**IEEE P802.15**

**Wireless Personal Area Networks**

|  |  |
| --- | --- |
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | Proposal for IEEE802.15.3d – THz PHY |
| Date Submitted | 8 November 2016 |
| Source | Thomas Kürner on behalf of TU Braunschweig, NICT, Hiroshima University, Glasgow University | Voice: Fax: E-mail: t.kuerner@tu-bs.de |
| Re: | In response to TG3d Call for Proposals (15-15-0936-04-003d) |
| Abstract | Draft proposal PHY section (section 11b)  |
| Purpose | To be considered in the IEEE802.15.3d standard |
| Notice | This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. |
| Release | The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15. |

|  |
| --- |
| **List of contributors** |
| Thomas Kürner | TU Braunschweig |
| Alexander Fricke | TU Braunschweig |
| Sebastian Rey | TU Braunschweig |
| Bile Peng | TU Braunschweig |
| Iwao Hosako, NICT | NICT |
| Akifumi Kasamatsu, NICT | NICT |
| Norihiko Sekine, NICT | NICT |
| Hiroyo Ogawa, NICT | NICT |
| Minoru Fujishima | Hiroshima University |
| Anthony Kelly | Glasgow University |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

[11b PHY specification for THz 5](#_Toc461142275)

[11b.1 General requirements 5](#_Toc461142276)

[11b.1.1 Regulatory Information 5](#_Toc461142277)

[11b.1.2 RF power measurements 5](#_Toc461142278)

[11b.1.3 Unwanted emissions 5](#_Toc461142279)

[11b.1.4 RF channelization 5](#_Toc461142280)

[11b1.5 Transmit PSD mask 8](#_Toc461142281)

[11b1.6 Error Vector Magnitude Calculation 9](#_Toc461142282)

[11b1.7 THz-PHY management 9](#_Toc461142283)

[11b1.7.1 Supported MCSs 9](#_Toc461142284)

[11b1.7.2 THz-PHY PIB 10](#_Toc461142285)

[11b.2 THz-SC PHY 12](#_Toc461142286)

[11b.2.1 Channelization of THz-SC PHY 12](#_Toc461142287)

[11b.2.2 Modulation and coding 12](#_Toc461142288)

[11b.2.2.1 MCS dependent parameters 12](#_Toc461142289)

[11b.2.2.2 Header dependent parameters 14](#_Toc461142290)

[11b.2.2.3 Timing-related parameters 14](#_Toc461142291)

[11b.2.2.4 Frame-related parameters 15](#_Toc461142292)

[11b.2.2.5 Modulation 16](#_Toc461142293)

[11b.2.2.6 Forward Error Correction 17](#_Toc461142294)

[11b.2.2.7 Stuff bits 17](#_Toc461142295)

[11b.2.2.8 Code spreading 17](#_Toc461142296)

[11b.2.2.9 Scrambling 17](#_Toc461142298)

[11b.2.3 THz-SC PHY frame format 17](#_Toc461142299)

[11b.2.3.2.1 THz-SC PHY header 18](#_Toc461142300)

[11b.2.3.3 THz-SC PHY Payload field 21](#_Toc461142301)

[11b.2.3.3.1 THZ-SC PHY Payload scrambling 21](#_Toc461142302)

[11b.2.3.3.2 Modulation 21](#_Toc461142303)

[11b.2.3.3.3 FEC 21](#_Toc461142304)

[11b.2.3.4 Pilot word and PPRE 21](#_Toc461142305)

[11b.2.3.4.1 Block and pilot word 21](#_Toc461142306)

[11b.2.3.4.2 PPRE 21](#_Toc461142307)

[11b.2.4 Transmitter specifications 22](#_Toc461142308)

[11b.2.4.1 EVM Requirement 22](#_Toc461142309)

[11b.2.4.2 Symbol rate 22](#_Toc461142310)

[11b.2.4.3 Transmit power-on and power-down ramp 22](#_Toc461142311)

[11b.2.5 Receiver specifications 22](#_Toc461142312)

[11b.2.5.1 Error rate criterion 22](#_Toc461142313)

[11b.2.5.2 Receiver sensitivity 23](#_Toc461142314)

[11b.2.5.3 Receiver maximum input level 23](#_Toc461142315)

[11b.2.6 PHY layer timing 23](#_Toc461142316)

[11b.2.6.1 Interframe space 23](#_Toc461142317)

[11b.2.6.2 Receive-to-transmit turnaround time 24](#_Toc461142318)

[11b.2.6.3 Transmit-to-receive turnaround-time 24](#_Toc461142319)

[11b.2.6.4 Time between successive transmissions 24](#_Toc461142320)

[11b.2.6.5 Channel switch 24](#_Toc461142321)

[11b.2.7 PHY management for THZ-SC PHY 24](#_Toc461142322)

[11b.2.7.1 Maximum frame size 24](#_Toc461142323)

[11b.2.7.2 Maximum transfer unit size 24](#_Toc461142324)

[11b.2.7.3 Minimum fragment size 25](#_Toc461142325)

[11b.3 THz-OOK PHY 25](#_Toc461142326)

[11b3.1 Channelization for THZ-OOK PHY 25](#_Toc461142327)

[11b.3.2 Modulation and Coding 25](#_Toc461142328)

[11b.3.2.1 Modulation 25](#_Toc461142330)

[11b.3.2.2 Forward Error Correction 26](#_Toc461142331)

[11b.3.2.3 MCS dependent parameters 26](#_Toc461142332)

***Insert the following clause as Clause 11b:***

# 11b PHY specification for THz

## 11b.1 General requirements

A compliant THz PHY shall implement at least one of the following PHY modes:

a) THz single carrier mode PHY (THz-SC PHY), as defined in 11b.2.

b) THz on-off keying mode PHY (THz-OOK PHY), as defined in 11b.3.

Unless otherwise stated, in all figures in this clause the ordering of the octets and bits as they are presented to the THz PHY for modulation is the same as defined in 6.1.

### 11b.1.1 Regulatory Information

The THz PHY operating frequency is within the 252.72 – 321.84 GHz range. The radio regulations have allocated the spectrum in the range of 252-275 GHz for the use of mobile and fixed services and allows the national administrations to allow the use of THz communications above 275 GHz as long as passive services in this band are protected from harmful interference.

### 11b.1.2 RF power measurements

Unless otherwise stated, all RF power measurements for the purpose of this standard, either transmit or receive, shall be made based on EIRP and any radiated measurements shall be corrected to compensate for the antenna gain in the implementation. The gain of the antenna is the maximum estimated gain by the manufacturer.

### 11b.1.3 Unwanted emissions

Conformant implementations shall comply with the in-band and out-of-band emissions for all operational modes as set by the applicable regulatory bodies.

### 11b.1.4 RF channelization

The THz PHY uses the channels defined in Figure 11b-1 and Table 11b-1.



