit (b_1)	Q-out
0	-1
1	1

Table 75d—16-QAM encoding table

Input bits (b_0 b_1)	I-out
00	-3
01	-1
11	1
10	3

Input bits (b_2 b_3)	Q-out
00	-3
01	-1
11	1
10	3

Table 75e—Modulation-dependent normalization factor K_{MOD}

Modulation	K_{MOD}
BPSK	1
QPSK	1/sqrt(2)
16-QAM	1/sqrt(10)

In the case that dual-carrier modulation (DCM) is used, the coded and interleaved binary serial input data, $b[i]$ where $i = 0, 1, 2, \ldots$, shall be divided into groups of 4N bits and converted into 2Ncomplex numbers using a technique called dual-carrier modulation. N is the number of data tones in one-half of the subcarriers. The conversion shall be performed as follows:

1) The 4Ncoded bits are grouped into N groups of 4 bits. Each group is represented as ($b[g(k)]$, $b[g(k)+1]$, $b[g(k) + \mathrm{N}]$, $b[g(k) + \mathrm{N}+1]$), where $k \in [0, \mathrm{N}-1]$ and

$$g(k) = \begin{cases} 2k & k \in \left[0, \frac{N}{2} - 1\right] \\ 2k + N & k \in \left[\frac{N}{2}, N - 1\right] \end{cases} . \tag{25}$$

2) Each group of 4 bits ($b[g(k)]$, $b[g(k)+1]$, $b[g(k) + \mathrm{N}]$, $b[g(k) + \mathrm{N}+1]$) shall be mapped onto a four-dimensional constellation, as shown in the figure below, and converted into two complex numbers ($d[k]$, $d[k + \mathrm{N}]$). The mapping between bits and constellation is enumerated in the table below.
3) The complex numbers shall be normalized using a normalization factor K_{MOD}.

The normalization factor $K_{MOD} = 1/\sqrt{10}$ is used for the dual-carrier modulation. In practical implementations, an approximate value of the normalization factor can be used, as long as the device conforms to the modulation accuracy requirements.

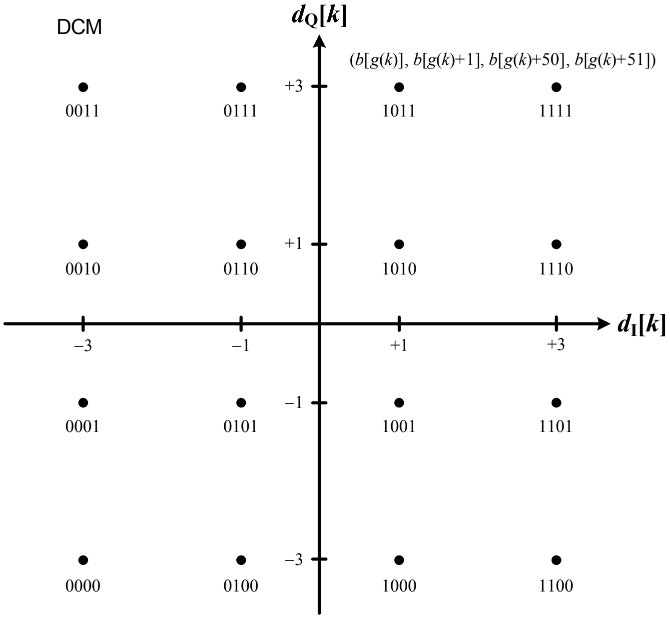


Figure 65q—DCM mapping for d[k]

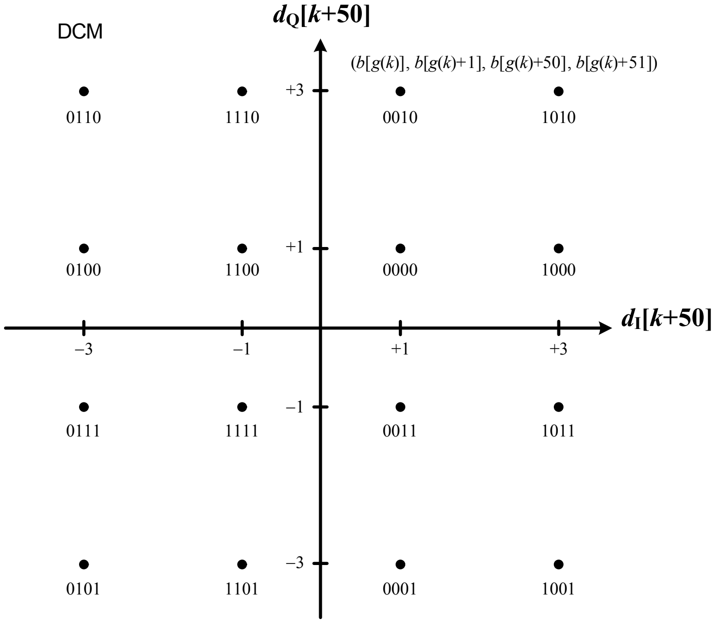


Figure 65r—DCM mapping for d[k+N]

Table 75f—Dual Carrier Modulation Encoding Table

Input Bit (*b*[*g*(*k*)], (*b*[*g*(*k*)+1], (*b*[*g*(*k*)+N)], (*b*[*g*(*k*)+N+1])	*d*[*k*] *I*-out	*d*[*k*] *Q*-out	*d*[*k*+N] *I*-out	*d*[*k*+N] *Q*-out
0000	-3	-3	1	1
0001	-3	-1	1	-3
0010	-3	1	1	3
0011	-3	3	1	-1
0100	-1	-3	-3	1
0101	-1	-1	-3	-3

Table 75f—Dual Carrier Modulation Encoding Table

Input Bit ($b[g(k)]$, ($b[g(k)+1]$, ($b[g(k)+N)]$, ($b[g(k)+N+1]$)	$d[k]$ *I*-out	$d[k]$ *Q*-out	$d[k+N]$ *I*-out	$d[k+N]$ *Q*-out
0110	-1	1	-3	3
0111	-1	3	-3	-1
1000	1	-3	3	1
1001	1	-1	3	-3
1010	1	1	3	3
1011	1	3	3	-1
1100	3	-3	-1	1
1101	3	-1	-1	-3
1110	3	1	-1	3
1111	3	3	-1	-1

6.12b.3.3 Modulation parameters

6.12b.3.4 Forward error correction (FEC)

The DATA field, composed of PSDU, tail, and pad parts, shall be coded with a convolutional encoder of coding rate R = 1/2 or 3/4, corresponding to the desired data rate. The convolutional encoder shall use the industry-standard generator polynomials, $g_0 = 133$ and $g_1 = 171$, of rate R = 1/2, as shown in Figure 65s.

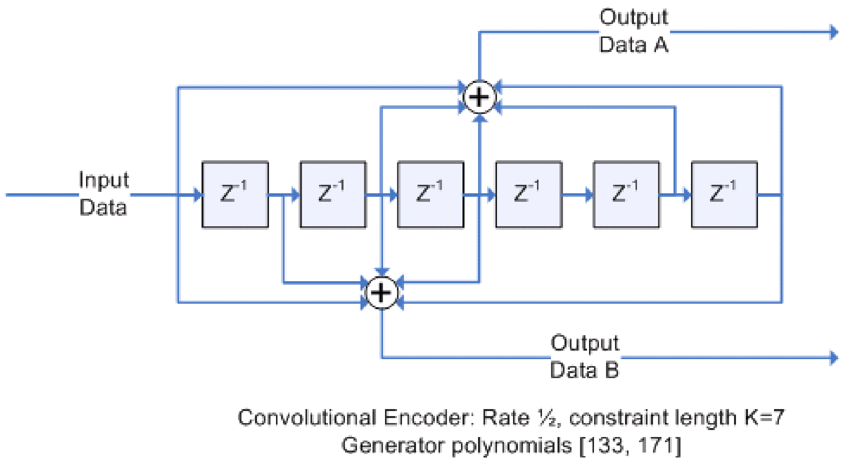


Figure 65s—Rate 1/2 convolutional encoder

The device shall support also coding rates of R=3/4, derived by puncturing as shown in Figure 65t:

Figure 65t—Puncturing for rate 3/4

6.12b.3.5 Interleaver

The interleaving is defined for each one of the 5 OFDM options, through the following Matlab scripts:

i = (Ncbps/Nrow)(k mod Nrow) + floor(k/Nrow), k = 0, 1, 2, … Ncbps -1

j = s*floor(i/s) + (i + Ncbps - floor(Nrow*i/Ncbps)) mod s, i = 0, 1, 2, …, Ncbps

s = max(Nbpsc/2, 1)Nbpsc => (BPSK =1, QPSK= 2, 16QAM = 4)

<u>OFDM Option 1:</u>

Ncbps = 96*{1,2}

Nrow = TBD

<u>OFDM Option 2:</u>

Ncbps = 48*{1,2,4}

Nrow = TBD

OFDM Option 3:

Ncbps = 24*{1,2,4}

Nrow = TBD

OFDM Option 4:

Ncbps = 12*{1,2,4}

Nrow = TBD

OFDM Option 5:

Ncbps = 6*{1,2,4}

Nrow = TBD

6.12b.3.6 Frequency spreading

Frequency spreading by 2x

Frequency spreading is a method of replicating PSK symbols on different carriers

The device shall offer the possibility to create a 2x repetition through frequency spreading.

The spreading is performed by repeating the data on one side of the DC tone to the other side, using the conjugate value of the data.

