IEEE 802.15.4k FSK PHY Working Draft version: 2012-01-05

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Contents

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1. Overview
	1. Scope
	2. Purpose
2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

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6. General PHY requirements
	1. FSK PHY specification

***Insert the following item at the end of the second list in 8.1:***

* LECIM FSK PHY: a multi-regional, frequency shift keying PHY operating at over-the-air data rates in support of LECIM applications
	+ 1. Operating frequency range

***Insert the following new rows at the end of table 66***

|  |  |  |  |
| --- | --- | --- | --- |
| **PHY****(MHz)** | **Frequency band****(MHz)** | **Spreading Parameters** | **Data parameters** |
| **Chip rate****(kchip/s)** | **Modulation** | **Bit rate****(kb/s)** | **Symbol rate****(ksymbols/s)** | **Symbols** |
| 470 | 470-510 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 780 | 779-787 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 863 | 863-870 | --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 915 | 902-928 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 917 | 917-923.5 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 920 | 920-928 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |
| 2450 | 2400-2483.5 | --- | GFSK/FSK | 37.5 | 37.5  | Binary |
| --- | GFSK/FSK | 25 | 25 | Binary |
| --- | FSK | 12.5(coordinator to end device only) | 12.5(coordinator to end device only) | Binary |

* + 1. Channel Assignments

<REVISIT> LECIM channel assignments match those used for the SUN PHY MR-FSK mode channel assignments. (Can this reference section 16? or do we want a separate channel page for LECIM?)

Table 1 - Total number of channels and first channel center frequencies for LECIM FSK PHYs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Frequency Band (MHz) | Modulation(Uplink/Downlink) | *ChanSpacing* (MHz) | *TotalNumChan* | *ChanCenterFreq0* (MHz) |
| 470-510 |  GFSK/FSK | 0.2 | 199 | 470.2 |
| 779-787 | 39 | 779.2 |
| 863-870 | 0.1 | 69 | 863.075 |
| 902-928 | 0.2 | 129 | 902.2 |
| 917-923.5 | 32 | 917.1 |
| 920.5- 923.5 | 15 | 920.6 |
| 2400-2483.5 | 416 | 2400.2 |

1. PHY services
	1. Overview
	2. PHY constants

|  |  |  |
| --- | --- | --- |
| **Constant** | **Description** | **Value** |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

* 1. PHY PIB attributes

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Valid Range** | **Description** |
| *phyLECIMFSKPreambleLength* | Integer | 1-100 | The number of 1-octet patterns (see 17.1.1.1) in the preamble.This value is only valid for the LECIM FSK PHY |
| * <REVISIT>: Reduce minimum to 1 for high capability coosrdinators, reduce maximum from 1000 to 100 since LECIM is focused on low energy.
 |
| *phyLECIMFSKPSDUMod* | Boolean | TRUE or FALSE | When TRUE, P-GFSK/P-FSK is enabled for the PSDU. When FALSE, GFSK/FSK modulation is enabled for the PSDU. |
| *phyLECIMFSKSpreading* | Boolean | TRUE or FALSE | When TRUE, spreading is enabled. When FALSE, spreading is disabled. |
| *phyLECIMFSKSpreadingFactor* | Integer | 1,2,4,8,16 | The spreading factor to be used when *phyLECIMFSKSpreading* is TRUE. |
| *phyLECIMFSKScramblePSDU* | Boolean | TRUE or FALSE | A value of FALSE indicates that data whitening of the PSDU is disabled. A value of TRUE indicates that data whitening of the PSDU is enabled.This value is only valid for the LECIM FSK PHY. |
| *phyLECIMFECEnabled* | Boolean | TRUE or FALSE | A value of TRUE indicates that FEC is turned on. A value of FALSE indicates that FEC is turned off.This value is only valid for the LECIM FSK PHY. |
| *phyLECIMFSKInterleavingEnabled* | Boolean | TRUE or FALSE | A value of TRUE indicates that interleaving is turned on. A value of FALSE indicates that interleaving is turned off.This value is only valid for the LECIM FSK PHY. |
|  |  |  |  |

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7. 15.4g PHYs
8. LECIM PHYs
	1. FSK PHY specification

The frequency shift keying PHY is described in the following subclauses.

* + 1. PPDU format for FSK

The FSK PPDU shall support the format shown in Figure 1.

