**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: |  |
| Abstract | Draft proposal OOK PHY section of HRCP PHY section (12a.3 HRCP-OOK PHY) |
| Purpose | Final proposal |
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**15.3: Wireless Medium Access Control**

**(MAC) and Physical Layer (PHY)**

**Specifications for High Rate Wireless**

Personal Area Networks (WPANs)
Amendment 3: High Rate Close Proximity Extension

Sponsor

**LAN/MAN Standards Committee**of the **IEEE Computer Society**

Approved <XX MONTH 20XX>

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Contents

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**Part 15.3: Wireless Medium Access Control**

**(MAC) and Physical Layer (PHY)**

**Specifications for High Rate Wireless**

Personal Area Networks (WPANs)
Amendment 3: High Rate Close Proximity Extension

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

12a.1.x Common PHY management for HRCP PHY modes

12a.1.x.1 Supported MCSs

The Supported data rates field in the DEV capabilities field, as described in 7.4.11a (HRCP capability), shall be formatted as illustrated in Figure 12a.1-x.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| bits:1 | 2 | 1 | 1 | 1 | 1 | 1 |
| OOK spreading | Number of Channel Bonding |  |  |  |  |  |

Figure 12a.1-x—Supported data rates field format for HRCP PHY modes

The OOK spreading field shall be set to one if spreading factor 2 is supported by the HRCP-OOK PHY DEV and shall be set to zero if spreading is not supported by the DEV.

The Number of Channel Bonding field indicates the number of bonded channels supported by the OOK-PHY DEV as defined in the Table 12.a-x.

Table 12a.1-x – Number of Channel Bonding field

|  |  |
| --- | --- |
| Value | Meaning |
| 00 | Channel bonding is not supported |
| 01 | Up to 2 channel bonding is supported |
| 10 | Up to 3 channel bonding is supported |
| 11 | Up to 4 channel bonding is supported |

12a.3 HRCP-OOK PHY

12a.3.1 PHY operating specifications of HRCP-OOK PHY

12a.3.1.1 Channel numbering

HRCP-OOK PHY may use channel bonding using up to four channels. HRCP-OOK PHY uses the channels defined in Table 12a.3-1. A compliant IEEE 802.15.3e implementation that implements the HRCP-OOK PHY shall support at least channel 2 which is the default channel for 802.15.3e.

Table 12a.3-1 – Channel numbering used by HRCP-OOK PHY

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| CHNL\_INDEX | Start frequency | Center frequency | Stop frequency | Remarks |
| 1 | 59.400 GHz | 60.480 GHz | 61.560 GHz | No channel bonding(Use only Channel 2 which is the default channel) |
| 2 | 59.400 GHz | 61.560 GHz | 63.720 GHz | Two channel bonding(Channel 2 and Channel 3) |
| 3 | 57.240 GHz | 60.480 GHz | 63.720 GHz | Three channel bonding(Channel 1, 2 and 3) |
| 4 | 57.240 GHz | 61.560 GHz | 65.880 GHz | Four channel bonding(Channel 1,2,3 and 4) |

Figure 12a.3-1 depicts the channels used by HRCP-OOK PHY.

Figure 12a.3-1 - Channels used by HRCP-OOK PHY

12a.3.2 Modulation and coding

12a.3.2.1 MCS dependent parameters

The chip rate of HRCP-OOK PHY is given in Table 12a.3-4. The entire HRCP-OOK frame shall be modulated with OOK as specified in 12a.3.2.5.1. The FEC for HRCP-OOK PHY shall be RS coding as specified in 12a.3.2.6. The MCS dependent parameters shall be set according to Table 12a.3-2. IEEE 802.15.3e implementation that implements the HRCP-OOK PHY shall support at least Mode 1 in the Table 12a.3-2.

Table 12a.3-2 – MCS dependent parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Mode | MCS identifier | Data rate (Mb/s) | Modulation | Spreading factor, LSF | FEC type |
| Mode 1 (No channel bonding) | 1 | 1630 | OOK | 1 | RS (240,224) |
| Mode 2 (2 channel bonding) | 0 | 1630 | 2 |
| 1 | 3260 | 1 |
| Mode 3 (3 channel bonding) | 0 | 2445 | 2 |
| 1 | 4890 | 1 |
| Mode 4 (4 channel bonding) | 0 | 3260 | 2 |
| 1 | 6519 | 1 |

Pilot symbols specified in xxxx are included in the calculation of Data rates.