Figure 65u indicates how the left half of the spectrum is replicated using conjugated versions of the PSK symbol

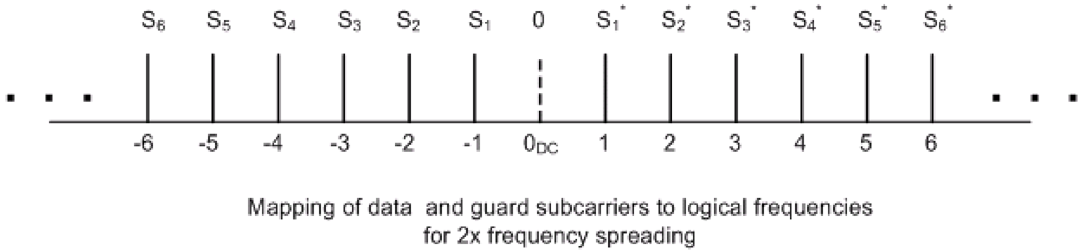


Figure 65u—Frequency spreading by 2x

Frequency spreading by 4x

Frequency spreading by 4x can be performed in 2 steps. First the lower half of the negative frequency tones can be copied to the upper half of the negative frequency tones. In the second step the left half of the spectrum is replicated using conjugated versions of the PSK symbols as is done for 2x frequency spreading. The pilot tones (shown with a dashed line in Figure 65v) are not replicated in Step 1.

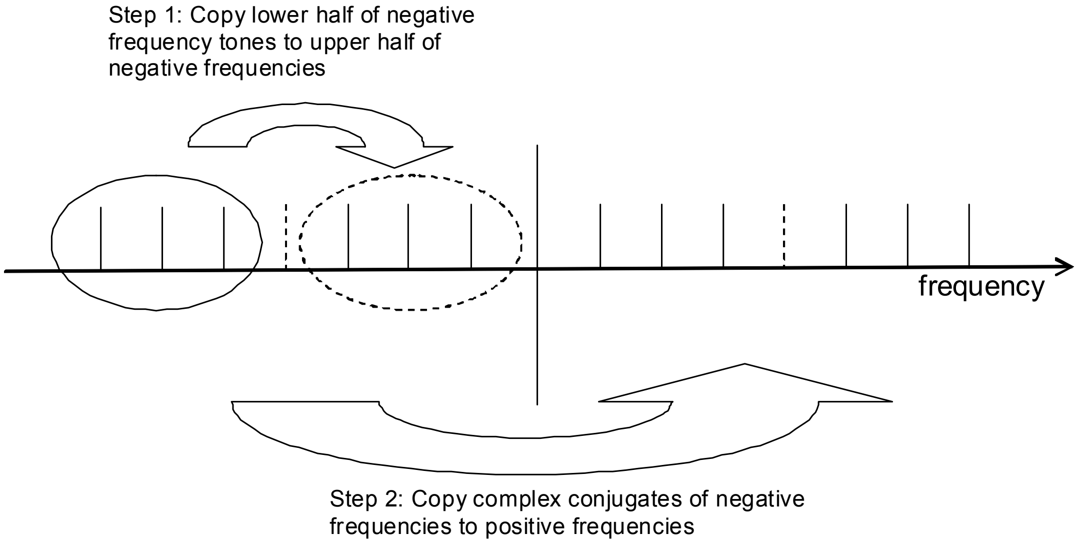


Figure 65v—Frequency spreading by 4x

6.12b.3.7 Pilot Tones / Null Tones

The pilot tones and null tones are defined as shown in Table 75g:

Table 75g—Number of Pilot and Null Tones for OFDM PHY

	OFDM Option 1	OFDM Option 2	OFDM Option 3	OFDM Option 4	OFDM Option 5
Active tones	104	52	26	14	6
# Pilot tones	8	4	2	2	2
# Data tones	96	48	24	12	4
#DC null tones	1	1	1	1	1

OFDM Option 1:

P-54,54 = {0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, -1, 0, 0, 0, 0, 0};

6.12b.3.8 Cyclic Prefix

A cyclic prefix shall be inserted before each OFDM symbol. The duration of the CP shall be 1/4 the symbol rate (25.6 us). It is a replication of the last part of the data symbol.

6.12b.3.9 PPDU Tail Bit Field (TAIL)

The PPDU tail bit field shall be six bits of “0,” which are required to return the convolutional encoder to the “zero state.” This procedure improves the error probability of the convolutional decoder, which relies on future bits when decoding and which may be not be available past the end of the message. The PLCP tail bit field shall be produced by replacing six scrambled “zero” bits following the message end with six nonscrambled “zero” bits.

6.12b.3.10 Pad Bits (PAD)

The number of bits in the DATA field shall be a multiple of N_{CBPS}, the number of coded bits in an OFDM symbol (24, 48, 96, or 192 bits for Option 1; 24, 48, 96, or 192 bits for Option 2; 12, 24, 48,or 96 bits for Option 3; 12, 24, or 48 bits for Option 4; 8 or 16 bits for Option 5). To achieve that, the length of the message is extended so that it becomes a multiple of N_{DBPS}, the number of data bits per OFDM symbol. At least 6 bits are appended to the message, in order to accommodate the TAIL bits, as described in 6.12b.3.9. The number of OFDM symbols, N_{SYM}; the number of bits in the DATA field, N_{DATA}; and the number of pad bits, N_{PAD}, are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}\left((8 \times \text{LENGTH} + 6)/N_{DBPS}\right)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS}$$

$$N_{PAD} = N_{DATA} - (8 \times \text{LENGTH} + 6)$$

The function ceiling (.) is a function that returns the smallest integer value greater than or equal to its argument value. The appended bits (“pad bits”) are set to “zeros” and are subsequently scrambled with the rest of the bits in the DATA field.

6.12b.3.11 Pulse shape

6.12b.4 Radio specification

6.12b.4.1 Transmit PSD Mask

The OFDM transmit PSD mask is TBD.

6.12b.4.2 Receiver minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in a table below which is TBD. The minimum input levels are measured at the antenna connector (NF is TBD and TBD dB implementation margins are assumed).

6.12b.4.3 Adjacent channel rejection

The adjacent channel rejection for OFDM is TBD.

6.12b.4.4 Alternate adjacent channel rejection

The alternate adjacent channel rejection for OFDM is TBD.

6.12c SUN DSSS

This standard specifies the following two PHYs for SUN applications:

- — An 915 MHz DSSS PHY employing offset quadrature phase-shift keying (O-QPSK) modulation
- — A 2450 MHz DSSS PHY employing O-QPSK modulation

The SUN DSSS PHY supports four independent bands of operation:

- the Chinese frequency band 779-787 MHz
- the European frequency band 863-870 MHz
- the ISM band 902-980 MHz
- the ISM band 2400-2483.5 MHz.

The SUN DSSS PHY supports multiple PSDU data rates within each supported frequency band, employing a concatenation of outer forward error correction coding (FEC), interleaving and inner low complexity block coding. The latter is referred to as *direct sequence spread spectrum* (DSSS). For a given frequency band, the chip rate is constant (related to regularity conditions) and the PSDU data rate is adopted by a variable spreading factor, leading to a constant RF-bandwidth.

During SHR and PHR, no outer FEC is applied but the spreading factor is considerably larger than the spreading factor during the PSDU part.

Modulation is either O-QPSK or, alternatively, GMSK.

6.12c.1 Data rates

The data rate of the P802.15.4g PHY shall be 500/250/125/62.5 kb/s.

The supported PSDU parameters along with the data rates are shown in Table 75h.

6.12c.2 SHR and PHR spreading

Table 75i shows the spreading parameters of (N,1)-type bit-to-chip mapping described in 6.12c.3.5.

6.12c.3 Modulation, spreading, and coding

The 915/2450 MHz PHY employs either 16-ary quasi-orthogonal spreading code or CA-CDM.
During each data symbol period, information bits are used to generate nearly orthogonal constant amplitude pseudo-random noise (PN) sequences to be transmitted.

Table 75h—PSDU parameters

Frequency band (MHz)	Chip rate (kchip/s)	RateMode	Differential Encoding	Spreading (Bit-to-chip mapping)	FEC rate	data rate (kbps)
779-787	500	0	no	(32,4)	1/2	31.25
		1	no	(16,4)	1/2	62.5
		2	no	(8,4)	1/2	125
		3	no	pass through	1/2	250
863-870	125	0	yes	(4,1)	1/2	15.625
		1	no	pass through	1/2	62.5
902-928	1000	0	yes	(16,1)	1/2	31.25
		1	no	(16,4)	1/2	125
		2	no	(8,4)	1/2	250
		3	no	pass through	1/2	500
2400-2483.5	1000	0	yes	(16,1)	1/2	31.25
		1	no	(16,4)	1/2	125
		2	no	(8,4)	1/2	250
		3	no	pass through	1/2	500

Table 75i—SHR, PHR parameters

Frequency band (MHz)	Chip Rate (kchip/s)	Differential Encoding	Spreading (Bit-to-chip mapping)	(SHR,PHR) duration (us)
779-787	500	yes	(32,1)	5632
863-870	125	yes	(16,1)	7168
902-928	1000	yes	(64,1)	5632
2400-2483.5	1000	yes	(64,1)	5632

The PN sequences for successive data symbols are concatenated, and the aggregate chip sequence is modulated onto the carrier using offset quadrature phase-shift keying (O-QPSK).

The SUN DSSS PHY shall employ direct sequence spread spectrum (DSSS) of variable spreading factors in conjunction with outer forward error correction coding (FEC).

6.12c.3.1 Reference modulator diagram

The functional block diagram in Figure 65w is provided as a reference for specifying the 915/2450 MHz PHY modulation and spreading functions. Bit-to-symbol and symbol–to-chip mapping is consisted of two options. One is the spreading method of legacy 802.15.4-2006, the other is the multiplexed spreading of CA-CDM.

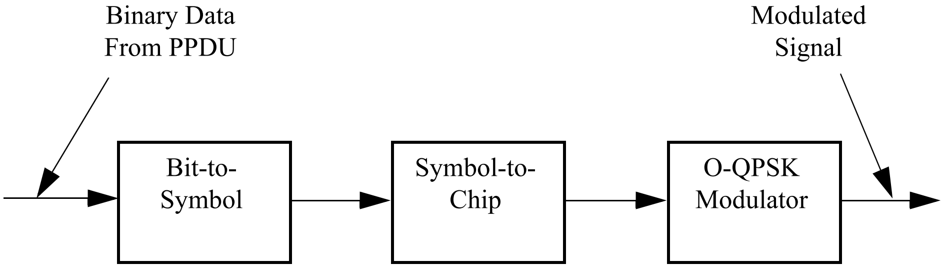


Figure 65w—Modulation and spreading functions

Figure 65x shows the reference modulator diagram.