**Figure 11b-1— THz PHY Channel Assignments**

**Table 11b-1—THz PHY channelization**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CHNL\_ID** | **Bandwidth** | **Start frequencya** | **Center frequency** | **Stop frequencya** |
| 1 | 2.16 | 252.72 | 253.8 | 254.88 |
| 2 | 2.16 | 254.88 | 255.96 | 257.04 |
| 3 | 2.16 | 257.04 | 258.12 | 259.2 |
| 4 | 2.16 | 259.2 | 260.28 | 261.36 |
| 5 | 2.16 | 261.36 | 262.44 | 263.52 |
| 6 | 2.16 | 263.52 | 264.6 | 265.68 |
| 7 | 2.16 | 265.68 | 266.76 | 267.84 |
| 8 | 2.16 | 267.84 | 268.92 | 270 |
| 9 | 2.16 | 270 | 271.08 | 272.16 |
| 10 | 2.16 | 272.16 | 273.24 | 274.32 |
| 11 | 2.16 | 274.32 | 275.4 | 276.48 |
| 12 | 2.16 | 276.48 | 277.56 | 278.64 |
| 13 | 2.16 | 278.64 | 279.72 | 280.8 |
| 14 | 2.16 | 280.8 | 281.88 | 282.96 |
| 15 | 2.16 | 282.96 | 284.04 | 285.12 |
| 16 | 2.16 | 285.12 | 286.2 | 287.28 |
| 17 | 2.16 | 287.28 | 288.36 | 289.44 |
| 18 | 2.16 | 289.44 | 290.52 | 291.6 |
| 19 | 2.16 | 291.6 | 292.68 | 293.76 |
| 20 | 2.16 | 293.76 | 294.84 | 295.92 |
| 21 | 2.16 | 295.92 | 297 | 298.08 |
| 22 | 2.16 | 298.08 | 299.16 | 300.24 |
| 23 | 2.16 | 300.24 | 301.32 | 302.4 |
| 24 | 2.16 | 302.4 | 303.48 | 304.56 |
| 25 | 2.16 | 304.56 | 305.64 | 306.72 |
| 26 | 2.16 | 306.72 | 307.8 | 308.88 |
| 27 | 2.16 | 308.88 | 309.96 | 311.04 |
| 28 | 2.16 | 311.04 | 312.12 | 313.2 |
| 29 | 2.16 | 313.2 | 314.28 | 315.36 |
| 30 | 2.16 | 315.36 | 316.44 | 317.52 |
| 31 | 2.16 | 317.52 | 318.6 | 319.68 |
| 32 | 2.16 | 319.68 | 320.76 | 321.84 |
| 33 | 4.32 | 252.72 | 254.88 | 257.04 |
| 34 | 4.32 | 257.04 | 259.2 | 261.36 |
| 35 | 4.32 | 261.36 | 263.52 | 265.68 |
| 36 | 4.32 | 265.68 | 267.84 | 270 |
| 37 | 4.32 | 270 | 272.16 | 274.32 |
| 38 | 4.32 | 274.32 | 276.48 | 278.64 |
| 39 | 4.32 | 278.64 | 280.8 | 282.96 |
| 40 | 4.32 | 282.96 | 285.12 | 287.28 |
| 41 | 4.32 | 287.28 | 289.44 | 291.6 |
| 42 | 4.32 | 291.6 | 293.76 | 295.92 |
| 43 | 4.32 | 295.92 | 298.08 | 300.24 |
| 44 | 4.32 | 300.24 | 302.4 | 304.56 |
| 45 | 4.32 | 304.56 | 306.72 | 308.88 |
| 46 | 4.32 | 308.88 | 311.04 | 313.2 |
| 47 | 4.32 | 313.2 | 315.36 | 317.52 |
| 48 | 4.32 | 317.52 | 319.68 | 321.84 |
| 49 | 8.64 | 252.72 | 257.04 | 261.36 |
| 50 | 8.64 | 261.36 | 265.68 | 270 |
| 51 | 8.64 | 270 | 274.32 | 278.64 |
| 52 | 8.64 | 278.64 | 282.96 | 287.28 |
| 53 | 8.64 | 287.28 | 291.6 | 295.92 |
| 54 | 8.64 | 295.92 | 300.24 | 304.56 |
| 55 | 8.64 | 304.56 | 308.88 | 313.2 |
| 56 | 8.64 | 313.2 | 317.52 | 321.84 |
| 57 | 12.96 | 252.72 | 259.2 | 265.68 |
| 58 | 12.96 | 265.68 | 272.16 | 278.64 |
| 59 | 12.96 | 278.64 | 285.12 | 291.6 |
| 60 | 12.96 | 291.6 | 298.08 | 304.56 |
| 61 | 12.96 | 304.56 | 311.04 | 317.52 |
| 62 | 17.28 | 252.72 | 261.36 | 270 |
| 63 | 17.28 | 270 | 278.64 | 287.28 |
| 64 | 17.28 | 287.28 | 295.92 | 304.56 |
| 65 | 17.28 | 304.56 | 313.2 | 321.84 |
| 66 | 25.92 | 252.72 | 265.68 | 278.64 |
| 67 | 25.92 | 278.64 | 291.6 | 304.56 |
| 68 | 51.84 | 252.72 | 278.64 | 304.56 |
| 69 | 69.12 | 252.72 | 287.28 | 321.84 |

a The start and stop frequencies are nominal values. The frequency spectrum of the transmitted signal needs to conform to the transmit power spectral density (PSD) mask for the PHY mode as well as any regulatory requirement.

The bandwidth of all channels are integer multiples of 2.16 GHz. The center frequencies for channels, whose CHNL\_ID is 33-68 are integer multiples of 2.16 GHz. The channel whose CHNL\_ID is TBD shall be defined as default channel.

### 11b1.5 Transmit PSD mask

The transmitted spectrum for both THz SC-PHY and THz OOK-PHY shall adhere to the transmit spectrum density (PSD) mask shown in Figure 11b-2. For the transmit mask measurements, the resolution bandwidth is set to 3 MHz and video bandwidth to 300 kHz. During OOK modulation, transmitters shall meet the shown PSD mask, with an additional single line spectrum of 40 dB above the 0 dB line in Figure 11b-2 within the frequency band of [–6 MHz,+6 MHz] from the carrier frequency.



**Figure 11b-2— Generic transmit spectral mask**

**Table 11b-2—Transmit spectrum mask limit**

|  |  |
| --- | --- |
| **Frequency** | **Relative Limit [dBr]** |
| $$|f-f\_{c}|\leq f\_{1}$$ | $$0$$ |
| $$f\_{1}\leq |f-f\_{c}|\leq f\_{2}$$ | $$-20(\left|f-f\_{c}\right|-f\_{1})/(f\_{2}-f\_{1})$$ |
| $$f\_{2}\leq |f-f\_{c}|\leq f\_{3}$$ | $$-20-5∙(\left|f-f\_{c}\right|-f\_{2})/(f\_{3}-f\_{2})$$ |
| $$f\_{3}\leq |f-f\_{c}|\leq f\_{4}$$ | $$-25-5∙(\left|f-f\_{c}\right|-f\_{3})/(f\_{4}-f\_{3})$$ |
| $$|f-f\_{c}|\geq f\_{4}$$ | $$-30$$ |

**Table 11b-3—Transmit spectrum mask parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel Bandwidth [GHz]** | $$f\_{1}[GHz]$$ | $$f\_{2}[GHz]$$ | $$f\_{3}[GHz]$$ | $$f\_{4}[GHz]$$ |
| 2.160 | **0.66** | **1.080** | **TBD** | **TBD** |
| 4.320 | **1.32** | **2.160** | **TBD** | **TBD** |
| 8.640 | **2.64** | **4.320** | **TBD** | **TBD** |
| 12.960 | **3.96** | **6.480** | **TBD** | **TBD** |
| 17.280 | **5.28** | **8.640** | **TBD** | **TBD** |
| 25.920 | **7.92** | **12.960** | **TBD** | **TBD** |
| 51.840 | **15.84** | **25.920** | **TBD** | **TBD** |
| 69.120  | **21.12** | **34.560** | **TBD** | **TBD** |

### 11b1.6 Error Vector Magnitude Calculation

The error vector magnitude (EVM) for the THz PHY shall be measured and calculated using the method defined in 11.1.7.1

### 11b1.7 THz-PHY management

#### 11b1.7.1 Supported MCSs

The Supported data rates field in the DEV capabilities field, as described in 6.4.11d (THz capability).

Note for the preparation of 6.4.11d:

In 6.4.11d the THz device field capability format can be based on figure 6-88b with b0 to b23 identical and the following bits different:

|  |  |  |
| --- | --- | --- |
| Bits | Capability | meaning |
| b24-b29 | SC supported modulation formats | b24: SC π/2-shift BPSK supportedb25: SC π/2-shift QPSK supportedb26: SC π/2-shift 8-PSK supportedb27: SC π/2-shift 8-APSK supportedb28: SC π/2-shift 16-QAM supportedb29: SC π/2-shift 64-QAM supported |
| b30 | OOK spreading | b30: OOK spreading used |
| b31 | Reserved |  |
| b31-b37 | Channel bandwidth supported | b31: 2.16 GHzb32: 4.32 GHzb33: 8.64 GHzb34: 12.96 GHzb35: 17.28 GHzb36: 25.92 GHzb37: 51.84 GHzb38: 69.12 GHz |
| b39-b70 | Spectrum part supported | Spectrum parts given in the smallest granularity of 2.16 GHz; spectrum range corresponds to the spectrum ranges defined by the spectrum ranges of CHNL\_ID 1 to 32)b(38+ CHNL\_ID)Note: in the final draft the spectrum may be given in absolute numbers here |
| b71 | Reserved |  |

#### 11b1.7.2 THz-PHY PIB

The PHY dependent PIB values for the THz PHY are given in Table 11b-4 and Table 11b-5. The PHY PIB characteristics group given in Table 11b-4 contains information that is common to most implementations while the PHI PIB implementation group provided in Table 11b-5 contains information that is more characteristic of a particular PHY implementation.

