**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | [802.15.4g] TG4g Call for Proposals, 2 February, 2009 | |
| Abstract | This document describes the details of a low complexity OFDM PHY that is being proposed to the TG4g group. It conforms to the suggested TOC documented suggested. | |
| Purpose | Discussion within the task group | |
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DRAFT TOC

# Overview

## General

## Scope

## Purpose

# Normative References

# Definitions

# Acronyms and Abbreviations

# General Description

## Introduction

## Architecture

### Physical layer (PHY)

### MAC sublayer

## Functional Overview (Informative)

## Concept of Primitives

# PHY Specification(s)

## General requirements and definitions

The PHY is responsible for the following tasks:

* Activation and deactivation of the radio transceiver
* Energy detection (ED) within the current channel
* Link quality indicator (LQI) for received packets
* Clear channel assessment (CCA) for carrier sense multiple access with collision avoidance
* (CSMA-CA)
* Channel frequency selection
* Data transmission and reception

This document specifies the an OFDM PHY that can be used in the 800/900MHz band as well as the 2.4GHz band and optionally in conjunction with the PHY’s defined in previous versions of the standard.

### Operating frequency range

This standard is intended to conform to established regulations in Europe, Japan, Canada, and the United States. The regulatory documents listed below are for information only and are subject to change and revision at any time. Devices conforming to this standard shall also comply with specific regional legislation. Additional regulatory information is provided in Annex F.

Europe:

* Approval standards: European Telecommunications Standards Institute (ETSI)
* Approval authority: National type approval authorities

Japan:

* Approval standards: Association of Radio Industries and Businesses (ARIB)
* Approval authority: Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT)

United States:

* Approval standards: Federal Communications Commission (FCC), United States
* Document: FCC CFR47, Section 15.xxx

Canada:

* Approval standards: Industry Canada (IC), Canada
* Document: GL36 [B32]

### Channel assignments

TBD Channel spacing is 300 kHz

### Minimum long interframe spacing (LIFS) and short interframe spacing (SIFS) periods

### RF power measurement

Unless otherwise stated all RF power measurements, either transmit or receive, shall be made at the appropriate transceiver to antenna connector. The measurements shall be made with equipment that is either matched to the impedance of the antenna connector or corrected for any mismatch. For devices without an antenna connector, the measurements shall be interpreted as effective isotropic radiated power (EIRP) (i.e., a 0 dBi gain antenna), and any radiated measurements shall be corrected to compensate for the antenna gain in the implementation.

### Transmit power

The maximum transmit power shall conform to local regulations. Refer to Annex F for additional information on regulatory limits. A compliant device shall have its nominal transmit power level indicated by its PHY parameter, *phyTransmitPower* (see 6.4).

### Out-of-band spurious emission

The out-of-band spurious emissions shall conform to local regulations. Refer to Annex F for additional information on regulatory limits on out-of-band emissions.

### Receiver sensitivity definitions

The receiver sensitivity definitions used throughout this standard are defined in Table below

|  |  |  |
| --- | --- | --- |
| Term | Definition | Condition |
| Packet Error Rate | Average fraction of transmitted packets that are not correctly received. | Average is measured using random PSDU Data of length 100, 1000 and 2047 octets |
| Receiver sensitivity | Threshold input signal power that yields a specified PER for packets of specified lengths | – PSDU length = 100, 1000, 2047 octets  – PER < 1%.  – Power measured at antenna terminals.  – Interference not present. |

## PHY service specifications

6.2.1 PHY data service

6.2.2 PHY management service

6.2.3 PHY enumerations description

## PPDU format

For convenience, the PPDU packet structure is presented so that the leftmost field as written in this standard shall be transmitted or received first. All multiple octet fields shall be transmitted or received least significant octet first and each octet shall be transmitted or received least significant bit (LSB) first. The same transmission order should apply to data fields transferred between the PHY and MAC sublayer.

