IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Title	Draft text for UWB wake-up radio
Date Submitted	17 November 2022
Source	Billy Verso (Qorvo), billy.verso at qorvo.com Michael McLaughlin (Qorvo),
Re:	Text contribution proposal to TG4ab for IEEE 802.15.4ab
Abstract	Text specifying the UWB wake-up radio addition to the Next Generation UWB enhancements project P802.15.4ab.
Purpose	This document provides draft text intended to be part of the final IEEE Std 802.15.4ab (amendment to IEEE Std 802.15.4). This draft text aims to specify the new text and amendments necessary to IEEE Std 802.15.4, to incorporate the UWB wake-up radio functionality as proposed by contribution 15-21-0557-00-04ab.
Notice	This document does not represent the agreed views of the IEEE 802.15 Working Group or IEEE 802.15.8 Task Group. It represents only the views of the participants listed in the "Source(s)" field above. 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	The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
Patent Policy	The contributor is familiar with the IEEE-SA Patent Policy and Procedures: <http://standards.ieee.org/guides/bylaws/sect6-7.html#6> and <http://standards.ieee.org/guides/opman/sect6.html#6.3>. Further information is located at <http://standards.ieee.org/board/pat/pat-material.html> and <http://standards.ieee.org/board/pat>.

.

Editorial instructions intended to be included in the text of IEEE Std 802.15.4ab are bold-italicized-black.

3 Definitions, acronyms, and abbreviations

3.2 Acronyms and abbreviations

Add the following new acronym(s)/abbreviation(s):

WU-RXDEV	wake-up receiver device
WU-TXDEV	wake-up transmitter device
WUB	wake-up burst

8. MAC services

8.1 Overview

8.2 MAC management service

8.2.1 Primitives supported by the MLME-SAP interface

Insert the following rows new rows into Table 8-1:

Table 8-1—Summary of the primitives accessed through the MLME-SAP

Name	Request	Indication	Response	Confirm
MLME-WU-RX	8.2.28.1	8.2.28.3	-	8.2.28.2
MLME-WU-TX	8.2.28.4	-	-	8.2.28.5

Insert at the end of subclause 8.2 new subclauses:

8.2.28 Primitives for wake-up radio control

8.2.28.1 MLME-WU-RX.request

The MLME-WU-RX.request is used to enable the wake-up receiver functionality.

The semantics of this primitive are:

```
MLME-WU-RX.request      (
                        WakeUpIdentifier,
                        )
```

The primitive parameters are defined in Table 1.

Table 1—MLME-WU-RX.request parameters

Name	Type	Valid range	Description
WakeUpIdentifier	Integer	0x0000–0xffff	This specifies the ID that the wake-up receiver will be looking to match with to trigger a wake-up. A value of zero is used to disable the wake-up receiver.

When the MLME-WU-RX.request primitive is received by a device supporting the wake-up receiver described in 15.8, the wake-up radio is enabled to operate as described in 15.8 and the MLME-UWB-WU-RX.confirm primitive is issued in response.

If the device is not capable as operating as a wake-up receive device (WU-RXDEV), the MLME-WU-RX.confirm primitive response shall indicate failure to enable the wake-up function via its status parameter.

When a wake-up message with correctly matched ID is received by the WU-RXDEV the wake-up receiver is disabled and the MLME-WU-RX.indication primitive is issued.

The upper layer may issue a MLME-WU-RX.request with WakeUpIdentifier parameter value of zero to disable the wake-up receiver functionality.

8.2.28.2 MLME-WU-RX.confirm

The MLME-WU-RX.confirm primitive is issued in response to an attempt to enable or disable the wake-up receiver functionality via the MLME-WU-RX.request primitive.

The semantics of this primitive are:

```
MLME-WU-RX.confirm (
                   Status,
                   )
```

The primitive parameter is defined in Table 2.

Table 2—MLME-WU-RX.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS, NOT_SUPPORTED, INVALID_PARAMETER	This parameter reports the result of the MLME-WU-RX.request.

The MLME-WU-RX.confirm primitive is generated by the MLME and issued to its next higher layer in response to an MLME-WU-RX.request primitive.

If the device is not capable as operating as a WU-RXDEV, the Status of NOT_SUPPORTED is returned.

If any parameter in the MLME-STS.request primitive is not supported or is out of range, the Status of INVALID_PARAMETER is returned.

If the request to enable or disable the wake-up receiver is successful, the MLME issues the MLME-WU-RX.confirm primitive with a Status of SUCCESS.