**Table 11b-4 -PHY PIB characteristics group parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| **Managed Object** | **Octets** | **Definition** | **Access** |
| PHYPIB\_Type | 1 | 0x03 = THz PHY | Read/Write |
| PHYPIB\_Mode | 1 | bit 1 = THz-SC PHYbit 2 = THz-OOK PHYbit 3-8 = ReservedA bit is set to one if the associated PHY is supported, and is set to zero otherwise. | Read/Write |
| PHYPIB\_RegDomainsSupported | Variable | One octet for each regulatory domain supported, as defined for PHYPIB\_CurrentRegDomain. | Read/Write |
| PHYPIB\_CurrentRegDomain | 1 | 0x00 = European Telecommunications Standards Institute (ETSI)0x01 = Federal Communications Commission (FCC)0x02 = Industry Canada (IC)0x03 = Association of Radio Industries and Businesses (ARIB) | Read/Write |
| PHYPIB\_DataRateVector | Variable | One octet for each supported MCS. The MSB indicates the THz PHY mode with MSB 0 = THz SC PHYMSB 1 = THz OOK PHYThe seven LSBs indicate the MCS supported for that mode using the encoding described in Table 11b-10 | Read/Write |
| PHYPIB\_ChannelBandwithSupported | 1 | b31-b38 in the dev capability field as defined 6.4.11d. | Read/Write |
| PHYPIB\_ChannelsSupported | 4 | b39-b70 in the dev capability field as defined 6.4.11d. | Read/Write |
| PHYPIB\_CurrentChannel | 1 | Indicates the channel that is currently being used, asdefined in 11b.1.4. | Read/Write |
| PHYPIB\_FrameLengthMax | 2 | pMaxFrameBodySize. | Read/Write |

The PHY PIB implementation group, Table 11b-5 contains information that is more characteristic of a particular PHY implementation than of the PHY as a whole.

**Table 11b-5—PHY PIB implementation group parameters**

|  |  |  |  |
| --- | --- | --- | --- |
| **Managed Object** | **Octets** | **Definition** | **Access** |
| PHYPIB\_MaxTXPower | 1 | The maximum TX power that the DEV is capable of using as defined in 6.4.11. The value is implementation dependent. | Read/Write |
| PHYPIB\_TXPowerStepSize | 1 | The step size for power control supported by the DEV, 6.4.12, value is implementation dependent. | Read/Write |
| PHYPIB\_NumPMLevels | 1 | Number of power management levels supported. The range is 1 to 8 and the value is implementation dependent.  | Read/Write |
| PHYPIB\_PMLevelReturn | Variable | Table of vectors with number of entries given by PHYPIB\_NumPMLevels. Each vector is the time required to change between power saving states of the PHY. Vector number 0 is the time required to change the PHY from the off state to a state where it is ready to receive commands. Other values are implementation dependent.  | Read/Write |

## 11b.2 THz-SC PHY

The THz-SC PHY is designed for extremely high PHY-SAP payload-bit rates between 1,3 Gb/s and 9,8 Gb/s using a single channel with a band width of 2.16 GHz and the maximum 315 Gb/s using a bandwidth of 69.12GHz.

The THZ-SC PHY supports π/2-shift BPSK, π/2-shift QPSK, π/2-shift 8-PSK, π/2-shift APSK, π/2-shift 16-QAM and π/2-shift 64-QAM. The modulation of π/2-shift BPSK is also used for preamble and header sequences, and all other modulations are used for a payload only. The modulations of π/2-shift BPSK and π/2-shift QPSK are mandatory for THz-SC PHY and other modulations are optional. The FEC scheme is specified by two LDPC codes with a code rate of 14/15 and a code rate of 11/15 and a Reed-Solomon code with a code rate of 239/255. The two LDPC codes are mandatory for the THz-SC PHY

### 11b.2.1 Channelization of THz-SC PHY

The RF channels are defined in Figure 11b-1 and Table 11b-1. A compliant implementation shall support at least the channel with the default CHNL\_ID as defined in section 11b.1.4 from the channels allocated for operation by its corresponding regulatory body.

The PHYPIB\_CurrentChannel is the CHNL\_ID of the current channel. For the purpose of the Remote Scan Request and Remote Scan Response commands, as described in 6.5.7.3 and 6.5.7.4, respectively, the Channel Index field is the CHNL\_ID in Table 11b-1 in 11b.1.4.

### 11b.2.2 Modulation and coding

#### 11b.2.2.1 MCS dependent parameters

The MCS dependent parameters shall be set according to Table 11b-6. The chip rate for all THz-SC PHY MCS is given in Table 11b-8. The data rates in the table are approximate values.