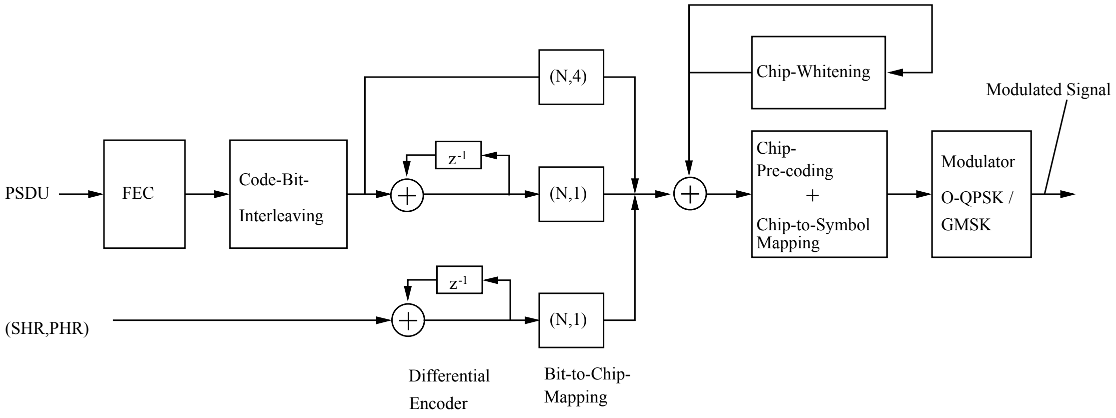


Figure 65x—Coding, interleaving, spreading and modulation

The reference modulator diagram for SUN DSSS is shown in Figure 65x. The bits of the SHR and PHR shall be differentially encoded (see 6.12c.3.4) and in addition (*N*,1)-type bit-to-chip mapping shall be applied as described in 6.12c.3.5.

The bits of the PSDU shall be first processed by forward error correction coding (FEC) as described in 6.12c.3.12, delivering a sequence of code-bits. The code-bits shall be interleaved as described in 6.12c.3.13. In addition, either one of two different spreading methods shall be applied depending on the frequency band and the *RateMode.*

The first spreading method applies differentially encoding of the interleaved code-bits (see 6.12c.3.4) and subsequently (*N*,1)-type bit-to-chip mapping as described in 6.12c.3.5.

The second spreading method applies (*N*,4)-type bit-to-chip mapping of the interleaved code-bits as described in 6.12c.3.5.

Depending on the frequency band and *RateMode*, the output sequences of the bit-to-chip mapper shall be whitened, as shown in 6.12c.3.7.

Depending on the type of modulation, the chip sequence shall be appropriately pre-coded in order to simplify demodulation without a priori knowledge of the modulator type, see 6.12c.3.8.

The sequences of pre-coded chips is finally passed to the modulator. There are two co-alternative options for modulation selected by *physUNDSSModulatorType*, which are *O-QPSK modulation*, as described in 6.12c.3.10, and, alternatively, *GMSK modulation*, as described in 6.12c.3.11.

6.12c.3.2 Bit-to-symbol mapping

All binary data contained in the PPDU shall be encoded using the modulation and spreading functions shown in Figure 65w. This subclause describes how binary information is mapped into data symbols.
For the case of (16,4) and (32,4) spreading, the 4 LSBs (b0, b1, b2, b3) of each octet shall map into one data symbol, and the 4 MSBs (b4, b5, b6, b7) of each octet shall map into the next data symbol. Each octet of the PPDU is processed through the modulation and spreading functions sequentially, beginning with the Preamble field and ending with the last octet of the PSDU.

For the case of CA-CDM, the 3 LSBs (b0, b1, b2) shall map into the first data symbol, and next 3 bits (b3, b4, b5) shall map into the next data symbol, and last 3 bits(b6, b7, b8) shall map into the last data symbol. These three data symbols are parallel processed through the CA-CDM functions (see 6.12c.3.6), except the SHR field.

6.12c.3.3 Symbol-to-chip mapping

For (16,4) and (32,4) direct spreading, each data symbol shall be mapped into a 16/32-chip PN sequence as specified in Table 75j and Table 75k, identical to the symbol-to-chip mapping table of IEEE802.15.4-2006. The PN sequences are related to each other through cyclic shifts and/or conjugation (i.e., inversion of odd-indexed chip values).

For the case of CA-CDM, four symbols including parity bits are parallel processed through the CA-CDM functions (see 6.12c.3.6).

Table 75j—Symbol-to-chip mapping for (16,4)

Data symbol (decimal)	Data symbol (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{14} c_{15})
0	0 0 0 0	0 0 1 1 1 1 1 0 0 0 1 0 0 1 0 1
1	1 0 0 0	0 1 0 0 1 1 1 1 1 0 0 0 1 0 0 1
2	0 1 0 0	0 1 0 1 0 0 1 1 1 1 1 0 0 0 1 0
3	1 1 0 0	1 0 0 1 0 1 0 0 1 1 1 1 1 0 0 0
4	0 0 1 0	0 0 1 0 0 1 0 1 0 0 1 1 1 1 1 0
5	1 0 1 0	1 0 0 0 1 0 0 1 0 1 0 0 1 1 1 1

Table 75j—Symbol-to-chip mapping for (16,4)

Data symbol (decimal)	Data symbol (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{14} c_{15})
6	0 1 1 0	1 1 1 0 0 0 1 0 0 1 0 1 0 0 1 1
7	1 1 1 0	1 1 1 1 1 0 0 0 1 0 0 1 0 1 0 0
8	0 0 0 1	0 1 1 0 1 0 1 1 0 1 1 1 0 0 0 0
9	1 0 0 1	0 0 0 1 1 0 1 0 1 1 0 1 1 1 0 0
10	0 1 0 1	0 0 0 0 0 1 1 0 1 0 1 1 0 1 1 1
11	1 1 0 1	1 1 0 0 0 0 0 1 1 0 1 0 1 1 0 1
12	0 0 1 1	0 1 1 1 0 0 0 0 0 1 1 0 1 0 1 1
13	1 0 1 1	1 1 0 1 1 1 0 0 0 0 0 1 1 0 1 0
14	0 1 1 1	1 0 1 1 0 1 1 1 0 0 0 0 0 1 1 0
15	1 1 1 1	1 0 1 0 1 1 0 1 1 1 0 0 0 0 0 1

Table 75k—Symbol-to-chip mapping for (32,4)

Data symbol (decimal)	Data symbol (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{30} c_{31})
0	0 0 0 0	1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0
1	1 0 0 0	1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0
2	0 1 0 0	0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0
3	1 1 0 0	0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1
4	0 0 1 0	0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1
5	1 0 1 0	0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0

Table 75k—Symbol-to-chip mapping for (32,4)

Data symbol (decimal)	Data symbol (b_0 b_1 b_2 b_3)	Chip values (c_0 c_1 … c_{30} c_{31})
6	0 1 1 0	1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1
7	1 1 1 0	1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1
8	0 0 0 1	1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1
9	1 0 0 1	1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1
10	0 1 0 1	0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1
11	1 1 0 1	0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0
12	0 0 1 1	0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0
13	1 0 1 1	0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1
14	0 1 1 1	1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0
15	1 1 1 1	1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0

6.12c.3.4 Differential encoding

Differential encoding is the modulo-2 addition (addition over GF(2)) of a raw bit with the previous encoded bit. This is performed by the transmitter and can be described by Equation (26):

$$E_n = R_n \oplus E_{n-1} \tag{26}$$

where

R_n is the raw bit being encoded

E_n is the corresponding differentially encoded bit

E_{n-1} is the previous differentially encoded bit

For each packet transmitted, R_0 is the first raw data bit to be encoded and E_{-1} is assumed to be zero.

If differential encoding is enabled during the PSDU part depending on the frequency band and *RateMode* (see Table 75h), it shall be continuously applied to the bits of the SHR, PHR and to the code bits at the output of the FEC, (see 6.12c.3.12).

If differential encoding is not enabled during the PSDU part depending on the frequency band and *RateMode* (see Table 75h), it shall be applied to the bits of the SHR and PHR only.

6.12c.3.5 Bit-to-chip mapping

For (N,1)-type bit-to-chip mapping, a single bit is mapped to a sequences of N binary valued chips: $\{0, 1\}^1 \rightarrow \{0, 1\}^N$. The number N of chips depends on the frequency band and *RateMode*, see Table 75h.

Table 75l to Table 75o show (N,1)-type bit-to-chip mapping used in the SUN DSSS PHY[1]. For $N = 1$, the chip value is equal to the input bit value (termed *pass through*).

Table 75l—(4,1)-Bit-to-chip mapping

Input bit	**Chip values (c_0 c_1 … c_3)**
0	1010
1	0101

Table 75m—(16,1)-Bit-to-chip mapping

Input bit	**Chip values (c_0 c_1 … c_{15})**
0	1011_ 0010_0011_ 1100
1	0100_ 1101_1100_0011

Table 75n—(32,1)-Bit-to-chip mapping

Input bit	**Chip values (c_0 c_1 … c_{31})**
0	0110_1001_0000_1010_1110_1100_0111_1100
1	1001_0110_1111_0101_0001_0011_1000_0011

Table 75o—(64,1)-Bit-to-chip mapping

Input bit	**Chip values (c_0 c_1 … c_{63})**
0	1010_1100_1101_1101_1010_0100_1110_0010_ _1111_0010_1000_1100_0010_0000_1111_1100
1	0101_0011_0010_0010_0101_1011_0001_1101_ _0000_1101_0111_0011_1101_1111_0000_0011

Note that for $N > 1$, (N,1)-type bit-to-chip mapping is always preceded by differential encoding, supporting non-coherent detection of the code bits. For $N = 1$ (pass through, no spreading), coherent detection is required, usually employing a phase control loop based on the received chip samples. In order to exploit the decoding capabilities of the outer FEC, it is recommended to compute a soft decision value of the detected information bits (soft-in-soft-out decoder).

---

[1] The codes (16,1), (32,1) and (64,1) are based on extended *m*-sequences of length 15, 31 and 63, respectively.

