### IEEE P802.11Wireless LANs

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| Proposed Draft WUR PHY Specification |
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Abstract

This document fills in the PHY portion of the draft outline recommended in document 802.11-17/1585r2.

It is based on the Task Group decisions recorded in document 802.11-17/575r8.

Tables and Figures numbers have been replaced by 32-X where ‘X’ is a letter. Once accepted for inclusion in the draft, the editor can convert to 32-N where ‘N’ is a number.

* Wake-Up Radio (WUR) PHY specification
* Introduction

Clause 32 (Wake-up Radio (WUR) PHY specification) specifies the PHY entity for orthogonal frequency division multiplexing (OFDM) and Multicarrier On-Off Keying (MC-OOK) system. In addition to the requirements in Clause 32 (Wake-up Radio (WUR) PHY specification), a STA that supports WUR PHY specification shall be capable of transmitting and receiving PPDUs that are compliant with the mandatory requirements of the following PHY specifications:

— Clause17 (Orthogonal frequency division multiplexing (OFDM) PHY specification).

A STA that supports WUR PHY specification may be a WUR transmitter STA. A WUR transmitter STA shall be capable of transmitting the WUR PPDU.

A STA that supports WUR PHY specification may be a WUR receiver STA. A WUR receiver STA shall be capable of receiving the WUR PPDU.

The WUR PHY is based on the PHY defined in Clause17 (Orthogonal frequency division multiplexing (OFDM) PHY specification).

The Wake-up Radio PHY provides support for data rates of 62.5kb/s and 250kb/s.

The Wake-up Radio PHY provides support for Manchester code, which shall be applied to all data rates for the WUR Data field.

The Wake-up Radio PHY provides support for TBD (channel bandwidth, data rate, code type, etc.).

A Wake-up Radio STA shall support the following features:

— TBD

A Wake-up Radio STA may support the following features:

— TBD

* WUR PHY service interface

**32.2.1 Introduction**

The WUR PHY provides an interface to the WUR MAC. The interface includes WUR\_TXVECTOR, WUR\_RXVECTOR and WUR\_PHY-CONFIG\_VECTOR.

Using the WUR\_TXVECTOR, the MAC supplies the PHY with per PPDU transmit parameters. Using the WUR\_RXVECTOR, the PHY informs the MAC of the received PPDU parameters. Using the WUR\_PHY-CONFIG\_VECTOR, the MAC configures the PHY for operation, independent of frame transmission or reception.

**32.2.2 WUR\_TXVECTOR and WUR\_RXVECTOR parameters**

The parameters in Table 32-A (WUR\_TXVECTOR and WUR\_RXVECTOR parameters) are defined as part of the WUR\_TXVECTOR parameter list in the PHY-TXSTART.request primitive and/or as part of the WUR\_RXVECTOR parameter list in the PHY-RXSTART.indication and PHY\_RXEND.indication primitives.

**Table 32-A – WUR\_TXVECTOR and WUR\_RXVECTOR parameters**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Condition** | **Value** | **WUR\_TXVECTOR** | **WUR\_RXVECTOR** |
| FORMAT |  | Determines the format of the PPDU.Enumerated type:WUR indicate WUR PPDU format | Y | Y |
| LLENGTH | FORMAT is WUR | Indicates the length of the PSDU in octets in the range of 1 to TBD. This value is used by the PHY to determine the number of octet transfers that occur between the MAC and the PHY. | Y | N |
| Otherwise | TBD |
| LDATARATE | FORMAT is WUR | Indicates the value representing 6 Mb/s in the 20 MHz channel. | Y | N |
| Otherwise | TBD |
| CHANNELCENTERFREQUENCY | FORMAT is WUR | TBD | Y | N |
| Otherwise | TBD |  |  |
| CHANNEL BANDWIDTH | FORMAT is WUR | TBD | Y | N |
| Otherwise | TBD | N | N |
| WUR\_DATARATE | FORMAT is WUR | Determines the transmission bandwidth of the WUR PPDU.Enumerated type:LDR indicates WUR Low Data Rate for the data rate 62.5 kb/sHDR indicates WUR High Data Rate for the data rate 250 kb/s | Y | Y |
| Otherwise | TBD | N | N |
| RSSI | FORMAT is WUR | TBD | N | Y |
| Otherwise | TBD | N | Y |

**32.2.3 WUR\_PHY-CONFIG\_VECTOR parameters**

The WUR\_PHY-CONFIG\_VECTOR carried in a PHY-CONFIG.request primitive for a WUR PHY contains an OPERATING\_CHANNEL parameter, which identifies the operating channel. The PHY shall set dot11CurrentFrequency to the value of this parameter.

