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IEEE Standard for Low-Rate Wireless Networks

Amendment 4: Higher Rate (2 Mb/s) Physical (PHY) Layer

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.15.4t™-2017
(Amendment to
IEEE Std 802.15.4™-2015
as amended by IEEE Std 802.15.4n™-2016,
IEEE Std 802.15.4q™-2016, and IEEE Std 802.15.4u™2016

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Approved 14 February 2017

IEEE-SA Standards Board

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Abstract: This amendment defines a physical layer for IEEE Std 802.15.4™-2015, capable of supporting 2 Mb/s data rates, utilizing the 2400–2483.5 MHz band, having backwards-compatibility to, and the same occupied bandwidth as, the present 2450 MHz O-QPSK physical layer, and capable of simple implementation. Target range should be at least 10 meters. This amendment defines modifications to the medium access control (MAC) sublayer needed to support this new physical layer.

Keywords: ad hoc network, IEEE 802.15.4™, low data rate, low power, LR-WPAN, mobility, PAN, personal area network, radio frequency, RF, short range, wireless, wireless personal area network, WPAN

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Mineo Takai
Kou Togashi
Billy Verso
Gabriel Villardi
Brian Weis
Makoto Yaita
Peter Yee
Yu Zeng
Chunhui (Allan) Zhu

Major contributions were received from the following individuals:

Koorosh Akhavan
Monique B. Brown
Edgar Callaway
Hendricus de Ruijter
Paul Gorday
Clinton C Powell

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Introduction

This introduction is not part of IEEE Std 802.15.4t-2017, IEEE Standard for Low-Rate Wireless Networks, Amendment 4: Higher Rate (2 Mb/s) Physical (PHY) Layer.

This amendment defines an additional data rate for the minimum shift keying (MSK) PHY specified in IEEE Std 802.15.4-2015, and any MAC modifications needed to support its implementation.

The new data rate, 2000 kbps, is specified for the 2400–2483.5 MHz band, and has the same occupied bandwidth as the present 2450 MHz O-QPSK physical layer. This data rate enables the use of devices with low energy consumption that operate in short, high-speed bursts, followed by relatively long sleep periods, resulting in a low-rate network with improved battery life.

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Amendment 4: Higher Rate (2 Mb/s) Physical (PHY) Layer

NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.

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5. General description

5.6 Architecture

5.6.1 Physical layer (PHY)

Change the dashed list following the second paragraph of 5.6.1 as indicated:

Coexistence with other wireless standards has been analyzed for the PHYs defined in this standard. These analyses can be found in the following documents:

- For the O-QPSK PHY, BPSK PHY, ASK PHY, CSSS PHY, HRP UWB PHY, and GFSK PHY: "Coexistence analysis of IEEE Std 802.15.4 with other IEEE standards and proposed standards" [B5][1].
- For the MSK PHY, with the exception of the 2000 kb/s data rate, and the LRP UWB PHY: "TG4f Coexistence Assurance Document" [B17].
- For the MSK PHY using the 2000 kb/s data rate: "Coexistence Assurance Document for 802.15.4t" [BX].
- For TVWS-FSK PHY, TVWS-OFDM PHY, and TVWS-NB-OFDM PHY: Chang and Seibert [B4].
- For TASK PHY and RS-GFSK PHY: Nair et al. [B9b].

[1]The numbers in brackets correspond to the numbers of the bibliography in Annex A.

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6. MAC functional description

Change the title of 6.17 as indicated:

6.17 Using link margin IE ~~in an RS-GFSK PAN~~

Change the first and second paragraphs of 6.17 as indicated:

A device may include a~~n RS-GFSK~~ Link Margin IE within an enhanced acknowledgment. The ~~RS-GFSK~~ Link Margin IE shall only be transmitted as part of an Enh-Ack frame.

If a device receives an Enh-Ack frame containing a~~n RS-GFSK~~ Link Margin IE, it may adjust its transmit power within its power control range in all following GTS transmissions directed to the originating device. The transmit power control shall ignore the ~~RS-GFSK~~ Link Margin IE when the device is transmitting non-GTS frames. If a device supports more than one data rate, a higher layer may use the information contained in the Link Margin IE to determine that the link margin is sufficient to support a higher data rate. The ~~RS-GFSK~~ Link Margin IE is described in 7.4.4.32.