When applying (N,4)-type bit-to-chip mapping, a 4-tuple of bits is mapped to a sequence of N binary valued chips: $\{0, 1\}^4 \rightarrow \{0, 1\}^N$.

Table 75p to Table 75r show (N,4)-type bit-to-chip mapping applied in the SUN DSSS PHY.

Table 75p—(8,4)-Bit-to-chip mapping

Input bits (b_0 b_1 $b_2 b_3$)	Chip values (c_0 c_1 … c_7)
0000	0000_0001
1000	1101_0000
0100	0110_1000
1100	1011_1001
0010	1110_0101
1010	0011_0100
0110	1000_1100
1110	0101_1101
0001	1010_0010
1001	0111_0011
0101	1100_1011
1101	0001_1010
0011	0100_0110
1011	1001_0111
0111	0010_1111
1111	1111_1110

For (N,4)-type bit-to-chip mapping, coherent detection is recommended, employing a phase control loop based on the maximum likelihood decision of the optimal code word with respect to the (N,4) block code. In order to exploit the decoding capabilities of the outer FEC, it is recommended to compute a soft decision value of each individual bit of the 4-tuple of information bits which correspond to the detected code word

Table 75q—(16,4)-Bit-to-chip mapping

Input bits (b_0 b_1 b_2b_3)	Chip values (c_0 c_1 … c_{15})
0000	0011_1110_0010_0101
1000	0100_1111_1000_1001
0100	0101_0011_1110_0010
1100	1001_0100_1111_1000
0010	0010_0101_0011_1110
1010	1000_1001_0100_1111
0110	1110_0010_0101_0011
1110	1111_1000_1001_0100
0001	0110_1011_0111_0000
1001	0001_1010_1101_1100
0101	0000_0110_1011_0111
1101	1100_0001_1010_1101
0011	0111_0000_0110_1011
1011	1101_1100_0001_1010
0111	1011_0111_0000_0110
1111	1010_1101_1100_0001

Table 75r—(32,4)-Bit-to-chip mapping

Input bits (b_0 b_1 b_2b_3)	Chip values (c_0 c_1 … c_{31})
0000	1101_1001_1100_0011_0101_0010_0010_1110
1000	1110_1101_1001_1100_0011_0101_0010_0010
0100	0010_1110_1101_1001_1100_0011_0101_0010
1100	0010_0010_1110_1101_1001_1100_0011_0101
0010	0101_0010_0010_1110_1101_1001_1100_0011
1010	0011_0101_0010_0010_1110_1101_1001_1100

Table 75r—(32,4)-Bit-to-chip mapping

0110	1100_0011_0101_0010_0010_1110_1101_1001
1110	1001_1100_0011_0101_0010_0010_1110_1101
0001	1000_1100_1001_0110_0000_0111_0111_1011
1001	1011_1000_1100_1001_0110_0000_0111_0111
0101	0111_1011_1000_1100_1001_0110_0000_0111
1101	0111_0111_1011_1000_1100_1001_0110_0000
0011	0000_0111_0111_1011_1000_1100_1001_0110
1011	0110_0000_0111_0111_1011_1000_1100_1001
0111	1001_0110_0000_0111_0111_1011_1000_1100
1111	1100_1001_0110_0000_0111_0111_1011_1000

6.12c.3.6 CA-CDM

CA-CDM is a spreading/coding method that can be used in bit-to-symbol mapping and symbol-to-chip mapping functions in Figure 65w. Incoming bit streams are converted to three parallel bit streams and are processed through the Hadamard modulation, odd parity encoding and spreading functions (see Figure 65y) sequentially, beginning with the PHR field and ending with the last octet of the PSDU.

The synchronization header (SHR) field, which includes preamble sequence and start of frame delimiter, does not pass through the Hadamard modulation/spreading functions but is spreaded using the predefined PN sequences for covering code in Table 75t, Table 75u, and Table 75v, respectively.

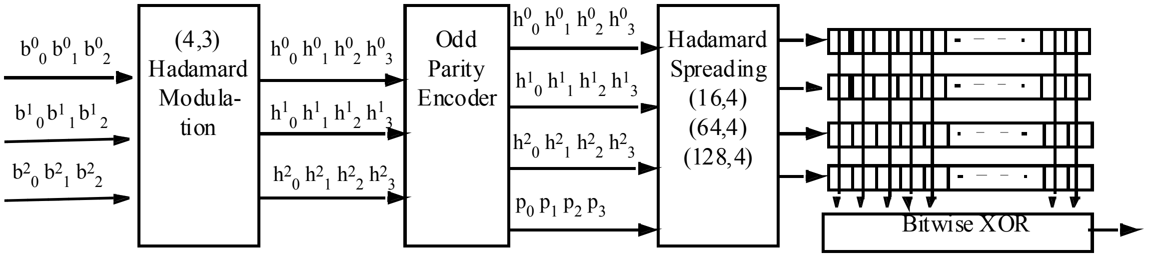


Figure 65y—Symbol to chip function of CA-CDM

.

PHY data	**Bits:0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**reserved**
CA-CDM	b^0_0	b^0_1	b^0_2	b^1_0	b^1_1	b^1_2	b^2_0	b^2_1	b^2_2

Figure 65z—Input data to CA-CDM

Within each octet of PHR and PPDU, the 3 LSBs (bit 0, 1, 2) shall map into the first data symbol ($b^{0}0$, $b^{0}1$, $b^{0}2$), the next 3 bits (bit 3, 4, 5) shall map into the next data symbol ($b^{1}0$, $b^{1}1$, $b^{1}2$), and the last 2bits (bit 6, 7) and one reserved bit shall map into the last data symbol($b^{2}0$, $b^{2}1$, $b^{2}2$) as illustrated in Figure 65z.

The 3 parallel 3-bit streams are converted to 3 parallel 4-bit streams through the (4,3) Hadamard modulator, known as the first order Reed-Mullar code, as illustrated in Table 75s. The odd parity encoder converts the 3 parallel 4-bit streams to 4 parallel 4-bit streams, including odd parity bits. Then the 4 parallel 4-bit streams are spreaded by 16/64/128 chip sequences depending on the spreading code of Table 1a using the Hadamard spreading module.

The logical expression of odd parity encoder is as follows.

$$p_0 = \overline{b^0{}_0 \oplus b^1{}_0 \oplus b^2{}_0}$$

$$p_1 = \overline{b^0{}_1 \oplus b^1{}_1 \oplus b^2{}_1}$$

$$p_2 = \overline{b^0{}_2 \oplus b^1{}_2 \oplus b^2{}_2}$$

The 4 parallel bit streams, passed through the Hadamard modulator/spreader, are bitwise XORed to make multiplexed output stream. Combination of the odd parity check code and the Hadamard modulation, the multiplexed output data streams have constant-amplitude. Finally the output data streams are multiplied by the covering code described in Table 75t, Table 75u and Table 75v for chip and symbol synchronization.

Table 75s—Symbol-to-chip mapping for (4,3) Hadamard modulation

Data symbol (decimal)	**Data symbol (b_0 b_1 b_2)**	**Chip values (c_0 c_1 c_2 c_3)**
0	0 0 0	1 1 1 1
1	0 0 1	1 0 1 0
2	0 1 0	0 0 1 1
3	0 1 1	0 1 1 0
4	1 0 0	1 0 0 1
5	1 0 1	1 1 0 0
6	1 1 0	0 1 0 1
7	1 1 1	0 0 0 0

The preamble of CA-CDM for (16,8), (64,8) and (128,8) is generated by repeating the covering code 4 times using Table 75t, Table 75u, and Table 75v, respectively. The resulting preamble duration is illustrated in Table 26. The leftmost chip number “0” in the diagram, with a value of “–1”, is transmitted first.

The SFD of CA-CDM for (16,8), (64,8) and (128,8) is the inverted covering code from Table 75t, Table 75u and Table 75v, respectively.

Table 75t—Covering code for 16 chip sequence

Covering code (c_0 c_1 … c_{14} c_{15})	Note
0 0 1 1 1 1 1 0 0 0 1 0 0 1 0 1	Data symbol 0 in Table 75j. (Table 37 of IEEE802.15.4-2006)

Table 75u—Covering code for 64 chip sequence

Covering code (c_0 c_1 … c_{62} c_{63})	Note
1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1	Data symbol [0‖8] in Table 75k. (Table 24 of IEEE802.15.4-2006)

Table 75v—Covering code for 128 chip sequence

Covering code (c_0 c_1 … c_{126} c_{127})	Note
1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0	Data symbol [0‖4‖8‖12] in Table 75k. (Table 24 of IEEE802.15.4-2006)

6.12c.3.7 Chip whitening

For improved signal properties of the modulated signal, the chip sequences shall be whitened, depending on the frequency band and *RateMode* as shown in Table 75w. For all other modes, no whitening shall be applied.

Chip whitening is the modulo-2 addition (addition over GF(2)) of a chip of the PSDU part at the output of the bit-to-chip mapper with the value of a cyclic m-sequence $S_{(k \bmod (2^m-1))}$ of length 2^m-1 for $m = 9$. This shall be performed by the transmitter and is described by Equation (27):

$$c'_k = c_k \oplus S_{(k \bmod 511)} \tag{27}$$

Table 75w—Chip Whitening

Frequency band (MHz)	RateMode
778-780	2,3
863-870	0,1
902-928	2,3
2400-2483.5	2,3

where

c_k is the raw PSDU chip being whitened
c'_k is the whitened chip.

Index k starts at 0, referring to the first chip of the PSDU part at the output of the bit-to-chip mapper and is increased by one at every chip interval. Figure 65aa shows the whitening process. At $k = 0$, the register shall be initialized with

$$(u_{k-1}, u_{k-1}, \ldots, u_{k-9}) = (1, 0, 0, 0, 0, 0, 0, 0, 0) \tag{28}$$

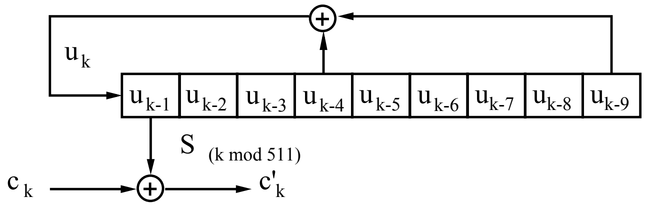


Figure 65aa—Chip whitening

6.12c.3.8 Chip pre-coding

Prior to passing the chip values to the modulator, the chip values are appropriately pre-coded which simplifies demodulation. Let $\{c_k\}$ be the chip sequence of the input to the pre-coder.

