**IEEE P802.15**

**Wireless Personal Area Networks**

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| --- | --- |
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# #1: PHY A,B,C tables

**Table 01. PHY A operating modes**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Modulation***(phyOccMcsID)* | **RLL***(phyOccRLLCode)* | **Optical clock rate***(phyOccOpticalClockRate)* | **FEC***(phyOccFec)* | **Bit Rate** |
| **PHY A operating modes** |
| UFSOOK |  |  |  |  |
| Twinkle VPPM |  |  |  |  |
| S2-PSK | Differential code | 10 Hz  | Temporal error correction | 5 bps |
| S8-PSK | Grey code | 10 Hz | Temporal error correction | 30 bps |
| HS-PSK | ½ code rate for S2-PSK; none for DS8-PSK | 10 kHz | Temporal error correction;Outer FEC with GF(16)  | 22 kbps |
| **PHY B operating modes** |
| RS-FSK | None | 30 Hz | XOR FEC | 60/90 bps |
| C-OOK | Manchester/ 4B6B | 2.2 kHz/ 4.4 kHz | Temporal error correction(DS rate=100/ DS rate=60) | 60/150/580/700 bps |
| CM-FSK | None | 10 Hz | Temporal error correction | 40/50/60bps |
| Packet PWM/PPM | None | 100 kHz | Temporal error correction | 5.5/ 8 kbps |
| **PHY C operating modes** |
| A-QL | None | 10 Hz | Hamming (11,15)/ None | 5.28/ 7.56 kbps(16x16 cells) |
| HA-QL | Differential code | 10 Hz | Hamming (11,15)/ None | 220/ 300 bps(8x8 cells) |
| VTASC | None |  |  |  |
| Invisible data embedded | None |  |  |  |

# #2: PHY dimming

**4.4.3.1.7 FSK dimming**

FSK achieves dimming by controlling the duty cycle of the signal. Figure 13 describes the dimming control mechanism by FSK.



**Figure 13- Schematic mechanism for FSK diming**

**8.5.2.4.4 S2-PSK dimming**

S2-PSK achieves dimming by controlling the amplitude of ones or zeros in OOK signal. Without controlling the amplitude, ones are at full brightness (totally “ON”), and zeros are at full darkness (totally “OFF”), enabling the average brightness at 50%. The configuration of ones’ amplitude allows the average brightness output at the dimmed level (<50%). Likewise, the configuration of zeros’ amplitude allows the average brightness output at the bright level (>50%). The desired dimming level is the average brightness of one and zero.

The clock rate of OOK modulation is fixed at a low frequency (200Hz for indoor or 125Hz for outdoor) throughout the transmission time and dimming control. Consequently, the amplitude controlling is performed. Hence the S2-PSK dimming is called Low-Clock-Rate OOK amplitude dimming.

**8.5.2.5.2 CM-FSK dimming**

CM-FSK implements FSK dimming by controlling the duty cycle of the FSK signal. Dimming is supported in steps of 10%.

**8.5.2.6.1 A-QL dimming**

Since A-QL is modulated at a low optical clock rate (such as 10Hz) that is perceptible by human eyes, dimming is not supported. The change of color of the background and the color modulation of the A-QL are independent.

**8.5.2.6.5 HA-QL dimming**

The change in color background does not affect to the data communication. Dimming is hence supported by controlling the background color. The delay time of dimming control should be synchronized to the symbol rate of transmission.

# #3: PPDU frame formats

**8.6.6.5 S8-PSK PPDU format**

|  |  |
| --- | --- |
| **Preamble**(see 8.6.6.5.1) | **PSDU**(see 8.6.6.5.2) |
| SHR | PHY payload |

The S8-PSK PPDU frame structure consists of the preamble field, and the PSDU PHY payload.

Without using the PHR field, the configuration of S8-PSK PHY frame format shall be implemented over the corresponding PHY PIB attributes:

* *phyOccMcsID* = 1: represents that S8-PSK is used
* Other configurable attributes include: *phyOccOpticalClockRate*, *phyOccDim*, *phyOccRLLCode*, *phyOccFec*, *phyS8pskNoLightSource*s, *phyS8pskModulationRate* shall specify the parameters used for the demodulation as given in table 188- PHY PIB attributes.

**8.6.6.6 Hybrid Spatial PSK (HS-PSK)**

|  |  |  |  |
| --- | --- | --- | --- |
| **Preamble** | **PHY header** | **HCS** | **PSDU** |
| SHR | PHR | PHY payload |

The HS-PSK PPDU frame structure consists of the preamble field, PHR sub-fields, and the PSDU PHY payload.