**Table 11b-6—MCS dependent parameters**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **MCS identifier** | **bandwidth (GHz)** | **modulation** | **FEC rate** | **data rate (Gb/s)****w/o PW** | **data rate (Gb/s)****w PW** |
| 0 | 2,16 | BPSK | 11/15 | 1,2907 | 1,1294 |
| 1 | 2,16 | BPSK | 14/15 | 1,6426 | 1,4373 |
| 2 | 2,16 | QPSK | 11/15 | 2,5813 | 2,2587 |
| 3 | 2,16 | QPSK | 14/15 | 3,2853 | 2,8747 |
| 4 | 2,16 | 8-PSK | 11/15 | 3,8721 | 3,3882 |
| 5 | 2,16 | 8-PSK | 14/15 | 4,9278 | 4,3119 |
| 6 | 2,16 | 8-APSK | 11/15 | 3,8721 | 3,3882 |
| 7 | 2,16 | 8-APSK | 14/15 | 4,9278 | 4,3119 |
| 8 | 2,16 | 16QAM | 11/15 | 5,1627 | 4,5173 |
| 9 | 2,16 | 16-QAM | 14/15 | 6,5707 | 5,7493 |
| 10 | 2,16 | 64-QAM | 11/15 | 7,7440 | 6,7760 |
| 11 | 2,16 | 64-QAM | 14/15 | 9,8560 | 8,6240 |
| 12 | 4,32 | BPSK | 11/15 | 2,5814 | 2,2588 |
| 13 | 4,32 | BPSK | 14/15 | 3,2852 | 2,8746 |
| 14 | 4,32 | QPSK | 11/15 | 5,1626 | 4,5174 |
| 15 | 4,32 | QPSK | 14/15 | 6,5706 | 5,7494 |
| 16 | 4,32 | 8-PSK | 11/15 | 7,7442 | 6,7764 |
| 17 | 4,32 | 8-PSK | 14/15 | 9,8556 | 8,6238 |
| 18 | 4,32 | 8-APSK | 11/15 | 7,7442 | 6,7764 |
| 19 | 4,32 | 8-APSK | 14/15 | 9,8556 | 8,6238 |
| 20 | 4,32 | 16QAM | 11/15 | 10,3254 | 9,0346 |
| 21 | 4,32 | 16-QAM | 14/15 | 13,1414 | 11,4986 |
| 22 | 4,32 | 64-QAM | 11/15 | 15,488 | 13,552 |
| 23 | 4,32 | 64-QAM | 14/15 | 19,712 | 17,248 |
| 24 | 8,64 | BPSK | 11/15 | 5,1628 | 4,5176 |
| 25 | 8,64 | BPSK | 14/15 | 6,5704 | 5,7492 |
| 26 | 8,64 | QPSK | 11/15 | 10,3252 | 9,0348 |
| 27 | 8,64 | QPSK | 14/15 | 13,1412 | 11,4988 |
| 28 | 8,64 | 8-PSK | 11/15 | 15,4884 | 13,5528 |
| 29 | 8,64 | 8-PSK | 14/15 | 19,7112 | 17,2476 |
| 30 | 8,64 | 8-APSK | 11/15 | 15,4884 | 13,5528 |
| 31 | 8,64 | 8-APSK | 14/15 | 19,7112 | 17,2476 |
| 32 | 8,64 | 16QAM | 11/15 | 20,6508 | 18,0692 |
| 33 | 8,64 | 16-QAM | 14/15 | 26,2828 | 22,9972 |
| 34 | 8,64 | 64-QAM | 11/15 | 30,976 | 27,104 |
| 35 | 8,64 | 64-QAM | 14/15 | 39,424 | 34,496 |
| 36 | 12,96 | BPSK | 11/15 | 7,7442 | 6,7764 |
| 37 | 12,96 | BPSK | 14/15 | 9,8556 | 8,6238 |
| 38 | 12,96 | QPSK | 11/15 | 15,4878 | 13,5522 |
| 39 | 12,96 | QPSK | 14/15 | 19,7118 | 17,2482 |
| 40 | 12,96 | 8-PSK | 11/15 | 23,2326 | 20,3292 |
| 41 | 12,96 | 8-PSK | 14/15 | 29,5668 | 25,8714 |
| 42 | 12,96 | 8-APSK | 11/15 | 23,2326 | 20,3292 |
| 43 | 12,96 | 8-APSK | 14/15 | 29,5668 | 25,8714 |
| 44 | 12,96 | 16-QAM | 11/15 | 30,9762 | 27,1038 |
| 45 | 12,96 | 16-QAM | 14/15 | 39,4242 | 34,4958 |
| 46 | 12,96 | 64-QAM | 11/15 | 46,464 | 40,656 |
| 47 | 12,96 | 64-QAM | 14/15 | 59,136 | 51,744 |
| 48 | 17,28 | BPSK | 11/15 | 10,3256 | 9,0352 |
| 49 | 17,28 | BPSK | 14/15 | 13,1408 | 11,4984 |
| 50 | 17,28 | QPSK | 11/15 | 20,6504 | 18,0696 |
| 51 | 17,28 | QPSK | 14/15 | 26,2824 | 22,9976 |
| 52 | 17,28 | 8-PSK | 11/15 | 30,9768 | 27,1056 |
| 53 | 17,28 | 8-PSK | 14/15 | 39,4224 | 34,4952 |
| 54 | 17,28 | 8-APSK | 11/15 | 30,9768 | 27,1056 |
| 55 | 17,28 | 8-APSK | 14/15 | 39,4224 | 34,4952 |
| 56 | 17,28 | 16QAM | 11/15 | 41,3016 | 36,1384 |
| 57 | 17,28 | 16-QAM | 14/15 | 52,5656 | 45,9944 |
| 58 | 17,28 | 64-QAM | 11/15 | 61,952 | 54,208 |
| 59 | 17,28 | 64-QAM | 14/15 | 78,848 | 68,992 |
| 60 | 25,92 | BPSK | 11/15 | 15,4884 | 13,5528 |
| 61 | 25,92 | BPSK | 14/15 | 19,7112 | 17,2476 |
| 62 | 25,92 | QPSK | 11/15 | 30,9756 | 27,1044 |
| 63 | 25,92 | QPSK | 14/15 | 39,4236 | 34,4964 |
| 64 | 25,92 | 8-PSK | 11/15 | 46,4652 | 40,6584 |
| 65 | 25,92 | 8-PSK | 14/15 | 59,1336 | 51,7428 |
| 66 | 25,92 | 8-APSK | 11/15 | 46,4652 | 40,6584 |
| 67 | 25,92 | 8-APSK | 14/15 | 59,1336 | 51,7428 |
| 68 | 25,92 | 16QAM | 11/15 | 61,9524 | 54,2076 |
| 69 | 25,92 | 16-QAM | 14/15 | 78,8484 | 68,9916 |
| 70 | 25,92 | 64-QAM | 11/15 | 92,928 | 81,312 |
| 71 | 25,92 | 64-QAM | 14/15 | 118,272 | 103,488 |
| 72 | 51,84 | BPSK | 11/15 | 30,9768 | 27,1056 |
| 73 | 51,84 | BPSK | 14/15 | 39,4224 | 34,4952 |
| 74 | 51,84 | QPSK | 11/15 | 61,9512 | 54,2088 |
| 75 | 51,84 | QPSK | 14/15 | 78,8472 | 68,9928 |
| 76 | 51,84 | 8-PSK | 11/15 | 92,9304 | 81,3168 |
| 77 | 51,84 | 8-PSK | 14/15 | 118,2672 | 103,4856 |
| 78 | 51,84 | 8-APSK | 11/15 | 92,9304 | 81,3168 |
| 79 | 51,84 | 8-APSK | 14/15 | 118,2672 | 103,4856 |
| 80 | 51,84 | 16QAM | 11/15 | 123,9048 | 108,4152 |
| 81 | 51,84 | 16-QAM | 14/15 | 157,6968 | 137,9832 |
| 82 | 51,84 | 64-QAM | 11/15 | 185,856 | 162,624 |
| 83 | 51,84 | 64-QAM | 14/15 | 236,544 | 206,976 |
| 84 | 69.12 | BPSK | 11/15 | 41,3024 | 36,1408 |
| 85 | 69.12 | BPSK | 14/15 | 52,5632 | 45,9936 |
| 86 | 69.12 | QPSK | 11/15 | 82,6016 | 72,2784 |
| 87 | 69.12 | QPSK | 14/15 | 105,1296 | 91,9904 |
| 88 | 69.12 | 8-PSK | 11/15 | 123,9072 | 108,4224 |
| 89 | 69.12 | 8-PSK | 14/15 | 157,6896 | 137,9808 |
| 90 | 69.12 | 8-APSK | 11/15 | 123,9072 | 108,4224 |
| 91 | 69.12 | 8-APSK | 14/15 | 157,6896 | 137,9808 |
| 92 | 69.12 | 16QAM | 11/15 | 165,2064 | 144,5536 |
| 93 | 69.12 | 16-QAM | 14/15 | 210,2624 | 183,9776 |
| 94 | 69.12 | 64-QAM | 11/15 | 247,808 | 216,832 |
| 95 | 69.12 | 64-QAM | 14/15 | 315,392 | 275,968 |

A block length for THz-SC PHY shall be 64 chips. A block is formed according to 11a.2.3.4.1. The pilot word (PW) length for THz-SC PHY shall be 0 or 8 chips. The PW length of 8 is mandatory and that of 0 chips is optional.

#### 11b.2.2.2 Header dependent parameters

The header dependent parameters shall be set according to Table 11b-7. The headers use an extended Hamming (EH) code, as defined in 11a.2.3.2.3.

**Table 11b-7—** **Header rate dependent parameters**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Bandwidth****(GHz)** | **Header rate (Mb/s)** | **Modulation Scheme** | **Spreading Factor, LSF** | **FEC** | **PW length (chips), LPW** | **Code bits per block, LCBPS** | **Number of occupied blocks, Nblock\_hdr** | **Number of stuff bits, LSTUFF** |
| 2.160 | 162 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 4.320 | 324 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 8.640 | 648 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 12.960 | 972 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 17.280 | 1296 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 25.920 | 1944 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 51.840 | 3888 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |
| 69.120  | 5184 | /2-shift BPSK | 4 | EH | 8 | 14 | 19 | 40 |

#### 11b.2.2.3 Timing-related parameters

Table 11b-8 lists the general timing parameters associated with the THz-SC PHY.