Each PPDU packet consists of the following basic components:

* A synchronization header (SHR), which allows a receiving device to synchronize and lock onto the bit stream
* A PHY header (PHR), which contains frame length information
* A variable length payload, which carries the MAC sublayer frame

The PPDU packet structure shall be formatted as illustrated below



### Synchronization Header (SHR)

The Synchronization Header is a binary sequence used to drive a BPSK modulator running at 100 kbps and is used to obtain frequency and time synchronization.



#### Preamble Field

The preamble field is a 1 0 1 0 sequence of variable length described by *phySHRDuration.*

#### SFD field

The SFD field is an extended 7 bit Barker word used to signify the start of the PHY Header. The SFD fields are inverted SFD fields as shown in the definition below.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Bit #** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| **SFD** | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |
| **SFD** | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |

The first SFD is can be used to wake up the processor, while the second SFD and the SFD can be used to perform fine frequency sync.

### PHY Header (PHR)

The PHY header shall be added after the SHR to convey information about both the PHY and the MAC that is needed at the receiver in order to successfully decode the PSDU. The PHY Header shall be transmitted at the lowest bit rate of 22.5 kbps.



#### Rate field

The rate field shall have the following values

|  |  |
| --- | --- |
| **Rate field (3 bits)** | **Data Rate (kb/s)** |
| 0 | 22.5 |
| 1 | 45 |
| 2 | 90 |
| 3 | 120 |
| 4 | 180 |
| 5 | 240 |
| 6 | 360 |
| 7 | Reserved |

#### Length field

This field describes the length of the PHY payload in octets.

#### Scrambler bits

TBD

#### Message type

The Message type field describes the type of message

|  |  |
| --- | --- |
| **Message type** | **Type** |
| 0 | RTS Request to send |
| 1 | CTS Clear to send |
| 2 | ACK Acknowledge |
| 3 | NAK Not Acknowledge |
| 4 | Data Packet |
| 5 - 7 | Reserved |

#### Header Check Sequence

The Header Check Sequence is a 16 bit CRC to verify the validity of the received PHY Header

#### Tail bits

The tail bit fields are required to return the convolutional encoder to the “zero state”. This procedure improves the error probability of the convolutional decoder, which relies on the future bits when decoding the message stream. The tail bit fields in the PHY header shall consist of four non-scrambled zeros.

### Data Payload ( PSDU)

The Data Payload contains the data to be transmitted as well as a CRC for integrity checking and tail bits to ensure optimal decoding. The data payload is encoded according to the data rate required.



#### Frame Payload Field

Contains the data payload

#### CRC Field

The CRC field is a 32 bit CRC taken over the data payload to validate the integrity of the payload

#### Tail bits

The tail bit fields are required to return the convolutional encoder to the “zero state”. This procedure improves the error probability of the convolutional decoder, which relies on the future bits when decoding the message stream. The tail bit fields in the PSDU shall consist of four non-scrambled zeros.

## PHY constants and PIB attributes

### PHY constants

The constants that define the characteristics of the PHY are presented in Table 22. These constants are hardware dependent and cannot be changed during operation.

|  |  |  |
| --- | --- | --- |
| **Constant** | **Description** | **Value** |
| *aMaxPHYPacketSize* | The maximum PSDU size (in octets) the PHY shall be able to receive | 2047 |
| *aTurnaroundTime* | RX-to-TX or TX-to-RX maximum turnaround time (in symbol periods) | 3 symbols (200us) |

