| | |
|---|---|
| Project | IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs) |
| Title | **Common Platform for narrow band frequency hopping PHY** |
| Date Submitted | [01 May, 2009] |
| Source | [Benjamin Rolfe]<br>[Jean Schwoerer]<br>[Cristophe Dugas]<br>[John Rouse]<br>[Cristina Seibert]<br>[George Flammer]<br>[Michael Schmidt]<br>[Jeritt Kent]<br><br>E-mail:<br>[ben @ blindcreek.com]<br>[jean.schwoerer @ orange-ftgroup.com]<br>[christophe.dugas @ coronis.com]<br>[john.rouse @ coronis.com]<br>[cseibert @ silverspringnet.com]<br>[gflammer @ silverspringnet.com]<br>[michael.schmidt @ atmel.com]<br>[Jeritt.Kent @ analog.com] |
| Re: | TG4g Proposals |
| Abstract | This document provides a framework for merging frequency narrow bandwidth hopping proposals offered to TG4g. It describes, as an example, a set of PHY features and characteristics derived from the multiple proposals that fit into the general class of proposals. |
| Purpose | Facilitate collaboration and convergence. |
| 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 |  |

# Smart Utility Networks (802.15.4g) PHY Amendment:

# Common Platform Framework Proposal

## Abstract

This document provides a framework for merging frequency narrow bandwidth hopping proposals offered to TG4g. It describes, as an example, a set of PHY features and characteristics derived from the multiple proposals that fit into the general class of proposals.

## Contents

## Tables

## Figures



# 1. Overview

## *1.1 General*

This document provides a framework and method to define a set of baseline features for a the 802.15.4g PHY. The focus of this version is on the idea of a common narrow band frequency hopping PHY derived from the substantially similar FHSS proposals presented in March 2009, and information provided by contributors in the interim. This document is combines features from the several narrow band frequency hopping proposals as listed in section 2. In this context "Narrow Band" means an occupied BW that allows for a channel spacing of < 500 KHz.

This is a starting point: the current draft is intended as a framework for facilitating the work of merging proposals into a coherent draft. The current content serves as an example of how the features of various proposals may be combined in a coherent manner, but is not intended to suggest that the merging work is done. This is intended as a collaborative tool.

The individual proposals referenced in this document have continued to evolve; nothing in this document is meant to supersede the detailed proposals being submitted by their respective authors. The intention is to provide a cooperative mechanism to enable all the various proposal authors to converge collaboratively on a common platform. As new proposals are submitted, this document should be revised with collaboration with the proposal authors. The common platform participants can begin working with technical editors as early as possible.

Mechanisms and methods are suggested for how differences can be managed. Again these are offered as examples of what might work, and may be considered a starting point for discussion. It is the basis of this proposed approach that the variety of proposals presented is driven by the variety of application needs and environmental conditions encountered in the SUN space, and that each proposal brings useful features. The composite approach will use the unique benefits of each proposal, to provide a sufficiently flexible, yet simply realizable, PHY that may be adaptable to the different conditions and applications, making the standard more broadly useful.

## *1.2 Purpose*

The purpose of this document is to

- Provide a frame work for combining the elements of TG4g PHY proposals in a logical way;
- Provide for identifying the most important features of proposals to combine into a common approach that is sufficiently flexible to meet the diverse needs encountered in SUN deployment, while remaining simple enough for low cost implementation.
- Support a collaborative process.
- Satisfy the goal of arriving at a common set of features that satisfy the essential needs identified by each participant.

## *1.3 Scope*

This proposal defines part of the alternate PHY amendment to IEEE 802.15.4 to addresses the Low Data Rate Wireless Smart Metering Utility Network requirements.

The scope of the PAR for 15.4g specifies an alternate PHY for 802.15.4 that addresses principally outdoor Low Data Rate Wireless Smart Metering Utility Network requirements, which supports all of the following:

- Operation in any of the regionally available license exempt frequency bands
- Data rate of at least 40 kbits per second but not more than 1000 kbits per second
- Principally outdoor communications
- PHY frame sizes up to a minimum of 1500 octets
- Simultaneous operation for at least 3 co-located orthogonal networks
- Connectivity to at least one thousand direct neighbors characteristic of dense urban deployment
- Provides mechanisms that enable coexistence with other systems in the same band(s) including IEEE 802.11, 802.15 and 802.16 systems.

## *1.4 Architecture of the Common Platform approach*

The tree in Figure 1 shows a general structure used in this document to organize the different features and capture the essential commonalities as well as useful alternatives. The scope of this version is on the FH branch only.