RS(240,224) shall be used for encoding the frame payloads of HRCP-OOK. Block length *L*block of HRCP-OOK PHY payload shall be 512 chips when *L*SF=1 is used, and *L*block shall be 1024 chips when *L*SF=2 is used. Pilot symbol length *L*P shall be 4 bits when *L*SF=1 is used, and *L*P shall be 8 bits when *L*SF=2 is used.

12a.3.2.2 Header rate dependent parameters

The header rate dependent parameters shall be set according to Table 12a.3-3

Table 12a.3-3 –Header rate dependent parameters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Channel Bonding | Header rate (Mb/s) | Modulation | Spreading factor, LSF | Pilot symbol length, LP | Coded bits per block, LCBPB | Number of occupied blocks, Lblock\_hdr | Number of stuff bits, LSTUFF  |
| No channel bonding | 55 | OOK | 16 | 0 | 32 | 8 | 0 |
| 2 channel bonding | 110 |
| 3 channel bonding | 165 |
| 4 channel bonding | 220 |

RS (32, 16) is used in the calculation.

RS(n+16, n) which is a shortened version of RS(240,224) where n is the number of octets in the frame header, shall be used for encoding the frame header of HRCP-OOK. The block length *L*block of the frame header shall be 512 chips regardless of the spreading factor *L*SF. Pilot symbols are not used in HRCP-OOK PHY frame header.

The MAC Subheaders in each aggregated subframes shall use the same MCS for the MAC frame body, thus the MCS remains the same within aggregated frames.

12a.3.2.3 Timing-related parameters

Table 12a.3-4 lists the general timing parameters associated with the HRCP-OOK PHY.

Table 12a.3-4 –Timing-related parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Description | Value | Unit | Formula |
| Rc | Chip rate | 1760(1 channel) | 3520(2 channel) | 5280(3 channel) | 7040(4 channel) | Mchip/s |  |
| Tc | Chip duration | 0.568 | 0.284 | 0.189 | 0.142 | ns | 1/ Rc |
| Lblock | Block length | 512(Frame header or Payload with SF=1) | 1024(Payload with SF=2) | chips |  |
| LP | Pilot symbol length | 4 | 8 | chips |  |
| TP | Pilot symbol duration | 2.273, 1.136, 0.758, 0.568 | 2.273, 1.515, 1.136 | ns |  |
| LDC | Length of data chips per subblock | 508 | chips |  |
| Tblock | Block duration | 290.9 | 145.5 | 97.0 | 72.7 | ns | Lblock X Tc |

12a.3.2.4 Frame-related parameters

The frame parameters associated with the HRCP-OOK PHY are listed in Table 12a.3-5 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 8,388,608.

Table 12a.3-5 –Frame-related parameters

|  |  |  |
| --- | --- | --- |
| Parameter | Description | Value |
| NSYNC  | Number of code repetitions in the SYNC sequence | 16 |
| TSYNC | Duration of the SYNC sequence | 1.16 us |
| NSFD | Number of code repetitions in the SFD | 4 |
| TSFD | Duration of the SFD | 0.29 us |
| NCES | Number of code repetitions in the CES | 8 |
| TCES | Duration of the CES | 0.58 us |
| Npre | Number of code repetitions in the PHY preamble | 28 |
| Tpre | Duration of the PHY preamble | 2.036 us |
| Lhdr | Length of the base headers in octets | 32 |
| Nblock\_hdr | Number of blocks in the base frame header | 8 |
| Thdr | Duration of the base frame header | Nblock\_hdr X Tblock |
| Lpayload | Length of frame payloads in octets | variable |
| LFCS  | Length of FCS in octets | 4 |
| LMFB | Length of the MAC frame body in octets | Lpayload +LFCS |
| LCBPS | Number of coded bits per block in the MAC frame body | 508 |
| Nblock\_MFB | Number of blocks for the MAC frame body | CEIL[(LMFB X 8)/(RFEC X LCBPS)](RFEC : FEC rate) |
| TMFB | Duration of the MAC frame body including Pilot symbols | Nblock\_MFB X Tblock |
| Tdatafield | Duration of the PHY Payload field | Nblock\_MFB X Tblock |
| Tframe | Duration of the frame | Tpre +Thdr +Tdatafield |

12a.3.2.5 Modulation

After channel encoding and spreading, the resulting bits shall be modulated using OOK as specified in 12a.3.2.5.1.