### PHY PIB attributes

The PHY PIB comprises the attributes required to manage the PHY of a device. The attributes contained in the PHY PIB are presented in Table 23. Attributes marked with a dagger (†) are read-only attributes (i.e., attribute can only be set by the PHY), which can be read by the next higher layer using the PLME-GET.request primitive. Attributes marked with an asterisk (\*) have specific bits that are read-only attributes (i.e., attribute can only be set by the PHY), which can be read by the next higher layer using the PLME-GET.request primitive and other bits that can be read or written by the next higher layer using the PLME-GET.request or PLME-SET.request primitives, respectively. All other attributes can be read or written by the next higher layer using the PLME-GET.request or PLME-SET.request primitives, respectively.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  | | --- | | Attribute | | |  | | --- | | Identifier | | |  | | --- | | Type | | |  | | --- | | Range | | |  | | --- | | Description | |
| *phyCurrentChannel* | 0x00 | Integer |  | The RF channel to use for all following transmissions and receptions |
| *phyChannelsSupported*† | 0x01 | Array |  | The array is composed of R rows, each of which is a bit string with the following properties: The 5 MSBs (b27, …, b31) indicate the channel page, and the 27 LSBs (b0, b1, …, b26) indicate the status (1=available, 0=unavailable) for each of the up to 27 valid channels (b*k* shall indicate the status of channel *k* as in 6.1.2) supported by that channel page. The device only needs to add the rows (channel pages) for the PHY(s) it |
| *phyTransmitPower\** | 0x02 | Bitmap |  | The 2 MSBs represent the tolerance on the transmit power: 00 = ± 1 dB 01 = ± 3 dB 10 = ± 6 dB and shall be read-only. The 6 LSBs, which may be written to, represent a signed integer in twos-complement format, corre- sponding to the nominal transmit power of the device in decibels rela- tive to 1mW. The lowest value of *phyTransmitPower* is interpreted as less than or equal to –32 dBm. |
| *phyCCAMode* | 0x03 | Integer |  | The CCA mode (see 6.9.9). |
| *phyCurrentPage* | 0x04 | Integer |  | This is the current PHY channel page. This is used in conjunction with *phyCurrentChannel* to uniquely identify the channel currently being used |
| *phyMaxFrameDuration*† | 0x05 | Integer |  | The maximum number of symbols in a frame: = *phySHRDuration + ceiling([aMaxPHYPacketSize + 1] x phySymbolsPerOctet)* |
| *phySHRDuration*† | 0x06 | Integer |  | The duration of the synchronization header (SHR) in symbols for the current PHY. |
| *phySymbolsPerOctet*† | 0x07 | Float | 0.33, 0.5, 0.66, 1, 1.33, 2.66, 5.33 | The number of symbols per octet for the current PHY |
|  |  |  |  |  |

## 2450 MHz PHY specifications

## 868/915 MHz band binary phase-shift keying (BPSK) PHY specifications

## 868/915 MHz band (optional) amplitude shift keying (ASK) PHY specifications

## 868/915 MHz band (optional) O-QPSK PHY specifications

## OFDM PHY Specifications

### Data rate

The following data rates and modulation methods are supported

|  |  |  |  |
| --- | --- | --- | --- |
| **Data Rate (kbps)** | **Modulation** | **Code Rate** | **Comment** |
| 360 | pi/4 DQPSK | uncoded |  |
| 240 | pi/4 DQPSK | 2/3 |  |
| 180 | pi/4 DQPSK | 1/2 |  |
| 120 | DBPSK | 2/3 |  |
| 90 | DBPSK | 1/2 |  |
| 45 | DBPSK | 1/4 | 2x Frequency spreading |
| 22.5 | DBPSK | 1/8 | 4x Frequency spreading |

### Modulation

#### Reference Modulator Diagram

The section describes the techniques for converting the binary message data into the final symbol to be transmitted. Data is convolutionally encoded, optionally punctured, interleaved and mapped onto a number of PSK constellations dependent upon the data rate. For data rates of 180 kbps and higher a π/4 DQPSK constellation shall be used, for data rates of 120 kbps and lower a DPSK constellation is used. These constellations are spread in frequency, according to the data rate, and mapped onto inputs to a 16 point IFFT for conversion to a time domain sequence. Finally a cyclic prefix is added before up-sampling and mixing to the channel frequency.