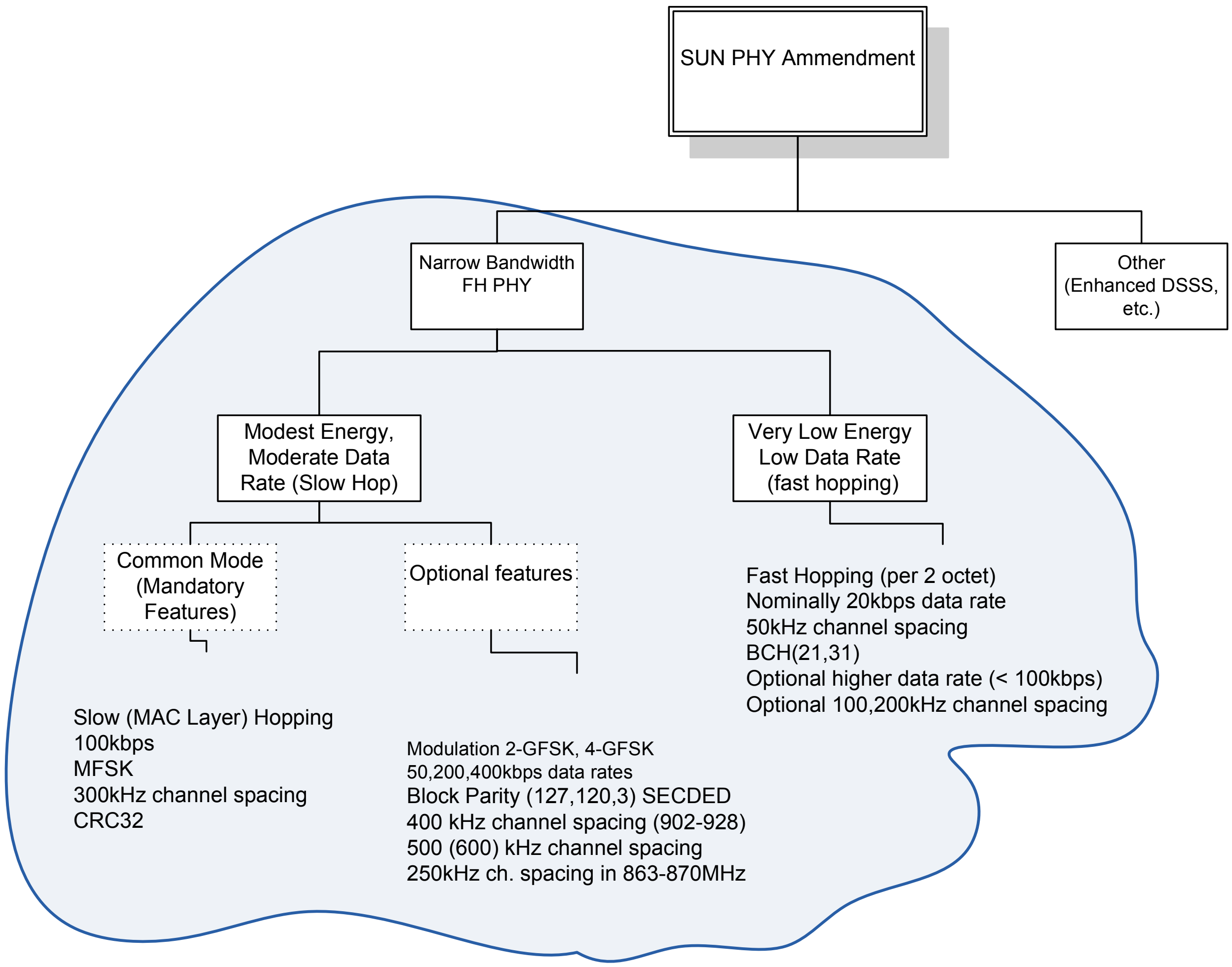



**Figure 1: Architecture**

The frequency hopping approaches described here use a channel bandwidth of ≤ 500 kHz. “Slow hopping” means that an entire PHY frame (PPDU) is transmitted on the channel before moving to the next channel in sequence; “fast hopping” means that the PPDU is split across multiple channels. The common practice in the 802 architecture is that the interface unit between MAC and PHY is the PSDU, so the terms “MAC hopping” and “PHY hopping” may also be used.

The “slow hopping” mode is optimized for moderate data rates and modest energy consumption with support for MAC layer energy saving; The “fast hopping” is optimized for very low energy consumption and low data rates; The terms Moderate Data Rate (MDR) and Very Low Energy (VLE) are used in this document to distinguish between the two modes.

Within each PHY option, we may address different frequency bands, regions covered, optional features addressed, etc.

# 2. References

P802.15.4g PAR:

https://development.standards.ieee.org/get-file/P802.15.4g.pdf?t=29196300024

Proposals used to prepare this draft:

1. 15-09-0135-01-004g-preliminary-proposal-for-a-multi-regional-sub-ghz-phy-for-802-15-4g.ppt [K. T. Le]
2. 15-09-0120-02-004g-coronis-ft-preliminary-proposal.ppt [Dugas, Rouse, Schwoerer]
3. 15-09-0118-03-004g-narrow-band-phy-preliminary-proposal.ppt [Seibert, Rolfe, Flammer]
4. 15-09-0127-02-004g-smart-grid-communications-preliminary-proposal.ppt [Mason, McCullough, Hart]

# 3. Definitions

TBD

# 4. Acronyms and Abbreviations

TBD

# 5. General Description of Wireless SUN

## *5.1 Introduction*

The proposed PHY targets the following characteristics of the Wireless SUN addressed here include:

- Low data rate: over the air data rates of at least 40kbps to 400kbps
- Very high reliability and availability
- High resilience and adaptability in the presence of interference and good coexistence properties with both like systems and non SUN systems.
- Support for Peer to Peer, minimal infrastructure-dependent operation
- Support for dynamic scaling to very large aggregate networks

## *5.2 Components of the SUN*

## *5.3 Network Topologies*

The network topologies described in 802.15.4-2006 are supported by the proposed PHY. The primary topology employed in SUN systems is peer-to-peer with mesh at the network layer. It is a basis assumption that frequency diversity is achieved by channel hopping (which in slow hopping is controlled by the MAC) and path diversity will be provided at higher (network) layers.

## *5.4 Architecture*

The W-SUN architecture is consistent with the architecture described in 802.15.4-2006.

### 5.4.1 General Characteristics of the narrow band PHY Sub-layer

The proposed PHY will support multiple regulatory domains and multiple bands. Multiple bands below 1000 MHz are provided, and the 2.4GHz band is specified. As regulatory changes may be underway in several nations specifically to address spectrum needs of the SUN deployment, this common features are band agnostic. The bands included in this version are representative and not an exhaustive set.

The general characteristics of the common platform include:

- Narrow band channels with many channels per band
  - Ability to use maximum transmit power as may be allowed by regulations and the ability for upper layers to adjust transmit power to fit the local regulations and/or operating conditions;
  - Multiple channel Bandwidths: <50kHz, <250kHz, <400kHz, TBD;
  - Multiple channel spacing: 50kHz, 300kHz, 400kHz, TBD;
- Robust, Simple FSK based modulation/demodulation
  - MSK modulation (other modulation index options?)
  - GFSK/MSK/GMSK (switch-able Gaussian filter)
  - 1 and 2 bit per symbol (2- and 4-FSK)
- Optional FEC
  - Block parity, BCC
- Support for efficient frequency hopping
  - Deterministic constraints on channel switch timing
  - Support for MAC layer synchronization mechanisms
- Simple PHY frame structure
  - Efficient support for IP (2047 Octet payload capable
  - Optional compressed header format
  - Optional expanded header format
  - 32-Bit CRC (MAC)
- Data “whitening” (scrambling)
  - 8 bit scrambler
  - Variable seed (may change per PPDU)
- Multiple data rates

  - 20 kbps, 50 kbps, 100 kbps, 200, 400 kbps
  - Other possible rates?
- Transmit Power Control (TPC) for adapting to regulator domain and to support adaptation to observed link conditions
- Monotonic Received Signal Strength Indication (RSSI)
- Flexible coexistence features
  - Channel diversity and hopping
  - Scalable transmit power (thus radio sphere of influence)
  - Support for low duty cycle operation

### 5.4.2 MAC Sub-layer (General Characteristics)

## *5.5 Functional Overview*

As per 802.15.4-2006.

