**IEEE P802.15**

**Wireless Personal Area Networks**

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1. Acronyms and Abbreviations

SDEV sensing device

CIR channel impulse response

OTA over the air

IE information element

MLME MAC layer management entity

OOB out of band

OSR oversampling ratio

SSR sensing sequence repetition

AoA angle of arrival

RSSI received signal strength index

1. UWB Sensing
	1. Introduction

Sensing is the use of PHY and MAC features of UWB devices to obtain measurements to estimate features such as range, velocity, and motion of objects in an area of interest. Sensing measurements can enable various applications such as presence detection and environmental mapping. Support for UWB sensing is optional. A device that supports the mandatory set of sensing features defined in this document is called a Sensing Capable Device (SDEV).

* 1. Terminology

The following nomenclature is used for SDEVs:

*Sensing Initiator:* An SDEV that initiates the RF sensing session with one or more other SDEVs.

*Sensing Responder:* An SDEV that responds to the sensing initiator.

*Sensing Transmitter*: An SDEV that sends the channel sounding PPDU to enable channel estimation for RF sensing purposes.

*Sensing Receiver:* An SDEV that receives the channel sounding PPDU from the transmitter and performs channel estimation.

*Sensing Requesting Device:* An SDEV that requests the sensing Channel Impulse Response (CIR) measurement report in a proxy application.

* 1. Operational modes for UWB sensing

In this section, an overview of sensing scenarios is provided. Based on the roles of the initiator and responder devices in the sensing task, we present possible sensing modes for 802.15.4ab.

* + 1. Basic sensing modes

In most RF sensing scenarios, the sensing initiator is the device where the RF sensing applications reside, and hence the sensing initiator may require the sensing measurement report. For the cases that the sensing initiator is the sensing transmitter, an Over-the-Air (OTA) sensing measurement report may be sent by the sensing responder to provide the measurement report to the sensing initiator. Additionally, in a proxy application, the device requesting the proxy operation may receive OTA CIR measurement report from the sensing initiator. Based on the roles of sensing devices, the possible scenarios are listed below:

* Mono-Static Sensing
* Bi-Static Sensing [Initiator=sensing receiver]
* Bi-Static Sensing [Initiator=sensing transmitter]
* Multi-Static Sensing [Initiator=sensing receiver]
* Multi-Static Sensing [Initiator=sensing transmitter], supporting scheduling of OTA CIR measurement reports from multiple responders.
* Proxy Mode
	+ 1. Frequency Stitching

Frequency stitching combines multiple carrier frequencies, to improve sensing link budget and accuracy. Frequency stitching is an optional feature for mono-static and bi/multi-static modes. Frequency stitching can be performed with overlapping carrier frequencies or non-overlapping carrier frequencies. Carrier frequency grid configuration determines the percentage of overlap of transmissions in frequency stitching. A carrier frequency grid configuration of 124.8 MHz indicates an overlap of 75%, carrier frequency grid configuration of 249.6 MHz indicates an overlap of 50% and a carrier frequency grid configuration of 374.4 MHz indicates an overlap of 25%. Carrier frequency grid configuration of 499.2 MHz indicates no overlap of transmissions in frequency stitching. The sensing report can be shared per transmission, or an aggregated report is sent after the last transmission.

* 1. Sensing Procedure
		1. General

The sensing procedure defines sensing frame exchange sequences for each of the sensing modes listed in Section 2.3. A sensing session consists of three phases:

* Session setup
* Sensing measurement instance(s)
* Session termination
	+ 1. Session setup

It is possible that SDEVs consume more power when sensing is enabled, therefore, a natural default for an application would be to have sensing disabled. The higher layer is responsible for enabling sensing in SDEVs involved in a sensing session.

The session setup phase can be done OOB. During the session setup phase, a sensing initiator and one or more sensing responders exchange capabilities and agree on the operational parameters of a sensing session. These parameters may include:

* Sensing mode: Bi-static sensing, or multi-static sensing
* Role of the initiator: Sensing receiver, sensing transmitter, sensing transmitter and sensing receiver
* Role of the responder: Sensing receiver, sensing transmitter, sensing transmitter and sensing receiver
* Sensing packet format (Section 2.5.2)
* Measurement report transmission mode: In-band, Out-of-Band (OOB)
* Measurement result format: Window-based CIR report or processed target report (Section 2.4.2.1)
* Frequency stitching enabled: Enable frequency stitching or disable frequency stitching
* Channel configuration for frequency stitching: The details are TBD
* Measurement report configuration for frequency stitching: The details are TBD.