#### DBPSK Modulation

*B(m)* denotes the modulation bit of a sequence to be transmitted, where *m* is the bit number. The sequence of modulation bits shall be mapped onto a sequence of modulation symbols *S(k)*, where *k* is the corresponding symbol number.

The modulation symbol *S(k)* shall result from a differential encoding. This means that *S(k)* shall be obtained by applying a phase transition *Dφ(k)* to the previous modulation symbol *S(k-1)*, hence, in complex notation:

S(k) = S(k-1)exp(jD*φ(k))*

*S(0) = 1*

The above expression for *S(k)* corresponds to the continuous transmission of modulation symbols carried by an arbitrary number of bursts. The symbol *S(0)* is the symbol before the first symbol of the first burst and shall be transmitted as a phase reference.

In the case of DBPSK modulation, the phase transition *Dφ(k)* shall be related to the modulation bits as shown in the table below.

|  |  |
| --- | --- |
| **B(k)** | **Dφ(k)** |
| 0 | -π/2 |
| 1 | +π/2 |

#### π/4 DQPSK Modulation

*B(m)* denotes the modulation bit of a sequence to be transmitted, where *m* is the bit number. The sequence of modulation bits shall be mapped onto a sequence of modulation symbols *S(k)*, where *k* is the corresponding symbol number.

The modulation symbol *S(k)* shall result from a differential encoding. This means that *S(k)* shall be obtained by applying a phase transition *Dφ(k)* to the previous modulation symbol *S(k-1)*, hence, in complex notation:

S(k) = S(k-1)exp(jD*φ(k))*

*S(0) = 1*

The above expression for *S(k)* corresponds to the continuous transmission of modulation symbols carried by an arbitrary number of bursts. The symbol *S(0)* is the symbol before the first symbol of the first burst and shall be transmitted as a phase reference.

In the case of π/4-DQPSK modulation, the phase transition *Dφ(k)* shall be related to the modulation bits as shown in the table below.

|  |  |  |
| --- | --- | --- |
| **B(2k-1)** | **B(2k)** | **Dφ(k)** |
| 1 | 1 | -3π/4 |
| 0 | 1 | +3π/4 |
| 0 | 0 | +π/4 |
| 1 | 0 | -π/4 |

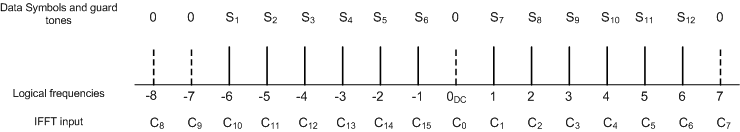
#### OFDM Modulation

The discrete-time signal, *sn*[k], shall be created by taking the IDFT of the stream of

complex values as follows:

Where is the complex value in the set of data sets to be transformed.

When no frequency spreading is used the mapping of the data symbols onto the IFFT inputs is shown below.



##### Cyclic Prefix

A cyclic prefix is appended to the beginning of the symbol to preserve the requirement that the channel imposes circular convolution on the signal when multipath delay is present. This is accomplished by copying the last 4 samples of the IFFT output and appending it as shown in the diagram below.



##### Implementation Considerations

A common way to implement an inverse discrete Fourier transform is by using an inverse Fast Fourier Transform (IFFT) algorithm. The logical frequency subcarriers 1 to 6 are mapped to the same numbered IFFT inputs, while the logical frequency subcarriers –6 to –1 are mapped into IFFT inputs 10 to 15, respectively. The rest of the inputs, 7 to 9 and the 0 (DC) input, are set to zero. The subcarrier falling at DC (0 th subcarrier) is not used to avoid difficulties in DAC and ADC offsets and carrier feed-through in the RF chain.