The configuration of HS-PSK PHY frame format shall also be implemented over the corresponding PHY PIB attributes:

* *phyOccMcsID* = 2: represents that HS-PSK is used
* Other configurable attributes include: *phyOccOpticalClockRate*, *phyOccDim*, *phyOccRLLCode*, *phyOccFec*, *phyHSpskNoLightSources, phyHSpskModulationRate, phyHSpskPsduLength* shall specify the parameters used for the demodulation as given in table 188- PHY PIB attributes.

**8.6.6.6.1 HS-PSK Preamble field**

The preamble field for HS-PSK the same as S8-PSK preamble in which two light sources (LEDs inside are spatial redundancy grouped) blink at the same frequency (e.g. 200Hz) and inverse phases.

Since HS-PSK is the hybrid modulation of S2-PSK and DSM-PSK, the duration for HS-PSK preamble is equivalent to the S2-PSK preamble.

|  |  |
| --- | --- |
| Duration | two S2-PSK bit times |
| S2-PSK state | 1 1 1 1 |
| DS8-PSK data | None |

1 means that the two light sources blink at the same frequency (200Hz) and inverse phases.

**8.6.6.6.2 HS-PSK PHR fields**

Besides configurable PHY PIB attributes used, PHR field shall optional used to notice the change of the following PHY PIB attributes:

**Table – HS-PSK PHR subfields**

|  |  |  |
| --- | --- | --- |
| **PHY header subfields** | **Bit-width** | **Explanation on usage** |
| DSM-PSK mode | 16 | The number of phases (i.e. value of M) used on DSM-PSK. |
| PSDU length | 16 | Length available at *phyHSpskPsduLength* configuration |
| HSC | 16 | Header check sequence |

**8.6.9 Asynchronous-Quick Link PPDU format**

|  |  |  |  |
| --- | --- | --- | --- |
| **Preamble** | **PHY header** | **HCS** | **PSDU** |
| SHR | PHR | PHY payload |

The A-QL PPDU frame structure consists of the preamble field, PHR sub-fields, and the PSDU PHY payload.

The configuration of HS-PSK PHY frame format shall also be implemented over the corresponding PHY PIB attributes:

* *phyOccMcsID* = 5: represents that A-QL is used
* Other configurable attributes include: *phyOccOpticalClockRate*, *phyOccDim*, *phyOccRLLCode*, *phyOccFec*, *phyAqlNoCells, phyAqlNoCellReference, phyAqlByteOrientedEnable, phyAqlNoColors, and phyAqlPsduLength* shall specify the parameters used for the demodulation as given in table 188- PHY PIB attributes.

**9.6.9.1** **Preamble field**

The preamble field for A-QL mode is four data-block times long. Each block time is for a specific preamble matrix as follows.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Duration | one block time | one block time | one block time | one block time |
| Preamble | A | A’ | A | A’ |

A and A’ are two inverse forms of the 2D-code.

$$A\_{M×M}=\left(\begin{matrix}1 0&\cdots &1 0\\\vdots &\ddots &\vdots \\0 1&\cdots &0 1\end{matrix}\right); A'\_{M×M}=\left(\begin{matrix}0 1&\cdots &0 1\\\vdots &\ddots &\vdots \\1 0&\cdots &1 0\end{matrix}\right); $$

By comparing a pair of preambles A and A’, the receiver is able to distinguish individual-cells on the transmitter.

**8.6.9.2 PHR fields**

Besides configurable PHY PIB attributes used, PHR fields shall optional used to notice the change of the following PHY PIB attributes:

**Table – A-QL PHR subfields**

|  |  |  |
| --- | --- | --- |
| **PHY header subfields** | **Bit-width** | **Explanation on usage** |
| A-QL mode | 16 | The number of colors shall be used for PSDUs. |
| PSDU length | 16 | Length available at *phyAqlPsduLength* configuration |
| HSC | 16 | Header check sequence |

**8.6.10 Hidden A-QL PPDU format**

|  |  |
| --- | --- |
| **Preamble** | **PSDU** |
| SHR | PHY payload |

The HA-QL PPDU frame structure consists of the preamble field, and the PSDU PHY payload.

Without PHR field, the configuration of HA-QL PHY frame format shall also be implemented over the corresponding PHY PIB attributes:

* *phyOccMcsID* = 6: represents that HA-QL is used
* Other configurable attributes include: *phyOccOpticalClockRate*, *phyOccDim*, *phyOccRLLCode*, *phyOccFec*, *phyHAqlNoCells, phyHAqlNoCellReference, phyHAqlByteOrientedEnable, and phyHAqlPsduLength* shall specify the parameters used for the demodulation as given in table 188- PHY PIB attributes.