8.2.28.3 MLME-WU-RX.indication

The MLME-WU-RX.indication primitive indicates the reception of the wake-up message.

The semantics of this primitive are:

```
MLME-WU-RX.indication ( )
```

The MLME-WU-RX.indication primitive has no parameters. When the wake-up receiver is enabled and a wake-up message with correctly matched ID is received by the WU-RXDEV, as described in 15.8, the wake-up receiver is disabled and an MLME-WU-RX.indication primitive is issued.

8.2.28.4 MLME-WU-TX.request

The MLME-WU-TX.request is used to initiate sending of the wake-up message.

The semantics of this primitive are:

```
MLME-WU-TX.request (
                   WakeUpIdentifier,
                   )
```

The primitive parameters are defined in Table 3.

Table 3—MLME-WU-TX.request parameters

Name	Type	Valid range	Description
WakeUpIdentifier	Integer	0x0001–0xffff	This specifies the ID to include in the transmitted wake-up message.

When the MLME-WU-TX.request primitive is received by a device supporting wake-up message transmission as described in 15.8, the wake-up message shall be transmitted as described in 15.8 with the ID field of the transmitted wake-up message being that supplied by the WakeUpIdentifier parameter. When the transmission of the wake-up message completes MLME-UWB-WU-TX.confirm primitive is issued.

If the device is not capable of sending the wake-up message the MLME-WU-RX.confirm primitive response shall indicate failure to transmit the wake-up message via its status parameter.

8.2.28.5 MLME-WU-TX.confirm

The MLME-WU-TX.confirm primitive is issued in response to an attempt to transmit the wake-up message via the MLME-WU-TX.request primitive.

The semantics of this primitive are:

```
MLME-WU-TX.confirm (
                   Status,
                   )
```

The primitive parameter is defined in **Table 4**.

Table 4—MLME-WU-TX.confirm parameters

Name	Type	Valid range	Description
Status	Enumeration	SUCCESS, NOT_SUPPORTED, INVALID_PARAMETER	This parameter reports the result of the MLME-WU-TX.request.

The MLME-WU-TX.confirm primitive is generated by the MLME and issued to its next higher layer in response to an MLME-WU-TX.request primitive.

If the device is not capable as operating as a WU-TXDEV, a Status value of NOT_SUPPORTED is returned.

If any parameter in the MLME-WU-TX.request primitive is not supported or is out of range, a Status of INVALID_PARAMETER is returned.

If the request to transmit the wake-up message is successful, then when the transmission completes, the MLME issues the MLME-WU-TX.confirm primitive with a Status value of SUCCESS.

11. PHY services

11.3 PHY PIB attributes

Insert the following new PHY PIB attribute into Table 11-2:

Table 11-2—PHY PIB attributes

Attribute	Type	Range	Description
:	:	:	:
pjyUwbWuPeriod	Integer	10-100	Period in milliseconds at which the WU-RXDEV samples the air for the wake-up message. This also defines the length of SYNC part of the wake-up sequence sent by the WU-TXDEV.
	:	:	:

15 HRP UWB PHY

15.1 General

Add the following paragraph at the end of clause 15.1:

The HRP UWB PHY also includes an optional wake-up radio mode of operation. A device with the ability to send the wake-up sequence shall be termed a wake-up transmitter device (WU-TXDEV) while a device with the ability to be awakened by receiving the wake-up sequence shall be termed a wake-up receiver device (WU-RXDEV).

Insert the following new clause 15.8:

15.8 Wake-up radio

15.8.1 Introduction

The UWB wake-up radio is predicated on a very-low power receive circuit able to detect a burst of UWB energy with certain characteristics. This receiver further reduces its power consumption by employing a low duty cycle of listening for the wake-up message. While the receiver design is generally not part of the 802.15.4 standard, [B1] gives quite a detailed description of a possible implementation for this wake-up receiver.

The wake-up message is based on millisecond spaced bursts of BPSK modulated UWB pulses at the 62.4 MHz PRF of the HRP UWB PHY, with each wakeup burst (WUB) consisting of 500 ±5% pulses (i.e., 4000 chips ±5%), which is approximately 8.0 μs in duration. The actual duration of the WUB will depend on the pulse sequence used for its generation, e.g., for optimum spectral whiteness an m-sequence needs to be exactly 511 pulses, and other sequences have similar restrictions. The modulating sequence should be a binary sequence with good auto correlation properties. Each WUB signals one bit using OOK where presence of the WUB is a binary 1 and absence of the WUB is a binary 0. The PRF of the burst must be accurate to ±20 ppm and since the WU-RXDEV may measure this PRF to give it a seed value for receiving the subsequent UWB packet, the same clock reference shall be used to generate both signals. The nominal burst rate shall be one burst per millisecond. With one WUB per millisecond the OOK data rate of the wake up is 1 kb/s.