# 6. PHY Specification

## *6.1 General Requirements and Definitions*

### 6.1.1 Operating frequency

The narrow band PHY is intended to operate over a variety of license exempt frequency bands. The narrow channel bandwidths enables use of many regionally available frequency bands, in small increments, making it possible to use small spaces which provide insufficient bandwidth for wider channel widths. The available spectrum varies regionally.

| Band | | PHY Mode Section | | | | |
|---|---|---|---|---|---|---|
| MHZ | | MDR-FH | VLE-FH | E-DSSS | Other | |
| 316 | 433 | √ | √ | | | |
| 470 | 510 | √ | | | | China (unverified) |
| 863 | 870 | √ | √ | | | |
| 902 | 928 | √ | √ | | | US |
| 950 | 956 | √ | | | | Japan (unverified) |
| 2400 | 2483 | | √ | √ | | |
| | | | | | | |

### 6.1.2 Channel assignments

*TBD.*

### 6.1.3 Minimum interframe spacing periods

*TBD*

### 6.1.4 RF power measurements

*TBD*

### 6.1.5 Transmit Power

The maximum transmit power shall conform to local regulations. Refer to Annex F for additional information on regulatory limits. TX power control is covered in sub-clause 6.4.

### 6.1.6 Out-of-band spurious emissions

Out of band unintentional emissions must conform to local regulations. Appendix F provides information of applicable regulatory limits known at the time standard was developed.

### 6.1.7 Receiver sensitivity definitions

*TBD*

## *6.2 PHY Service Specification*

*TBD*

## *6.3 PPDU Format*

A conformant device shall implement at least one of the following frame formats (and may implement multiple formats). Upon reception an unrecognized frame format is ignored. For each PHY frame below, a unique Start Frame Delimiter will be used.

The PHY frame structure is shown in Figure 2.

| | | | | | | |
|---|---|---|---|---|---|---|
| Octets: variable | 2 | 1 | 2 | | | variable |
| Bits: variable | 16 | 8 | 4 | 1 | 11 | |
| Preamble | SFD | Scrambler Seed | FCTRL | EXT | Frame Length | PSDU Includes FCS |
| SHR | | PHR | | | | PHY Payload |

**Figure 2: Structure of PPDU**

Optionally the compressed PHY frame format may be used

| | | | | | |
|---|---|---|---|---|---|
| Octets: variable | 2 | 2 | | | variable |
| Bits: variable | 16 | 4 | 1 | 11 | |
| Preamble | SFD | FCTRL | EXT | Frame Length | PSDU Includes FCS |
| SHR | | PHR | | | PHY Payload |

**Figure 3: Structure of PPDU with compressed header**

Table 1 shows the start frame delimiter for each frame format.

Synchronization Header (SHR): The SHR is always sent unscrambled and unencrypted and not scrambled (in the clear). It consists of two parts, the preamble and the Start Flag Delimiter (SFD). The Preamble is a repeated pattern, where the number of repetitions can be variable, set by the MAC via the PIB attribute *phyPreambleLength*; the receiver once tracking the preamble will be triggered by the SFD to begin frame reception. The SFD values are given in 0.

PHY Header (PHR): The PHY header is always sent unscrambled and unencrypted (in the clear). The scrambler seed may be suppressed via the compressed frame form. The PHR consists of the following:

1. Scrambler Seed
2. Frame Control
3. PHR extension bit
4. Frame Length

The frame control field includes bits to signal data rate and FEC used for the payload.

PHY Payload (PSDU) is sent scrambled. The PSDU may contain any valid MPDU.

CRC-32: to support the longer payload length IEEE CRC-32 is used. The CRC generation method is described in 6.3.7.

## 6.3.1 Preamble Field

The preamble bits are sent prior to the 16-bit Start Frame Delimiter (SFD). The preamble provides for receiver centering, bit edge detection, and timing recovery. The preamble is a variable sequence of an alternating one/zero bits (0xAA). The length of the preamble is controlled by the MAC via the *phyPreambleLength* PIB attribute.

Optionally, the preamble pattern may also be set by the MAC via the *phyPreambleValue* PIB attribute.

### 6.3.2 SFD Field

A SFD establishes frame timing. The SFD shall be inserted after the preamble. The SFD indicates the end of the SHR and the start PHY header (PHR). The SFD is a 16-bit sequence selected from the values in Table 1.The SFD uniquely identifies the PHY header format that follows, the compressed form or the full PHR. Additional SFD values can be added to support additional PHR as needed.

| Mul | SFD Value | Remarks |
|---|---|---|
| Full | 0xF3A0 | |
| Compressed | TBD | |

**Table 1: SFD Values**

If a receiving device receives an unrecognized SFD, it shall reject the frame.

### 6.3.3 Scrambler Seed Field

This single octet value seeds the data whitening scrambler. On transmit, the field is set to the value used for transmission of the PPDU. Upon reception, this value is used to seed scrambler. The scrambler is described below in 6.6.4. The scrambler seed should be changed by the MAC, at least upon packet retries, to assure that if a data pattern is encountered that “un-whitens” scrambler on transmission, it is assured not to happen on the retry.

### 6.3.4 Frame Control Field

The frame control field signals the data rate and FEC option used for the payload part of the PPDU. The payload data rate field supports implementation of multiple PHY data rates and provides a means for over the air signaling of the rate at which the PPDU payload is transmitted. The 2 bit field supports 4 data rate options as shown in [the table]. The SHR and PHR are transmitted using the default 100kbps data rate (DR=00b).

| FCTRL | | | | |
|---|---|---|---|---|
| Bits: | 2 | | 2 | |
| | FEC : | | Data Rate : | |
| | 00b | No FEC | 00b | Payload at default data rate |
| | 01b | BCC Coding | 01b | Payload at optional rate A |
| | 10b | Block Parity | 10b | Payload at optional rate B |
| | 11b | Other | 11b | Payload at optional rate C |

**Table 2: FEC and Data Rate Field**

The actual data rates corresponding to the data rate index differ between the PHY mode and are given in the “Data Rate” clause for each mode. The intention is that is only capable if signaling different data rate and FEC when used in PHY modes that allow exchange of the PHR, for example switching between 2-GFSK and 4-GFSK (with the same channel BW, etc).

