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**Wireless Personal Area Networks**

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| Source | [Yeong Min Jang][Kookmin University][address] | Voice: [ ]Fax: [ ]E-mail: [yjang@kookmin.ac.kr] |
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# 16. PHY VII specifications

## 16.1. RS-OFDM

The Rolling Shutter Orthogonal Frequency Division Multiplexing (RS-OFDM) Modulation for high-speed OCC system uses the PHY VII – Singular Point Source.

The PHY VII Operating Modes system specifications are given in Table xxx. The additional PHY Operating Modes by RS-OFDM for Smart Device is presented the Table xxx – PHY VII Operating Modes.

**Table xxx – PHY VII Operating Modes**

|  |  |
| --- | --- |
| **PHY Operating Modes** |  |
| **Modulation** | **RLL Code** | **Optical Clock Rate** | **FEC** | **OFDM symbol length** | **Data rate** |
| RS-OFDM | None | 20 kHz | Hamming (15,11) | 64 | 1.92 kbps |
| 40 kHz | RS (15,11) | 128 | * 1. bps
 |

### *16.1.1. Reference architecture*

A reference architecture to implement RS-OFDM is shown in Figure xxx



Figure xxx. Rolling Shutter OFDM block diagram

### *16.1.2. Encoder configuration*

A packet of data is modulated using OFDM modulation. The optical clock rate is at 20 kHz or 40 kHz. The optical clock rate at which RS-OFDM symbols are clocked out is configurable over PHY PIB attribute *phyOfdmOpticalClockRate*.



Figure xx. RS-OFDM data packet structure

The data packet structure is as shown in Figure xx. A packet consists of multiple similar data sub-packets to avoid missing data between adjacent images' gap time.

### *16.1.3. Hermitian Mapping*

Unlike the conventional OFDM in Radio Frequency, instead of feeding the data symbol directly into the IDFT block, each symbol must pass through the Hermitian block. The signal is then fed into the IFFT. The special purpose of the Hermitian block is that it ensures the output of the IDFT is entirely real. The modes of RS-OFDM shall be configured via the PHY PIB attribute *phyOfdmMode.* And the length of RS-OFDM symbol shall be configured via the PHY PIB attribute *phyOfdmFrame.*

### *16.1.4. Sequence Number inserting*

The data sub-packet payload shall consist of two subparts: SN data, payload. The SN Data consists of asynchronous information, which helps the receiver side decode data. SN shall be implemented over the PHY PIB attribute *phyOfdmSn*

### *16.1.5. Forward error correction (FEC)*

The data sub-packet payload may be coded by FEC to protect the payload from error. Hamming (8,4) or Reed Solomon (15,11) code may be used as an FEC. FEC shall be configured via the PHY PIB attribute *phyOfdmFEC*

Table xx shows PHY PIB attributes.

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** |
| *phyOfdmOpticalClockRate* | Integer | 0-7 | The optical clock rate (or symbol rate)applied for OFDM.0: 8 kHz1: 10 kHzOthers: Reserved |
| *phyOfdmMode* | Integer | 0-3 | This specifies the mode of OFDMmodulation.0: DCO-OFDM1: ACO-OFDMOther values: Reserved |
| *phyOfdmFec* | Integer | 0-7 | This attribute specifies FEC for OFDM modulation.0: None1: FEC: Hamming (8/4)2: FEC: Hamming (15/11)3: FEC: RS(15,11)Other values: Reserved |
| *phyOfdmFrame* | Integer | 0-3 | This attribute specifies the symbol length of OFDM frame.0: 321: 64Other values: Reserved |
| *phyOfdmSn* | Integer | 0-3 | This attribute specifies the length of Sequence Number per packet of OFDM0: 2 bits1: 3 bits Other values: reserved |

## 16.2. MIMO C-OOK

The Multiple Input Multiple Output Camera On-Off Keying (MIMO C-OOK) Modulation for high-speed OCC system uses the PHY VII – Multiple Point Source.

The PHY VII Operating Modes system specifications are given in Table 151. The additional PHY Operating Modes by MIMO C-OOK for Smart Device is presented the Table 151 – PHY VII Operating Modes.