Change the fourth and fifth paragraphs of 6.17 as indicated:

The algorithm that controls the transmission of the ~~RS-GFSK~~ Link Margin IE and the algorithm that acts on the reception of the ~~RS-GFSK~~ Link Margin IE are outside the scope of this standard.

If the security level, as described in 9.4.1.1, of the incoming Enh-Ack frame containing the ~~RS-GFSK~~ Link Margin IE is lower than that of the frame being acknowledged, then the ~~RS-GFSK~~ Link Margin IE shall be ignored.

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7. MAC frame formats

7.2 General MAC frame format

7.2.10 FCS field

Change the first paragraph of 7.2.10, including breaking the paragraph into two separate paragraphs, as indicated, and add the following new paragraph:

The FCS field contains a 16-bit ITU-T CRC or a 32-bit CRC equivalent to ANSI X3.66-1979. The FCS is calculated over the MHR and MAC payload parts of the frame; these parts together are referred to as the calculation field.

Devices compliant with one or more of the SUN PHYs or TVWS PHYs shall implement the 4-octet FCS.

Devices compliant with the MSK PHY implementing the 2000 kb/s data rate shall implement both the 2-octet and 4-octet FCS, as indicated by the contents of the Extended PHR field described in 18.1.2. If the Extended PHR field is set to one, the 4-octet FCS shall be used; if the Extended PHR field is set to zero, the 2-octet FCS shall be used.

7.4 IEs

7.4.4 Nested IE

7.4.4.1 Format of nested IE

Change Table 7-16 as indicated (the entire table is not shown):

Table 7-16—Sub-ID allocation for short format

Sub-ID value	Name	Enhanced Beacon	Enhanced ACK	Data	Multipurpose	MAC command	Format subclause	Use description	Used by	Created by
0x37	~~RS GFSK~~ Link Margin IE		X				7.4.4.32	6.17	UL, MAC	UL, MAC
0x39	Multi-PHY IE	X	X	X	X		7.4.4.34	18.2a	UL	UL
~~0x39~~0x3a–0x7f	Reserved									

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Change the title and first paragraph of 7.4.4.32 and the title of Figure 7-101a as indicated:

7.4.4.32 ~~RS-GFSK~~ Link Margin IE

The ~~RS-GFSK~~ Link Margin IE is optional and shall only be used in Enh-Ack frames ~~that use the RSGFSK-PHY~~. The IE Content field of the ~~RS-GFSK~~ Link Margin IE shall be formatted as illustrated in Figure 7-101a.

Figure 7-101a—~~RS-GFSK~~ Link margin IE content field format

Change the equation in 7.4.4.32 as indicated:

$$\text{Link Margin} = S_{\text{received}} - S_{\underline{\text{sensitivity}}}$$

where

S_{received} is the received power, in dBm, during a frame as measured in the receiver.

$S_{\underline{\text{sensitivity}}}$ is the ~~receiver sensitivity as specified in 32.4.3~~ lowest input power required by the receiver, for the PHY that was used during the received frame. The conditions at which the lowest input power is determined are as follows: the packet error rate (PER) is 1%, and each packet in the PER measurement has a PSDU containing random data with a length of 250 octets.

Change the third and fourth paragraphs of 7.4.4.32 as indicated:

~~S_{received} shall be obtained with an accuracy of equal to or less than ± 6 dB.~~ The accuracy of S_{received} and $S_{\underline{\text{sensitivity}}}$ is left to the implementer.

For example, if ~~the~~a frame is received ~~power is –71 dBm while receiving a frame transmitted in MCS 2 with FEC disabled~~ with $S_{\text{received}} = -72$ dBm and the receive sensitivity ($S_{\underline{\text{sensitivity}}}$) is –102 dBm, then ~~this frame~~ the subsequent Enh-Ack frame may have the ~~RS-GFSK~~ Link Margin IE included ~~in a subsequent Enh-Ack frame~~ with the link margin field set to ~~2~~30 dB.