The session setup phase consists of the following steps:

1. Transmission of a sensing session setup request frame by the sensing initiator to a sensing responder, followed by transmission of an Ack frame by the responder, and
2. Transmission of a sensing session setup response by the responder to the sensing initiator to either
	1. Accept the parameters proposed by the initiator, or
	2. Reject and provide responder’s preferred operational parameters in the sensing session response frame,

followed by the transmission of an Ack frame by the sensing initiator.

* + 1. Sensing measurement instances

A sensing session consists of one or more measurement instances. A measurement instance consists of sensing control phase, sensing phase, and optional sensing measurement report phase.

Sensing Control Phase

Sensing Phase

Sensing Measurement

 Report Phase

Figure 1: Sensing Measurement Instance

Sensing session parameters configured during session setup phase may be updated during the control phase.

A sensing initiator or a sensing responder starts a sensing phase by transmitting a sensing PPDU type which is agreed upon during the session setup or control phase.

A measurement report phase may follow the sensing PPDU transmission.

* + - 1. Sensing measurement report

A measurement report phase may be performed after the measurement phase. Measurement report can be transmitted in-band or via OOB methods.

The measurement report phase is performed after the sensing phase. For the case that the initiator is the transmitter, responder shall provide measurement report to the initiator, and measurement report phase is mandatory.

Two types of sensing measurement reports are specified. The MLME sensing measurement report is used to transmit the sensing measurement results to the application layer of the initiator device. It is sent from the MAC layer to the upper layers within a device over the MAC Layer Management Entity (MLME). Depending on the role of the sensing devices, an OTA sensing measurement report may also be required to transmit the sensing measurement results from a responder to the initiator or from the initiator to the sensing requesting device in the proxy mode. The OTA CIR report can be sent in-band or via OOB methods.

Both an MLME sensing measurement report and OTA sensing measurement report carry the sensing measurement results. Two types of sensing measurement result formats are considered:

* An SDEV shall support a window-based CIR measurement report which carries the CIR in a specified window. This type is used for most bi-static and multi-static sensing applications.
* Processed target feature report: An SDEV may optionally process the CIR report, to generate range/velocity and Angle of Arrival (AoA) for each object. The definition of computation methods is TBD.

The selection of the sensing result format depends on the sensing application, sensing mode and sensing node capability. It is negotiated during the sensing session set up phase through the sensing capability exchange.

* + - * 1. Window-based CIR measurement report

The CIR is estimated from the received sensing PPDU packets. In this case, a window-based approach for the CIR sensing report is used to provide consistency for multiple CIR measurement reports across packets. A sensing report bitmap is used to signal the taps present in the CIR report. The bitmap offset () specifies the offset of the first tap from the reference tap, as shown in Figure 2.



Figure 2: Sensing window parameters defined relative to the reference tap

Single CIR window with bitmap of a fixed length is specified through OOB means. The bitmap length is negotiated and determined through other means, and it is fixed during sensing session.

In the mandatory mode, initiator proposes the bitmap, based on its sensing area of interest, from a limited set of bitmap options. Bitmap is fixed during the session and does not change from packet to packet. To limit the test burden for the mandatory CIR report bitmap mode, an SDEV shall support the following bitmap configurations:

* For each bitmap length M = {32, 64, 128, 256}, two strings of all ones, with equal length L = {16, 32, …, M/2}. The gap options between them are defined as

Support for an optional variable bitmap mode in which the bitmap varies from packet to packet is under consideration.

Following CIR report parameters and specifications shall be supported by an SDEV:

* The earliest detected CIR tap is the reference tap for the window. Optional support for other reference tap options is under consideration:
	+ Other specific time instances can be specified as reference points (for example via OOB) when there is external synchronization.
	+ The strongest detected tap, if there are multiple equally strongest taps, then the earliest one is selected.
* The CIR measurement report shall be sampled at Over Sampling Ratio (OSR) of 2, to balance reasonable accuracy, complexity, and report overhead. OSR is defined with respect to signal BW.
	+ When the CIR of an effective larger bandwidth is obtained by an SDEV, OSR is defined with respect to the aggregated BW.
* The CIR measurement report signed I/Q values for each Rx chain shall be represented using 16 bits.