* WUR PHY
* Introduction

This subclause provides the procedure by which PSDUs are converted to and from transmissions on the wireless medium.

During transmission, a PSDU is processed and appended to the PHY preamble including legacy preamble and WUR-Sync field to create the WUR PPDU. At the legacy receivers the legacy preamble is accordingly processed to aid in protection of the WUR PSDU. At the wake-up receiver the WUR-Sync is accordingly processed to aid in the detection, demodulation, and delivery of the PSDU.

* WUR PPDU format

A single PPDU format is defined for this PHY: the WUR-PPDU format. Figure 32-A shows the WUR-PPDU format.



Figure 32- A -- WUR-PPDU format

The fields of the WUR-PPDU format are summarized in Table 32-B.

Table 32-B -- Fields of the WUR-PPDU

|  |  |
| --- | --- |
| **Field** | **Description** |
| L-STF | Non-HT Short Training field |
| L-LTF | Non-HT Long Training field |
| L-SIG | Non-HT SIGNAL field |
| BPSK-Mark | A BPSK modulated OFDM symbol |
| WUR-Sync | Wake-Up Radio Synchronization field |
| WUR-Data | Wake-Up Radio Data field carrying the PSDU |

The WUR-Sync can either be 64 µs or 128 µs long and is determined by the rate of the data field WUR-Data.

* Transmitter block diagram

The generation of each field in a WUR-PPDU uses the following blocks:

1. Manchester-based encoder
2. Waveform signal generation

Figure 32-B to Figure 32-C show example transmitter block diagrams. The actual structure of the transmitter is implementation dependent. The transmitter block diagrams for L-STF, L-LTF, and L-SIG are described in Section 21.3.3.



Figure 32- B – An Example of a WUR signal generator for the Sync field for Antenna $i\_{TX}$

An example of a WUR signal generator for the Sync field, for Antenna $i\_{TX}$, is shown in Figure 32-B. The Sync bit sequence is then used to switch between the On waveform generator (On-WG) and the Off waveform generator (Off-WG).



Figure 32-C -- The WUR signal generator for the Data field

An example of a WUR signal generator for the Data field is shown in Figure 32-C. The information bits are mapped by a Manchester-based encoder. Each coded bit is then used to switch between the On waveform generator (On-WG) and the Off waveform generator (Off-WG).

**32.3.4.1 General**

This subclause provides an overview of the WUR-PPDU encoding process.

See section TBD.

**32.3.4.2 Construction of the L-STF**

See section TBD.

**32.3.4.3 Construction of the L-LTF**

See section TBD.

**32.3.4.4 Construction of the L-SIG**

See section TBD.

**32.3.4.5 Construction of the BPSK-Mark**

<Texts to be filled>

**32.3.4.6 Construction of the WUR-Sync**

<Texts to be filled>

**32.3.4.6 Construction of the WUR-Data**

<Texts to be filled>

* WUR Data Rates

The WUR Data Rate indicates the data rate used in the WUR Data field of the WUR PPDU. There are two possible data rates: 62.5 kb/s and 250 kb/s, respectively, and differentiated by the pre-defined sequence in the WUR-Sync field. Rate-dependent parameters are shown in Table 32-L (WUR Data Rates). Manchester-based code is applied to both WUR data rates. Multicarrier On-Off Keying (MC-OOK) is used for modulation of both WUR data rates.