**Table 151 – PHY VII Operating Modes**

|  |
| --- |
| **PHY Operating Modes** |
| **Modulation** | **RLL Code** | **Optical Clock Rate** | **FEC** | **Data Rate** **(two LEDs)** |
| MIMO C-OOK | Manchester  | 8 kHz | Hamming (15,11) | 4.8 kbps |
| 4B6B | 8 kHz | RS (15,11) | 7.2 kbps |
| Manchester | 10 kHz | Hamming (15,11) | 6.0 kbps |
| 4B6B | 10 kHz | RS (15,11) | 9.0 kbps |

### *16.2.1. Reference architecture*

The PHY VII with supported data rates and operating conditions is shown in Table 151 – PHY VII Operating Modes for Multiple Input Multiple Output Camera On-Off Keying (MIMO C-OOK) Modulation with high-speed OCC system uses the PHY VII - Multiple Point Source.

The proposed Multiple Input Multiple Output Camera On-Off Keying (MIMO C-OOK) was designed with the following characteristics:

* Modulation methods include line coding (Manchester code and 4B6B)
* The Optical clock rate is at 8 kHz or 10 kHz
* Sequence Number part was put in the head and tail of packets
* Multiple light sources were applied to increase the data rate

A reference architecture to implement MIMO C-OOK is shown in Figure 217



Figure 217. MIMO C-OOK block diagram

### *16.2.2 Encoder configuration*

A packet of data is modulated using OOK modulation. The optical clock rate is at 8 kHz or 10 kHz. The optical clock rate at which MIMO C-OOK symbols are clocked out is configurable over PHY PIB attribute *phyMimoCookOpticalClockRate.*



Figure 218. MIMO C-OOK data packet structure

The data packet structure is as shown in figure 218. A packet consists of multiple similar data sub-packets to avoid missing data between adjacent images' gap time. The number of repetitions depends on the communication mode specified later. The configuration of preamble shall be implemented over the PHY PIB attribute *phyMimoCookPreambleSymbol*.

Table 152—Data sub-packet format

|  |  |
| --- | --- |
| **Preamble** | **Data sub-packet payload** |
| **Start SN data****(Sequence Number)** | **Payload** | **End SN data****(Sequence Number)** |
| 011100  | Manchester coding |
| 0011111000  | 4B6B coding |

### 16.2.3 RLL coding

The data sub-packet payload shall consist of three subparts: the Start SN data, payload, and the End SN Data. The Start SN Data and the End SN Data shall carry the same information, which consists of the asynchronous information. SN shall be implemented over the PHY PIB attribute *phyMimoCookSn*

### 16.2.4 Forward error correction (FEC)

The data sub-packet payload may be coded by FEC to protect the payload from error. Hamming (8,4) or Reed Solomon (15,11) code may be used as an FEC. FEC shall be configured via the PHY PIB attribute *phyMimoCookFEC*

**Table xx shows PHY PIB attributes.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** |
| *phyMimoCookOpticalClockRate* | Integer | 0-7 | The optical clock rate (or symbol rate)applied for MIMO C-OOK.0: 8 kHz1: 10 kHzOthers: Reserved |
| *phyMimoCookRLLCode* | Integer | 0-7 | This specifies the RLL coding for MIMO C-OOKmodulation.0: Manchester1: 4B6B codingOther values: Reserved |
| *phyMimoCookFec* | Integer | 0-7 | This attribute specifies FEC for MIMO C-OOKmodulation.0: None1: Hamming (8/4)2: Hamming (15/11)3: Hamming (8/4),Other values: Reserved |
| *phyMimoCookPreambleSymbol* | Integer | 0-3 | This attribute specifies the preamblesymbol of PSDU of MIMO C-OOK.0: 6B symbol (preamble = 011100)1: 10B symbol (preamble = 0011111000)2–3: Reserved |
| *phyMimoCookSn* | Integer | 0-3 | This attribute specifies the length of Sequence Number per packet of MIMO C-OOK0: 2 bits1: 3 bits 2-3: reserved |

## 16.3. O-NOMA

### *16.3.1. Reference architecture*

*Updating.*

### *16.3.2. Encoder configuration*

*Updating.*

### *16.3.3. Forward error correction (FEC)*

*Updating.*

## 16.4. MIMO-OOK

The Multiple Input Multiple Output On-Off Keying (MIMO-OOK) Modulation based on RoI signaling for Optical IoT system uses the PHY VII – Multiple Point Source.