# #4: PHY constants and attributes table

**Table 188- PHY PIB attributes**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Attribute** | **Ident.** | **Type** | **Range** | **Description** |
| phyOccMcsID | - | Int. | 0-TBD | This attribute identifies the OCC modulation.0: S2-PSK1: S8-PSK2: HS-PSK3: C-OOK4: CM-FSK5: A-QL6: Hidden A-QL (HA-QL)7-TBD: Reserved |
| phyOccOpticalClockRate | - | Int. | 0-15 | The optical clock rate (or symbol rate) applied for S2-PSK, S8-PSK, CM-FSK, and screen modulations (A-QL, and HA-QL); C-OOK; and DSM-PSK modulations respectively.0-3: 5 Hz/10 Hz/15 Hz/20 Hz4-5: 2.2 kHz/ 4.4 kHz6-7: 10 kHz/ 50 kHz8-15: Reserved |
| phyOccDim  | - | Int. | 0-1000 | Refer to *phyDim* (0x02 Identifier), IEEE 802.15.7-2011 std. OCC dimming is configured in steps of TBD %. |
| phyOccRLLCode | - | Int. | 0-7 | This specifies the RLL coding corresponding to the specific OCC modulation (phyOccMcsID):In case of S2-PSK modulation, the RLL coding is 0: None 1: Differential code ½ rate Other values: ReservedIn case of S8-PSK modulation, the RLL coding is 0: None 1: 3 bits Grey code Other values: ReservedIn case of HS-PSK, the RLL coding is 0: None  1: 1/2 code rate for S2-PSK and none for DS8-PSK Other values: ReservedIn case of C-OOK modulation, the RLL coding is 0: Manchester 1: 4B6B coding Other values: ReservedIn case of CM-FSK modulation, the RLL coding is 0: None Other values: ReservedIn case of A-QL modulation, the RLL coding is 0: None Other values: ReservedIn case of HA-QL modulation, the RLL coding is 0: None  1: Differential ½ code  Other values: Reserved |
| phyOccFec | - | Int. | 0-7 | This attribute specifies FEC corresponding to the specific OCC modulation (phyOccMcsID):In case of S2-PSK modulation, 0: None (temporal error correction is optionally used) Other values: ReservedIn case of S8-PSK modulation, 0: None (temporal error correction is optionally used) Other values: ReservedIn case of HS-PSK modulation, 0: None for both S2-PSK and DS8-PSK 1: None for S2-PSK and RS (15, 11) for DS8-PSK Other values: ReservedIn case of C-OOK modulation, 0: Temporal repeating code DS rate=100 1: Temporal repeating code DS rate=60 Other values: ReservedIn case of CM-FSK modulation, 0: None Other values: ReservedIn case of A-QL modulation, 0: None 1: Hamming (11,15) Other values: ReservedIn case of HA-QL modulation, 0: None 1: Hamming (11,15) Other values: Reserved |
| Below PHY attributes shall be present if phyOccMcsID = 0 (i.e. S2-PSK modulation). |
| phyS2pskNoLightSources | - | Int. | 0-3 | The number of light sources used to modulate S2-PSK signal.0: two light sources1-3: Reserved |
| phyS2pskModulationRate | - | Int. | 0-7 | This attribute specifies the modulation frequency used for S2-PSK.0: 200 Hz1: 125 Hz2-7: Reserved |
| Below PHY attributes shall be present if phyOccMcsID = 1 (i.e. S8-PSK modulation). |
| phyS8pskNoLightSources | - | Int. | 0-3 | The number of light sources used to modulate S8-PSK signal.0: two light sources, each consists of 4 LEDs.1: four light sources, each consists of 4 LEDs (4x4 Digital Signage Tx).2-3: Reserved |
| phyS8pskModulationRate | - | Int. | 0-7 | This attribute specifies the modulation frequency used for S8-PSK.0: 800 Hz1-7: Reserved |
| Below PHY attributes shall be present if phyOccMcsID = 2 (i.e. HS-PSK modulation). |
| phyHSpskNoLightSources | - | Int. | 0-7 | The number of light sources used to modulate HS-PSK signal.0: two light sources, each consists of 8 LEDs.1: two light sources, each consists of 10 LEDs.1-7: Reserved |
| phyHSpskHighStreamMode | - | Int. | 0-7 | The modulation of high data stream.0: DS8-PSK mode1: DS10-PSK mode2-7: Reserved |