One suitable signal would be a length 511 m-sequence. For the largest operating range of wakeup, each burst should be sent at the maximum power level allowed by regulation.

15.8.2 General operation

The MLME-WU-RX.request primitive is used to enable the wake-up radio operation. When enabled, the WU-RXDEV receiver shall turn on every *pjyUwbWuPeriod* to sample the air for 1 ms looking for a WUB. The *pjyUwbWuPeriod* value is a trade-off between the wake-up latency and the energy budgets of the WU-RXDEV and the WU-TXDEV. For correct operation *pjyUwbWuPeriod* should be the same value in both the WU-RXDEV and the WU-TXDEV.

The MLME-WU-TX.request primitive is used in the WU-TXDEV to sends the wake-up message when it wishes to wake up a WU-RXDEV. The wake-up message consists of a SYNC of repeated binary 1 sent for *pjyUwbWuPeriod* followed by a single binary 0 “Start Bit” to delineate the end of the SYNC, followed by the OOK encoded wake-up ID of the device that the WU-TXDEV wishes to wake.

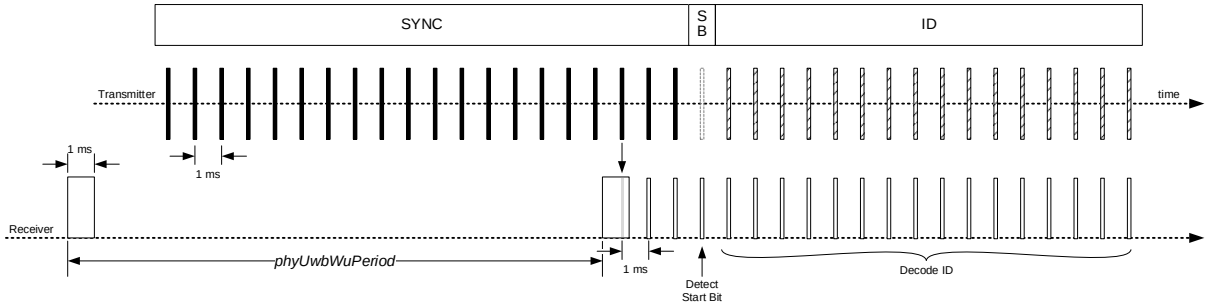

Figure 1 – example of wake-up radio general operation

Figure 1 illustrates an example of the wake-up operation. In this example the WU-RXDEV turns on every 20 ms to listen for a WUB. The first time it does this it does not detect a WUB, but for the second time the WR-TXDEV is sending the wake-up message SYNC and the WU-RXDEV detects a WUB. Once this occurs the WU-RXDEV changes mode to turn on in each successive millisecond just for the 8 μs interval when subsequent WUB transmissions are expected. On the third of these (in this example) the binary 0 start bit is seen, and thereafter the WU-RXDEV continues sampling for 16 ms to receive the OOK modulated 16-bit ID.

Note– in practice the on periods of the wake-up receiver would be slightly larger than 8 μs to account for any impreciseness in the WUB timing.

If the received ID matches with the ID that the WU-RXDEV expects for its wake-up as set by the MLME-WU-RX.request primitive, the WU-RXDEV issues the MLME-WU-RX.indication primitive to signal successful wake up to the upper layer, which is then responsible for progressing into whatever active mode of operation is appropriate. If the received ID fails to match the expected ID, the WU-RXDEV returns to turning on every pjyUwbWuPeriod to sample for 1 ms to await another wake up signal/

If the received ID fails to match the expected ID, the WU-RXDEV returns to the original mode of turning on every pjyUwbWuPeriod to sample for 1 ms to await another wake up signal.

If the received ID matches with the ID that the WU-RXDEV expects for its wake-up as set by the MLME-WU-RX.request primitive, the wake-up receiver is disabled and the WU-RXDEV issues the MLME-WU-RX.indication primitive to signal successful wake up to the upper layer, which is then responsible for progressing into whatever active mode of operation is appropriate.

Annex A

(informative)
Bibliography

Insert the following references into Annex A in alphanumeric order:

[B1] Michael Mc Laughlin, Ryan Bunch, Marcus Granger Jones, “UWB Wakeup Signalling” IEEE 802.15 document 15-21-0557-00-04ab, 2022.