The PHY VII Operating Modes system specifications are given in Table 153. The additional PHY Operating Modes by MIMO-OOK for Smart Device is presented the Table 155– PHY VII Operating Modes.

**Table 155 – PHY VII Operating Modes**

|  |
| --- |
| **PHY Operating Modes** |
| **Modulation** | **RLL Code** | **Optical Clock Rate** | **FEC****(Reed Solomon)** | **Data Rate** **(two LEDs)** |
| MIMO-OOK | Manchester  | 20 Hz | RS (15,11) | 40 bps |
| 4B6B | 20 Hz | RS (15,11) | 40 bps |
| Manchester | 30 Hz | RS (15,11) | 60 bps |
| 4B6B | 30 Hz | RS (15,11) | 1. ps
 |

### *16.4.1. Reference architecture*

A reference architecture to implement MIMO-OOK is shown in Figure 217



Figure 217. MIMO-OOK block diagram

### *16.4.2. Encoder configuration*

A packet of data is modulated using OOK modulation. The optical clock rate is at 20 Hz or 30 Hz. The optical clock rate at which MIMO-OOK symbols are clocked out is configurable over PHY PIB attribute *phyMimoOokOpticalClockRate.*

s

Figure xx. MIMO-OOK data packet structure

The data packet structure is as shown in Figure xx. The clock rate of the MIMO-OOK scheme was set up lower than (at least two times) the camera frame rate to eliminate the variation effect of frame rate.

To access multiple light sources, we have added the node ID part to each frame. Each user will be defined by a unique ID, so that the receiver can categorize the signal from different users. Defining users by ID nodes helps the system accept dozens of users, up to hundreds of users.

Table 152—Data sub-packet format

|  |  |
| --- | --- |
| **Preamble** | **Data sub-packet payload** |
| **LED-ID** | **Payload** |
| 011100  | Manchester coding |
| 0011111000  | 4B6B coding |
| 00011111110000 | 8B10B coding |

### *16.4.3. RLL coding*

RLL coding shall be applied in the payload subfield to maintain an average brightness at 50%. Manchester code and 4B6B code are suggested for OOK mode. The configuration of RLL code shall be implemented over the PHY PIB attribute *phyMimoOokRLLCode*. Manchester code and 4B6B code are suggested for MIMO-OOK mode.

### *16.4.4. Forward error correction (FEC)*

The data sub-packet payload may be coded by the inner FEC to protect the payload from error. Hamming (8,4) or (15,11) code may be used as an inner FEC.

Additionally, outer FEC may also be used to protect the PHR and PSDU. When outer FEC is enabled, RS(15,11) shall be implemented.

FEC shall be configured via the PHY PIB attribute *phyMimoOokFEC*

Both inner FEC and outer FEC shall be configured via the PHY PIB attribute *phyMimoOokFEC*.

**Table xx shows PHY PIB attributes**

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** |
| *phyMimoOokOpticalClockRate* | Integer | 0-7 | The optical clock rate (or symbol rate)applied for MIMO-OOK.0: 20 Hz1: 30 HzOthers: Reserved |
| *phyMimoOokRLLCode* | Integer | 0-7 | This specifies the RLL coding for MIMO C-OOKmodulation.0: Manchester1: 4B6B coding2: 8B10B codingOther values: Reserved |
| *phyMimoOokFec* | Integer | 0-7 | This attribute specifies FEC for MIMO-OOKmodulation.0: None1: Hamming (8/4)2: Hamming (15/11)3: Hamming (8/4),4: Hamming (15/11)Other values: Reserved |
| *phyMimoOokPreambleSymbol* | Integer | 0-7 | This attribute specifies the preamblesymbol of PSDU of MIMO-OOK.0: 6B symbol (preamble = 011100)1: 10B symbol (preamble = 0011111000)2**: 14B symbol (preamble=****00011111110000)**Other values: Reserved |
| *phyMimoOokLedId* | Integer | 0-3 | This attribute specifies the length of LED-ID data for MIMO-OOK0: 2 bits1: 3 bitsOther values: Reserved |

# 17. PHY VIII specifications

## *17.1. HOOK-OFDM*

The Hybrid Orthogonal Frequency Division Multiplexing- On-Off Keying (HOOK-OFDM) Modulation for high-speed OCC system uses the PHY VIII – Singular Point Source.