* Timing related parameters

Timing-related constants defines the timing-related parameters for WUR PPDU formats.

|  |
| --- |
| Table 32-C Timing-related constants |
| Parameter | Value | Description |
|  | 312.5 kHz | Subcarrier frequency spacing for WUR PPDU |
| *TDFT,*WUR | 3.2 µs | IDFT/DFT period for the WUR PPDU |
| *TGI,*WUR | 0.8 µs | Guard interval duration for the WUR PPDU |
| *TGI,*L-LTF | 1.6 µs | Guard interval duration for the L-LTF field |
| *TSYM-LDR* | 4 µs  | Duration of WUR LDR OOK symbol in WUR Data field |
| *TSYM-HDR* | 2 µs  | Duration of WUR HDR OOK symbol in WUR Data field |
| *TSYM* | *TSYM-LDR* or *TSYM-HDR* depending on WUR Data Rate | Duration of OOK symbol in WUR Data field |
| *TSync* | TBD | Duration of OOK symbol in WUR-Sync field |
| *T*L-STF | 8 µs = 10 × *TDFT,*WUR /4 | Non-HT Short Training field duration |
| *T*L-LTF | 8 µs = 2 × *TDFT,*WUR + *TGI,*L-LTF | Non-HT Long Training field duration |
| *T*L-SIG | 4 µs | Non-HT SIGNAL field duration |
| *T*BPSK-Mark | 4 µs | BPSK-Mark field duration |
| *T*WUR-Sync-LDR | 128 µs | WUR-Sync field duration for WUR LDR |
| *T*WUR-Sync-HRD | 64 µs | WUR-Sync field duration for WUR HDR |

 Frequently used parameters defines parameters used frequently in Clause 32.

|  |
| --- |
| Table 32-D Frequently used parameters |
| Symbol | Explanation |
| *NSPDB* | Number of OOK symbols per information data bit.For WUR LDR, *NSPDB* =4. For WUR HDR, *NSPDB* =2. |
| *NTX* | Number of transmit chains |
| *NWUR-Sync* | Number of OOK symbols in the WUR-Sync field$=TBD$ |

* Mathematical description of signals

The transmitted signal is described in complex baseband signal notation. The actual transmitted signal on transmit chain$ i\_{TX}$, $r\_{RF}^{(i\_{TX})}(t)$, is related to the complex baseband signal by the relation shown in Equation (32-xx).

$r\_{RF}^{(i\_{TX})}(t)=Re\{r\_{WUR-PPDU}^{(i\_{TX})}\left(t\right)exp⁡(j2πf\_{c}t)\}$ (32-xx)

Where

Re{.} Represents the real part of a complex variable
$f\_{c}$is the center frequency

 $r\_{WUR-PPDU}^{(i\_{TX})}\left(t\right)$ is the baseband WUR signal on transmit chain $i\_{TX}$.

The transmitted RF signal is derived by up-converting the complex baseband signal, which consists of
several fields. The timing boundaries for the various fields are shown in Figure 32-D where *NWUR-Sync* is the
number of WUR-Sync symbols and is defined in Table 32-TBD.



Figure 32-D - Timing boundaries for the WUR-PPDU Fields

The time offset, $t\_{Field}$, determines the starting time of the corresponding field relative to the start of L-STF
(*t* = 0).

The baseband signal is constructed by the concatenation of several fields as shown in the Figure 32-D. It can be mathematically described as

$$r\_{WUR-PPDU}^{(i\_{TX})}\left(t\right)=r\_{L-STF}^{(i\_{TX})}\left(t\right)+r\_{L-LTF}^{(i\_{TX})}\left(t-t\_{L-LTF}\right)+r\_{L-SIG}^{(i\_{TX})}\left(t-t\_{L-SIG}\right)+r\_{BPSK-Mark}^{(i\_{TX})}\left(t-t\_{BPSK-Mark}\right) +r\_{WUR-Sync}^{(i\_{TX})}\left(t-t\_{WUR-Sync}\right)+r\_{Data}^{(i\_{TX})}\left(t-t\_{Data}\right)$$

The timing offset values for various fields are given below:

$$t\_{L-LTF}=T\_{L-STF}$$

$$t\_{L-SIG}=t\_{L-LTF}+T\_{L-LTF}$$

$$t\_{BPSK-Mark}=t\_{L-SIG}+T\_{L-SIG}$$

$$t\_{WUR-Sync}=t\_{BPSK-Mark}+T\_{BPSK-Mark}$$

$$t\_{Data}= t\_{WUR-Sync}+T\_{WUR-Sync}$$

Where $T\_{Field}$ is the duration of the field. $T\_{WUR-Sync}$ is the duration of WUR-Sync field; $T\_{WUR-Sync}=T\_{WUR-Sync-LDR}$, if low rate is transmitted and $T\_{WUR-Sync}=T\_{WUR-Sync-HDR}$, if high rate is transmitted. The duration of different fields of the WUR-PPDU are provided in Tab. 32-2.