In the window-based CIR report, the CIR measurement report consists of two parts:

* The first part contains sensing control parameters. It consists of the number of receiving antennas, bitmap length, bitmap offset, and the bitmap. The sensing control parameters may or may not be present in the CIR Measurement Report depending on when the initiator needs them.
* The second part contains content fields for the CIR measurement report. It consists of CIR in-phase and quadrature values for each chain, normalization factor for each chain, and Received Signal Strength Index (RSSI) for each chain. Table 1 illustrates the mandatory baseline parameters for CIR report.

Table 1: Mandatory baseline CIR report parameters

|  |  |  |
| --- | --- | --- |
| **Field** | **Field length** | **Comments** |
| **Control fields** |
| Number of Rx antennas  | 2 bits | Up to 4 Rx antennas |
| Bitmap length | 2 bits | 32, 64, 128, 256 |
| Bitmap offset | 10 bits | Up to one SENS symbol |
| Bitmap  | Variable, up to 256 bits | Max length = 256 |
| **Content fields for each receiver chain** |
| Timing offset of the reference tap | 6 bits | First arrival tap offset from CIR report grid. In units of Ranging counter time unit defined in section 6.1.9.4 of 802.15.4z-2020. |
| Normalization factor for I/Q |  4 bits (power of two, corresponds to bit shift) | Common normalization value for In-phase and Quadrature values; (0-15 bit shifts) |
| RSSI |  8 bits | A measure of the received signal strengthat the antenna, measured for each pair of (Rx antenna, SENS segment). |
| CIR In-phase values | 16 bits (mandatory), 10, 12 ,14 (optional\*) | Per tap; normalized |
| CIR Quadrature values | 16 bits (mandatory), 10, 12 ,14 (optional\*) | Per tap; normalized |

\* For the CIR I/Q number of bits, the 10, 12 and 14 bit representations are optional, and they can be achieved by optional power of two scaling and quantization as described in document number 15-23-267-00-04ab.

* + - * 1. Processed target feature report

Support for the processed target feature report is optional. An SDEV may optionally process the CIR report, to generate range/velocity and Angle of Arrival (AoA) for each object. The definition of computation methods is TBD.

* + 1. Sensing session termination phase

In the sensing session termination phase, UWB devices stop performing measurements and terminate the sensing session.

* 1. Sensing by proxy
		1. General

SBP is a procedure that allows a 4ab advanced device which supports SBP to request another SDEV to perform sensing on its behalf. Implementation of SBP is optional.

A 4ab advanced device which supports SBP shall set the SBP subfield of the UWB HRP Capability Information field in the HRP UWB Association Request command to 1.

* + 1. SBP setup

The SBP setup procedure consists of the following steps:

1. The sensing requesting device may transmit an SBP Request IE to the sensing initiator. The SBP Request IE includes valid SBP parameters and sensing control parameters. The sensing initiator shall send an acknowledgement to the sensing requesting device in response to a successful reception of the SBP Request IE. The SBP Request IE, as specified in 2.6.3, can be included in out-of-band signalling or custom messages.
2. The sensing initiator may issue an SBP Response IE to the sensing requesting device. The SBP Response IE includes the status code parameters. The sensing requesting device shall send an acknowledgement to the sensing initiator in response to a successful reception of the SBP Response IE. The SBP Response IE, as specified in 2.6.4, can be included in out-of-band signalling or custom messages.
	* 1. SBP reporting

In the SBP reporting procedure, the sensing initiator may sequentially transmit one or more sensing measurement reports of the corresponding sensing measurement exchange to the sensing requesting device. Alternatively, the sensing initiator may transmit an aggregated sensing measurement report to the sensing requesting device, which includes one or more sensing measurement reports of the corresponding sensing measurement exchange.

* + 1. SBP session termination phase

An SBP procedure can be terminated either by the associated sensing requesting device or the sensing initiator by transmitting an SBP Termination IE at any time.

If the sensing initiator transmits an SBP Termination IE or receives an SBP Termination IE from the sensing requesting device to indicate the termination of the SBP procedure, the sensing initiator should terminate corresponding sensing session with all the sensing responders involved in the sensing session. The SBP Termination IE, as specified in 2.6.5, can be included in out-of-band signalling or custom messages.