7.4.4.33 RS-GFSK device capabilities IE

Change the sixth paragraph of 7.4.4.33 as indicated:

The Link Margin field in Figure 7-101c shall be set to one if acting on the ~~RS-GFSK~~ Link Margin IE, as described in 6.17, is supported and shall be set to zero otherwise. When the Link Margin field is set to one, the device shall be responsive to the received ~~RS-GFSK~~ Link Margin IE as described in 7.4.4.32, when its control range allows.

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Insert the following subclause 7.4.4.34 after 7.4.4.33:

7.4.4.34 Multi-PHY IE

The Multi-PHY IE is optional. The IE Content field of the Multi-PHY IE shall be formatted as illustrated in Figure 7-101d.

Bits: 0	1	2–7
2450 MHz band, 250 kb/s O-QPSK PHY	2450 MHz band, 2000 kb/s MSK PHY	Reserved

Figure 7-101d—Multi-PHY IE content field format

The value of the field shall be set to one when the device sending the IE supports the corresponding PHY, and shall be set to zero otherwise.

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8. MAC services

8.2 MAC management service

8.2.1 Primitives supported by the MLME-SAP interface

Add the following new row to Table 8-1 (the entire table is not shown) as indicated, in alphabetical order by name:

Table 8-1—Summary of the primitives accessed through the MLME-SAP

Name	Request	Indication	Response	Confirm
MLME-PHY-DETECT		8.2.5.4*		

8.2.5 Communications notification primitives

Change the second paragraph of 8.2.5 as indicated:

The MLME-BEACON-NOTIFY.indication primitive is used to notify the next higher layer when a beacon or enhanced beacon is received during normal operating conditions. The MLME-COMMSTATUS.indication primitive is used to notify the next higher layer that an error has occurred during the processing of a frame that was instigated by a response primitive. The MLME-PHY-DETECT.indication primitive is used to notify the next higher layer that the 250 kb/s O-QPSK PHY has been detected during operation of the 2000 kb/s, 2450 MHz MSK PHY.

Add the following new subclause 8.2.5.4, including Table 8-14a, after 8.2.5.3 as indicated:

8.2.5.4 MLME-PHY-DETECT.indication

The MLME-PHY-DETECT.indication primitive is used to inform the next higher layer that the 250 kb/s O-QPSK PHY has been detected.

The semantics of this primitive are as follows:

```
MLME-PHY-DETECT.indication      (
                                CurrentPHY
                                )
```

The primitive parameter is defined in Table 8-14a.

Table 8-14a— MLME-PHY-DETECT.indication parameter

Name	Type	Valid range	Description
CurrentPHY	Enumeration	MSK_PHY_2000	PHY used when 250 kb/s O-QPSK PHY is detected.

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10. General PHY requirements

10.1 General requirements and definitions

10.1.2 Channel assignments

10.1.2.2 Channel numbering for 868 MHz, 915 MHz, and 2450 MHz bands

Change the first paragraph of 10.1.2.2 as indicated:

This subclause does not apply to the SUN PHY, ~~or~~ LECIM PHY, or MSK PHY specifications. For explanations of channel numbering for the SUN PHYs and LECIM PHYs, see 10.1.2.8 and 10.1.2.10, respectively. For explanations of channel numbering for the MSK PHY, see 10.1.2.6.

10.1.2.6 Channel numbering for MSK PHY 2450 MHz band

Change the first paragraph of 10.1.2.6, including breaking the paragraph into two separate paragraphs, as indicated:

The MSK PHY 2450 MHz band uses channel page 7 with the channel numbers defined in Table 10-8 and Table 10-8a. A total of 42 frequency channels numbered 15 to 56 on channel page 7 are available in the band from 2400 MHz to 2483.5 MHz for the 250 kb/s data rate. A total of 16 frequency channels numbered 57 to 72 on channel page 7 are available for the 2000 kb/s data rate. Different subsets of these frequency channels are available in different regions of the world.

Compliant receivers operating at 250 kb/s shall implement all channels in Table 10-8, defaulting to channel 47 unless modified by higher layers. The multiple narrow channels for the narrowband MSK 2450 MHz PHY are specified in order to improve coexistence with other 2450 MHz services. Compliant receivers operating at the 2000 kb/s data rate shall implement all channels in Table 10-8a with no default channel. The selection of specific channels is out of the scope of this standard~~, being performed by higher layers~~.