The PHY VIII Operating Modes system specifications are given in Table xx. The additional PHY Operating Modes by HOOK-OFDM for Smart Device is presented the Table xx – PHY VIII Operating Modes.

**Table xx – PHY VIII Operating Modes**

|  |  |
| --- | --- |
| **PHY Operating Modes** |  |
| **Modulation** | **Mode** | **Optical Clock rate** | **Modulation**  | **RLL Code** | **FEC****(Convolution code)** | **Packet length** | **Total data rate** |
| HOOK-OFDM | Mode 1 | 16 kHz | ACO-OFDM | None | CC (3/4) | 32 | 20.16 kbps |
| OOK | Manchester | CC (3/4) | 20 |
| Mode 2 | 32 kHz | DCO-OFDM | None | CC (3/4) | 32 | 38.40 kbps |
| OOK | Manchester | CC (3/4) | 40 |
| Mode 3 | 16 kHz | ACO-OFDM | None | CC (3/4) | 64 | 48.00 kbps |
| OOK | 4B6B | CC (3/4) | 24 |
| Mode 4 | 32 kHz | DCO-OFDM | None | CC (3/4) | 64 | 94.08 kbps |
| OOK | 4B6B | CC (3/4) | 48 |

### *17.1.1. Reference architecture*

A reference architecture to implement HOOK-OFDM is shown in Figure xx.



Figure xx. HOOK-OFDM block diagram

### *17.1.2. Encoder configuration*

A packet of data is modulated using OFDM modulation. The optical clock rate is at 16 kHz or 32 kHz. The configuration of the mode of HOOK-OFDM scheme shall be implemented via the PHY PIB attribute *phyHookOfdmMode*



Figure xx. Data frame structure of hybrid OFDM-OOK scheme. (a) OOK packet. (b) OOK data (c) hybrid signal (d) OFDM signal. (change color)

In each ‘high’ and ‘low’ period of C-OOK waveform, we can embed the high-frequency OFDM waveform to increase data rate of the system.

In the low data rate stream, we apply the C-OOK frame as the above figure. With high data rate stream, each period of C-OOK waveform will be put one OFDM frame to generate hybrid waveform.

### *17.1.3. Hermitian mapping*

Unlike the conventional OFDM in Radio Frequency, instead of feeding the data symbol directly into the IDFT block, each symbol must pass through the Hermitian block. The signal is then fed into the IFFT. The special purpose of the Hermitian block is that it ensures the output of the IDFT is entirely real.

### *17.1.4. Sequence Number inserting*

The data sub-packet payload shall consist of two subparts: SN data, payload. The SN Data consists of asynchronous information, which helps the receiver side decode data.

SN shall be implemented over the PHY PIB attribute *phyHookOfdmSn*

### *17.1.5. Forward error correction (FEC)*

The data sub-packet payload may be coded by FEC to protect the payload from error. Convolution code (CC) may be used as an FEC.

The configuration of error correction for HOOK-OFDM, including FEC for OOK scheme and FEC for OFDM scheme, shall be implemented via the PHY PIB attribute *phyHookOfdmFec*

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** |
| *phyHookOfdmMode* | Integer | 0-7 | The modeapplied for HOOK-OFDM.0: Mode 11: Mode 22: Mode 33: Mode 4Others: Reserved |
| *phy**HookOfdmSn* | Integer | 0-3 | This attribute specifies the length of Sequence Number per packet of HOOK-OFDM0: 2 bits1: 3 bits 2-3: reserved |
| *phyHookOfdmFec* | Integer | 0-7 | This attribute specifies FEC for HOOK-OFDM modulation.0: None1: Hamming (8/4)2: Hamming (15/11)3: RS(15,11)Other values: Reserved |

## *17.2. HS2PSK-OFDM*

The Hybrid Orthogonal Frequency Division Multiplexing- Spatial-2 Phase Shift Keying (HS2-PSK-OFDM) Modulation for high-speed OCC system uses the PHY VIII – Multiple Point Source. The output waveforms are a hybrid modulation of S2-PSK and OFDM.