12a.3.2.5.1 OOK

HRCP-OOK frames shall be modulated using OOK. The OOK modulation shall use variable amplitudes to represent the data. As shown in Figure 12a.3.2, OOK shall be represented by two points in the constellation map. The simplest form of OOK represents a binary '1' with the presence of the signal, and a binary '0' with the absence of it. The normalization factor, *K*MODshall be sqrt(2).



Figure 12a.3-2 - Constellation diagram for OOK

12a.3.2.6 Forward Error Correction

Only RS block codes as specified in 12a.3.2.6.1 shall be used for HRCP-OOK PHY.

12a.3.2.6.1 Reed-Solomon block codes in GF(28)

The RS(240,224), which is the mother code, shall be used for encoding the frame payloads of HRCP-OOK. RS(n+16, n), a shortened version of RS(240,224) where n is the number of octets in the frame header, shall be used for encoding the frame header of HRCP-OOK.

The systematic RS code shall use the following generator polynomial:



where α = 0x02 is a root of the binary primitive polynomial *p(x)*=1+*x*2+*x*3+*x*4+*x*8. As notation, the element

*M = b*7*x*7 + *b*6*x*6 + *b*5*x*5 + *b*4*x*4 + *b*3*x*3 + *b*2*x*2 + *b*1*x*1 + *b*0, has the binary representation *b7b6b5b4b3b2b1b0*, where *b7* is the msb and *b0* is the lsb.

The mapping of the information octets ***m*** = (*m223, m222, …, m0*) to codeword octets ***c*** = (*m223, m222, …, m0, r15, r14, …, r0*) is achieved by computing the remainder polynomial *r(x)*:



where *m*(*x*) is the information polynomial:

$$m\left(x\right)=\sum\_{k=0}^{223}m\_{k}x^{k}$$

and *rk* (*k* = 0, …, 15), and *mk* (*k* = 0, …, 223) are elements of GF(28). The message order is as follows: *m*223 is the first octet of the message and *m*0 is the last octet of the message.

For a shortened RS(*Linf* + 16, *Linf*), 224- *Linf* zero elements are appended to the incoming *Linf* octet message as follows:

*mk* = 0, *k* = *Linf*, …, 223

These inserted zero elements are not transmitted. A shift-register implementation of the RS encoder RS(*Linf* +16, *Linf*) is shown in Figure 12a.3-3, with additions and multiplications over GF(28). After *m*0 has been inserted into the shift register, the switch shall be moved from the message polynomial input connection to the shift register output connection (right-to-left).



Figure 12a.3-3 - Reed-Solomon encoder GF(28)

12a.3.2.7 Code spreading

To increase robustness in frame header and MAC frame body, code spreading is used. The following two categories of spreading are used for HRCP-OOK PHY:

1. Pseudo random binary sequence (PRBS) codes by linear feedback shift register (LFSR) specified in 12a.3.2.7.1 shall be applied for code spreading for HRCP-OOK frame header.
2. Simple bit repetition in which each bit is repeated n times, where n is the spreading factor, shall be applied for code spreading for HRCP-OOK payloads.

12a.3.2.7.1 PRBS generation with LFSR

For HRCP-OOK frame header spreading, spreading factor of length 16 shall be used, and the data bits shall be spread with a PRBS generated using an LFSR, as shown in Figure 12a.3-4. Since the output of the spreader is a factor of *LSF* larger than the input, the input shall hold while the feedback and output clock.



Figure 12a.3-4 – PRBS generation by LFSR

The 15 bit seed value of the LFSR shall be: [*x*–1, *x*–2, …, *x*–15] = [0101 0000 0011 111].

12a.3.2.8 Scrambling

The frames shall be scrambled by modulo-2 addition of the data with the output of a PRBS generator, as illustrated in Figure 12a.3-4 with *LSF* = 1.