##### Demodulation

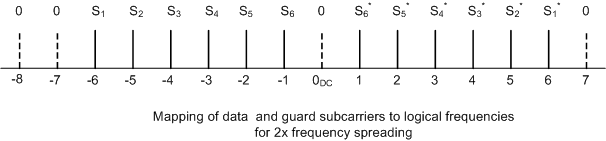
Typically demodulation does not require explicit channel estimates or channel tracking and demodulation of the OFDM symbol can be achieved by using a 16 point FFT and differentially demodulating the corresponding tones of each successive symbol. However the standard allows for more sophisticated coherent demodulation if this is warranted in the opinion of the implementor.

#### Frequency Spreading and De-spreading

As a measure to improve robustness two levels of spreading the data across frequency shall be used

##### 2x Frequency Spreading

The complex differentially encoded symbols S1 through S6 are mapped directly to the lower set of tones, whereas they are flipped and conjugated before being mapped to the upper set of tones as shown in the diagram. This simple process enforces Hermitian symmetry and guarantees that the time domain waveform is real only, with no imaginary components. This has advantages for simplification of the transmitter hardware for devices that support only lower data rates.



##### 2x Frequency De-spreading

De-spreading is accomplished using the reverse process of conjugation and combining. It is not the intention to prescribe the receiver structure, however the diagram below gives an example of a simple receiver structure to illustrate the process of differential demodulation and combination of soft decisions.



##### 4x Frequency Spreading

The complex differentially encoded symbols S1 through S3 replicated and mapped onto the lower set of tones, whereas they are flipped and conjugated before being mapped to the upper set of tones as shown in the diagram. This simple process enforces Hermitian symmetry and guarantees that the time domain waveform is real only, with no imaginary components. This has advantages for simplification of the transmitter hardware for devices that support only lower data rates.



##### 4x Frequency De-spreading

De-spreading is accomplished using the reverse process of conjugation and combining. It is not the intention to prescribe the receiver structure, however the diagram below gives an example of a simple receiver structure to illustrate the process of differential demodulation and combination of soft decisions.



#### Convolutional Encoder

Robustness against channel errors is provided by a convolutional encoder and puncturing matrices to achieve the desired code rate as described by Hagenauer in [1].

The convolutional encoder shall use the rate *R* = ½ code with generator polynomials, *g*0 = 23 , *g*1 = 35. The bit denoted as “A” shall be the first bit generated by the encoder, followed by the bit denoted as “B”.



##### Puncturing

Additional coding rates are derived from the “mother” rate *R* = ½ convolutional code by employing “puncturing”. Puncturing is a procedure for omitting some of the encoded bits at the transmitter (thus reducing the number of transmitted bits and increasing the coding rate) and inserting a dummy “zero” metric into the decoder at the receiver in place of the omitted bits. The puncturing patterns are illustrated in the following figure.

For the last block of bits, the process shall be stopped at the point at which encoder output bits are exhausted, and the puncturing pattern applied to the partially filled block.



The PLCP header shall be encoded using a coding rate of *R* = 1/2. The encoder shall start from the “all zero state”. After the encoding process for the PLCP header has been completed, the encoder shall be reset to the “all zero state” before the encoding starts for the PSDU; in other words, the encoding of the PSDU shall also start from the “all zero state”.

The PSDU shall be encoded using the appropriate coding rate of *R* = 1/2, 4/5.

#### Bit Interleaving

The coded and padded bit stream shall be interleaved prior to modulation to provide robustness against burst errors. The size of the interleaver is variable depending upon the message length but shall not exceed 512 bits.

### Radio Specification

#### Operating Frequency Range

The OFDM PHY will operate in the 800/900MHz band and in the 2.4GHz ISM band.

#### Transmit PSD Mask

The transmitted spectral mask shall have break points at the following emissions levels relative to the maximum spectral density of the signal

* 0 dBr from -125 kHz to 125 kHz around the center frequency
* -18 dBr at 175 kHz frequency offset
* -30 dBr at 300 kHz frequency offset and above

For all other intermediate frequencies, the emissions level is assumed to be linear in the dB scale. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in the figure below.