For each of the L-STF, L-LTF, L-SIG, BPSK-Mark fields and subfields of the WUR-Sync and WUR-Data, the baseband signal is obtained by taking the Inverse Discrete Fourier Transform (IDFT) as described below

Equation is TBD

* WUR PHY Preamble
* Introduction

The WUR supports two data rates for the WUR: (i) Low data rate of 62.5 kb/s. This provides (ii) High data rate of 250 kb/s.

The rate of the data portion of the WUR PPDU will be indicated using WUR-Sync. There will not be an explicit field in the WUR packet to indicate the data rate. To indicate a low data rate for data portion of WUR PPDU, a repeated sequence ([W W]) is transmitted. Here W is a 64 µs long sequence. To indicate a high data rate, a bitwise complement of the sequence W is transmitted.

* Non-WUR portion of WUR PHY preamble

The Non-WUR portion of the WUR PHY preamble consists of four fields: L-STF, L-LTF, L-SIG and BPSK-Mark. All of these fields are 20 MHz.

The L-STF is constructed according to section 21.3.4.2.

The L-LTF is constructed according to section 21.3.4.3.

The L-SIG is constructed according to section 21.3.4.4 and 21.3.8.2.4. The value of TXTIME used in section 21.3.8.2.4 is set as TBD.

The BPSK-Mark is a single 20-MHz OFDM symbol with BPSK modulation. The values of the BSPK subcarriers is TBD.

* WUR-Sync field

**32.3.8.3.1 Introduction**

The structure of the WUR-Sync Field depends on the Data Rate of the data field. For LDR the duration of the WUR-Sync Field is 128 µs. For HDR the duration of the WUR-Sync Field is 64 µs. The WUR-Sync Field is used by the receiver for packet detection, symbol timing recovery and determination of the Data Rate.

**32.3.8.3.2 Cyclic Shift for WUR-Sync Field**

TBD

**32.3.8.3.3 WUR-Sync Field for Low Data Rate**

For the Low Data Rate the WUR-Sync Field is constructed as a multicarrier on-off keying (MC-OOK) signal. The OOK signal is constructed by concatenating two copies of the sequence TBD-bit sequence $W$, where each bit in the sequence is duration TBD µs. The bit sequence $W$ is given by,

$$\begin{array}{c}W=\{TBD, TBD, …, TBD\}\#\left(1\right)\end{array}$$

The OOK symbol modulates the OFDM symbol.

**32.3.8.3.4 WUR-Sync Field for High Data Rate**

For the High Data Rate the WUR-Sync Field is constructed as a multicarrier on-off keying (MC-OOK) signal. The OOK signal is constructed as the bit-wise complement of the sequence TBD-bit sequence $W$, where each bit in the sequence is duration TBD µs, where W is given in Equation 1. This bit-wise complement sequence is given by,

$$\begin{array}{c}\overbar{W}=\{TBD, TBD, …, TBD\}\#\left(3\right)\end{array}$$

The OOK symbol modulates the OFDM symbol.

* WUR Data field

The WUR Data field shall be encoded by Manchester-based encoding. Encoded bits corresponding to each input bit are shown in Table 32.E (Encoded bits for WUR-LDR) and Table 32.F (Encoded bits for WUR-HDR) for WUR-LDR and WUR-HDR, respectively.