For O-QPSK modulation, the chip sequence $\{c_k\}$ shall be pre-coded by

$$c'_k = \begin{cases} c_k, \operatorname{mod}(k, 4) \in \{0, 1\} \\ \neg c_k, \operatorname{mod}(k, 4) \in \{2, 3\} \end{cases} \tag{29}$$

where $\neg$ is negation over GF(2).

For GMSK modulation, the chip sequence $\{c_k\}$ shall be pre-coded by

$$c'_k = c_k \oplus c_{k-1} \text{ with } c_{-1} = 0 \tag{30}$$

where $\oplus$ is addition over GF(2).

6.12c.3.9 Chip-to-symbol mapping

A chip value shall be mapped into a binary real valued symbol out of {-1,1} by the mapping

$$\zeta(c) = \begin{cases} -1, & c = 0 \\ 1, & c = 1 \end{cases} \tag{31}$$

6.12c.3.10 Modulation parameters for O-QPSK

The raised cosine pulse shape with roll-off factor of $r = 0.8$ is used to represent each baseband symbol and is described by

$$p(t) = \begin{cases} \dfrac{\sin(\pi t/T_c)}{\pi t/T_c} \times \dfrac{\cos(r\pi t/T_c)}{1 - 4r^2t^2/T_c^2}, & t \neq 0 \\ 1, & t = 0 \end{cases} \tag{32}$$

where the chip duration T_c is the inverse of the chip rate, see Table 75h.

Given the discrete-time sequence $\{c'_k\}_0^{N_{PPDU}-1}$ of N_{PPDU} consecutive chip samples at the output of the chip pre-coder, the continuous-time pulse shaped complex baseband signal is given by

$$y_{OQPSK}(t) = \sum_{k=0}^{N_{PPDU}-1} \zeta(c'_{2k})p(t-2kT_c) + j\zeta(c'_{2k+1})p(t-2kT_c-T_c) \tag{33}$$

with ζ according to Equation (31). Due to pre-coding according to Equation (29):

$$y_{OQPSK}(t) = \sum_{k=0}^{N_{PPDU-1}} \zeta(c_k)\, j^k p(t-kT_c) \tag{34}$$

where the sequence $\{c_k\}_0^{N_{PPDU}-1}$ refers to the chip sequence at the input to the pre-coder.

6.12c.3.11 Modulation parameters for GMSK

Gaussian Minimum Shift Keying (GMSK) can be co-alternatively applied, which can be beneficial for transmitter design and power efficiency of battery-run devices.

Devices employing GMSK instead of raised cosine shaped O-QPSK shall comply with the regulations of the corresponding frequency band.

Given the discrete-time sequence $\{c'_k\}_0^{N_{PPDU}-1}$ of N_{PPDU} consecutive chip samples at the output of the chip pre-coder, the complex baseband signal is

$$y_{GMSK}(t) = \exp\left(j2\pi h \sum_{k=0}^{N_{PPDU}-1} \zeta(c'_k) \int_{-\infty}^{t-kT_c} g(\tau)d\tau\right) \tag{35}$$

where the chip duration T_c is the inverse of the chip rate, $h = 1/2$ is the modulation index and g is the Gaussian pulse given by

$$g(t) = \frac{1}{2}\mathrm{erf}\left(\gamma\left(\frac{t}{T}+\frac{1}{2}\right)\right) - \frac{1}{2}\mathrm{erf}\left(\gamma\left(\frac{t}{T}-\frac{1}{2}\right)\right) \quad (36)$$

with $T = T_c$, $\gamma = \sqrt{\frac{2}{\ln 2}}\pi BT$ and $\mathrm{erf}(t) = \frac{2}{\sqrt{\pi}}\int_0^t \exp(-\tau^2)d\tau$. The factor BT shall be equal to 0.5.

The nominal deviation is $\frac{1}{2T_c}$.

The actual deviation shall be between 70% and 130% of the nominal deviation. For the chip sequence {...0101...}, the deviation shall be between 70% and 110% of the nominal deviation. For the chip sequence {....00001111...}, the deviation shall be between 80% and 130% of the nominal deviation.

Pre-coding according to Equation (30) can be motivated as follows. It is known that a GMSK signal given in Equation (35) with $BT \geq 0.5$ can be well approximated by

$$y_{GMSK}(t) \approx \sum_k \zeta(d_k)\, j^k h_0(t-kT_c) \quad (37)$$

where

$$d_k = d_{k-1} \oplus c'_k \quad (38)$$

and h_0 refers to the main Laurent impulse relating to the Gaussian impulse g. The transformation of Equation (30) removes the recursive part according to Equation (38), so that the transmit signal is just a frequency shifted BPSK signal of the sequence $\{\zeta(c_k)\}$:

$$y_{GMSK}(t) \approx \sum_k \zeta(c_k)\, j^k h_0(t-kT_c) \quad (39)$$

Since the influence of inter chip interference caused by h_0 is small for $BT = 0.5$, no particular a priori knowledge of the modulation type is required on the receiver side, i.e. devices employing either O-QPSK or GMSK modulation are interoperable.

6.12c.3.12 Forward error correction (FEC)

Forward error correction coding shall be employed on the PSDU bits, applying 1/2 rate convolutional coding with constraint length $K = 7$ using the generator polynomials shown in Equation (40) and Equation (41).

$$G_0(x) = 1 + x^2 + x^3 + x^5 + x^6 \quad (40)$$

$$G_1(x) = 1 + x + x^2 + x^3 + x^6 \quad (41)$$

The encoder is shown in Figure 65ab where addition is over GF(2).

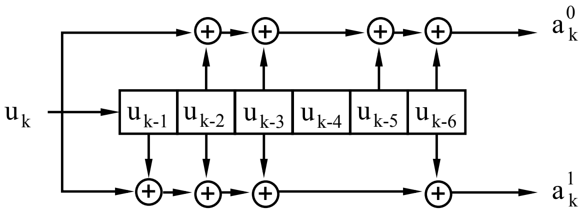


Figure 65ab—Convolutional encoder

Prior to convolutional encoding, the PSDU shall be extended by appending a termination sequence of 6 zero bits as shown inFigure 65ac.

PSDU	000000

Figure 65ac—PSDU extension prior to encoding

The output sequence of code bits *z* shall be generated according to Equation (42):

$$z = \{\ldots\ a_k^0, a_k^1, a_{k+1}^0, a_{k+1}^1, a_{k+2}^0, a_{k+2}^1\ \ldots\} \tag{42}$$

6.12c.3.13 Code-bit-interleaving

<editor's note: A detailed description of the interleaver is subject to further investigation.>

Interleaving of code bits shall be employed in order to improve robustness against burst errors, especially in conjunction with (*N*,4)-type bit-to-chip mapping[2].

Table 75x shows the maximum interleaver depth N_I^{max} of code bits for each frequency band. For a PSDU length L_{PSDU} less than $\frac{1}{16}N_I^{max}$ octets, the interleaver depth is reduced to $16L_{PSDU}$.

Table 75x—Maximum interleaver depth

Frequency band (MHz)	**Maximum interleaver depth N_I^{max} (number of code bits)**
779-787	256
863-870	128
902-928	256
2400-2483.5	256

---

[2] A misdetection based on (*N*,4)-type bit-to-chip mapping causes a burst of up to 4 erroneous code bits being passed to the outer FEC.

6.12c.4 Radio specification

6.12c.4.1 Clock offset tolerance

The clock offset tolerance shall be less or equal to ± 20 ppm. Carrier frequency offset and symbol timing drift due to clock offset shall be locked.

6.12c.4.2 Receiver sensitivity

Under the conditions specified in 6.1.7, a compliant device shall be capable of achieving a sensitivity of the values given in Table 75y or better.

Table 75y—Required receiver sensitivity [dBm]

Frequency band (MHz)	***RateMode***			
	0	1	2	3
779-787	-105	-100	-95	-90
863-870	-105	-100		
902-928	-105	-100	-95	-90
2400-2483.5	-105	-100	-95	-90

6.12c.4.3 Adjacent channel rejection

The interference-to-signal ratio (ISR) is the maximum ratio of the signal power of an interferer relative to the signal power of the desired signal that leads to a frame error rate (FER) less than 0.01. The adjacent channel rejection shall be measured as follows: the desired signal shall be a compliant signal of this PHY, of pseudo-random PSDU data. The desired signal is input to the receiver at a level 3 dB above the maximum allowed receiver sensitivity given in Table 75y.

The interfering signal shall be a compliant signal of this PHY with:

pseudo-random PSDU

the same chip rate as the as the desired signal

chip-whitening enabled

O-QPSK modulation

The interferer is separated in frequency by $|\Delta f|$ from the carrier frequency of the desired channel with a minimum ISR as shown in Table 75z. The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 6.1.7, under these conditions.

Table 75z—Minimum interference-to-signal ratio (ISR) depending on $|\Delta f|$

frequency band (MHz) 779-787	$|\Delta f|$ (MHz)	1.0	2.0
	ISR (dB)	0	25
frequency band (MHz) 863-870	$|\Delta f|$ (MHz)	0.25	0.5
	ISR (dB)	0	20
frequency band (MHz) 902-928	$|\Delta f|$ (MHz)	2.0	4.0
	ISR (dB)	0	30
frequency band (MHz) 2400-2483.5	$|\Delta f|$ (MHz)	2.0	4.0
	ISR (dB)	0	30

6.13 General radio specifications

6.13.1 TX-to-RX turnaround time

6.13.2 RX-to-TX turnaround time

Insert the following paragraph at the end of 6.13.2:

In the case of the MRFSK PHY, the RX-to-TX turnaround time is defined as the shortest time possible at the air interface from the trailing edge of the last symbol of a received PPDU to the leading edge of the first symbol of the next transmitted PPDU. The RX-to-TX turnaround time shall be less than or equal to 1 ms.