The synchronization header (SHR), PHY header (PHR), and PHY payload components are treated as bit strings of length n, numbered b0 on the left and bn-1 on the right. When transmitted, they are processed b0 first to bn-1 last, without regard to their content or structure.

All reserved fields shall be set to zero upon transmission and shall be ignored upon reception.

|  |  |  |
| --- | --- | --- |
|  |  | **Octets** |
|  |  | N | variable |
| Preamble | SFD | As defined in 17.1.1.3 | PSDU |
| SHR | PHR | PHY Payload |

Figure 1 - Format of the FSK PPDU

* + - 1. Preamble Field

The Preamble field shall contain *phyLECIMFSKPreambleLength* (as defined in 9.3) multiples of the 8-bit sequence “01010101”.

* + - 1. SFD

The SFD shall be either a 2 or 4-octet sequence selected from the list of values shown in Table 2

 The SFD is transmitted starting from the leftmost bit (i.e., starting with b0).

Table 2 - SFD Values

|  |  |  |
| --- | --- | --- |
| TBD |  |  |
|  | 1001 0000 0100 1110 |  |

* + - 1. PHR

The format of the PHR is shown in Figure 2. All multi-bit fields are unsigned integers and shall be processed MSB first. Table 3 shows the relationship between the contents of the FCS Type field and the length of the transmitted FCS.

The Frame Length field (L6-L0) specifies the total number of octets contained in the PSDU (prior to FEC encoding, if enabled). The most significant bit (leftmost) shall be transmitted first.

It is important to note that LECIM networks are commissioned networks and strive to minimize energy consumption in battery powered end devices. As such, not all parameters are signaled with bits in the PHR, but are instead assumed to be programmed into the network devices at commissioning. The parameters configuring the use of data whitening, FEC, interleaving, spreading and modulation type are considered commissioned parameters and are not signaled in the PHR

|  |  |  |
| --- | --- | --- |
| **Bit string index** | 0 | 1-7 |
| **Bit mapping** | FCS | L6-L0 |
| **Field name** | FCS Type | Frame Length |

Figure 2 - PHR

Table 3 Relationship between FCS Type field and transmitted FCS length

|  |  |
| --- | --- |
| **FCS Type field Value** | **Transmitted FCS length** |
| 0 | 4 octets |
| 1 | 2 octets |

Or Alternatively:

FCS length is a commissioned parameter as well and the PHR is:

|  |  |  |
| --- | --- | --- |
| **Bit string index** | 0 | 1-7 |
| **Bit mapping** | R0 | L6-L0 |
| **Field name** | Reserved | Frame Length |

* + - 1. PSDU Field

The PSDU field carries the data of the PPDU.

* + 1. Modulation and coding for FSK

The modulation for the FSK PHY shall be FSK/GFSK and P-FSK/P-GFSK.

Table 3 shows the modulation and channel parameters for the standard-defined PHY operating modes for the 863 MHz, 915 MHz, 917 MHz, 920 MHz, and 2450 MHz bands.

Although there are multiple data rates for each frequency band in Table 3, there is no over-the-air, dynamic data rate changing mechanism defined for this PHY. It is left to the system designer to select the appropriate data rates for the deployment during the design and commissioning of each specific network. The FSK LECIM PHY is not intended to be a multi-rate PHY with over-the-air signaling of chaning data rates.

Table 4 - FSK modulation and channel parameters\*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frequency band****(MHz)** | **Parameter** | **37.5 kbps** | **25 kbps** | **12.5 kbps** |
| 470-510(China) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 779-787(China) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 863-870(Europe) | End device to coordinator | Not supportable due to regulations | GFSK/P-GFSK | Not supported |
| Coordinator to end device | Not supportable due to regulations | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 100 | 100 | 100 |
| 902-928(US ISM) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 917-923.5(Korea) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 920-928(Japan) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |
| 2400-2483.5(Worldwide) | End device to coordinator | GFSK/P-GFSK | GFSK/P-GFSK | Not supported |
| Coordinator to end device | FSK/P-FSK | FSK/P-FSK | FSK |
| Modulation Index | 0.5 | 1.0 | 4.0 |
| Channel Spacing (kHz) | 200 | 200 | 200 |

\*Data rates shown are over-the-air data rates (the data rate transmitted over the air regardless whether the FEC is enabled or not).