| phyHSpskModulationRate | - | Int. | 0-7 | This attribute specifies the modulation frequency used for S2-PSK and DSM-PSK of HS-PSK.0: 200Hz for S2-PSK and 80 kHz for DS8-PSK1: 200Hz for S2-PSK and 400 kHz for DS8-PSK2-7: Reserved |
| phyHSpskPsduLength | - | Int. | TBD | This is to specify the length of the high-speed link of HS-PSK.TBD |
| Below PHY attributes shall be present if phyOccMcsID = 3 (i.e. C-OOK modulation). |
| phyCookDSrate | - | Int. | 0-7 | This attribute specifies the Data Sub-frame rate (DS rate) of C-OOK.0: 60 DS/sec1: 100 DS/sec2-7: Reserved |
| phyCookSFsymbol | - | Int. | 0-7 | This attribute specifies the SF symbol of PSDU of C-OOK.0: 6B symbol1: 10B symbol2-3: Reserved |
| phyCookAb | - | Int. | 0-3 | This attribute specifies the amount of Asynchronous bit (Ab) per data sub-frame of C-OOK.0: 1 bit1: 2 bit2-3: Reserved |
| Below PHY attributes shall be present if phyOccMcsID = 4 (i.e. CM-FSK modulation). |
| phyCmfskAb | - | Int. | 0-1 | This attribute specifies the number of asynchronous bits (Ab) used to insert to the pack of data bits in prior to mapping a frequency in CM-FSK.0: 1 Ab is used to support the asynchronous communication1: 2 Ab(s) is used to support the detection of missing symbols during reception. |
| phyCmfskNoFrequency | - | Int. | 0-3 | This attribute specifies the number of frequencies used to modulate data in CM-FSK.0: 32-FSK1: 64-FSK2-3: Reserved |
| phyCmfskFrequencySeparation | - | Int. | 0-7 | This attribute specifies the frequency separation in CM-FSK.0: 50 Hz1: 100 Hz2-7: Reserved |
| phyCmfskNoPhase | - | Int. | 0-3 | This attribute specifies the number of phases used to modulate data in CM-FSK.0: None1: 2-PSK2-3: Reserved |
| phyCmfskPreamble1 | - | Int. | 0-3 | This attribute specifies the frequency value of the first preamble (fSF) in CM-FSK.0: 200Hz1-3: Reserved |
| phyCmfskSplitterEnable | - | Boolean | T/F | This attribute enables whether the splitter usage in between frequency symbols in CM-FSK.FALSE: Disable (Default)TRUE: Enable |
| Below PHY attributes shall be present if phyOccMcsID = 5 (i.e. A-QL modulation). |
| phyAqlNoCells | - | Int. | 0-7 | The number of individual cells on Tx in A-QL mode.0: 16x16 cells1-7: Reserved |
| phyAqlNoCellReference | - | Int. | 0-3 | The number of cells per each of four reference corners in A-QL mode.0: 1 cell reference1: 2x2 cell reference2-3: Reserved |
| phyAqlByteOrientedEnable | - | Boolean | T/F | The enabler of byte-oriented mode in A-QL mode.FALSE: Disable (bit-oriented)TRUE: Enable (byte-oriented) |
| phyAqlNoColors | - | Int. | 0-3 | The number of colors used in A-QL mode.0: Grey marking (no color)1: 2 colors2: 4 colors3: 8 colors |
| phyAqlPsduLength | - | Int. | TBD | This is to specify the length of PSDUTBD |
| Below PHY attributes shall be present if phyOccMcsID = 6 (i.e. HA-QL modulation). |
| phyHAqlNoCells | - | Int. | 0-7 | The number of individual cells on Tx in HA-QL mode.0: 8x8 cells1: 16x16 cells2-7: Reserved |
| phyHAqlNoCellReference | - | Int. | 0-3 | The number of cells per each of four reference corners in HA-QL mode.0: 1 cell reference1-3: Reserved |
| phyHAqlByteOrientedEnable | - | Boolean | T/F | The enabler of byte-oriented mode in HA-QL mode.FALSE: Disable (bit-oriented)TRUE: Enable (byte-oriented) |
|  |  |  |  |  |
|  |  |  |  |  |

# #5: PHY A specifications

**13.3.1.4 RLL Coding**

The RLL coder shall be implemented to protect the signal from the rotation of camera and the error caused by the time deviation between a pair of light sources on the rolling image.