In the case of the SUN DSSS PHY, the RX-to-TX turnaround time is defined as the shortest time possible at the air interface from the trailing edge of the last symbol of a received PPDU to the leading edge of the first symbol of the next transmitted PPDU. The RX-to-TX turnaround time shall be less than or equal[3] to *aSUN_DSSS_PHY_TurnaroundTime*.

6.13.3 Error-vector magnitude (EVM) definition

Insert the following paragraph before the first paragraph in 6.13.3:

This subclause does not apply to the MRFSK PHY.

This subclause does not apply to the SUN DSSS PHY if GMSK is the only supported modulation.

Change the last paragraph of 6.13.3 as indicated:

With the exception of the UWB PHY transmitter as described in 6.12, ~~and~~ the CSS PHY transmitter as described in 6.6, and the OFDM PHY transmitter as described in 6.12b, a transmitter shall have EVM values of less than 35% when measured for 1000 chips. The error-vector measurement shall be made on baseband I and Q chips after recovery through a reference receiver system. The reference receiver shall perform carrier lock, symbol timing recovery, and amplitude adjustment while making the measurements.

---

[3] In addition to power ramp up time, the processing delay due to (Viterbi) decoding of the convolutional code seems to be most relevant for this time. The proposed time of 1 ms implies very relaxed requirements to the signal processing part of the decoder.

6.13.4 Transmit center frequency tolerance

6.13.5 Transmit power

6.13.6 Receiver maximum input level of desired signal

Change the first paragraph of 6.13.6 as indicated:

The receiver maximum input level is the maximum power level of the desired signal present at the input of the receiver for which the error rate criterion in 6.1.7 is met. A receiver shall have a receiver maximum input level greater than or equal to –20 dBm with the exception of a UWB receiver, which shall have a maximum input level greater than or equal to –45 dBm/MHz, and an OFDM receiver, which shall provide a maximum PER of 10% at a PSDU length of 1000 bytes.

Receiver maximum input level of desired signal: -10 dBm up to 0 dBm

6.13.7 Receiver ED

6.13.8 Link quality indicator (LQI)

Change the first paragraph of 6.13.8 as indicated:

The LQI measurement is a characterization of the strength and/or quality of a received packet. The measurement may be implemented using receiver ED, a signal-to-noise ratio estimation, RSSI, or a combination of these methods. The use of the LQI result by the network or application layers is not specified in this standard.

Insert the following paragraph at the end of 6.13.8:

If RSSI is used, it should be implemented as a monotonic variable with at least 3dB resolution and a minimum of 50 dB, covered with an 8-bit field.

Link quality indicator (LQI): RSSI + per-hop packet loss ratio.

6.13.9 Clear channel assessment (CCA)

Insert the following new subclauses after 6.13.9:

6.13.9a Channel to channel slew times (per band) (max)

The channel switch time shall not exceed 500 µs.

6.13.9b Transmit and power amplifier rise and fall times (max)

The power amplifier rise and fall times shall not exceed 100 µs.

7. MAC sublayer specification

The text in Clause 7 originates from a single submission, with the exception of some of the FSC text in 7.2.1.9. The part of the text originating from two different submissions is differentiated using two colors.

Insert the following text at the end of the dashed list in 7:

- Synchronizing to support MAC frequency hopping (optional)
- Channel selection for MAC frequency hopping control (optional)
- Link quality assessment
- Enforcing regulatory constraints, including channel occupancy limits and channel visit requirements
- Providing a reliable link between peer MAC entities, achieved with packet acknowledgements and retransmissions

7.1 MAC sublayer service specification

7.1.1 MAC data service

7.1.2 MAC management service

7.2 MAC frame formats

7.2.1 General MAC frame format

Replace Figure 79 with the following figure:

Octets: 2	**1**	**0/2**	**0/2/8**	**0/2**	**0/2/8**	**0/5/6/10/14**	**variable**	**2/4**
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
		Addressing fields						
MHR							MAC Payload	MFR

Figure 79—General MAC frame format

7.2.1.1 Frame Control field

7.2.1.2 Sequence Number field

7.2.1.3 Destination PAN Identifier field

7.2.1.4 Destination Address field

7.2.1.5 Source PAN Identifier field

7.2.1.6 Source Address field

7.2.1.7 Auxiliary Security Header field

7.2.1.8 Frame Payload field

7.2.1.9 FCS field

Change the first paragraph of 7.2.1.9 as indicated:

The FCS field ~~is~~ may be either 2 or 4 octets in length and contains a 16-bit ITU-T CRC or a 32-bit CRC (equivalent to ANSI X3.66-1979), respectively. The FCS is calculated over the MHR and MAC payload parts of the frame.

Insert the following paragraph after the first paragraph in 7.2.1.9:

If data whitening is employed, the FCS is calculated prior to scrambling; on reception, the FCS is calculated after de-scrambling.

Change the second paragraph of 7.2.1.9 as indicated:

The 2-octet FCS shall be calculated using the following standard generator polynomial of degree 16:

Change the third paragraph of 7.2.1.9 as indicated:

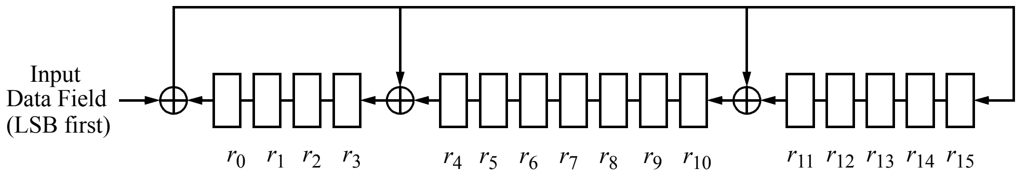
The 2-octet FCS shall be calculated for transmission using the following algorithm:

Change the sixth paragraph as indicated:

The 2-octet FCS for this case would be the following:

Replace Figure 81 as indicated:

CRC-16 Generator Polynomial: $G(x) = x^{16} + x^{12} + x^5 + 1$



1. Initialize the remainder register (r_0 through r_{15}) to zero.
2. Shift MHR and payload into the divider in the order of transmission (LSB first).
3. After the last bit of the data field is shifted into the divider, the remainder register contains the FCS.
4. The FCS is appended to the data field so that r_0 is transmitted first.

Figure 81—Typical 2-octet FCS implementation

Insert the following paragraphs at the end of 7.2.1.9:

Two generator polynomials are suggested for the 32-bit FSC option.

The CRC is used over the PSDU (i.e., MPDU). The CRC to be used is a 32K (Koopman).

The generator polynomial shall be as shown in the following equation:

$$G_{32}(x) = x^{32} + x^{30} + x^{29} + x^{28} + x^{26} + x^{20} + x^{19} + x^{17} + x^{16} + x^{15} + x^{11} + x^{10} + x^{7} + x^{6} + x^{4} + x^{2} + x + 1 \quad (43)$$

The 4-octet FCS is calculated using the following standard generator polynomial of degree 32:

$$G_{32}(x) = x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^{8} + x^{7} + x^{5} + x^{4} + x^{2} + x + 1 \quad (44)$$

The 4-octet FCS is the one's complement of the modulo 2 sum of the two remainders in a) and b):

a) The remainder resulting from [(xk*(x^{31}+x^{30}+...)] divided (modulo 2) by $G_{32}(x)$, where the value *k* is the number of bits in the calculation field.

b) The remainder resulting from the calculation field contents, treated as a polynomial, is multiplied by x^{32} and then divided by $G_{32}(x)$.

At the transmitter, the initial remainder of the division shall be preset to all ones and then modified via division of the calculation field by the generator polynomial $G_{32}(x)$. The one’s complement of this remainder is the 4-octet FCS field.

At the receiver, the initial remainder shall be preset to all ones. The serial incoming bits of the calculation field and FCS, when divided by $G_{32}(x)$ in the absence of transmission errors, result in a unique non-zero remainder value. The unique remainder value is the polynomial shown in Equation (45):

$$x^{31}+x^{30}+x^{26}+x^{25}+x^{24}+x^{18}+x^{15}+x^{14}+x^{12}+x^{11}+x^{10}+x^{8}+x^{6}+x^{5}+x^{4}+x^{3}+x+1 \qquad (45)$$

7.2.2 Format of individual frame types

7.2.2.1 Beacon frame format

Replace Figure 82 with the following figure:

Octets: 2	1	4/10	0/5/6/10/14	2	variable	variable	variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Superframe Specification	GTS fields (Figure 83)	Pending address fields (Figure 84)	Beacon Payload	FCS
MHR				MAC Payload				MFR

Figure 82—Beacon frame format

7.2.2.2 Data frame format

Replace Figure 90 with the following figure:

Octets: 2	1	(see 7.2.2.2.1)	0/5/6/10/14	variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Data Payload	FCS
MHR				MAC Payload	MFR

Figure 90—Data frame format

7.2.2.3 Acknowledgment frame format

Replace Figure 91 with the following figure:

Octets: 2	1	2/4
Frame Control	Sequence Number	FCS
MHR		MFR

Figure 91—Acknowledgment frame format

7.2.2.4 MAC command frame format

Replace Figure 92 with the following figure:

Octets: 2	1	(see 7.2.3)	0/5/6/10/14	1	variable	2/4
Frame Control	Sequence Number	Addressing fields	Auxiliary Security Header	Command Frame Identifier	Command Payload	FCS
MHR				MAC Payload		MFR

Figure 92—MAC command frame format

7.2.3 Frame compatibility

7.3 MAC command frames

7.4 MAC constants and PIB attributes

7.5 MAC functional description

Annex G

(informative)

Regulatory requirements

The changes to this annex originate from one submission.