**Table 11b-8—Timing-related parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Description** | **Value** | **Unit** | **Formula** |
| *R*c | Chip rate | 1760 … 42240 | Mchip/s | *B*×*1760/[2.16GHz]* |
| *T*C | Chip duration | ~0.023…~0.568 …  | ns | 1/*R*C |
| *L*block | block length | 64 | chips |  |
| *L*PW | Pilot word length | 0 | 8 | chips |  |
| *T*PW | Pilot word duration | 0 | ~1,472…~4,544 | ns | *LPW*×*TC* |
| *L*DC | Data chips per block | 64 | 56 | chips |  |
| *T*block | block duration | ~37.504 … ~1.472 | ns | *L*block×*T*c |
| *R*block | block rate | 26.663 … 679.347 | MHz | 1/ *T*block |

#### 11b.2.2.4 Frame-related parameters

The frame parameters associated with the PHY are listed in Table 11b-9 where CEIL is the ceiling function, which returns the smallest integer value greater than or equal to its argument. The maximum frame duration occurs when the number of octets in the PHY Payload field is 524288.

**Table 11b-9—Frame-related parameters**

|  |  |  |
| --- | --- | --- |
| **Parameter** | **Description** | **Value** |
| *N*SYNC | Number of code repetitions in the SYNC sequence | 14 or 28 |
| *T*SYNC | Duration of the SYNC sequence | ~1.019 µs or ~2.036 µs |
| *N*SFD | Number of code repetitions in SFD | 1 |
| *T*SFD | Duration of the SFD | ~0.073 µs  |
| *N*CES | Number of code repetitions i the CES | 11 |
| *T*CES | Duration of the CES | ~0.8000 µs |
| *N*pre | Number of code repetitions in the PHY preamble | 26 or 40 |
| *T*pre | Duration of the PHY preamble | ~1.891 µs or ~2.909 µs |
| *L*hdr | Length of the header in octets | 14 |
| *N*block\_hdr | Number of subblocks in the base frame header | CEIL[*L*hdr × 8 × *L*SF / (*L*subblock *–* *L*PW)] |
| *T*hdr | Duration of the base frame header | *N*block\_hdr × *T*block =~0.691 µs |
| *L*payload | Length of frame payload in octets | Variable |
| *L*hds | Length of the MAC header in octets | 4 |
| *N*subframe | Number of subframes | Variable between 1 and 256 |
| *L*FCS | Length of FCS in octest | 4 |
| *L*MFB | Length of MAC frame body in octets | *Lpayload + (Lhds + LFCS) Nframe* |
| *NPRPE* | Number of code repetitions in the PPRE | 26 |
| *TPRPE* | Duration of PPRE | ~1.891 µs |
| *Nbloc*k\_*PRPE* | Number of blocks between PPRE | Variable between 1024 and 4096 |
| *NCBPC* | Number of coded bits per chip in the MAC frame body | 1,2,3,3,4 and 6 for BPSK, QPSK, 8PSK, 8-APSK, 16-QAM and 64 QAM, respectively |
| *NPPRE\_frame* | Number of PPREs per frame | CEIL[(*Nblock\_*MFB / (*L*Block × 512)] - 1 |
| *T*PPRE\_interval | Interval of PPRE insertion | *T*block × *N*bloc\_PPRE + *T*PW |
| *L*CBPS | Number of coded bits per subblock in the MAC frame body | (*L*block *–* *L*PW) x *N*CBPC |
| *Nblock\_MFB* | Number of blocks in the MAC frame body | CEIL[(*L*MFB × 8) / (*R*FEC × *L*CBPS)] (RFEC: FEC Rate) |
| *T*MFB | Duration of the MAC and PHY frame body | *N*block\_MFB × *T*block |
| *T*datafield | Duration of the PHY datafield | *T*MFB + (*N*PPRE\_frame + 1) × *T*PW + *N*PPRE\_frame× *T*PPRE |
| *T*frame | Duration of the frame | *T*pre + *T*hdr + *T*datafield |

#### 11b.2.2.5 Modulation

After channel encoding and spreading, the bits shall be inserted into the constellation mapper.

The constellations of π/2-shift BPSK, π/2-shift QPSK and π/2-shift 8-PSK used for the THz-SC PHY are the same as illustrated in Figure 11-10 (a), (c) and (d), respectively, in 11.2.2.5.1 and 12.2.2.5.2. The constellations of π/2-shift 16QAM and π/2-shift 64QAM used for the THz-SC PHY are the same as illustrated in Figure 11-29 in 11.3.2.6.

The constellation diagram of π/2-shift 8-APSK is shown in figure 11b-4. The The π/2-shift 8-APSK shall encode 3 bits per symbol, with input bit *d*1 being the earliest in the stream. The π/2-rotation is performed in the same manner as in 11.2.2.5.1.



**Figure 11b-4— π/2-shift 8-APSK**

#### 11b.2.2.6 Forward Error Correction

The forward error correction (FEC) schemes are specified in this subclause. Supporting the following two rate-compatible LDPC codes, *i*.*e*. a rate-14/15 LDPC(1440,1344) code as defined in 11.2.2.6.3 and a rate-11/15 LDPC(1440,1056) code as defined in 11a.2.2.6, are mandatory for THz-SC PHY.

#### 11b.2.2.7 Stuff bits

Stuff bits shall be added to the end of the encoded MAC frame body if the number of the encoded data bits is not an integer multiple of the length of the data portion in the block. The number of stuff bits is computed for each subframe if standard aggregation is employed. The calculation of stuff bits follows the definition in 11a.2.2.7 where NCBPB is defined in TABLE for each MCS of the THz-SC PHY.

TABLE

|  |  |  |
| --- | --- | --- |
| MCS Identifier | NCBPB (pilot word length = 0) | NCBPB (pilot word length = 8) |
|  |  |  |
| TBD | TBD | TBD |
| TBD | TBD | TBD |
| TBD | TBD | TBD |
| TBD | TBD | TBD |

#### 11b.2.2.8 Code spreading

Table 11a-12 shows the spreading table for a frame header. The most significant bit of the output shall be transmitted first in Table 11a-12.

#### 11b.2.2.9 Scrambling

The frames shall be scrambled by modulo-2 addition of the data with the output of a PRBS generator, as defined in 11a.2.2.9.

### 11b.2.3 THz-SC PHY frame format

The THZ-SC PHY frame shall be formatted as illustrated in Figure 11-18.

The Frame Header field for the THz-SC PHY frame shall be formatted as illustrated in Figure 11a-4. It shall be constructed according to 11a.2.3.2.

The PHY preamble is described in 11a.2.3.1. The MAC header is defined in 6.2. The PHY header is defined in 11b.2.3.1.1, and the HCS is defined in 11a.2.3.2.2. The header FEC is defined in 11a.2.3.2.3. The PHY Payload field consisting of the MAC frame body, the pilot preamble (PPRE) and stuff bits, is described in 11b.2.3.2. The PPRE is described in 11b.2.3.3.2. The stuff bits are described in 11a.2.2.7.

#### 11b.2.3.1.1 THz-SC PHY Frame header

The THz-SC PHY header shall be formatted as illustrated in Figure 11b-5.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bits: b0-b6** | **b7** | **b8-b11** | **b12-b13** | **b14** | **b15-b35** |
| MCS | Pilot word | Scrambler seed ID | PPRE | Reserved | Frame length |

**Figure 11b-5—** **PHY header format for THz-SC PHY**

The MCS field shall be set according to the values in Table 11b10[[1]](#footnote-1).

The Pilot Word field shall be set to one if the pilot word used in the current frame and shall be set to zero if otherwise.

The Scrambler Seed ID field contains the scrambler seed identifier value, as defined in 11.2.2.10.

The PPRE field shall be set according to the values in Table 11a-15.

The Frame Length field shall be an unsigned integer equal to the number of octets in the MAC frame body of a regular frame, excluding the FCS.