### 6.3.5 PHY Header Extension Field

This bit is reserved for future extension of the PHY header. For this version of the standard this bit shall be set to zero upon transmission. In future versions this may be used to signal that additional header bits follow the frame length field.

### 6.3.6 Frame Length Field

The 11 bit field is set on transmission to the size of the PSDU (PHY payload). The maximum legal size of the PSDU (MPDU) is 2047 octets. Upon reception, this field indicates the number of octets to receive following the length field.

### 6.3.7 Frame Check Sequence Field

The Frame Check Sequence (FCS) is an IEEE CRC-32 (equivalent to ANSI X3.66-1979). On transmission, the CRC-32 is calculated over the PSDU (MPDU) prior to scrambling; on reception the FCS is calculated after de-scrambling. The FCS scope, referred to here as the calculation field, is the entire PHY payload (PSDU), and does not include the PHR.

The MSB of the FCS is the coefficient of the highest order term and the field is sent over the wireless medium commencing with the coefficient of the highest-order term.

The FCS is calculated using the following standard generator polynomial of degree 32:

G(x) = x32 + x26 + x23 + x22 + x16 + x12 + x11 + x10 + x8 + x7 + x5 + x4 + x2 + x + 1

The FCS is the one's complement of the modulo 2 sum of the remainders in "a" and "b" below:

a) The remainder resulting from ((xk*(x31+x30+...)) divided (modulo 2) by G(x). The value k is the number of bits in the calculation field.
b) The remainder resulting from the calculation field contents, treated as a polynomial, is multiplied by X32 and then divided by G(x).

At the transmitter, the initial remainder of the division shall be preset to all ones and is then modified via division of the calculation fields by the generator polynomial G(x). The ones complement of this remainder is the FCS field.

At the receiver, the initial remainder shall be preset to all ones. The serial incoming bits of the calculation fields and FCS, when divided by G(x) in the absence of transmission errors, results in a unique non-zero remainder value. The unique remainder value is the polynomial:

x31+x30+x26+x25+x24+x18+x15+x14+x12+x11+x10+x8+x6+x5+x4+x3+x+1

### 6.3.8 PSDU Field

The PSDU field has a variable length and carries the data of the PHY packet.

## *6.4 PHY constants and PIB attributes*

The PIB attributes for the narrow band PHY are shown in below.

| Attribute | Ident-tifier | Type | Range | Description |
|---|---|---|---|---|
| *phyPreambleLength* | | integer | TBD | Specifies number of bits sent in preamble |
| *phyPreambleValue* | | bit field | 8 bit field | Preamble bit pattern that is repeated *phyPreambleLength times; can not be all zeros.* |
| | | | | |
| | | | | |

**Table 3 –PHY PIB Attributes**

## *6.5 Enhanced DSSS PHY*

### 6.5.1 Data rates

### 6.5.2 Modulation and spreading

### 6.5.3 Radio specifications

## *6.6 Moderate Data Rate Narrow Band PHY Specification*

This section is the detailed specifications for the moderate data rate narrow band “slow hopping” mode of operation.

### 6.6.1 Data Rate(s)

The MDR PHY provides data rates of 100, 200 and 400 kbps by a combination of varying channel bandwidth and modulation. The default data rate is 100kbps using 1 bit per symbol FSK modulation with no BCC or block parity coding (code rate = 1).

*Need to complete this table…here is what I know so far*

| Chan Spacing kHz | Chan BW kHz | Modulation | Bit rate kbps | Note |
|---|---|---|---|---|
| 300 | 250 | 2-MSK, 2-GFSK | 100 | |
| 300 | 250 | 4-GFSK | 200 | |
| 250 | TBD | 2-GFSK | 50, 100 | 863-870MHz band |
| 250 | TBD | 4-GFSK | 200 | 863-870MHz band |
| 400 | TBD | 2-FSK, TBD | 200 | |
| 600 | 500 | 2-MSK, 2-GFSK | 200 | 2.4GHz |
| 600 | 500 | 4-MSK, 4-GFSK | 400 | 2.4GHz |
| 500 | 500 | 2-GFSK | 200 | 868-870MHz band |
| 500 | 500 | 4-GFSK | 400 | 868-870MHz band |

The channel spacing is the distance between center frequencies; the channel bandwidth is the 20dB occupied BW. The data rate in the above table is the over the air bit rate. If BCC or block parity coding is used, the effective data rate is reduced according to the code rate.

## 6.6.2 Data Transfer

Figure 4 shows the processing steps to create and transfer a PHY packet.

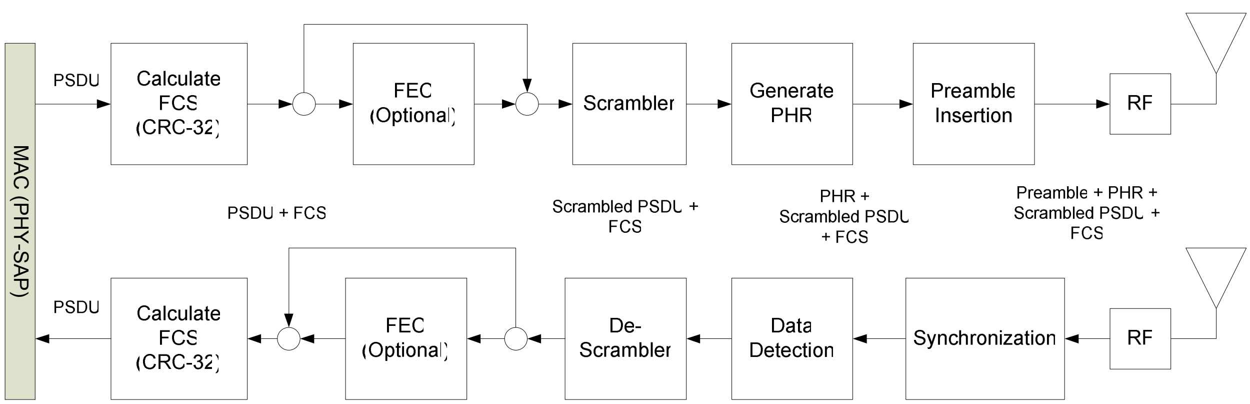



**Figure 4: PHY Signal Flow**

The PHY Frame format is shown in Figure 2. The steps to encode the PSDU (PHY Payload) into a PPDU for transmission are illustrated in Figure 5. Note that when FEC coding is used the maximum size of the MPDU (PSDU) must be adjusted by the coding rate (*CRadj* in the figure).