The scrambler shall be used for the MAC header, HCS, and MAC frame body. The PHY preamble, PHY header, and RS bits shall not be scrambled. The polynomial for the PRBS generator used by the scrambler shall be as shown in the following equation:

*g**D*= 1 + *D*14 + *D*15

where *D* is a single bit delay element. The polynomial forms not only a maximal length sequence, but also is a primitive polynomial. By the given generator polynomial, the corresponding PRBS, is generated as shown in the following equation:

*xn* = *xn* – 14 ⊕*xn* – 15*n* = 012

The initialization sequence is defined by the following equation:

*xinit* =  *x*–1*x*–2*x*–3*x*–4*x*–5*x*–6*x*–7*x*–8*x*–9*x*–10*x*–11*x*–12*x*–13*x*–14*x* –15

The scrambled data bits, *sn*, are obtained by the following equation:

*sn* = *bn* ⊕ *xn*

where *bn* represents the unscrambled data bits. The side-stream de-scrambler at the receiver shall be initialized with the same initialization vector, *xinit*, used in the transmitter scrambler. The initialization vector is determined from the Scrambler Seed ID field contained in the PHY header of the received frame.

The 15 bit seed value chosen shall be computed from the Scrambler Seed ID field by the following equation:

[*x*–1*x*–2…*x*–15] = [11010000101 *S*1 *S*2 *S*3 *S*4]

The seed identifier value is set to 0000 when the PHY is initialized and is incremented in a 4-bit rollover counter for each frame that is sent by the PHY. The value of the seed identifier that is used for the frame is sent in the PHY header.

For a Scrambler Seed ID field set to all zero, the first 16 bits should be as shown in the following equation:

[*x*0*x*1…*x*15] = [0001111000111010]

The 15-bit seed value is configured as follows. At the beginning of each PHY frame, the register is cleared, the seed value is loaded, and the first scrambler bit is calculated. The first bit of the data of the MAC header is modulo-2 added with the first scrambler bit, followed by the rest of the bits in the MAC header, MAC and MAC frame body. The pilot symbol shall be excluded from the scrambling process.

12a.3.3 HRCP-OOK PHY frame format

The HRCP-OOK PHY frame shall be formatted as illustrated in Figure 12a.3-5.

|  |  |  |
| --- | --- | --- |
| PHY Payload field | Frame Header (Base header) | PHY Preamble |

Figure 12a.3-5—HRCP-OOK PHY frame format

The Frame Header field for the PHY frame shall be formatted as illustrated in Figure 12a.3-6.

|  |
| --- |
| Frame header (Base header) |
| RS parity bits | HCS | MAC Header | PHY Header |

Figure 12a.3-6—Frame Header format

The PHY preamble is defined in 12a.3.3.1. The MAC header is defined in 7.2. The PHY header is defined in 12a.3.3.2.1, and the HCS is defined in 12a.3.3.2.2. The PHY Payload field consisting of the MAC frame body and stuff bits, is described in 12a.3.3.3.

12a.3.3.1 PHY Preamble

A PHY preamble shall be added prior to the frame header to aid receiver algorithms related to AGC setting, timing acquisition, frequency offset estimation, frame synchronization, and channel estimation.

The PHY preamble shall be transmitted at the chip rate defined in Table 12a.3-4.

A single mandatory preamble is defined for HRCP-OOK PHY based on the Golay sequence of length 128, denoted **a**128 and **b**128, as shown in Table 12a.3-6.

Table 12a.3-6 –Golay sequence with length 128

|  |  |
| --- | --- |
| **Sequence name** | **Sequence value** |
| **a**128 | 0x0536635005C963AFFAC99CAF05C963AF |
| **b**128 | 0x0A396C5F0AC66CA0F5C693A00AC66CA0 |

Figure 12a.3-7 shows the structure of the HRCP-OOK PHY preamble. The preambles shall be modulated in OOK waveform.



Figure 12a.3-7—HRCP-OOK preamble structure

12a.3.3.1.1 Frame synchronization (SYNC)

The frame synchronization (SNYC) field is used for frame detection and uses a repetition of codes for a higher robustness. The SNYC field shall consist of 16 code repetitions of Golay sequence **a**128 as given in Table 12a.3-6.

12a.3.3.1.2 Start frame delimiter (SFD)

The Start frame delimiter (SFD) field is used to establish frame timing and to indicate MCS related parameters. The SFD field shall consist of 4 code repetitions of Golay sequence **a**128 or **b**128 as given in Table 12a.3-6. The usage of the four SFD codes shall be as follows: 1 for delimiter and CES selection, 3 for indicating OOK MCS related parameters including number of bonded channels and the spreading factor.