Table 32.E Manchester-based encoded bits for WUR- LDR

|  |  |
| --- | --- |
| Input bit | Encoded bits |
| 0 | 1 0 1 0 |
| 1 | 0 1 0 1 |

Table 32.F Manchester-based Encoded bits for WUR-HDR

|  |  |
| --- | --- |
| Input bit | Encoded bits |
| 0 | 1 0 |
| 1 | 0 1 |

The encoded binary data shall be modulated using MC-OOK, i.e., encoded bits 0 and 1 shall be represented by OFF and ON symbols, respectively. The duration of the MC-OOK symbol corresponding to each encoded bit is dependent on WUR Data Rate. It is 4 µs for WUR-LDR while it is 2 µs for WUR-HDR. The MC-OOK symbol corresponding to each input bit for WUR-LDR is shown in Table 32.G SymLDROff and SymLDROn denote OFF and ON symbols with 4 µs duration for WUR-LDR, respectively. The MC-OOK modulated symbol corresponding to each input bit for WUR HDR is shown in Table 32.H. SymHDROff and SymLDROn denote OFF and ON symbols with 2 µs duration for WUR-HDR, respectively.

Table 32.G MC-OOK symbols for WUR-LDR

|  |  |
| --- | --- |
| Input bit | MC-OOK modulated symbol |
| 0 | [SymLDROn, SymLDROff, SymLDROn, SymLDROff] |
| 1 | [SymLDROff, SymLDROn, SymLDROff, SymLDROn] |

Table 32.H MC-OOK symbols for WUR-HDR

|  |  |
| --- | --- |
| Input bit | MC-OOK modulated symbol |
| 0 | [SymHDROn, SymHDROff] |
| 1 | [SymHDROff, SymHDROn] |

SymLDROn, SymLDROff, SymHDROn, SymHDROff symbols can be constructed by populating contiguous 13 subcarriers. When a single band is used for tranmission of WUR PPDU the OOK waveform of WUR PPDU is generated by using contiguous 13 subcarriers with a subcarrier spacing of 312.5 kHz the center subcarrier is null. The other coefficients are TBD. Indices for contiguous 13 subcarriers are TBD.

* WUR transmit specification
	+ - 1. Transmit spectrum mask

NOTE 1—In the presence of additional regulatory restrictions, the device has to meet both the regulatory requirements and the mask defined in this subclause.

NOTE 2—Transmit spectral mask figures in this subclause are not drawn to scale

NOTE 3—For rules regarding TX center frequency leakage levels, see 22.3.18.4.2. The spectral mask requirements in this subclause do not apply to the RF LO.

* + - 1. Spectral flatness
			2. Transmit center frequency and symbol clock frequency tolerance
			3. Modulation accuracy
			4. Time of Departure accuracy

<Texts to be filled>

* WUR receiver specification

For tests in this subclause, the input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**32.3.11.1 Receiver minimum input sensitivity**

The packet error ratio (PER) shall be less than 10% for a PSDU length of TBD octets with the rate-dependent input levels listed in Table 32-I.

Table 32-I - Receiver minimum input level sensitivity

|  |  |
| --- | --- |
| Modulation | Minimum sensitivity(dBm) |
| WUR-LDR | TBD |
| WUR-HDR |  TBD |

**32.3.11.2 Adjacent channel rejection**

Adjacent channel rejection for shall be measured by setting the desired signal’s strength 3 dB above the rate dependent sensitivity specified in Table 32-I and raising the power of the interfering signal of TBD MHz bandwidth until 10% PER is caused for a PSDU length of TBD octets. The power difference between the interfering and desired channel is the corresponding adjacent channel rejection. The center frequency of the adjacent channel shall be placed TBD MHz away from the center frequency of the desired signal.

The interfering signal in the adjacent channel shall be a conformant OFDM signal, unsynchronized with the signal in the channel under test, and shall have a minimum duty cycle of 50%. For a conforming OFDM PHY, the corresponding rejection shall be no less than specified in Table 32-J

Table 32-J - Minimum required adjacent and nonadjacent channel rejection levels

|  |  |
| --- | --- |
| Modulation | Adjacent channel rejection (dB) |
| WUR-LDF | TBD |
| WUR-HDR | TBD |