## 2.6.

* + 1.
		2.
	1. Sensing block and round structure

The ranging block/round/slot structure in Figure 6-48j of 802.15.4z-2020 can be generalized to define sensing blocks, rounds, and slots.

Sensing

Round 0

Sensing

Round 1

Sensing

Round 2

Sensing

Round 3

Sensing

Round N-1

**…..**

Sensing

Slot 0

Sensing

Slot 1

Sensing

Slot 2

Sensing

Slot 3

Sensing

Slot M-1

**…..**

Sensing Block

Figure 3: Illustration of sensing block, round and slot structure

A sensing block is a period for sensing. Each sensing block consists of several sensing rounds, where a sensing round is a period of sufficient duration to complete one entire sensing measurement instance. Each sensing round is subdivided into an integer number of sensing slots. First slot (slot 0) of each round is used for control phase. One or multiple slots are used for the sensing phase, in which a sensing PPDU is transmitted. Multiple slots may be scheduled for measurement report phase. The time unit used in specifying the duration of sensing block, sensing round, and sensing slot is the RSTU as specified in Section 6.9.1.5 of 802.15.4z-2020.

Two example of measurement instance realization using sensing block structure are given below.

1. Bi-Static Sensing [Initiator=sensing transmitter], with measurement report.

**…..**

Sensing Round: One measurement instance

Sensing Slot

Sensing phase

Measurement report phase

**…..**

Sensing Slot

Control phase

Figure 4: Sensing round for bi-static sensing with measurement report

1. Bi-Static Sensing [Initiator=sensing receiver], no measurement report is required.

Sensing Round: One measurement instance

Sensing Slot

Sensing phase

**…..**

Sensing Slot

Control phase

Figure 5: Sensing round for bi-static sensing without measurement report

* 1. Information Elements for Sensing Scheduling and Control
		1. Scheduling IE

The scheduling Information Element (IE) defined in DCN 15-23-62/r3 is used by a sensing initiator to schedule a sensing session.

* + 1. Application Control IE

The sensing filed of the application control IE, defined in DCN 15-23-61/r1 is used to define sensing control parameters. The control field of the AC IE includes at least the parameters in Table 2.

Table 2: Sensing Control field of the AC IE

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bits: 0 | 1 | 2 | variable | variable | variable |
| Common Sensing Control Present | CIR Report Parameters Present | Frequency Stitching Parameters Present | Common Sensing Control Config | CIR Report Parameters Config | Frequency Stitching Parameters Config |

Common sensing control field of AC IE includes the parameters in Table 3.

Table 3: Common control field

|  |  |  |  |
| --- | --- | --- | --- |
| Bits: 0-1 | 2 | 3-4 | 5-7 |
| Sensing mode | Responder role | Sensing Packet format | Reserved |

Sensing mode options are monostatic, bi-static, multi-static and proxy.

Responder role can be transmitter or receiver.

CIR Report field of AC IE includes the parameters in Table 4.

Table 4: CIR report parameters field

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Bits: 0-1 | 2-3 | 4-5 | 6 | 7 | 8 | 9-18 | 19-23 | 24 | 4-64 octets |
| CIR I/Q number of bits | Bitmap mode  | Bitmap length (if bitmap mode=1or 2) /sub-window length if bitmap mode=0) | Process CIR report for Range | Process CIR report for Velocity | Process CIR report for AOA measurement | Bitmap offset | Bitmap Gap (present if bitmap mode=0) |  Compression | Bitmap (present if bitmap mode=1) |

The bitmap mode defined in Table 5.

Table 5: Bitmap modes

|  |  |
| --- | --- |
| Bitmap Mode | Definition |
| 0 | Initiator sets bitmap from predefined subset of bitmaps in section 2.4.3.1.1. |
| 1 | Initiator sets bitmap from configs not specified in the defined subset. |
| 2 | Responder sets bitmap and reports it. |

When compression bit=1 in Table 4, CIR report can be compressed based on DEFLATE method. Details of the DEFLATE method are TBD and will be provided. Support for compression of the CIR report is optional.

Frequency stitching field of AC IE includes the parameters in Table 6.