SFD1 is defined as the delimiter and SFD1 also indicates that whether CES is adopted after the SFD4.

* The value of SFD1 is -**a**128, : SFD 1 indicates delimiter and also indicates CES shall not be adopted.
* The value of SFD1 is -**b**128, : SFD 1 indicates delimiter and also indicates CES shall be adopted.

SFD2, SFD3, and SFD4 indicate OOK MCS related parameters as shown in Table 12a.3-7.

Table 12a.3-7 –SFD for OOK MCS selection

|  |  |
| --- | --- |
| **SFD pattern (SFD2, SFD3, SFD4)** | **Meaning** |
| **+a**128**+a**128**+a**128 | No channel bonding, SF=1 |
| **+a**128**+a**128**-a**128 | Two channel bonding, SF=2 |
| **+a**128**-a**128**+a**128 | Two channel bonding, SF=1 |
| **+a**128**-a**128**-a**128 | Three channel bonding, SF=2 |
| **-a**128**+a**128**+a**128 | Three channel bonding, SF=1 |
| **-a**128**+a**128**-a**128 | Four channel bonding, SF=2 |
| **-a**128**-a**128**+a**128 | Four channel bonding, SF=1 |
| **-a**128**-a**128**-a**128**~ -b**128**-b**128**-b**128 | Reserved |

In OOK waveform, a negative sequence shall be derived by bit inverting as follows: –x = Bit\_Inverting(x), where x is a sequence in the form of binary bit 0 and 1. Bit\_Inverting(x) is an operation to invert all the binary bits 0 of a sequence x to 1 and invert all the binary bits 1 of a sequence x to 0.

12a.3.3.1.3 Channel estimation sequence (CES)

If the value of SFD1 is -**b**128, and CES is adopted, the CES field shall be constructed from four Golay complementary sequences **a**128, –**a**128, **b**128 and –**b**128 as shown in Figure 12a.3-7. Each sequence shall be preceded by a cyclic prefix (i.e., a copy of the last 64 bits of the sequence) and followed by a cyclic postfix (i.e., a copy of the first 64 bits of the sequence). The pair of Golay complementary sequences **a**128 and **b**128 is given in Table 12a.3-6, where both sequences in the form of binary bit 0 and 1. Another pair of Golay complementary sequences –**a**128 and –**b**128 shall be derived from the previous pair of **a**128 and **b**128 by bit inverting.

12a.3.3.1.4 Preamble Repetition

If channel bonding is used and the number of bonded channels is n, then each subfield of the preamble is repeated n times for higher robustness as depicted in Figure 12a.3-8. By using repetition, duration of preamble, SYNC, SFD, and CES (*Tpre, TSYNC , TSFD, TCES*) remains unchanged when the channel bonding is used.



Figure 12a.3-8—Preamble repetition

Figure 12a.3-9 shows an example of preamble repetition when two channel bonding is used.

 Figure 12a.3-8—Example of Preamble repetition

12a.3.3.2 Frame Header

A frame header shall be added after the PHY preamble. The frame header conveys information in the PHY and MAC headers necessary for successfully decoding the frame.

The construction of the frame header is shown in Figure 12a.3-9. The detailed process of the construction is as follows:



Figure 12a.3-9—Frame header construction process

1. Form the base frame header as follows:
2. Construct the PHY header based on information provided by the MAC.
3. Compute the 16 bit HCS using ITU-T CRC-16 over the combined PHY and MAC headers.
4. Append the HCS to the MAC header.
5. Scramble the combined MAC header and HCS, as described in 12a.3.2.8.
6. Compute the 128 bit RS parity bits by encoding the concatenation of the PHY header, scrambled MAC header and scrambled HCS into a shortened RS block code, as described in 12a.3.2.6.1. RS(n+16, n) where n is the number of octets in the frame header is used.
7. Form the frame header by concatenating the PHY header, scrambled MAC header, scrambled HCS, and RS parity bits.

The resulting frame header shall be modulated as shown in Figure 12a.3-9.

1. Spread the frame header with a PRBS generated using an LFSR as described in 12a.3.2.7.1, and the spreading factor shall be 16.
2. Map the frame header onto OOK waveform, as described in 12a.3.2.5.1.