**Table 11b-10—** **Modulation and coding scheme identifier**

|  |  |
| --- | --- |
| **MCS** | **MCS identifier** |
| 0000000 | 0 |
| 0000001 | 1 |
| 0000010 | 2 |
| 0000011 | 3 |
| 0000100 | 4 |
| 0000101 | 5 |
| 0000110 | 6 |
| 0000111 | 7 |
| 0001000 | 8 |
| 0001001 | 9 |
| 0001010 | 10 |
| 0001011 | 11 |
| 0001100 | 12 |
| 0001101 | 13 |
| 0001110 | 14 |
| 0001111 | 15 |
| 0010000 | 16 |
| 0010001 | 17 |
| 0010010 | 18 |
| 0010011 | 19 |
| 0010100 | 20 |
| 0010101 | 21 |
| 0010110 | 22 |
| 0010111 | 23 |
| 0011000 | 24 |
| 0011001 | 25 |
| 0011010 | 26 |
| 0011011 | 27 |
| 0011100 | 28 |
| 0011101 | 29 |
| 0011110 | 30 |
| 0011111 | 31 |
| 0100000 | 32 |
| 0100001 | 33 |
| 0100010 | 34 |
| 0100011 | 35 |
| 0100100 | 36 |
| 0100101 | 37 |
| 0100110 | 38 |
| 0100111 | 39 |
| 0101000 | 40 |
| 0101001 | 41 |
| 0101010 | 42 |
| 0101011 | 43 |
| 0101100 | 44 |
| 0101101 | 45 |
| 0101110 | 46 |
| 0101111 | 47 |
| 0110000 | 48 |
| 0110001 | 49 |
| 0110010 | 50 |
| 0110011 | 51 |
| 0110100 | 52 |
| 0110101 | 53 |
| 0110110 | 54 |
| 0110111 | 55 |
| 0111000 | 56 |
| 0111001 | 57 |
| 0111010 | 58 |
| 0111011 | 59 |
| 0111100 | 60 |
| 0111101 | 61 |
| 0111110 | 62 |
| 0111111 | 63 |
| 1000000 | 64 |
| 1000001 | 65 |
| 1000010 | 66 |
| 1000011 | 67 |
| 1000100 | 68 |
| 1000101 | 69 |
| 1000110 | 70 |
| 1000111 | 71 |
| 1001000 | 72 |
| 1001001 | 73 |
| 1001010 | 74 |
| 1001011 | 75 |
| 1001100 | 76 |
| 1001101 | 77 |
| 1001110 | 78 |
| 1001111 | 79 |
| 1010000 | 80 |
| 1010001 | 81 |
| 1010010 | 82 |
| 1010011 | 83 |
| 1010100 | 84 |
| 1010101 | 85 |
| 1010110 | 86 |
| 1010111 | 87 |
| 1011000 | 88 |
| 1011001 | 89 |
| 1011010 | 90 |
| 1011011 | 91 |
| 1011100 | 92 |
| 1011101 | 93 |
| 1011110 | 94 |
| 1011111 | 95 |

#### 11b.2.3.2 THz-SC PHY Payload field

The THZ-SC PHY Payload field is the last component of the frame, and is constructed as shown in Figure 11-23.

The PHY Payload field shall be constructed as follows:

1. Scramble the MAC frame body according to 11.2.2.10.
2. Encode the scrambled MAC frame body as specified in 11b.2.2.6.
3. Add stuff bits to the encoded and scrambled MAC frame body according to 11b.2.2.7.
4. Map the resulting MAC frame body onto the appropriate constellation as described in 11b.2.2.5.
5. Build blocks from the resulting MAC frame body according to 11a.2.3.4.1.
6. Insert PPRE periodically as described in 11b.2.3.3.2.

##### 11b.2.3.2.1 THZ-SC PHY Payload scrambling

The THZ-SC PHY payload shall use the scrambling process defined in 11.2.2.10

##### 11b.2.3.2.2 Modulation

Modulation for the MAC frame body is defined in 11b.2.2.5.

##### 11b.2.3.2.3 FEC

FEC for the MAC frame body is defined in 11b.2.2.6.

#### 11b.2.3.3 Pilot word and PPRE

##### 11b.2.3.3.1 Block and pilot word

The block and pilot word is defined as in 11a.2.3.4.1

##### 11b.2.3.3.2 PPRE

The PPRE is defined as in 11a.2.3.4.2

### 11b.2.4 Transmitter specifications

#### 11b.2.4.1 EVM Requirement

The EVM of a compliant transmitter shall be measured and calculated as defined in 11.1.7 and shall not

exceed the values given in Table 11b-11 for the indicated mode. Note that this requirement assumes a conducted measurement.

**Table 11b-11 Max EVM**

|  |  |  |  |
| --- | --- | --- | --- |
| MCS Identifier | Modulation | FEC Rate | Max. EVM [dB] |
| 0,12,24,36.48,60,72,84 | BPSK | 11/15 | TBD |
| 1,13,25,37,49,61,73,85 | BPSK | 14/15 | TBD |
| 2,14,26,38,50,62,74,86 | QPSK | 11/15 | -12 |
| 3,15,27,39,51,63,75,87 | QPSK | 14/15 | -15 |
| 4,16,28,40,52,64,76,88 | 8-PSK | 11/15 | TBD |
| 5,17,29,41,53,65,77,89 | 8-PSK | 14/15 | TBD |
| 6,18,30,42,54,66,78,90 | 8-APSK | 11/15 | TBD |
| 7,19,31,43,55,67,79,91 | 8-APSK | 14/15 | TBD |
| 8,20,32,44,56,68,80,92 | 16QAM | 11/15 | -18 |
| 9,21,33,45,57,69,81,93 | 16-QAM | 14/15 | -22 |
| 10,22,34,46,58,70,82,94 | 64-QAM | 11/15 | -25 |
| 11,23,35,47,59,71,83,95 | 64-QAM | 14/15 | -29 |

#### 11b.2.4.2 Transmitter Frequency Tolerance

The transmitted center frequency tolerance shall be TBD at maximum.

#### 11b.2.4.3 Symbol rate

The THz SC PHY shall be capable of transmitting at the chip rate, as defined in Table 11b-8, to within ±25 s/s.

The MAC parameter, pPHYClockAccuracy, shall be ±25 s/s.

#### 11b.2.4.4 Transmit power-on and power-down ramp

The transmit power-on ramp is defined as the time it takes for the RF power emitted by the compliant DEV to rise from less than 10% to greater than 90% of the maximum power to be transmitted in the frame.

The transmit power-on ramp shall be less than 9.3 ns.

The transmit power-down ramp is defined as the time it takes for the RF power emitted by the compliant DEV to fall from greater than 90% to less than 10% of the maximum power to be transmitted in the frame.

The transmit power-down ramp shall be less than 9.3 ns.

The transmit power ramps shall be constructed such that the emissions conform to the unwanted emissions specification defined in 11a.1.3.

### 11b.2.5 Receiver specifications

#### 11b.2.5.1 Error rate criterion

The error rate criterion shall be a frame error rate (FER) of less than 8% with a frame payload length of 214 octets. The error rate should be determined at the PHY SAP interface after any error correction methods

(excluding retransmission) required in the proposed device has been applied. The measurement shall be

performed in AWGN channel.

#### 11b.2.5.2 Receiver sensitivity

The receiver sensitivity is the minimum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11b2.5.1 is met. The error ratio shall be determined after any error correction has been applied. A compliant DEV that implements the THz SC PHY shall achieve at least the reference sensitivity listed in Table 11b-12.

**Table 11b-12—** **Reference sensitivity levels for MCS**

|  |  |  |  |
| --- | --- | --- | --- |
| MCS Identifier | Modulation | FEC Rate | Receiver Sensitivity [dBm] |
| 0,12,24,36.48,60,72,84 | BPSK | 11/15 | TBD |
| 1,13,25,37,49,61,73,85 | BPSK | 14/15 | TBD |
| 2,14,26,38,50,62,74,86 | QPSK | 11/15 | -61 |
| 3,15,27,39,51,63,75,87 | QPSK | 14/15 | -58 |
| 4,16,28,40,52,64,76,88 | 8-PSK | 11/15 | TBD |
| 5,17,29,41,53,65,77,89 | 8-PSK | 14/15 | TBD |
| 6,18,30,42,54,66,78,90 | 8-APSK | 11/15 | TBD |
| 7,19,31,43,55,67,79,91 | 8-APSK | 14/15 | TBD |
| 8,20,32,44,56,68,80,92 | 16-QAM | 11/15 | -55 |
| 9,21,33,45,57,69,81,93 | 16-QAM | 14/15 | -51 |
| 10,22,34,46,58,70,82,94 | 64-QAM | 11/15 | -49 |
| 11,23,35,47,59,71,83,95 | 64-QAM | 14/15 | -45 |

#### 11b.2.5.3 Receiver maximum input level

The receiver maximum input level is the maximum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11b.2.5.1 is met. A compliant receiver shall have a receiver maximum input level of at least –10 dBm for each of the modulation formats that the DEV supports.