Table 6: Frequency stitching parameters field

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 0 | 1-4 | 5-6 | 7 | 8-11 | 12-13 | 14-15 |
| Frequency stitching direction | Base channel number or channel number | Carrier frequency grid configuration ID | Channel sequence order identifier | Number of transmissions | Feedback control | Reserved |

Frequency Stitching Direction – Indicates the direction of usage of channels, from base channel, for frequency stitching.

Base channel number or channel number – Indicates the starting channel for performing UWB sensing when frequency stitching is enabled.

Carrier frequency grid configuration Identifier – Indicates the configuration of carrier frequency grid for frequency stitching. Table 7 defines the carrier frequency grid configuration identifiers.

**Table 7: Carrier Frequency Grid Configuration**

|  |  |
| --- | --- |
| Carrier Frequency Grid Configuration Identifier | Definition |
| 0 | No Overlap of channels for frequency stitching |
| 1 | 374.4 MHz carrier frequency grid (25% overlap in consecutive channels) |
| 2 | 249.6 MHz carrier frequency grid (50% overlap in consecutive channels) |
| 3 | 124.8MHz carrier frequency grid (75% overlap in consecutive channels) |

Channel sequence order identifier– In frequency stitching, both in-sequence channel order (specified by channel sequence order =0), as illustrated in Fig.6 (left), and out-of-sequence channel order, as illustrated in Fig. 6 (right), shall be supported. In table 6, in-sequence channel order is specified by channel sequence order identifier = 0, and out—of-sequence channel order is specified by channel sequence order identifier = 1.

Figure 6: In-sequence channel order (left), and out-of-sequence channel order (right)

The out-of-sequence channel order could be computed according to CH((p\*(OF+1) MOD (N)) + (p\*(OF+1) DIV (N))), where p = 0 ... (N-1) and DIV denotes integer division. When the carrier frequency grid configuration identifier is 0 or 1, the in-sequence channel order shall be applied. The formula CH((p\*(OF+1) MOD (N)) + (p\*(OF+1) DIV (N))) shall not be applied to the in-sequence channel order.

Number of transmissions – Indicates the total number of transmissions done with frequency stitching.

Feedback Control – Indicates if the report is shared per transmission or an aggregated report is shared after the last transmission. Table 8 indicates the values used for feedback control.

**Table 8: Feedback Control**

|  |  |
| --- | --- |
| Feedback control | Definition |
| 0 | Feedback after each sensing transmission |
| 1 | Feedback for all transmissions at the end of last transmission |
| 2 | Feedback for the aggregated channel at the end of last transmission |

* + 1. SBP Request IE

The SBP Request IE is used by the sensing requesting device to send the SBP parameters and sensing control parameters to the sensing initiator. The SBP request IE may also convey the preferred sensing responder address parameters. The content field of the SBP Request IE shall be formatted as shown in Table 9.

**Table 9: SBP Request IE Content field format**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Bits:****0** | **1-2** | **3** | **4-7** | **8** | **9** | **10** | **11-14** |
| Address Size | SBP Procedure Expiry Exponent | Sensing Responder | Number of Sensing Responders | Mandatory Number of Sensing Responders | Sensing Initiator Address Presence | Preferred Sensing Responder List | Number of Preferred Sensing Responders |

|  |  |  |  |
| --- | --- | --- | --- |
| **Bits:****15** | **Octets:****0/2/8** | **Variable** | **Variable** |
| Mandatory Preferred Sensing Responders | Sensing Initiator Address | Sensing Control | Sensing Responder Address List |

The Address Size field specifies the size of the addresses used in the SBP Request IE. If the Address Size field is zero, all addresses in the SBP Request IE are short addresses. If the Address Size field is one, all addresses in the SBP Request IE are extended addresses.

The value of the SBP Procedure Expiry Exponent field contains an unsigned integer. The SBP Procedure Expiry Exponent value is equal to ms. This parameter indicates the termination time for the SBP procedure in the event of no frame exchange sequence.

When the Sensing Responder field is set to 1, it signifies that the sensing requesting device wants to join the sensing procedure as a sensing responder initiated by the sensing initiator. Conversely, when the Sensing Responder field is set to 0, it indicates that the sensing requesting device does not wish to participate in the sensing procedure used by the sensing initiator.

The Number of Sensing Responders field denotes the number of sensing responders needed for the sensing initiator to fulfill the SBP request. If the Sensing Responder field is set to 1, the value specified in the Number of Sensing Responders field includes the sensing requesting device itself.