G.1 IEEE Std 802.15.4

G.1.1 Introduction

G.1.2 Applicable U.S. (FCC) rules

G.1.2.1 Section 15.35 of FCC CFR47

G.1.2.2 Section 15.209 of FCC CFR47

G.1.2.3 Section 15.205 of FCC CFR47

G.1.2.4 Section 15.247 of FCC CFR47

Insert the following paragraphs at the end of G.1.2.4:

Frequency hopping systems within the bands of 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz have hopping channel carrier frequencies separated by a minimum of 25 kHz or the 20 dB bandwidth of the hopping channel, whichever is greater.

For frequency hopping systems operating in the 902–928 MHz band, if the 20 dB bandwidth of the hopping channel is less than 250 kHz, the system will use at least 50 hopping frequencies and the average time of occupancy on any frequency will not be greater than 0.4 seconds within a 20 second period. If the 20 dB bandwidth of the hopping channel is 250 kHz or greater, the system will use at least 25 hopping frequencies and the average time of occupancy on any frequency will not be greater than 0.4 seconds within a 10 second period. The maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz.

Frequency hopping systems operating in the 2400–2483.5 MHz band use at least 15 non-overlapping channels. The average time of occupancy on any channel cannot be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems which use fewer than 75 hopping frequencies may employ intelligent hopping techniques to avoid interference to other transmissions. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 non-overlapping channels are used.

The maximum peak output power of the intentional radiator cannot exceed the following:

- For frequency hopping systems in the 2400-2483.5 MHz band employing at least 75 hopping channels, and all frequency hopping systems in the 5725-5850 MHz band, the maximum is 1 W. For all other frequency hopping systems in the 2400-2483.5 band, the maximum is 0.125 W.
- For frequency hopping systems operating in the 902-928 MHz band, the maximum is 1 W for systems employing at least 50 hopping channels. The maximum is 0.25 W for systems employing less than 50 hopping channels but at least 25 hopping channels.

Insert after Annex L the following new annex (Annex M):

Annex M

(informative)

Band Adaptation Considerations

This annex originates from one submission.

M.1 Introduction

The following text provides detailed information on channel numbering for individual frequency bands using the guidelines described in 6.1.2.

M.2 902–928 MHz

In the 902–928 MHz band, the channel center frequencies are computed using Equation (1), where n is the channel number. A channel spacing of 300 kHz is used.

$$902.3 + (n \times 0.3)\text{, for } n = 0,...84 \qquad (1)$$

The center frequencies for each channel in the 900 MHz band are shown in Table M.1.

Table M.1—900 MHz band channel assignment

0:902.30	10:905.30	.	63:921.20	76:925.10
1:902.60	11:905.60	.	64:921.50	77:925.40
2:902.90	12:905.90	.	65:921.80	78:925.70
3:903.20	13:906.20	.	66:922.10	79:926.00
4:903.50	14:906.50	.	67:922.40	80:926.30
5:903.80	15:906.80	.	68:922.70	81:926.60
6:904.10	16:907.10	.	69:923.00	82:926.90
7:904.40	17:907.40	.	70:923.30	83:927.20
8:904.70	18:907.70	.	71:923.60	84:927.50

M.3 2400–2483.5 MHz

In the 2400–2483.5 MHz band, the channel center frequencies are computed using Equation (2), where n is the channel number. A channel spacing of 300 kHz is used.

$$2400.3 + (n \times 0.3)\text{, for } n=0,...260 \qquad (2)$$

The center frequencies for each channel in the 2400 MHz band are included in Table M.2. A guard band of 5 MHz is allocated at the high end of this frequency band, to meet emission regulations associated with the restricted 2483.5 to 2500 MHz band.

Table M.2—2400 MHz band channel assignment

0:2400.30	.	258:2477.7
1:2400.60	.	259:2478.0
2:2400.90	.	260:2478.3

M.4 868–870 MHz

The center frequencies for each channel in the 868 MHz band are included in Table M.3. A channel spacing of 250 kHz is used.

Table M.3—868 MHz band channel assignment

0:868.15
1:868.45
2:868.825
3:869.075
4:869.525

Insert after Annex L the following new annex (Annex N):

Annex N

(normative)

The use of Format Change Frame in Multi-Rate Multi-Region FSK (MR2-FSK)

This annex originates from one submission.

N.1 Introduction

Format Change Frame (FCF) shall be used to switch from one data rate to another, as well as to change the PHY type (e.g., switching from the lowest FSK data rate to the middle and/or highest FSK data rate, switching from the FSK standard PHY to some legacy PHY, or switching from FSK PHY to the OFDM PHY).

The following subclauses describe the use of Format Change Frame.

N.2 Switching from the lowest data rate FSK to the middle and/or highest data rate FSK

N.2.1 Transmitter changes the PHY data rate from the mandatory data rate of 40 kbps to the middle and/or highest data rate

Octets						
variable	2	2				
Preamble	SFD	Header FEC1 (5 bits)	Legacy (1 bit)	Format change (1 bit)	Settling delay (1 bit)	Modulation/channel/data rate (8 bits)
SHR		PHR				

Figure N.1—Format of the MR2-FSK FCF

The transmitter shall take the following actions.

a) The transmitter shall build the Format Change Frame as follows (respecting the structure described in Figure N1):
   1) The transmitter sets the Legacy bit to 0.
   2) The transmitter shall set the Format Change bit to 1.
   3) The transmitter shall set the Settling Delay bit value to
      - A value of 0 if the delay required by the receiver to reconfigure its radio is the standard delay value.
      - A value of 1 if the delay required by the receiver to reconfigure its radio is less/bigger than the standard delay value.

    4) The transmitter shall encode information about PHY Parameters for the new data rate into the 8-bit field “Modulation/Channel/Data Rate” of Format Change Frame.This information is used by the receiver to reconfigure it radio and is standardized.

b) The transmitter shall send the Format Change Frame at the mandatory bit rate of 40 kbps and with the PHY parameters defined for this data rate.
c) The transmitter shall send the Format Change Frame respecting the signal flow as described in Clause 6, MR2-FSK signal flow diagrams.
d) The transmitter shall wait a (Settling Delay) time before sending the Normal Frame.
e) The transmitter shall build the Normal Frame with the following value for PHR fields (respecting the structure described in Figure N2):
    1) The Legacy bit shall be set to 0.
    2) The Format Change bit shall be set to 0.
    3) The transmitter shall set the remaining fields from the normal frame PHR as indicated by MAC primitives and/or PIB (see also Clause 6, Section MR2-FSK PPDU structure).
f) The transmitter shall send the Normal FRame at the bit rate indicated within the field “Modulation/Channel/Data rate” and respecting the signal flow described in Clause 6, MR2-FSK signal flow diagram.

N.2.2 Transmitter does not change the PHY data rate and transmits at the mandatory data rate of 40 kbps

The transmitter shall take the following actions:

a) The transmitter builds the Normal Frame as follows (respecting the structure described in Figure N2):
    1) The transmitter sets the Legacy bit to 0.
    2) The transmitter sets the Format Change Frame bit to 0.
    3) The transmitter sets the remaining fields from the normal frame PHR as indicated by MAC primitives and/or PIB.
b) The transmitter sends the Normal Frame following the PHY signal flow as described Clause 6, Section MR2-FSK signal flow diagram.
c) The transmitter sends the “Normal Frame” at the mandatory bit rate of 40 kbps and with the PHY Parameters defined for this data rate.

N.3 Switching from the standard MR2-FSK to a legacy PHY

The transmitter shall take the following actions:

a) The transmitter builds the Format Change Frame as follows (respecting the structure described in Figure 6.3.1):
    1) The transmitter sets the Legacy field bit to 1.
    2) The transmitter sets the Format Change field value to 0.
    3) The transmitter sets the Settling delay field value to:
        - A value of 0 if the delay required by the receiver to reconfigure its radio is a standard Settling Delay value.
        - A value of 1 if the delay required by the receiver to reconfigure its is smaller/bigger than the standard Settling Delay value.
    4) The transmitter encodes information about legacy PHY Parameters for the new data rate into the 8-bit field “Modulation/Channel/Data rate” of Format Change Structure. This information

is used by the receiver to reconfigure its radio. This information is defined by specific to a legacy system and is not standardized.

b) The transmitter sends the Format Change Frame at the mandatory bit rate of 40 kbps and with the PHY Parameters defined for this data rate.

c) The transmitter sends the Format change frame respecting the signal flow as described in Clause 6, Section MR2-FSK signal flow.

d) The transmitter waits the standard Settling Delay time before sending the legacy PHY frame.

e) The transmitter builds the legacy PHY frame with the structure defined by vendors, but not standardized.

f) The transmitter sends the legacy PHY frame at the bit rate indicated within the field “Modulation/Channel/Data rate” of Format Change frame. The transmission of the legacy PHY frame may or not respect the signal flow as described in Clause 6, Section MR2-FSK signal flow.

Octets								
variable	2	2						
Preamble	SFD	Header FEC1 (5 bits)	Legacy (1 bit)	Format change (1 bit)	PSDU FEC (optional) (2 bits)	Data whitening (1 bit)	RFU (2 bits)	Network ID (4 bits)
SHR		PHR (continued in Figure N.3)						

Figure N.2—Format of the MR2-FSK NF (continued in Figure N.3)

Octets		
2		variable
Header FEC2 (5 bits)	Frame length (11 bits)	PSDU
PHR (continuation)		PHY payload

Figure N.3— Format of the MR2-FSK NF (continuation)

N.4 Switching from MR2-FSK to a different PHY/modulation

The transmitter shall take the following actions:

a) The transmitter builds the Format Change Frame as follows (respecting the structure described in Figure N1):
    1) The transmitter sets the Legacy field bit to 0.
    2) The transmitter sets the Format Change field value to 1.
    3) The transmitter sets the Settling delay field value to:
        — A value of 0 if the delay required by the receiver to reconfigure its radio is a standard Settling Delay value.
        — A value of 1 if the delay required by the receiver to reconfigure its is smaller/bigger than the standard Settling Delay value.