Change the table title of Table 10-8 as indicated (the table is not shown), and insert the new Table 10-8a after Table 10-8:

Table 10-8–MSK 2450 MHz mandatory PHY channel frequencies for 250 kb/s data rate

Table 10-8a—MSK 2450 MHz mandatory PHY channel frequencies for 2000 kb/s data rate

Channel number	Center frequency (MHz)
57	2405
58	2410
59	2415
60	2420
61	2425
62	2430
63	2435

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Table 10-8a—MSK 2450 MHz mandatory PHY channel frequencies for 2000 kb/s data rate *(continued)*

Channel number	Center frequency (MHz)
64	2440
65	2445
66	2450
67	2455
68	2460
69	2465
70	2470
71	2475
72	2480

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11. PHY services

11.2 PHY constants

Change Table 11-1 (the entire table is not shown) as indicated:

Table 11-1—PHY constants

Constant	Description	Value
aMaxPHYPacketSize	The maximum PSDU size (in octets) the PHY shall be able to receive.	2047 for the following PHYs: SUN, TVWS, RCC, ~~and~~ LECIM FSK, and MSK with a 2000 kb/s data rate ~~PHYs~~. For LECIM DSSS PHY, this is not a constant; refer to *phyLecimDsssPsduSize*. 127 for all other PHYs.
aTurnaroundTime	RX-to-TX or TX-to-RX turnaround time (in symbol periods), as defined in 10.2.1 and 10.2.2	For the SUN, TVWS, and LECIM FSK PHYs, the value is 1 ms expressed in symbol periods, rounded up to the next integer number of symbol periods using the ceiling() function.[a] For the LECIM DSSS PHY, the value is 1 ms expressed in modulation symbol periods, rounded up to the next integer number of symbol periods using the ceiling() function. For the MSK PHY with a data rate of 2000 kb/s, the value is 384 symbol periods. The value is 12 for all other PHYs.

[a]The function ceiling() returns the smallest integer value greater than or equal to its argument value.

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18. MSK PHY

18.1 PPDU formats

Change the first paragraph of 18.1 as indicated, and insert the following figures (Figure 18-0a and Figure 18-0b) after the first paragraph of 18.1:

The MSK PHY shall use the PPDU formats described in 12.1, except that the Preamble field is 32 symbols (4octets) and the bits in each octet shall be "10101010." In addition, when implementing the 2000 kb/s data rate, the PHR field is formatted either as illustrated in Figure 18-0a or Figure 18-0b, depending on the value of the Extended PHR field defined in 18.1.2.

Bits: 0–6	7
Frame Length LSB	Extended PHR

Figure 18-0a—Format of the PHR with the extended PHR field set to zero for 2000 kb/s data rate

Bits: 0–6	7	8–11	12–15
Frame Length LSB	Extended PHR	Frame Length MSB	Reserved

Figure 18-0b—Format of the PHR with the extended PHR field set to one for the 2000 kb/s data rate

Insert the following subclauses (18.1.1–18.1.3) after Figure 18-0b:

18.1.1 Frame length LSB field

The frame length LSB field specifies the seven least significant bits of the frame length. The frame length is defined as the total number of octets contained in the PSDU (i.e., PHY payload).

18.1.2 Extended PHR field

The Extended PHR field determines the presence of the frame length MSB field described in 18.1.3. When the Extended PHR field is set to zero, the PHR shall be formatted as shown in Figure 18-0a. When the Extended PHR field is set to one, the PHR shall be formatted as shown in Figure 18-0b. The value of the Extended PHR field shall be selected by the transmitting MAC in an implementation-dependent manner, consistent with the requirement that frames having a frame length greater than 127 octets shall have the Extended PHR field set to one.

This field also indicates the length of the FCS, as described in 7.2.10. Devices that implement the 2000 kb/s data rate shall be capable of supporting the reception of both FCS lengths.

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18.1.3 Frame length MSB field

The frame length MSB field, when present, specifies the four most significant bits of the frame length defined in 18.1.1. As an example, a length of 497 is encoded with the frame length MSB field set to 1100 and the frame length LSB field set to 100 0111.