The Mandatory Number of Sensing Responders field determines the interpretation of the requested number of sensing responders specified in the Number of Sensing Responders field by the sensing initiator. If the Mandatory Number of Sensing Responders field has a value of 0, it means that the requested number of sensing responders serves as an upper limit, and the sensing requesting device accepts measurements even with a smaller number of responders. On the other hand, if the Mandatory Number of Sensing Responders field has a value of 1, it signifies that the requested number of sensing responders is a mandatory requirement.

The Sensing Initiator Address Presence field when one indicates the presence of the Sensing Initiator Address field, or not present when zero.

When the Preferred Sensing Responder List field is set to 1, it signifies that the sensing requesting device specifies a preferred set of sensing responders to be included by the sensing initiator in the sensing procedure for fulfilling the SBP request. Conversely, if the Preferred Sensing Responder List field is set to 0, the Sensing Responder Address List field is not included.

The Number of Preferred Sensing Responders field represents the number of preferred sensing responders with corresponding addresses included in the Sensing Responder Address List field when the Preferred Sensing Responder List field is set to 1. If the Sensing Responder field is also set to 1 in this scenario, the value specified in the Number of Preferred Sensing Responders field includes the address of the sensing requesting device. The Number of Preferred Sensing Responders field is reserved when the Preferred Sensing Responder List field is set to 0. If both the Sensing Responder field and the Preferred Sensing Responder List field are set to 1, the address of the sensing requesting device is included in the Sensing Responder Address List field.

The Mandatory Preferred Sensing Responder field determines whether the preferred sensing responders should be treated as mandatory by the sensing initiator if the Preferred Sensing Responder List field is set to 1. A value of 1 means that the sensing initiator is obligated to include only the SDEVs listed in the Sensing Responder Address List field within the SBP Request IE during the sensing procedure for fulfilling the SBP request. On the other hand, a value of 0 indicates that the sensing initiator has the option to include SDEVs not listed in the Sensing Responder Address List field within the SBP Request IE when satisfying the SBP request. The Mandatory Preferred Sensing Responder field is reserved when the Preferred Sensing Responder List field is 0. When the Mandatory Preferred Sensing Responder field is set to 1, the Number of Sensing Responders and Mandatory Number of Sensing Responders fields are reserved.

The Sensing Initiator Address field specifies the address of the sensing initiator.

The Sensing Control field is described in 2.6.2 Application Control IE.

The Sensing Responder Address List field is present only if the Preferred Sensing Responder List field is set to 1. The Sensing Responder Address List field contains one or more addresses that indicate the set of preferred sensing responders to include in the sensing procedure used by the sensing initiator to satisfy the SBP request.

* + 1. SBP Response IE

The SBP Response IE is used by the sensing initiator to send the SBP parameters and sensing control parameters as well as the status code parameters to the sensing requesting device. The content field of the SBP Response IE shall be formatted as shown in Table 10.

**Table 10-SBP Response IE Content field format**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Bits:****0** | **1-2** | **3-6** | **7** | **8** | **9-15** |
| Address Size | SBP Status Code | Number of Sensing Responders | Sensing Requesting Device Address Presence  | Sensing Responder List | Reserved |

|  |  |  |  |
| --- | --- | --- | --- |
| **Octets:****2** | **0/2/8** | **Variable** | **Variable** |
| Sensing Session ID | Sensing Requesting Device Address | Sensing Control | Sensing Responder Address List |

The Address Size field specifies the size of the addresses used in the SBP Response IE. If the Address Size field is zero, all addresses in the SBP Response IE are short addresses. If the Address Size field is one, all addresses in the SBP Response IE are extended addresses.

The SBP Status Code field shall have one of the values specified in Table 11.

Table 11 -Values of the SBP Status Code field in the SBP Response IE

|  |  |
| --- | --- |
| **Sensing Mode field value** | **Meaning** |
| 0 | SUCCESS |
| 1 | REJECT |
| 2 | REJECTED\_WITH\_SUGGESTED\_CHANGES |
| 3 | Reserved |

The Number of Sensing Responders field represents the number of sensing responders utilized by the sensing initiator in the sensing procedure to fulfill the SBP request, if the SBP Status Code field in the SBP Response IE is SUCCESS. Conversely, if the SBP Status Code field in the SBP Response IE is REJECTED\_WITH\_SUGGESTED\_CHANGES, the Number of Sensing Responders field suggests the number of sensing responders to consider.