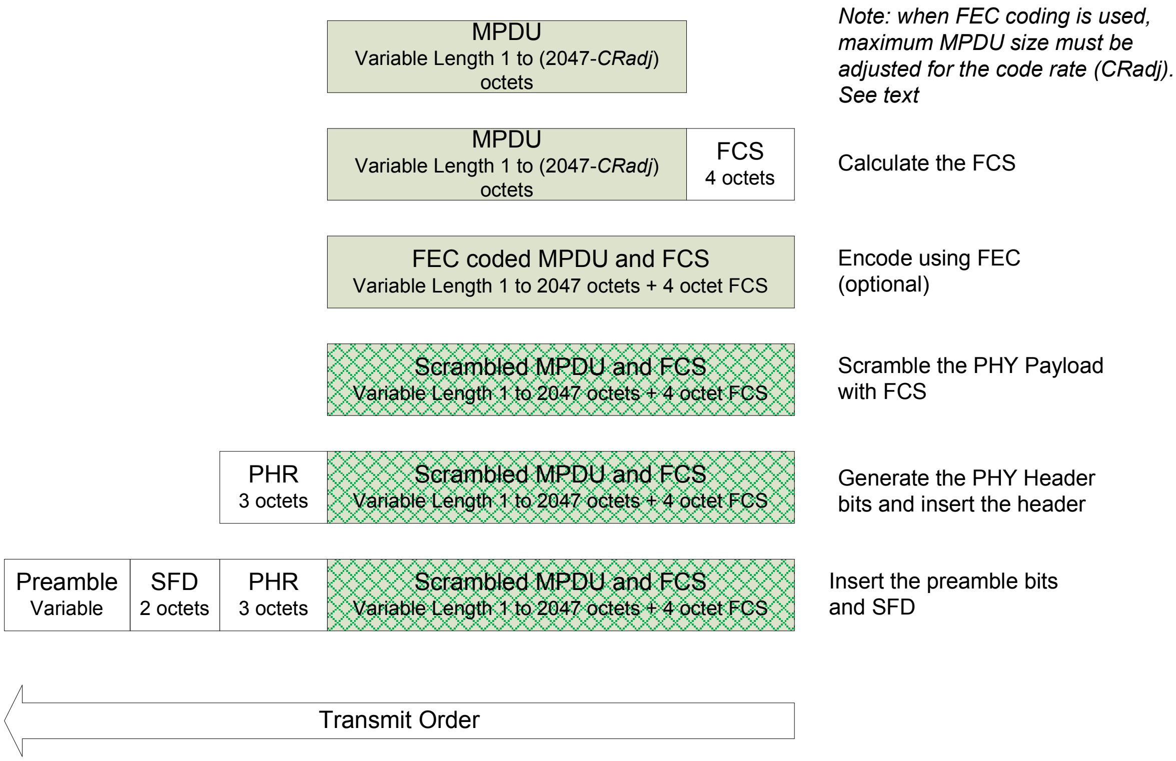



**Figure 5: PPDU Encoding Process**

#### 6.6.2.1 Transmit Procedure
#### 6.6.2.2 Receive Procedure
### 6.6.3 Modulation and Coding

The default modulation is minimum Frequency Shift Keying (MSK) with the modulation deviation frequency ($f_{dev}$) of 25kHz, ±5kHz, with the option of Gaussian FSK (GFSK) modulation (BT=0.5, h=1). For 2-MSK and 2-GFSK, each data symbol encodes 1 information bit. In 4-GFSK each data symbol encodes 2 information bits.

#### 6.6.3.1 Reference Modulator Diagram

The functional block diagram for the FSK modulator (with is shown in Figure 6. The frequency offset from center (deviation) is nominally 25kHz. The offset is toggled by the transmit data bit so that a positive offset is generated for a “1” and a negative offset is generated for a “0”.

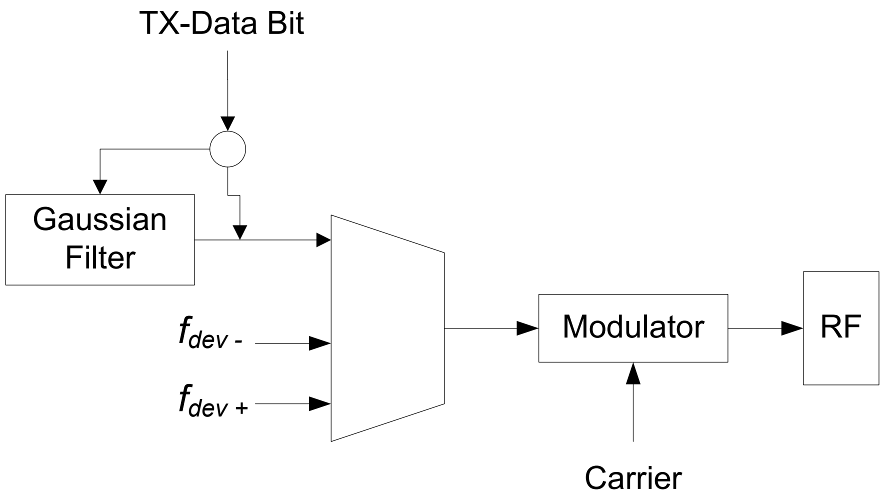



**Figure 6: Reference Modulator Diagram (FSK)**

### 6.6.3.2 Bit to symbol mapping

Each FSK symbol represents one data bit for MSK and 2-GFSK, and 2 data bits for 4-GFSK.

### 6.6.3.3 FSK Modulation

The FSK signal is defined as:

*[insert mathematical description of FSK signal used].*

The FSK modulation parameters are shown in Table 4.

| | MSK | GFSK | Data Rate |
|---|---|---|---|
| *Mod. Index* | 0.5 | 0.5 | 100 kbps |
| $f_{dev}$ | 25 kHz | 25 kHz | 100 kbps |
| *BT* | - | 0.5 | 100 kbps |
| *h* | - | 1 | 100 kbps |
| *…* | | | |
| *(add for other data rates)* | | | |
| | | | |

**Table 4: MDR FSK Parameters**

### 6.6.3.4 Error Correction Coding

With the potentially long packets supported by the PHY, a simple low-overhead FEC can be beneficial in some operational situations. In other situations the overhead of coding lengthens the "exposure window" to interference and thus can be harmful to reliability. To provide the greatest flexibility and adaptability to the MAC and higher layers, a low overhead FEC option(s) is (are) provided.