18.2 Data rate

Change the first paragraph of 18.2, and change Table 18-1 as indicated:

All available data rates for the 433 MHz and 2450 MHz bands are shown in Table 18-1. When operating in the 433 MHz band, ~~The default~~ the mandatory data rate of the MSK PHY shall be 250 kb/s; all other data rates are optional. ~~Additional optional data rates for the 433 MHz band are shown in Table 18-1.~~

Table 18-1—Data rates for MSK PHY

DataRate as used in MCPS-DATA primitives	Data rate (kb/s)	Band (MHz)
1	31.25	433
2	100	433
3	250	433 or 2450
4	2000	2450

Insert the following new subclause 18.2a after 18.2:

18.2a Multi-PHY functionality

A transmitting device may send a Multi-PHY IE, as described in 7.4.4.34, indicating which PHYs are supported. If a device detects a different modulation or data rate being used on the channel, a higher layer may decide, e.g., to change the modulation and/or data rate, or move the receiving device to another channel.

18.4 MSK modulation

18.4.3 Bit-to-symbol mapping

Change the second paragraph of 18.4.3 as indicated, and replace the formula with the following new formula and variable list:

In Table 18-4, f_c is the channel center frequency, as defined in Table 10-7, ~~and~~ Table 10-8, and Table 10-8a. ~~and~~ Δf is defined as follows:

$$\Delta f = \frac{1}{4 \times T_s}$$

where T_s is the symbol duration.

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18.4.4 Signal modulation

Change the first paragraph of 18.4.4 as indicated:

When implementing the 2000 kb/s data rate, the bit sequences are modulated onto the carrier using GMSK modulation, for which the Gaussian filter BT is 0.5. The MSK modulation of all other band and data rate combinations shall be FSK with modulation index h = 0.5. ~~This modulation index corresponds to minimum frequency spacing that allows two FSK signals to be coherently orthogonal.~~

Change the second paragraph of 18.4.4 as indicated, and replace the formula with the following new formula:

As shown in Figure 18-2, MSK modulation has two possible frequencies over any symbol interval, which differ~~s~~ in frequency ~~by half the bit rate~~ as follows:

$$f_2 - f_1 = \frac{1}{2T_s}$$

18.5 MSK PHY requirements

18.5.2 Transmit PSD mask

Change the second paragraph of 18.5.2 and Table 18-5 as indicated:

The transmitted spectral products shall be less than the limits specified in Table 18-5. For both relative and absolute limits, average spectral power shall be measured using a 100 kHz resolution bandwidth. For the relative limit, the reference level shall be the highest average spectral power measured within a given range of the carrier frequency. The given range is ±100 kHz for the data rate of 31.25 kb/s, ±300 kHz for 100 kb/s, ±600 kHz for 250 kb/s, and ±1 MHz for 2000 kb/s.~~±300 kHz, or ±100 kHz of the carrier frequency (respective to data rate).~~

Table 18-5—MSK PHY transmit PSD limit

Frequency band	Data rate	Frequency	Relative limit	Absolute limit
433 MHz	31.25 ~~ksymbols~~kb/s	$\|f - fc\|$ > 200 kHz	–20 dB	–20 dBm
	100 ~~ksymbols~~kb/s	$\|f - fc\|$ > 600 kHz	–20 dB	–20 dBm
	250 ~~ksymbols~~kb/s	$\|f - fc\|$ > 1.2 MHz	–20 dB	–20 dBm
2450 MHz	250 ~~ksymbols~~kb/s	$\|f - fc\|$ > 1.2 MHz	–20 dB	–20 dBm
	2000 kb/s	$\|f - fc\|$ > 3.5 MHz	–20 dB	–30 dBm

18.5.3 Symbol rate

Change the second paragraph of 18.5.3 as indicated:

The transmitted symbol rate for 2450 MHz band shall be either 250 ksymbol/s with an accuracy of ±300 × 10^{-6}, or 2000 ksymbol/s with an accuracy of ±40 × 10^{-6}.

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Annex A

(informative)

Bibliography

Insert the following reference into Annex A in alphanumeric order

[BX] "Coexistence Assurance Document for 802.15.4t," IEEE 802.15 document 15-16-00408-01-004t, 2016.

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Consensus

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