### 11b.2.6 PHY layer timing

The values for the PHY layer timing parameters are defined Table 11b-13.

**Table 11b-13—PHY layer timing parameters**

|  |  |  |
| --- | --- | --- |
| **PHY parameter** | **Value** | **Subclause** |
| pPHYSIFSTime | 0.2 μs, 2.0 μs, 2.5 μs (default) | 11b.2.6.3 |
| pPHYChannelSwitchTime | 100 μs | 11b.2.6.5 |

#### 11b.2.6.1 Interframe space

A conformant implementation shall support the IFS parameters, as described in 7.4.1, given in Table 11b-14.

**Table 11b-14— IFS parameters**

|  |  |  |
| --- | --- | --- |
| **MAC parameter** | **Corresponding PHY parameter** | **Definition** |
| MIFS | pPHYMIFSTime | 11b.2.6.4 |
| SIFS | pPHYSIFSTime | 11b.2.6.3 |
| pBackoffslot  | pPHYSIFSTime+pCCADetectTime | 11.2.7.1 |
| RIFS | 2\*pPHYSIFSTime+pCCADetectTime | 8.4.1 |

#### 11b.2.6.2 Receive-to-transmit turnaround time

The receive to transmit turnaround time shall be pPHYSIFSTime, including the power-up ramp specified in 11b.2.4.4. The receive to transmit turnaround time shall be measured at the air interface from the trailing edge of the last symbol received until the first symbol of the PHY preamble is present at the air interface.

#### 11b.2.6.3 Transmit-to-receive turnaround-time

The transmit to receive turnaround time shall be less than pPHYSIFSTime, including the power-down ramp

specified in 11b.2.4.4.

#### 11b.2.6.4 Time between successive transmissions

The minimum time between successive transmissions shall be pPHYMIFSTime, including the power-up ramp specified in 11b.2.4 The pPHYMIFSTime shall be measured at the air interface from the trailing edge of the last symbol transmitted until the first symbol of the PHY preamble is present at the air interface.

#### 11b.2.6.5 Channel switch

The channel switch time is defined as the time from the last valid bit is received at the antenna on one channel until the DEV is ready to transmit or receive on a new channel. The channel switch time shall be less than pPHYChannelSwitchTime.

### 11b.2.7 PHY management for THz-SC PHY

The PHY PIB comprises the managed objects, attributes, actions, and notifications required to manage the THz-SC PHY layer of a DEV.

#### 11b.2.7.1 Maximum frame size

The maximum frame length allowed, pMAXFrameBodySize, shall be 1048576 octets. This total includes the MAC frame body, but not the PHY preamble, base header, (PHY header, MAC header and HCS). The maximum frame length also does not include the stuff bits.

#### 11b.2.7.2 Maximum transfer unit size

The maximum size data frame passed from the upper layers, pMaxTransferUnitSize, shall be 1048572 octets. If security is enabled for the data connection, the upper layers should limit data frames to 524288 octets minus the security overhead as defined in 6.3.4.2, 6.2.8.1.2, or 6.2.8.2.2.

#### 11b.2.7.3 Minimum fragment size

The minimum fragment size, pMinFragmentSize, allowed with the THz-SC PHY shall be 4096 octets.

## 11b.3 THz-OOK PHY

The THz-OOK PHY is designed for cost effective devices that require low power, low complexity and simple design. For applications using this PHY, transmission ranges of a few tens of centimeters are targeted. The THz-OOK PHY supports a single modulation scheme, OOK and a single FEC scheme, RS.

#### 11b3.1 Channelization for THz-OOK PHY

The possible channels are the same as defined in 11b.1.4. The transmit spectral masks for the THz-OOK PHY are the same as defined in 11b1.5.

### 11b.3.2 Modulation and Coding

The entire THz-OOK frame shall be modulated with OOK as specified in 11b.3.2.5. The MCS dependent parameters shall be set according to Table 11b-15. The chip rate of THz-OOK PHY is given in Table 11b-17. The FEC for THz-OOK PHY shall be RS coding as specified in 11b.3.2.6.

#### 11b.3.2.1 MCS dependent parameters

Table 11b-15 –– MCS dependent parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **MCS identifier** | **bandwidth (GHz)** | **Spreading****Factor****LSF** | **FEC rate** | **data rate (Gb/s)****w/ PW** | **data rate (Gb/s)****w/o PW** |
| 0 | 2.16 | 1 | 224/240 | 1,64266667 | 1,43733333 |
| 1 | 4.32 | 1 | 224/240 | 3,28533333 | 2,87466667 |
| 2 | 8.64 | 1 | 224/240 | 6,57066667 | 5,74933333 |
| 3 | 12.96 | 1 | 224/240 | 9,856 | 8,624 |
| 4 | 17.28 | 1 | 224/240 | 13,1413333 | 11,4986667 |
| 5 | 25.92 | 1 | 224/240 | 19,712 | 17,248 |
| 6 | 51.84 | 1 | 224/240 | 39,424 | 34,496 |
| 7 | 69.12 | 1 | 224/240 |  |  |

.

A block length for THz-SC PHY shall be TBD chips. The pilot word (PW) length for THz-SC PHY shall be 0 or 8 chips. The PW length of 8 is mandatory and that of 0 chips is optional.

#### 11b.3.2.2 Header dependent parameters

The header dependent parameters shall be set according to the values defined for the SC-PHY in Table 11b-7.

#### 11b.3.2.3 Timing-related parameters

The general timing parameters for the THz-OOK PHY shall be set as defined for the THz-SC PHY according to Table 11b-8.

#### 11b.3.2.4 Frame-related parameters

The frame parameters associated with the THz-OOK PHY are the same as for the THZ-SC PHY which are defined in in Table 11b-9.

#### 11b.3.2. 5 Modulation

THz-OOK frames shall be modulated using OOK. The OOK modulation shall use variable amplitudes to represent the data. As shown in Figure 11b-6, OOK shall be represented by two points in the constellation map. The normalization factor, *K*MODshall be sqrt(2).



**Figure 11b-6 Constellation Diagram for OOK**

The actual transmitted RF signal can be written as follows:

$$S\_{RF}(t)=\sum\_{k=0}^{N\_{chip}-1}a\_{k}s\_{b}(t-kT\_{c})cos⁡(2πf\_{c}t)$$

where

SRF (t) is the transmitted RF signal

Tc is the chip duration

Nchip is the number of transmitted chips in the transmitted OOK PHY frame

fc is the center frequency

ak is a binary value in the transmitted frame

SB(t) is the baseband pulse shape

#### 11b.3.2.6 Forward Error Correction

The forward error correction schemes for the THz-OOK PHY are the same as defined in 11b.2.2.6.

#### 11b.3.2.7 Stuff bits

TBD

#### 11b.3.2.8 Code spreading

For increased robustness, code spreading shall be applied to THz-OOK frame headers and payloads according to 11a.3.2.7.

#### 11b.3.2.9 Scrambling

Scrambling of THz-OOK fields shall be performed as defined in 11a.3.2.8.

### 11b.3.3 THz-OOK PHY frame format

The THZ-OOK PHY frame shall be formatted as illustrated in Figure 11-18.The Frame Header field for the THz-OOK PHY frame shall be formatted as illustrated in Figure 11a-20. It shall be constructed according to 11a.2.3.2.

The PHY preamble is described in 11a.3.3.1. The MAC header is defined in 6.2. The PHY header is defined in 11b.3.3..1, and the HCS is defined in 11a3.3.2.2. The header FEC is defined in 11a.2.3.2.3. The PHY Payload field consisting of the MAC frame body, and stuff bits, is described in 11a.3.3.3. The stuff bits are described in 11a.3.3.3.