Table 5 - FSK symbol duration used for MAC and PHY timing parameters

|  |  |
| --- | --- |
| **Frequency Band (MHz)** | **FSK symbol timing used for MAC and PHY timing parameters (µs)** |
| 470-510(China) | 26.67 |
| 863-870 (Europe) | 40 |
| 902-928 (US ISM) | 26.67 |
| 917-923.5 (Korea) | 26.67 |
| 920-928 (Japan) | 26.67 |
| 2400-2483.5 (Worldwide) | 26.67 |

The use of P-FSK/P-GFSK modulation for PSDU data is controlled by PIB attribute *phyLECIMFSKPSDUMod,* as defined in 9.3. The modulation for preamble, SFD and PHR shall be FSK/GFSK regardless of *phyLECIMFSKPSDUMod*.

FSK/GFSK encodes one bit by transmitting a frequency modulated signal $m\left(t\right)$ with duration$T\_{s}$, i.e., $0\leq t< T\_{s}$. P-FSK/P-GFSK encodes two bits by transmitting a FSK/GFSK modulated signal $m\left(t\right)$ with $T\_{s}$ duration in one of two possible positions (also known as time deviation), i.e., $0\leq t< T\_{s}$ and $T\_{s}\leq t <2T\_{s}$.

* + - 1. Reference modulator diagram

The functional block diagram in Figure 3 is provided as a reference for specifying the FSK PHY data flow processing functions. The subclause number in each block refers to the subclause that describes that function. Each bit shall be processed using the bit order rules defined in 17.1.1.

When FEC is enabled, the PHR and PSDU shall be processed for coding as a single block of data (see 17.1.2.4). When data whitening is enabled, the scrambling shall be only applied over the PSDU (see 17.1.3). When spreading is enabled, the spreading shall be applied over PHR and PSDU (see 17.1.2.6).

All fields in the PPDU shall use the same symbol rate and modulation order, unless otherwise specified elsewhere in this standard.



Figure - FSK reference modulator diagram

* + - 1. Bit-to-symbol mapping

The nominal frequency deviation, ∆f, shall be

$$\left(\frac{symbol rate x modulation index}{2}\right)$$

The symbol encoding for FSK/GFSK and P-FSK/GFSK modulation is shown in Table 5 and Table 6, where the maximum frequency deviation, fdev is equal to ∆f.

Table 6 – FSK/GFSK symbol encoding

|  |  |  |
| --- | --- | --- |
| Symbol ($b\_{o}$) | Frequency deviation | Time deviation |
| 0 | $$-f\_{dev}$$ | 0 |
| 1 | $$+f\_{dev}$$ | 0 |

Table 7 – P-FSK/P-GFSK symbol encoding

|  |  |  |
| --- | --- | --- |
| Symbol $(b\_{0}, b\_{1})$ | Frequency deviation | Time deviation  |
| 00 | $$-f\_{dev}$$ | 0 |
| 01 | $$-f\_{dev}$$ | $$T\_{s}$$ |
| 10 | $$+f\_{dev}$$ | 0 |
| 11 | $$+f\_{dev}$$ | $$T\_{s}$$ |

* + - 1. Modulation quality

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

* + - * 1. Frequency deviation tolerance

The GFSK modulation frequency tolerance is measured as a percentage of the frequency deviation dictated by the modulation index. The measured frequency deviation shall be ± 20% of the ideal frequency deviation, as shown in Figure 4. A binary one shall be represented by a positive frequency deviation, and a binary zero shall be represented by a negative frequency deviation.

The symbol timing shall be less than ± 20 ppm.



Figure 4 Eye diagram for FSK

* + - * 1. Zero crossing tolerance

The excursions for the zero crossings for all trajectories of the eye diagram shall be constrained to within ±12.5% of the symbol time Ts, as shown in Figure 4.

* + - 1. Forward error correction

The FSK PHY shall perform FEC as defined in 16.3.2.6. The use of spreading is controlled by PIB attribute *phyLECIMFECEnabled*, as defined in 9.3.

* + - 1. Code-symbol interleaving

The FSK PHY shall perform interleaving as defined in 16.1.2.5. The use of spreading is controlled by PIB attribute phyLECIMFSKSpreading, as defined in 9.3.

* + - 1. Spreading

The use of spreading is controlled by PIB attribute *phyLECIMFSKSpreading*, as defined in 9.3. The spreading factor (SF) can be 1, 2, 4, 8, or 16. The variable spreading factor is indicated by PIB attribute *phyLECIMFSKInterleavingEnabled,* as defined in 9.3*.*

For spreading, a single input bit $(b\_{0})$ is mapped into the spreading bits $(c\_{0}, c\_{1}, …, c\_{SF-1})$.as shown in Figure 5 and its mapping is represented in Table 7.