The Sensing Requesting Device Address Presence field when one indicates the presence of the Sensing Requesting Device Address field, or not present when zero.

The Sensing Responder List field is set to 1 to indicate that the Sensing Responder Address List field is present. If the Sensing Responder List field is set to 0, the Sensing Responder Address List field is not present.

The Sensing Session ID field specifies the session ID of the sensing session corresponding to the SBP procedure.

The Sensing Requesting Device Address field specifies the address of the sensing requesting device.

The Sensing Control field is described in 2.6.2 Application Control IE.

The Sensing Responder Address List field is present only if the Sensing Responder List field is set to 1. The field contains one or more addresses that indicate the set of sensing responders involved in the sensing session corresponding to the SBP procedure if the SBP Status Code field is SUCCESS. Conversely, if the SBP Status Code field is REJECTED\_WITH\_SUGGESTED\_CHANGES, the Sensing Responder Address List field suggests the preferred sensing responders to consider.

* + 1. SBP Termination IE

The SBP Termination IE is used either by the associated sensing requesting device or the sensing initiator to terminate the corresponding SBP procedure. The content field of the SBP Response IE shall be formatted as shown in Table 12.

**Table 12 - SBP Termination IE Content field format**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Bits:****0** | **1** | **2-7** | **Octets:****0/2/8** | **2** |
| Address Size | Destination Address Presence | Reserved | Destination Address | Sensing Session ID |

The Address Size field specifies the size of the addresses used in the SBP Termination IE. If the Address Size field is zero, all addresses in the SBP Termination IE are short addresses. If the Address Size field is one, all addresses in the SBP Termination IE are extended addresses.

The Destination Address Presence field when one indicates the presence of the Destination Address field, or not present when zero.

The Destination Address field specifies the address of the intended SDEV to which the SBP Termination IE is transmitted.

The Sensing Session ID field specifies the session ID of the sensing session corresponding to the SBP procedure to be terminated.

The UWB HRP Capability Information field shall be formatted as illustrated in Table 13.

**Table 13– HRP UWB Capability Information field format**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Bits: 0 | 1 | 2–3 | 1 | TBD | TBD | … | 15 |
| LDPC | High Throughput | Supported AIFS | SBP | TBD | TBD | … | TBD |

* 1. UWB Sensing PHY
		1. RF requirements: Sensing Pulse Shape

The same pulse shape shall be used for the entire sensing packet and all the pulses within one sensing packet shall be modulated with a constant amplitude.

The transmitted pulse shape p(t) shall be constrained by its cross-correlation function with a standard reference pulse shape, r(t). The normalized cross-correlation function between two waveforms is defined as follows:

where *Er* and *Ep* are the energies of r(t) and p(t), respectively, *p*\* denotes the complex conjugate of *p*, and Re{.} indicates that the real part is used.

The reference pulse r(t) is a time-bounded Kaiser pulse with a parameter of .

where I0 is the zeroth-order modified Bessel function of the first kind, L is the duration of the pulse which is set to 3 chips.

The transmitted pulse p(t) shall have a magnitude of the cross-correlation function whose main lobe is greater than or equal to 0.92 for a duration of at least *Tw,* as defined in 802.15.4-2020 table 15-12, and any sidelobe shall be no greater than 0.1 . For the purposes of testing a pulse for compliance, the following are defined: Let be the magnitude of the cross-correlation of p(t) and r(t), and , for *i* = 1, 2,…, be a set of critical points as follows:

The maximum of the function occurs at one of these critical points, , where for all values of . The requirements thus states that for some continuous set of values that contain the point , the function is greater than or equal to 0.92. In addition, the second constraint on the value of sidelobes may be stated mathematically as for all .

To help with interoperability in sensing scenarios, the transmitted pulse should exhibit both minimum precursor energy and minimum postcursor energy. The transmitted pulse shape p(t) should be constrained by a symmetric time domain mask with solid line shown below, where A’, B’ and C’ are the points A, B and C mirrored in t = 0, respectively.. Tp is the inverse of the chip frequency.



Figure 7: Recommended time domain mask for UWB sensing PHY pulse.