The PHY VIII Operating Modes system specifications are given in Table xx. The additional PHY Operating Modes by HS2PSK-OFDM for Smart Device is presented the Table xx – PHY VIII Operating Modes.

|  |  |
| --- | --- |
| **PHY Operating Modes** |  |
| **Modulation** | **Mode** | **Optical Clock rate** | **Modulation**  | **RLL Code** | **FEC****(Convolution code)** | **Packet length** | **Total data rate** |
| HOOK-OFDM | Mode 1 | 16 kHz | OFDM | None | CC (3/4) | 32 | 20.16 kbps |
| S2-PSK | Manchester | CC (3/4) | 20 | 20 bps |
| Mode 2 | 32 kHz | OFDM | None | CC (3/4) | 32 | 38.40 kbps |
| S2-PSK | Manchester | CC (3/4) | 30 | 30 bps |
| Mode 3 | 16 kHz | OFDM | None | CC (3/4) | 64 | 48.00 kbps |
| S2-PSK | 4B6B | CC (3/4) | 12 | 12 bps |
| Mode 4 | 32 kHz | OFDM | None | CC (3/4) | 64 | 94.08 kbps |
| S2-PSK | 4B6B | CC (3/4) | 24 | 1. ps
 |

### *17.2.1. Reference architecture*

A reference architecture to implement HS2PSK-OFDM is shown in Figure xxx



Figure xx. HS2PSK-OFDM block diagram

A packet of data is modulated using OFDM modulation. The optical clock rate is at 16 kHz or 32 kHz. The configuration of the mode of HS2PSK-OFDM scheme shall be implemented via the PHY PIB attribute *phyHs2pskOfdmMode*



Figure xx. Hybrid S2PSK OFDM waveform (change color)

### *17.2.2. Sequence Number inserting*

The data sub-packet payload shall consist of two subparts: SN data, payload. The SN Data consists of asynchronous information, which helps the receiver side decode data.

SN shall be implemented over the PHY PIB attribute *phyHs2pskOfdmSn*

### *17.2.3. Forward error correction (FEC)*

The data sub-packet payload may be coded by FEC to protect the payload from error. Convolution code (CC) may be used as an FEC.

The configuration of error correction for HS2PSK-OFDM, including FEC for S2-PSK scheme and FEC for OFDM scheme, shall be implemented via the PHY PIB attribute *phyHs2pskOfdmFec*



S2-PSK waveform

In each ‘high’ and ‘low’ period of S2-PSK waveform, we can embed the high-frequency OFDM waveform to increase data rate of the system.

In the low data rate stream, we apply the S2-PSK frame as the above figure. With high data rate stream, each period of S2-PSK waveform will be put one OFDM frame to generate hybrid waveform.



Figure xxx. Data frame structure for Rolling-OFDM system in high speed stream

|  |  |  |  |
| --- | --- | --- | --- |
| **Attribute** | **Type** | **Range** | **Description** |
| *phyHs2pskOfdmMode* | Integer | 0-7 | The modeapplied for HS2PSK-OFDM.0: Mode 11: Mode 22: Mode 33: Mode 4Others: Reserved |
| *phyHs2pskOfdmSn* | Integer | 0-3 | This attribute specifies the length of Sequence Number per packet of HS2PSK -OFDM0: 2 bits1: 3 bits 2-3: reserved |
| *phyHs2pskOfdmFec* | Integer | 0-7 | This attribute specifies FEC for HS2PSK-OFDM modulation.0: None1: Hamming (8/4)2: Hamming (15/11)3: RS(15,11)Other values: Reserved |

## *17.3. BPPM*

### *17.3.1. Reference architecture*

*Updating.*

### *17.3.2. Encoder configuration*

*Updating.*

### *17.3.3. Forward error correction (FEC)*

*Updating.*