The block length *L*block of the frame header shall be 512 chips regardless of the spreading factor *L*SF. Pilot symbols are not used in the frame header.

The LFSR for the spreader is reset between the header and payload.

12a.3.3.2.1 HRCP-OOK PHY header

The HRCP-OOK PHY header shall be formatted as illustrated in Figure 12a.3-10.

|  |  |  |  |
| --- | --- | --- | --- |
| bits:4 | 23 | 1 | 4 |
| Reserved | Frame Length | Aggregation | Scrambler Seed ID |

Figure 12a.3-10—PHY header format for HRCP-OOK PHY

The Scrambler Seed ID field contains the scrambler seed identifier value, as defined in 12a.3.2.8.

The Aggregation field shall be set to one if aggregation is used, it shall be set to zero otherwise.

The Frame Length field shall be an unsigned integer equal to the number of octets in the MAC frame body including frame payload(s), MAC subheader(s) in the aggregated frames, and FCS(s), but not including the frame header and the preamble.

12a.3.3.2.2 Base header HCS

The combination of the PHY header and MAC header shall be protected with an ITU-T CRC-16 base HCS. The ITU-T CRC-16 is described in 11.2.9.

12a.3.3.2.3 Base header FEC

The concatenation of the PHY header, scrambled MAC header and scrambled HCS shall use shortened systematic RS(*n*+16,*n*) , a shortened version of RS(240,224), for the FEC, where *n* is the number of octets in the combined PHY header, MAC header and HCS. The 128 RS parity bits are appended after the scrambled HCS as shown in 12a.3-9.

12a.3.3.3 HRCP-OOK PHY Payload field

The HRCP-OOK PHY Payload field is constructed as shown in Figure 12a.3-11.



Figure 12a.3-11—HRCP-OOK PHY Payload construction process

The PHY Payload field shall be constructed as follows:

1. Scramble the MAC frame body according to 12a.3.2.8.
2. Encode the scrambled MAC frame body as specified in 12a.3.2.6. RS(240,224) shall be used for encoding the frame body.
3. Stuff bits are added to the end of the encoded MAC frame body if the number of the encoded data bits is not an integer multiple of 508 which is the length of the data portion in single block corresponding to SF=1. In this case, add stuff bits to the end of the encoded MAC frame body until the number of the encoded data bits including the added stuff bits reaches an integer multiple of 508. The stuff bits shall be set to zero and then scrambled using the continuation of the scrambler sequence that scrambled the MAC frame body in 12a.3.2.8.
4. If SF= 2, spread the encoded and scrambled MAC frame body using bit repetition with SF=2 in which each bit is repeated twice.
5. Map the resulting MAC frame body onto OOK waveform, as described in 12a.3.2.5.1.
6. Build blocks from the resulting MAC frame body as specified in 12a.3.3.3.5.

12a.3.3.3.1 HRCP-OOK PHY Payload scrambling

The SC PHY payload shall use the scrambling process defined in 12a.3.2.8.

12a.3.3.3.2 Modulation

Modulation for the MAC frame body is defined in 12a.3.2.5.1.

12a.3.3.3.3 FEC

FEC for the MAC frame body is defined in 12a.3.2.6.

12a.3.3.3.4 Code spreading

Simple bit repetition with spreading factor 2 in which each bit is repeated twice shall be applied for code spreading for the MAC frame body.

12a.3.3.3.5 Blocks and Pilot symbol

Pilot symbols are used in HRCP-OOK PHY for timing tracking, compensation for clock drift and compensation for frequency offset error. Furthermore, pilot symbols act as a known cyclic prefix and enables frequency domain equalization if desired. In frequency domain equalization, the data is handled in the unit of blocks.

In HRCP-OOK data payload, the transmit symbols shall be divided into block of length *N* = 508 × SF, where SF is the spreading factor. This transmit symbol block shall be appended with pilot symbol as described in Figure 12a.3-12.



Figure 12a.3-12—HRCP-OOK frame format with pilot symbols

The pilot symbols consist of a sequence of length *Np* = 4 × SF. The pilot symbols for SF=1 and SF=2 shall be chosen according to Table 12a.3-8.