The mask is centered at t = 0. A’, B’ and C’ are the points A, B and C mirrored in t = 0, respectively

* Point A: (1.37, 0.04)
* Point B: (1.37, 0.3)
* Point C: (0.88, 0.3)
	+ 1. Sensing PPDU format
			1. General

An SDEV shall support transmission and reception of packets as specified in Table 2. Figure 7 depicts the position of sensing field in the packets.

Table 14: PPDU SENS packet structure configurations

|  |  |  |
| --- | --- | --- |
| **SENS packet configuration specifier**  | **Position of SEN in the PPDU** | **Support** |
| 0 | The SENS field is placed after SFD.  | Mandatory |
| 1 | The SENS field is placed after SFD and before PHR | Optional |
| 2 | The SENS field is placed after Payload | Optional |

Figure 8: PPDU packet formats for sensing

SFD

SYNC

PHR

Payload

SENS

SFD

SYNC

PHR

Payload

SENS

SYNC

SFD

SENS

**SENS2**

**SENS0**

**SENS1**

Arrow shows RMARKER

reference position.

Sensing primitives and PHY attributes will be defined such that higher layers can request a packet configuration for sensing.

For each sensing packet, one RMARKER is defined to enable potential non-secure ranging using sensing packets. The position of the RMARKER is at the peak of first pulse after SFD.

* + - 1. SHR field
				1. SYNC field

The SDEV shall support the length 91 codes specified in Table 15-7a of 802.15.4z-2020, with the parameters specified in Table 15-7b.

The SDEV shall support transmission and reception of PSR values of 32, and 64. Support for PSR values of 16, 128 and 256 is optional.

* + - * 1. SFD field

There are no changes in the SFD field of sensing packets from those already defined in 802.15.4z-2020, specified in table 15-7c.

* + - 1. PHR field

There are no changes in the PHR field of SENS1 and SENS2 packets from those already defined in 802.15.4z-2020, section 15.2.7.3.

* + - 1. PHY Payload field

Payload data rates of 1.95, 7.8, 31.2, 62.4 Mbps shall be supported for SENS1 and SENS2. The support of 124.8 Mbps is optional.

BCC K=7 is used as the FEC for SNES1 and SENS2 packets.

* + - 1. SENS field

The SDEV shall support length 91 codes specified in Table 15-7a of 802.15.4z-2020. The code sequences are spread using the delta function of length , to generate sensing symbol according to table 15-7b of 802.15.4z-2020. when both SENS and SYNC use length 91 sequences, they shall use same code index from table 15-7a.

The SENS field consists of one to four blocks of active segments, separated by gaps. Support for 2, 3 and 4 segments are optional for an SDEV. The number of symbols in a segment is defined as sensing symbol repetition (SSR). The duration of each gap interval is one SENS symbol, or equivalently 364 chips (~729ns). The SDEV shall support transmission and reception of SSR= 32, 64, 128. Support for SSR=16, 256 and 512 is optional. Figure 8 shows SENS field in SENS0 and SENS2 fields, and Figure 9 shows the SENS field in SENS1 packet. These figures represent the case of one or two segments, and they can be generalized to three or four segments.



Figure 9: SENS Segments for SENS0 and SENS2 packets



Figure 10: SENS Segments for SENS1 packet

Sensing primitives and PHY attributes will be defined such that higher layers can request a given set of values for SSR and number segments.

For sensing packets SENS0, SENS1 and SENS2, one CIR report is generated per SENS segment per receiver antenna. No CIR report is required from other fields of the packet.

Sensing CIR report is optionally supported with non-sensing packets (dynamic-data packet, MMS and SP0-3). The field used for CIR report generation should be agreed during control phase.

An SDEV may optionally support an additional mode of sensing only for SENS0 packet, where all three fields (SYNC, SFD, and SENS) use the same length 127 code from Table 15-7 of the 15.4 standard, with spreading factor of L=4. This brings the PRF to 62.4MHz. In this case, the sequence index selection for sensing sequence shall follow same groupings of (code index, UWB channel) as specified in table 15-7 of 802.15.4-2020. SYNC PSR and SFD length options in this mode are the same as HPRF mode, as discussed in section 2.6.2.2.

Packet transmission sequences are under consideration to facilitate optional support for frequency stitching across carrier frequencies spaced apart in multiples of 124.8MHz. For frequency stitching mode, if intra-packet frequency stitching is enabled, extended gap size between SENS segments will be adopted. The duration of extended gap is 40 sensing symbols.