    4) The transmitter encodes information about the new PHY Parameters into the 8-bit field “Modulation/Channel/Data rate” of Format Change Structure. This information is used by the receiver to reconfigure its radio and is standardized.

b) The transmitter sends the Format Change Frame at the mandatory bit rate of 40 kbps and with the PHY Parameters defined for this data rate.

c) The transmitter sends the “Format change frame” respecting the signal flow as described in Clause 6, Section MR2-FSK signal flow.

d) The transmitter builds the PHY frame with the structure defined by the new PHY/modulation.

e) The transmitter waits the Settling Delay time before sending the PHY frame at the new PHY/modulation.

f) The transmitter sends PHY frame at the bit rate indicated within the field “Modulation/Channel/Data rate” of Format Change frame. The transmission of the new PHY frame it with respect to the signal flow of the new PHY.

Insert after Annex L the following new annex (Annex O):

Annex O

(informative)

Supporting communication with legacy devices

This annex originates from one submission.

O.1 Introduction

Supporting legacy devices and not standing existing deployed equipment with the deployment of new standards compliant devices is an important issue that should be supported.

Providing standards compliment devices to effectively exploiting the new standard a method is introduced without reduction or constraint to performance.

It is recognized that some percentage of legacy systems will be able to benefit from the proposed system due to performance or hardware constraints.

The legacy support portion provides a standardized off ramp of standards compliant communication to accommodate non standard specified communication for legacy support.

O.2 Requirements for legacy system for support within MR2-FSK PHY

In order to benefit from the legacy support option, existing deployed devices must be firmware upgradable and would need to be compliment to a very basically minimal set of specifications set out in the standard. These requirements include:

a) To set 40 kbps data rate with 2 FSK modulation and a modulation index of 1.
b) To comply to the associated band plan and frequency channels.
c) Must be over-the-air upgradable.

It is not required for these devices to become full standard compliant. And it is foreseen that different frame structures and physical layer specifications can be utilized beyond the ad lib “Frame format” field.

If this option is utilized, the standards compliment devices will have the need to support these legacy protocol.

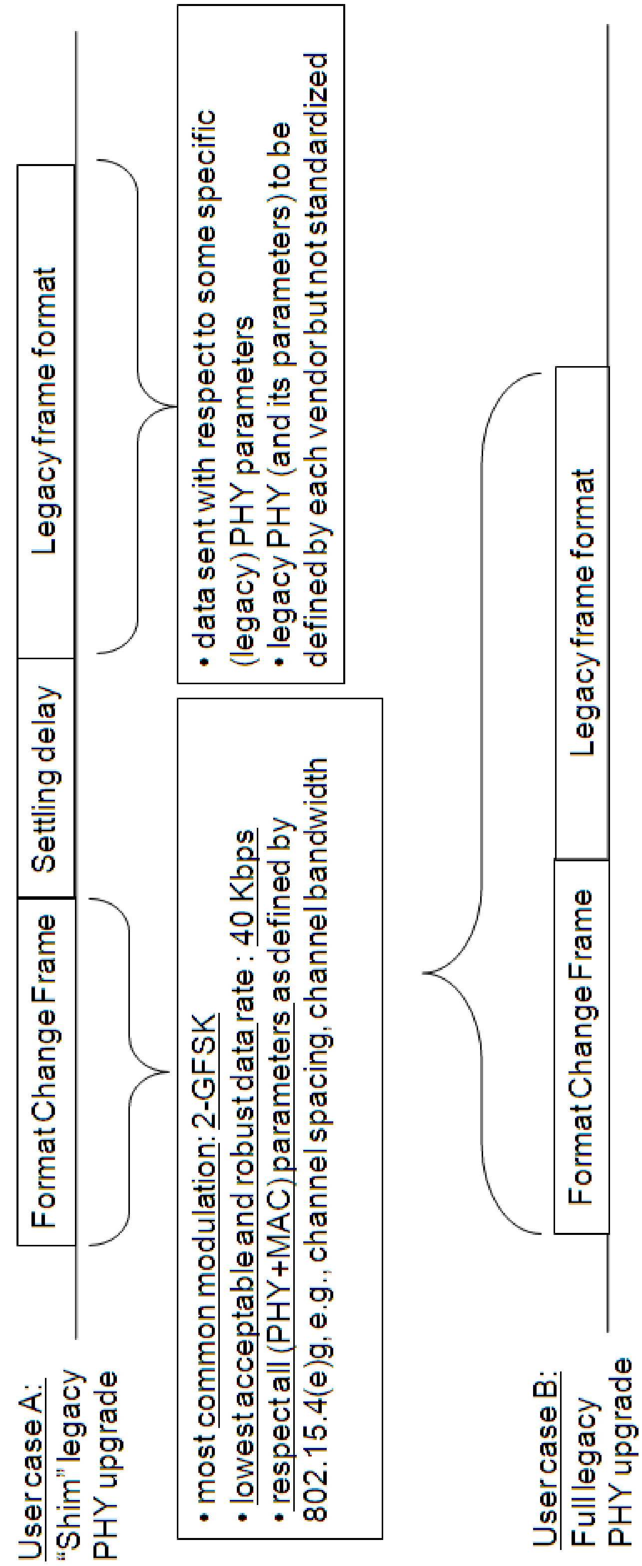
O.3 Methodology

The method of functioning of the legacy support system is explained in the following Figure O.1.

A legacy device have an upgraded protocol stack that enables transmissions starting with the Format Change Frame at the specified standardized physical layer parameters.

The dual-stack standards compliant device receives the Format Change Frame and recognizes the need to switch to a “new” PHY to support communication with legacy systems.

The legacy data is sent using the legacy device physical layer communication specification.



- most common modulation: 2-GFSK
- lowest acceptable and robust data rate : 40 Kbps
- respect all (PHY+MAC) parameters as defined by 802.15.4(e)g, e.g., channel spacing, channel bandwidth

- data sent with respect to some specific (legacy) PHY parameters
- legacy PHY (and its parameters) to be defined by each vendor but not standardized

Figure O.1—Two use cases for supporting communication with legacy devices

Once communication frame has been terminated standard devices revert to listening mode in P802.15.4g compliant mode.

Communication in the opposite direction is carried out in identical sequence.

Legacy devices that can support full upgrade to become standards compliant is a secondary use case (see Figure O.1, use case B). Here, the communication between legacy devices and standard devices is done as described in Annex N, Section N.2.2: "Transmitter does not change the PHY data rate and transmits at the mandatory data rate of 40 kbps".

O.4 Example of a flow decision tree to be implemented based on information from Frame Change Format

The flow diagram shown in Figure O.2 depicts an example of how a P802.15.4g compliant device will react in the presence of a legacy device solicitation passing a frame in legacy support mode

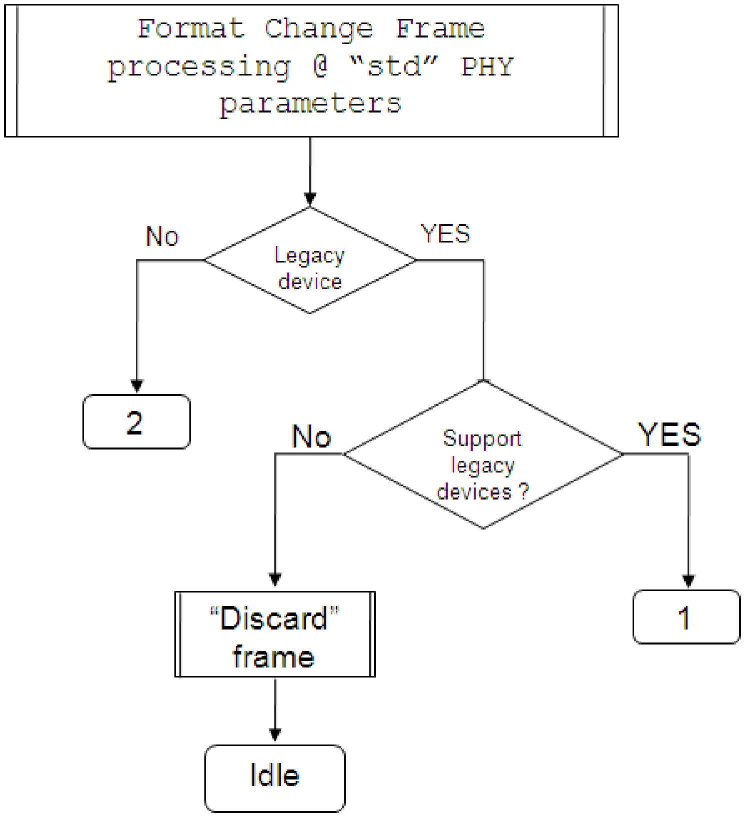


Figure O.2—Diagram with message processing as a function of Legacy bit value and support or not of the communication with legacy systems (continued in Figure O.3).

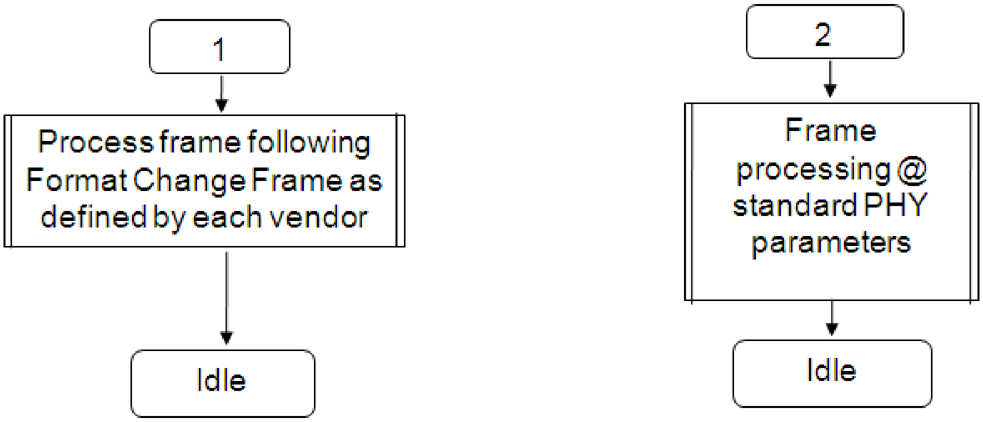


Figure O.3—Diagram with message processing as a function of Legacy bit value and support or not of the communication with legacy systems (continuation from Figure O.2).