#### *6.6.3.4.1 Block Parity*

The block parity provides for Single Error Correction, Double Error Detection (SECDED), which provides for correction of single bit errors and strengthens the detection of multiple bit errors. An extended hamming code (128,120,4) is used. For each 15 octets of payload data, one octet of parity check bits is inserted. The block parity can be viewed as (and implemented) as (127,120,3) BCH, extended by an extra parity bit, with generator polynomials:

x7+x3+1 (BCH) and x+1 (extra parity)

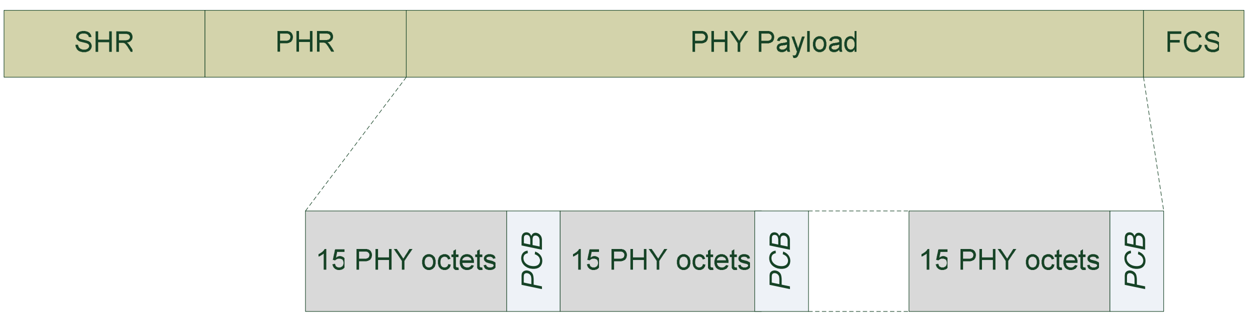



**Figure 7 Block Parity Diagram**

#### *6.6.3.4.2 Binary Block Coding*

*Add description of BCC*

## 6.6.4 Data Whitening

An 8-bit scrambler is applied to data bits to whiten the output. The scrambler is an additive, 8-stage (255 bit sequence) shift register generator with taps at bits [8,4,3,2] as shown in Figure 8.

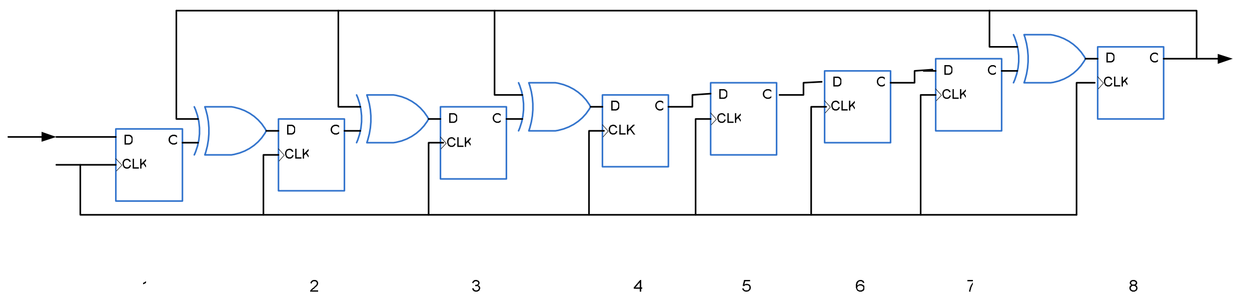



**Figure 8: Scrambler Shift Register Representation**

The transmitter scrambler seed is provided by the MAC for each PSDU Note that if the scrambler is seeded with all zeros, it is effectively disabled, so this value should not be used. On receive, the scrambler seed is set based on the Channel ID / Scrambler Seed value in the PHR.

*[Can add alternate taps if needed – only one presentation provided this detail]*

## 6.6.5 Transmit Power Control

Transmit power control is used to enhance reliability, maximize spectral efficiency (reuse) by optimizing radio range (and thus SOI) to conditions, and enhance coexistence by reducing interference with other services. The PHY PIB parameter *phyTransmitPower* as defined in 802.15.4-2006 provides resolution of 1dB and a range of -32 dBm to 31 dBm, and an implementation may provide 1, 3 or 6 dB steps. The NB PHY will be added to specify the minimum and maximum TX power provided by the implementation (the meaningful range of *phyTransmitPower* in other words). A conformant implementation shall provide at least 16 power levels, with the highest power implemented indicated in the PHY PIB attribute *phyMaxTxPower* and the minimum specified by *phyMinTxPower*.

## 6.6.6 MDR narrow band PHY parameters

| Parameter | Value | Notes |
|---|---|---|
| TBD | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

## *6.7 Very low energy, low data rate narrow band PHY mode*

The focus of the very low energy (VLE) mode is on reduced energy consumption over data rate. In some applications identified for SUN energy consumption is more important than data rate. This PHY mode employs fast frequency hopping (the PSDU is spread to multiple frequencies), 20 kbps and mechanisms to enable very low duty cycle operation.

The low data rate PHY uses a frequency hopping scheme where the PPDU is spread across multiple frequencies operating in available sub-GHz bands, with support for ultra-low power management..

### 6.7.1 Data rates

A base data rate of 19.2 kbps is supported.

| Chan Spacing kHz | Chan BW kHz | Modulation | Bit rate kbps | Note |
|---|---|---|---|---|
| 50 | 50 | GFSK | 19.2 | |

### 6.7.2 Data Transfer

The MAC Interface Data Packet Description is the structure of the frame passed from the MAC Layer to the PHY Layer. The structure is the following:

| GIW | DA | SA | PN | CB | LGF | DTF | Payload |
|---|---|---|---|---|---|---|---|
| 32 bits | 6 bytes | 6 bytes | 1 byte | 1 byte | 1 byte | 1 byte | N bytes |

GIW (FL + EX-FT + FT + Ext) is coded with BCH(21,31) + Parity

Following data are protected with a BCH(21,31) code, a parity bit and Interleaving

**GIW**: composed of four fields representing 21 bits, encoded with BCH(21,31) + parity → 32 bits

FL: Frame length giving the number of blocks on 4 bits (1 block is 21 bytes),

EX-FT: Extended frame type (4 bits)