Figure 5 - Spreading function

Table 8 - Input bit to spreading bits mapping

|  |  |  |
| --- | --- | --- |
|  | Input bit$(b\_{0})$ = 0 | Input bit$(b\_{0})$ = 1 |
| SF = 1 | $(c\_{0})$ = 0 | $(c\_{1})$ = 1 |
| SF = 2 | $(c\_{0}, c\_{1})$ = 01 | $(c\_{0}, c\_{1})$ = 10 |
| SF = 4 | $\left(c\_{0}, …, c\_{3}\right)$ = 0101 | $(c\_{0}, …, c\_{3})$ = 1010 |
| SF = 8 | $(c\_{0}, …, c\_{7})$ = 01010101 | $(c\_{0}, …, c\_{7})$ = 10101010 |
| SF = 16 | $(c\_{0}, …, c\_{15})$ = 0101010101010101 | $(c\_{0}, …, c\_{15})$ = 1010101010101010 |

* + 1. Data whitening for FSK

The FSK PHY shall perform data whitening as defined in 16.1.3. The use of data whitening is controlled by PIB attribute *phyLECIMFSKScramblePSDU*, as defined in 9.3.

* + 1. FSK PHY RF Requirements
			1. Operating Frequency Range

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

* + - 1. Regulatory compliance

It is the responsibility of the implementer to verify and ensure that the device is in compliance with all regulatory requirements in the geographic region where the device is deployed or sold. Conformance with this standard does not guarantee compliance with the relevant regulatory requirements which may apply.

* + - 1. Radio frequency tolerance

The single-sided clock frequency tolerance *T* at the transmitter, in ppm, shall be as follows:

T = 20 ppm for all sub-GHz bands,

T = 40 ppm for the 2450 MHz band.

* + - 1. Channel switch time

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

* + - 1. Transmit spectral mask

The transmit spectral content shall conform to all local regulations.

* + - 1. Receiver sensitivity

Under the conditions specified in 8.1.7, a compliant PHY device shall be capable of achieving a sensitivity of -85 dBm or better.

The receiver shall also support system operation with a link budget including at least 120 dB of path loss.

* + - 1. Receiver interference rejection

The minimum receiver interference rejection levels are given in Table 8. The adjacent channel is one on either side of the desired channel that is closest in frequency to the desired channel, and the alternate channel is one more removed from the adjacent channel. For example, when channel 15 is the desired channel, channel 14 and channel 16 are the adjacent channels, and channel 13 and channel 17 are the alternate channels.

Table 9 - Minimum receiver interference rejection requirements

|  |  |
| --- | --- |
| **Adjacent channel rejection** | **Alternate channel rejection** |
| 10 dB | 30 dB |

The adjacent channel rejection shall be measured as follows: the desired signal shall be a compliant GFSK/FSK PHY signal, as defined by 17.1.2, of pseudo-random data. The desired signal is input to the receiver at a level 3 dB greater than the maximum allowed receiver sensitivity given in 17.1.4.6.

In either the adjacent or the alternate channel, a compliant signal, as defined by 17.1.2, is input at the level specified in Table 8 relative to the desired signal. The test shall be performed for only one interfering signal at a time. The receiver shall meet the error rate criteria defined in 8.1.7 under these conditions.

* + - 1. Tx-to-Rx turnaround time

The FSK PHY shall meet the requirements for TX-to-RX turnaround time as defined in 8.2.1.

* + - 1. Rx-to-Tx turnaround time

The FSK PHY shall meet the requirements for RX-to-TX turnaround time as defined in 8.2.2.

* + - 1. Transmit power

A transmitter shall be capable of transmitting at least –3 dBm. The maximum transmit power is limited by local regulatory bodies.

The transmitter shall also support system operation with a link budget including at least 120 dB of path loss.

* + - 1. Receiver maximum input level of desired signal

FSK PHY shall have a receiver maximum input level greater than or equal to –20 dBm using the measurement defined in 8.2.4

* + - 1. Receiver ED

The FSK PHY shall provide the receiver ED measurement as described in 8.2.5.

* + - 1. Link quality indicator

The FSK PHY shall provide the LQI measurement as described in 8.2.6.

* + - 1. Clear channel assessment (CCA)

The FSK PHY shall use the one of the CCA methods as described in 8.2.7.

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