The PPDU shall utilize RLL coding at code rate 1/2 as follows.

|  |  |  |
| --- | --- | --- |
| **Duration** | **one bit time** | **one bit time** |
| Data bit | 0 | 1 |
| RLL coding | 0 0 | 0 1 |

After RLL coding, the output sequence shall be feed into S2-PSK Encoder.

Merged DS8-PSK decoding tables 211-217:

**Table 211: Demapping S\_Phase from states under dimming**

|  |  |
| --- | --- |
| **8-states Input** | **S\_Phase Output** |
| **Dimming 1/8** | **Dimming 2/8** | **Dimming 3/8** | **Dimming 4/8** | **Dimming 5/8** | **Dimming 6/8** | **Dimming 7/8** |
| 1000 0000 | 1000 0001 | 1000 0011 | 1000 0111 | 1000 1111 | 1001 1111 | 1011 1111 | 1 |
| 0100 0000 | 1100 0000 | 1100 0001 | 1100 0011 | 1100 0111 | 1100 1111 | 1101 1111 | 2 |
| 0010 0000 | 0110 0000 | 1110 0000 | 1110 0001 | 1110 0011 | 1110 0111 | 1110 1111 | 3 |
| 0001 0000 | 0011 0000 | 0111 0000 | 1111 0000 | 1111 0001 | 1111 0011 | 1111 0111 | 4 |
| 0000 1000  | 0001 1000 | 0011 1000 | 0111 1000 | 1111 1000 | 1111 1001 | 1111 1011 | 5 |
| 0000 0100  | 0000 1100 | 0001 1100 | 0011 1100 | 0111 1100 | 1111 1100 | 1111 1101 | 6 |
| 0000 0010 | 0000 0110 | 0000 1110 | 0001 1110 | 0011 1110 | 0111 1110 | 1111 1110 | 7 |
| 0000 0001 | 0000 0011 | 0000 0111 | 0000 1111 | 0001 1111 | 0011 1111 | 0111 1111 | 8 |

Merged DS8-PSK decoding tables 218-224 (presence of x\_state under bad-sampling):

**Table 211: Demapping S\_Phase from states under dimming**

|  |  |
| --- | --- |
| **8-states Input** | **S\_Phase Output** |
| **Dimming 1/8** | **Dimming 2/8** | **Dimming 3/8** | **Dimming 4/8** | **Dimming 5/8** | **Dimming 6/8** | **Dimming 7/8** |
| xx00 0000 | 1x00 000x | 1x00 00x1 | 1x00 0x11 | 1x00 x111 | 1x0x 1111 | 1xx1 1111 | 1 |
| 0xx0 0000 | x1x0 0000 | 11x0 000x | 11x0 00x1 | 11x0 0x11 | 11x0 x111 | 11xx 1111 | 2 |
| 00xx 0000 | 0x1x 0000 | x11x 0000 | 111x 000x | 111x 00x1 | 111x 0x11 | 111x x111 | 3 |
| 000x x000 | 00x1 x000 | 0x11 x000 | x111 x000 | 1111 x00x | 1111 x0x1 | 1111 xx11 | 4 |
| 0000 xx00  | 000x 1x00 | 00x1 1x00 | 0x11 1x00 | x111 1x00 | 1111 1x0x | 1111 1xx1 | 5 |
| 0000 0xx0  | 0000 x1x0 | 000x 11x0 | 00x1 11x0 | 0x11 11x0 | x111 11x0 | 1111 11xx | 6 |
| 0000 00xx | 0000 0x1x | 0000 x11x | 000x 111x | 00x1 111x | 0x11 111x | x111 111x | 7 |
| x000 000x | x000 00x1 | x000 0x11 | x000 x111 | x00x 1111 | x0x1 1111 | xx11 1111 | 8 |

**15.1.3.5 Error correction**

****

**Figure 326 –Hamming (11,15) code for 16x16 cells Tx**

A temporal error correction is applied. The block rate (i.e. the optical clock rate) is 10 Hz, much less than the frame rate of camera to ensure that every block of data is sampled more than once. The majority voting of all images those sampled on the block of data is to correct the error.

Also, Hamming (11, 15) is optionally used in within the data block. The value of PHY PIB attribute, *phyOccFec*, shall determine whether Hamming code is used or not. In example of 16x16 cells Tx, 22 bytes information shall be coded into 16 codewords, each consists of 15 bits, to be transmitted at once. Likewise in 8x8 cells Tx, 4 blocks of data (each consists of 11 bits) shall be coded into 4 codewords (each consists of 15 bits).