FT: Frame Type (8 bits)

Ext: Extended (5 bits)

| | | | |
|---|---|---|---|
| b20b19b18b17b16 | Extension | - | Reserved for future |
| b15 | (FT) Multiple Command | 0 | Last command |
| | | 1 | Other command to come |
| b14b13 | (FT) Addressing Mode | 00b | Point to point |
| | | 01b | Broadcast |
| | | 10b | Reach The Root |
| | | 11b | Polling |
| b12 | (FT) Frame Type | 0 | Control Frame |
| | | 1 | Data Frame |
| B11b10b9 | (FT) Protocol Identification | 000b | Version 1,0 |
| b8 | (FT) Request/Answer | 0 | Request Frame |
| | | 1 | Answer Frame |
| b7 | (EX-FT) Not used | - | Reserved for future |
| b6 | (EX-FT) Synchronized Frame | 0 | Not synchronized frame |
| | | 1 | Synchronized frame |
| b5 | (EX-FT) Not used | - | Reserved for future |
| b4 | (EX-FT) Transmission Type | 0 | Bi-direction |
| | | 1 | Mono-direction |
| B3b2b1b0 | (FL) Frame Length | | Number of blocks (1 block is 21 bytes) |

**DA**: Destination address (6 bytes)

**SA**: Source address (6 bytes)

**PN**: Packet Number (1 byte)

**CB**: Control Byte (1 byte)

| | | | |
|---|---|---|---|
| b7 | *reserved* | - | - |
| b6 | RELAY | 0 | Packet is not relayed |
| | | 1 | Packet is relayed |
| b5 | EXT : Extension | 0 | CB is 1 byte length |
| | | 1 | CB is 2 bytes length (not used in actual Wavenis) |
| b4 | *reserved* | - | - |
| b3b2b1 | PP : Packet Position | 000b | Not used |
| | | 001b | FirstP : First Packet |
| | | 010b | MidP : Middle Packet |
| | | 011b | Not used |
| | | 100b | LastP : Last Packet |
| | | 101b | UniP : Unique Packet |
| b0 | WACK : Window ACK | 0 | Data packet must be acknowledged by LLC layer |
| | | 1 | Data packet must not be acknowledged by LLC layer |

**LGF:** Frame length (1 byte). This is N+2 where N is the Length of the Payload field

**DTF:** Frame Type (1 byte). 0x03 for Application frame and 0x04 for Service frame.

## 6.7.3 Modulation and spreading

### 6.7.3.1 Bit to symbol mapping

Each GFSK modulated symbol encodes one information bit.

### 6.7.3.2 FSK Modulation

The VLE mode uses GFSK modulation as described in 6.6.3.3. The modulation parameters used in the VLE mode are shown in Table 5.

| | GFSK |
|---|---|
| *Mod. Index* | 0.5 |
| $f_{dev}$ | |
| *BT* | 0.5 |
| *h* | 1 |

**Table 5: VLE FSK Parameters**

### 6.7.3.3 Error Correcting Code

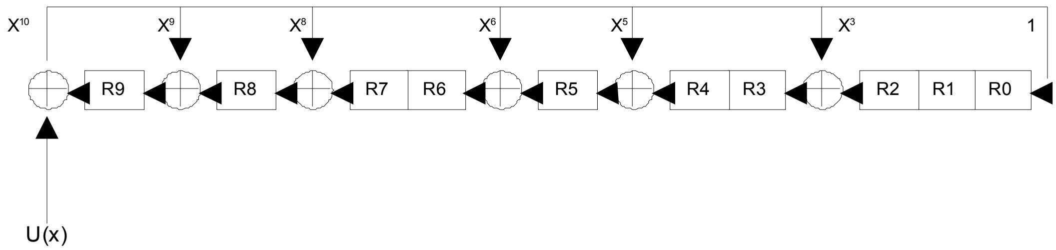
BCH(31,21) coding (1/3 redundancy) is used, with data whitening and interleaving to enhance reliability.

#### *6.7.3.3.1 BCH(21,31)*

The frame is divided in n 21 bits words. On each 21 bits word, a BCH(21,31) is applied giving as a result 10 bits of redundancy. A parity bit is added which gives the following 32 bits result:

| | | |
|---|---|---|
| 31 | 30 21 | 20 0 |
| Parity | 10 redundancy bits | 21 data bits |

Encoding structure *(To be verified):*




$(R(x) = R0 + R1x + R2x2 + R3\ x3 + R4\ x4 + R5\ x5 + R6\ x6 + R7\ x7 + R8\ x8 + R9\ x9)$

#### *6.7.3.3.2 Parity*

The parity bit is not used.

### 6.7.3.4 Data Interleaving

Each 256 bit data block (GIW not concerned) is placed in a 16x16 matrix as follow:

| | | Output | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Input | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 |
| | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 |
| | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 |
| | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 |
| | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 |
| | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 | 138 | 139 | 140 | 141 | 142 | 143 |
| | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 |
| | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 |
| | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 | 189 | 190 | 191 |
| | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 |
| | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 |
| | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 |
| | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 | 253 | 254 | 255 |

Input: First 32 bit word in input is 0,1,2,3,...,28,29,30,31

Output: First 32 bit word in output is 0,16,32,48,...,193,209,225,241

Etc...

#### 6.7.3.5 Data Whitening

Need description. Is it substantially similar to section 6.6.4 ? D

### 6.7.4 Operating Frequency Range

#### 6.7.4.1 Channel assignments

Channel assignment is defined through a combination of

-channel mode

-channel page

-channel number

Radio_mode = channel mode + channel page

#### 6.7.4.2 Channel numbering

A total of 512 channels numbered 0 to 511 are available per channel page.

K = channel number

| | **Channel mode 1/ page 0** |
|---|---|
| K | Frequency |
| 0 | 868.07525 |
| 1 | 868.12520 |
| 2 | 868.17515 |
| 3 | 868.22510 |
| 4 | 868.32500 |
| 5 | 868.37495 |
| 6 | 868.42490 |
| 7 | 868.47485 |
| 8 | 868.52480 |
| 9 | 868.77455 |
| 10 | 868.82450 |
| 11 | 868.87445 |
| 12 | 868.92440 |
| 13 | 868.97435 |
| 14 | 869.02430 |

| | |
|---|---|
| 15 | 869.07425 |
| 16 | 869.12420 |

Channel mode 2/ page 0:

Fc (Mhz) = 902,1312 Mhz * k * CS (kHz) /1000

CS = 57,6 (kHz)

Channel [0 ; 448]

Fc (Mhz) [902,1312 ; 927,936]

### 6.7.4.3 Channel pages

Channel pages are available per channel mode.