Dependent on local regulations, additional limitations on the permitted transmissions and on the absolute transmit power levels may apply. These regulations are not described in this standard.



#### Symbol Rate

The OFDM symbol rate shall be 15 ksymbols/s

#### Receiver Sensitivity

Under the conditions specified in 6.1.7, a compliant device shall be capable of achieving a sensitivity of

**TBD** dBm or better.

#### Receiver Jamming Resistance

TBD

#### Clock Synchronization

The transmit center frequencies and the symbol clock frequency shall be derived from the same reference oscillator.

## General radio specifications

### TX-to-RX turnaround time

The TX-to-RX turnaround time shall be less than or equal to *aTurnaroundTime* (see 6.4.1*)*.

The TX-to-RX turnaround time is defined as the shortest time possible at the air interface from the trailing

edge of the last chip (of the last symbol) of a transmitted PPDU to the leading edge of the first chip (of the

first symbol) of the next received PPDU.

The TX-to-RX turnaround time shall be less than or equal to the RX-to-TX turnaround time.

### RX-to-TX turnaround time

The RX-to-TX turnaround time shall be less than or equal to *aTurnaroundTime* (see 6.4.1*)*.

The RX-to-TX turnaround time is defined as the shortest time possible at the air interface from the trailing

edge of the last chip (of the last symbol) of a received PPDU to the leading edge of the first chip (of the first

symbol) of the next transmitted PPDU.

### Error-vector magnitude (EVM) definition

EVM calculation as per 6.9.3 of the 2006 amendment.

The relative constellation RMS error, averaged over all subcarriers of the OFDM symbols and over all of the frames, shall not exceed the values given in the table below.

|  |  |
| --- | --- |
| **Modulation** | **Relative constellation error (dB)** |
| DBPSK | -9dB (~35%) |
| π/4 DQPSK | -12dB (~25%) |

### Transmit center frequency tolerance

The transmitted center frequency tolerance shall be ±20 ppm maximum.

### Transmit power

A device shall provide support for transmit power control (TPC). This functionality can be used with the objective of minimizing the transmit power spectral density, while still providing a reliable link for the transfer of information.

|  |  |
| --- | --- |
| **TXPWR\_LEVEL** | **Transmit Power** |
| 0 | tbd |
| 1 |  |
| 2 |  |
| 3 |  |
| 4 |  |
| 5 |  |
| 6 |  |
| 7 |  |

### Receiver maximum input level of desired signal

### Receiver Energy Detection (RSSI)

A device may indicate the strength in decibels of the incoming signal. The RSSI is a monotonically increasing function of the energy received at the antenna. It is a value between 0 and 255.

### Link quality indicator (LQI)

A device shall be capable of estimating the link quality (LQE) of the received channel, where the link quality shall be defined as an estimate of the SNR available after the FFT and will include all implementation losses associated with that particular receiver architecture (quantization noise, channel estimation errors, etc.).

Devices shall be capable of estimating values in the range from -6 dB to +23dB. All estimated values, when measured under static channel conditions, shall be monotonically increasing with signal strength over the entire reporting range. Note that the estimates may exhibit saturation behavior at values higher than tbd3 dB.

Finally, the link quality estimates shall be made on a packet-by-packet basis.

The LQE is reported using the Link Quality Indicator (LQI) using the following mapping table

|  |  |
| --- | --- |
| **LQI** | **Description** |
| 0 | Link Quality too poor to be estimated |
| 1..30 | LQI = (LQE + 7) dB |
| 31 | Link Quality Saturated |

### Clear channel assessment (CCA)

The start of a valid OFDM transmission at a receiver level equal to or greater than the minimum sensitivity for a 22.5kbps transmission shall cause CCA to indicate that the channel is busy with a probability > 90% within CCA DetectTime.

# MAC Sublayer Specification

## MAC sublayer service specification

### MAC data service

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### MAC constants

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