Table 12a.3-8 –OOK pilot symbols

|  |  |
| --- | --- |
| **Spreading Factor** | **Pilot symbols** |
| 1 | 1010 |
| 2 | 11001100 |

The pilot symbol is modulated with OOK.

12a.3.4 Transmitter specifications

12a.3.4.1 Error Vector Magnitude

Eye opening for OOK is described in D2.7

12a.3.5 Receiver specifications

12a.3.4.1 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. The measurement shall be performed in AWGN channel.

12a.3.4.2 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 12a.3.4.1 is met. A compliant DEV that implements the HR-OOK PHY shall achieve at least the reference sensitivity listed in Table 12a.3-9.

Table 12a.3-9 –Reference sensitivity levels for MCS

|  |  |  |
| --- | --- | --- |
| Mode | MCS identifier | Receiver sensitivity |
| Mode 1 (No channel bonding) | 1 (SF=1) | -52 dBm |
| Mode 2 (2 channel bonding) | 0 (SF=2) | -52 dBm |
| 1 (SF=1) | -49 dBm |
| Mode 3 (3 channel bonding) | 0 (SF=2) | -50 dBm |
| 1 (SF=1) | -47 dBm |
| Mode 4 (4 channel bonding) | 0 (SF=2) | -49 dBm |
| 1 (SF=1) | -45 dBm |

12a.3.4.3 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 12a.3.4.1 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.

12a.3.4.4 Receiver clear channel assessment performance

A compliant receiver provides CCA capability by performing energy detection in the received signal bandwidth. The start of a valid preamble sequence at a receive level equal to or greater than the minimum sensitivity for the HRCP-OOK, as described in 12a.3.4.2, shall cause CCA to indicate medium busy with a probability of >90% within pCCADetectTime. The receiver CCA function shall in all circumstances report

medium busy with any signal 20 dB above the minimum sensitivity for the HRCP-OOK. The CCA detection time shall be equal to pCCADetectTime.

12a.3.6 PHY layer timing

The values for the PHY layer timing parameters are defined in Table 12a.3-10.

Table 12a.3-10 –PHY layer timing parameters

|  |  |  |
| --- | --- | --- |
| PHY parameter | Value | Subcluase |
| pPHYSIFSTime | 0.2 us, 2.0 us, 2.5 us (default) | 12a.3.6.3 |
| pCCADetectTime | 4 us | 12a.3.4.4 |

12a.3.6.1 Interframe space

A conformant implementation shall support the IFS parameters, as described in 8.4.1, given in 12a.3-11.

Table 12a.3-11 – IFS parameters

|  |  |  |
| --- | --- | --- |
| MAC parameter | Corresponding PHY parameter | Definition |
| SIFS | pPHYSIFSTime | 12a.3.6.3 |
| pBackoffslot | pPHYSIFSTime + pCCADetectTime | 12a.3.6.3, 12a.3.6.4 |
| BIFS | pPHYSIFSTime + pCCADetectTime | 12a.3.6.3, 12a.3.6.4 |
| IIFS | pPHYSIFSTime | 12a.3.6.3, 12a.3.6.4 |
| RIFS | 2 X pPHYSIFSTime + pCCADetectTime | 12a.3.6.3, 12a.3.6.4 |

12a.3.6.2 Receive-to-transmit turnaround time

The receive to transmit turnaround time shall be pPHYSIFSTime. 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.

12a.3.6.3 Transmit-to-receive turnaround time

The transmit to receive turnaround time shall be less than pPHYSIFSTime

12a.3.7 PHY management for HRCP-OOK PHY

12a.3.7.1 Maximum frame size

The maximum frame length allowed, pMAXFrameBodySize, shall be 8,388,608 octets. This total includes the MAC frame body including frame payload(s), MAC subheader(s) in the aggregated frames, and FCS(s), but not including the frame header and the preamble. The maximum frame length also does not include the stuff bits.

12a.3.7.2 Maximum transfer unit size

The maximum size data frame passed from the upper layers, pMaxTransferUnitSize, shall be 8,388,576 octets. If security is enabled for the data connection, the upper layers should limit data frames to 8,388,576 octets minus the security overhead as defined in 7.3.4.2, 7.2.8.1.2, or 7.2.8.2.2.

12a.3.7.3 Minimum fragment size

The minimum fragment size, pMinFragmentSize, allowed with the SC PHY shall be 512 octets.

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