### 6.7.4.4 Channel modes

Three channel modes are available, corresponding to the available frequency bands, channel mode and channel page.

| | | | | |
|---|---|---|---|---|
| Channel mode 0 | 868 multifrequency | | | |
| | Page 0 | GFSK modulation | 19,2 kb/s | |
| Channel mode 1 | 915 FHSS | | | |
| | | GFSK modulation | 19,2 kb/s | |
| Channel mode 2 to TBD | Reseved for evolution (ex 863-870 FHSS) | | | |

## 6.7.5 Frequency hopping

### 6.7.5.1 On the 868 MHz band

Frequency hopping is sequence is defined by the following table. Preample frequency is used to transmit PHR other carrier frequencies are used in ascending order of the hop number. Fixed hopping table:

| | |
|---|---|
| Preamble frequency | 868,32500 |
| | |
| Hop number | Frequency (MHz) |
| 1 | 868,07525 |
| 2 | 868,87445 |
| 3 | 868,37495 |
| 4 | 868,92440 |

| | |
|---|---|
| 5 | 868,22510 |
| 6 | 868,77455 |
| 7 | 869,12420 |
| 8 | 868,47485 |
| 9 | 868,97435 |
| 10 | 868,42490 |
| 11 | 869,02430 |
| 12 | 868,17515 |
| 13 | 869,07425 |
| 14 | 868,52480 |
| 15 | 868,12520 |
| 16 | 868,82450 |

### 6.7.5.2 On the 915 MHz band

Frequency hopping is sequence is defined by the following table. Preamble frequency is used to transmit PHR other carrier frequencies are used in ascending order of the hop number. Fixed Hopping table:

| Hop Number | Frequency (MHz) | Hop Number | Frequency (MHz) |
|---|---|---|---|
| 0 | 915,3216 | 43 | 922,0608 |
| 1 | 904,8384 | 44 | 911,1744 |
| 2 | 915,9552 | 45 | 922,2336 |
| 3 | 905,2992 | 46 | 911,3472 |
| 4 | 916,1856 | 47 | 922,4064 |
| 5 | 905,6448 | 48 | 911,52 |
| 6 | 916,3584 | 49 | 913,0176 |
| 7 | 905,8176 | 50 | 924,2496 |
| 8 | 916,704 | 51 | 913,3632 |
| 9 | 907,3152 | 52 | 924,768 |
| 10 | 918,5472 | 53 | 913,7088 |
| 11 | 907,6608 | 54 | 925,1136 |
| 12 | 918,8928 | 55 | 913,8816 |
| 13 | 907,8336 | 56 | 925,4592 |
| 14 | 919,0656 | 57 | 920,2752 |
| 15 | 908,0064 | 58 | 909,216 |
| 16 | 919,2384 | 59 | 920,448 |
| 17 | 922,5792 | 60 | 909,3888 |
| 18 | 912,0384 | 61 | 920,6208 |
| 19 | 923,1552 | 62 | 909,7344 |
| 20 | 912,4992 | 63 | 920,7936 |
| 21 | 923,5584 | 64 | 910,656 |
| 22 | 912,672 | | |

| | |
|---|---|
| 23 | 923,7312 |
| 24 | 912,8448 |
| 25 | 908,1792 |
| 26 | 919,4112 |
| 27 | 908,5248 |
| 28 | 919,584 |
| 29 | 908,8704 |
| 30 | 919,9296 |
| 31 | 909,0432 |
| 32 | 920,2752 |
| 33 | 905,9904 |
| 34 | 917,0496 |
| 35 | 906,1632 |
| 36 | 917,2224 |
| 37 | 906,336 |
| 38 | 917,3952 |
| 39 | 906,5088 |
| 40 | 917,568 |
| 41 | 921,1392 |
| 42 | 911,0016 |

### 6.7.6 Transmit Power Control

TBD

### 6.7.7 VLE Parameters

*Insert specification table*

## *6.9 General radio specifications*

*This goes in section 6.9 in 15.4*

### 6.9.1 TX-to-RX turnaround time

The Tx to Rx turnaround ime should be better than 1ms.

### 6.9.2 RX-to-TX turnaround time

For the MDR mode: The RX-to-TX turnaround time shall be less than or equal to 1 ms and shall be greater than or equal to the TX-to-RX turnaround time.

For the VLE mode: The Rx to Tx turnaround time should be better than 100μs.

## 6.9.3 Receiver Sensitivity

VLE mode: Sensitivity (dBm) should be lower than -105dBm under the conditions specified in 6.1.7.

## 6.9.4 Transmit center frequency tolerance

VLE Mode: +/- 10ppm from -20 to +70°C.

## 6.9.5 Transmit power limits

### 6.9.5.1 RF power measurement

For power measurement (power, spurious), the power is a radiated measurement

The power is defined as radiated power ERP or EIRP with the following relation :

-EIRP (dBm) = ERP (dBm) + 2,1 dB

For product without antenna but with antenna connector, the relation between conducted power (Pc) measured at the antenna connector matched at the impedance of the antenna is

EIRP = Pc +Ga (dBi)

where Ga is the isotropic antenna Gain expressed in dBi.

### 6.9.5.2 RF Power limit

Maximum EIRP is 1W, or less, in order to comply with local regulations

## 6.9.6 Receiver maximum input level of desired signal

For VLE mode: -20dBm.

## 6.9.7 Receiver ED

For VLE mode: The energy detector should detect 5 dB below sensitivity. After receiver activating, the energy detector should return a busy medium in 1ms.

## 6.9.8 Link quality indicator (LQI)

The use of RSSI as part of LQI is proposed, as a monotonic variable with at least 3dB resolution and a total range of around 100 dB, covered with an 8-bit field.

### 6.9.9 Clear channel assessment (CCA)

MDR mode: Either an “always clear” (UWB style) CCA or DSSS LBT type of CS can be used.

VLE mode: The “always clear (UWB style) CCA will be used.

### 6.9.10 Transmit & power amplifier rise and fall times (max)

TBD.

# 7. MAC Sublayer Specification

*TBD*

# Annex E (informative) Coexistence

# Annex F Regulatory (informative)