#### 11b.3.3.1 THz-OOK PHY Frame header

The THz-OOK PHY header shall be formatted as illustrated in Figure 11b-7.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bits: b0-b3** | **b4** | **B5-b8** | **B9-b10** | **B11** | **B12-b32** |
| MCS | Pilot word | Scrambler seed ID | PPRE | Reserved | Frame length |

**Figure 11b-7—** **PHY header format for THz-OOK PHY**

The MCS field shall be set according to the values in Table 11b19.

The Pilot Word field shall be set to one if the pilot word used in the current frame and shall be set to zero if otherwise.

The Scrambler Seed ID field contains the scrambler seed identifier value, as defined in 11.2.2.10.

The Frame Length field shall be an unsigned integer equal to the number of octets in the MAC frame body of a regular frame, excluding the FCS.

**Table 11b-16—** **Modulation and coding scheme**

|  |  |
| --- | --- |
| **MCS** | **MCS identifier** |
| 000 | 0 |
| 001 | 1 |
| 010 | 2 |
| 011 | 3 |
| 100 | 4 |
| 101 | 5 |
| 110 | 6 |
| 111 | 7 |

#### 11b.3.3.2 THz- OOK PHY Payload field

The THz-OOK PHY Payload field is the last component of the frame, and is constructed as shown in Figure 11a-26.

The PHY Payload field shall be constructed as follows:

1. Scramble the MAC frame body according to 11b.3.3.2.1.
2. Encode the scrambled MAC frame body as specified in 11b.3.3.2.3.
3. Add stuff bits to the encoded and scrambled MAC frame body according to 11b.3.2.7.
4. Map the resulting MAC frame body onto the appropriate constellation as described in 11b.3.2.5.
5. Build blocks from the resulting MAC frame body according to 11a.2.3.4.1.

##### 11b.3.3.2.1 THZ- OOK PHY Payload scrambling

The THZ-OOK PHY payload shall use the scrambling process defined in 11.2.2.10 / 11a.3.2.8?

##### 11b.3.3.2.2 Modulation

Modulation for the MAC frame body is defined in 11b.3.2.5.

##### 11b.3.3.2.3 FEC

FEC for the MAC frame body is defined in 11b.3.2.6.

#### 11b.3.3.3 Blocks and pilot word

The block and pilot word is defined as in 11a.3.3.3.5

### 11b.3.4 Transmitter specifications

#### 11b.3.4.1 EVM Requirement

Eye opening for OOK is described in G.7.

#### 11b.3.4.2 Transmit center frequency tolerance

#### 11b.3.4.3 Symbol rate

The THz OOK PHY shall be capable of transmitting at the chip rate, as defined in Table 11b-17, to within ±25 s/s.

The MAC parameter, pPHYClockAccuracy, shall be ±25 s/s.

#### 11b.3.4.4 Transmit power-on and power-down ramp

The transmit power-on ramp is defined as the time it takes for the RF power emitted by the compliant DEV to rise from less than 10% to greater than 90% of the maximum power to be transmitted in the frame.

The transmit power-on ramp shall be less than TBD ns.

The transmit power-down ramp is defined as the time it takes for the RF power emitted by the compliant DEV to fall from greater than 90% to less than 10% of the maximum power to be transmitted in the frame.

The transmit power-down ramp shall be less than TBD ns.

The transmit power ramps shall be constructed such that the emissions conform to the unwanted emissions specification defined in 11a.1.3.

### 11b.3.5 Receiver specifications

#### 11b.3.5.1 Error rate criterion

The error rate criterion shall be a frame error rate (FER) of less than 8% with a frame payload length of 214 octets. The error rate should be determined at the PHY SAP interface after any error correction methods

(excluding retransmission) required in the proposed device has been applied. The measurement shall be

performed in AWGN channel.

#### 11b.3.5.2 Receiver sensitivity

The receiver sensitivity is the minimum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11b3.5.1 is met. The error ratio shall be determined after any error correction has been applied. A compliant DEV that implements the THz OOK PHY shall achieve at least the reference sensitivity listed in Table 11b-21.

**Table 11b-17 Reference Sensitivity Levels for THz OOK MCS**

|  |  |  |  |
| --- | --- | --- | --- |
| MCS Identifier | Bandwidth [GHz] |  | Max. Receiver Sensitivity [dBm] |
| 0 | 2.16 |  | TBD |
| 1 | 4.32 |  | TBD |
| 2 | 8.64 |  | TBD |
| 3 | 12.96 |  | TBD |
| 4 | 17.28 |  | TBD |
| 5 | 25.92 |  | TBD |
| 6 | 51.84 |  | TBD |

#### 11b.3.5.3 Receiver maximum input level

The receiver maximum input level is the maximum power level of the incoming signal, in dBm, present at the input of the receiver for which the error rate criterion in 11b.3.5.1 is met. A compliant receiver shall have a receiver maximum input level of at least –10 dBm for each of the modulation formats that the DEV supports.

### 11b.3.6 PHY layer timing

The values for the THz-OOK PHY layer timing parameters are defined Table 11b-22.

**Table 11b-18—PHY layer timing parameters**

|  |  |  |
| --- | --- | --- |
| **PHY parameter** | **Value** | **Subclause** |
| pPHYSIFSTime | 0.2 μs, 2.0 μs, 2.5 μs (default) | 11b.3.6.3 |
| pPHYChannelSwitchTime | 100 μs | 11b.3.6.5 |

#### 11b.3.6.1 Interframe space

A conformant implementation shall support the IFS parameters, as described in 7.4.1, given in Table 11b-23.

**Table 11b-19— IFS parameters**

|  |  |  |
| --- | --- | --- |
| **MAC parameter** | **Corresponding PHY parameter** | **Definition** |
| MIFS | pPHYMIFSTime | 11b.3.6.4 |
| SIFS | pPHYSIFSTime | 11b.3.6.3 |
| pBackoffslot  | pPHYSIFSTime+pCCADetectTime | 11.2.7.1 |
| RIFS | 2\*pPHYSIFSTime+pCCADetectTime | 8.4.1 |

#### 11b.3.6.2 Receive-to-transmit turnaround time

The receive to transmit turnaround time shall be pPHYSIFSTime, including the power-up ramp specified in 11b.3.4.4. The receive to transmit turnaround time shall be measured at the air interface from the trailing edge of the last symbol received until the first symbol of the PHY preamble is present at the air interface.

#### 11b.3.6.3 Transmit-to-receive turnaround-time

The transmit to receive turnaround time shall be less than pPHYSIFSTime, including the power-down ramp

specified in 11b.3.4.4.

#### 11b.3.6.4 Time between successive transmissions

The minimum time between successive transmissions shall be pPHYMIFSTime, including the power-up ramp specified in 11b.3.4 The pPHYMIFSTime shall be measured at the air interface from the trailing edge of the last symbol transmitted until the first symbol of the PHY preamble is present at the air interface.

#### 11b.3.6.5 Channel switch

The channel switch time is defined as the time from the last valid bit received at the antenna on one channel until the DEV is ready to transmit or receive on a new channel. The channel switch time shall be less than pPHYChannelSwitchTime.

### 11b.3.7 PHY management for THZ- OOK PHY

The PHY PIB comprises the managed objects, attributes, actions, and notifications required to manage the THz-OOK PHY layer of a DEV.

#### 11b.3.7.1 Maximum frame size

The maximum frame length allowed, pMAXFrameBodySize, shall be 1048576 octets. This total includes the MAC subheader and the MAC frame body, but not the PHY preamble, base header, (PHY header, MAC header and HCS). The maximum frame length also does not include the stuff bits.

#### 11b.3.7.2 Maximum transfer unit size

The maximum size data frame passed from the upper layers, pMaxTransferUnitSize, shall be 1048572 octets. If security is enabled for the data connection, the upper layers should limit data frames to 524288 octets minus the security overhead as defined in 6.3.4.2, 6.2.8.1.2, or 6.2.8.2.2.

#### 11b.3.7.3 Minimum fragment size

The minimum fragment size, pMinFragmentSize, allowed with the THz-OOK PHY shall be 4096 octets.

1. In this proposal the MCS field includes also the combination with different bandwidths. It might be an option to split the MCS filed into a field containing the MCS identifier only and a field containing a bandwidth identifier only [↑](#footnote-ref-1)