**32.3.11.3 Nonadjacent channel rejection**

<Texts to be filled>

**32.3.11.4 Receiver maximum input level**

<Texts to be filled>

**32.3.11.5 CCA sensitivity**

<Texts to be filled>

* WUR transmit procedure

<Texts to be filled>

* WUR receive procedure

<Texts to be filled>

* WUR PLME

**32.4.1 Table of PHY MIB Attributes(suspending)**

**32.4.2 TXTIME and PSDU Length calculation**

The number of equivalent symbols with the symbol duration equal to 4 μs legacy OFDM symbol duration is computed from the length of LDR PSDU(LENGTH) indicated in L-SIG field for LDR as follows:

$N\_{L-Sym}=(8×LENGTH ×N\_{SPDB})-\frac{T\_{WUR-Sync-LDR}}{T\_{L-Sym}}-1$ (32-xxx1)

where

$N\_{SPDB}$ is defined in Table 32-D (Frequently used parameters)

 $T\_{L-Sym}=4μs$

The number of equivalent symbols with the symbol duration equal to 4$ μs$ legacy OFDM symbol duration is computed from the length of PSDU(LENGTH) indicated in L-SIG field for HDR as follows:

$N\_{L-Sym}=(8×LENGTH×N\_{SPDB})-\frac{T\_{WUR-Sync-HDR}}{T\_{L-Sym}}-1$ (32-xxx2)

The value of the TXTIME parameter shall be calculated for an WUR PPDU with LDR using Equation(32-xxx3).

$$TXTIME=T\_{L-STF}+T\_{L-LTF}+T\_{L-SIG}+T\_{BPSK-Mark}+T\_{WUR-Sync-LDR}+T\_{L-Sym}×N\_{L-Sym}$$

(32-xxx3)

$T\_{L-STF}$ is defined in Table 32-C(Timing-related constants)

$T\_{L-LTF}$ is defined in Table 32-C(Timing-related constants)

 $T\_{L-SIG}$ is defined in Table 32-C (Timing-related constants)

 $T\_{BPSK-Mark}$ is defined in Table 32-C (Timing-related constants)

 $T\_{WUR-Sync}$ is defined in Table 32-C (Timing-related constants)

 $T\_{WUR-Sym}$ is defined in Table 32-C (Timing-related constants)

The value of the TXTIME parameter shall be calculated for an WUR PPDU with LDR using Equation(32-xxx4).

$$TXTIME=T\_{L-STF}+T\_{L-LTF}+T\_{L-SIG}+T\_{BPSK-Mark}+T\_{WUR-Sync-HDR}+T\_{L-Sym}×N\_{L-Sym}$$

(32-xxx4)

where

 $T\_{WUR-Sync}$ is defined in Table 32-C (Timing-related constants)

 $T\_{WUR-Sym}$ is defined in Table 32-C (Timing-related constants)

**32.4.3 Table of time and length characteristics**

**Table 32-K—WUR PPDU Time and Length Characteristics**

|  |  |
| --- | --- |
| **Characteristics** | **Value** |
| aCCAMinTime | TBD µs  |
| aPPDUMaxTime | 5.484 ms |
| aPSDUMaxLength | 166 octets (see NOTE 1) |
| aRxPHYStartDelay | 88 µs (see NOTE 2) |
| NOTE 1-This is the maximum length in octets for a WUR PPDU with HDR, single stream, and limited by 1332 possible data symbols in aPPDUMaxTime. This is the maximum PSDU length a WUR PHY could support assuming no restrictions in MAC.NOTE 2-This value arises from the time to the end of WUR-Sync with HDR. |

* Parameters for WUR-Data Rates

The rate-dependent parameters for 62.5 kb/s and 250 kb/s are given in Table 32-L. Manchester-based encoding shall be used for all the data rates for the Data field of the WUR PPDU.

**Table 32-L—WUR PPDU-Data Rates**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Data Rate | Modulation | SymbolStructure | Equivalent Information Bit Duration | *NSPDB* | Data rate (kb/s) |
| LDR | OOK | Information 0 | 4 µs ON+4 µs OFF+4 µs ON+4 µs OFF | 16 µs | 4 | 62.5 |
| Information 1 | 4 µs OFF+4 µs ON+4 µs OFF+4 µs ON |
| HDR | OOK | Information 0 | 2 µs ON+2 µs OFF | 4µs | 2 | 250 |
| Information 1 | 2 µs OFF+2 µs ON |